Diseño Conceptual de las Esclusas Post Panamax

SINGLE LIFT LOCK SYSTEM

TASK 3 – ALIGNMENT OPTIMISATION

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Executive Summary

The alignment optimization study for the third lock and by-pass canal at the Pacific Ocean side of the Panama Canal comprises three tasks :

- the nautical analysis of the access to the new locks,
- the analysis of the local geo-technical conditions,
- the optimization of the excavation volumes.

Each of these tasks is fully reported in the report of the triple lift lock configuration, and additionally in this report on the single lift lock configuration. Indeed, as far as the nautical analysis is concerned, there are no essential new nautical parameters which govern the alignment as compared to the triple lift lock alignment.

The local geo-technical situation is characterized by the presence of two main formations, as there are: the “La Boca” formation, which is a rather soft rock layer, and the “Basalt” formation, which is a very hard and sound rock layer.
As the lock length is much shorter compared to the triple lift lock structure, it was possible to locate the entire single lift lock structure (except the entrance walls) in the sound Basalt rock formation, which can be considered as a major advantage for the very long term behavior of the structure. Even so, this could be achieved for the third lane as well as for the fourth lane of locks.
This optimum geo-technical location could be achieved by shifting the alignment to the east, without interfering with the nautical condition of keeping the lock entrance at five ship lengths away from the intersection point of the new canal axis with the existing canal axis.

Finally, the excavation volumes for this new alignment have been calculated with the software MX. It is shown that the excavation volumes for the by-pass canal vary between 74 million m³ and 76 million m³, according to the chosen position of the lock structure, which alters a little according to the width of the center wall (between third and fourth lanes).
These volumes are very close to the one that has been calculated for the P1A alignment of the triple lift configuration.
It should be noticed that the alignment optimization studies have been performed assuming that the by-pass canal is a straight line connection between the Pacific entrance and Gatun Lake (as the P1 alignment indicated in the TOR). It is recommended to further investigate whether the excavation volumes can be reduced considerably if the alignment would be slightly curved in the section between the lock and Gatun lake.

1 General Considerations

The Alignment Optimization study has been performed and reported for the triple lift configuration. The main objectives were:

- To minimize excavation volumes for the bypass canal
- To obtain the best geological conditions for the lock structure
- To meet nautical access requirements

The calculation of the excavation volumes has been repeated for two new alignments (P1C en P1D) which have been developed together with Task 4a (lock siting and lay out). The order of magnitude of excavation volumes is similar to the one of P1A, varying between 74 and 76 million cubic meters.

The recommendations of the nautical analysis for the triple lift configuration study can be retained as there is no essential nautical difference between P1A and P1C/P1D. The general requirement of keeping the lock entrance at five ship lengths distance from the crossing of the new bypass axis with the existing canal has been implemented for the single lift lock configuration (see drawings D3-0-203/204/205).

Drawings 203 and 204 show 3 different alignments (P1C-P1D-P1E) related to the width of the center wall between the third and fourth lane (as will be highlighted in Task 4a). Alignment P1E gives a distance of 1825 m to the intersection point, which is some hundred meters less than the required five ship lengths, and could still be accepted, but finally has not been retained for constructional reasons. Alignments P1C and P1D can be considered as equivalent.

It has been discussed to rotate the axis towards the existing excavation in order to minimize the excavation volume drastically (reference can be made to alignment P1B of the triple lift configuration where the volume was reduced by 15 million m³) and at the same time increase the distance to the intersection point with the existing canal axis. This possibility has not been retained for the following reasons:

1. It would require to make a bend in the bypass canal at the upstream side of the lock in order to avoid a connection with the Miraflores lake. Such a bend is not necessarily a major problem, but from the nautical point of view it is recommended to have a straight canal (especially for the Post-Panamax vessels). Furthermore, such an alternative to the P1 alignment should be studied in more detail.

2. The lock structure would be situated close to the hillside and complicate very severely the constructions of the WSB, expecially when they are not stacked (two by two). This can also be illustrated by drawing D3-0-205, where the P1C alignment is shown on the aerial photo.

Finally, the geological situation is much more advantageous for the single lift configuration than for the triple lift locks.
Indeed, due to its length, it was impossible to locate the triple lift lock structure entirely in the sound Basalt formation. The single lift lock, being much shorter, on the contrary can be positioned entirely in this rock layer, even when considering the future fourth lane construction. The positioning of the lock structure in the Basalt formation requires the knowledge of the construction width of the entire lock structure, and therefore it has been analyzed together with the lock wall construction (see task 4b "Lock Walls").

The two retained alignments P1C and P1D are shown on the geological plan view of drawings D3-0-201 and 202.
Reference is made to Tasks 4a and 4b for further explanation on this subject.

2 Excavation Volumes

2.1 INTRODUCTION

Because of capacity reasons the need of a bypass canal on the Pacific side of the Panama Canal, bypassing the existing *Pedro Miguel* and *Miraflores* locks, has emerged.

Harza Engineering Company (2000) performed an evaluation of lock channel alignments investigating alignments both on the Pacific and the Atlantic entrances of the Panama Canal.

In this draft final report, the second lock configuration (single lift) is studied for two alignments, called *P1C* and *P1D*. Both those alignments are situated on the west side of the currently existing *Pedro Miguel* and *Miraflores* locks. The alignments P1C and P1D are situated in the vicinity of the triple lift lock alignment *P1*. The alignments and lock position were determined in order to obtain good foundation conditions for the locks. Alignment P1C is shown on drawing D3-0-201. Alignment P1D is shown on drawing D3-0-202.

The purpose of this report is to present the methodology and the results of the volume calculations for the excavation of the bypass canal (alignments P1C and P1D) on the Pacific side of the Panama Canal (third lane option only).

2.2 DATA

2.2.1 SURVEY INFORMATION

All levels are referenced to *Precise Level Datum (PLD)*. All positions are indicated in *meter North American Datum 1927 (Universe Tranverse Mercator* projection).

The topography at the proposed location of the bypass canal is taken from the digital file *curvas-nivel.dwg*. The file *pachyd.txt* provides bathymetrical data at the location of the old excavation (of around 1940) and at the connection of the Pacific edge of the bypass canal with the existing canal (however not complete). The survey information of the file *cartagen.dwg*, containing the survey of the relatively recent excavation close to the *Pedro Miguel* locks, was incorporated. The (bathymetrical) survey information in certain low areas remains missing, as can be seen on drawing D3-0-008. The MX-software, used for the volume calculations, assumes an interpolated natural ground level in the areas where no survey information is available. The bathymetrical information at the location of the connection between the bypass canal and the Gatun side of the existing canal is missing and therefore the volume calculations exclude that volume.

2.2.2 CANAL/LOCK POSITION

The position of the alignments P1C and P1D is taken from drawings D3-0-201 and D3-0-202 respectively (third lane option). These drawings define the position of the canal and the lock with single lift configuration (rolling gates, locomotives). The width of the canal is 220 m, 4 times the width of the design Post-Panamax vessel.

The canal bottom levels used in the calculations are listed in *Table 1*. The canal levels on both sides of the lock and close to them will be slightly lower (deeper) than the levels in *Table 1*, but this effect has been neglected in the calculations.

	Canal Level [*m PLD*]
Gatun-side of lock	+ 7.16
Pacific-side of lock	- 19.08

Table 1: bypass canal bottom elevations assumed for volume calculations

For P1C and P1D the dimensions of the lock structures were based on the lock design as indicated on drawings D3-0-201 and D3-0-202 respectively.

The excavation level of the (single) lock chamber was taken at –20.6 m PLD.

2.2.3 GEOLOGICAL INFORMATION

The canal side slopes are determined based on the drawings:

- TERCER JUEGO DE ESCLUSAS, PACIFICO, ALINEAMIENTO P1, SECCION LONGITUDINAL MOSTRANDO VALORES DE CR%, RQD%, UCS, y PLT, PERFIL 1 (ESTE), FEBRERO 2002 (filename: *SEC1 Y SEC1CR.dwg*).
- TERCER JUEGO DE ESCLUSAS, PACIFICO, ALINEAMIENTO P1, SECCION LONGITUDINAL MOSTRANDO VALORES DE CR%, RQD%, UCS, y PLT, PERFIL 3 (OESTE), FEBRERO 2002 (filename: *SEC3 Y SEC3CR.dwg*).
- MAPA GEOLOGICO CON SERIE TP1, TP1C Y TP2 Y TYP2C + MIRAFLORES, JUNIO 5 DE 2002 (filename: *PERFILES 4 Y 5 SERIE P1, PM, Y M*.dwg).
- *CUT SLOPE TYPES.dwg*
- MAPA GEOLOGICO CON SERIE TP1, TP1C Y TP2, TP2C + MIRAFLORES, REVISADO POR CPP MARZO 2002, *D2-0-001.dwg*

On drawings D3-0-014 and D3-0-015 the topography as obtained on the eastern and western edge of the *P1* canal bottom is superimposed on the geological profiles of drawing MAPA GEOLOGICO CON SERIE TP1, TP1C Y TP2 Y TYP2C + MIRAFLORES, JUNIO 5 DE 2002 (filename: *PERFILES 4 Y 5 SERIE P1, PM, Y M*.dwg). It can be seen that the natural ground level of the geological profile does not correspond with the topography in certain locations along the sections.

It appears there is a similar problem with the geological profiles at the proposed P1 lock location. The geological profiles referred to, are:

- PACIFICO, ALINEAMIENTO P1, SECCION LONGITUDINAL MOSTRANDO VALORES DE CR%, RQD%, UCS, y PLT: PERFIL 1 (ESTE), ACP, FEBRERO 2002 (*sec1ysec1cr.dwg*).
- PACIFICO, ALINEAMIENTO P1, SECCION LONGITUDINAL MOSTRANDO VALORES DE CR%, RQD%, UCS, y PLT: PERFIL 2 (CENTRO), ACP, FEBRERO 2002 (*sec2ysec2cr.dwg*).
- PACIFICO, ALINEAMIENTO P1, SECCION LONGITUDINAL MOSTRANDO VALORES DE CR%, RQD%, UCS, y PLT: PERFIL 3 (OESTE), ACP, FEBRERO 2002 (*sec3ysec3cr.dwg*).

To determine the canal slopes the geological information of the above drawings is used. For the volume calculations the topography as described in section 3.2.1 is used.

Apart from the geological profiles mentioned above, the following digital geological data were also provided:

- xls-file *base de datos pozos M* containing the logs of M1-M439.
- xls-file *PM general data base* containing the logs of PM1-PM504.

On drawing D3-0-009 the location of the loggings M1-M439, PM1-PM504 is shown. It can be seen that for large parts of the *P1* there is no digital geologic information available.

The folders *TP1C-01, …, TP1C-34, TP2C-01, …, TP2C-15* containing geological information, were also provided. The files have different extensions: *NDX, PDT, 000, 001, P* and they are unreadable without the appropriate *Logdraft* software.

2.3 SOFTWARE

The software used to calculate the excavation volume is MX (MOSS).

2.4 METHODOLOGY

2.4.1 GENERAL

MX is used to calculate the total volume to be excavated for the alignments P1C and P1D.

The results of the volume calculations are subdivided in sub-results for different parts along the canal (see drawings D3-0-206, D3-0-207):

- ch. 1000 – 6000
- ch. 6000 – 10000

An extra excavation width of 10 m behind the lock wall has been incorporated to allow for the excavation of the foundation slab for the lock walls.

For alignment P1D the excavation for the entire wall between the third lane option and the fourth lane option has been incorporated.

The volume of the saving basins is not incorporated in the calculation.

In case sufficient digital geological data would be available, the 3-D modelling of the different sub-volumes (for each of the strata) would be possible. Due to the lack of available digital loggings within the canal alignments it is not possible to make digital models of the surfaces separating the different layers.

The different geological sections available can be used to estimate the different sub-volumes. The advantage of using the longitudinal sections is that they comprise the full synthesis of the geological information of the area (not limited to merely borehole logs). Certainly when the density of the boreholes is relatively low, it is not without risk to use the interpolated surfaces between the boreholes. Using a geological longitudinal section over a certain width of the canal is an approximation, although it can be said that the information on the longitudinal section itself is already a kind of average as the different borings have not been done on single straight lines (scattered around the alignment of the longitudinal section).

2.4.2 SUB-VOLUMES

The available geological long-sections that are used for estimating the sub-volumes are:

- PACIFICO, ALINEAMIENTO P1, SECCION LONGITUDINAL MOSTRANDO VALORES DE CR%, RQD%, UCS, y PLT: PERFIL 1 (ESTE), ACP, FEBRERO 2002 (*sec1ysec1cr.dwg*), providing a geological long-section between chainage (ch.) 6000 and 9000.
- PACIFICO, ALINEAMIENTO P1, SECCION LONGITUDINAL MOSTRANDO VALORES DE CR%, RQD%, UCS, y PLT: PERFIL 2 (CENTRO), ACP, FEBRERO 2002 (*sec2ysec2cr.dwg*), providing a geological long-section between ch. 6000 and 9000.
- PACIFICO, ALINEAMIENTO P1, SECCION LONGITUDINAL MOSTRANDO VALORES DE CR%, RQD%, UCS, y PLT: PERFIL 3 (OESTE), ACP, FEBRERO 2002 (*sec3ysec3cr.dwg*), providing a geological long-section between ch. 6000 and 9000.
- MAPA GEOLOGICO CON SERIE TP1, TP1C Y TP2 Y TYP2C + MIRAFLORES, JUNIO 5 DE 2002 (filename: *PERFILES 4 Y 5 SERIE P1, PM, Y M*.dwg), providing geological longitudinal sections between ch.. 1000 and 6000 on the eastern and western edge of the *P1* canal bottom.

The location of the 3 geological long-sections between ch. 6000 and 9000 is indicated on drawing D3-0-006.

To determine the contribution of the different strata to the total volume for the alignments P1C and P1D the division percentages used for alignment P1 were applied (approximation).

2.4.3 CANAL SLOPES

From the outside geological long-sections the typical slope types can be deducted for both sides of the P1 canal. Due to the variation in the lithography when moving in a direction perpendicular to the canal axis, this approach is approximate.

In drawing *cutslopetypes.dwg* the stepped slope patterns for five different types of material are indicated (type A, B, C, D and E). On the long-sections *sec1ysec1cr.dwg*, *sec3ysec3cr.dwg*, *perfiles4y5seriep1,pm,ym.dwg* the material types *A*, *B*, *C*, *D* and *E* are indicated. The stepped slope as indicated on *cutslopetypes.dwg* is replaced by a smooth slope yielding approximately the same overall slope as indicated on drawing *cutslopetypes.dwg*. In *Table 2* the slopes used in the volume calculations for the five types of material are indicated.

Material Type	Slope
very hard rock (type A)	45° (1V:1H)
hard rock (type B)	40° (0.84V:1H)
medium hard to medium soft rock (type C)	22° (0.4V:1H)
soft rock to medium hard soil (type D)	15° (0.27V:1H)
overburden (type E)	15° (0.27V:1H)

Table 2: canal slopes per material type

Due to the relative proximity of alignments P1, P1C and P1D, the chainage-slope relation that was used for P1 is also used for alignments P1C and P1D.

The western sound rock slopes of the canal are based on the longitudinal sections *perfiles4y5seriep1,pm,ym.dwg* (west side) for the lower chainages and on *sec3ysec3cr.dwg* for the higher chainages. In this way the following slopes are obtained for the western side, underneath the overburden and weathered rock layers (see *Table 3*):

Chainage	Type of Sound Rock	Sound Rock Slope
1000 – 1755	D	15° (0.27V:1H)
1755 – 2220	B	40° (0.84V:1H)
2220 – 2970	D	15° (0.27V:1H)
2970 – 3325	B	40° (0.84V:1H)
3325 – 3650	D	15° (0.27V:1H)
3650 – 6815	B	40° (0.84V:1H)
6815 – 7585	C	22° (0.4V:1H)
7585 – 8245	A	45° (1V:1H)
8245 – 8610	C	22° (0.4V:1H)
8610 – 10300	A	45° (1V:1H)

Table 3: sound rock slopes for west side of P1C and P1D

The eastern sound rock slopes of the canal are based on the longitudinal sections *perfiles4y5seriep1,pm,ym.dwg* (east side) for the lower chainages and on *sec1ysec1cr.dwg* for the higher chainages. In this way the following slopes are obtained for the eastern side, underneath the overburden and weathered rock layers (see *Table 4*):

Chainage	Type of Sound Rock	Sound Rock Slope
1000 – 2060	D	15° (0.27V:1H)
2060 – 3310	B	40° (0.84V:1H)
3310 – 3775	C	22° (0.4V:1H)
3775 – 7180	B	40° (0.84V:1H)
7180 – 8300	A	45° (1V:1H)
8300 – 10300	C	22° (0.4V:1H)

Table 4: sound rock slopes for east side of P1C and P1D

On drawing *sec1ysec1cr.dwg* (east bank) it can be seen that from ch. 8500 till 8700 approximately a basalt intrusion is underlying the *La Boca* formation. For the determination of the canal slopes this basalt intrusion is neglected (type C slope is assumed). On drawing *perfiles4y5seriep1,pm,ym.dwg* it can be seen that for the east side between ch. 2200 and 2800 the *Cucaracha* formation is underlying the thick above layers. For the determination of the canal slopes the *Cucaracha* formation is neglected and a type B slope, corresponding with the above *Pedro Miguel* and magmatic layers, is assumed.

Because of the variation in lithology and discontinuities, the typical cut slopes that were used should be refined by detailed local rock mass stability assessments at the early stage of the excavation works. In this respect, detailed wedge stability calculations should be performed. The detailed design of the final slopes/rock support will then have to be done.

According to the different geological longitudinal sections the average thickness of the combined overburden and weathered rock layers is approximately 12 m (average overburden thickness 8 m, average weathered rock thickness 4 m). It is considerably smaller at certain locations and considerably larger at other locations. In view of the uncertainty about the geological longitudinal sections (see section 3.2.3), a uniform vertical thickness of 12 m is assigned to the combined overburden and weathered rock layer for the calculation of the total excavation volume. A slope angle of 15° (or 0.27V:1H) can be assumed for this combined layer. On drawing D3-0-206 the sound rock slopes along the canal are drawn for P1C. On drawing D3-0-207 the sound rock slopes along the canal are drawn for P1D. An additional volume has been added to the calculation results for the sound rock slopes to incorporate the milder slope at the top of the embankment (overburden, weathered rock).

In the volume calculation for P1C and P1D a slope of 2V:1H is assumed next to the lock wall.

2.5 RESULTS

2.5.1 P1C

For alignment P1C the following total excavation (sub-)volumes are obtained (see *Table 5)*:

Sub-area	Total excavation volume [m^3]
1000 – 6000	58 531 000
6000 – 10000	15 718 000
TOTAL	**74 249 000**

Table 5: P1C total excavation volumes

For sub-area *1000-6000* the following divide into the different materials is obtained, see *Table 6*:

Sub-area *1000-6000*	Excavation volume [m^3]
overburden	9 306 000
weathered rock	7 375 000
basalt/diabase	12 292 000
form. Pedro Miguel	23 998 000
form. Cucaracha	5 560 000
TOTAL	**58 531 000**

Table 6: P1C excavation volumes for sub-area 1000-6000

For sub-area *6000-10000* the following divide into the different materials is obtained, see *Table 7*:

Sub-area *6000-10000*	**Excavation volume [m^3]**
overburden	6 335 000
weathered rock	1 823 000
basalt/diabase	4 621 000
form. La Boca	2 939 000
TOTAL	**15 718 000**

Table 7: P1C excavation volumes for sub-area 6000-10000

The breakdown of the total excavation volume for P1C obtained, is as follows (*Table 8*):

Material	**Total excavation volume [m^3]**
overburden	15 641 000
weathered rock	9 198 000
basalt/diabase	16 913 000
form. Pedro Miguel	23 998 000
form. La Boca	2 939 000
form. Cucaracha	5 560 000
TOTAL	**74 249 000**

Table 8: material breakdown for P1C excavation

2.5.2 P1D

For alignment P1D the following total excavation (sub-)volumes are obtained (see *Table 9*):

Sub-area	**Total excavation volume [m^3]**
1000 – 6000	59 153 000
6000 - 10000	17 123 000
TOTAL	**76 276 000**

Table 9: P1D total excavation volumes

For sub-area *1000-6000* the following divide into the different materials is obtained, see *Table 10*:

Material	**Total excavation volume [m^3]**
overburden	9 405 000
weathered rock	7 453 000
basalt/diabase	12 422 000
form. Pedro Miguel	24 253 000
form. Cucaracha	5 620 000
TOTAL	**59 153 000**

Table 10: P1D excavation volumes for sub-area 1000-6000

For sub-area *6000-10000* the following divide into the different materials is obtained, see *Table 11*:

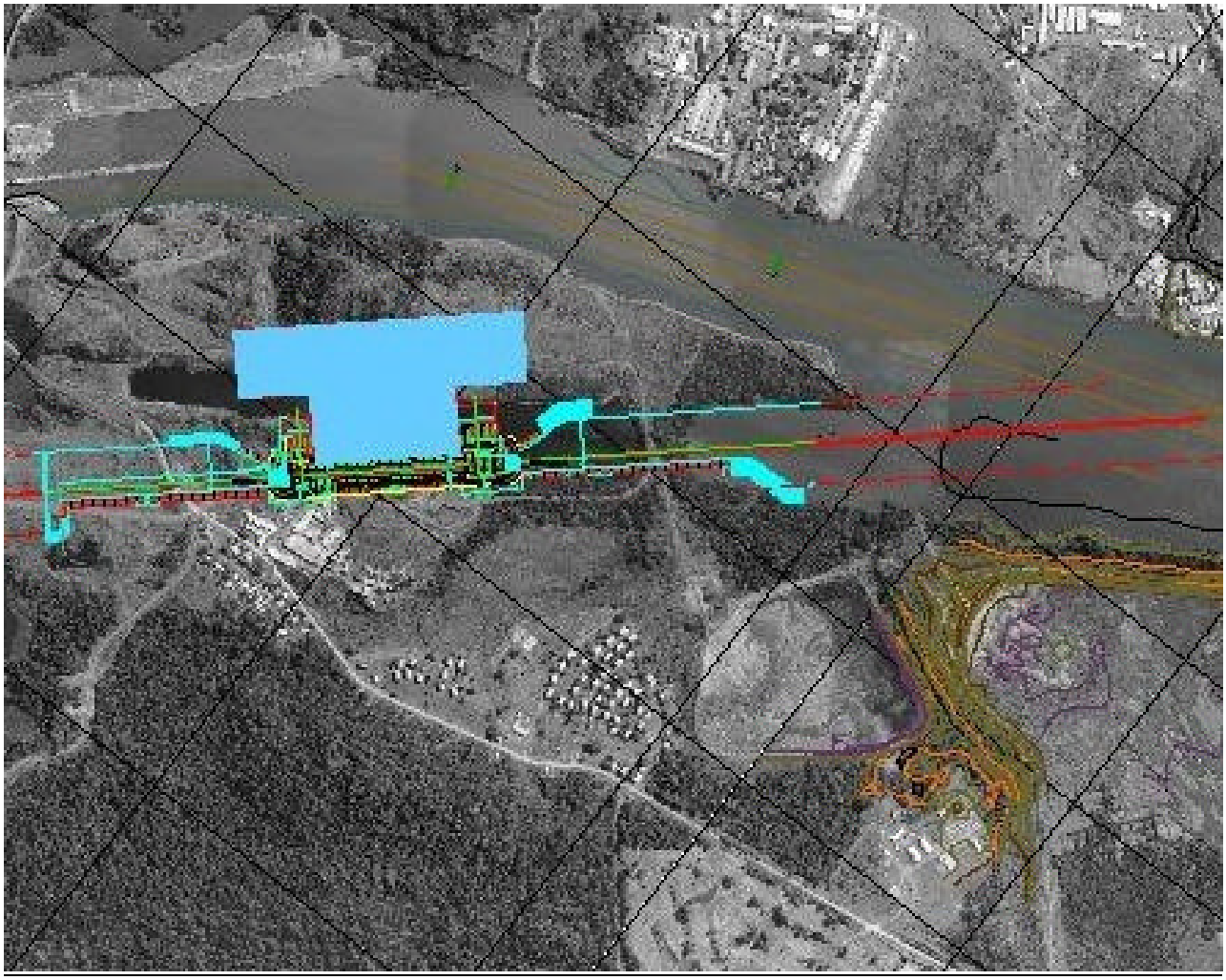
Sub-area *6000-10000*	**Excavation volume [m^3]**
overburden	6 901 000
weathered rock	1 986 000
basalt/diabase	5 034 000
form. La Boca	3 202 000
TOTAL	**17 123 000**

Table 11: P1D excavation volumes for sub-area 6000-10000

The breakdown of the total excavation volume for P1C obtained, is as follows (*Table 12*):

Material	**Total excavation volume [m^3]**
overburden	16 306 000
weathered rock	9 439 000
basalt/diabase	17 456 000
form. Pedro Miguel	24 253 000
form. La Boca	3 202 000
form. Cucaracha	5 620 000
TOTAL	**76 276 000**

Table 12: material breakdown for P1D excavation



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SINGLE LIFT LOCK SYSTEM

TASK 4

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Executive Summary

Task 4 – Conceptual design – Configuration 2 : single lift lock system

This report contains the conceptual design of a single lift lock structure for the new Post Panamax locks at the Pacific side of the Panama Canal.

The Task 4 Report contains following subtasks:

- a. Lock siting and Lay-out
- b. Lock Walls & Lock Heads
- c. Emptying and Filling System
- d. Lock Operating Gates
- e. Culvert and conduit Valves
- f. Operating Machinery
- g. Lighting
- h. Electrical Power and Power Requirements
- i. Entrance Walls (see report on configuration 1)
- j. Operating Structures
- k. Cofferdams (not applicable)
- l. Construction Plan and Schedule
- m. Cost Estimation

For each of these tasks a separate report has been prepared, together they make the report of Task 4.

Before summarizing the results of these conceptual studies, it is important to remind that the design is especially based on following special criteria and requirements, as has been discussed on several occasions with ACP:

- The new locks are a demand driven system, and its operating times determine the capacity
- of the system.
- Reliability is another basic requirement, as any shutdown time means loss of income.
- Maintenance has to be kept to a minimum.
- Construction cost should be minimized.
- Operation facilities and systems should be kept simple and reliable.

Lock siting and layout

The lock siting and layout of the single lift lock structure has been determined mainly in function of geotechnical considerations, as it has been shown that it is possible to locate the entire lock structure (except the entrance walls) for both third and fourth lane together in the sound Basalt rock formation. At the same time the other two essential design criteria have been met (nautical access and excavation volumes).

In order to achieve this optimum location, the width of the center wall of the lock structure has been kept to a minimum taking into account the third and fourth lane construction.
Three solutions have been considered, and option 2 corresponding with alignment P1C has been retained for further design purposes. Indeed, option 2 allows to minimize the construction width of the center wall to 55,40 m which is considerably less than option 1 (102 m). At the other hand option 3 allows to further reduce this width, but it can only be done by constructing both the third and fourth lane walls together as a combined structure (caisson type wall). This solution leads to a considerable increase of the investment cost for the construction of the third lane lock complex, as the double wall is certainly more expensive than a single wall (although the total investment for a double wall is considerably lower than it would be for two single walls). An important advantage of option 3 is most certainly the fact that the interference of the construction of the future fourth lane with the operation of the third lane will be minimized.

It is recommended that ACP evaluates these technical and economical benefits before a final decision is made whether to retain option 2 or 3.

The single lift lock system will be operated with six water saving basins. As the study showed out that it is impossible to stack all six basins on one pile (as it is in the T.O.R.), two alternatives have been considered:

- one with six staggered water saving basins
- one with 3 piles of two stacked water saving basins

The second alternative requires a lot of structural concrete work and showed to be much more expensive than the first one if space requirements are not constraining (120 million USD for the staggered solution versus 213 million USD for the alternative with 3 piles of two stacked basins).

As it has been shown that it is possible to install the six staggered basins in the area between the lock chambers and the existing canal to the Miraflores locks, the first solution has been retained for further design purposes.

The final layout of the single lift lock is shown on drawing D4-A-201.

The drawing shows the general lock dimensions with the rolling gates and their recess, the arrangement of the water saving basins, entrance walls and road access. It also shows the disposition of technical buildings and other equipment and installations.

Attention is drawn again to the fact that a vessel positioning system with locomotives has been implemented for this single lift lock system. The consultant has explained to ACP that major difficulties will be encountered with this system as the total head of 30 m will result in very steep and varying inclinations of the towing cables, making it practically impossible to guide the vessels through the lock. It is recommended that the vessel positioning system for the single lift lock in particular, should be the subject of a separate study or investigation.

Lock walls

The choice of the lock wall type depends mainly on geo-technical and seismic conditions, loadings (water levels, sill levels) and filling and emptying system.
As the lock structure is situated entirely in the Basalt rock formation, a number of possibilities of lock wall type are excluded.
As loading conditions are rather severe, and the requirement to have a very performing E/F system (with large culvert dimensions), the choice of a gravity type lock wall has been self-evident.
Of course it is clear that even the gravity type lock wall may lead to a lot of different alternatives which have to be investigated and optimized during further studies.

As the lock walls are situated mainly in rock, it has been suggested that no structural lock bottom floor is required.

Special attention has been paid to the load cases:
- earthquake
- dry lock chamber condition

It is shown that the dry lock chamber condition is more stringent than the earthquake event. The dry lock chamber has been considered as an accidental loading condition.

In this conceptual design, the lock wall dimensions have been chosen primarily in order to minimize excavation. For the eastern lock wall a reinforced concrete structure has been chosen as this is the most convenient disposition allowing to construct the lowest water saving basin adjacent to the lock wall, which may also lead to a reduction of the loadings acting on the wall.

For the western lock wall an option with a reinforced concrete structure has been evaluated against an option where roller compacted concrete (RCC) has been combined with reinforced concrete (RC). A solution without using steel reinforcement (mass concrete gravity wall type) has not been considered as experience has shown that the application of reinforcement has become common practice in modern quay and lock wall construction methods, as apparently they also have led to more economical structures. However, during further and detailed design it is recommended to investigate if such a solution could be envisaged for the Panama locks.

A third solution has been considered, as it seemed useful or even necessary to minimize the construction width of the center wall between third and (future) fourth lane locks (see alignment optimization and lock siting).
This could be obtained by combining both lock walls in one structure, which is commonly known as a caisson wall in reinforced concrete.

The three possible basic wall types are shown on drawing D4-B-206; for each of them the specific pros and cons have been highlighted and it was concluded to retain the solution with the combination of roller compacted concrete (RCC) and reinforced concrete (RC), for mainly constructional reasons (in order to allow the construction of the fourth lane wall without interfering too much with the operation of the fourth lane) and economical reasons.

However attention should be given to option 3 as it has some main advantages in relation to the two others, as there are:

- an important cost saving when the total construction cost of both third and fourth lane locks are considered
- an optimization of the center wall width
- a better positioning of the rail tracks (if any)
- realization of a very stable and reliable wall type
- further minimization of hindrance during the fourth lane construction to the operation of the third lane lock

It is recommended that ACP should evaluate these advantages against the disadvantage of an earlier investment required for the construction of a combined wall, before rejecting it only for this financial constraint.

Filling and emptying system – Water Saving Basins

The Consultant proposes to build 6 side-by-side staggered water saving basins, on the east bank of the third lane. This disposition allows **to save 75 % of the total water required to lock 2 ships** (alternate mode). Besides, the westbank remains free for the future fourth lane construction.

The chamber and water saving basin levels have been set up using a software developed by the Consultant. This software gives the minimum and maximum water levels reached in the chamber and the 6 basins making allowance for all the likely Gatun lake and Pacific Ocean levels and for a possible residual filling depth between the chamber and the basins. Moreover, it provides the water consumption and the water saving rate for every lockage as well as the daily number of up- or down-locked ships.

The Consultant has listed the different kinds of filling and emptying systems and has carried out a multicriteria analysis taking into account filling and emptying times, strengths on the hawsers and water turbulence, easiness of maintenance and system reliability and cost. The hydraulic design also makes allowance for the proposal of not dewatering the lock chamber for economic and maintenance reasons and integrates the remarks relative to civil engineering, gate and valves design. Eventually, the Consultant proposes **a side-wall culvert and ports filling and emptying system.**

As highlighted in the TOR, two concepts of the filling and emptying (F/E) system have been developed:

- The first one provides a filling (or emptying) all along the lock chamber by means of lateral culverts and ports. The water saving basin culverts are connected to the F/E system.

- The second one consists in filling (or emptying) all along the lock chamber through longitudinal culverts connected to secondary culverts and ports placed in the bottom floor. The water saving basin culverts are connected to the F/E system.

The two systems have been modeled and predesigned with the hydraulic calculation software Flowmaster ®.

During the simulations, several values of the following parameters have been tested:

- Culvert and port size
- Number of ports
- Initial head between the lock and the basins
- Schedule of the valves control

leading to a feasible but not optimized configuration.

Flowmaster allows to recover amongst others:

- The filling and emptying times
- The flow rate in all the circuit components
- The velocities in all the circuit components

The calculated filling and emptying times fit with the times required by the TOR. The velocities reached in culverts and ports are acceptable, taking into account that the maximum velocities could be reduced by providing adapted shapes to the circuits components (especially the ports).

Several culvert and port arrangements are given for both systems.

Both systems provide a uniform flow distribution and an upstream-downstream and east-west balanced filling whether the water saving basins are used or not.

From an economic point of view the second solution is far more expensive because of its concrete bottom floor. Consequently, the Consultant advises to retain the first one, i.e. **a filling and emptying system with side-wall culverts and lateral ports distributed all along the lock chamber**.

This report also provides, at a conceptual level of design, a study of the eventual risks concerning the cavitation phenomenon and highlights the problems of the strengths on hawsers and the difficulties to assess them.

Finally, some additional studies have been carried out, especially concerning the general conditions to construct the water saving basins and a basic definition of the pumping recycling system (pumps, electric power, energy consumption).

The next stage of the filling and emptying system conception should mainly allow to:

- Optimize the culvert and port dimensions and shape, making allowance for a comprehensive valve opening schedule.

- Define the port distribution along the lock chamber, their position and orientation.
- Study of the cavitation phenomenon
- Evaluate the expected strengths on the hawsers

This stage will require a study on a physical scale model. The results achieved on this model are required before or together with the feasibility study, and in any case before the bidding procedure.

Lock Gates

Lock gate selection and analysis for both the triple and the single lift lock configurations has led to the application of the "Rolling gate" type. This choice has been justified by means of a multi criteria analysis to evaluate the miter gates and the rolling gates. The rolling gate type is the only existing lock gate type for this size of Post Panamax locks, and has been successfully used in Europe, especially in Belgium where the locks of Berendrecht, Zandvliet in Antwerp and Vandamme in Zeebruges are the largest in the world.
Furthermore, the rolling gate type has some particular advantages that are of utmost importance for the new locks that will be demand driven. One main advantage is certainly that the gate is moved horizontally in the transversal direction of the lock, into a lock gate recess chamber, which can be easily dewatered, and as such represents an ideal maintenance place and position. As there are two lock gates and lock gate chambers on each lock head, it is practically impossible that the traffic should be interrupted due to failure of a lock gate. Moreover, a lock gate can be floated and can be towed away as a vessel if necessary (for example if replacement is required, or when using the gate as a bulkhead to dewater the lock chambers).

As compared to the triple lift lock configuration, it is clear that the downstream lock gates of the single lift configuration are much larger and heavier.
It is a fact that such an enormous rolling gate has never been built before, and might lead to a certain hesitation to go for it.
At the other hand, when compared to seegoing vessels and large pontoons, it is a steel truss construction which normally can easily be built on a shipyard. Furthermore, the same conclusion can be made as far as miter gates are concerned, and these could even cause more constraining technical problems.

The rolling gates have been designed for the normal operating conditions, as well as to withstand the total water head that occurs during the dry lock chamber situation. The procedure to empty the single lift lock structure would be that the outer gates are floated away from their normal position to additional recess positions up- and downstream, where they can be positioned and sunk to retain the water head from Lake Gatun and the Pacific Ocean.

In the case of the downstream gates however, it seems better not to use the large gates as a bulkhead as the maneuvering will be rather complicated when compared to the upstream gates. A possibility would be to use an upstream gate for this purpose.

Other alternatives are possible, for example a configuration in which each lock gate head can be dewatered using the gates as bulkheads, this would only require additional recesses around the lock heads.

The lock gate structures have been analyzed using 2D- and 3D-structural engineering software and according to the expert's experience with rolling gates in Belgium. This analysis allowed to determine and verify the general dimensions of the different gates, the dimensions of the steel truss structure, and consequently it was possible to make a fairly accurate estimation of the weight of the steel structure.

Other auxiliaries, such as wheel barrow wagons, supports, etc, have been assessed according to the experience with the Berendrecht and Van Cauwelaert locks in Antwerp, which were also designed by the CPP-experts.

Culvert and conduit valves

Similar to the selection procedure for the lock gates, a multi criteria analysis has been carried out for the three-lifts configuration to select the most convenient valve type for lock culverts and conduits. The most suitable valve was found to be the vertical fixed wheel type moved by means of a vertical hydraulic cylinder. It remains valid for the single-lift configuration

This is the same type of valve and operating system that is used at the Berendrecht lock, and has proved to be very reliable.

Nowadays vertical-lift valves of that type are preferred for big locks because they are cheaper to build and do not require the large space that is necessary for other valves as reverse tainter type for example.

In order to guarantee a maximum of reliability, the valves on the culverts are made redundant (two parallel valves per culvert, each operating on half of the culvert section. Each valve has a rectangular section of 4.5m wide x 7.5m high.

The valves on the conduits (in between the water saving basins and the lock chamber culverts) are not made redundant as such, but there are always two conduits for one WSB, which in fact gives the same redundancy as for the culverts. The valves on the culverts are 4.8m wide x 7.5m high.
Opening times of 2min (opening) and 1min (closing) have been considered and can be achieved.

The valves have been designed for maximum operating and maintenance conditions, can easily be set in dry conditions using bulkheads at both sides of the valves, and can be reached through vertical shafts on both sides.

Operating Machinery

Control system

The control system shall be efficient, safe and reliable and will require a minimum of staffing. The proposition for the control system of the 3-rd lane of locks of Panama is a distributed control system with several PLC's and a redundant optical fibre network connecting all the devices. Operator workstations shall be installed in the central control room and shall allow the control of all the installation. This is a very open system that allows future PLC's extensions by the simple

connection of new devices on the network. But for reasons of redundancy and proximity during exceptional or maintenance operations, a local control near the concerned equipment shall be supplied.

Gate operating machinery

Each rolling gate is moved by steel cables connected at anchorage points by compensating beams on both sides of the gate and wound around the cable drums of a winch. The two cable drums are driven by variable speed motors through gear boxes.

That type of machinery has been successfully used on the biggest existing lock gates (Berendrecht, Zandvliet, Zeebruges,..).

The two main AC motors are duplicating the drive in the event of failure of one motor. Moreover, a small emergency motor can be used to move the gate at reduced speed if the two main motors are not available.

Valves operating machinery

The culvert and conduit valves are operated by hydraulic cylinders. The pressure oil to open a valve is provided by separate hydraulic power units. The valves can be closed by gravity.

Each valve can be locally operated during maintenance from a control board located next to the hydraulic power unit.

The hydraulic cylinder solution is widely used and the technique has improved a lot especially by increasing the size and operating pressure. ACP has in particular a good experience through the replacement of existing operating mechanism of miter gates by hydraulic cylinders.

Lighting

Based on the experience of ACP, a lighting system is proposed that solves the main problems of the existing system. The most important problems of existing locks lighting are first of all the lack of visibility at the extreme ends of the lock chamber and in the lock chamber between ship and walls. The lights on high mast produce a glare that interferes with the pilot's visibility, in addition, they are subject to corrosion and maintenance problems.

The lock chambers and gates will be illuminated by use of floodlights turned down in lighted vertical recesses in order to solve the problem of lack of visibility of the water level in the locks chamber and the space between the ship and the chamber walls. It will also provide to the pilot a clear cut reference.

It is clear that the high masts solution giving actually satisfaction to operating people does not need to be replaced by anything else. We tried to facilitate the maintenance of the lighting fixtures by use of a ladder and platform combined with safety harness. To reduce the interference of high mast lighting with the pilot's visibility and to reduce light pollution, the use of asymmetric lamps and

deflectors are recommended. Corrosion effects can be reduced by improving the quality of material and tightness level.

The number of masts has been based on a illumination level of 100 lux (instead of 86 lux at Gatun) remaining almost constant all over the working area.

The locomotive boom lights remain useful but should be improved.

Electrical Power and Power Requirements

The starting point of the power grid is supposed to be the Miraflores substation (12 kV).

A high voltage loop including 4 HV substations for the 3rd lane has been judged as the most suitable solution. The total power (without reserve) for the four substations is about 8.000 kVA
In order to take into account the 4th lane, 4 additional substations have to be added.
The total power for the 3rd and 4th lanes together would be 12.400 kVA. However, as all equipment does not work at the same time (coefficient 0.6) and taking into account 15 % future possible extension (reserve coefficient of 1.15), the total power to take into consideration for the design of the high voltage network is 8.600 kVA for the 3rd and 4th lane.

The power liaison between HV1 and HV3 and between HV2 and HV4 makes it possible to supply all the substations in case of a double failure.
In the alternative 2, during normal operation, the two sides of the locks are independent

Two diesel emergency sets of 1000kVA are necessary to supply all substations in case of failure of the high voltage loop and as redundancy in case of the failure of one substation.

Entrance walls

Entrance walls have been designed according to the layout and the requirements of the imposed vessel positioning system with locomotives, which lead to a long western entrance wall.
The wall type which has been retained is similar to the lock wall, but doesn't require the integration of the culverts, and is not exposed to the same water heads.
Proper fendering will be installed at the lock entrance to avoid damage to the walls and lock gate recesses.

Operating Structures

The location and dimensions of the operating structures are indicated on drawing D4-A-201.

The operating structure include the HV electrical rooms, the maintenance buildings, the rolling gates technical rooms, the culvert and WSB technical buildings, the emergency diesel set room and the control room.

Cofferdams

As far as the lock structure is concerned, there is no need for the construction of cofferdams to isolate the construction site from the existing canal and lake. If the excavation of the new bypass canal is scheduled together with the construction of the lock, it is recommended that the lock's excavation area is separated from the new canal by means of sufficient large dams with gentle sloping angles. These dams will have to be removed by dredging when the lock structure is completed.

Construction Plan and Schedule

The construction plan shows one possible arrangement of the different Construction areas. The main access to the works being the existing road on the South East of the Project Area.
The Construction Schedule assumes that the works progress from North to South. It shows that the total construction time for the Locks and associated WSB will be approximately five and a half years. The excavation works during the three first years are on the critical path. The work production capacity was based on the information gathered from various large Construction Projects undertaken during the last ten years. If the excavation production rate could be increased to a much higher level, then the critical path would certainly be shifted into the concreting activities.

Cost Estimation

The cost estimation of the three alternatives which were investigated for the single lift locks are summarized in the table below.

Item	Description		Combination 1-B	Combination 2-A	Combination 3-B
			Total USD - 2002	Total USD - 2002	Total USD - 2002
1	Total project cost without WSB		791,000,000	780,000,000	935,000,000
2	Total project cost with WSB		897,000,000	887,000,000	1,042,000,000
3	Cost of WSB´s alone (postponed construction value as to year 2002)		179,000,000	179,000,000	179,000,000

(triple lift = 956.698.998 USD)

Note : the triple lift configuration is ± 1000 m longer than the single lift configuration. This means that the excavation cost for the canal will be considerably higher in the single lift configuration, thus compensating the difference in construction cost.

Not included in the cost estimation of the lock structure are following important items:

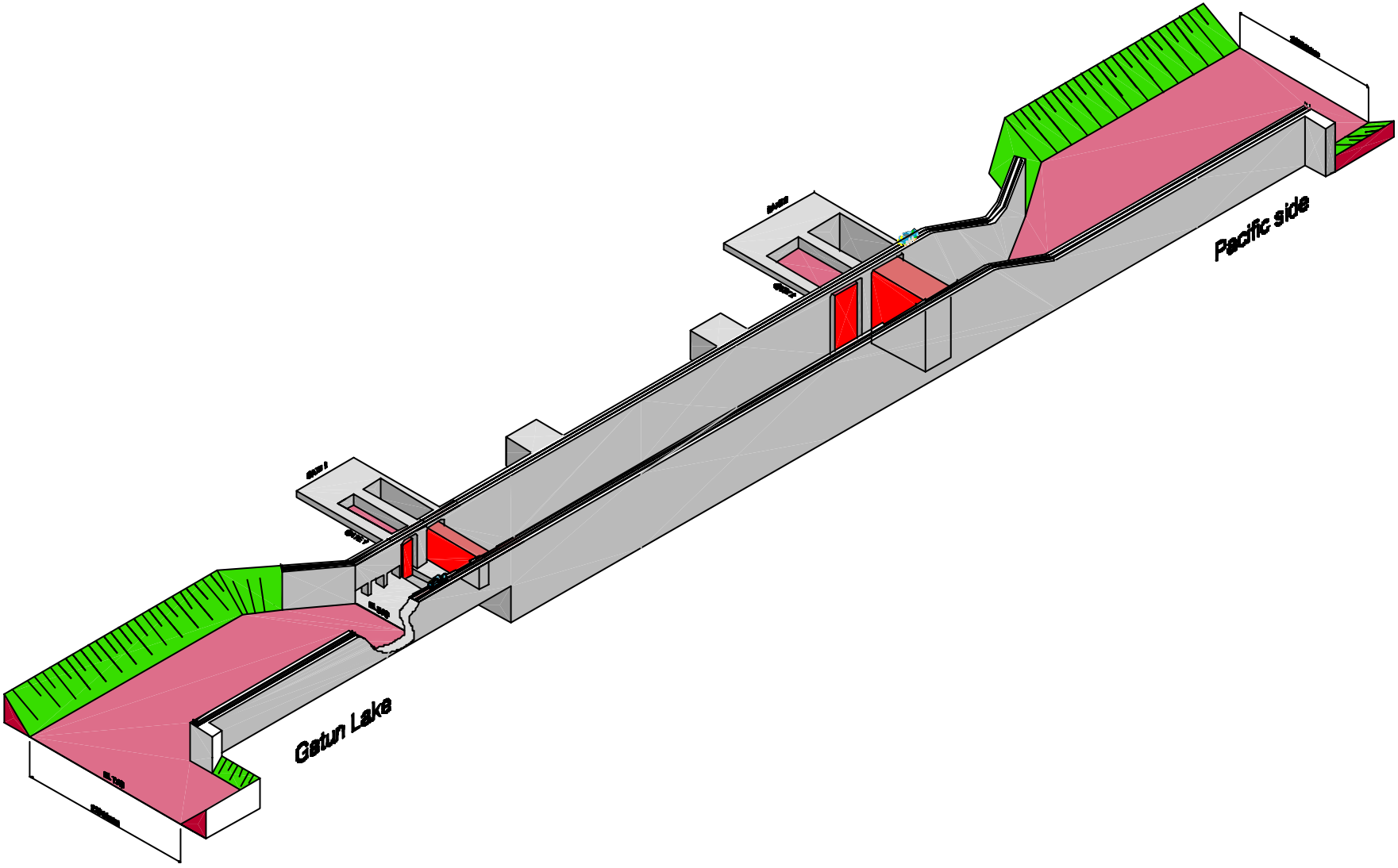
- the vessel positioning system (locomotives or tugboats)
- lower and upper pumping reservoirs and conduits
- road infrastructure outside the lock area
- diversion Rio Cocoli

Task 4 – Conclusions

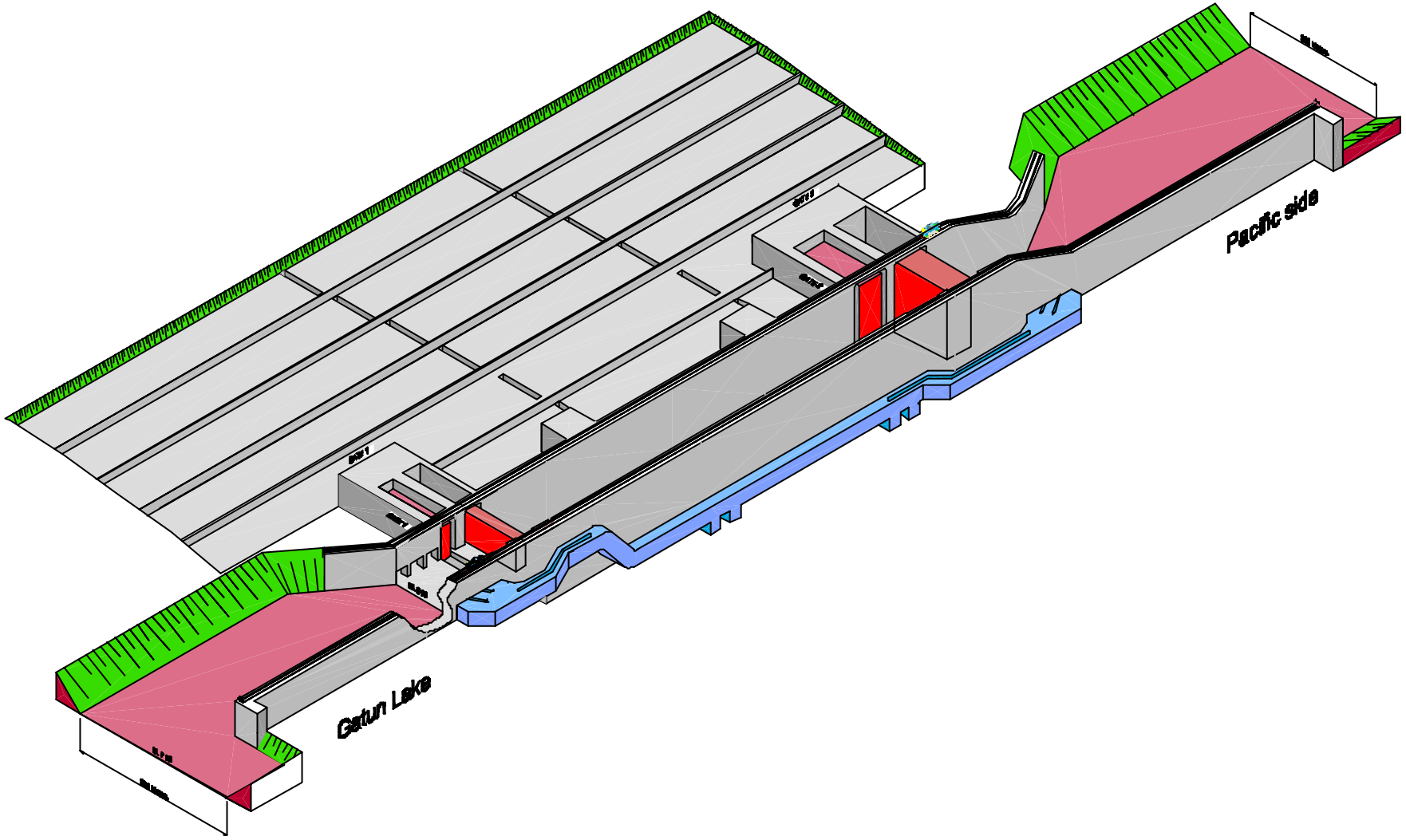
The conceptual design of the single lift lock complex has resulted in the development of a system which meets the requirements of the T.O.R. and the specific design criteria:

- the new locks will allow for 15 lockages a day in alternate mode;
- the design of the water saving basins meets with the 75 % saving requirement;
- the implementation of water basins is required to guarantee a well balanced filling of the lock chamber
- the systems which were retained for design purposes are based on proven techniques, although it has to be admitted that the downstream gates have such large dimensions that they cannot be compared to existing rolling gate structures;
- maintenance and involved costs are kept to a minimum using rolling gates, as well as an emptying and filling system in the lock side walls;
- the construction cost has been minimized and is lower than the one for the triple lift configuration;
- operating facilities have been kept simple and reliable;
- the vessel positioning system with locomotives will be difficult to operate, and needs further investigation;

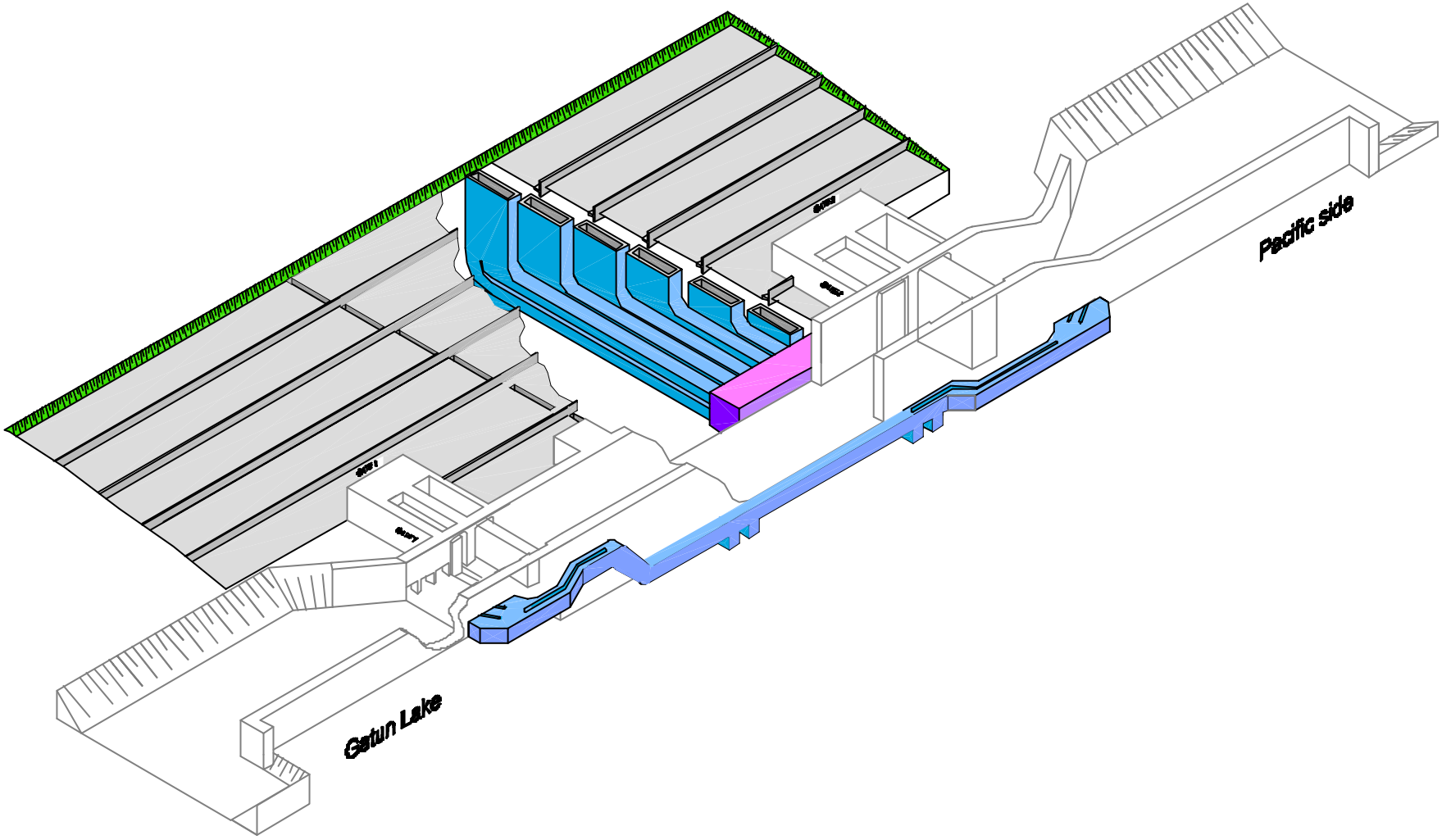
SINGLE LIFT CONFIGURATION



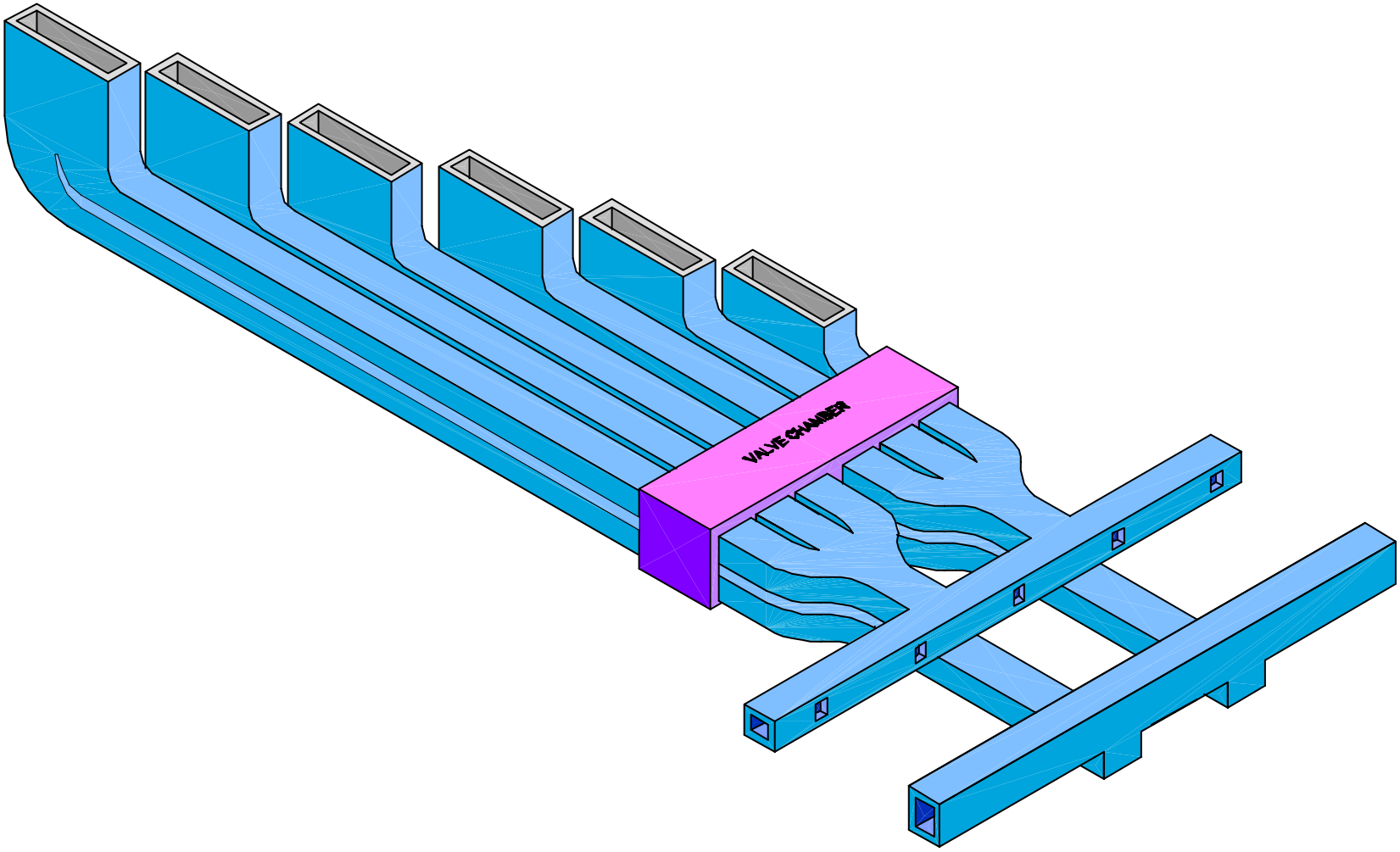
SINGLE LIFT CONFIGURATION



SINGLE LIFT CONFIGURATION



SINGLE LIFT CONFIGURATION



Diseño Conceptual de las Esclusas Post Panamax

TASK 4

A – LOCK SITING AND LAY-OUT

R4-A

Tractebel Development Engineering · TECHNUM · COYNE ET BELLIER · CNR PROJETS

in association with

ZAD · IMDC · SBE · FITA · AOSO

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1 Lock Siting and Lay Out

1.1 INTRODUCTION.

The P1 alignment has been retained as the most suitable alignment for the future third and fourth lanes of the new Post Panamax Locks at the Pacific side of the Canal. The alignment optimization analysis has been reported in the Task 3 documents.
The lock siting and lay-out has been further examined as the subject of Task 4a, and the results of this analysis are reported in this document and referenced drawings.
The lock site has been determined mainly in function of geo-technical considerations, also taken into account that excavations have to be minimized. At the other hand, nautical requirements are also very important as the lock entrance should be situated at least at a distance of five ship lengths away from the intersection of the bypass canal axis with the existing entrance canal to the Miraflores locks..
The lock lay out further depends on several conditions and requirements, such as :

- the construction of a fourth lane in the near future
- the vessel positioning system with locomotives
- the construction and space requirements of water saving basins (six WSB are imposed)

A powerpoint presentation was given during meeting M6 (December 2002 – Panama) on lock siting, it is added to this report in Appendix 1.

1.2 LOCK SITING.

The geo-technical analysis showed out that different geological substrata are recognized in the lock area. As compared to the triple lift lock structure, where it is not possible to have the entire lock structure in one homogeneous rock bottom (lock structure is over 1500m in length), the single lift lock structure can be entirely positioned in the sound Basalt formation, thus providing excellent

foundation conditions for the structure. The entrance walls will be partly in the La Boca formation, but this can be considered as a minor disadvantage.

Another important consequence of being able to locate the single lift lock structure entirely in the Basalt formation, is that the Pedro Miguel Fault is most probably not interfering. At the other hand, as the demarcation of the different substrata is based upon a limited number of borings and apparently has been done by interpolation, additional borings or other purposeful geo-technical investigation will be required to determine the exact limits of the Basalt formation.
In order to determine the most convenient position of the single lift lock structure within the Basalt formation, it was necessary to determine at first the width of the locks complex. As it is imposed by the terms of reference that a fourth lane might be constructed in the near future shortly after opening of the third lane, it is necessary to provide enough space for this fourth lane locks in the Basalt formation as well.
The construction of the east wall of the fourth lane lock should be undertaken in such a way that the operation of the third lock complex is not interrupted. This can either be arranged by providing enough space between the fourth and third lane, or by applying a construction technique which allows to minimize the future center wall width. According to this consideration, alternative solutions have been proposed under Task 4B “Lock Walls”, and reference is made to that report for further explanation.
Three alternatives have been worked out and have following characteristics :

- Option 1 : allows construction of the fourth lane wall by sufficient distance from the third lane wall; the distance is determined by the sloping angle (1:2) of excavation and provision of sufficient work space. In this way the width of the center wall is 102m, which can be considered as rather large but still acceptable as it is compatible with the 6B future canal width as shown on drawing D3-0-204.. At the other hand, as already brought to the attention in the Task 3 “General Considerations”, the corresponding alignment P1E does not meet the five ship lengths requirement (for a good understanding see drawing D3-0-203 “Comparison of lock alignments”)

- Option 2 : allows construction of the fourth lane wall very close to the third lane wall due to the application of roller compacted concrete. In this case the width of the center wall is reduced to 55.40m and as such the corresponding alignment P1C can be shifted a little more to the west in order to meet the nautical condition. At the same time more space becomes available at the east side for the water saving basins.

- Option 3 : third and fourth lane walls are combined in one single caisson wall reducing the construction width further to 36m. It corresponds with alignment P1D which is to be preferred from the nautical point of view (longest distance between lock entrance and existing canal), as well as the space available at the east is concerned for the WSB. At the other hand, the excavation volumes for P1D are slightly higher than for P1C (see report R3-0-021 on “Excavation volumes”, where a difference of 2 million m³ has been calculated). Finally option 2 is recommended to be retained as the reference for the single lift lock structure as the option 3 also requires a more important investment cost for the third lock complex, as this solution will indeed be more expensive than a single wall as set forward in option 2 (+/- 40%), although the total construction cost of option 3 is considerably less expensive than the two walls of option 2 (+/- 30%).

It should be noticed that the obtained minimum width of the center wall in both solutions 2 and 3 depends also and merely on the implementation of the positioning system with locomotives. A system with tug boats would allow to further minimize the center wall width to +/-32m, and at the same time further reduce the construction cost of the wall. This reflection is quite important because a system with locomotives will be very difficult to operate in the case of a single lift system with a height difference of +/-30m between the entrance wall and the lock wall.

1.3 LOCK LAY OUT.

The lock lay out, as proposed, is shown on drawing D4-A-201. It shows the single lift configuration with rolling gates and locomotives.
The locomotive system has been imposed as a vessel positioning system fot this conceptual design phase. The rail tracks have to be installed all over the lock, including the entrance walls (western entrance walls have a length of 1.5 x the ship length). The required space for a double track (towing and return track) has been fixed at 15m, as decided during meeting M2.
The fact that the tracks have to cross the gate recesses (east side of the lock), leads to the necessity of removable bridges (4 pieces in total). Even so, in order to allow maintenance operations to the gates, some free space is required between the top level of the gate and the bridge. This has as a main consequence that the level of the top of the lock walls has been fixed at 3m above the maximum water level in the lock chamber (instead of 2.13m in the T.O.R.). As an additional measure to reduce construction height for the single lift lock configuration, the downstream gates have been equipped with two lower rolling wagons instead of the wheel barrow system.
Another consequence of the locomotive tracks is the position of the valve chamber on the longitudinal culvert. As the culvert is normally situated down below the rail tracks, it is not possible to install the valve chamber without diverting the culvert 15m away from the lock wall.

The water saving basins are shown on drawing D4-A-203 in plan view and D4-A-202 in cross section. Advantage has been taken from the existing third locks excavation (1939), thus minimizing excavation volumes. Contrary to the arrangement of the third lock water saving basins, the deepest (or lowest) WSB has been kept closest to the lock as the wall excavation is much more important. Even so, the lock wall is at the same time the limit of this lowest basin, which is of economical interest – for the WSB as well as for the lock wall.
As there are six water saving basins, more space is required in the transverse direction of the lock than in the triple lift lock configuration. As there is a hill at the east side of the lock, a solution had to be looked for to minimize the excavation by trying to avoid the hill (see drawing D3-0-205). In this case of the single lift lock it is possible to increase the length of the basins because there are no adjacent lock chambers. The length of the basins has therefore been increased to the double, thus reducing the width by the same ratio. In this way excessive excavation has been avoided, and the total excavation volume for the WSB has been estimated at a little less than 2 million m³. Further optimization might be possible during detailed design, possibly by adapting the shape and the lay-out of the basins.

Drawing D4-A-201 shows the general arrangement for traffic at the single lift lock configuration.:

- traffic (lock related traffic) is arranged around the water saving basins, with two main access roads leading to the waterfront on the east side of the lock. The longitudinal walls between the parallel basins are not accessible for traffic.
- the area occupied by the locomotive tracks can also be used for traffic if the rails are properly embedded in the pavement.
- the lock gates at the Gatun lake side will be equipped with a movable bridge deck which will allow traffic to cross the gate and the lock.
- the lock site can be linked with the existing roads at the east and the west.

Drawing D4-A-201 also shows the position proposed for :

- lighting poles
- high voltage rooms
- control buildings
- ware houses
- valve chambers
- technical lock gate operating buildings
- bollards
- fenders
- ladders

Finally, it is interesting and important to stress that the imposed vessel positioning system has quite some impact on the lay out of the lock :
- there is a necessity of having a long entrance wall at both sides of the lock,
- the rail tracks have to cross the gate recesses on the east, and the top of the walls needs to be raised (3m above maximum water level)
- the main culvert needs to be diverted to install the valve chambers,
- the rail tracks take an area of 15m wide.

1.4 PUMPING BASIN.

Drawing D4-B-213 shows provisions to connect both culvert outlets at the Pacific side of the lock with a pumping reservoir on the east side of the entrance. A valve chamber has to be installed at the connection with the canal. Reference is made to the report on the filling and emptying system for more details (R4-C).

1.5 RIO COCOLI DIVERSION.

The new lock site for the single lift configuration is situated downstream of the river “Rio Cocoli”, which runs actually into the Miraflores lake.
As this lake is some 10m lower than the future third lane canal, the river has to be diverted either by means of a culvert passing beneath the new bypass canal, or to the Pacific side of the lock by means of a pipe or a new canal. Both solutions are expensive, and therefore another solution is proposed. This solution can be similar to the one which has been shown for the triple lift configuration on drawing D3-0-005.

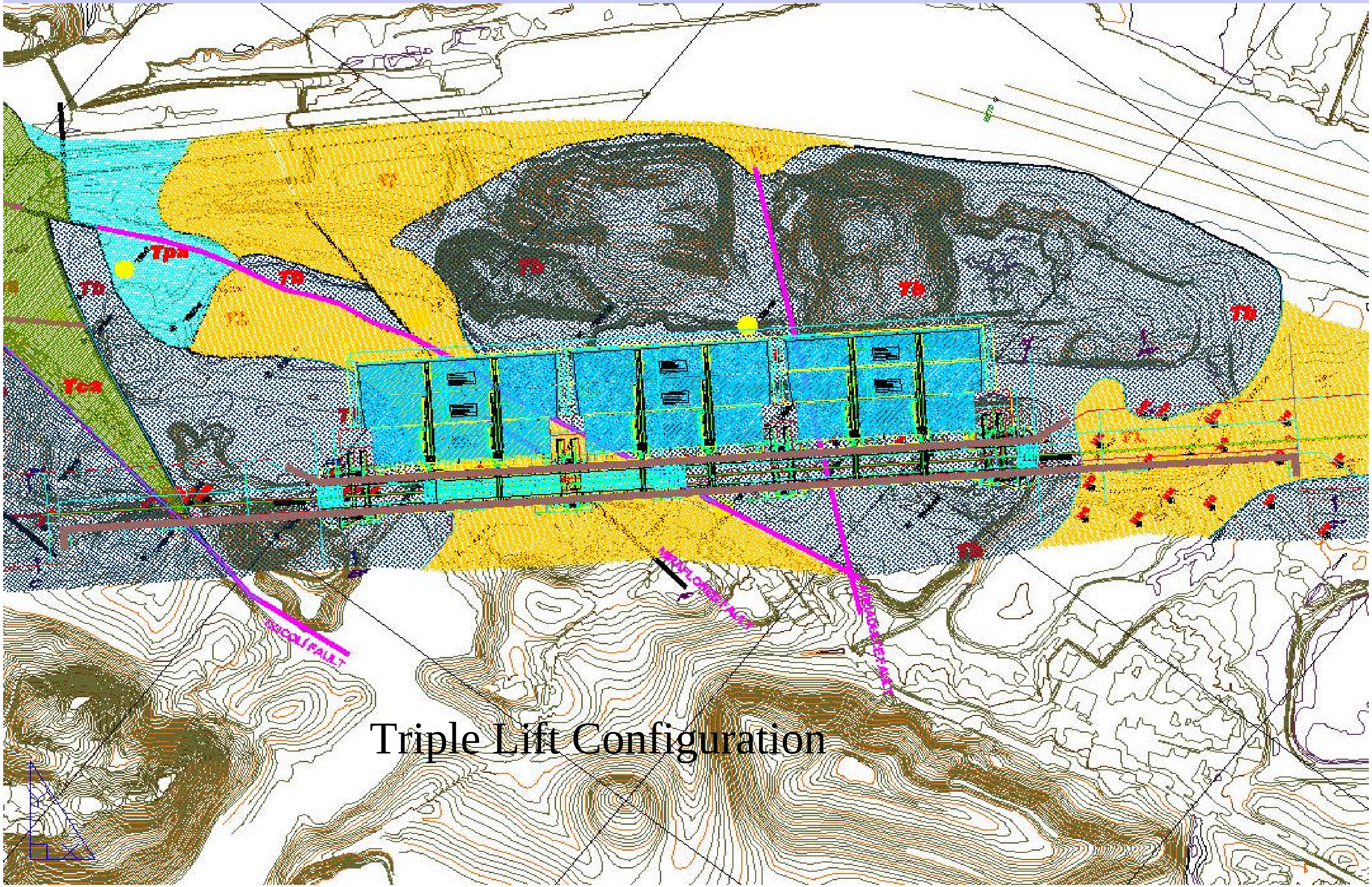
1.6 APPENDIX 1

LOCK SITING : Specific conditions

- Geological situation
- Nautical access
- Space requirements (WSB)
- Excavation

Geological Situation

- The triple lift lock structure is situated in both Basalt and La Boca formations due to its length (see next slide)
- The single lift lock structure is +/- 1/3 in length and can be situated entirely in Basalt
- It is suggested that the fourth lane lock should also be situated in Basalt



Triple Lift Configuration

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CNR PROJETS
COYNE ET BELLIER
FITA AOSO
IMDC

Geological Situation

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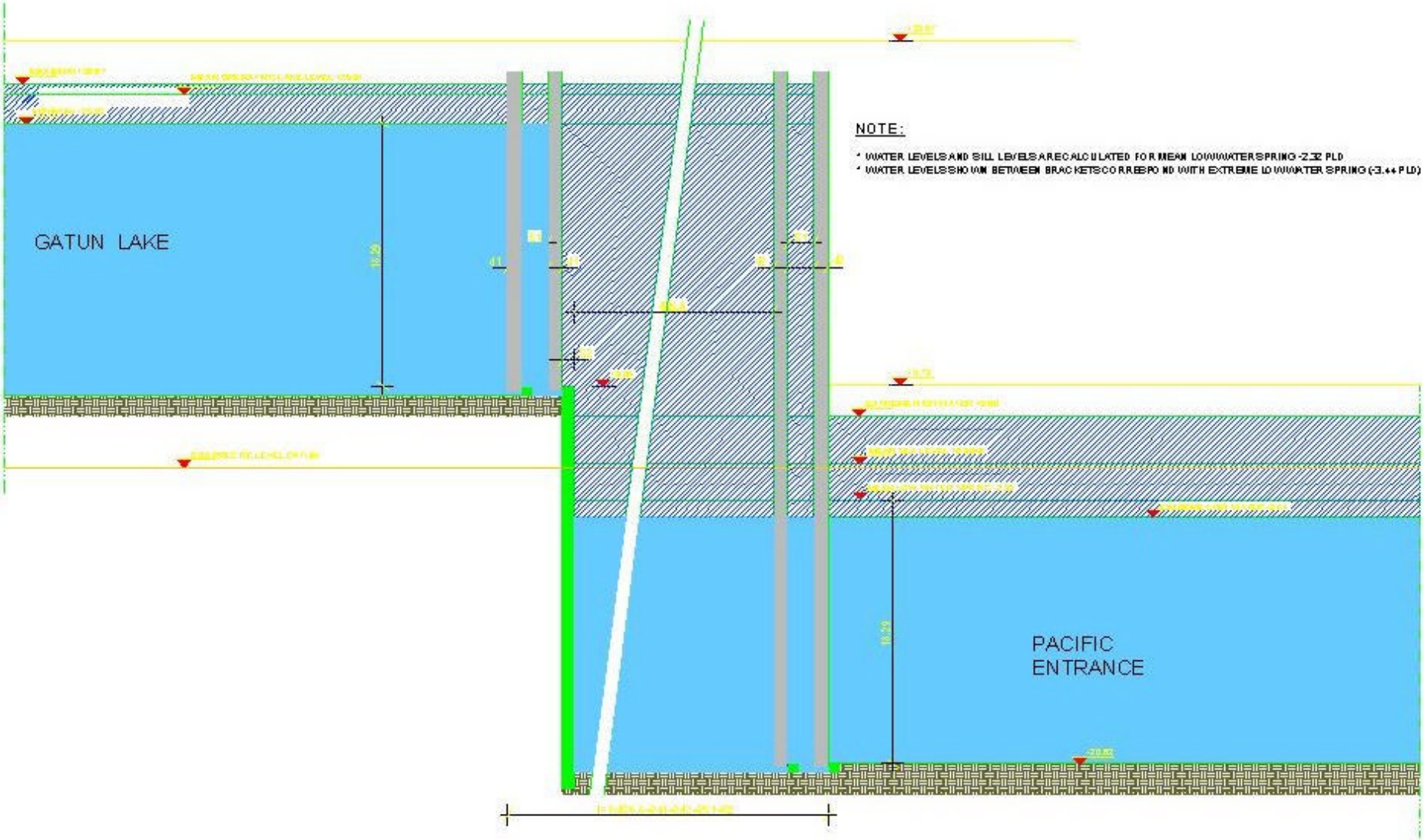
- The single lift lock structure is +/- 1/3 in length and can be situated entirely in Basalt
- It is suggested that the fourth lane lock should also be situated in Basalt

Single lift configuration



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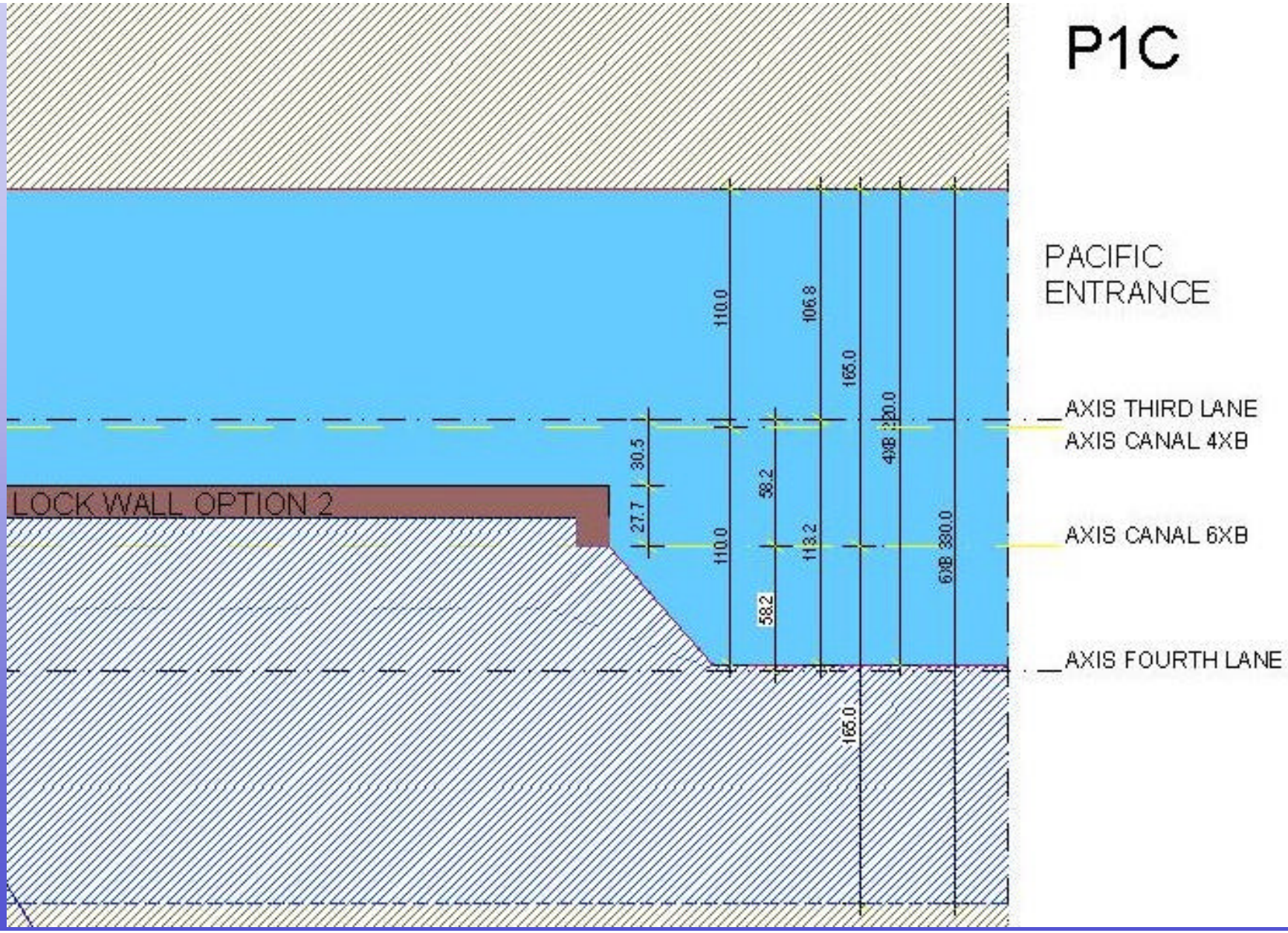
FITA AOSO

IMDC



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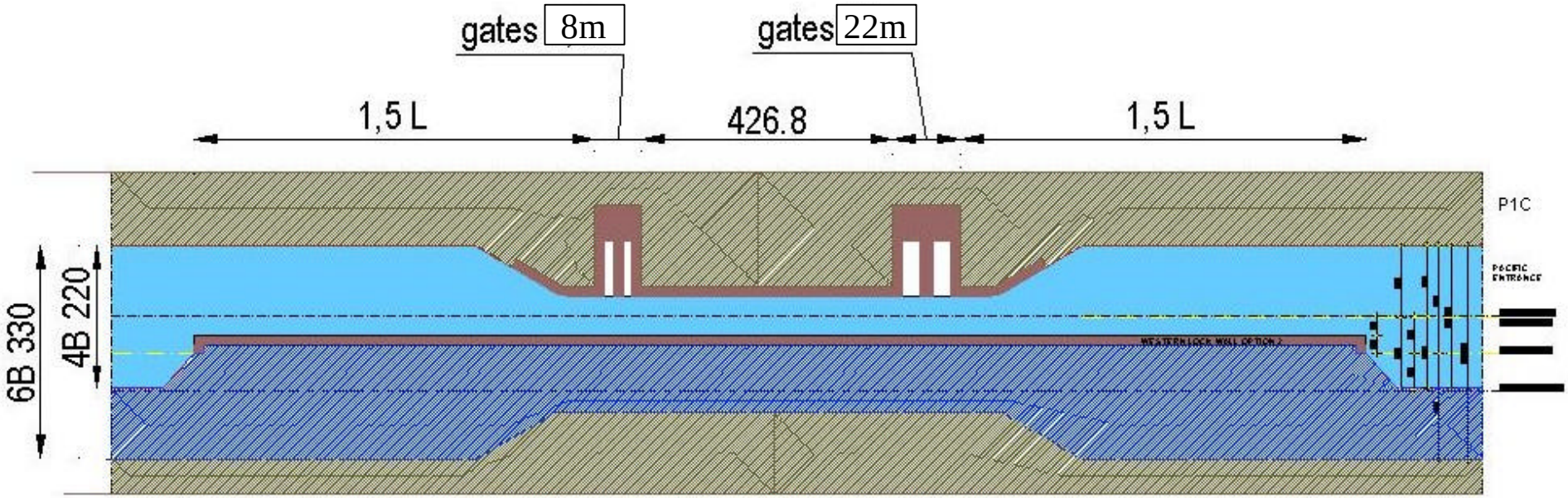
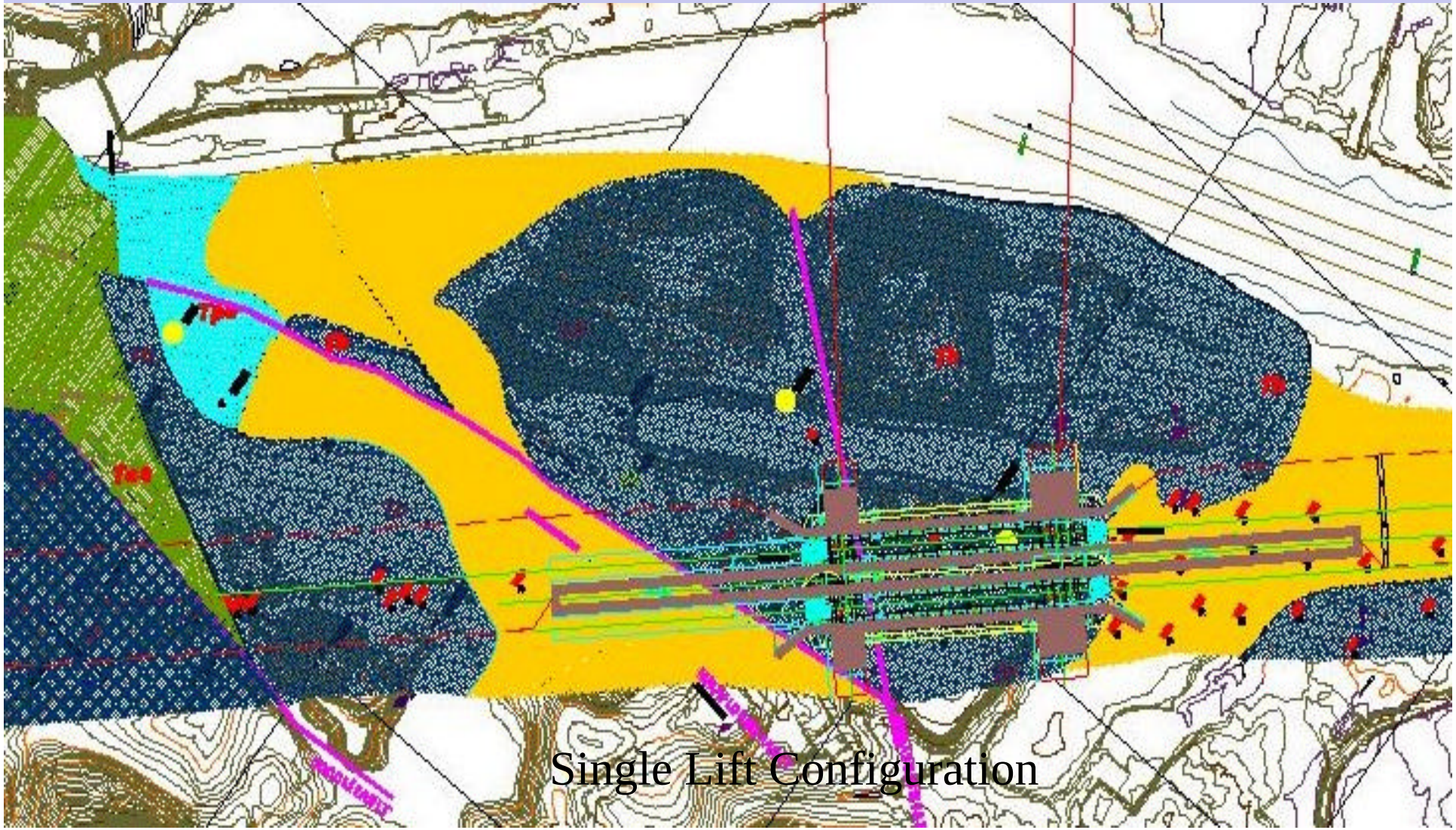

gates 8m
gates 22m
1,5 L
426.8
1,5 L
P1C
6B 330
4B 220



Single Lift Configuration

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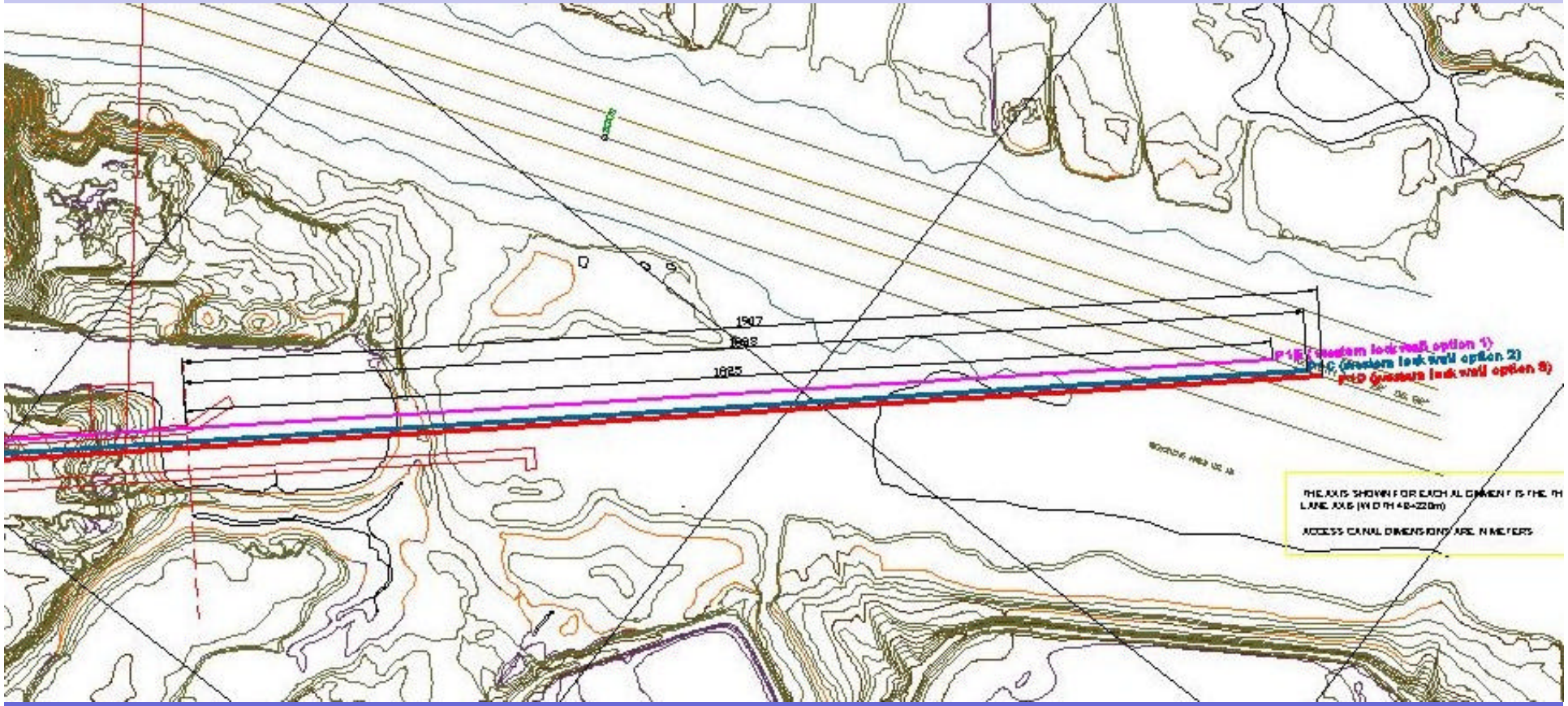
Nautical Access

- Different alignments (P1C – P1D – P1E) according to width of the center wall
- Required stopping length 5L



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PORT OF ANTWERP

Space Requirements

- Six parallel water saving basins

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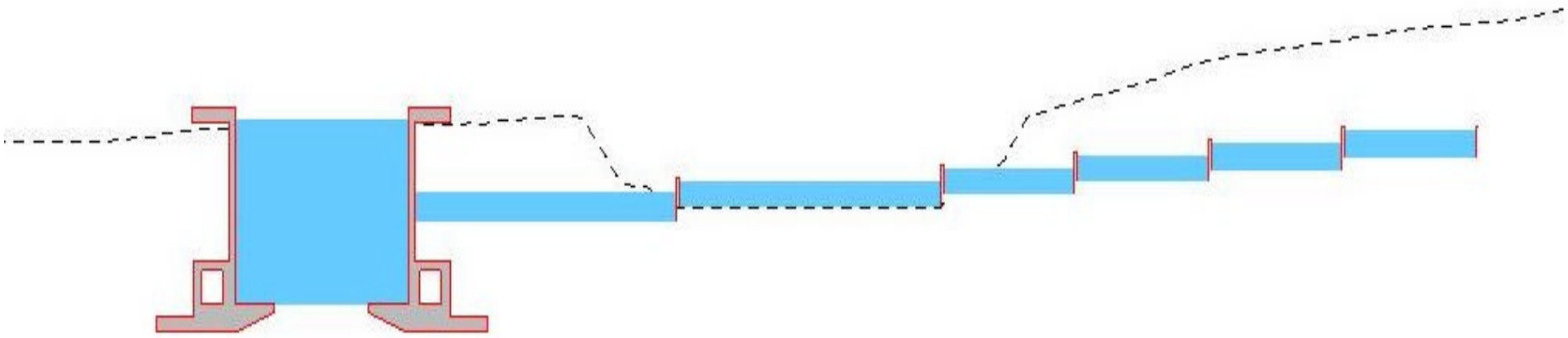
Excavation



Water saving basins

- Additional excavation of 2.000.000m³ of rock
- Space required : over 225.000m² (22.5ha)
- Stacked basins would save excavation and space, but are considerably more expensive

Diseño Conceptual de las Esclusas Post Panamax

TASK 4

B - LOCK WALLS

R4-B

Tractebel Development Engineering
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in association with

IMDC
SBE
FITA AOSO

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Appendix I

1 Lock Walls

1.1 DESIGN CRITERIA

Design criteria for the new lock structures have been given in report R2-A "Design Criteria – Part A: General Design Criteria" and report R2-B "Design Criteria – Part B: Specific Design Criteria".

Additional design criteria which are related to the results of previous studies and investigations are the following:

- Levels of sills and top of walls (see drawing D2-0-201 Design Levels)
- Dimensions and lay-out of culverts, and ports in the lock walls
- Lock siting and corresponding geo-technical conditions
- Type and dimensions of lock gates

Reference is made to following drawings:

- D4-B-201 Eastern and Western Lock Walls + Entrance Walls : longitudinal view
- D4-B-202 Plan view on entrance Gatun Lake side
- D4-B-203 Plan view on lock chamber
- D4-B-204 Plan view on entrance Pacific side
- D4-B-205 Cross section Eastern Lock Wall
- D4-B-206 Cross sections Western Lock Walls

1.2 LOCK WALL TYPES

The choice of a technical-economical convenient lock wall type depends on several criteria, such as:

- Geo-technical conditions
- Loadings

- Seismic conditions

Several lock wall types are described in literature. A presentation on lock wall types was made during meeting M3 in Panama (week 25; June 2002). A handout of this power point presentation is given in the final report of the triple lift configuration..

One major condition that governs the choice is the geo-technical situation of the lock siting. The single lock configuration (lock heads and walls) is situated entirely in rock (basalt).

Therefore it is impossible or/and not recommended to use sheet piles, slurry walls or piled structures.
Due to the imposed positioning system with locomotives, it is not possible to have sloped lock walls in the lock chambers, on the contrary it requires the construction of vertical retaining walls.

The lock wall types that can be retained for the third locks project are:
- The gravity wall
- The anchored wall

The construction of these lock wall types requires large open excavations with great depth. The anchored wall type in rock could be considered as an economical solution by saving excavation volumes (if vertical or very steep excavations can be realized), but at the other hand the culvert in the wall situated at the future bottom chamber level is an insurmountable problem to do so. There are also some doubts about the life expectancy of grout anchors. Therefore, the anchored wall will not be retained for the lock walls. It could however be useful for other retaining walls, for example along the water saving basins.

The most feasible construction type is consequently a gravity type wall. Reference can be made to several existing structures, such as the existing Miraflores lock walls, locks in Belgium (Antwerp), and many others, which show that the gravity type wall is a very reliable structure.

Advantages of the gravity wall are essentially as follows:
- Construction in open (dry) excavation allows a very sound quality control and accordingly guarantees a maximum life expectancy for the structure
- Culverts and conduits can easily be incorporated in the structure
- With a rock foundation there will normally be negligible settlements, and as such the lock structure will require only a minimum of maintenance.
- The lock gate recesses can easily be integrated in the lock wall structure

Some special attention has to be paid to following aspects:
- The lock wall has to be equipped with expansion joints, a maximum length of +/- 30 m for each wall partition will be adopted. In each joint a synthetic or rubber flexible expansion joint will be fixed in the concrete walls, in order to guarantee water tightness of the system.
- Special care has to be taken to avoid concrete cracking and/or deformation due to shrinking and exposure to extreme temperatures.

This can be realized by means of protection against sun exposure, cooling, proper concrete-mix composition, application of low heat cement, low water/cement ratio, addition of fine aggregates such as silica-fume and/or special additives.

1.3 ALTERNATIVE SOLUTIONS FOR THE GRAVITY TYPE LOCK WALL

The retained alternatives for the gravity type lock wall in rock are shown on drawings D4-B-205 and 206.
A powerpoint presentation was given during meeting M6 in Panama (December 2002), a copy of part of this presentation is added to this report in appendix I.
Distinction has been made between the lock wall at the east side and the one at the west side of the lock.

At the east side, the lock wall is adjacent to the water saving basins which are staggered one next to each other with the deepest basin close to the lock wall. The lock wall is designed to retain and withstand the full pressure of the backfill to the top and the full water pressure behind the wall, as ACP wishes to postpone possibly the construction of the WSB. If the decision would be taken to construct the WSB together with the lock wall, it could be designed for the corresponding more favorable conditions (less backfill, lower water pressure behind the wall). However at this moment it is assumed that the economical benefit is negligible, and certainly does not compensate the investment cost of the water saving basins. It can be considered as an optimization to be done during detailed design.

The lock wall shape is similar to the one of the triple lift configuration, but the dimensions are proportionally larger as the total height of the wall is nearly 1.6 times more than the one of the triple lift configuration. The excavation in rock has been taken 1:2 (H:V), and in order to minimize excavations for the WSB, the lowest basin is put the closest to the lock wall. In this case the application of roller compacted concrete has not been retained as the WSB would be further away from the lock wall. At the other hand the thickness of the front wall has been increased from 2 up to 3m to compensate for the absence of backfill.
The width at the foundation level has been determined in function of required safety against overturning; sliding is impossible due to the embedment in solid rock.
In order to minimize excavation volumes, a heavy toe at the front side has been foreseen, instead of enlarging the footing backwards.

The culvert with dimensions 9m x 7.5 m (W x H) which extends all over the lock, is integrated in the lower part of the lock wall. (The attention is drawn to the fact that these dimensions have been reversed for practical reasons, this does not change the dimensioning of the wall).
Due to the culvert, the lower part of the lock wall has to be a reinforced concrete structure. On top of this structure, a reinforced concrete wall with counterforts at regular distances (6m) retain the backfill and the water in the WSB.

At the wall's top surface provisions are made to install the locomotives, and a cable duct is integrated in between the towing and return track. In doing so, a 26.2m wide work platform is created, which should normally be sufficient for lock operations.

The backfilling with crushed stones is a natural drain, keeping the water level at a sufficiently low level, and is also very useful to lower the water level behind the wall if for any reason one should decide to dewater the lock chamber.. It can be a recuperation of the excavation of the basalt rock formations.

At the west side of the lock the situation is different: there are no water saving basins, and provisions have to be made to construct the fourth lane in the future.
Reference is made to Task 3 and Task 4a where the alignment and the lock siting have been investigated and where it was found that a minimum width of the center wall is to be preferred. Three alternatives have been investigated :

1) Option 1 (corresponds with alignment P1E) : gravity wall in RC
2) Option 2 (corresponding with alignment P1C : gravity wall with RC+RCC
3) Option 3 (corresponding with alignment P1D) : caisson wall in RC

Each of these solutions shown on drawing D4-B-206 have specific advantages, from the technical as well as from the economical point of view. These will be highlighted in the following descriptions :

Option 1 Gravity type wall in RC.

This wall type is very similar to the east wall as well as to the RC wall type of the triple lift configuration. Due to the height a rather large excavation is required when considering a sloping angle of 1:2 (H:V). As this western wall has to be kept in service during a future extension with the fourth lane construction, a safe distance has to be adopted between the lock wall work surface and the excavation required for the construction of the fourth lane lock wall. A minimum working surface width of 30m has been provided and in doing so, a width of 102m is required for the center wall. This value has been considered too large to meet with the lock siting and alignment requirements. Due to the fact that the entire lock structure has to be kept in the basalt formation, the structure has to be shifted towards the east and the existing entrance canal of the Miraflores locks in the same proportion as the center wall becomes wider. In this case of option 1 the distance between the new entrance canal axis and the crossing with the existing canal axis becomes considerably smaller than the requires five ship lengths. Another problem is due to the water saving basins, which will also shift to the east and thus require more excavation at the hillside.
As a consequence it is not recommended to retain option 1 for the third lock structure. Nevertheless, a cost estimation has been worked out, merely as a reference for comparison.

Option 2 Gravity wall type in RC+RCC.

The disadvantage of the large excavation and its consequence regarding the width of the center wall can be avoided by using a lock wall type with roller compacted concrete. Indeed, as this solution allows entire excavation behind the wall, the fourth lane wall can be constructed immediately adjacent to it.. Of course one has to ensure stability in this

second phase of excavation while the third locks are in operation (lock chamber filled and construction site dewatered). At the other hand, the center wall cannot be made smaller than the width required to install the position system (locomotives) and the culverts (including deviated sections at the lock head positions – valve chambers). That's one of the reasons for the rotation of the culverts by 90 degrees as shown on the drawing, thus reducing the culvert width by 1.50m. This is possible without other consequences because at the east side of the lock the culvert is not interfering with the lock gate chamber (as the lock gate chamber is located at the east side). The cross section over the split culvert (which is merely theoretical because that position is in practice located in the lock head) allows to determine the minimum width of the lock wall and as such, of the center wall. The result is a center wall which is 55.40m wide, and this solution still allows to construct the fourth lane wall in a later phase when the third lane is in operation. This is consequently the solution which is recommended to be retained for the third lock structure.

Option 3 Caisson wall in RC.

Some further considerations about construction width and positioning of rail tracks versus culverts have led to a third possible option, in which the fourth and third lane walls are combined in one construction, which has been conceived as a caisson wall in reinforced concrete.
As this solution would allow to adapt the rail disposition immediately to serve the third and fourth lane together, the return track can be positioned in the middle of the center wall. Doing so, the required deviation of the culverts at the valve chamber is minimized, thus further reducing the center wall width to a minimum of 36m.
A caisson type wall as a combination of third and fourth lane lock walls has several advantages when compared to the preceding ones, amongst others the most important :

- minimum excavation and minimum construction width for the third and fourth lane together;
- minimum concrete volume
- very stable and reliable structure
- no risk of disturbing the operation of the third lock during construction of the fourth lane
- minimum investment cost
- best position of the alignment and the lock siting

At the other hand it has to be considered that the additional investment, which can be estimated at 40% of the option 2, has to be financed in a very early stage, as the fourth lane might probably only be constructed at the soonest 10 years after the opening of the third lane. And another constraint is the fact that the dimensions of the fourth lane lock will be fixed for the future as the lock wall will already exist.
As a consequence, although this solution shows some very interesting advantages, it has not been retained as the basic solution for the third lock structure, the cost estimation however will indicate the required additional investment cost which will allow ACP to decide whether this option has to be retained for detailed design and further optimization studies or not.

1.4 LOCK WALL ANALYSIS

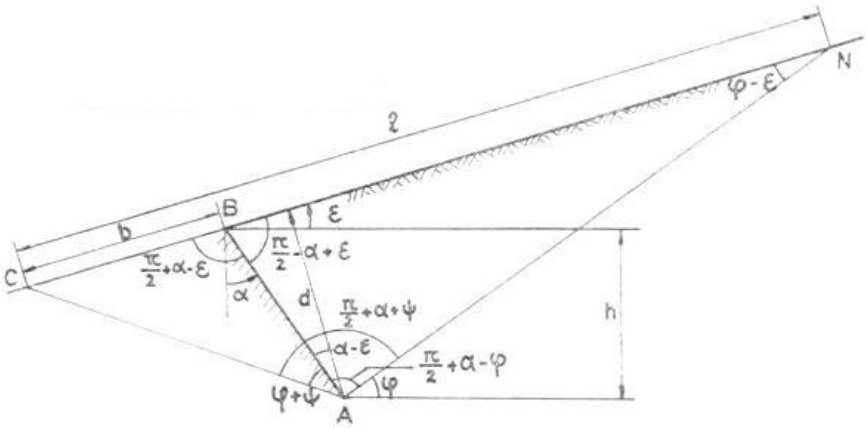
1.4.1 LOADS

A. Self Weight (case 1)

Concrete γ= 24.5 kN/m³
Wet Soil γ= 20.0 kN/m³
Dry Soil γ= 18.0 kN/m³

B. Earth Pressure (case 2)

The active earth pressure will be calculated using the formula of COULOMB-PONCELET



$$\lambda_a = \frac{\cos^2(\varphi - \alpha)}{\cos^2\alpha \cos(\alpha + \psi)\left(1 + \sqrt{\frac{\sin(\varphi + \psi)\sin(\varphi - \varepsilon)}{\cos(\alpha + \psi)\cos(\varepsilon - \alpha)}}\right)^2}$$

The angle of friction in the filling of crushed stone is 45°
On the surface a load p=10 kN/m² is applied. (5 kN/m² in seismic conditions)

C. Water Pressure (case 3)

Inside the lock, the minimum water level will be applied.
At the backside of the wall the maximum water level of the lock chamber will be applied.

D. Seismic Loads

D.1 Earthquake level

According to the PIANC "Seismic Design Guidelines for port structures" two levels of earthquake motions have to be considered

Level 1 (L1): the level of earthquake motions that are likely to occur during the life – span of the structure
Level 2 (L2): the level of earthquake motions associated with infrequent rare events.
(Return period = 475 years for port structures with a life-span of 50 years)

For each level an acceptable damage level is defined.

D.2 Performance Grade

The highest performance grade (Grade S) is applicable for

- critical structures with potential for extensive loss of human life and property
- key structures that are required to be serviceable for recovery from earthquake disaster
- critical structures that, if disrupted, devastate economic and social activities

This means that the level of damages is:

- Structural: minor or no damage
- Little or no loss of serviceability

for both levels L1 and L2.

D.3 Analysis type

As this report concerns a conceptual design we will use the simplified analysis.

D.4 Equivalent seismic coefficient ke

Results for the design earthquakes: (See R2-A)

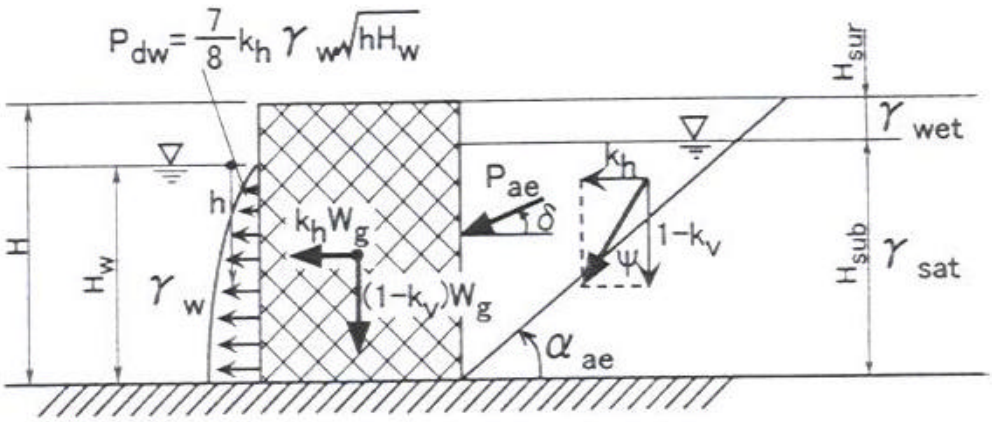
Return periods->	**MCE** -	**MDE** 950 yrs	**OBE** 145 yrs	***SMDE*** *1000 yrs*	***SDE*** *475 yrs*
North Panama Deformed Belt	0.21	0.16	0.13	*0.16*	*0.15*
Pedro Miguel Fault	0.21	0.18	0.13	*0.18*	*0.16*
Recommended PGA (in g) ***(for rock conditions)***	**0.21**	**0.18**	**0.13**	***0.18***	***0.16***
	ICOLD			*UBC*	

With MCE = Maximum Credible Earthquake
MDE = Maximum Design Earthquake
OBE = Operating Basis Earthquake
SMDE = Site Maximum Design Earthquake
SDE = Site Design Earthquake

MDE for L2 will be used. This means that only small deformations during MDE will be allowed.
L1 is not determining

In addition, the calculations for MCE will be repeated, allowing higher deformations but no loss of stability.

k_e = PGA/g for PGA < 0.2 g for retaining walls
so $k_v = k_h$ = 0.18 for MDE
and $k_v = k_h$ = 0.21 for MCE



(a)

Case 7: Seismic loads on concrete structure
Case 4: Earth Pressure in seismic conditions

E. Water Pressure in Dry Lock Conditions (case 5)

Identical as case 3 but no water pressure at the front side

F. Bollards / Locomotives (case 6)

The forces needed to move a ship into the lock depends on:

- The water displacement of the ship
- The velocity of entering the lock
- The angle of the lines
- The ratio cross section ship/lock
- etc.

The calculation of these forces is very complicated and can only be determined with physical model tests.

The lock walls for the Berendrecht lock were designed for a horizontal load of 50kN/m.

The wall is divided into segments of about 30m, so the total horizontal load applied to one segment is 1500kN.

The maximal horizontal force of the locomotives at the existing locks is 312kN per locomotive. With 2 locomotives on one segment of 30m, the total horizontal load on this segment is 624kN.

So the forces that will be taken into account for the new lock are a factor 2.4 higher than those of the existing locks.
This assumption has to be confirmed by physical model tests.

The weight of the locomotives is not included in the actual calculations, because they can be considered as favorable for general stability of gravity type walls.

1.4.2 LOAD COMBINATIONS

According to ROSA 2000

A. Quasi Permanent Load Combination

CASE101 = 1.00 x [1] + 1.00 x [2] + 1.00 x [3] + 1.00 x [6]

B. Accidental Load Combination - MDE

CASE102 = 1.00 x [1] + 1.00 x [3] + 1.00 x [4a] + 1.00 x [7a]

cases [4a] and [7a] are the seismic loads related with the MDE

C. Rare Load Combination

CASE103	= 1.00 x	[1]	+ 1.00 x	[2]	+ 1.00 x	[5]

D. Fundamental Load Combinations

CASE 104	= 1.20 x	[1]	+ 1.20 x	[2]	+ 1.00 x	[3]	+ 1.20 x	[6]
CASE105	= 0.90 x	[1]	+ 1.20 x	[2]	+ 1.00 x	[3]	+ 1.20 x	[6]
CASE106	= 1.20 x	[1]	+ 1.20 x	[2]	+ 1.00 x	[5]		
CASE107	= 0.90 x	[1]	+ 1.20 x	[2]	+ 1.00 x	[5]		

E. Accidental Load Combination - MCE

CASE108	= 1.00 x	[1]	+ 1.00 x	[3]	+ 1.00 x	[4b]	+ 1.00 x	[7b]

cases [4b] and [7b] are the seismic loads related with the MCE

The MCE-values will be used for the criteria concerning global stability (turn over, deep seated sliding).

1.4.3 CRITERIA

According to ROSA 2000

A. Sliding along the base

Not applicable in basalt rock.

B. Turn over

Load Combination	Criterion
101	Compression zone A' > 90% A
103	Compression zone A' > 75% A
104 to 107	Compression zone A' > 10% A
108	Compression zone A' > 10% A

C. Load Bearing Capacity

$\gamma_d \cdot q_{ref} < q_u$
γ_d . = 1.4 for load combination 104 to 107
γ_d . = 1.0 for load combination 102 (MDE)

q_u = ultimate load bearing capacity

q_{ref} = reference pressure

D. Deformations

The deformations will be checked for frequent and rare load combinations 101, 102 (MDE) and 103

E. Concrete Stresses

Fundamental load combinations: 103 tot 107: 1.125 x $\sigma_c < 0.85\ f_{ck}/1.5$
Accidental load combination: 102 (MDE): $\sigma c < 0.85\ f_{ck}$

The factor 1.125 is a result of combination of the different factors in the load combinations between ROSA 2000 and Eurocode

F. Global Stability

Not applicable for Basalt Rock

1.4.4 SOFTWARE

The calculations are made by means of "EFFEL", a finite element program.
The model which will be used is a 2D-model.

In addition, a verification with PLAXIS will be made.

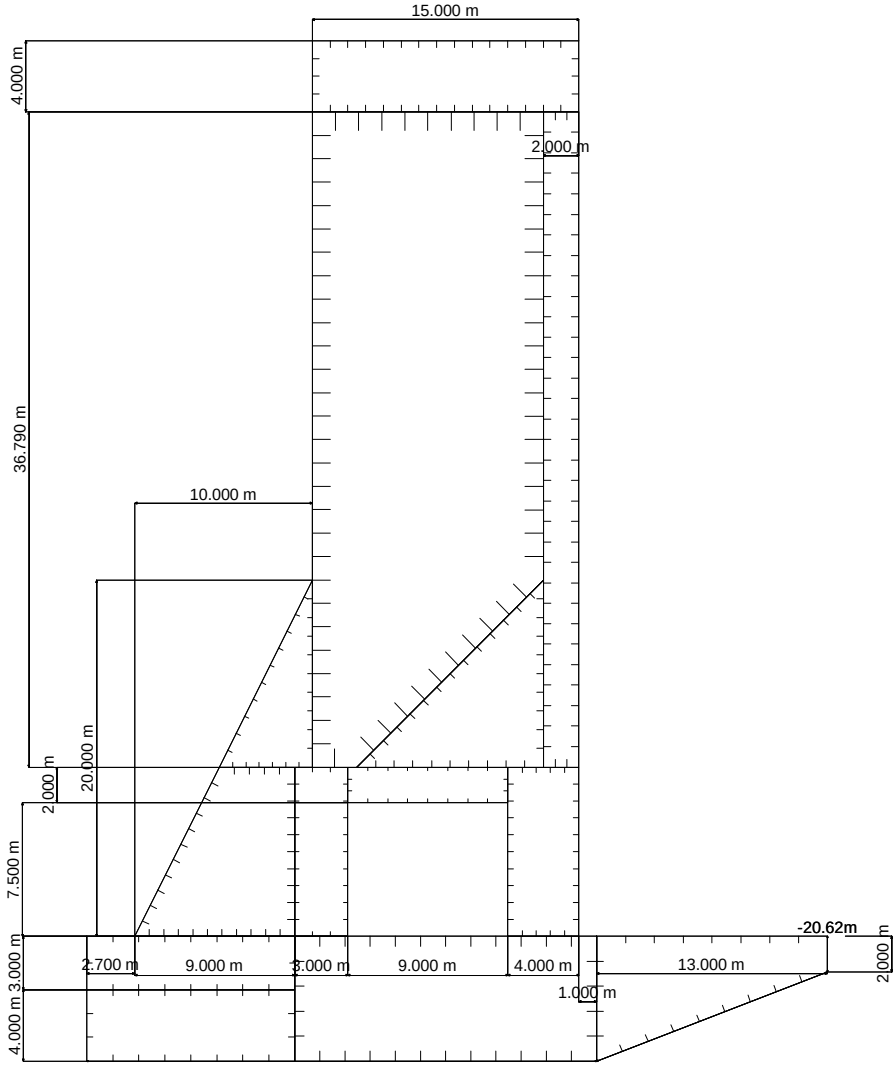
PLAXIS is a finite element package specifically intended for the analysis of deformation and stability in geo technical engineering projects.

1.5 TYPE 1 – REINFORCED CONCRETE

See Drawing D4-B-206 OPTION 1

1.5.1 INPUT DATA

A. Geometry



B. Materials

Material	E kN/m²	Nu	W/V kN/m3	Alpha
CONCRETE	19620000	0.100	24.525	0.0000100
COUNTERFORT	3270000	0.100	10.000	0.0000100
Rock	12500000	0.000	0.000	0.000000

The E-modulus for the buttresses is only 1/6th of the one for concrete, because there is only one counterfort of 1m every 6m.

C. Supports

The rock base is modeled by means of a linear support.

Vertical:
Linear support with K= 1000000kN/m² is introduced.
This support only works when compressed.
Horizontal:
Linear support with K= 1000000kN/m² is introduced.
This support only works when compressed.
The K-values are estimated values.

In order to evaluate the results, especially the deformations, a second model will be built where the rock base is modeled as an elastic material. In this second model the connection at the bottom of the wall between concrete and rock can be compressed or tensed. To deal with this problem, the tensed zone is replaced by a gap. The deformations of both models will be compared.

D. Loads

D.1 Self Weight (case 1)

D.2 Earth Pressure (case 2)

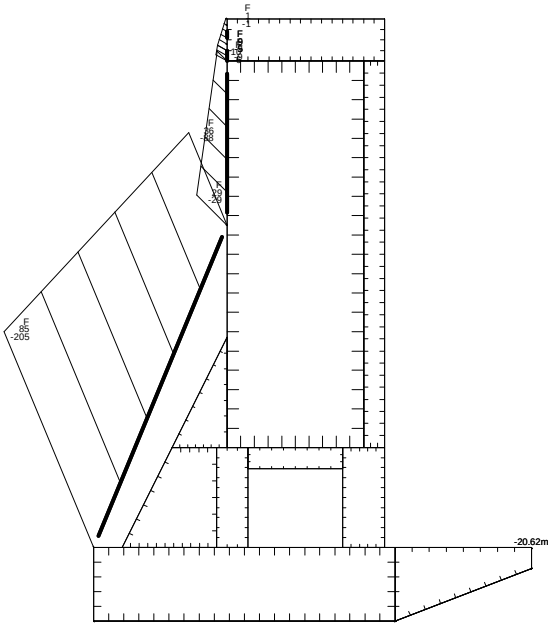
It is assumed that the rock does not exert any pressure on the wall.

from	29.67		26.67	
			λav =	λah =
λa =	0.1620		0.0810	0.1403
ϕ =	45		δ =	30
α =	0		α+δ =	30
z	p		**pv**	**ph**
29.67	10		0.810	1.403
26.67	64		5.183	8.977

from	26.67	to	25.67	
			λav =	λah =
λa =	0.1620		0.0810	0.1403
ϕ =	45		δ =	30
α =	0		α+δ =	30
z	p		**pv**	**ph**
26.67	64		5.183	8.977
25.67	74		5.992	10.379

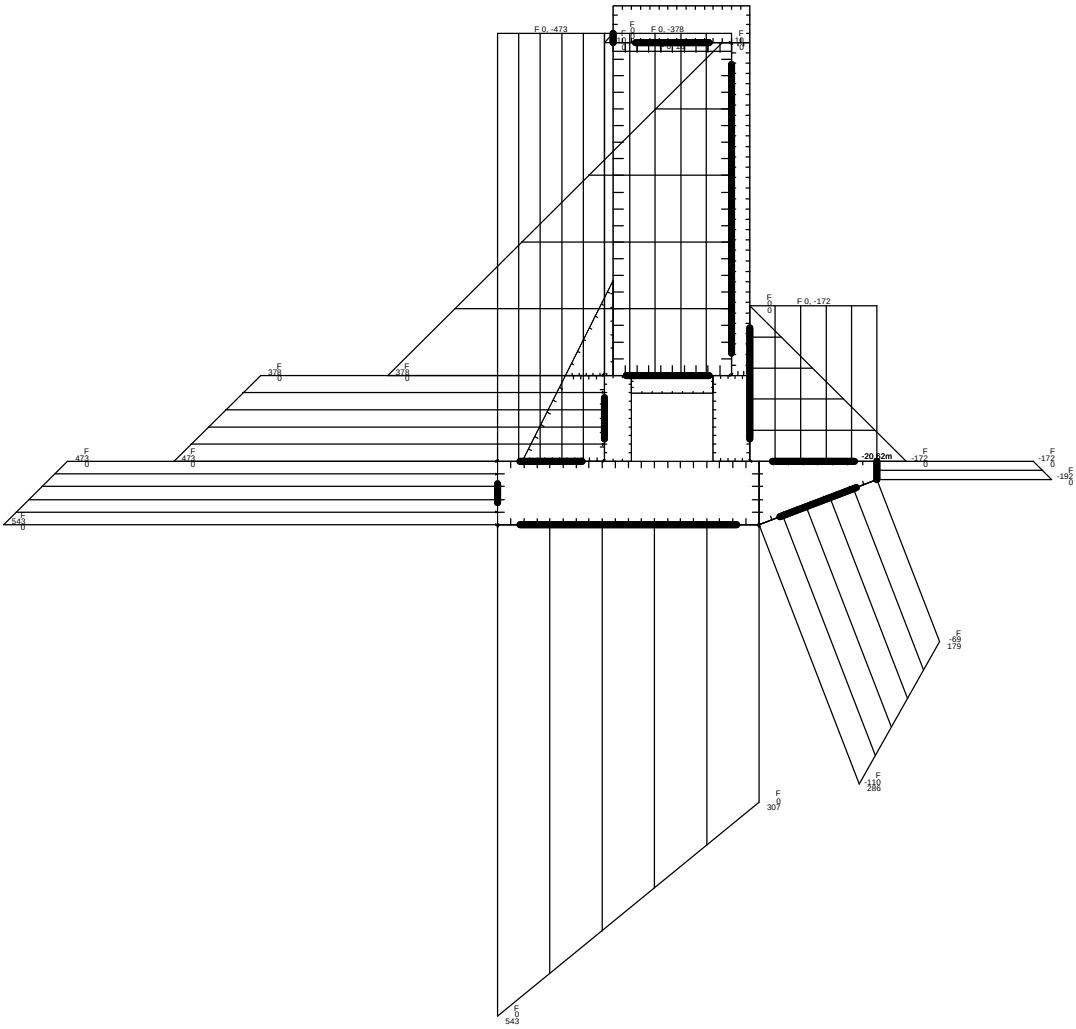
from	25.67	to	10.04	
			λav =	λah =
λa =	0.1768		0.1250	0.1250
ϕ =	45		δ =	45
α =	0		α+δ =	45
	p		**pv**	**ph**
25.67	74		9.250	9.250
10.04	230.3		28.788	28.788

from	10.04	to	-20.62	
			λav =	λah =
λa =	0.4483		0.4142	0.1716
ϕ =	45		δ =	45
α =	22.5		α+δ =	67.5
	p		**pv**	**ph**
10.04	230.3		95.393	39.513
–20.62	536.9		222.391	92.117



D.3 Water Pressure (case 3)

Water level inside the lock: -3.44 m
Water level outside the lock: +26.67m



D.4 Seismic Loads

According to the PIANC regulations for Seismic design of Port Structures

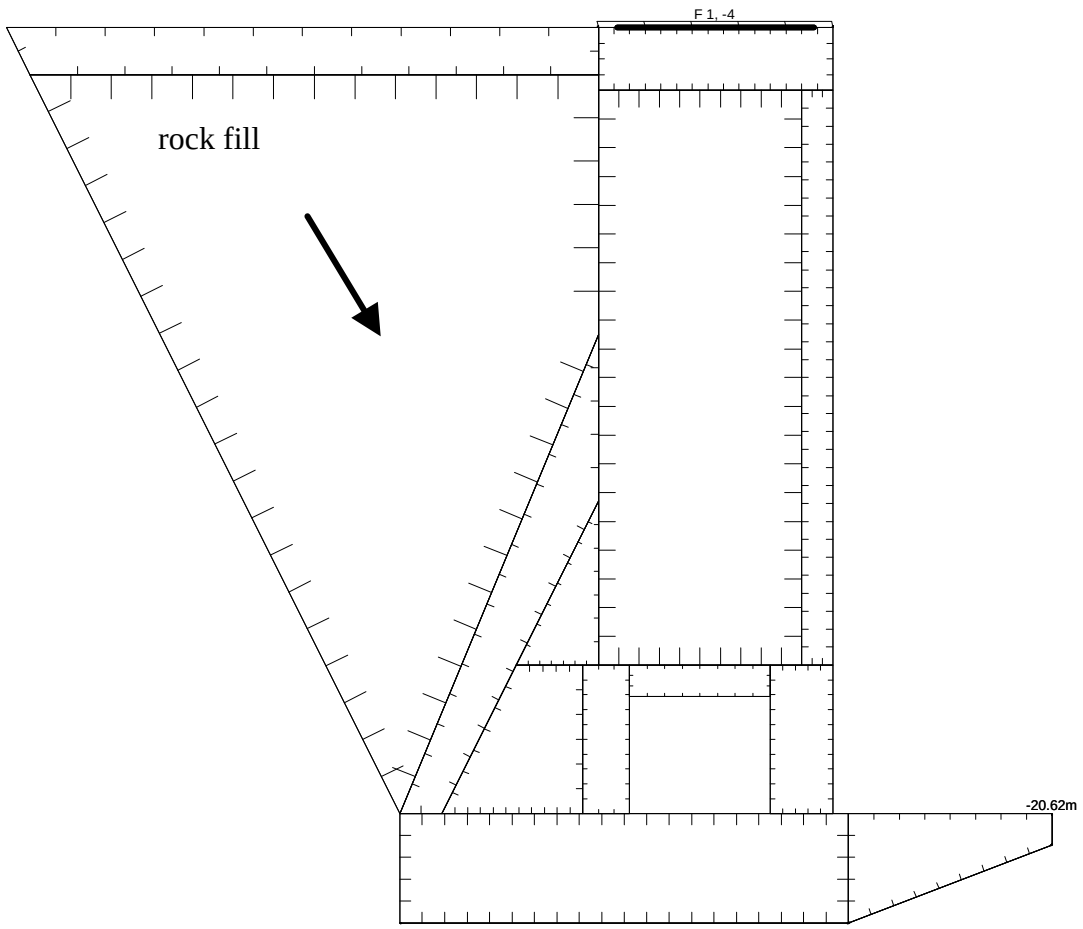
a) with $k_v = k_h = 0.18$ for MDE
b) with $k_v = k_h = 0.21$ for MCE

Case 7: Seismic loads on concrete structure
Case 4: Earth Pressure in seismic conditions

In case 4 the total weight of the rock fill between wall and rock is considered.

$G_v = (1-0.18)\ G$
$G_h = 0.18\ G$

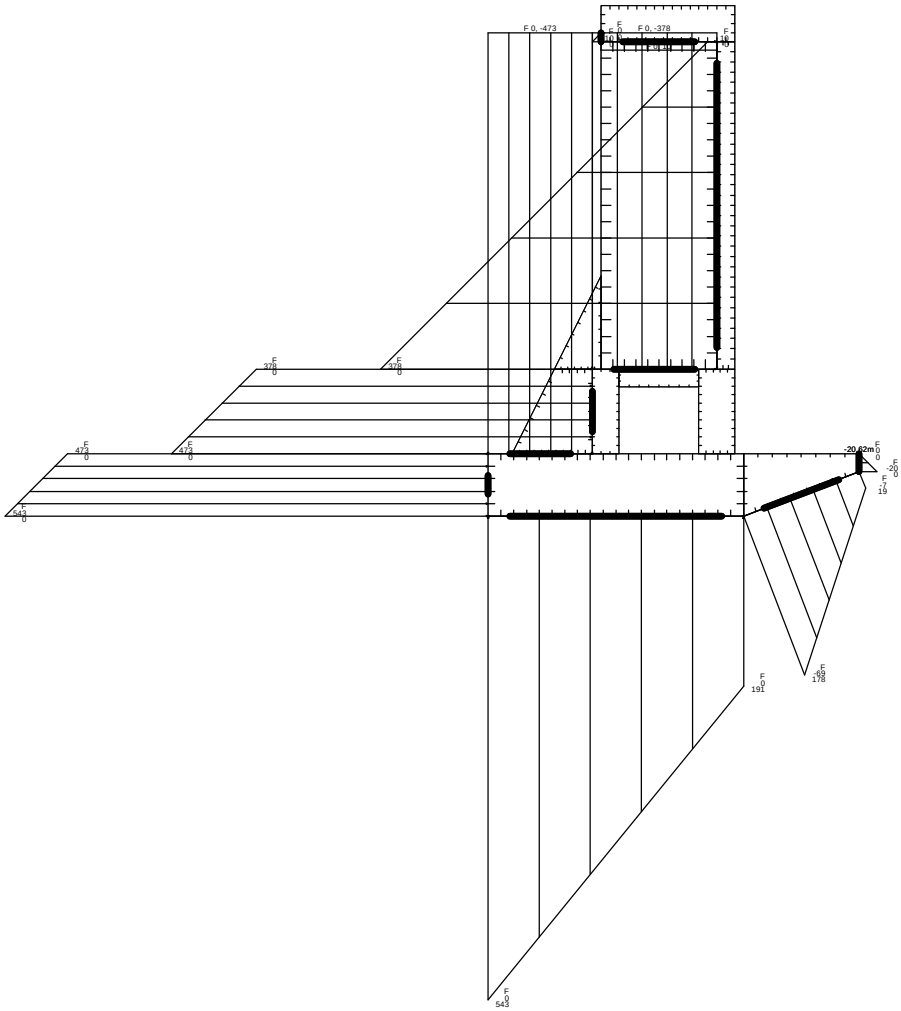
With G the weight of the filling
G_v the vertical component of the weight in seismic conditions
G_h the horizontal component of weight in seismic conditions



D.5 Water Pressure in Dry Lock Conditions (case 5)

Water level inside the lock: -20.62 m
Water level outside the lock: +9.46m

At the rear side of the wall and the bottom the same water pressure is used as in case 3. This is a very conservative assumption.



D.6 Locomotives (case 6)

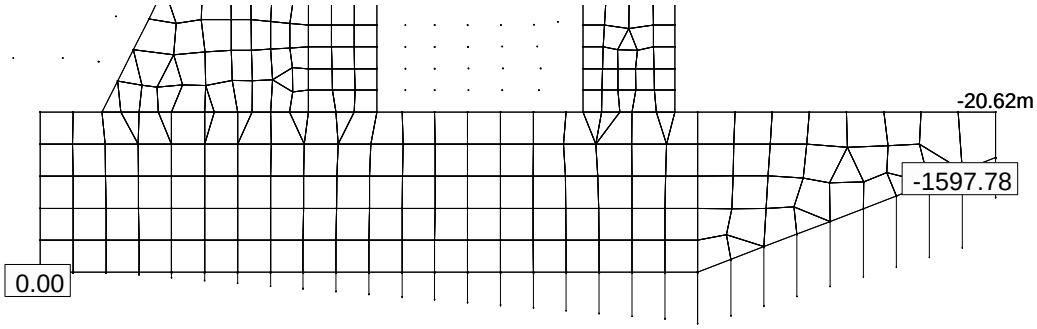
A horizontal load of 50kN/m will be applied

1.5.2 TURN OVER

According to the requirements of ROSA 2000, the compressed zone has to be calculated with a triangular/trapezoidal distribution of stresses. This can be done using a very small value for the elastic support.
The real compressed zone, calculated with a realistic elastic support will be smaller.

A. Quasi Permanent Load Combination 101 – Lock in service

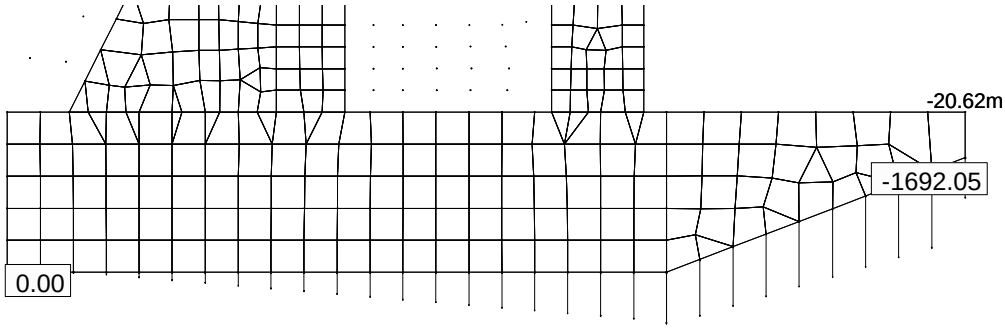
Criterion: Compression zone A' > 90% A



The vectors drawn are the support reactions in each node and not the soil pressure.

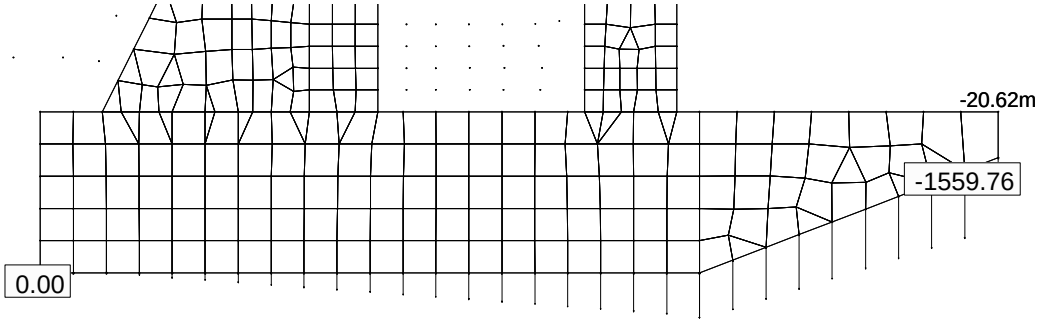
B. Rare Load Combination 103 – Dry Lock Conditions

Criterion: Compression zone A' > 75% A



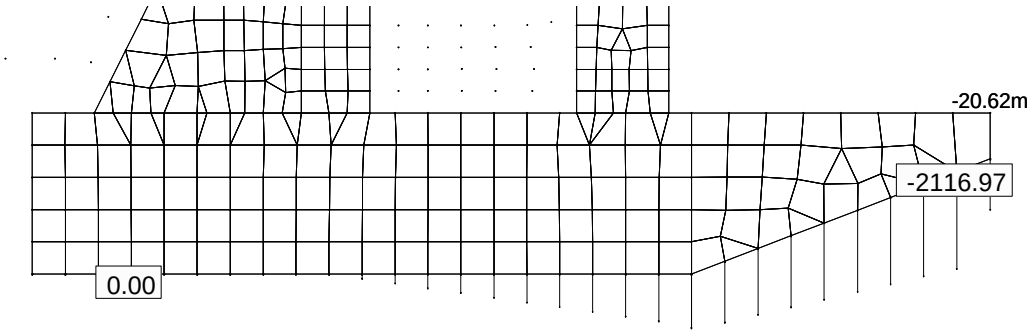
C. Fundamental Load Combinations 104 to 107

Criterion: Compression zone A' > 10% A



D. Accidental Load Combination 108 – Earth Quake MCE

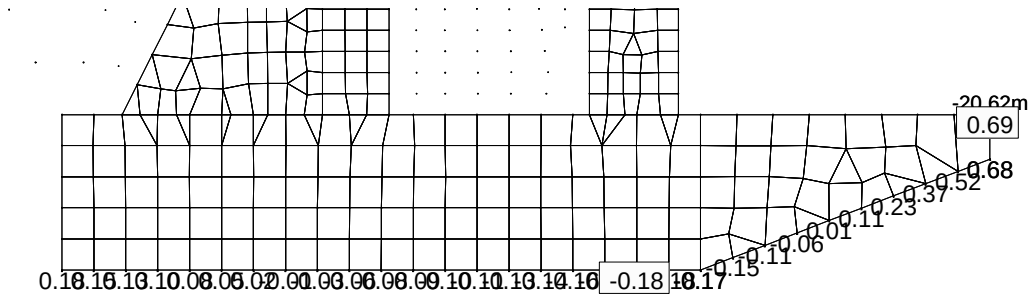
Criterion: Compression zone A' > 10% A



1.5.3 LOAD BEARING CAPACITY

A. Fundamental Load Combinations 104 to 107

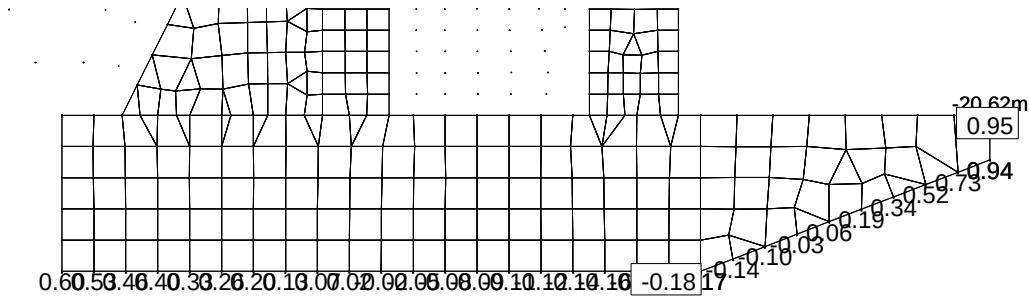
Criterion: $\gamma_d \cdot q_{ref} < q_u$
with γ_d . = 1.4



The maximum vertical displacement at the bottom of the wall is 0.18 cm
This means a vertical pressure of 0.0018 x 1000000 kN/m² = 1800 kN/m² = 1.8 MPa

B. Accidental load combination 102

Criterion: $\gamma_d \cdot q_{ref} < q_u$
with γ_d . = 1.0 for load combination 102

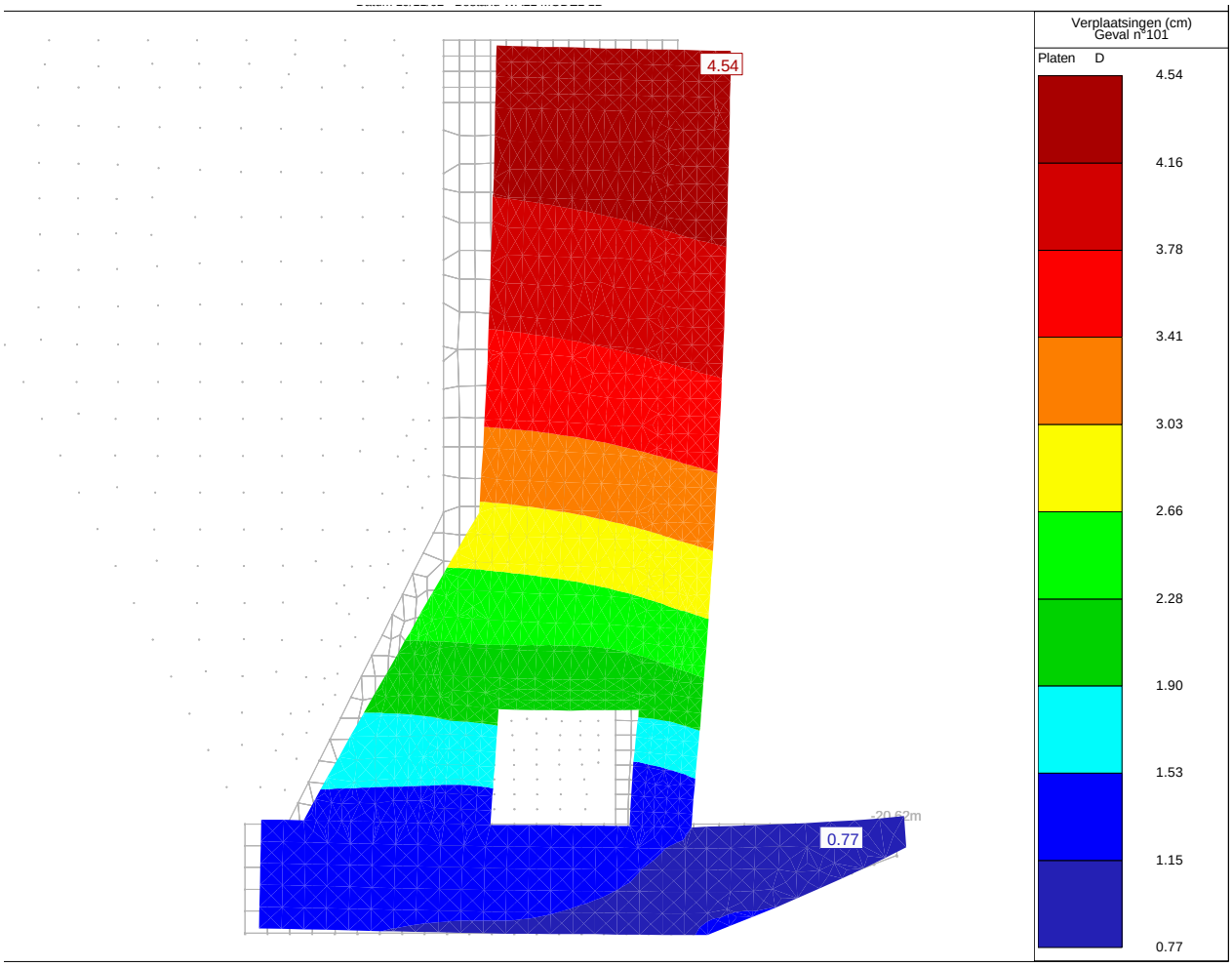


The maximum vertical displacement at the bottom of the wall is 0.18 cm
This means a vertical pressure of 0.0018 x 1000000 kN/m² = 1800 kN/m² = 1.8 MPa

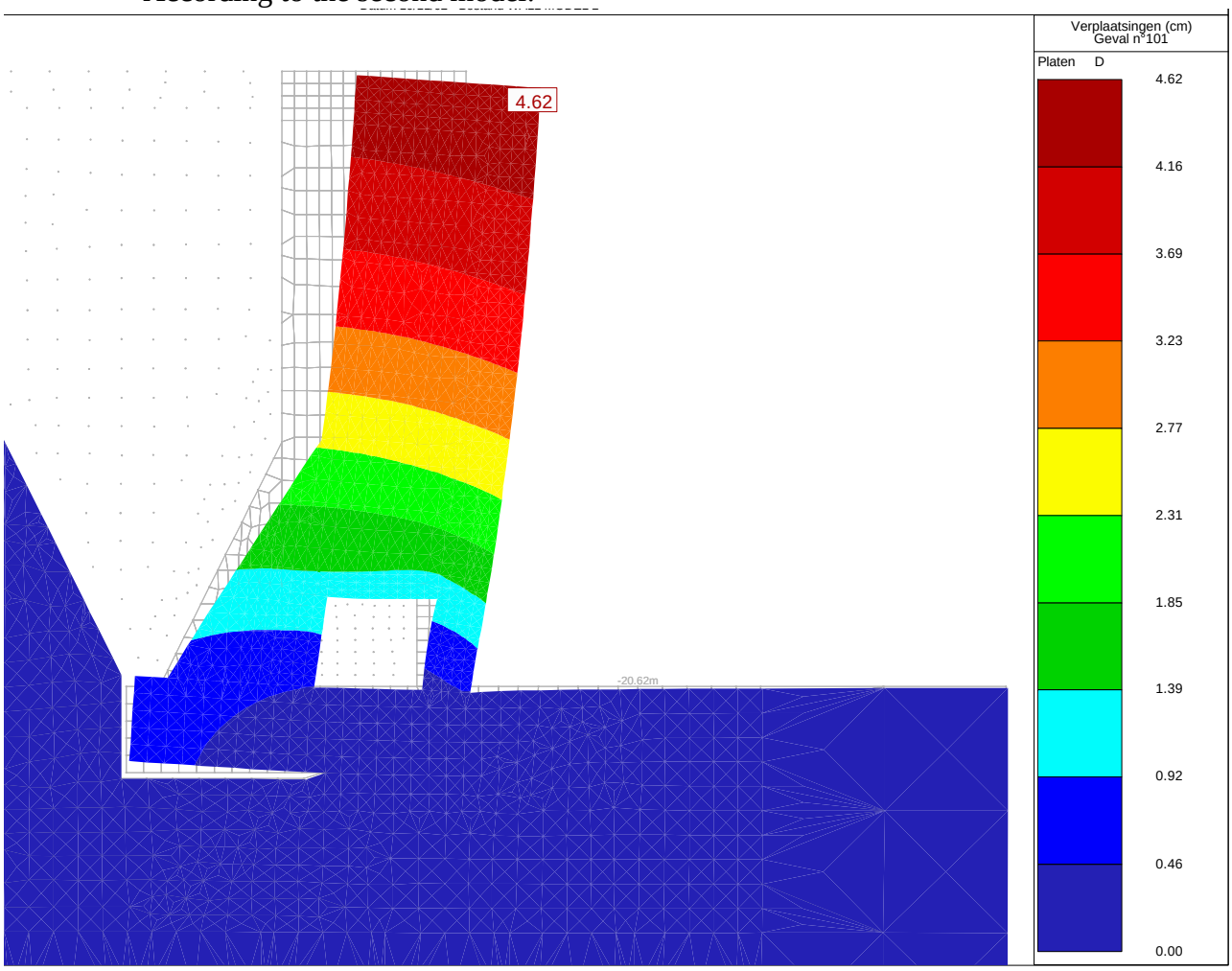
According report R2 Design Criteria the Uni-axial Compressive Strength of the basalt rock varies from 15 to 100MPa.

1.5.4 DEFORMATIONS

A. Load Combination 101 (Lock in Service)

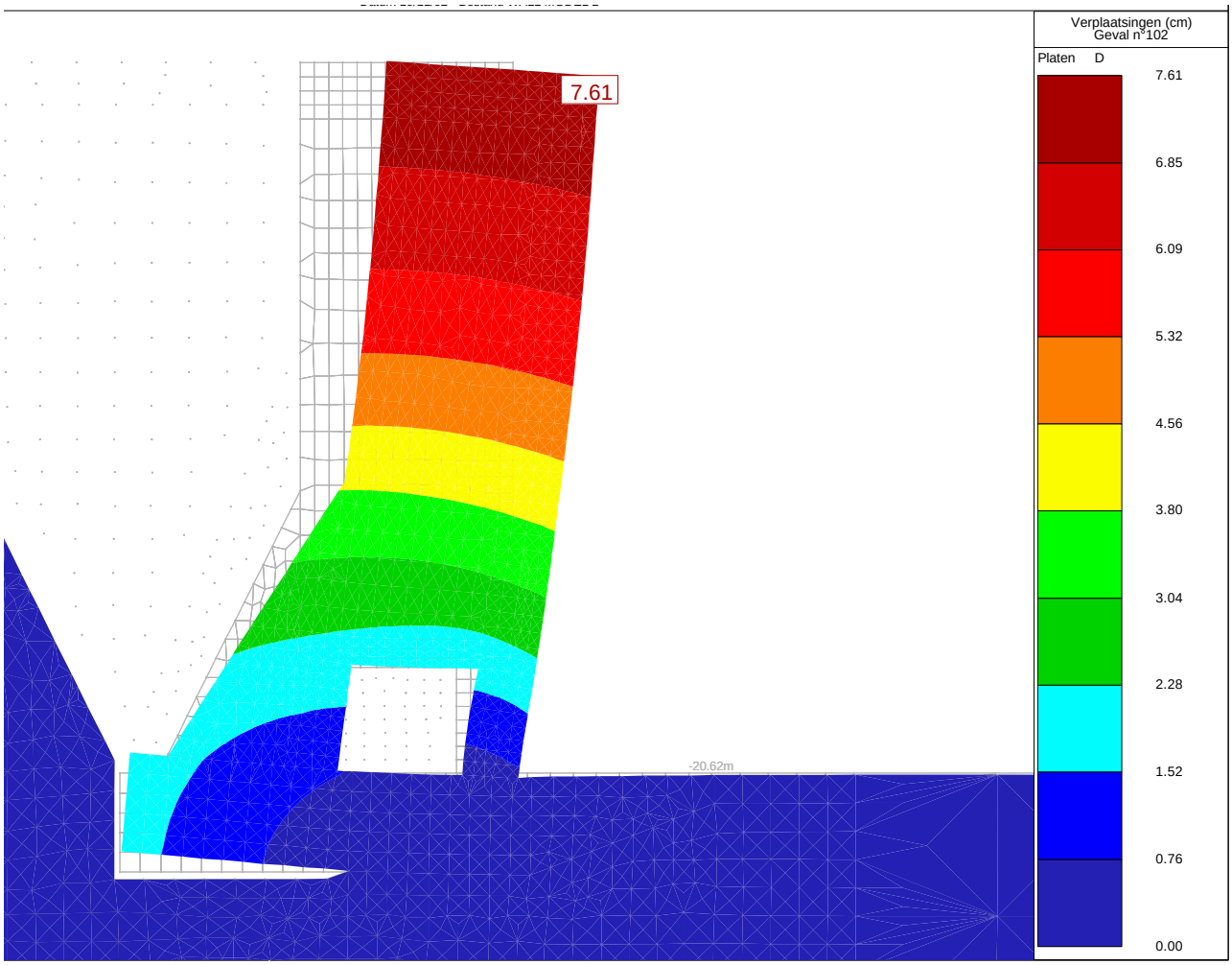


According to the second model:

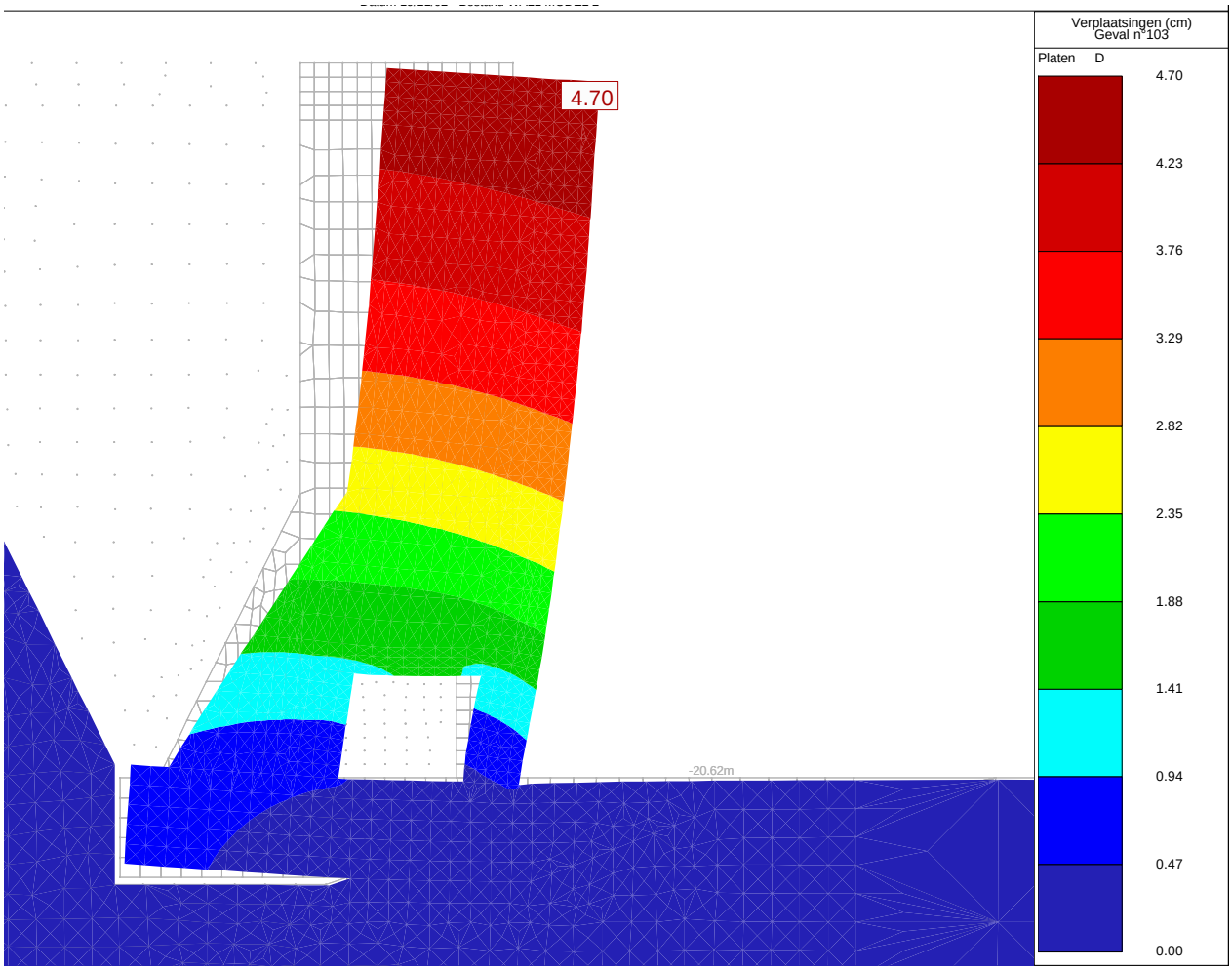


It can be noticed that the deformations are almost equal to those of the previous model, which means that the estimated K-value of the linear support is a good assumption.

B. Load Combination 102 (Earth Quake)



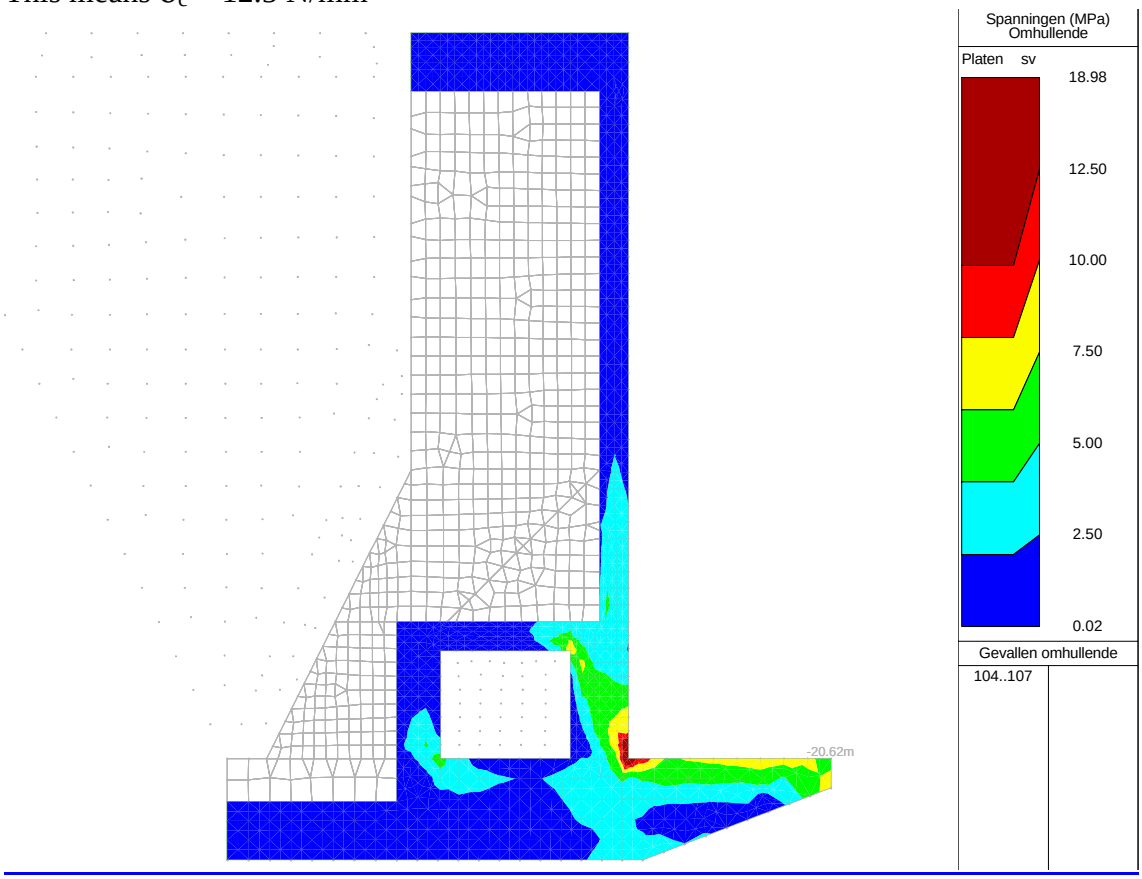
C. Load Combination 103 (Dry Lock Conditions)



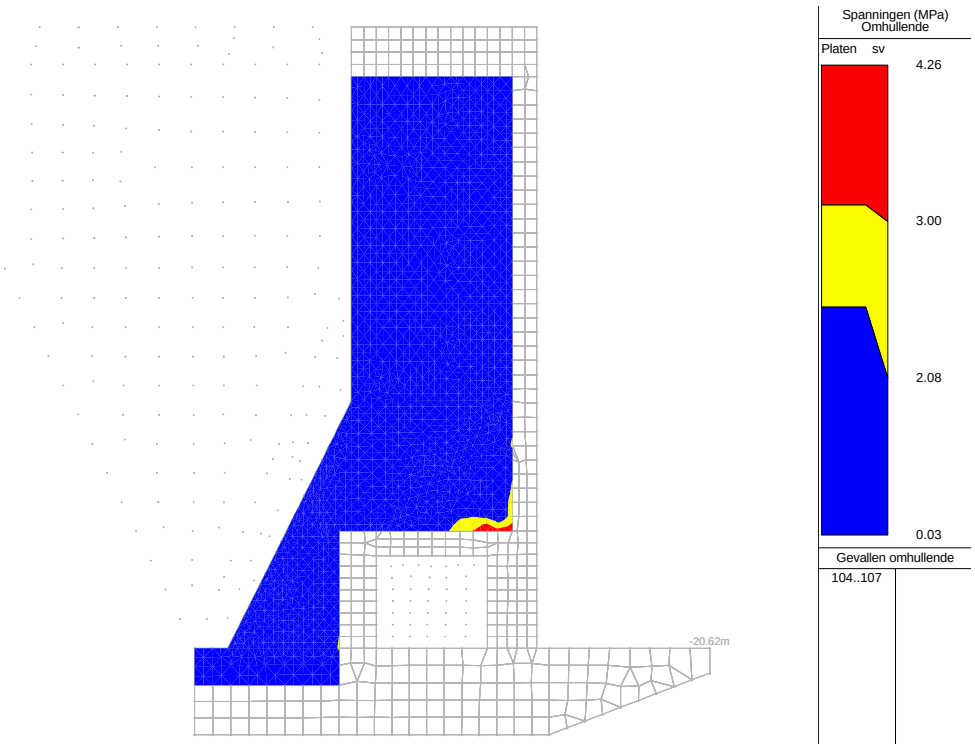
1.5.5 CONCRETE STRESSES

A. Fundamental load combinations 104 tot 107:

1.125 x σ_c < 0.85 f_{ck}/1.5
This means σ_c < 12.5 N/mm²



With counterforts of 1m every 6m, the stresses found in the model have to be limited to σ_c < 1/6 x 12.5 N/mm² = 2.08 N/mm²

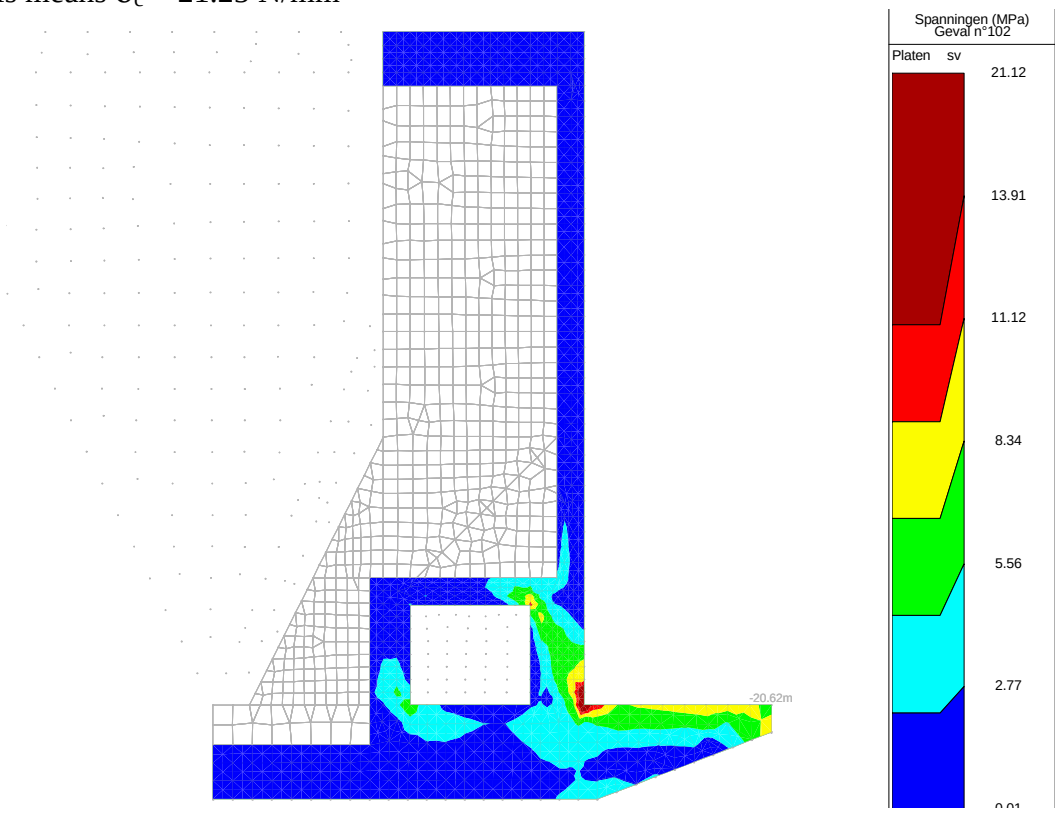


The concentration of high stresses is located in a very small area. They can be overcome by applying a bevel angle.

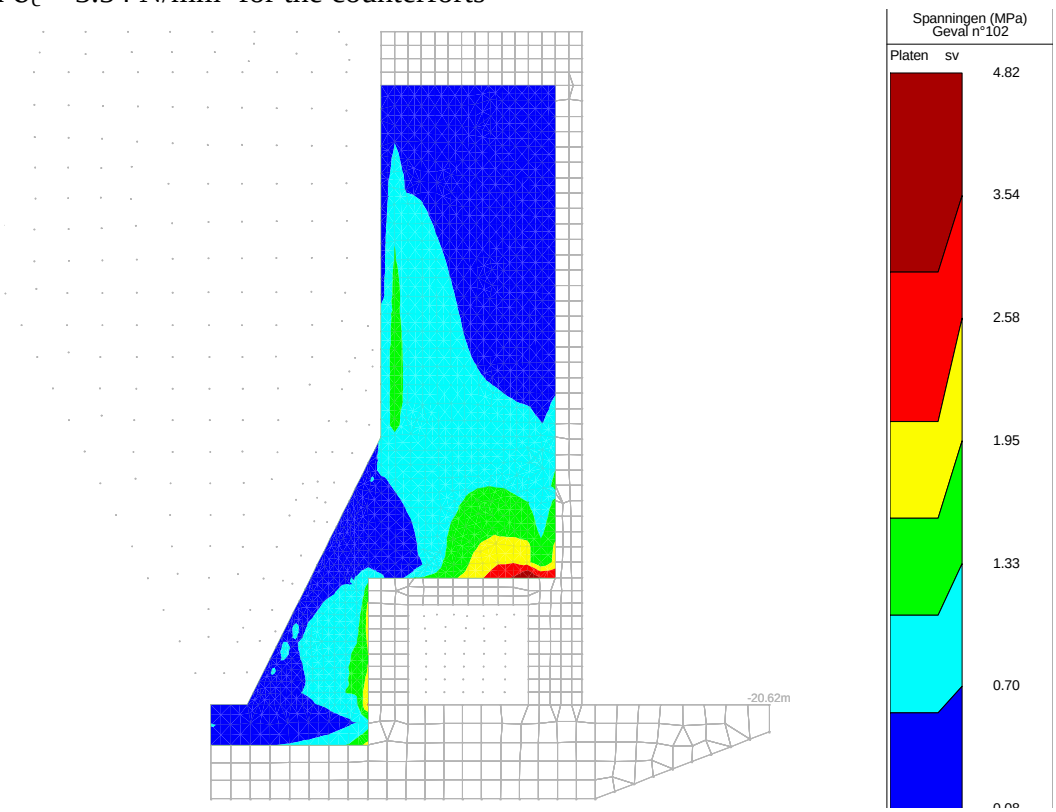
The results are satisfying for this conceptual design. Details have to be studied by means of a 3D-model.

B. Accidental load combination 102:

$\sigma_c < 0.85\ f_{ck}$
This means $\sigma_c < 21.25$ N/mm²



and $\sigma_c < 3.54$ N/mm² for the counterforts



1.5.6 SUMMARY

Criterion	Quasi Permanent Load Combination - Service (101)	Accidental Load Combination - MDE (102)	Rare Load Combination - Dry Lock Condition (103)	Fundamental Load Cmbination (104)	Fundamental Load Cmbination (105)	Fundamental Load Cmbination (106)	Fundamental Load Cmbination (107)	Accidental Load Combination - MCE (108)
Turn over								
Compression zone A' > 90% A	OK	-	-	-	-	-	-	-
Compression zone A' > 75% A	-	-	OK	-	-	-	-	
Compression zone A' > 10% A	-	-	-	OK	OK	OK	OK	OK
Load Bearing Capacity								
1.4 $q_{ref} < q_u$	-	-	-	OK	OK	OK	OK	-
$q_{ref} < q_u$	-	OK	-	-	-	-	-	-
Deformations								
maximal displacement (cm)	4.5	7.6	4.7	-	-	-	-	-
Concrete stresses								
1.125 x $\sigma c < 0.85$ fck/1.5	-	-	-	OK	OK	OK	OK	-
$\sigma c < 0.85$ fck	-	OK	-	-	-	-	-	-
Deep Seeted Sliding								
	-	-	-	-	-	-	-	-

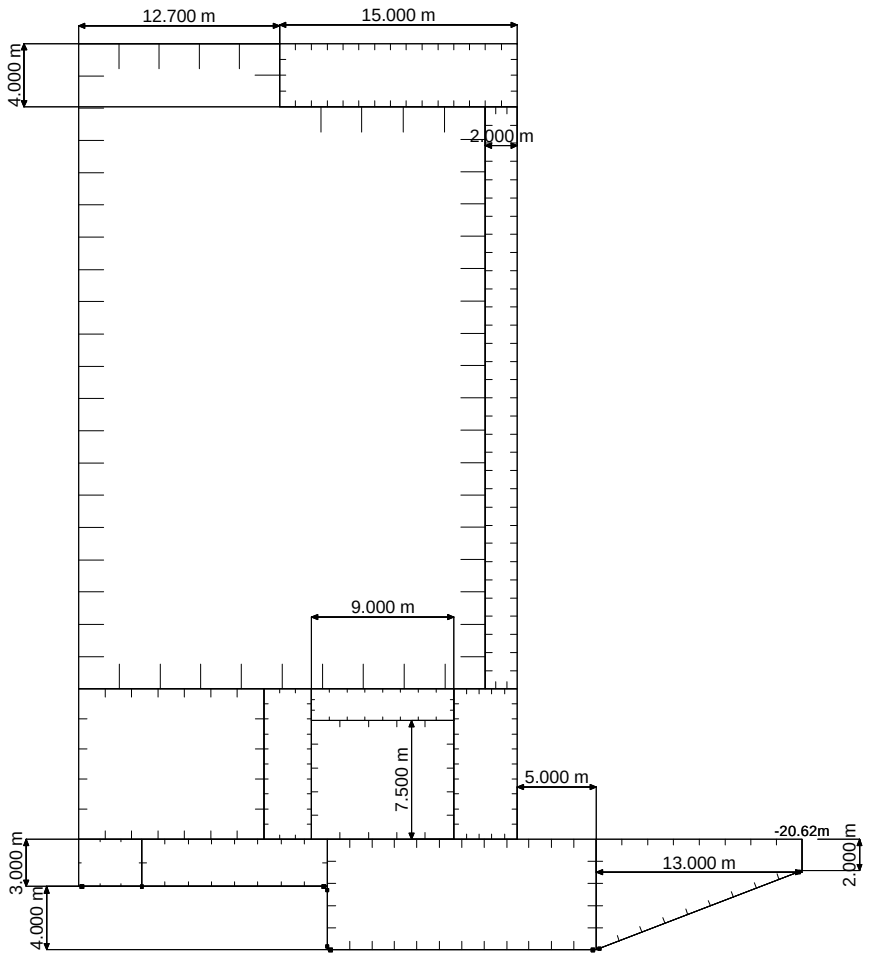
1.6 TYPE 2 – WITH ROLLER COMPACTED CONCRETE

See Drawing D4-B-206 OPTION 2

The stability of this type in normal conditions is less critical then the stability of type 1.
Only the stability of the wall during the construction of lane 4 has to be checked.

1.6.1 INPUT DATA

A. Geometry



‹

B. Materials

Material	E kN/m²	Nu	W/V kN/m3	Alpha
CONCRETE	19620000	0.100	24.525	0.0000100
RCC	19620000	0.100	23.00	0.0000100
Rock	12500000	0.000	0.000	0.000000

The E-modulus for the buttresses is only 1/6th of the one for concrete, because there is only one counterfort of 1m every 6m.

C. Supports

Same as for Type 1

D. Loads

D.1 Self Weight (case 1)

D.2 Water Pressure (case 3)

Water level inside the lock: +26.67
Water level outside the lock: -23.62m

D.3 Seismic Loads

According to the PIANC regulations for Seismic design of Port Structures with $k_v = k_h = 0.18$ for MDE

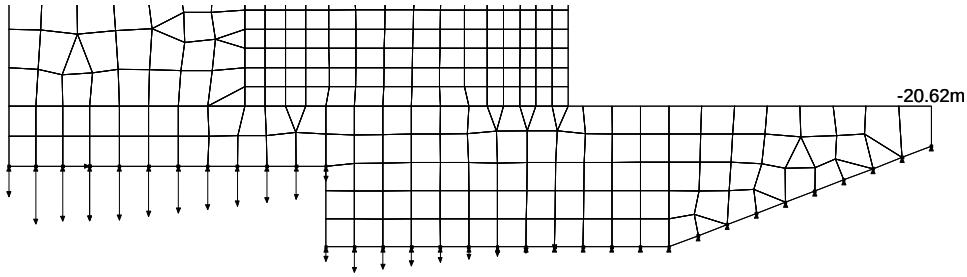
D.4 Locomotives (case 6)

A horizontal load of 50kN/m will be applied

1.6.2 TURN OVER

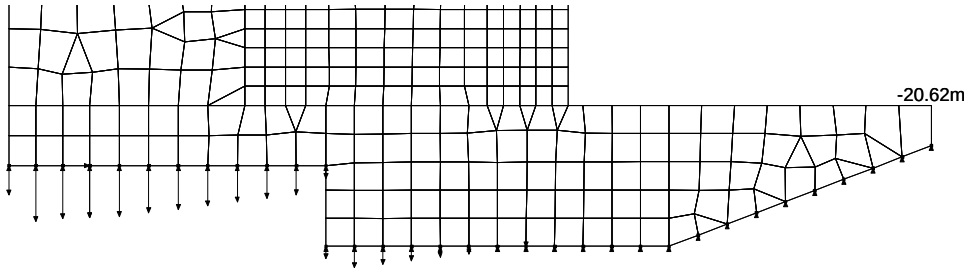
A. Load Combination 101 – Lock in service

Criterion: Compression zone A' > 75% (only during construction period)



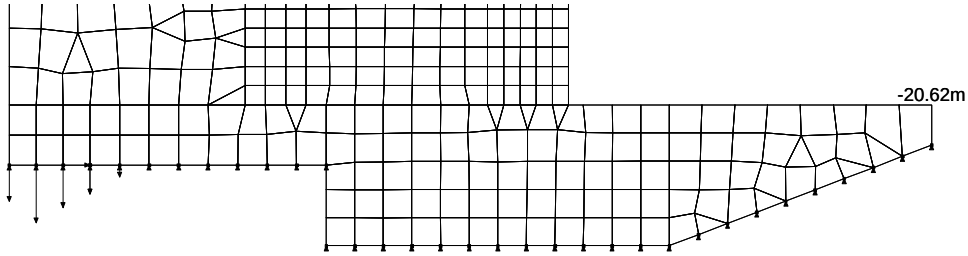
B. Fundamental Load Combinations 105

Criterion: Compression zone A' > 10% A



C. Accidental Load Combination 102 – Earth Quake MDE

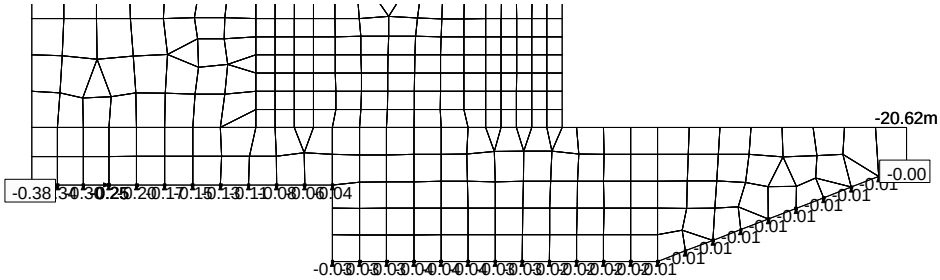
Criterion: Compression zone A' > 10% A



1.6.3 LOAD BEARING CAPACITY

A. Fundamental Load Combinations 105

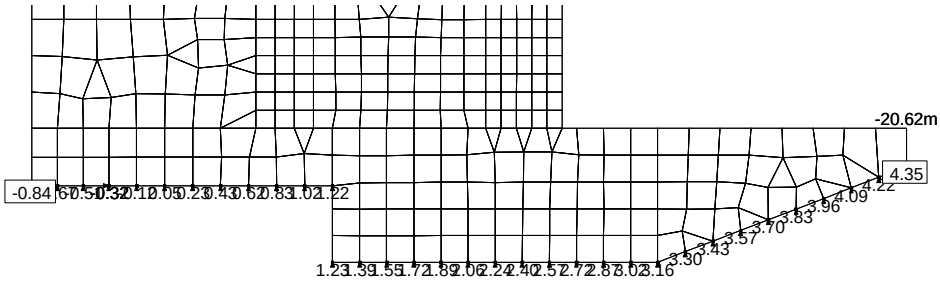
Criterion: $\gamma_d \cdot q_{ref} < q_u$
with γ_d . = 1.4



The maximum vertical displacement at the bottom of the wall is 0.38 cm
This means a vertical pressure of 0.0038 x 1000000 kN/m² = 3800 kN/m² = 3.8 MPa

B. Accidental load combination 102

Criterion: $\gamma_d \cdot q_{ref} < q_u$
with γ_d . = 1.0 for load combination 102

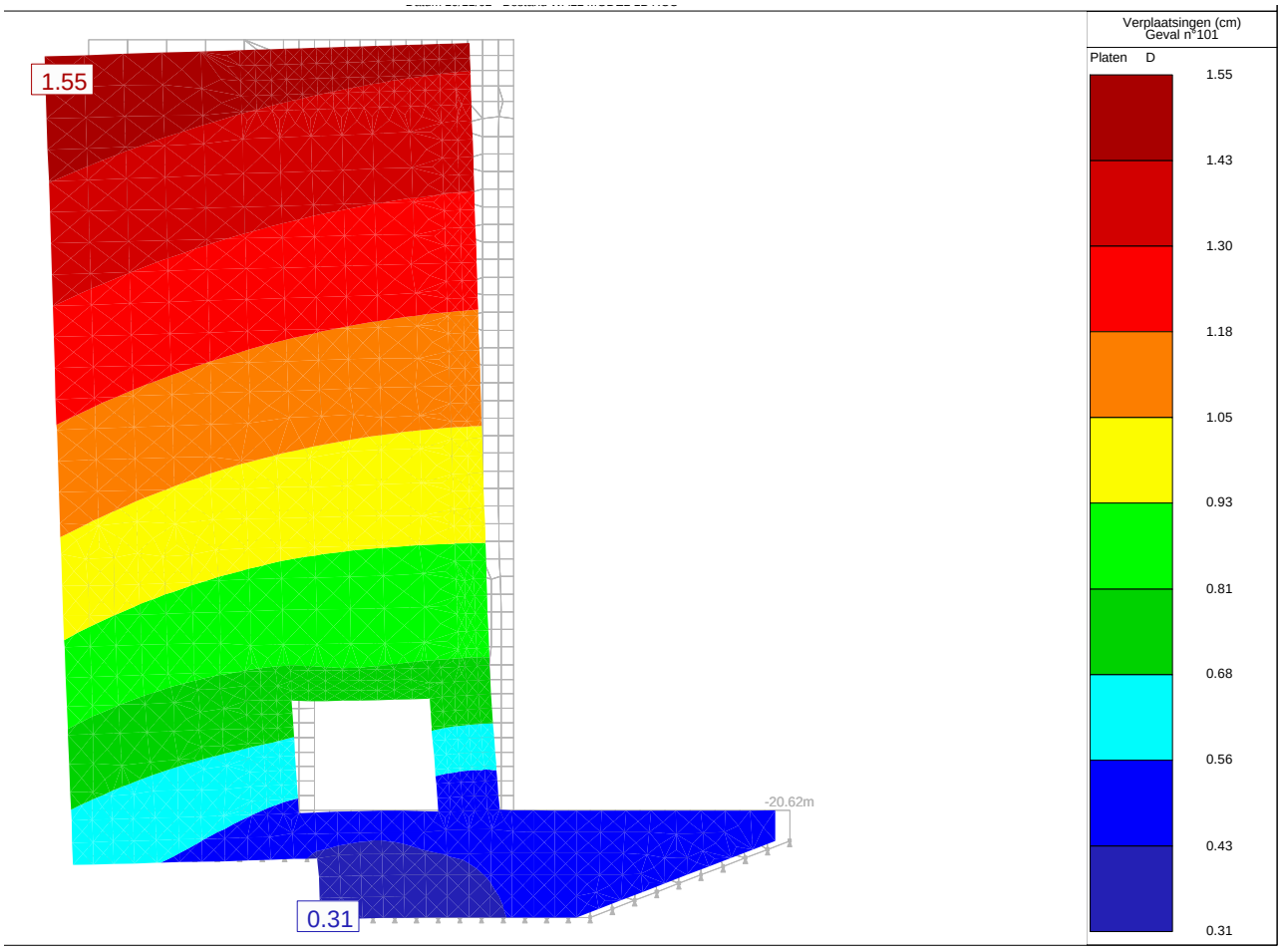


The maximum vertical displacement at the bottom of the wall is 0.84 cm
This means a vertical pressure of 0.0084 x 1000000 kN/m² = 8400 kN/m² = 8.4 MPa

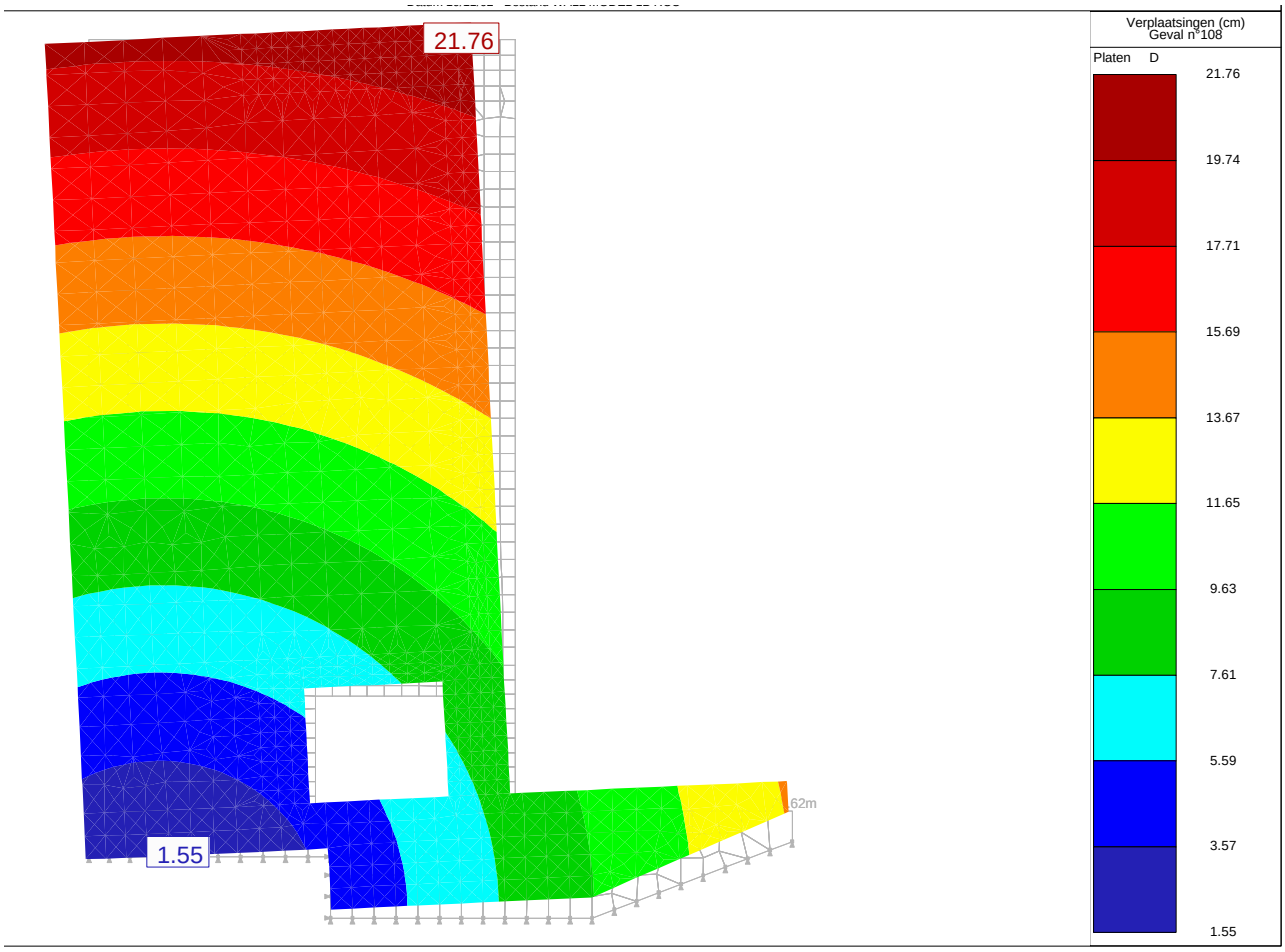
According report R2 Design Criteria the Uni-axial Compressive Strength of the basalt rock varies from 15 to 100MPa.

1.6.4 DEFORMATIONS

A. Load Combination 101 (Lock in Service)



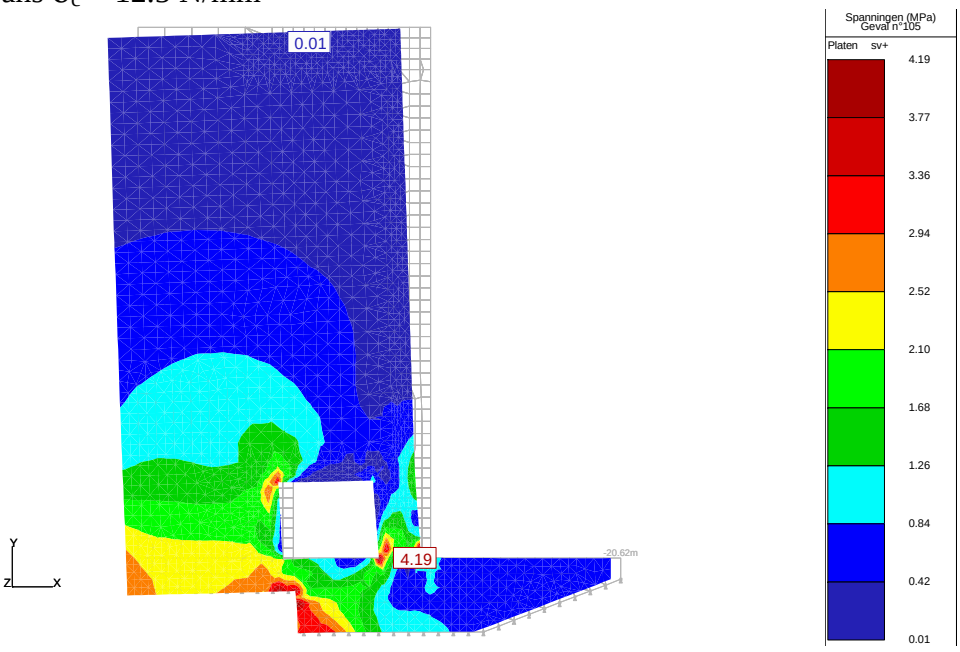
B. Load Combination 102 (Earth Quake)



1.6.5 CONCRETE STRESSES

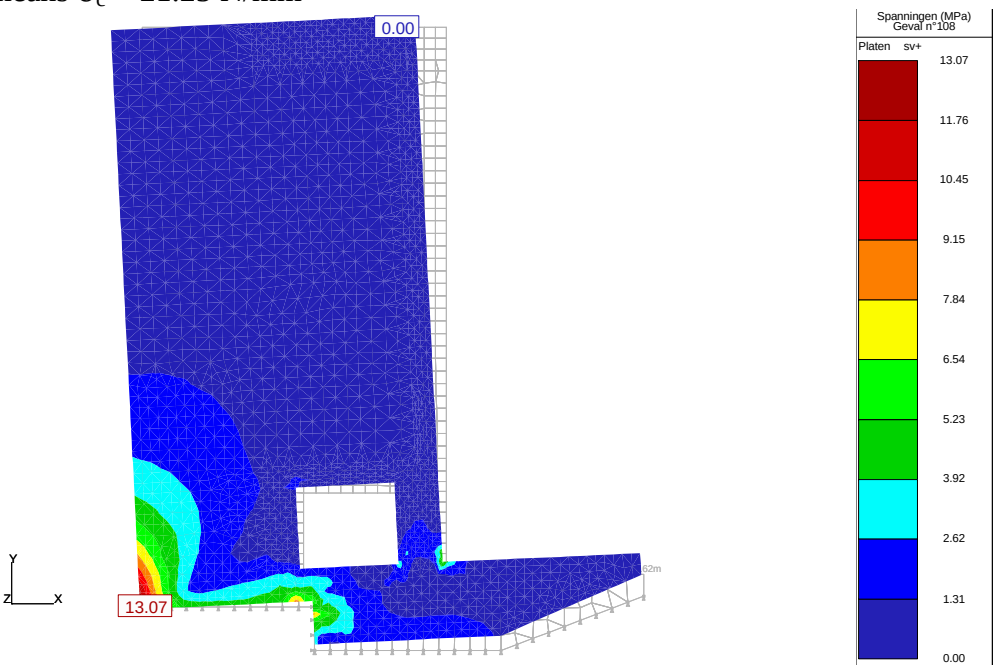
A. Fundamental load combinations 105:

$1.125 \times \sigma_c < 0.85\ f_{ck}/1.5$
This means $\sigma_c < 12.5$ N/mm²



B. Accidental load combination 102:

$\sigma_c < 0.85\ f_{ck}$
This means $\sigma_c < 21.25$ N/mm²

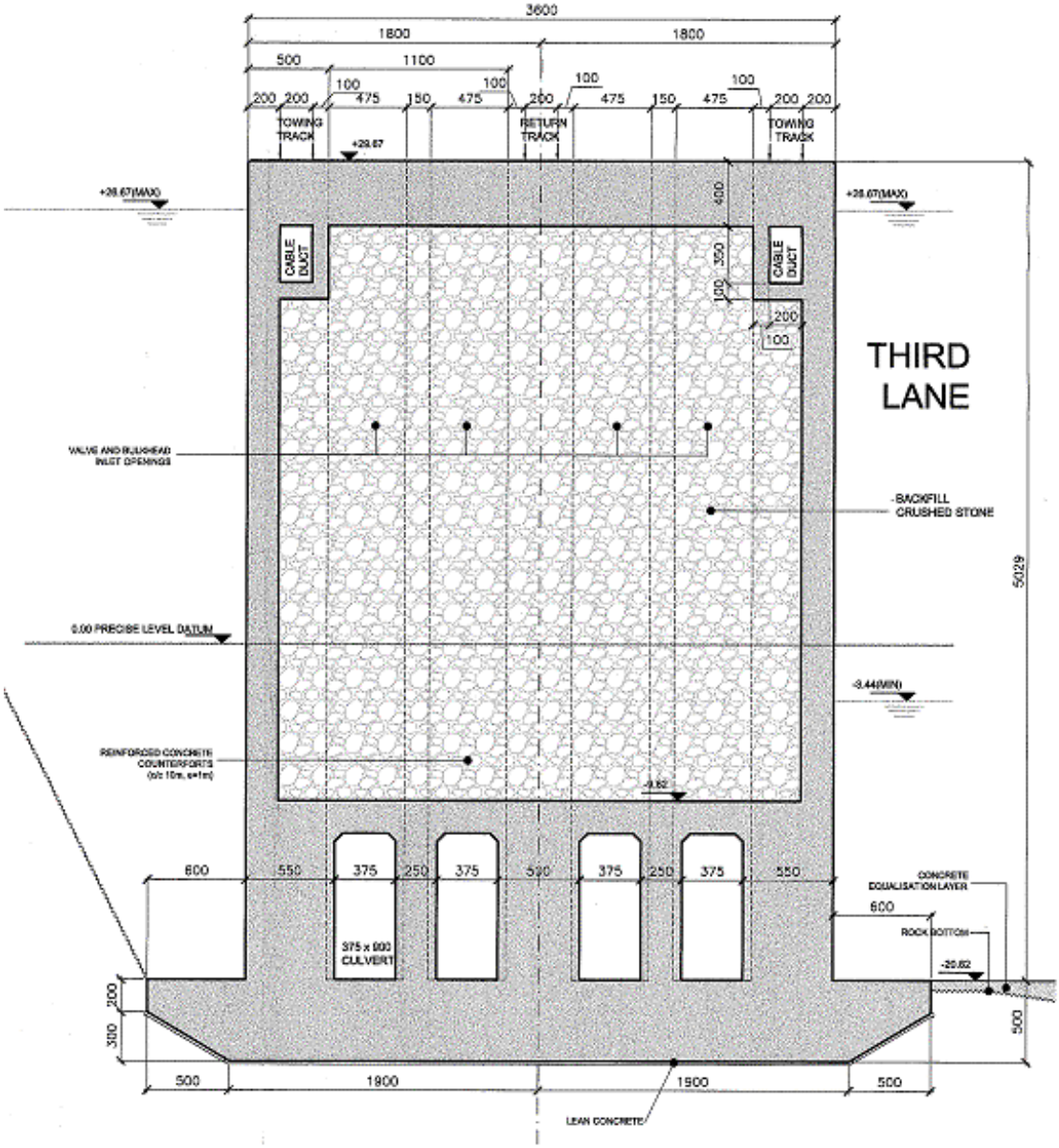


1.6.6 SUMMARY

Criterion	Quasi Permanent Load Combination - Service	Accidental Load Combination - MDE	Fundamental Load Combination
	101	102	105
Turn over			
Compression zone A' > 90% A	OK	-	-
Compression zone A' > 75% A	-	-	-
Compression zone A' > 10% A	-	-	OK
Load Bearing Capacity			
$1.4\ q_{ref} < q_u$	-	-	OK
$q_{ref} < q_u$	-	OK	-
Deformations			
maximal displacement (cm)	1.6	21.8	-
Concrete stresses			
$1.125 \times \sigma c < 0.85\ fck/1.5$	-	-	OK
$\sigma c < 0.85\ fck$	-	OK	-
Deep Seeted Sliding			
	-	-	-

1.7 TYPE 3 – CAISSON

See Drawing D4-B-206 OPTION 3



1.7.1 TURN OVER

In the table below, the horizontal and vertical reaction, as well as the acting point are calculated.

CASE 1 - SELF WEIGHT								
	h	l	γ	x	z	V	H	M
1	2.00	**48.00**	24.50	24.00	1.00	2352		56448
1	3.00	42.00	24.50	24.00	-1.50	3087		74088
2	9.00	4.00	24.50	24.00	6.50	1764		42336
2	9.00	7.50	10.00	24.00	6.50	1350		32400
1	9.00	13.00	24.50	24.00	6.50	2867		68796
1	2.00	36.00	24.50	24.00	12.00	1764		42336
2	35.29	2.00	24.50	24.00	30.65	3458		83002
1	35.29	32.00	20.00	24.00	30.65	22586		542054
1	4.00	36.00	24.50	24.00	50.29	3528		84672
					CASE 1	**42756**		**1026132**
CASE 3 - WATER PRESSURE								
	h	l	γ	x	z	V	H	M
	52.29		10		14.43		-13671	-197276
	22.18		10		4.39		2460	10807
	-3.5	6.00	10	45.00		-210		-9450
	-3.5	6.00	10	3.00		-210		-630
	-22.18	36.00	10	24.00		-7985		-191635
	-30.11	36.00	10	30.00		-5420		-162594
					CASE 3	**-13825**	**-11211**	**-550778**
CASE 4 - SEISMIC LOADS								
	h	l	γ	x	z	V	H	M
1	2.00	48.00	24.50	24.00	1.00	-494	-494	-12348
1	3.00	42.00	24.50	24.00	-1.50	-648	-648	-14586
2	9.00	4.00	24.50	24.00	6.50	-370	-370	-11298
2	9.00	7.50	10.00	24.00	6.50	-284	-284	-8647
1	9.00	13.00	24.50	24.00	6.50	-602	-602	-18360
1	2.00	36.00	24.50	24.00	12.00	-370	-370	-13336
2	35.29	2.00	24.50	24.00	30.65	-726	-726	-39687
1	35.29	32.00	20.00	24.00	30.65	-4743	-4743	-259180
1	4.00	36.00	24.50	24.00	50.29	-741	-741	-55040
					CASE 4	**-8979**	**-8979**	**-432482**
CASE 5 - WATER PRESSURE IN DRY LOCK CONDITIONS								
	h	l	γ	x	z	V	H	M
	52.29		10		14.43		-13671	-197276
	5.00		10		-1.33		125	-167
	-3.50	6.00	10	45.00		-210		-9450
	-3.50	6.00	10	3.00		-210		-630
	-5.00	36.00	10	24.00		-1800		-43200
	-47.29	36.00	10	30.00		-8512		-255366
					CASE 5	**-10732**	**-13546**	**-506088**
CASE 6 - BOLLARDS								
	h	l	γ	x	z	V	H	M
1					52.29		50	2615
					CASE 6		**50**	**2615**

		LOAD COMBINATIONS							
		101	**102**	**103**	**104**	**105**	**106**	**107**	**108**
M	Moment	477969	104657	520044	683718	375878	725271	417431	42872
G	Vertical Load	28931	21235	32023	37482	24655	40574	27748	19952
e	excentricity	7.479	19.071	7.760	5.759	8.755	6.125	8.956	21.851
	A'	48.000	14.786	48.000	48.000	45.736	48.000	45.131	6.446
	A'/A	1.00	0.31	1.00	1.00	0.95	1.00	0.94	0.13
	criterion	>0.90	>0.10	>0.75	>0.10	>0.10	>0.10	>0.10	>0.10

The turn over criteria are fulfilled

1.7.2 OTHER CRITERIA

Comparing the dimensions of this type to the dimensions of the previous type, it is clear that this type will meet with the other criteria.

2 Lock Heads

2.1 DESIGN CRITERIA

Design criteria for the new lock structures have been given in report R2-A "Design Criteria – Part A: General Design Criteria" and report R2-B "Design Criteria – Part B: Specific Design Criteria".

Additional design criteria which are related to the results of previous studies and investigations are the following:

- Levels of sills and top of walls
- Dimensions and lay-out of culverts, and ports in the lock walls
- Lock siting and corresponding geo-technical conditions
- Type of lock gates
- Type of lock walls

2.2 LOCK HEAD DESIGN

The lock head is a massive construction housing the lock gates and culvert valves.

One major condition is the geo-technical situation of the lock siting. In the 1-step configuration lock heads 1 and 2 are situated in rock (basalt).

For further specifications about the foundation in basalt we refer to report R4-B of the triple lift lock system

For the lock head design reference is made to the drawings:

Lock head 1 D4-B-207/208/209
Lock head 2 D4-B-210/211/212

For the lock gates design reference is made to the drawings:

D4-D-201/202/203

For the lock head 1, a vertical wall is added to the foundations at the Pacific side. This wall is needed because of the great difference in water levels due to the one step lock and the fact that the water saving basins are located next to the lock head. This vertical element acts as a foundation element and a ground retaining structure.

In lock head 2 we have to deal with the very large lock gates. To reduce the hydraulic resistance when the gates are rolled into the recesses the open space around the gates has to be maximized. Because seals are only required at the Pacific side, the space of 3 m used inside the recesses is also applied near the entrance of the recesses at the Lake Gatun side. The area of evacuation of water is increased by openings (2 x 5m x 7m) towards the lock chamber below the lowest water level.

Cantilever structures are foreseen in the recesses for the maintenance wagons. Because of the weight of the gate a large number of wagons are necessary. One supplementary console is foreseen at the Lake Gatun side for a guidance wheel.

In this report a section taken through the lock gate recesses of the lock head 2 is checked. Lock head 1 of the single lift configuration is similar to lock head 1 of the triple lift configuration.

2.3 LOCK HEAD ANALYSIS

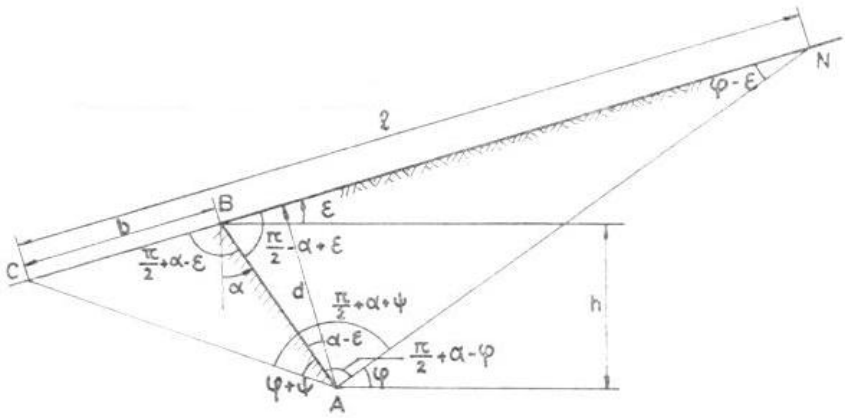
2.3.1 LOADS

A. Self Weight (case 1)

Concrete γ= 24.5 kN/m³
Wet Soil γ= 20.0 kN/m³
Dry Soil γ= 18.0 kN/m³

B. Earth Pressure (case 2)

The active earth pressure will be calculated using the formula of COULOMB-PONCELET



$$\lambda_a = \frac{\cos^2(\varphi - \alpha)}{\cos^2\alpha \cos(\alpha + \psi)\left(1 + \sqrt{\frac{\sin(\varphi + \psi)\sin(\varphi - \varepsilon)}{\cos(\alpha + \psi)\cos(\varepsilon - \alpha)}}\right)^2}$$

The angle of friction in the filling of crushed stone and sand is 45°
On the surface a load p=10 kN/m² is applied. (5 kN/m² in seismic conditions)

C. Water Pressure (case 3)

At the side of the Gatun Lake or lock chamber the maximum water level of that chamber will be applied. This level will also be applied in the recess at that side. At the side of the lower chamber the minimum water level of the Pacific Ocean will be applied. This level will also be applied in the recess at that side.

D. Seismic Loads

D.1 Earthquake level

According to the PIANC "Seismic Design Guidelines for port structures" two levels of earthquake motions have to be considered

Level 1 (L1): the level of earthquake motions that are likely to occur during the life – span of the structure
Level 2 (L2): the level of earthquake motions associated with infrequent rare events.
(Return period = 475 years for port structures with a life-span of 50 years)

For each level an acceptable damage level is defined.

D.2 Performance Grade

The highest performance grade (Grade S) is applicable for

- critical structures with potential for extensive loss of human life and property
- critical structures that, if disrupted, devastate economic and social activities

This means that the level of damages is:

- Structural: minor or no damage
- Little or no loss of serviceability

for both levels L1 and L2.

D.3 Analysis type

As this report concerns a conceptual design we will use the simplified analysis.

D.4 Equivalent seismic coefficient ke

Results for the design earthquakes: (See R2-A)

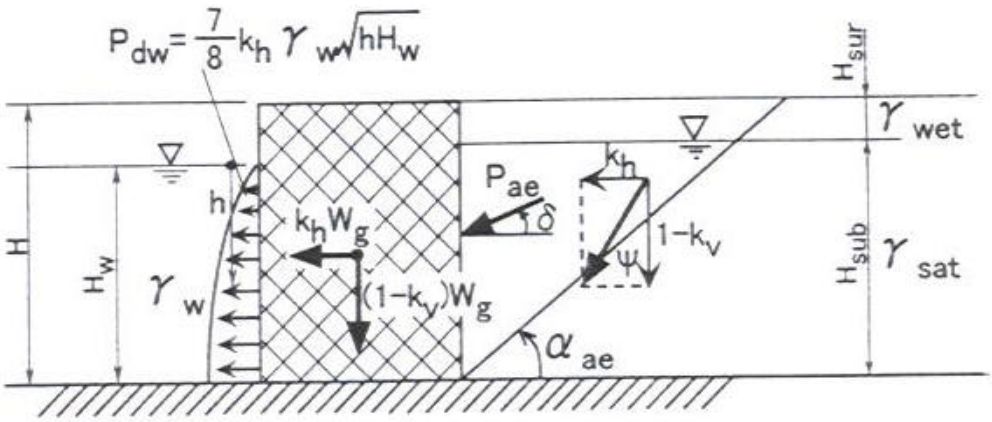
Return periods->	**MCE** -	**MDE** 950 yrs	**OBE** 145 yrs	***SMDE*** *1000 yrs*	***SDE*** *475 yrs*
North Panama Deformed Belt	0.21	0.16	0.13	*0.16*	*0.15*
Pedro Miguel Fault	0.21	0.18	0.13	*0.18*	*0.16*
Recommended PGA (in g) ***(for rock conditions)***	**0.21**	**0.18**	**0.13**	***0.18***	***0.16***
	ICOLD			*UBC*	

With MCE = Maximum Credible Earthquake
MDE = Maximum Design Earthquake
OBE = Operating Basis Earthquake
SMDE = Site Maximum Design Earthquake
SDE = Site Design Earthquake

We will use the MDE for L2. This means that we will allow only small deformations during MDE
L1 is not determining

In addition, we will repeat the calculations for MCE, allowing higher deformations but no loss of stability.

k_e = PGA/g for PGA < 0.2 g for retaining walls
so $k_v = k_h$ = 0.18 for MDE
and $k_v = k_h$ = 0.21 for MCE



(a)

Case 8: Seismic loads on concrete structure
Case 4: Earth pressure in seismic conditions

E. Water Pressure in Dry Recess Conditions (case 5 & 6)

In case 5 the one recess on the side of the lock chamber is put in dry conditions. In case 6 both recesses are put in dry conditions.

F. Maintenance Support Wagon (case 7)

The reaction forces of the maintenance support wagons located onto the walls of the gate recesses are taken into account. .

2.3.2 LOAD COMBINATIONS

According to ROSA 2000

A. Quasi Permanent Load Combination

CASE 101	= 1.00 x	[1]	+ 1.00 x	[2]	+ 1.00 x	[3]	+ 1.00 x	[7]

B. Accidental Load Combination - MDE

CASE 102	= 1.00 x	[1]	+ 1.00 x	[3]	+ 1.00 x	[4a]	+ 1.00 x	[8a]

cases [4a] and [8a] are the seismic loads related with the MDE

C. Rare Load Combination

CASE 103	= 1.00 x	[1]	+ 1.00 x	[2]	+ 1.00 x	[5]
CASE 104	= 1.00 x	[1]	+ 1.00 x	[2]	+ 1.00 x	[6]

D. Fundamental Load Combinations

CASE 105	= 1.20 x	[1]	+ 1.20 x	[2]	+ 1.00 x	[3]	+ 1.20 x	[7]
CASE 106	= 0.90 x	[1]	+ 1.20 x	[2]	+ 1.00 x	[3]	+ 1.20 x	[7]
CASE 107	= 1.20 x	[1]	+ 1.20 x	[2]	+ 1.00 x	[5]		
CASE 108	= 0.90 x	[1]	+ 1.20 x	[2]	+ 1.00 x	[5]		
CASE 109	= 1.20 x	[1]	+ 1.20 x	[2]	+ 1.00 x	[6]		
CASE 110	= 0.90 x	[1]	+ 1.20 x	[2]	+ 1.00 x	[6]		

E. Accidental Load Combination - MCE

CASE 111	= 1.00 x	[1]	+ 1.00 x	[3]	+ 1.00 x	[4b]	+ 1.00 x	[8b]

cases [4b] and [8b] are the seismic loads related with the MCE

The MCE-values can be used for the criteria concerning global stability like turning over. This is however not critical for the lock heads and will not be examined in the report.

2.3.3 CRITERIA

According to ROSA 2000

A. Sliding along the base

Due to the ground pressure at both sides of the lock head, sliding will not occur.

B. Turn over

The lock head cannot turn over, due to dimensions and the ground pressure at both sides of the head.

C. Load Bearing Capacity

$\gamma_d \cdot q_{ref} < q_u$
γ_d . = 1.4 for load combination 105 to 110
γ_d . = 1.0 for load combination 102 (MDE)

qu = ultimate load bearing capacity
qref = reference pressure

D. Deformations

The deformations will be checked for frequent and rare load combinations 101, 102 (MDE), 103 and 104.

E. Concrete Stresses

Fundamental load combinations: 105 tot 110: 1.125 x $\sigma c < 0.85$ fck/1.5
Accidental load combination: 102 (MDE): $\sigma c < 0.85$ fck

The factor 1.125 is caused by the different factors in the load combinations between ROSA 2000 and EuroCode

F. Global Stability

Global stability will not be a problem, when the items in part C, D and E are checked.

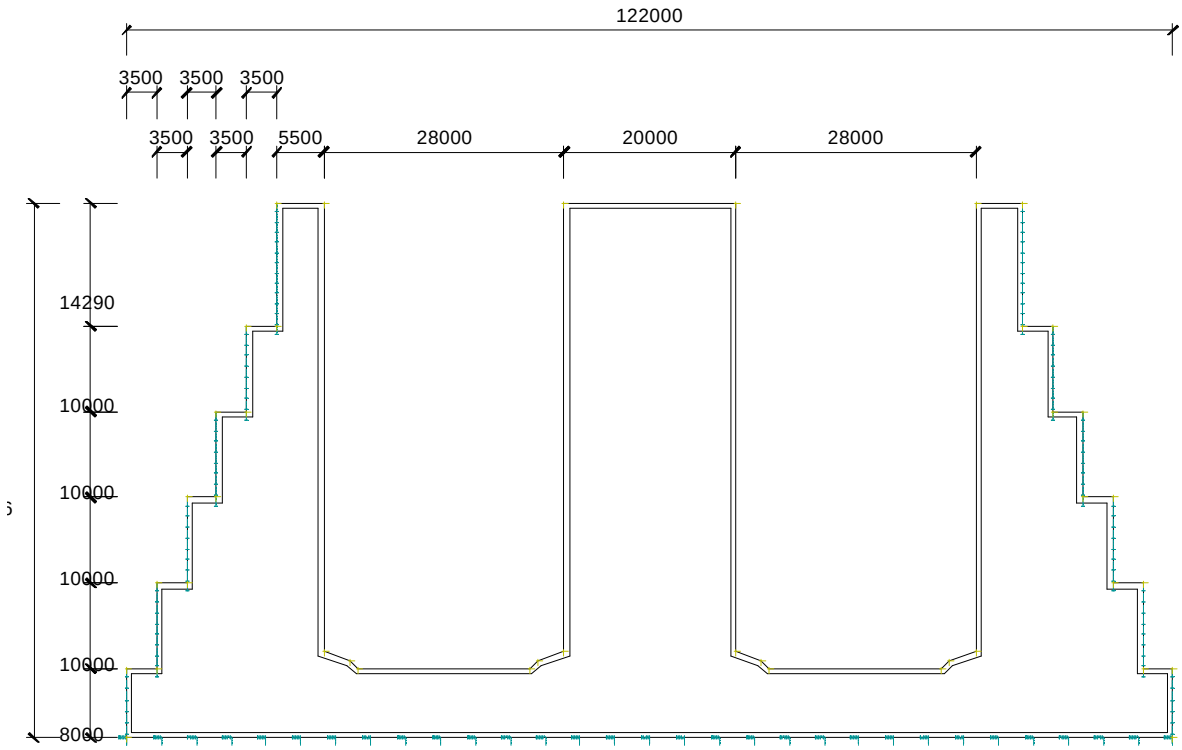
2.3.4 SOFTWARE

The calculations are made by means of “Esa Prima win”, a finite element program. The model we will use is a 2D-model.

2.4 FOUNDATION IN BASALT – INPUT AND RESULTS

2.4.1 INPUT DATA

A. Geometry



B. Materials

Material	E kN/m²	Nu	W/V kN/m3	Alpha
CONCRETE	19620000.000	0.100	24.525	0.0000100

C. Supports

The rock base is modeled by means of a linear support.

Vertical lock head elements:
Linear support with K= 200.000 kN/m² is introduced.
This support only works when compressed.

Horizontal rock base:
Linear support with K= 1.000.000 kN/m² is introduced.
This support only works when compressed. A small horizontal support is given to the rock base, to avoid trivial results of the calculation.

The K-values are estimated values.

D. Loads

D.1 Self Weight (case 1)

D.2 Earth Pressure (case 2)

It is assumed that the rock does not exert any pressure onto the wall.

side upper chamber

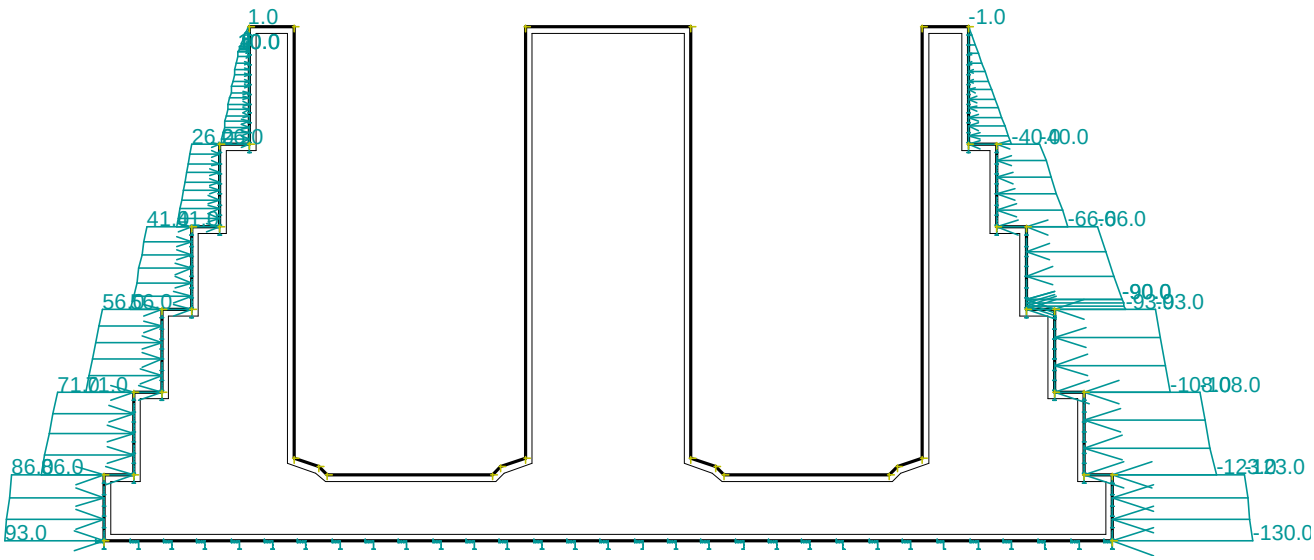
		λ_{ah}	λ_{av}
λ_a	0.1716	0.1486	0.0858
Depth (m)	Pressure (kN/m²)	p_h (kN/m²)	p_v (Kn/m²)
0.00	10	1	1
3.00	64	10	5
14.29	177	26	15
24.29	277	41	24
34.29	377	56	32
44.29	477	71	41
54.29	577	86	49
59.29	627	93	54

side lower chamber

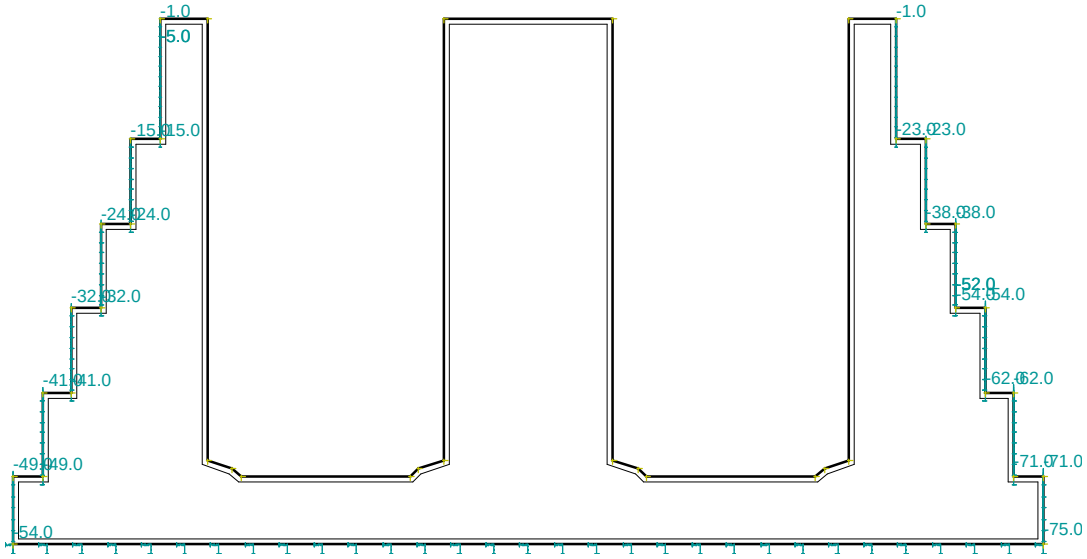
		λ_{ah}	λ_{av}
λ_a	0.1716	0.1486	0.0858

Depth (m)	Pressure (kN/m²)	p_h (kN/m²)	p_v (kN/m²)
0	10.0	1	1
14.29	267.2	40	23
24.29	447.2	66	38
33.11	606.0	90	52
34.29	627.8	93	54
44.29	727.8	108	62
54.29	827.8	123	71
59.29	877.8	130	75

Horizontal component:



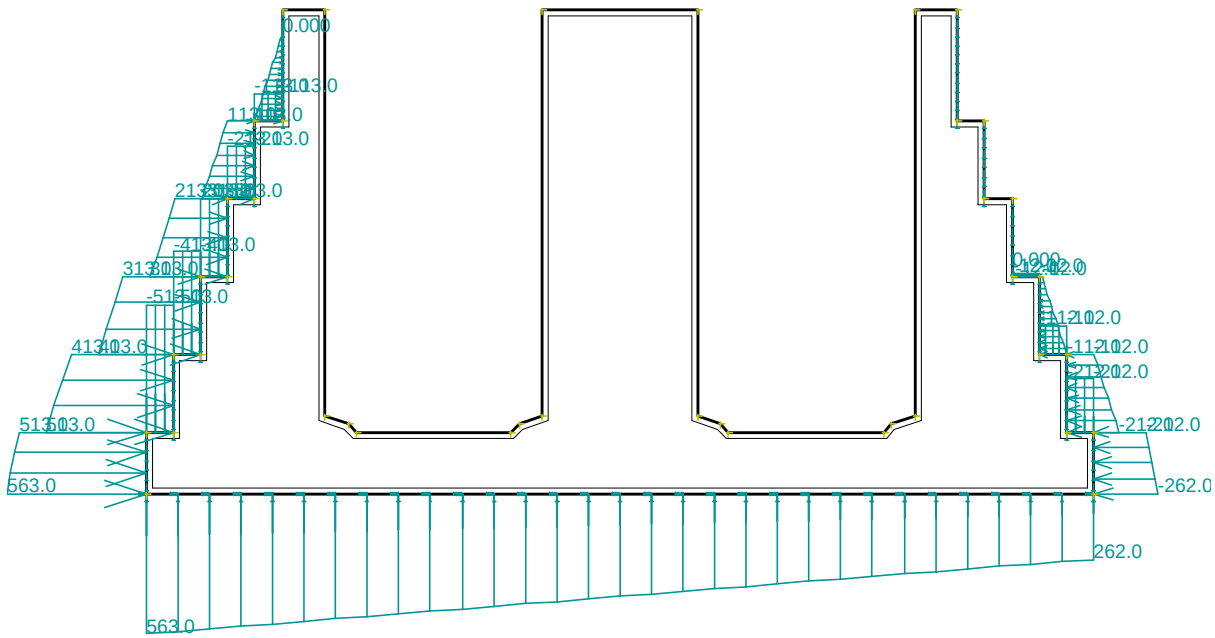
Vertical component:



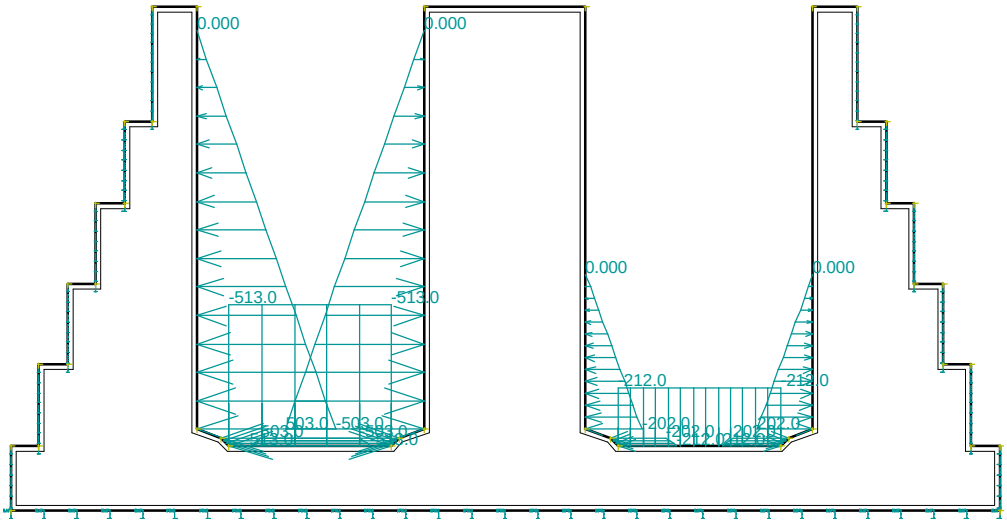
D.3 Water Pressure (case 3)

Water level side Gatun Lake (maximum): + 26.67 m PLD
Water level side Pacific Ocean (minimum): - 3.44 m PLD

Water pressure onto the sides and bottom of the lock head.



Water pressure inside the lock head



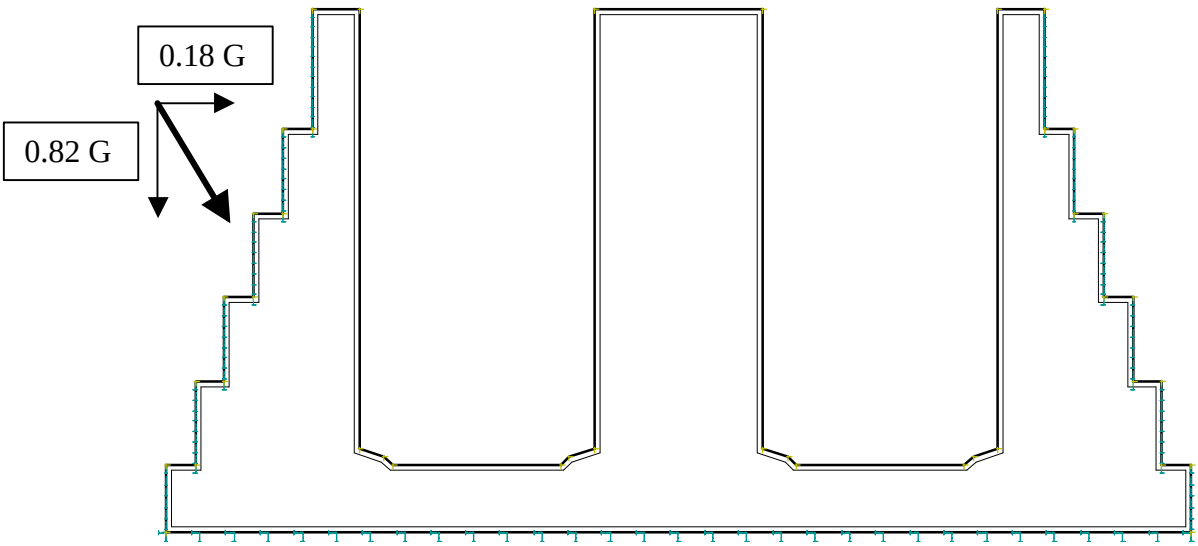
D.4 Seismic Loads

According to the PIANC regulations for Seismic design of Port Structures

c) with $k_v = k_h = 0.18$ for MDE
d) with $k_v = k_h = 0.21$ for MCE

Case 8: Seismic loads on concrete structure
Case 4: Earth Pressure in seismic conditions

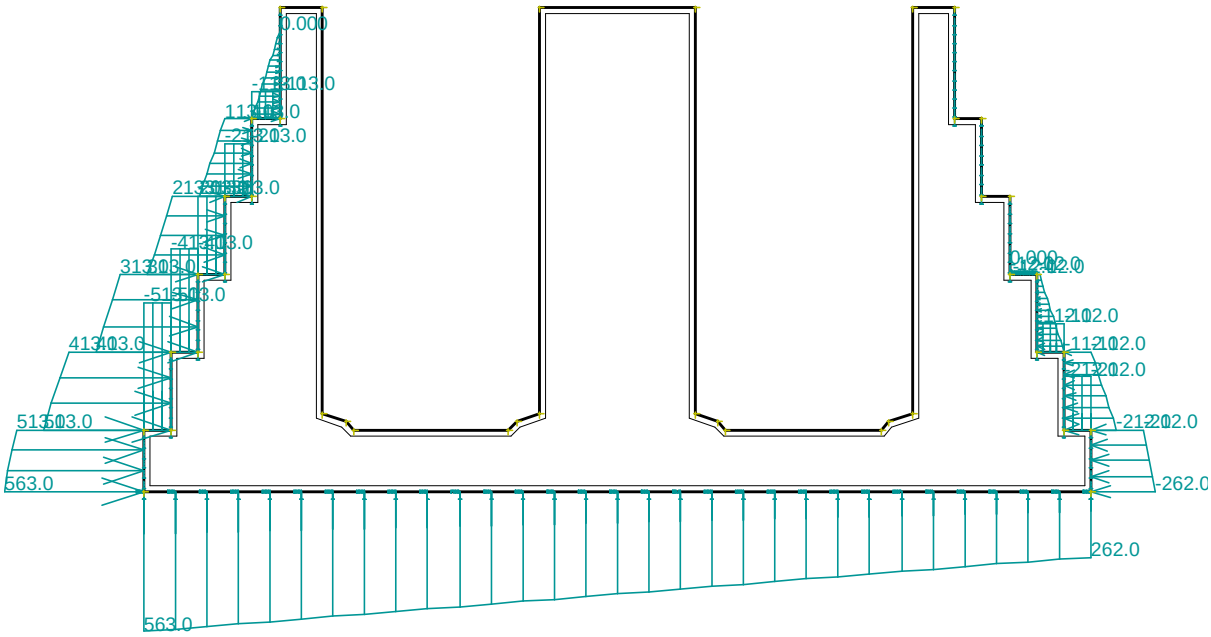
Gv = (1-0.18) G
Gh = 0.18 G
With G the weight of concrete or filling
Gv the vertical component in seismic conditions
Gh the horizontal component in seismic conditions



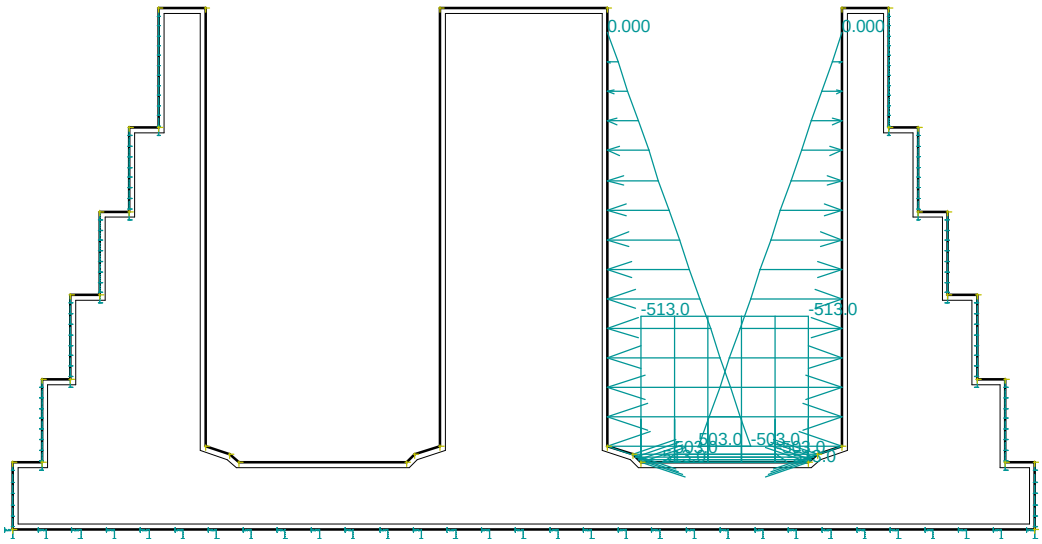
D.5 Water Pressure in Dry Lock Conditions (case 5 - 6)

In case 5 the recess on the side of the lock chamber is put in dry conditions. In case 6 both recesses are put in dry conditions.

Case 6: normal water pressure without water pressure inside the lock head



Case 5: normal water pressure combined with a maximum water level in the gate recess near the Pacific Ocean

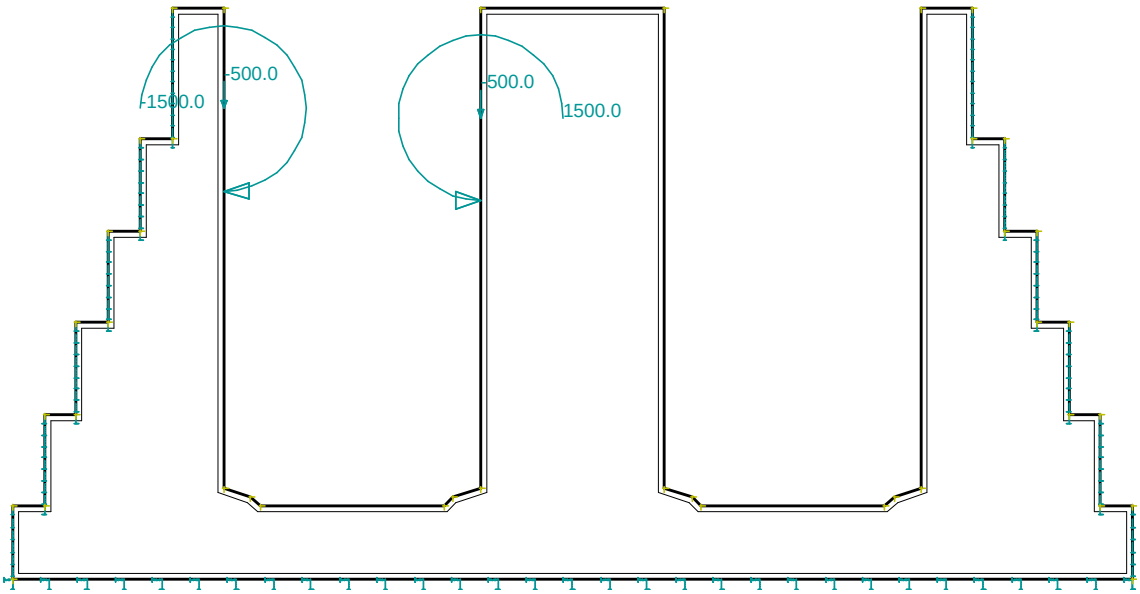


D.6 Maintenance support wagon (case 7)

Loads due to the maintenance support wagons are determined:

Total load gate 2 : 18000 tons
Total number of wagons : 46
Load for 1 wagon : 391 tons

A load of 500 tons is taken into account, placed on a distance of 3 meters from the wall.



2.4.2 LOAD BEARING CAPACITY

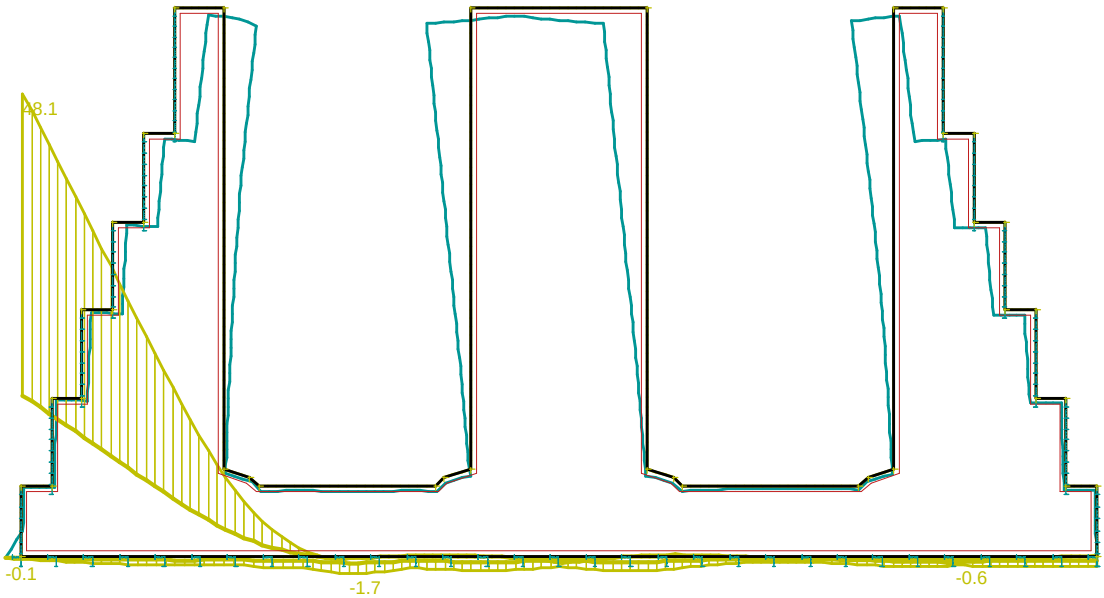
A. Fundamental Load Combinations 105 to 110

Criterion: $\gamma_d \cdot q_{ref} < q_u$
with γ_d . = 1.4

The maximum vertical displacement at the bottom of the wall is 1.7 mm
This means a vertical pressure of 0.0017 x 1000000 kN/m² = 1700 kN/m² = 1.7 MPa

According report R2-A the uni-axial Compressive Strengths of the basalt rock varies from 15 to 100 MPa.

Vertical movement



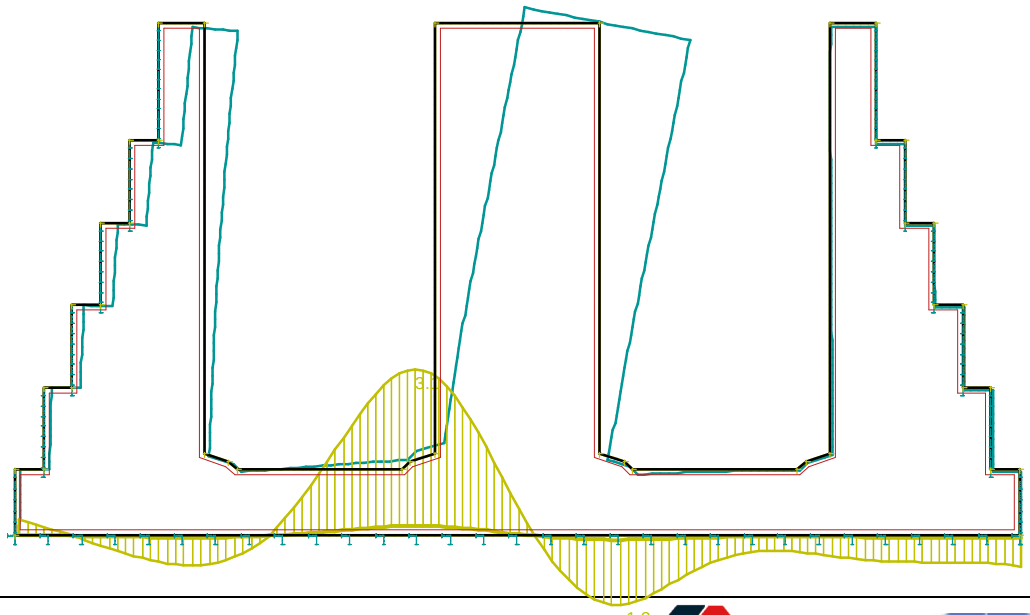
B. Accidental load combination 102

Criterion: $\gamma_d \cdot q_{ref} < q_u$
with γ_d . = 1.0 for load combination 102

The maximum vertical displacement at the bottom of the wall is 1.3 mm
This means a vertical pressure of 0.0013 x 1000000 kN/m² = 1300 kN/m² = 1.3 MPa

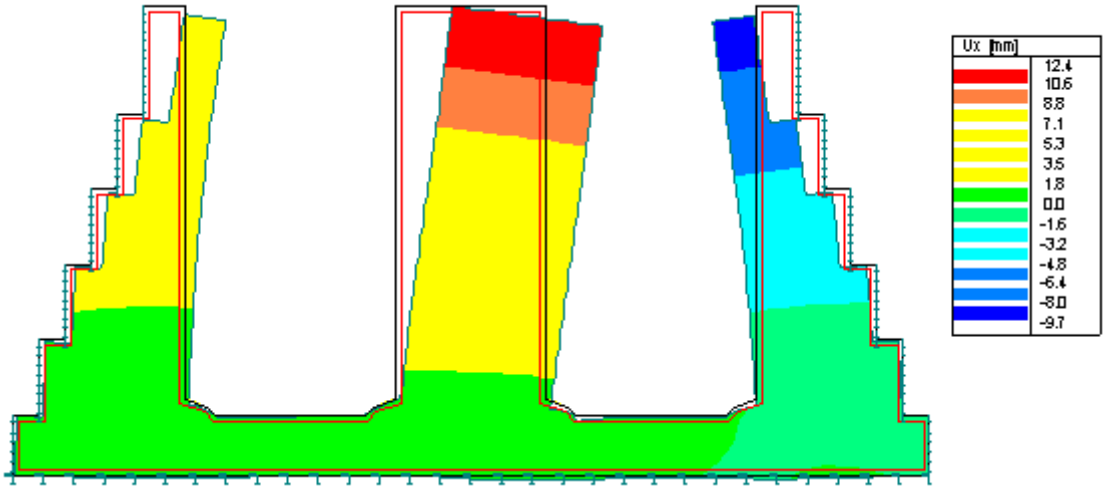
According report R2-A the uni-axial Compressive Strengths of the basalt rock varies from 15 to 100MPa.

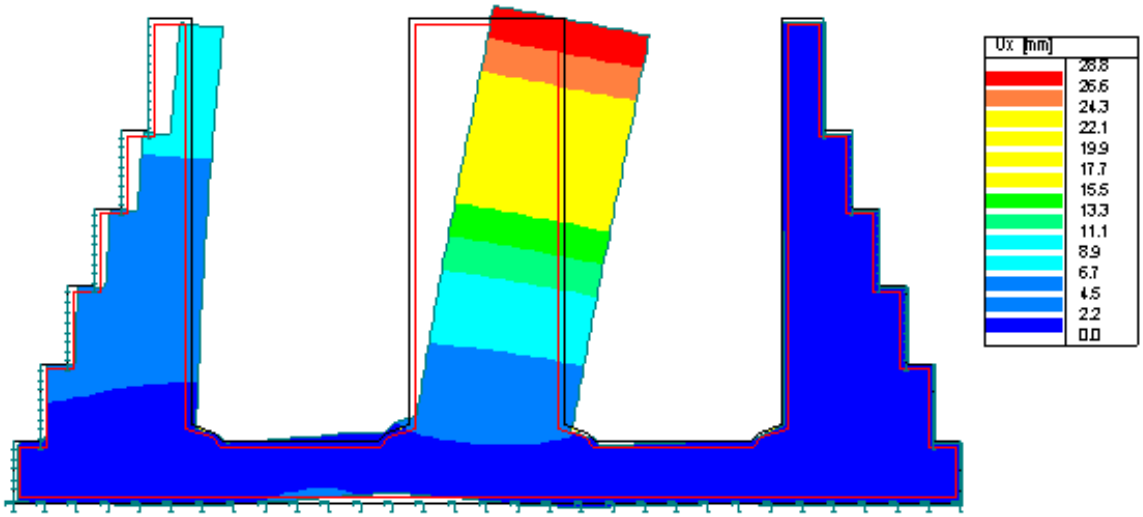
Vertical movement



2.4.3 DEFORMATIONS

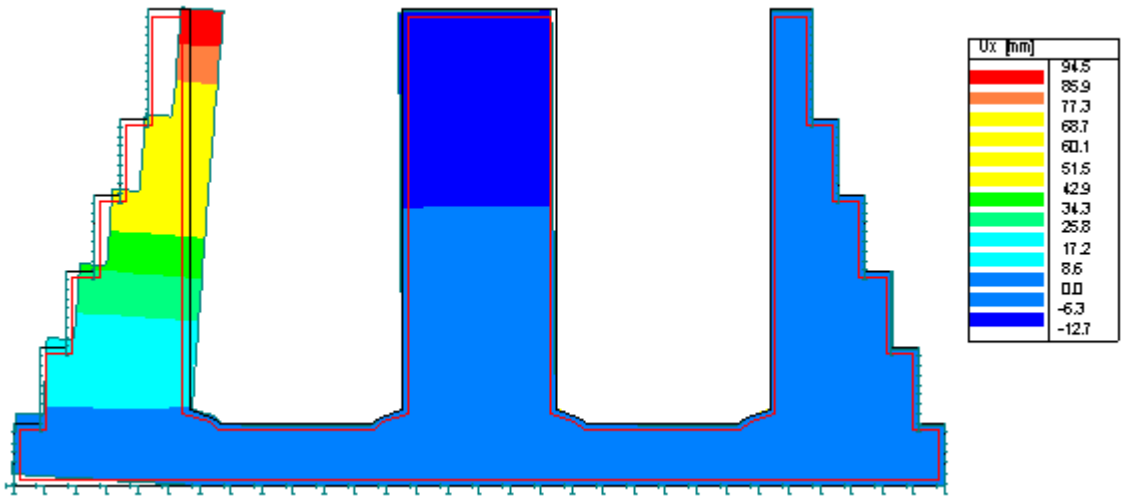
A. Load Combination 101 (Lock in Service)



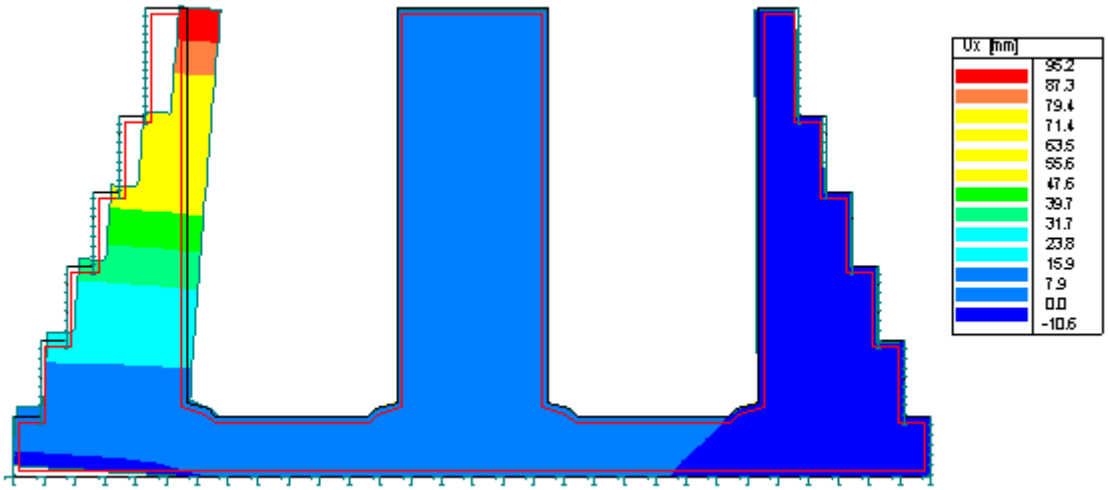


B. Load Combination 102 (Earth Quake)

C. Load Combination 103 (1 gate recess in dry conditions)



D. Load Combination 104 (2 gate recesses in dry conditions)



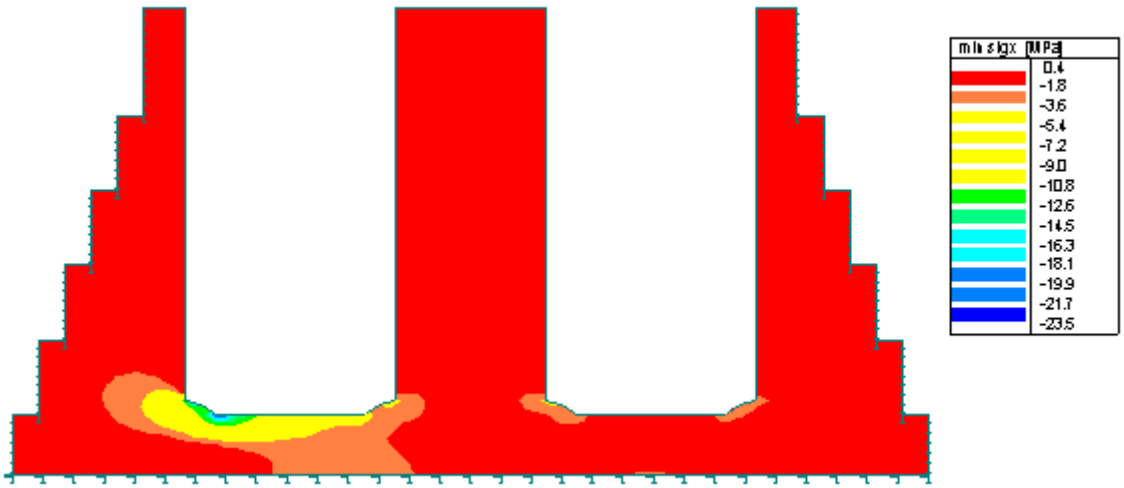
2.4.4 CONCRETE STRESSES

A. Fundamental load combinations 105 tot 110:

1.125 x σ_c < 0.85 f_{ck}/1.5
This means σ_c < 12.5 N/mm²

The results are satisfying for this conceptual design. Details have to be studied by means of a 3D-model.

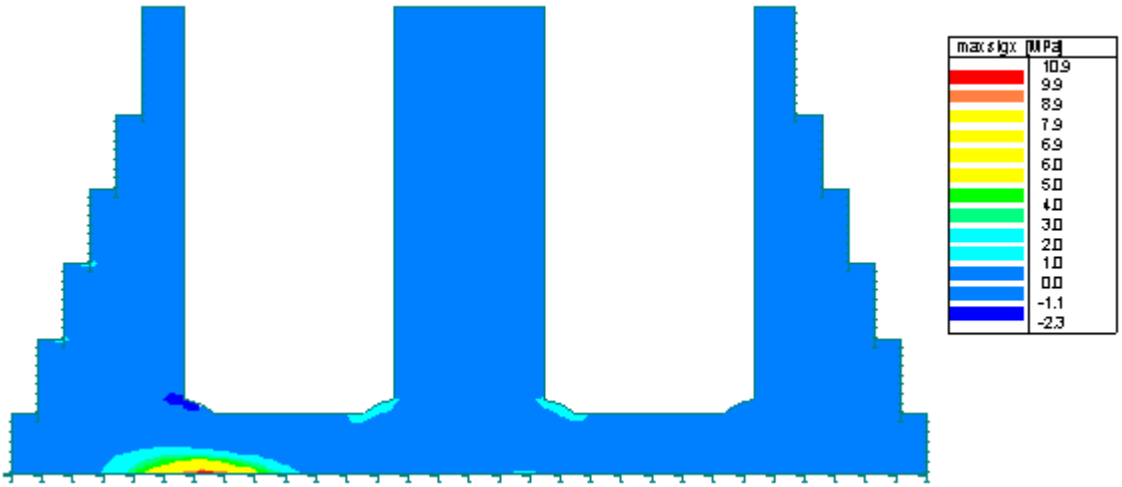
Stresses in the horizontal direction – maximum compression = 23.5 N/mm²



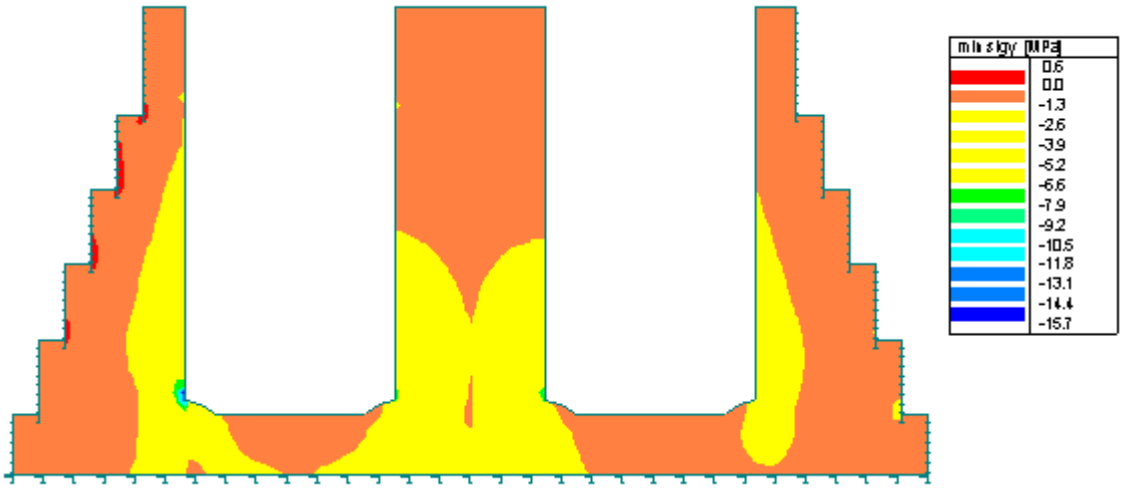
The stresses go up to 23.5 N/mm². These high values are a result of the modeling of the structure. High values are shown near the corners of the connection wall – floor. These values must not be taken into account to verify the concrete stresses.

To check this statement the tension stresses in the concrete structure have been plotted, these will be taken by the steel reinforcement. The values amount to 10.9 N/mm² < 12.5 N/mm².

Stresses in the horizontal direction – maximum tension = 10.9 N/mm²



Stresses in the vertical direction – maximum compression = 15.7 N/mm²

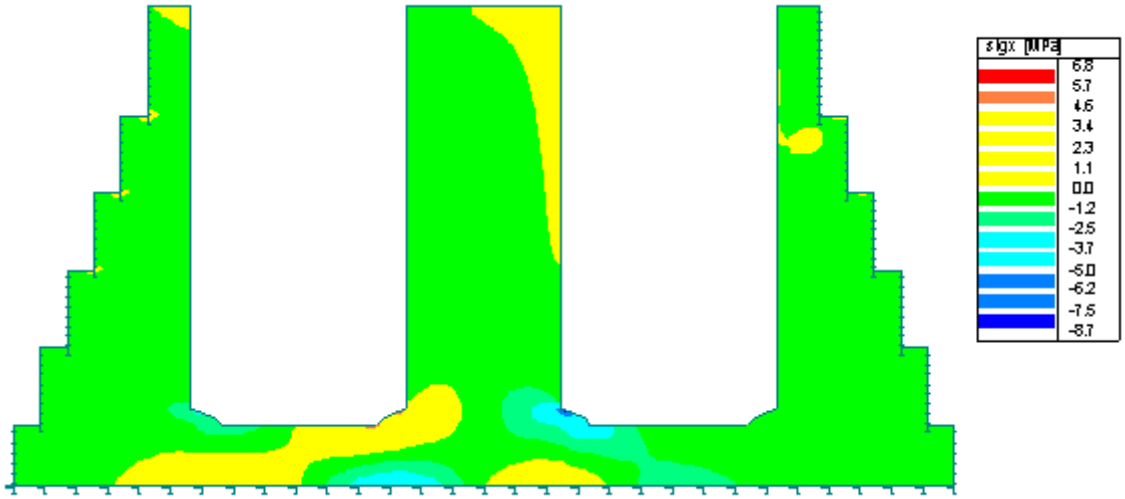


For these stresses in the vertical direction, the same remark as for the stresses in horizontal direction can be made.

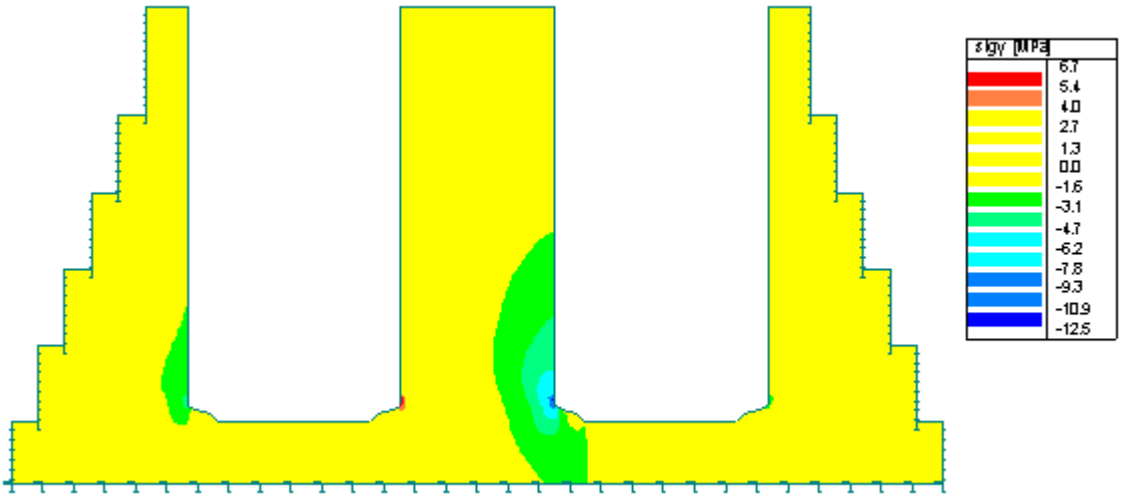
B. Accidental load combination 102:

$\sigma_c < 0.85\ f_{ck}$
This means $\sigma_c < 21.25$ N/mm²

Stresses in horizontal direction – maximum compression = 8.7 N/mm²



Stresses in vertical direction – maximum compression = 12.3 N/mm²



2.4.5 SUMMARY

	quasi permanent load combination - service	accidental load combination - MDE	rare load combination - dry gate recess	rare load combination - dry gate recess	Fundamental load combination	Fundamental load combination	Fundamental load combination	Fundamental load combination	Fundamental load combination	Fundamental load combination
	101	**102**	**103**	**104**	**105**	**106**	**107**	**108**	**109**	**110**
Load Bearing Capacity										
$1.4\ q_{ref} < q_u$	-	-	-	-	OK	OK	OK	OK	OK	OK
$q_{ref} < q_u$	-	OK	-	-	-	-	-	-	-	-
Deformations										
Max horizontal displacement (cm)	1.24	2.88	9.45	9.62	-	-	-	-	-	-
Concrete stresses										
$1.125 \times \sigma_c < 0.85\ f_{ck}/1.5$	-	-	-	-	OK	OK	OK	OK	OK	OK
$\sigma_c < 0.85\ f_{ck}$	-	OK	-	-	-	-	-	-	-	-

2.5 CONTACT STRESSES

2.5.1 BOTTOM SEAL

Forces onto the bottom seal

Maximum horizontal reaction forces at the sill bearing occur during retaining of the (maximum) water level difference. They result directly from the 2D-beam grid model computations presented in appendix A after an optimization of the stiffness of the cantilever bottom ends of the vertical frames. Doing so uplift from the sill bearing of the skin plating at the gate bottom edges is avoided.

To derive the maximum contact stress, the minimum spreading length (along the wooden beams of 500 mm width) is mentioned in the tables below.

.

	Reaction force at frame (3.15 m length)	Max. contact stress (min. 440 mm)
Gate S1	5700 kN	26 N/mm²

	Reaction force at frame (2.65 m length)	Max. contact stress (min. 540 mm)
Gate S2	4500 kN	17 N/mm²

The results mentioned in the report of the lay-out of the rolling gates are used.

A. Calculation of the contact stresses

The bottom seal is made of two basalt (or a similar material) elements: one for the direct contact with the gate and one making the placement of a habitat possible.

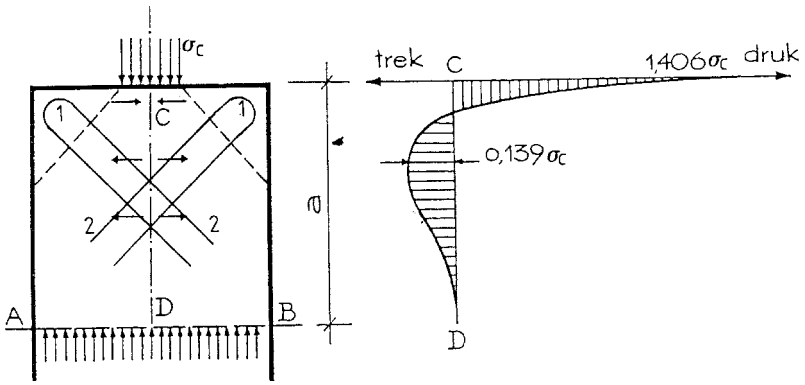
Because of the gap in the second stone we cannot spread the force vertically. In our calculation a contact height of 35 cm is used.

Horizontally the force can be spread over an angle of 45 degrees. A contact width of 200 cm + 54 cm + 200 cm = 454 cm is obtained. Only 315 cm is taken into account, being the distance between the vertical frames.

Accordingly the contact stresses onto the concrete can be derived:

5700 kN / (35 cm x 315 cm) = 5.17 N/mm²

The maximum tensile stresses within the seal caused by the contact stress can be estimated by formulas in literature.



$\sigma_t = 0.139 \times \sigma_c$
$\sigma_t = 0.139 \times 26$ N/mm² = 3.61 N/mm² < 6.67 N/mm² = 10 N/mm²/1.5

The tensile strength is kept below the admissible tensile strength of the material, which is mentioned in the design criteria. No additional safety factor is used for the contact stresses because the dry lock is seen as a rare load combination (safety factor = 1).

2.5.2 LATERAL BEARINGS

A. Forces onto the lateral bearings

Maximum horizontal reaction forces at the lateral bearings (on the lock walls) occur during retaining of the (maximum) water level difference. From the 2D-beam grid model computations presented in appendix A, the reaction forces at the horizontal frames are obtained (corresponding to the same optimized stiffness distribution as mentioned sub 4.5.3). Subsequently the part of the vertical frame structure at the contact with the lock walls is modeled as a continuously elastically supported beam, which is loaded by these reaction forces. The maximum contact stresses are listed below.

We use the results mentioned in the report of the lay-out of the rolling gates.

Gate S1	Max. contact stress (at R1)
	45 N/mm²

Gate S2	Max. contact stress at R1	Max. contact stress at R6
	35 N/mm²	42 N/mm² (*)

(*) Based on our experience with 3D-modelling of the recently designed new rolling gates for the Van Cauwelaert lock (Port of Antwerp) we expect that the contact stresses at R6 are overestimated at least by 5 N/mm² due to the underestimation of the beam stiffness at the air chamber.

B. Calculation of the contact stresses

The vertical seal is made of a basalt (or a similar material) element. The sealing at the side with the gate recesses is different from the one on the other side, because it has to work as seal for the bulkhead.

The maximum contact stresses that are given remain constant along several meters in height. Therefore we can not spread the force in the vertical direction.

Horizontally the force can be spread over the width of the sealing stone. A contact width of 160 cm is obtained.

Thus the contact stresses onto the concrete can be derived:

45 N/mm² x 500mm/1600mm = 14.1 N/mm²

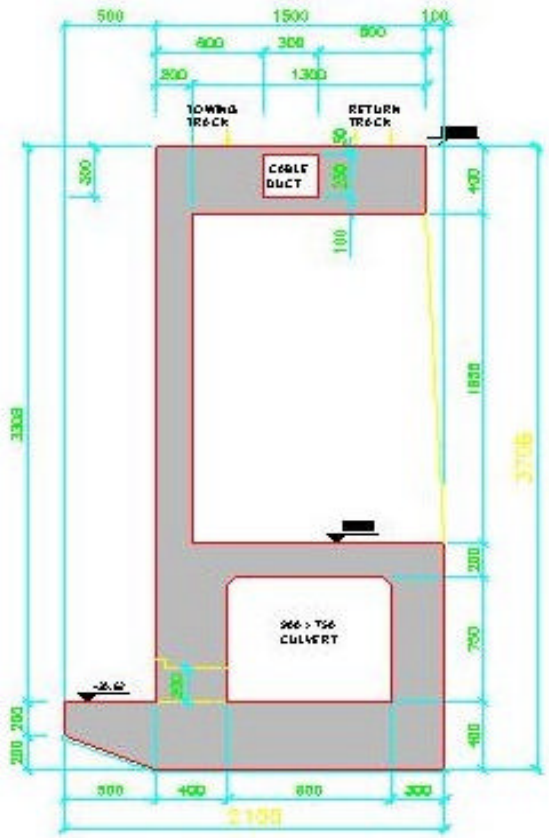
The maximum tensile stresses within the seal caused by the contact stress can be estimated by formulas in literature.

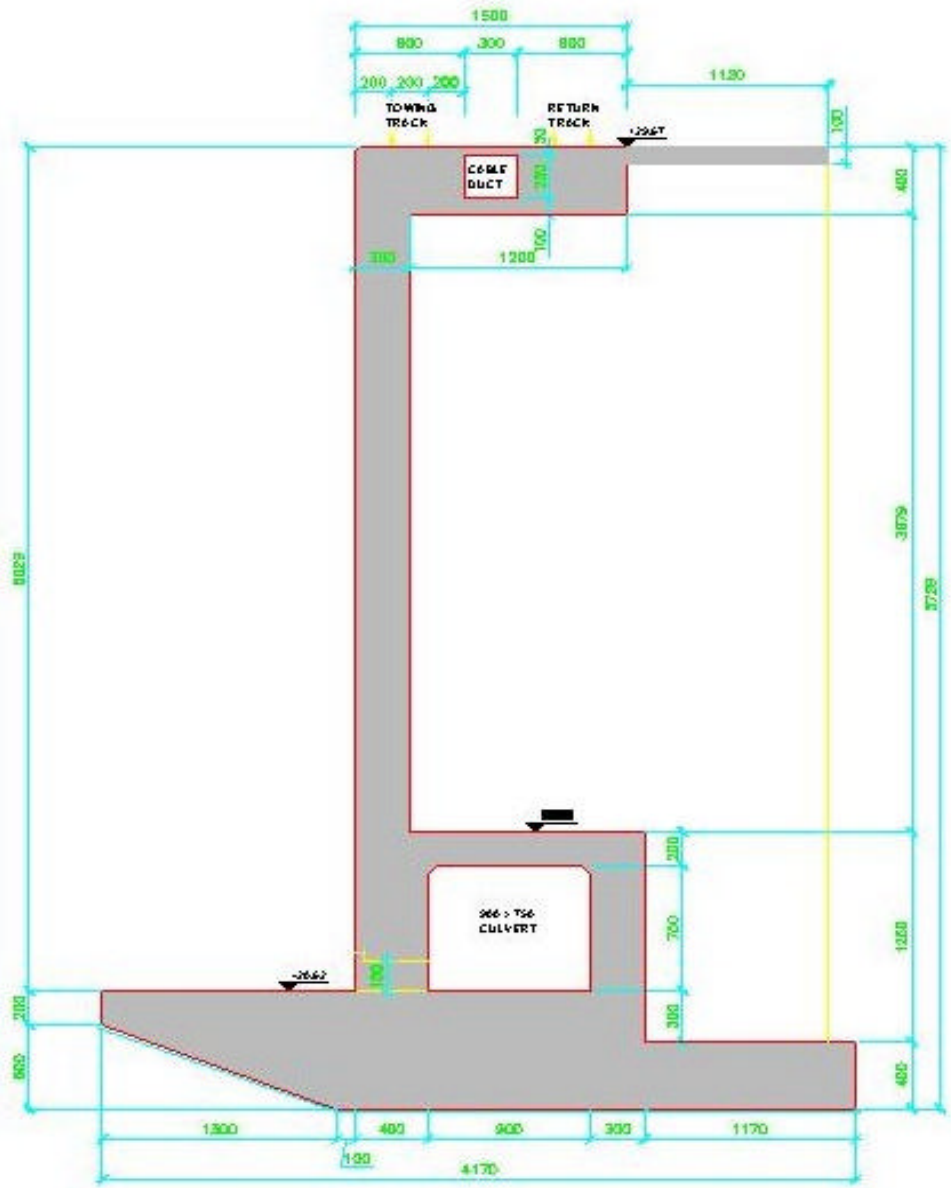
$\sigma_t = 0.139 \times \sigma_c$
$\sigma_t = 0.139 \times 45$ N/mm² = 6.26 N/mm² < 6.67 N/mm² = 10 N/mm²/1.5

The tensile strength is kept below the admissible tensile strength of the material, which is mentioned in the design criteria. No additional safety factor is used for the contact stresses because the dry lock is seen as a rare load combination (safety factor = 1).

APPENDIX I

Excerpt of Powerpoint Presentation on Lock Walls
(16.December 2002 – Meeting M6 in Panama)





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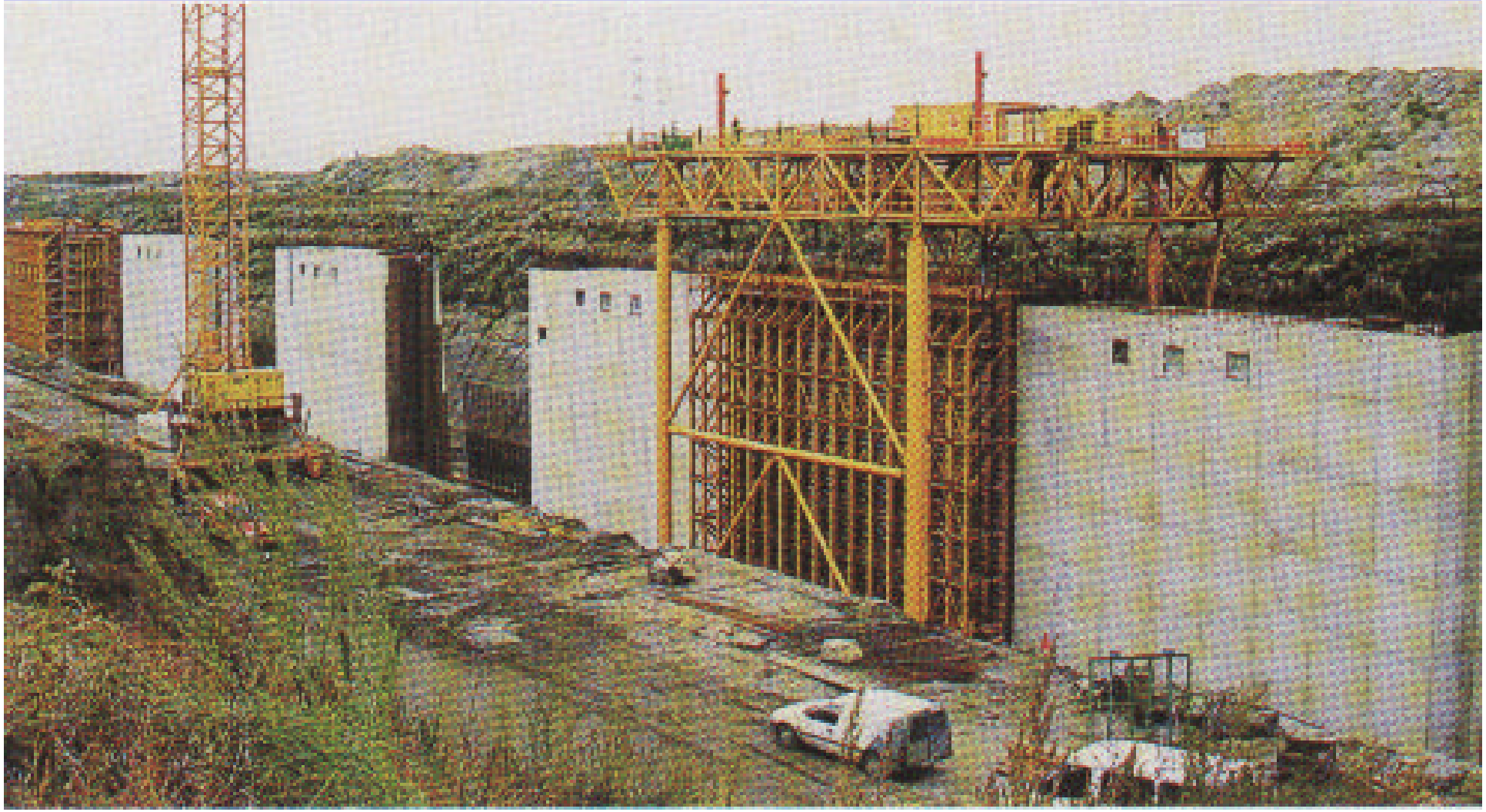

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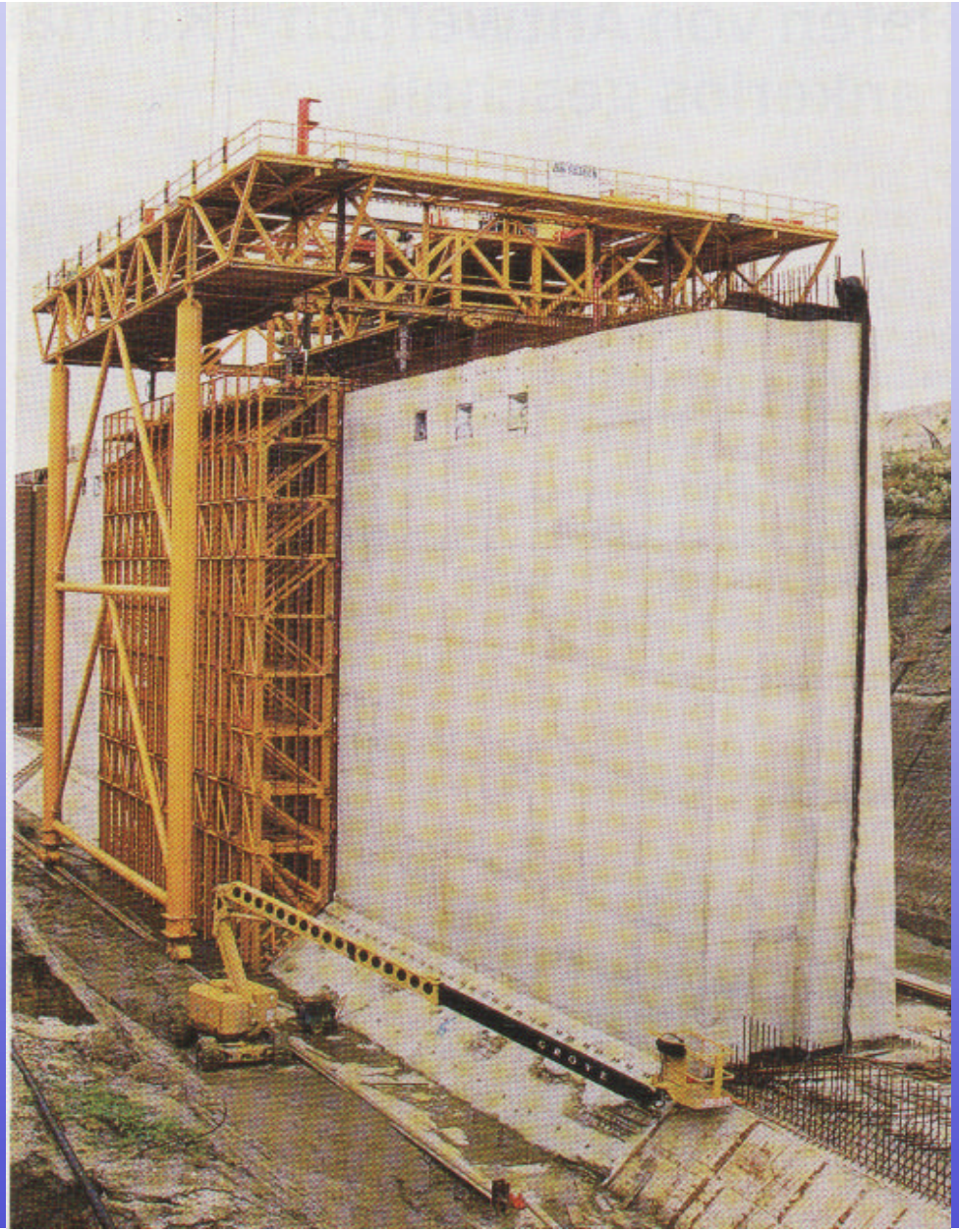

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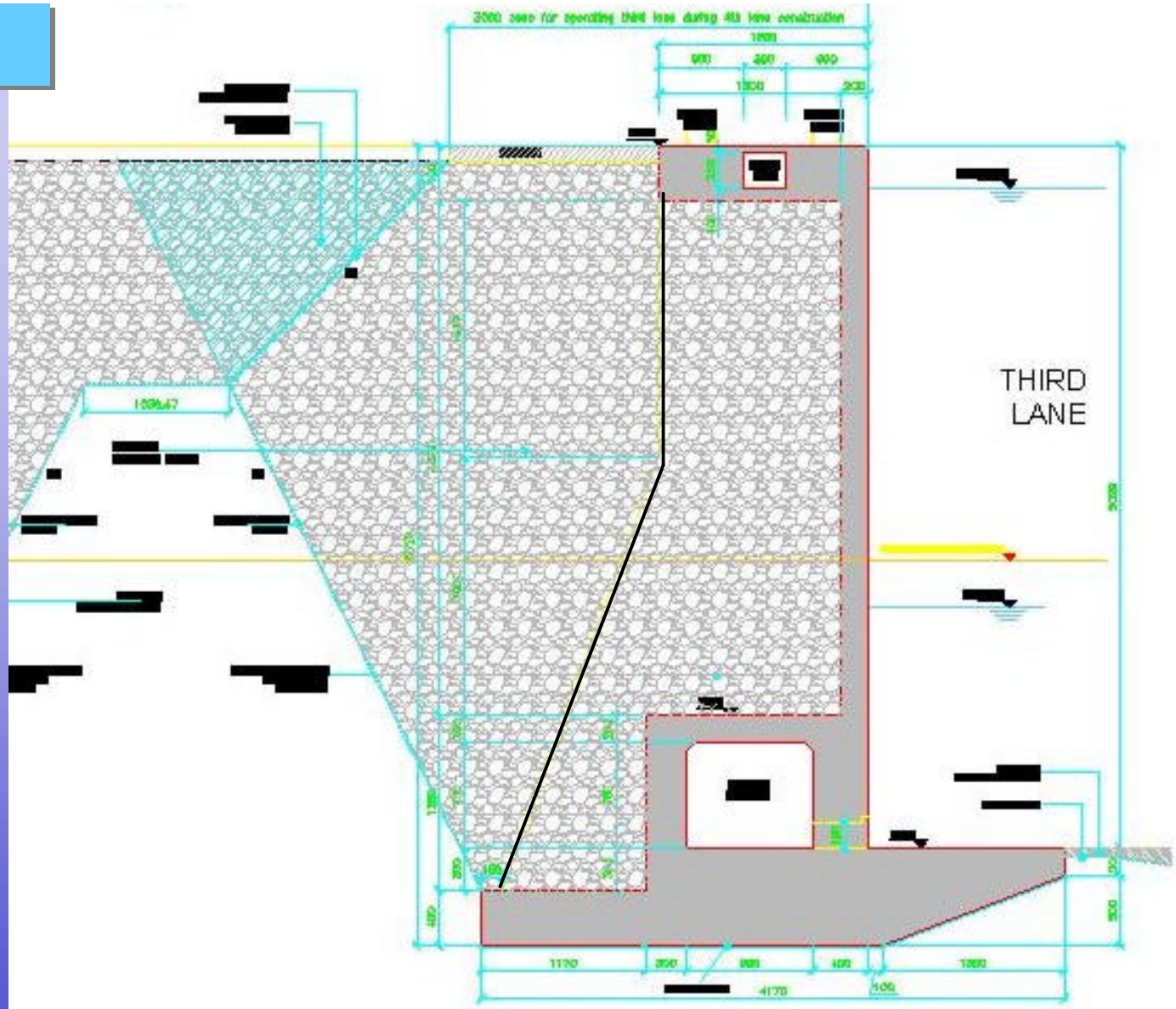

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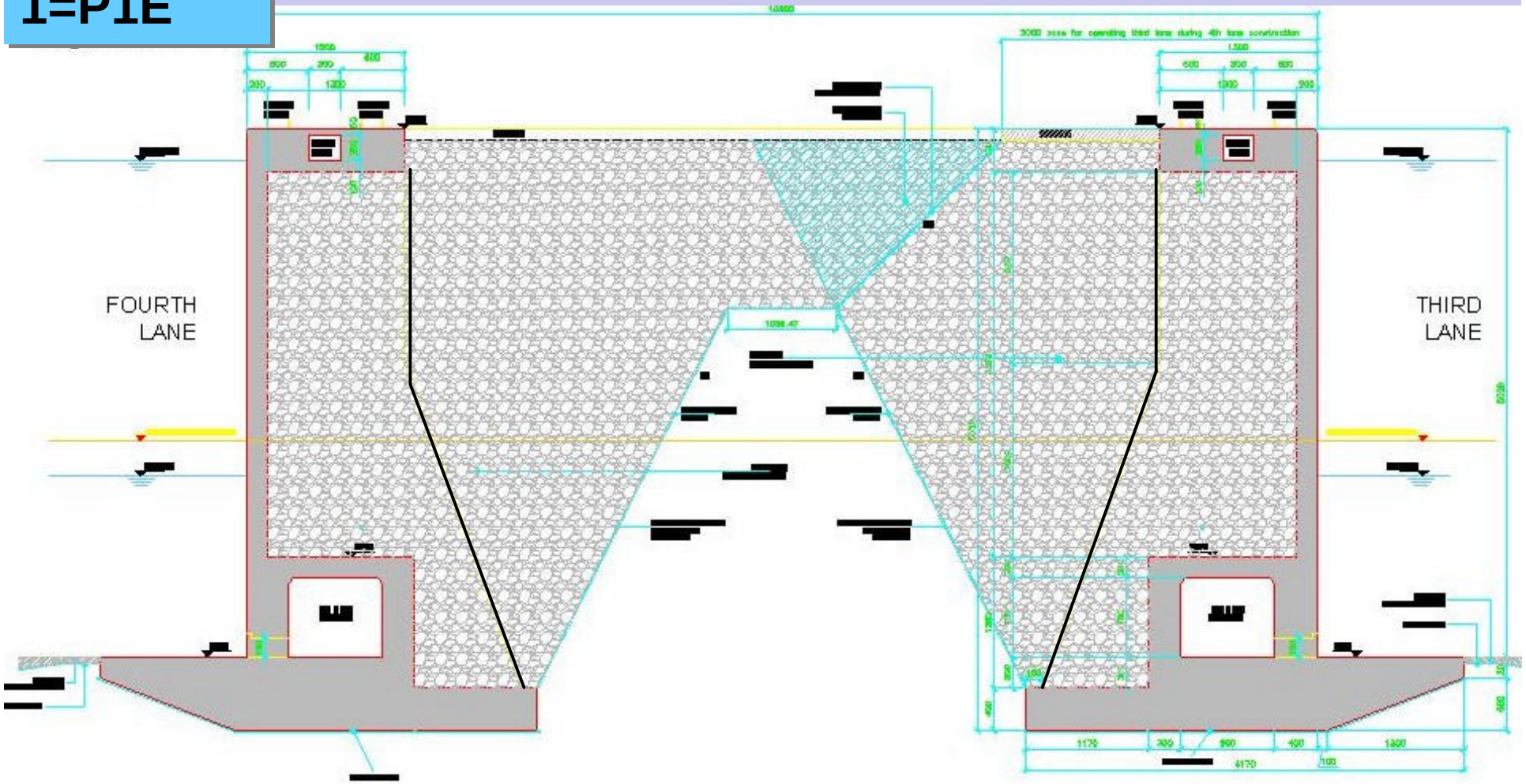

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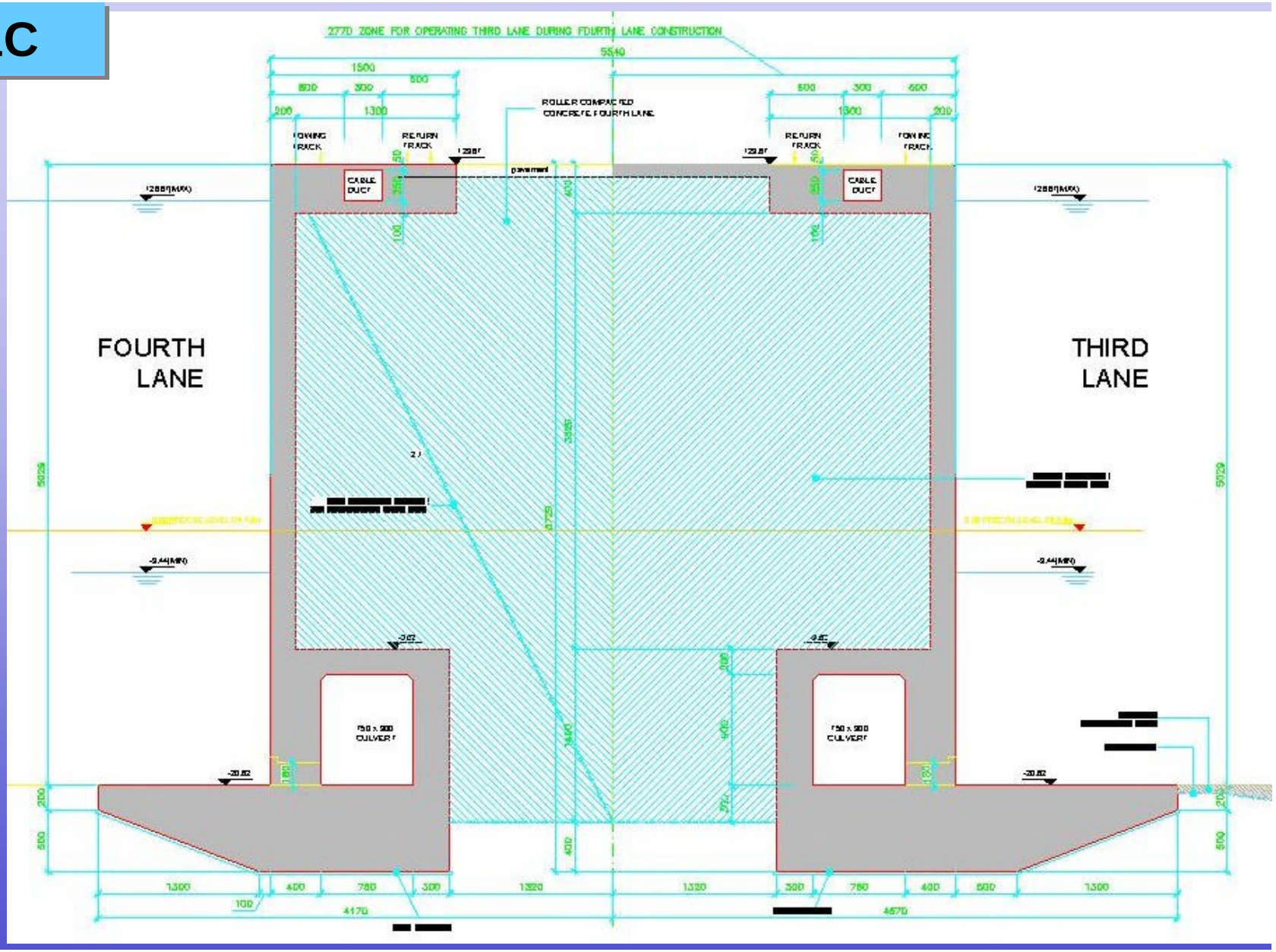

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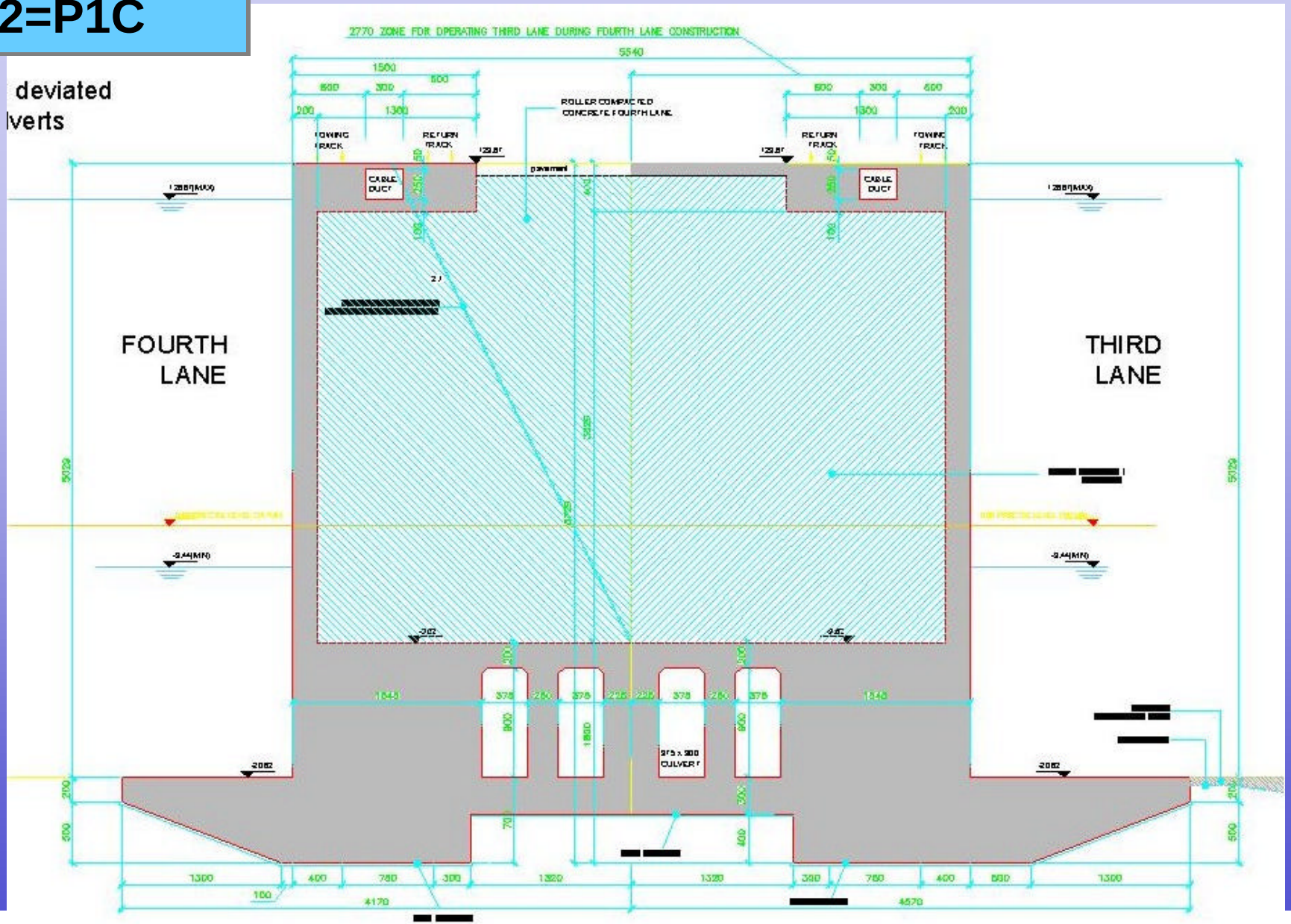
deviated
lverts



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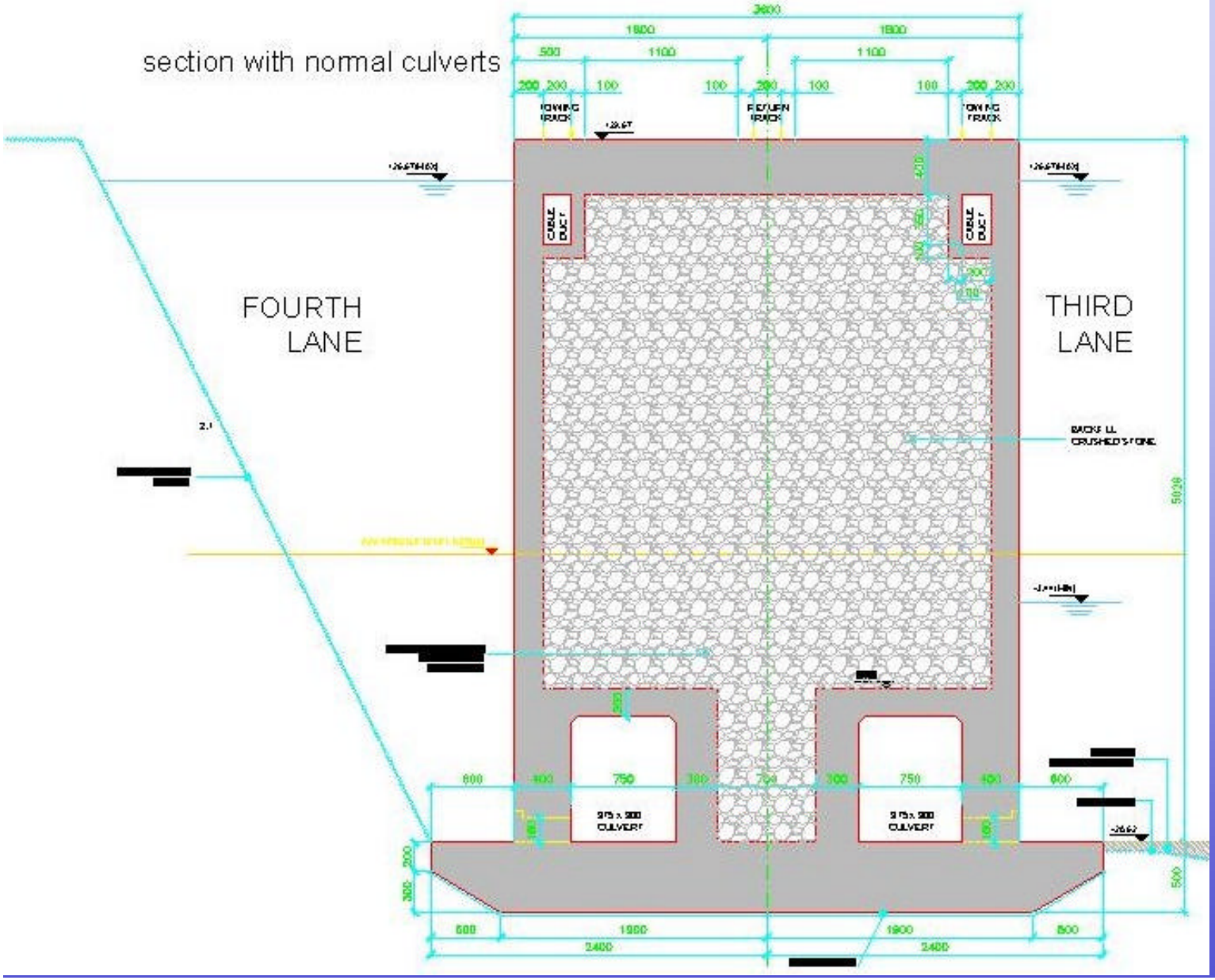
section with normal culverts



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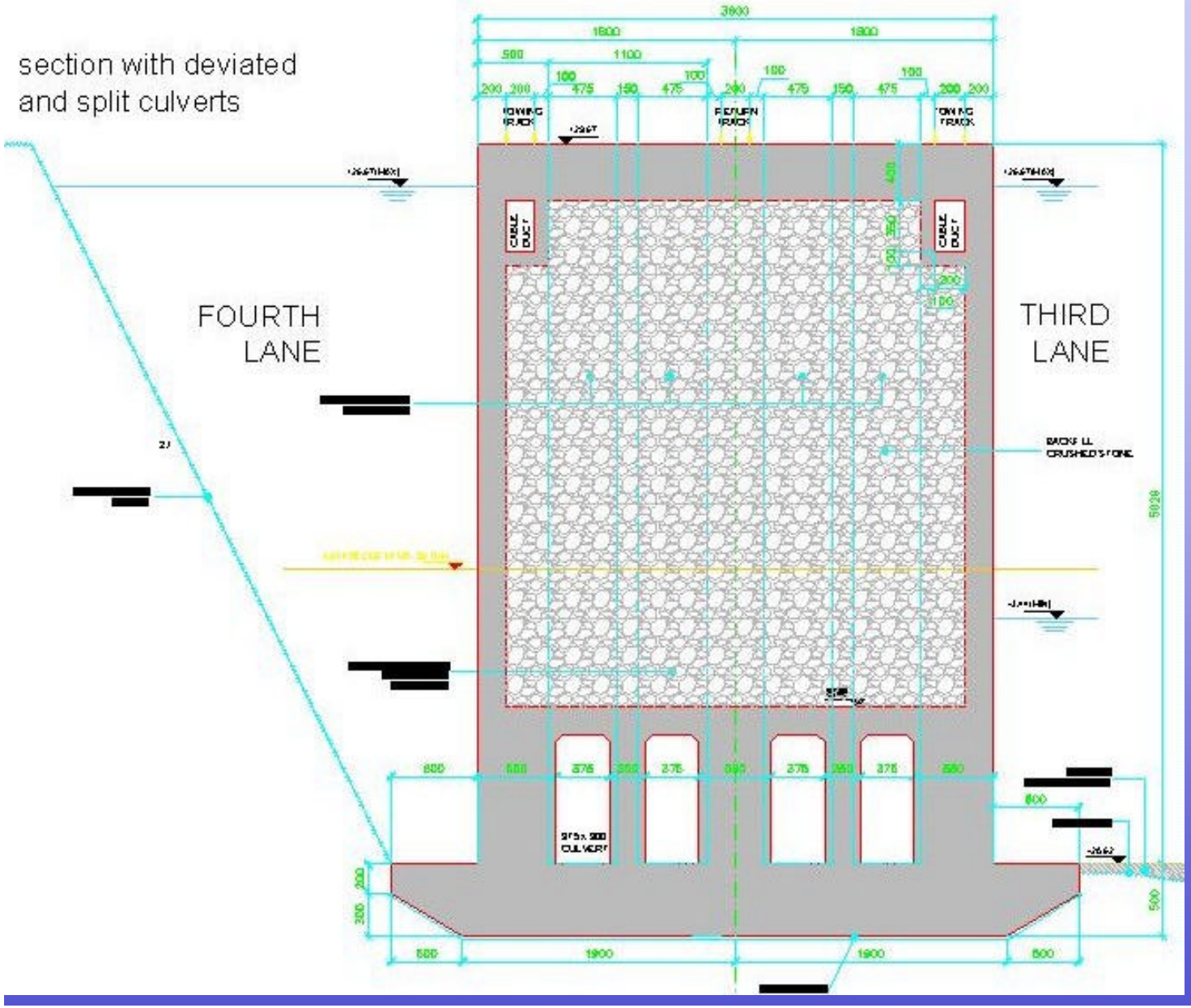
section with deviated and split culverts



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Diseño Conceptual de las Esclusas Post Panamax

TASK 4

C – FILLING AND EMPTYING SYSTEM

R4-C

in association with

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ANNEXES

1 FOREWORD

1.1 CONTRACT

This report is performed within the scope of the contract n° SAA-97462 awarded January 16th to the Consortium named CPP (Consorcio Post Panamax) by the client ACP (Autoridad del Canal de Panama).

This contract concerns the conceptual design study of the new locks of the Panama Canal.

1.2 SCOPE OF WORK

This report concerns the second configuration of the 3rd line of Post Panamax locks, a single lift lock system with water saving basins sparing at least 75 % of the water (the first configuration, a three lift lock system has been studied in a first phase of the study and has been presented in the final report under section R4-C).

The scope of work briefly consists in :

- Setting the levels of the chamber and the saving basins
- Determining the best system to fill and empty the chamber of the lock, in terms of safety for the ships, operation speed, efficiency and cost
- Designing at a conceptual level the whole hydraulic structure of the best solution described above
- Designing at a conceptual level a recycling system of the water normally spilled in the ocean
- Determining the best solution to save at least 75 % of the water.

2 INTRODUCTION

2.1 BACKGROUND

The actual locks of the Panama Canal are going to be saturated in less than ten years. In addition, the present locks are not able to transit the Post Panamax vessels.

The "Autoridad del Canal de Panama" is conducting a study to evaluate the feasibility of a third line of locks for bigger vessels. Nevertheless, there is no sufficient water at the present time to operate the new locks, that's why new solutions have to be found.

None of these kinds of locks have yet been designed. The engineering work starts with a conceptual design study. The purpose of this study is not to design in detail the locks but to allow ACP to choose the best solution according to the following themes: hydraulic filling and emptying systems, means to save water, type of gates, civil works, …

The design itself will be provided by other studies.

2.2 BRIEF DESCRIPTION

The Panama isthmus is sailed by the ships thanks to the so-called Panama Canal. This channel is mainly composed by the lake Gatun, and two sets of locks, one on the Atlantic side and one on the Pacific side of the canal.

The Pacific coast locks are composed of two distinct blocks, which frame the lake Miraflores :

- A set of two lines of two steps locks, on the Pacific side, the Miraflores locks, for nearly two third of the head
- A set of two lines of single step locks, on the Gatun lake side, the Pedro Miguel locks, for the remaining head

Each lock has the following dimensions:

- Useful length : 305 m
- Useful width : 33.50 m
- Draft : 13 m

The maximum tidal range on the Pacific coast is nearly 7 m, the level of the Gatun Lake can be lowered by a little more than 2 m during extremely dry periods such as an El Niño drought (from 26.14 m PLD to 23.90 m PLD). The usual fluctuation is closer to 2.0 m (26.7 m PLD to 24.9 m PLD).

All the locks are able to handle 65 000 dwt ships, called Panamax ships, scheduling in convoy, i.e. the ships sail 12 hours in one way and the next 12 hours in the other way.

The present locks will be saturated in a few years. In addition they are not able to pass the larger ships: 105 000 dwt container vessel, 140.000 dwt bulk carrier and further up to 200 000 dwt ships, called Post Panamax. The ACP (Autoridad del Canal de Panama) is then studying to build new and larger locks.

The main problem from a hydraulic point of view is the lack of water to operate these new locks. Present locks are yet consuming nearly all the water of the watershed. During the dry season, the resource is lower than the consumption and the level of the lake decreases. In addition, some other needs (municipal and industrial), are increasing drastically, competing with the water demand required to operate the locks.

The present hydraulic project has two main purposes:

- Designing efficient hydraulic circuits for filling and emptying operations

- Proposing water saving systems (in addition to new resources)

The present project on the Pacific side consists in the stepping of the head at one single place, by means of a single lift lock (2nd configuration) to the West of the present alignment. This new lock requires also a new channel as indicated in the lock alignment optimization chapter.

3 TERMS OF REFERENCE

3.1 LEVELS

3.1.1 GATUN LAKE

Maximum level: +26.67 m PLD
Minimum level: +23.90 m PLD

3.1.2 PACIFIC OCEAN

Ranging from – 3.44 to +3.60 m PLD

It is admitted to design the bottom levels of the chambers (sills) with the Mean Low Water Spring (MLWS) level, i.e. –2.32 PLD

3.2 SIZES - DIMENSIONS

- Useful length of the locks (between inner gates) : 426.80 m
- Useful width of the locks : 61.00 m
- Draft (minimum water over the sills) : 18.30 m
- Freeboard : 2.13 m (to be justified)

3.3 WATER SAVING RATE

The single step lock system shall be configured to save at least 75 % of the water required for one lockage.

A provision shall be taken into consideration in the design for recycling the spilled water at the outlet of the lowest lock level and the intake for the transfer of the water to the highest lock level

3.4 OPERATING TIME

It is desired for the single lift to reach a filling or emptying time suitably proportioned towards the 8-10 min lap time requested for each lock of the three lift lock system (1st configuration) without using the water saving basins. That means for instance trying to reach for the single lift a global operating time for each lockage that would allow the same number of ships pass through the lock, as in the triple lift configuration.
The time needed for a lockage using the water saving basins is not specified, nevertheless it must not increase too much the filling /emptying times.

The consultant set a target time of about 24', corresponding to a 1.25 m/min speed variation of the chamber water level, equal to the present locks'.

3.5 NUMBER OF SOLUTIONS TO BE STUDIED

At least two solutions for the filling and emptying system have to be studied.

3.6 COST AND MAINTENANCE OF THE SYSTEM

Special attention will be paid to these points:

- A compromise has to be reached between the level of efficiency of the system and the corresponding costs.
- The redundancy of the system as it is very important to obtain a high level of reliability, minimizing traffic interruptions.

4 DESIGN CRITERIA & ASSUMPTIONS

4.1 DESIGN CRITERIA

Reference is made to the reports:

- R2 – A : Part A General Design Criteria
- R2 – B : Part B Specific Design Criteria
- R4 – C : Filling and emptying system (Final report configuration 1)

4.2 ASSUMPTIONS

- Saving 75 % of the lockage water implies the use of 6 saving basins or less basins and an additional pumping device. According to the TOR, no solution with less than 6 water saving basins will be studied.

- The water saving basins will be built only on one side of the lock. An implementation on both sides would require too much space, which is already reserved for the 4th lane project

- The possibility of stacking the water saving basins on a single pile will be examined. However, it is possible that, due to the tidal amplitude of the Pacific Ocean, the level variations inside the water saving basins make it impossible to stack the basins on one single pile. The water saving basins should though be located on multiple piles on one side of the lock.

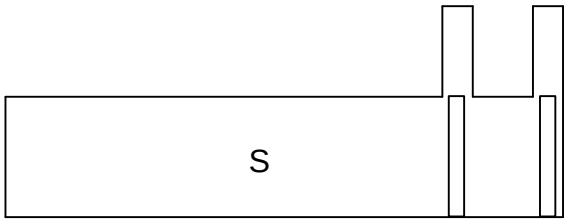
- The use of a single lock reduces drastically the total length of the system, compared to the first configuration of 3 locks. This will allow to extend the length of the water saving basins beyond the lock chamber, thus reducing the total width of the system.

- Considering the operating time, and to be in accordance with the results of the triple lift configuration, the target time for filling and emptying the chamber using the water saving basins is

approximately 35 minutes. Shorter times would lead to too large culverts and conduits. In addition, this value has been chosen because it corresponds to the time required to pass the same number of ships as in the first configuration, thus leading to easy comparisons between these two configurations.

- The average filling time without any water saving basin should lead to a level fluctuation velocity in the lock of about 1.25 m/s (present value).

- The surface of the lock which is taken into consideration for the filling / emptying simulations is 33 800 m². It includes the surface between the adjacent gates, the surface of the gate slots and part of the gate surface (75 %):



- The valves will be of the vertical plane valve type, rectangular, with rollers.

- Depending on the number of circuits, the valves will be duplicated or not. Each valve will be surrounded by slots in order to insert stoplogs for maintenance or repair works. According to ACP's demand, these slots will have the same size as the main valve slots so that they can be equipped with auxiliary valves if required. Access shafts for material and personnel will be provided on both sides of the main valves.

- The scheduling in convoy mode which is the present way to lock ships, will not be retained for the 3rd lane of locks in that configuration.

- Smaller ships than the Panamax should use a priori the existing lanes of locks. However, the design of the filling system will take into consideration the possibility for smaller ships to get locked in the new lock. This will influence in particular the admissible rate of turbulence in the chamber.

5 LEVELS OF THE CHAMBER AND WATER SAVING BASINS FLOORS.

All elevations are referred to precise level datum (P.L.D)

5.1 PRESENTATION OF THE METHOD AND INPUT DATA

This study consists in calculating the water surface elevations, in the chamber and in the WSBs, at anytime during the lockage and whatever the lake or the ocean levels are. It then allows to calculate the chamber and water saving basins main characteristics (bottom and top elevation).

All the calculations are carried out with the software developed by the Consultant. This software is presented in paragraph 5.2.

➢ **The Pacific Ocean levels**

To carry out the simulations, the tides of the Pacific Ocean have been taken into account, considering:

- A 12.47 hours period. This value was determined with the 1991 year data (resolution with Statgraphics? software)
    - The initial maximum and minimum levels defined in the TOR (-3.44 m PLD; + 3.60 m PLD)

The resulting equation is shown below:

$$Z_{Pacific} = 3.52 * \sin\left(\frac{2p}{12.47} * t\right) + Z_{mean}$$

with $Z_{mean} = 0.08$ m

The curve resulting from this equation is given in annex 2.1.

- **The Gatun lake levels**

According to the TOR, the maximum and minimum values are:

Maximum level: ..... +26.67 m PLD
Minimum level: ..... +23.90 m PLD

- **Freeboard and draft**

Freeboards and drafts taken into account for the design of the structures are in concordance with the design criteria:

	Draft (m)	Freeboard (m)
Chamber	18.30	2.13 (*)
Water saving basins	1.00 (**)	0.80

The freeboard of 2.13 m given by the TOR is adopted. The freeboard depends on the oscillation amplitudes of the water level in the chamber during lockage. A scale model is required to get a precise assessment of the oscillations; same remark for the saving basins freeboard.

Concerning the saving basins draft, calculations have been made without any draft; in fact, a draft of about 1.0 m should be adopted in order to prevent vortex formation (see §8.4).

The adopted values do not affect the results of the calculations.

Note (*): it will be seen in other reports concerning the second configuration (especially the one about the lock walls) that a value of 3.00 m is adopted for the freeboard.

Note (**): see § 11.4 for justification

- **Scheduling**

The simulations are undertaken with the ‘’alternate’’ scheduling.

➢ **Characteristic operating times**

Operation times in the simulations are the following:

	duration time (min)
gate opening (closing)	7 (5)
total chamber filling or emptying time	30
water saving basin filling or emptying	4
movement of ship (in or out)	30

5.2 WATER LEVELS CALCULATION

A specific software has been developed to calculate the water level in the chambers and the water saving basins during the different stages of a lockage in the case of **a single step lock with six water saving basins.**

The software is able to simulate cycles scheduled in alternate mode:

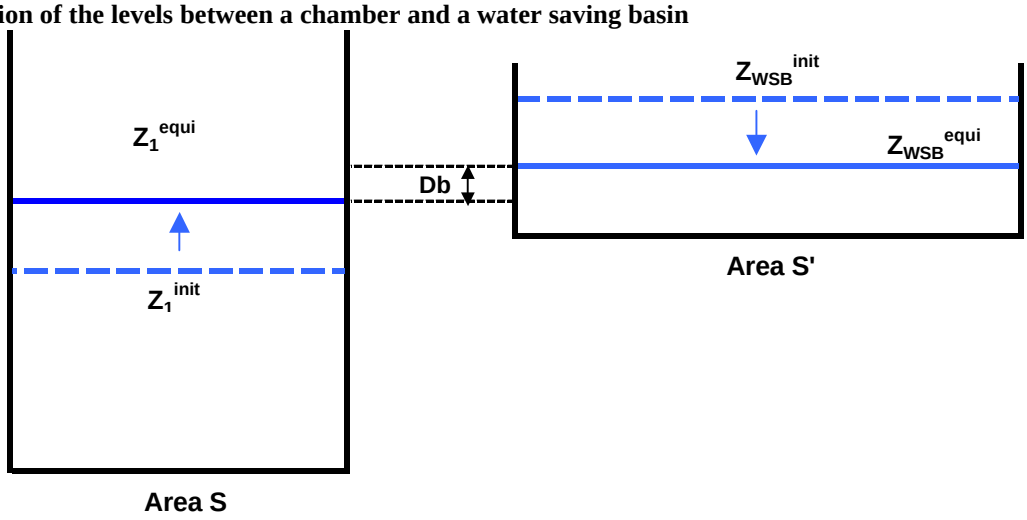
- Gatun lake ? ? Pacific Ocean
- Pacific Ocean ? ? Gatun lake

The software gives the water saving rate and the volume of water taken from the Gatun Lake during a lockage.

The equations used in the software are based on the equalization of water levels between the chamber and the water saving basins (see the explanation below).

5.2.1 DESCRIPTION OF THE CALCULATION METHOD

➢ **Equalization of the levels between a chamber and a water saving basin**



Volume transfer equation system

$$\begin{cases} \left[Z_{WSB}^{init} - Z_{WSB}^{equi}\right]S' = \left[Z_1^{equi} - Z_1^{init}\right]S \\ Z_{WSB}^{equi} = Z_1^{equi} + Db \end{cases}$$

System solution

$$Z_1^{equi} = \frac{Z_1^{init}.S + Z_{WSB}^{init}.S' - Db.S'}{S + S'} = \frac{Z_1^{init} + m.\left(Z_{WSB}^{init} - Db\right)}{1+m} \quad \text{with} \quad m = \frac{S'}{S}$$

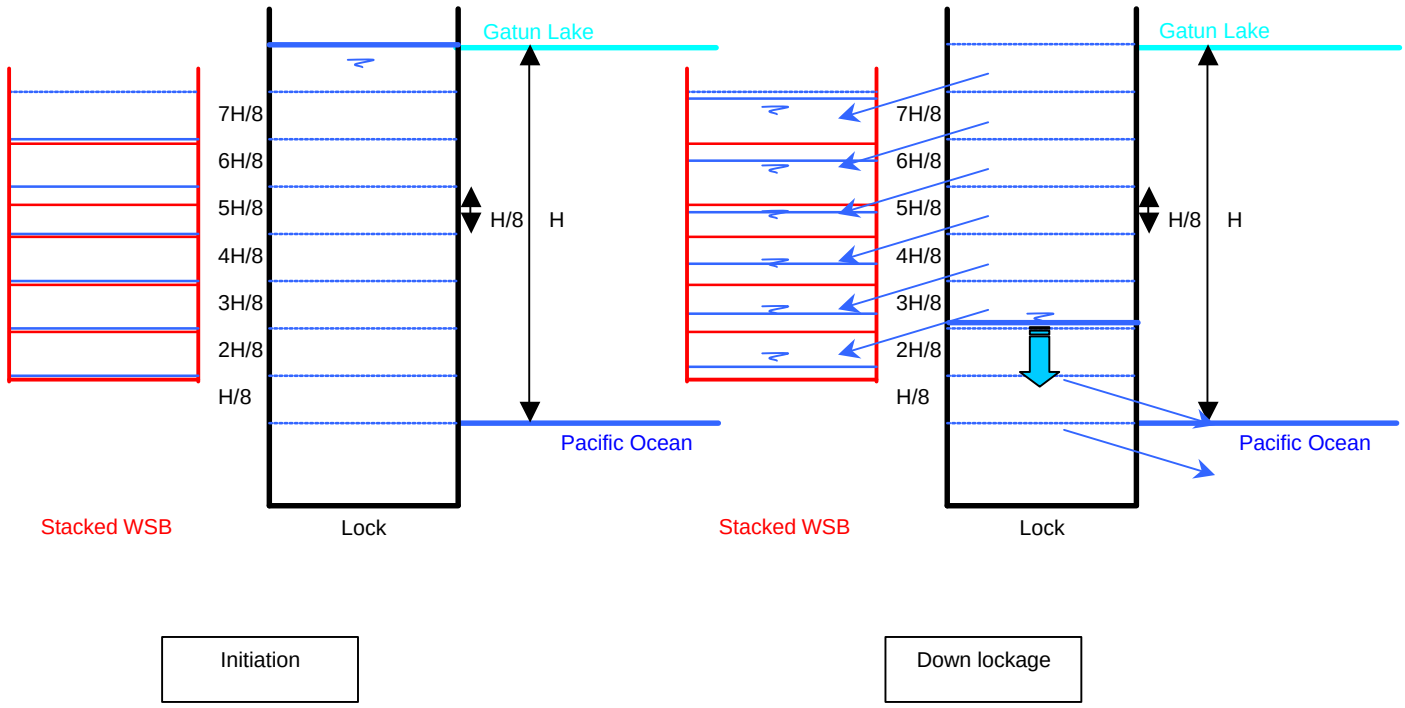
$$Z_{WSB}^{equi} = \frac{Z_1^{init} + m.Z_{WSB}^{init} + Db}{1+m}$$

where *Db* (residual filling depth) is about 10 to 20 cm.

5.2.2 INITIALIZATION OF WATER SURFACE ELEVATION IN THE CHAMBER AND WATER SAVING BASINS

At the beginning of a simulation, the initialization of the water surface elevation in the chambers and water saving basins depends on the lake level, the initial Ocean level and the direction of the lockage.

The drawings below illustrate the way of initializing the water surface elevations (drawings made for *m* = 1 and stacked water saving basins on one single pile)

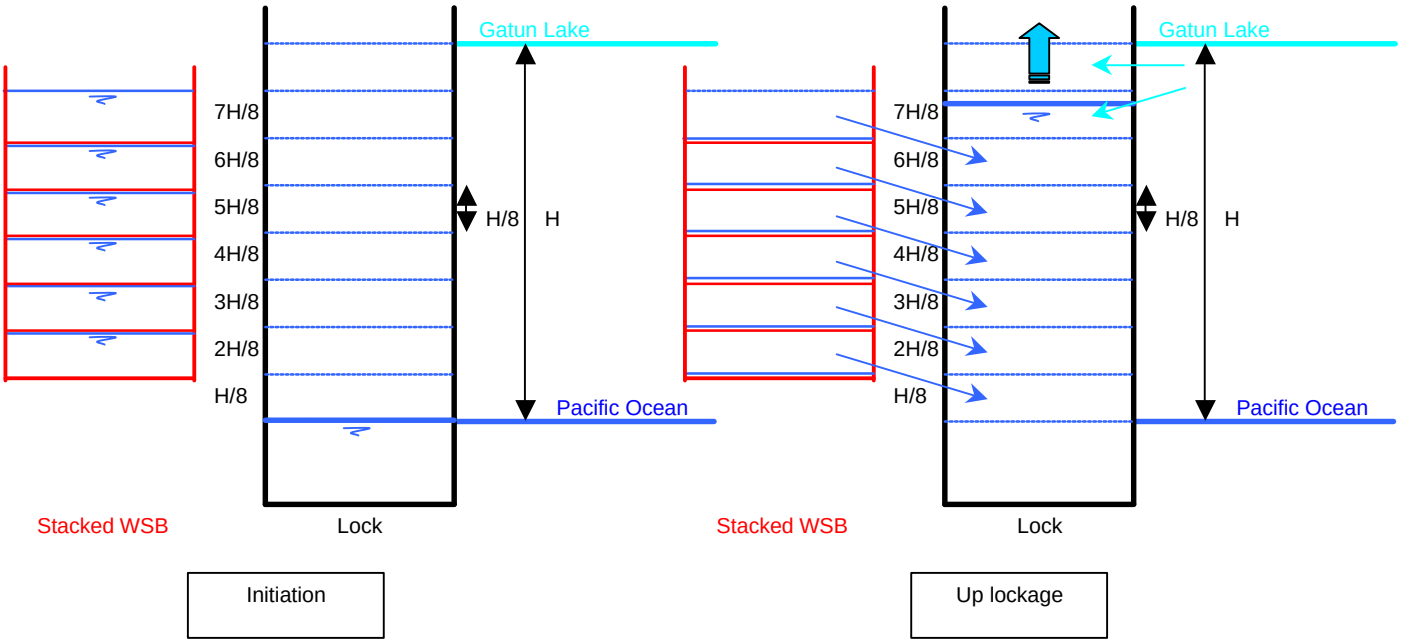


- Lockage from lake to ocean

When the simulation starts, the water surface elevations are initialized as below :

- Chamber : ..... Zlake
  Upper WSB (n°1): ..... 6H/8 + Zocean
  WSB n°2: ..... 5H/8 + Zocean
  WSB n°3: ..... 4H/8 + Zocean
  WSB n°4: ..... 3H/8 + Zocean
  WSB n°5: ..... 2H/8 + Zocean
  Lower WSB (n°6): .... H/8 + Zocean

➢ Lockage from ocean to lake



When the simulation starts, the water surface elevations are initialized as below :

- Chamber : ..... ZOcean
  Upper WSB (n°1): ..... 7H/8 + Zocean
  WSB n°2: ..... 6H/8 + Zocean
  WSB n°3: ..... 5H/8 + Zocean
  WSB n°4: ..... 4H/8 + Zocean
  WSB n°5: ..... 3H/8 + Zocean
  Lower WSB (n°6): .... 2H/8 + Zocean

5.3 DEFINITION OF THE BOTTOM SETTING SCENARIOS

The levels of the chambers and the water saving basins given below have been set on the two simulations defined hereafter :

➢ The levels of the bottom floors and top of the chamber have been set with the combinations of the following values :

- Gatun Lake : + 26.67 m PLD ; + 23.90 m PLD
- Pacific Ocean : ranging from + 2.40 m PLD to – 2.32 m PLD

- The levels of the bottom floors and tops of the water saving basins have been set with the combinations of the following values :

  - Gatun Lake : + 26.67 m PLD ; + 23.90 m PLD
  - Pacific Ocean : ranging from + 3.60 m PLD to – 3.44 m PLD

- The water saving basins and lock chamber have the same area (*m = 1*), the residual filling depth is:
  - *Db* = 0.1 m

For the simulation, the initial levels have been calculated with the mean value of the Pacific Ocean level. The scenarios have been tested over a 15 cycles period (1 cycle corresponds to 24 hours of alternate cycles of downlockage or uplockage). The total duration time of the simulation represents nearly 15 days.

The graphs resulting from the simulation with those parameters are shown in the annexes 2.2 and 2.3.

In addition, more than 80 scenarios have been performed with different values of m and Db.

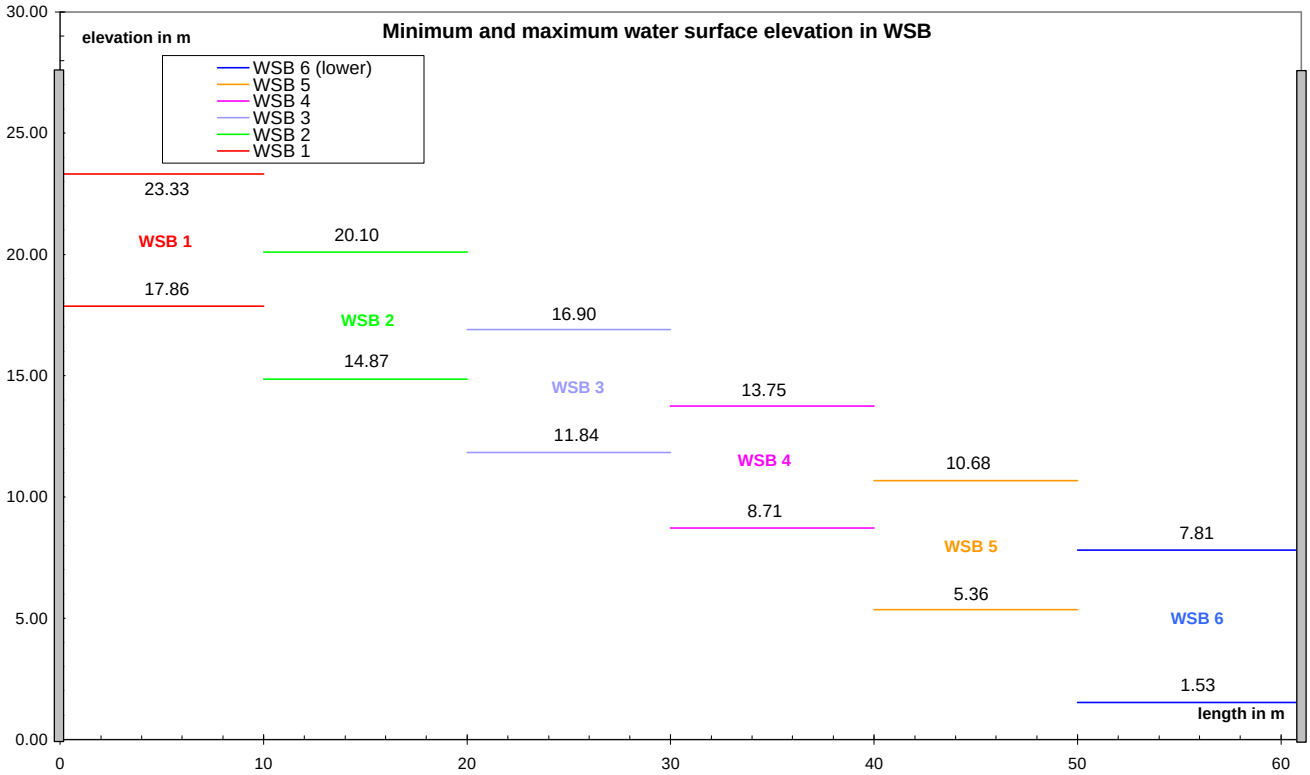
5.4 RESULTS

The results achieved with the scenarios defined as above and concerning the chamber and the water saving basins dimensions are presented in the charts below.

Zlac	Db (Residual filling depth)		Chamber level	Upper WSB (n°1) level	WSB n°2 level	WSB n°3 level	WSB n°4 level	WSB n°5 level	Lower WSB (n°6) level
26.67	0	maxi	26.67	23.40	20.14	16.92	13.76	10.66	7.76
		mini	-3.44	19.99	16.63	13.22	9.72	6.00	1.81
23.9	0	maxi	23.90	20.97	18.07	15.19	12.37	9.62	7.07
		mini	-3.44	17.91	14.90	11.84	8.68	5.31	1.46
26.67	0.1	maxi	26.67	23.33	20.10	16.90	13.75	10.68	7.81
		mini	-3.44	19.94	16.60	13.22	9.75	6.05	1.88
23.9	0.1	maxi	23.90	20.90	18.02	15.17	12.37	9.63	7.12
		mini	-3.44	17.86	14.87	11.84	8.71	5.36	1.53
26.67	0.2	maxi	26.67	23.25	20.05	16.87	13.75	10.69	7.86
		mini	-3.44	19.89	16.58	13.22	9.77	6.10	1.96
23.9	0.2	maxi	23.90	20.83	17.97	15.14	12.36	9.65	7.17
		mini	-3.44	17.81	14.85	11.84	8.73	5.41	1.61

This chart shows that with 6 water saving basins it is impossible to stack them all on a single pile. The level variations of the Pacific Ocean result in level crossings in the different water saving basins .

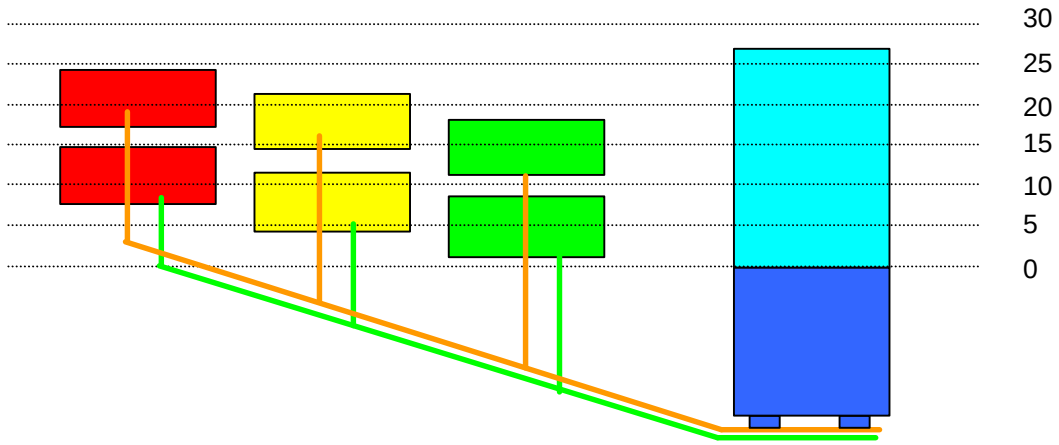
Trying to stack the water saving basins on two piles, with numbers 1, 3, 5 on one hand and numbers 2, 4, 6 on the other hand, shows that the distances between the bottoms and the roofs are not sufficient to insert the separation sills required between the basins. The chart below shows the level envelopes of the different water saving basins in the case they would be all stacked on one another. WSB1 interferes with WSB2, WSB2 interferes with WSB1 and WSB3, and so on.

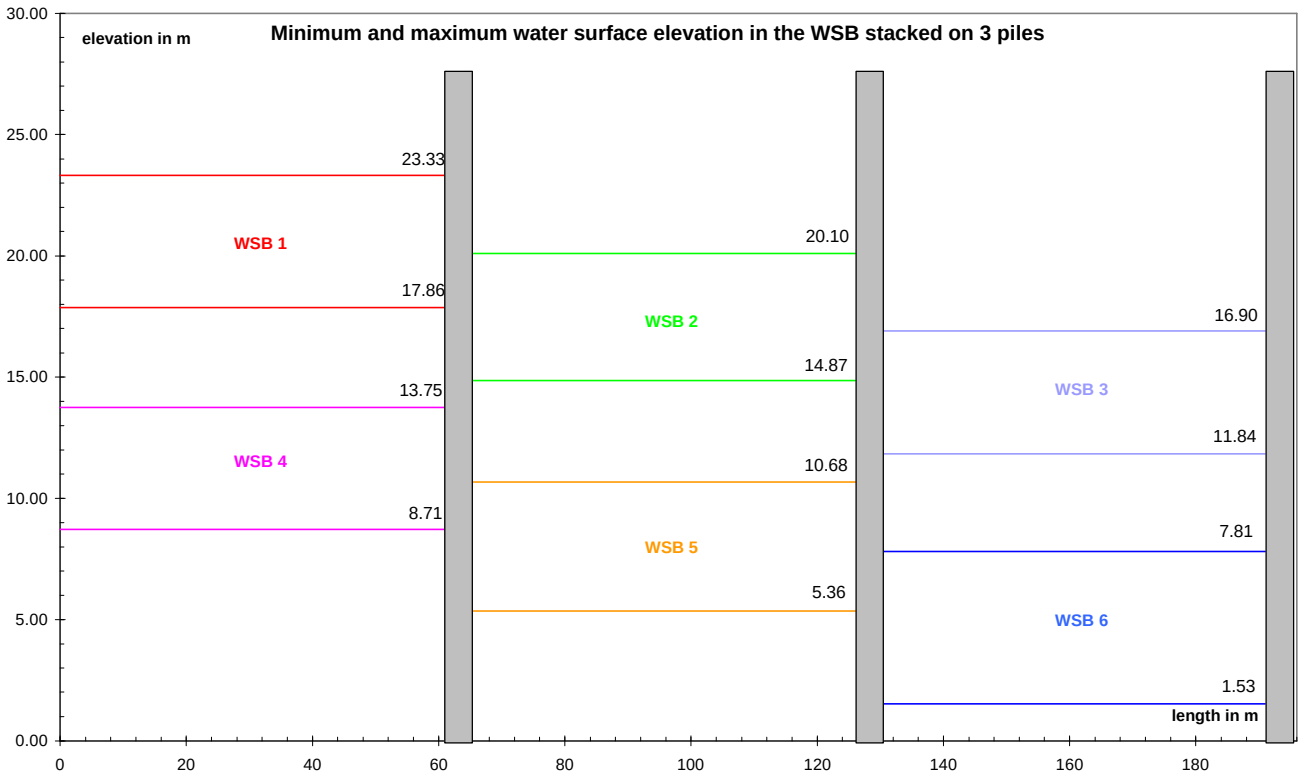


This main result shows that using 6 stacked water saving basins will force to stack the basins two by two. Hence, the only possible configuration would be: WSB1 and WSB4, WSB2 and WSB5, WSB3 and WSB6. It would let enough room between the basins to take into account the separation sills and the remaining depth of water in the water saving basins .

Considering a residual depth of 1 meter for the basins and a freeboard of 0.80 m, the previous chart shows that the remaining room between the couples of basins would be of 2 meters. This shows that no sufficient room is left for the filling/emptying system of the superior basins to be placed between the upper and the inferior basins. The calculation was also made with m = 2 and it was shown that only a few centimetre could be gained, which is not solving the problem.

The flooding system would therefore have to cross the lower basins, as shown on the next drawing.


30
25
20
15
10
5
0

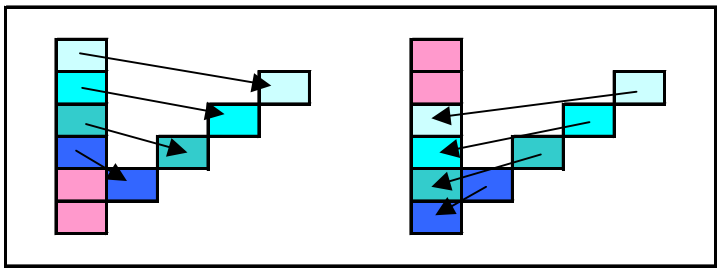

elevation in m
Minimum and maximum water surface elevation in the WSB stacked on 3 piles
30.00
25.00
20.00
15.00
10.00
5.00
0.00
23.33
17.86
13.75
8.71
WSB 1
WSB 4
20.10
14.87
10.68
5.36
WSB 2
WSB 5
16.90
11.84
7.81
1.53
WSB 3
WSB 6
length in m
0
20
40
60
80
100
120
140
160
180

6 Calculation of the water saving rate

6.1 SINGLE LIFT LOCK

6.1.1 EQUAL AREA FOR WATER SAVING BASIN AND LOCK CHAMBER

- *Water saving rate*

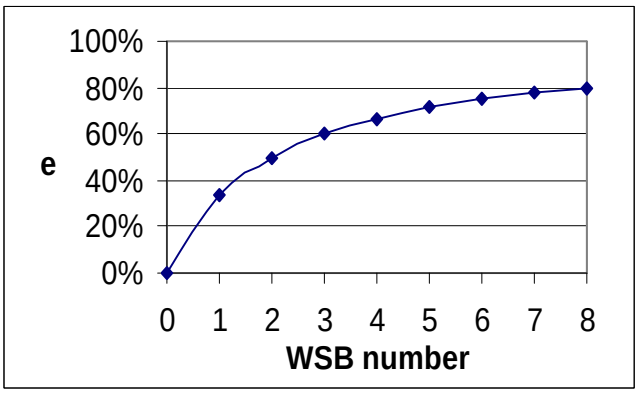


Let n be the number of water saving basins.
According to the previous scheme, the water saving rate is given by:

$$e = \frac{n}{n+2} \quad \text{(\% of the chamber volume)}$$

- Evolution of the water saving rate with number of basins

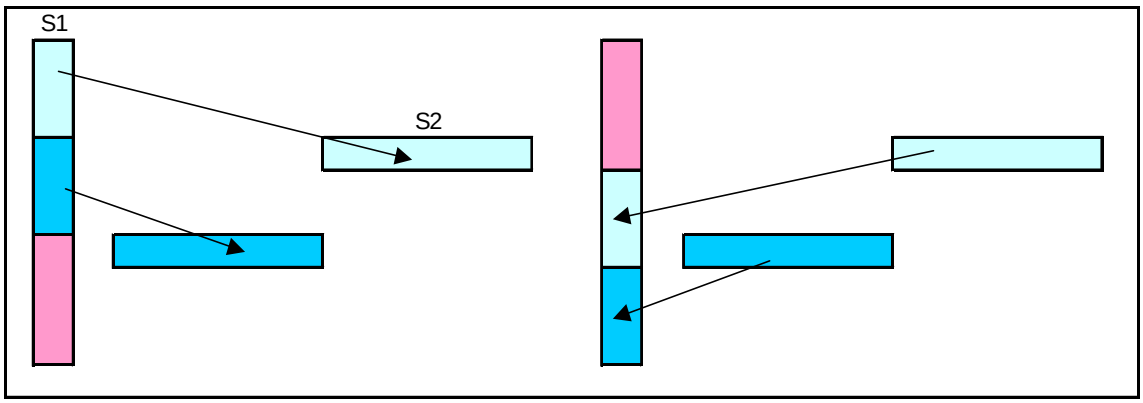
number saving basin	water saving rate	additional saving rate
0	0%	
1	33%	33%
2	50%	17%
3	60%	10%
4	67%	7%
5	71%	5%
6	75%	4%
7	78%	3%
8	80%	2%



After the fourth saving basin, it can be seen that adding another basin does not improve the water saving rate with more than 5 %.

6.1.2 DIFFERENT AREA FOR WATER SAVING BASIN AND LOCK CHAMBER

- *Water saving rate*



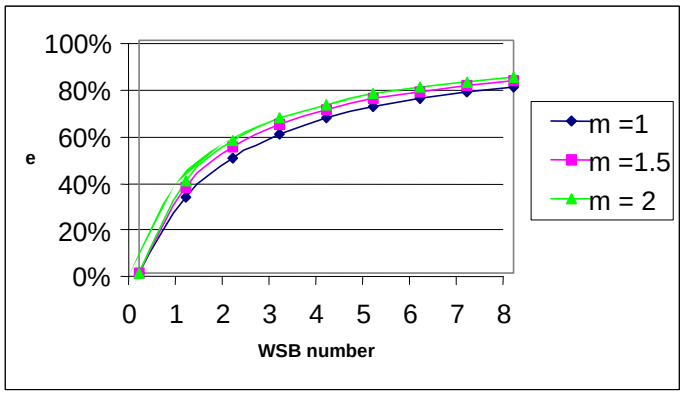
Let n be the number of water saving basins
Let m be the ratio water saving basin area / chamber area
m= S_2 / S_1

The water saving rate is given by:

$$e = \frac{nm}{nm + n + 1}$$

- Evolution of water saving rate with number of basins

number WSB	Water saving basin rate m = 1		
	1	**1.5**	**2**
0	0%	0%	0%
1	33%	38%	40%
2	50%	55%	57%
3	60%	64%	67%
4	67%	71%	73%
5	71%	75%	77%
6	75%	78%	80%
7	78%	81%	82%
8	80%	83%	84%

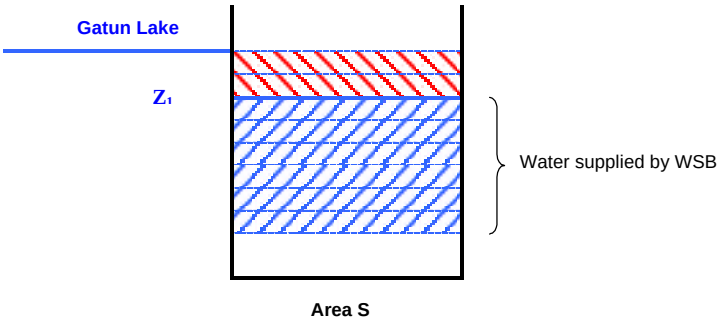


Increasing the surface of the saving basins has little effect on the water saving rate.

6.2 CALCULATION BY THE SOFTWARE

The total head between the Gatun lake and the Pacific varies in relation to the Pacific Ocean tides. So specific calculations are made by the software to assess the water consumption (volume of water taken from the Gatun Lake) and the water saving rate for every lockage.

- Water consumption

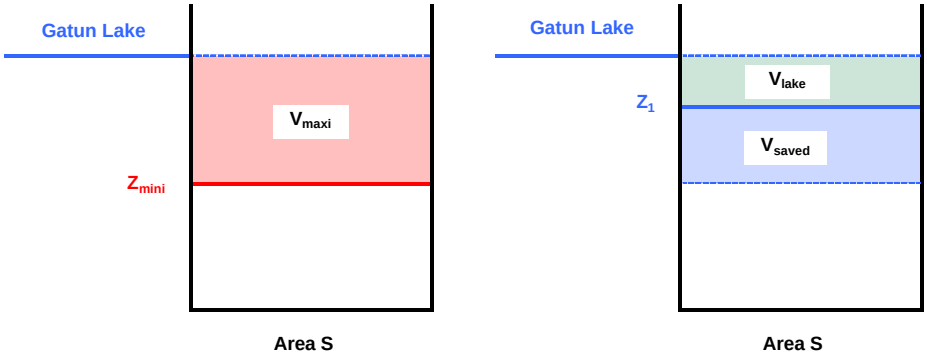


Let Z_1 be the water level in the upper lock at the end of the basins-to-lock operations. The software merely calculates the volume taken from the lake by:

$$V_{lake} = (Z_{lake} - Z_1) * S$$

This volume is calculated for every filling operation of the lock.

- Water saving rate



Let Z_{mini} be the water level in the upper lock at the beginning of the filling operation. Without any water saving basin, the volume of water required to fill the lock chamber would be equal to:

$$V_{\max i} = (Z_{lake} - Z_{\min i}) * S$$

The water saving basins permits to save a volume equal to:

$$V_{saved} = (Z_1 - Z_{\min i}) * S$$

The water saving rate is then calculated by the relation:

$$e = \frac{V_{saved}}{V_{\max i}}$$

The water saving rate is calculated for every filling operation of the lock and at the end of the simulation. The final water saving rate is calculated by:

$$E = \frac{\sum V_{saved}}{\sum V_{\max i}}$$

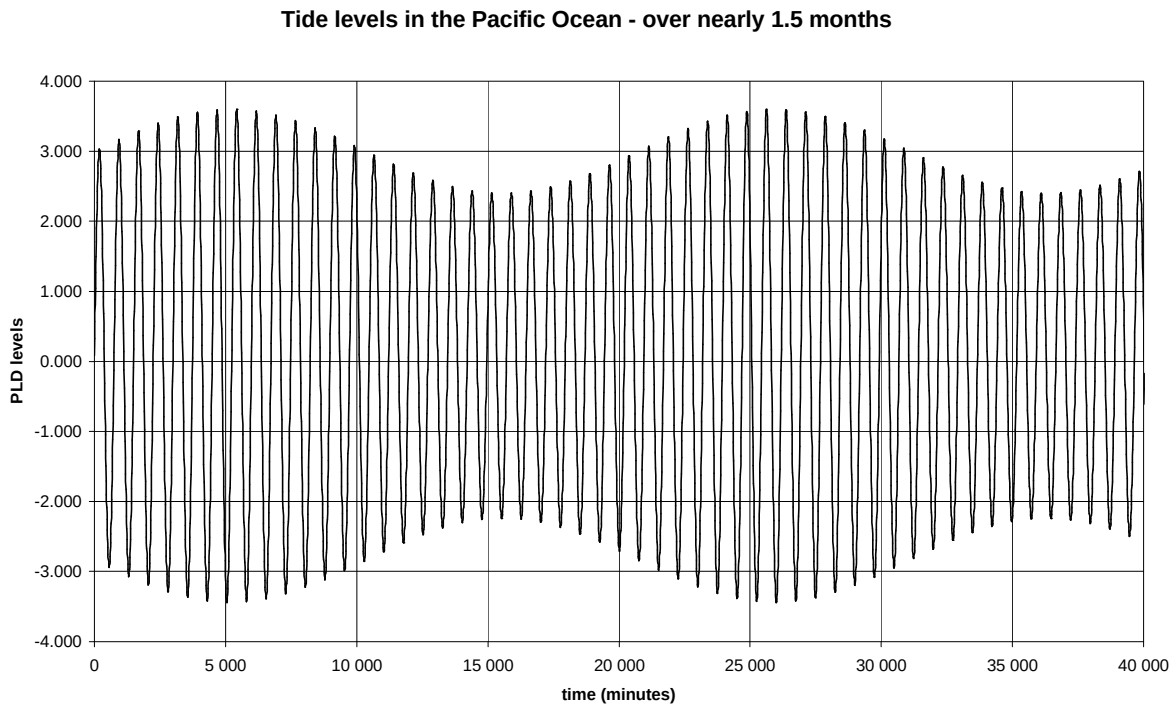
The results achieved with the software are coherent with the theoretical ones.

6.3 RECOMMENDATIONS

The initial chamber and water saving basins floors and wall elevations, the number of possible transits, and the water consumption calculations are established with the present hypothesis and data introduced in the software developed by the Consortium CPP. These results are still applicable with the final filling and emptying times developed with Flowmaster? and the design operating times.

After this conceptual study, the Consultant CPP recommends the following :

- Introduce a second sinusoïdal curve in the software in order to be more conform with the tidal regime (see below)



- Introduce decimal values for the different operating times

7 FILLING AND EMPTYING SYSTEMS

7.1 GENERAL DIMENSIONAL CRITERIA

This paragraph presents an analysis of the different types of filling and emptying systems and their suitability for the new locks of Panama (3rd lane).

In this report, the analysis of these systems is made for the second configuration: a single lock with **or without** water saving basins.

The choice of an emptying and filling system depends on the following criteria:

- Maximum head between the water saving basins and the Pacific or between the Gatun Lake and the Pacific in the case of a use without the water saving basins (main criteria)
- Time required by the TOR for the filling and/or the emptying
- Flushing (water turbulence, especially in the chamber during the filling)
- Strengths on the hawsers of the ships
- Use the water saving basins or not
- Type of the ships (commercial, leisure)
- Reliability and serviceability (weakened performance)
- Cost of the system

The choice can also be influenced by some other secondary criteria:

- Nature of the foundations
- Type of the lock structures (walls, bottom floor, …)
- Type of the gates (if they are previously designed for a special matter)
- Location of the lock : in a channel, along a river
- Lock operating procedure
- Easiness of building
- Security

7.2 LAKE TO LOCK OR LOCK TO OCEAN CONNECTIONS

7.2.1 MAIN TYPES OF SYSTEMS

Reminding the points presented in the report of the first configuration (R4 – C), the different systems for filling and emptying (F/E) are the followings:

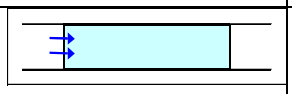
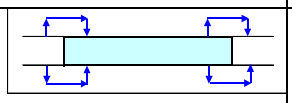
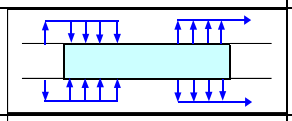
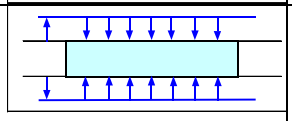
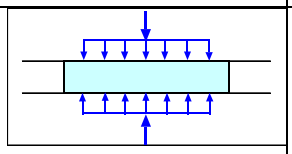
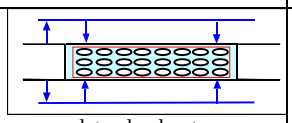
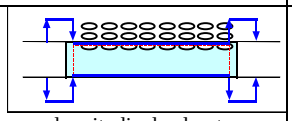
- through the gates
- around the gates
- through lateral ports connected to longitudinal culverts
- through ports in the bottom floor

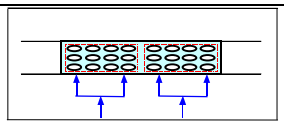
The two first systems lead to a F/E operation concentrated at only one extremity of the lock chamber. The two last systems are characterized by a distribution of the flow all along the lock chamber.

In a first approach, with a single step lock system, the maximum head is 30.11 m (26.67 m + 3.44 m). This head is reduced to approximately 7.50 m when using 6 saving basins for each stage of filling or emptying.

7.2.2 DESCRIPTION OF THE SYSTEMS

The complete description of those different systems was made in the report of the first configuration. One should refer to it for more details. The table below shows the main systems.

Type	Scheme	Operation	Advantages	Drawbacks
1. Through the gates		• valves inside gates • rotation, lifting or lowering gate	• suitable for low heads • low global cost • culverts necessary only for WSB connections	• unbalanced filling • maximum longitudinal water movements in the chamber • high strengths on hawsers • necessary energy dissipating system • piston effect on an entering ship
2. Around the gates		• culverts around the gate	• suitable for low heads • low global cost	• unbalanced filling → important filling time • high strengths on hawsers • piston effect on an entering ship
3. Around the gates with lateral culverts		• lateral culverts and ports • Berendrecht type	• better balanced flow distribution • better energy dissipation	• unbalanced filling piston effect on an entering ship
4. Through lateral culverts and ports		• lateral culverts all along the chamber • connection to chamber by ports	• well balanced filling • untouched bottom floor → no complete emptying required • better energy dissipation • suitable for medium heads from 10 to 15 m • no piston effect	• high cost
5. Lateral filling from the lake		• lateral culverts and ports all along the chamber • lateral connection to the pool	• very good balanced filling • reduced piston effect	• longer lengths of the primary culverts • room for the lateral channel (4th lane lock project) • cost
6. Through lateral culverts and ports in the bottom floor	 lateral culverts	• lateral culverts and ports in the bottom floor	• very good flow distribution • low efforts on the hawsers • reduced piston effect	• very expensive • lower level of excavations • possible damages to the ports by ship anchors
7. Through longitudinal culverts and ports in the bottom floor	 longitudinal culverts	• longitudinal culverts and ports in the bottom floor • ports supplied by a secondary network of culverts	• very good flow distribution • low efforts on the hawsers • reduced piston effect	• very expensive • lower level of excavations • possible damages to the ports by ship anchors

8. Through ports in the bottom floor Lateral connection to the Gatun Lake and to the ocean	 transversal culverts	• Lateral culverts on one side • ports supplied by a secondary network of culverts • Donzère type	• very good flow distribution • low efforts on the hawsers • reduced piston effect	• very expensive • possible damages to the ports by ship anchors • room for the lateral channel (4th lane lock project)

7.2.3 SUITABLE SYSTEMS FOR THE PANAMA SINGLE STEP LOCK

According to the former description, the suitable systems for the single step lock projects are described hereafter.

As described before, the main difference with the first configuration of the triple lift lock system is that the head is concentrated on a single lock.

- *Through the gates*

This system was not proposed for the 3-step lock because of its drawbacks, concerning energy dissipation and the synchronized operation of the valves of the double gate system imposed by ACP for security and maintenance purposes.

As a consequence, this system is unacceptable for the single lock system.

- *Around the gates*

This system has been studied more thoroughly in the first configuration. However, it was demonstrated that it was less efficient concerning the flow repartition in the chamber given by the system of lateral culverts and ports on the whole length of the chamber. Moreover, this system is considered to be unsuitable in the case the water saving basins are not used.

This system is not retained for the second configuration.

- *Lateral culverts and ports*

This system allows a well-balanced filling of the chamber. Moreover, a concrete bottom floor is not required.

In addition to those advantages, the water is able to flow backwards through the culverts when a ship enters the lock, reducing the piston effect.

This system was studied more thoroughly in the first configuration and it was demonstrated that it was the best technical-economical solution.

It is also suitable for the second configuration and will be studied further on.

- *Through the bottom floor*

This system is a very good one from the hydraulic point of view in case of high heads, because of its ability to dissipate correctly the residual energy in the water mattress of the lock and to reduce the flow movements in the chamber.

The drawbacks are:

- the additional cost due to the necessity of excavating the chamber to a lower level in order to include the system of vertical ports in an expensive reinforced lock bottom floor

- the necessity for the chamber to be totally emptied to allow ports and conduits inspection and maintenance; it is a fact that the ports can be damaged by the ship anchors.

This solution will be proposed as the second one for the single lift configuration, as two systems have to be proposed according to the T.O.R.

7.3 CONNECTIONS LOCK – WATER SAVING BASINS

7.3.1 MAIN TYPES OF SYSTEMS

Those systems have already been described in the first configuration report and will be summed up hereafter.

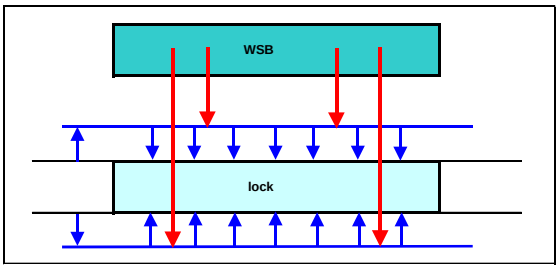
In order to get a good dissipation of energy and to reduce strengths on hawsers, a well-balanced filling of the chamber by the basins is required between:

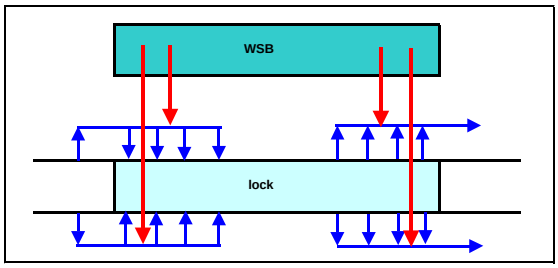
- Upstream - downstream
- East bank - West bank

Note that emptying the lock chamber requires less attention in term of energy dissipation.
Pool-to-lock and WSB-to-lock filling systems can be connected (with different possibilities of connection) or can be independent.

- *Connected systems*

Connections are made as follows:

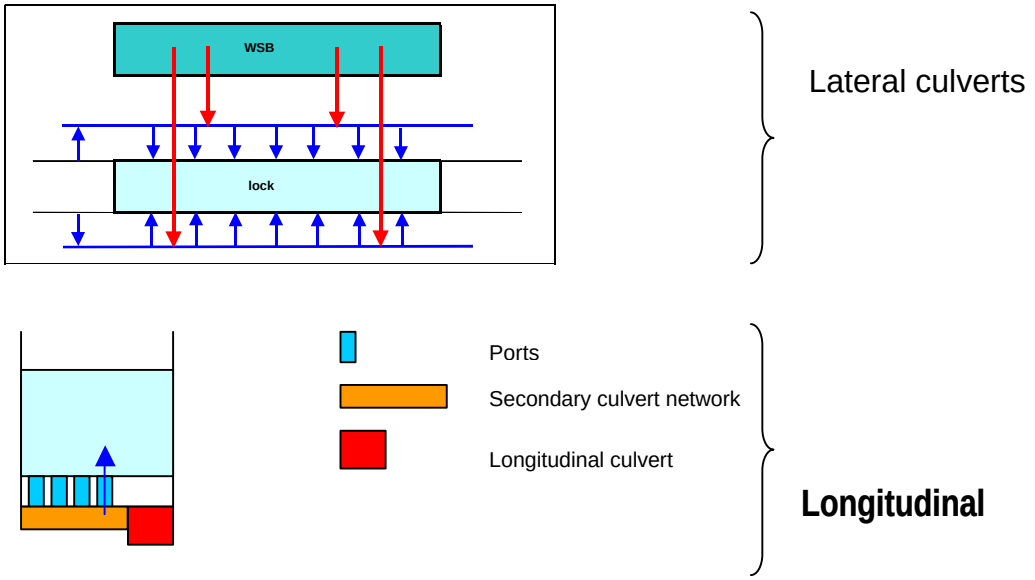




The connection often requires culverts with bends resulting in more head losses and additional singular head loss at the connection point.

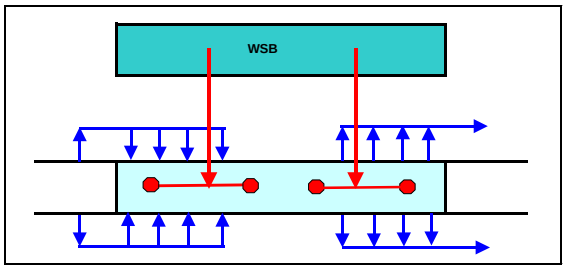
On the systems presented above the water saving basins circuits are connected separately to the east and the west banks. However each water saving basin circuit (red) could be connected to both side-wall culverts (blue).This would improve the filling and emptying operations in debased conditions (if a valve is out of order) but it would also increase the head loss.

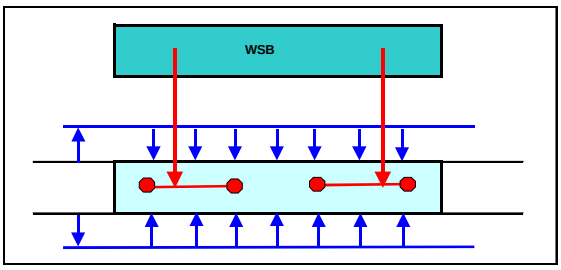
The connection can also be done through longitudinal culverts, placed under the bottom floor, those culverts feeding vertical ports situated in the flooring tile, by means of secondary networks.



- *Independent systems*

Pool-to-lock and WSB-to-lock filling systems are independent (as in the Laperrière lock project in France). As the pool-to-lock system uses side-wall culverts, the WSB-to-lock system can only pass through the bottom floor.





Independent systems permit to build very simple circuits, avoiding bends and thus additional head losses.

7.3.2 APPLICATION FOR PANAMA 1-STEP LOCK

According to the experience brought by the first configuration study, connected circuits are proposed for the first solution consisting of lateral culverts and ports. The alternative of separated circuits from the water saving basins to east and west banks that permits to reduce head losses, is also taken into account.

As the second solution consists in longitudinal culverts, secondary culverts and vertical ports placed under the bottom floor, it is logical to keep connected circuits.

7.4 SOLUTIONS TO BE STUDIED

According to what precedes, the best solutions concerning the filling and emptying system for the single lift lock are:

1- lateral culverts and ports all along the lock chamber (called first solution)
2- F/E system through the bottom floor (called second solution)

Other solutions are not suitable (through the gates or around the gates with a simple culvert) in case of a single lift lock.

The system through the bottom floor is probably the best one from the hydraulic point of view. On the contrary, culverts need to be built under the bottom floor level, which requires an extensive additional structural work, leading to much higher construction costs than those for the first solution.

The solution 1 allows to design a lock structure without a structural bottom floor. The dry lock chamber condition is not necessarily required, leading to technical and economical advantages.

According to ACP, the second solution must allow to empty completely the chamber for maintenance purposes. Consequently gates must be strengthened and civil works and gate costs increase.

The solution 2 will be studied further on, because despite its higher cost, it would allow to function more efficiently without any water saving basin under the high head of 30 m. However, the filling time would have to be increased to limit the efforts on the hawsers.

The proposed system between water saving basin and lock is a system connected to the pool-to-lock system in both solutions, with separated circuits on east and west banks.

Solutions 1 and 2 have been studied more thoroughly and are presented hereafter in this report.

8 HYDRAULIC DESIGN OF THE FILLING /EMPTYING SYSTEM

In this part, two solutions of the filling / emptying system have to be studied. In accordance to the previous chapter, those systems will correspond to a lateral alimentation with culverts and ports incorporated in the lock walls, and to a bottom alimentation through bottom culverts and ports.

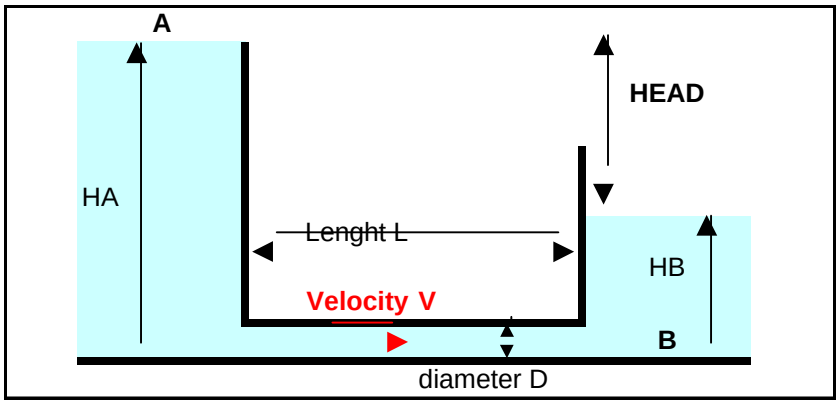
Both solutions have to be studied, for the single lift lock system with 6 water saving basins.

The total length of the whole structure, which is considerably shorter than in the first configuration, allows to design water saving basins which are longer than the chamber itself if necessary.

The design of the F/E system will depend mostly on the geometry of the water saving basins spatial arrangement.

8.1 HYDRAULIC DESIGN GUIDELINE

- *Influence of head losses*



Theoretical approach hereafter permits to point out the influence of singular head losses. The scheme hereafter represents the hydraulic link between the chambers (or the saving basin):

The application of the Bernoulli equation between A and B leads to:

$H_A = H_B + V^2/2g$ + singular head losses + regular head losses

- singular head losses: each = K $V^2/2g$, K depending on type (K = 0.5 for a 90°bend…)
- regular loss of head loss : = ? L/D $V^2/2g$

Generally, regular head losses are not important compared to singular head losses.

$$H_A = H_B + V^2/2g + K_1 V^2/2g + K_2 V^2/2g + K_3 V^2/2g + \ldots + l\, L/D\, V^2/2g = H_B + \left(1 + K_1 + K_2 + \ldots + l\, L/D\right) V^2/2g$$

Velocity $V = \sqrt{\dfrac{2g(H_A - H_B)}{1 + K_1 + K_2 + K_3 + \ldots\ldots + l\, L/D}}$

Example

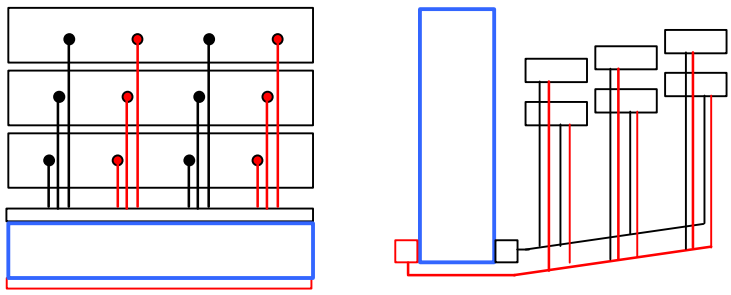
Considering a head of 2.5 m, V = 7 m/s (if no head losses), and so $V^2/2g$ = 2.5 m
If two 90° bends are introduced in the hydraulic circuit, additional head losses are 2 * 0.5 $V^2/2g$. Referring to the previous formula, two 90° bends reduce the head of 50 % and the velocity of 30 %.

As Q = V *S with S = Surface and Q = discharge ;
Keeping the same filling or emptying time despite the two 90° bends implies to increase the culverts area of 30%, that is to say to increase the culverts diameter of 15%.

To conclude, **avoiding singular head losses and consequently multiplication of bends is absolutely necessary for the hydraulic design of the filling and emptying system.**

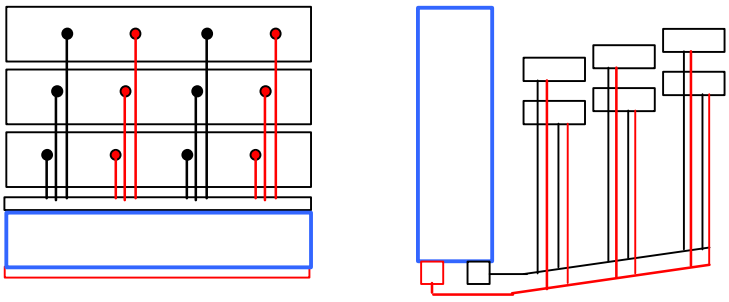
8.2 DESCRIPTION OF THE SPATIAL CONFIGURATIONS

Type 1



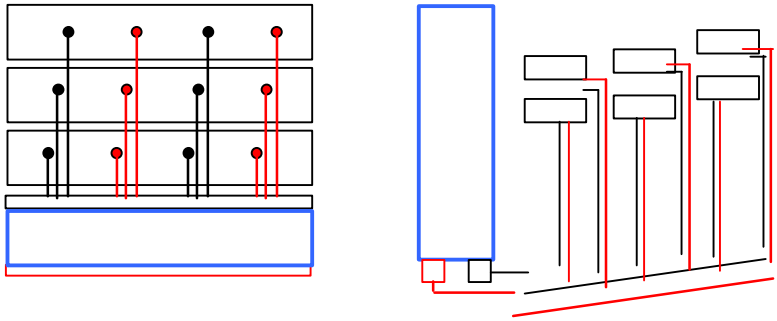
6 basins stacked on 3 piles, lateral culvert alimentation

Type 2



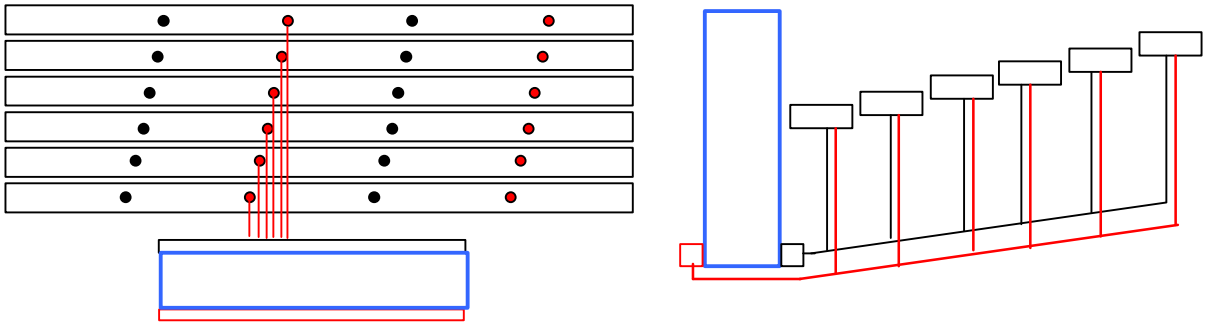
6 basins stacked on 3 piles, bottom culvert alimentation

Type 3



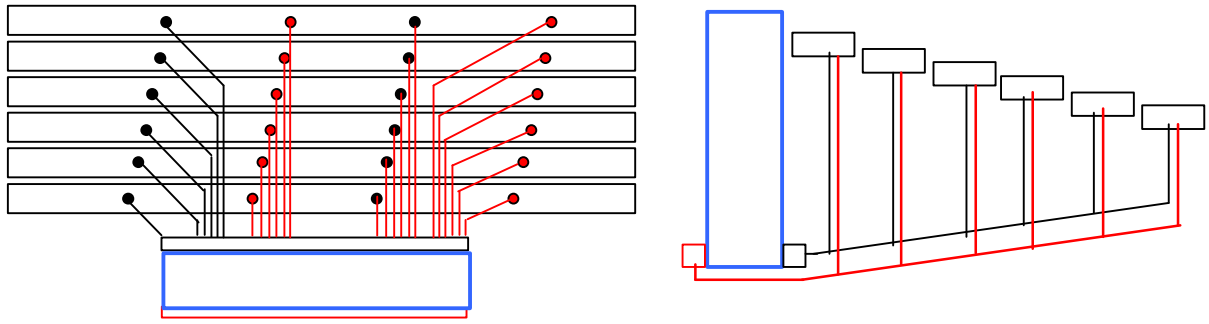
6 basins stacked on 3 piles, bottom culvert alimentation

Type 4



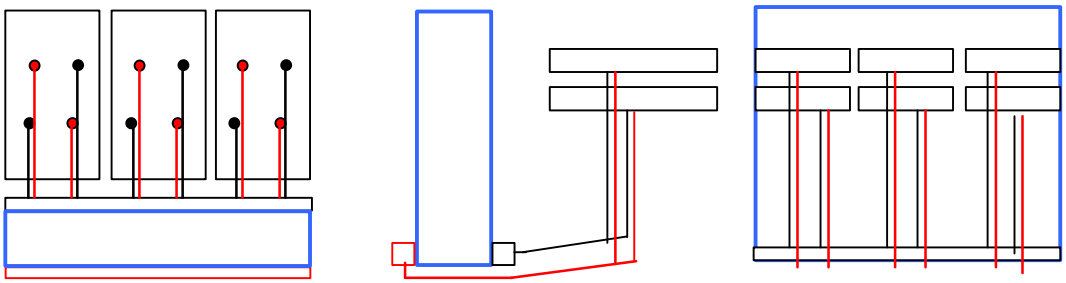
6 basins, lateral (or bottom) culvert alimentation

Type 5



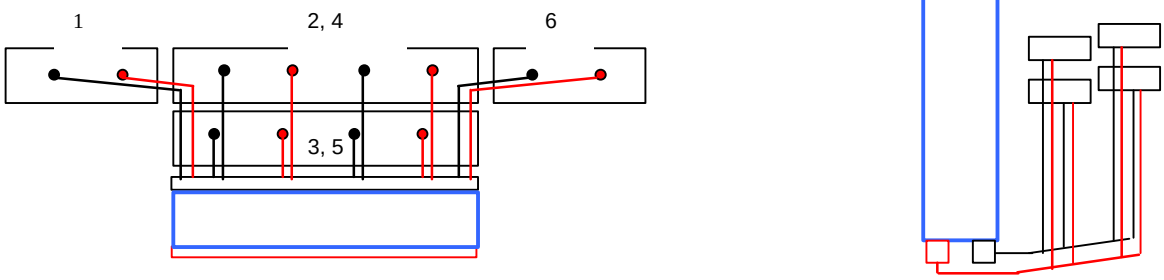
6 basins, lateral (or bottom) culvert alimentation

Type 6



6 basins stacked on 3 piles, lateral (or bottom) culvert alimentation

Type 7



6 basins stacked on 4 piles, lateral (or bottom) culvert alimentation

The two first types result from the level analysis shown in 5.4. The only possible way to stack the water saving basins is on 3 piles of 2 basins. Therefore, the feeding circuits of the upper basins of each pile would have to pass through the lower basins. In that case, the total width of the lock and the basins would be very close to the one reached with the triple lift lock configuration. The lower basins would be a little longer in order to take into consideration the lost volume due to the connection circuits of the superior basins. This configuration has the same advantages as in the first configuration concerning the

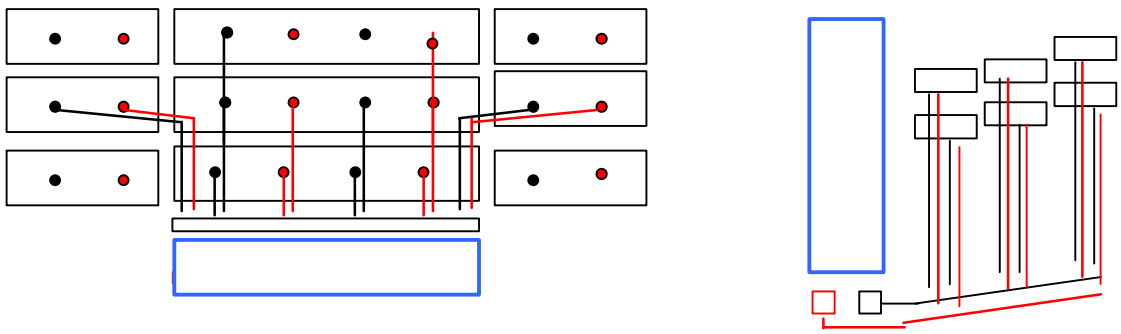
well balanced flow from the water saving basins to the chamber: 4 intakes connect each water saving basin to the culverts. The main drawback would be the complexity of the feeding conduits, especially in the case each one would reach the culverts separately (no combining manifold).

Type 3 concerns the same disposition as 1 and 2 but the circuits connecting the upper basins to the lock chamber no longer pass through the inferior basins. They pass vertically between two piles, which is a constructive advantage. The main drawback would be the feeding of these circuits because, as the water intakes would be lateral to the water saving basins and because the water height inside the basins is low, this system would function with a complex geometry. Moreover, in regard to the former disposition, it would add important head losses.

Types 4 and 5 consist in basins twice longer and twice narrower than the chamber itself, in order to avoid interference with the existing hills on the east side of the lock. Those systems would provide a good flow distribution in the water saving basins.

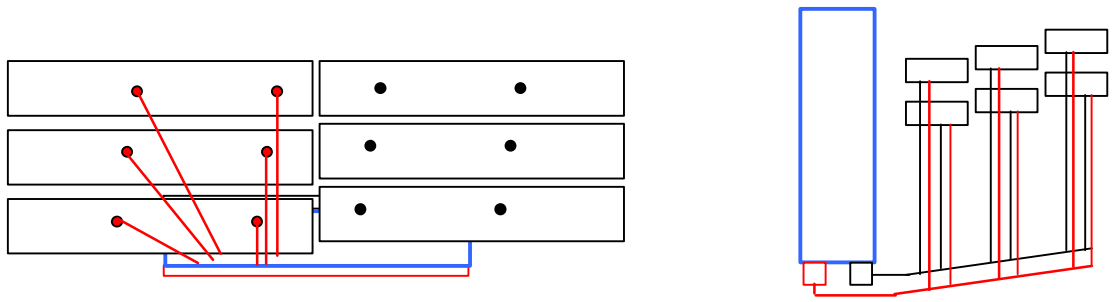
Types 6 and 7 are alternatives of types 1 and 2. For type 6, it could be possible to imagine water saving basins with geometric forms fitting the hill contours. Type 7 can also be declined in order not to stack the water saving basins on piles, according to the affordable room between the chamber and the hill, as for instance:

Type 8



6 independent basins, lateral (or bottom) culvert alimentation

Type 9



6 independent basins, lateral (or bottom) culvert alimentation

The schemes of types 6 to 9 show that the main drawback of those solutions would be a non – symmetrical alimentation of the culverts. Moreover, with a minimum of 4 connections between the water saving basins and the culverts, it would be very difficult to construct and it would lead to very long and variable conduit lengths.

8.3 TYPES OF WATER SAVING BASINS TO BE STUDIED

As a result of the former analysis, we recommend to go on studying types that:

- preserve the symmetry of the culvert feeding (each basin should feed symmetrically the culverts)
- authorize 4 points of connection between the water saving basins and the culverts

Consequently, types 1 and 4 will be studied more thoroughly.

Type 1 corresponds to the TOR since a solution with stacked water saving basins will be studied.

Type 4 is a variant of one of the two solutions proposed for the first configuration of a lock system.

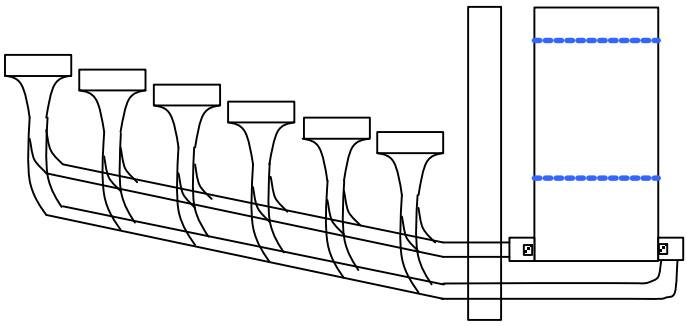
8.4 SOLUTIONS TO BE STUDIED

Combining the conclusions of paragraphs 7.4 and 8.2, the possible configurations are:

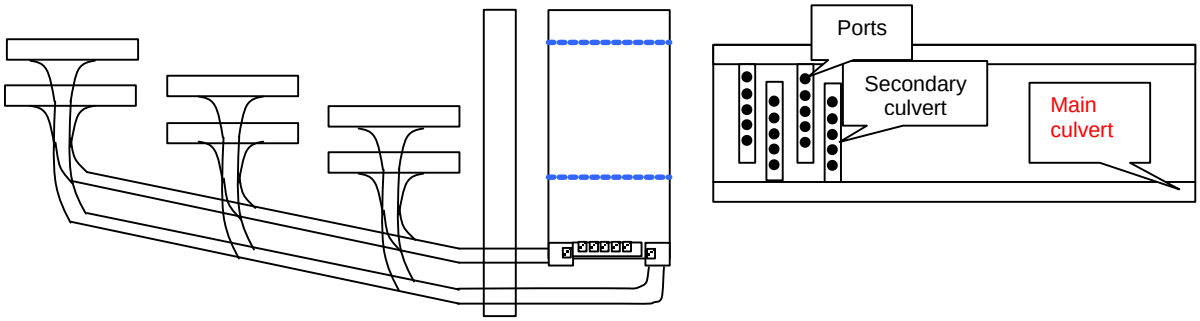
	water saving basins configuration	
Feeding system	6 basins side by side	6 basins stacked 2 by 2
Lateral culverts and ports	**1**	**2**
Bottom culverts, secondary network and vertical ports	**3**	**4**

Every combination is possible and would lead to similar results in terms of lockage times. Further on we'll study combinations 1 and 4:

- chamber with lateral alimentation by culverts and ports and 6 side by side water saving basins connected to the lateral culverts. The number of ports shall be identical as in configuration 1 (20 ports for each side wall culvert)



- chamber with longitudinal culverts under the bottom floor, with a secondary network as it exists in the actual Panama locks. This chamber will be equipped with 6 water saving basins stacked on 3 lateral piles, connected to the culverts. The number of secondary culverts shall be equal to the number of ports in the former solution, which is 20. Each secondary culvert should be equipped with 5 ports.



8.5 SOFTWARE AND METHODS USED IN THE STUDY

The emptying/filling systems have been studied with the software FLOWMASTER 2. A description of this tool have been given in the report of the first configuration.

The mark FLOWMASTER is a Community Trade Mark of FLOWMASTER HOLDING BV.

8.6 CALIBRATION OF THE SOFTWARE

The calibration of the software was based on the physical model study of the Panama canal locks performed in 1942.

The Flowmaster model gave good results, since the flow rate difference remained under 10 %. All documents concerning this test and the two other ones are given in annex 3.4. of the first configuration report.

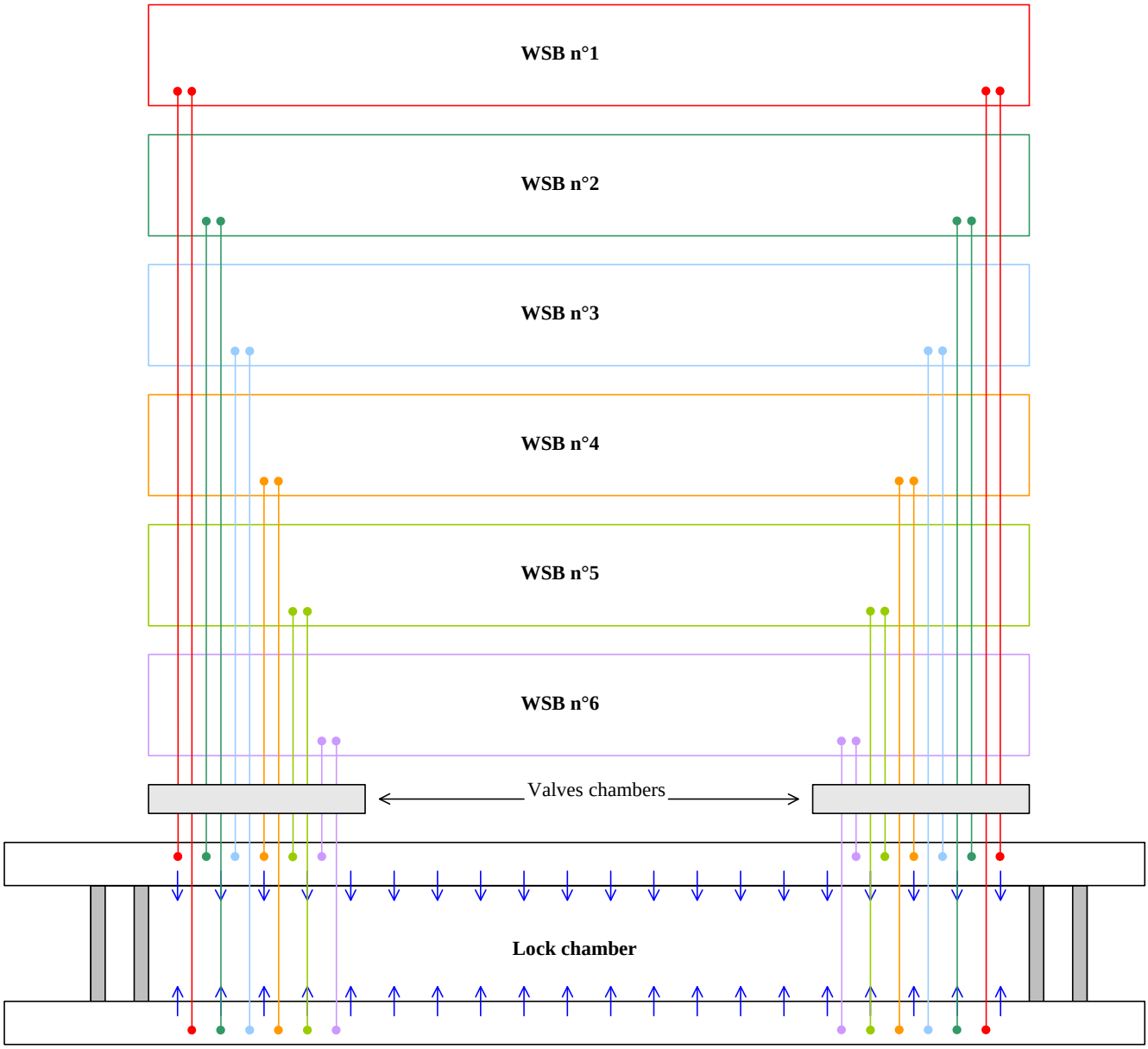
8.7 HYDRAULIC DESIGN OF THE FIRST SOLUTION

The first filling/emptying system presented hereafter use lateral culverts and ports. It is based on the second solution of the first configuration. The longitudinal culverts are used for filling and emptying the lock. It has been demonstrated for the first configuration that this system was preferable because of its ability to provide a good repartition of the flood and redundancy in case of a valve default.

8.7.1 DESCRIPTION

The hydraulic system is based on two lateral culverts (one in each side of the lock walls) each one connected to the lock chamber by means of ports. The connection with the water saving basins is made by 4 culverts per basin.

The sketch hereafter gives an overview of the modelled system:



As for the first configuration, this configuration could be improved by connecting the culverts from the water saving basins to the longitudinal culverts using combining manifolds of 3 to 1 for instance. This would allow to reduce the number of connections and the total length of culverts, especially for the ones that are connected to the opposite side. This configuration hasn't been tested with Flowmaster, such components definitely have to be tested and optimised on a scale model.

From a general point of view, the filling time is proportional to the head loss. The main sources of head loss are:

- linear head losses
- singular head losses especially due to bends. For instance, a 90° bend leads to 50% loss of the kinetic energy. In case of many bends, singular head losses increase drastically. Accordingly, during the network design bends must be avoided as much as possible, and consequently this has been one of the main goal of the present hydraulic study.

Pool to lock and lock to pool filling & emptying system

According to the consultant experience, gathering the upstream valves on one side of the lock is more interesting from an electromechanical and a maintenance points of view. Nevertheless, in that case, the numerous culverts that would be needed under the chamber to connect the opposite culvert would result in high head losses and too long filling times. Consequently the positioning of the valves on both sides of the lock chamber is the best solution.

A homogeneous filling of the chamber is obtained by spreading the flow input over a sufficiently long distance through a sufficient number of ports. In the present case, the chamber supplying is ensured over 320 m by 20 ports on both sides of the lock chamber. Ports are uniformly spaced by 15 m.

Due to head losses the head decreases along the culvert, leading to more discharge in the upstream ports and less in the downstream ports, thus resulting in a non - uniform flow distribution. To avoid this drawback, the culvert size must be large enough in order to reduce head losses and obtain a head which is as constant as possible all along the culvert.

NB : as the filling system is also the emptying one, no hydrodynamic shape could be adopted to reduce turbulence.

NB: the water can partially flow backwards through the filling/emptying system when a ship enters the chambers. Consequently, the piston effect resulting from the ship entrance in the lock chamber can be reduced

Connection water saving basins – chamber

The same ports of the emptying / filling system are used. Each basin is connected to both lateral culverts in two points (see on sketch above). Consequently, using the water saving basins leads to a perfect upstream-downstream symmetry and quite a good left-right side symmetry (due to different head losses).

There are in total 24 culverts connecting the water saving basins to the chamber (4 culverts per water saving basin).

This system could be improved by using combining manifolds in order to reach the lateral culverts with fewer circuits. However, as shown in the first configuration report, this could introduce higher head losses. This particular point will have to be checked on the physical scale model.

8.7.2 SIZE OF CULVERTS AND PORTS

Different shapes of culvert are suitable: circular, square or rectangular. As the valves are rectangular, the culvert shape should be the same, in order to avoid the construction of complicated formworks. In addition, a rectangular shape is easier to build and will be cheaper.

The hydraulic design leads to the following sizes:

	Shape	Size	Section (m²)	Quantity	Total section (m²)
Side-wall culverts	rectangular	7.5 m x 9 m	67.5	2	135
WSB-to-lock culvert	rectangular	6 m x 6 m	36	4 per basin	144
Ports	rectangular	1.8 m x 1.8 m	3.24	40, 20 per lock side	129.6

As far as the water saving basins are concerned, the number of culverts, the section and the total section of the culverts and ports are to be considered for each of the three saving basins.

Compared to the first solution, the size and number of culverts have been globally retained. As the number of ports used in lock-to-lock operations has doubled, the port size has been reduced in order to achieve a flow distribution as uniform as possible.

8.7.3 FLOWMASTER MODEL PARAMETERS

The components' parameters of the first solution have been retained for this solution. The main information concerning the most important components are given hereafter :

- **Culvert** : the culvert size is given above; the absolute roughness of the inner surface is 0.025 mm, which corresponds to the absolute roughness of a smooth concrete pipe (cf. Internal Flow System from D.S. Miller).

- **Valve** : the valves used in the model are valve gates with a section equal to the pipe section.

- **Discrete loss** : in order to take into account the kinetic energy dispersal in every chamber (or component assimilated to a chamber), discrete losses have been introduced downstream the ports with a loss coefficient of 1. The reverse flow coefficient is taken equal to 0.5.

- **T-junctions** : T-junctions are used to model the ports. Loss coefficients in T-junctions are automatically set depending on the two branch flow and area ratios. The calibration of those components demonstrated that they are suitable to model the ports.

8.7.4 FILLING AND EMPTYING TIMES

About 80 simulations have been run with Flowmaster in order to estimate the filling and emptying times, the flow rate and maximum velocities reached in the culverts. The simulations take into account all the likely Gatun Lake and Pacific Ocean levels.

Two kinds of simulation have been performed:

- lockage using water saving basins
- lockage not using water saving basins

1- Lockage using water saving basins in filling/emptying phases

The table below gives an overview of the filling and emptying times for lockage in alternate mode with water saving basins. This table takes into account the minimum and the maximum fall that can be reached between the pool and the lock chambers or between a water saving basins and the lock chamber either during filling or emptying phases, according to the simulations with the software.

The filling and emptying times have been determined for a valve opening time of 2 min (either for pool-to-lock or basins-to-lock operations).

The filling time of the lock from the lake and the emptying time of the lock to the ocean are different because of the head losses taken into account. These are higher for the filling phase (higher turbulence).

The total time is the sum of the lock-to-pool time plus the 6 basin-to-lock times.

		emptying of lock chamber		filling of lock chamber	
		head in m	time in s	head in m	time in s
WSB n° 1 (upper WSB)	maxi	6.7	229	6.7	236
	mini	5.9	219	5.8	223
	mean	**6.3**	**224**	**6.3**	**230**
WSB n° 2	maxi	6.7	228	6.8	237
	mini	5.8	215	5.7	221
	mean	**6.3**	**222**	**6.3**	**229**
WSB n° 3	maxi	6.8	228	7.0	240
	mini	5.7	212	5.5	216
	mean	**6.3**	**221**	**6.3**	**229**
WSB n° 4	maxi	6.9	228	7.5	247
	mini	5.6	208	5.1	209
	mean	**6.3**	**219**	**6.3**	**228**
WSB n° 5	maxi	7.2	231	8.5	262
	mini	5.4	202	4.1	188
	mean	**6.3**	**218**	**6.3**	**228**
WSB n° 6 (lower WSB)	maxi	7.9	241	10.9	300
	mini	4.8	190	1.9	134
	mean	**6.4**	**217**	**6.4**	**229**
Lake (filling) Ocean (emptying)	maxi	10.2	609	6.7	667
	mini	2.4	288	5.9	624
	mean	**6.3**	**473**	**6.3**	**646**

total time	maximum	1994	33' 14"	2189	36' 29"
	minimum	1534	25' 34"	1815	30' 15"
	mean	**1794**	**29' 54"**	**2019**	**33' 39"**

For all those simulations, the velocities in culverts and ports do not exceed 7 m/s, there is consequently no risk of a quick erosion of the culverts and ports.

The total times for the filling operation range from 30’15” to 36’29”. The average filling time is 33’39”.

The total times for the emptying operation range from 25’30” to 33’15”. The average emptying time is 29’54”.

NB: the valve closing time is not included in the total time given above.

Graphics representing the flow rate and the water surface elevation in the lock chamber are given in:

- annexes 3-1 and 3-2 for the basin to lock and Lake to lock filling operation of the upper and lower WSB.
- annexes 3-3 and 3-4 for the basin to lock and lock to Ocean emptying operation of the upper and lower WSB

In order to include in the total operation time the valves closing time, a simulation was done on the upper and on the lower saving basin.

The annex 3-3 (3/4) shows the influence of the valve closing times on the total operation time. It demonstrates that without any concealing of the closing time (the closing of the valves starts when the levels in the lock and in the water saving basin are the same), the water surface elevation of the lock when the valve closes largely exceeds the WSB level.

Considering the flow between the lock and the upper water saving basin, starting the valve closure 1 min before the equalization of the levels leads to a level difference between the lock and the WSB superior to 10 cm which is the maximum residual filling depth.

Starting the valve closure 55 sec. before the equalization of the levels leads to a level difference between the lock and the WSB inferior to 10 cm.

As a result, considering that each valve closing operation could be almost totally concealed (concealing times between 5 and 10 sec.), the total filling time of the lock would be increased up to 34’40”.

The same methodology, applied to the emptying operation, leads to a total emptying time of 30’54”.

Conclusion: The target time of 35’ for any filling or emptying operation is respected.

2- Lockage without using water saving basins during filling and emptying phases

Those simulations only concern the lake -to-lock filling or emptying operation.

The simulation was made with the maximum head of 30 m between the lake and the lock or between the lock and the Ocean.

The maximum velocity exceeds the value of the design criteria, which would enforce to reduce the opening time of the valves.

The filling and emptying times are respectively:

Head in meters	**Filling time**	**Emptying time**
30	24’ 24”	17’ 44”

This filling time gives an average raising velocity of the lock water level of 1.23 m/s which complies with the design criteria (1.25 m/s).

Graphics representing the flow rate and the water surface elevation in the lock chamber are given in annex 3-5.

The initial head between the initial levels is far higher than in the first solution. Consequently, the velocities in the culverts and the ports increase drastically and overshoot the allowable value (calculations give maximum velocities of about 12 m/s). Filling and emptying times are also shortened. A suitable solution to reduce the velocities is to slow down the valve opening rate.

A calculation was done with a new valve opening rate in order to limit the speed in the culverts up to 8 m/s. The results are shown in annex 3-6. The filling time would approximately raise of 2 minutes and the emptying time of 2 ‘ 45.

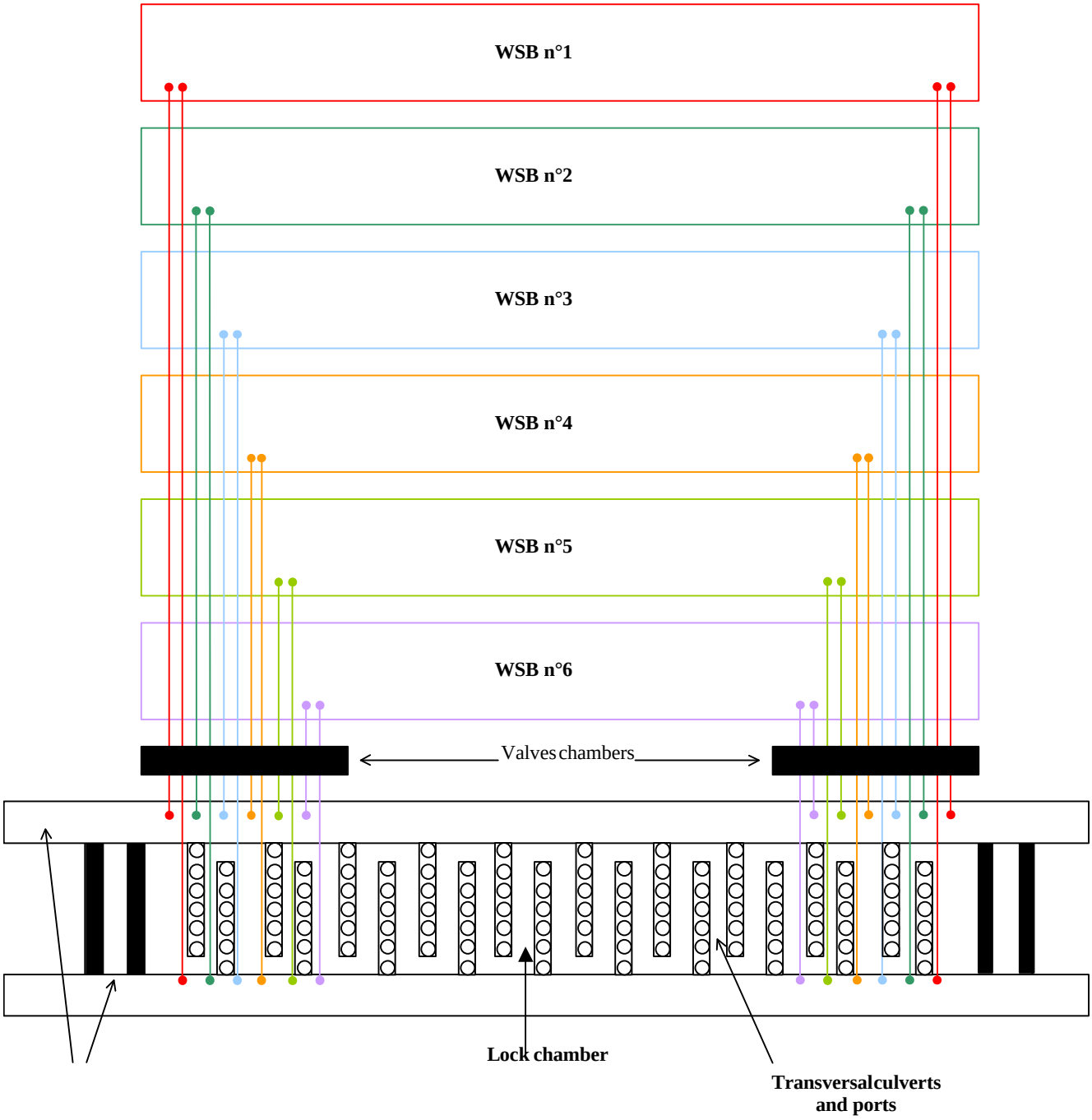
8.8 HYDRAULIC DESIGN OF THE SECOND SOLUTION

The second solution uses bottom culverts with secondary networks and vertical ports. The purpose of the secondary network is to implement a good longitudinal and lateral discharge repartition and a low rate of residual energy to dissipate inside the chamber.

8.8.1 DESCRIPTION

The hydraulic system is based on two longitudinal culverts beneath the bottom floor of the chamber, each one connected to the lock chamber by means of secondary culverts. The secondary culverts are equipped with ports. The connection with the water saving basins is made by 4 culverts per basin.

The sketch hereafter gives an overview of the system:



Filling & emptying system

The chamber supplying is ensured over 320 m by 10 secondary culverts connected to each longitudinal culvert. The secondary culverts are spaced out with 30 m; the overlapping of the two systems results in a distance of 15 m between two secondary culverts. Each secondary culvert is equipped with 6 ports uniformly spaced out.

Connection Water saving basins – chamber

The connection is very similar to the first solution.

8.8.2 SIZE OF CULVERTS AND PORTS

Different shapes of culvert can be considered: circular, square or rectangular. As the valves are rectangular, the culvert shape should be the same, in order to avoid the construction of complicated formworks and additional head losses in transition. In addition, a rectangular shape is easier to build and will be cheaper.

The hydraulic design leads to the following size:

	Shape	Size	Section (m²)	Quantity	Total section (m²)
Side-wall culverts	rectangular	7.5 m x 9 m	67.5	2	135
Transversal culvert	rectangular	2.5 m x 2.5 m	6.25	20, 10 per lock side	125
WSB-to-lock culvert	rectangular	6 m x 6 m	36	4 per basin	144
Ports	circular	1.15 m diameter	1.04	120, 6 per transversal culvert	124.6

As far as the water saving basins are concerned, the number of culverts, the section and the total section of the culverts and ports are to be considered for each of the six saving basins.

Compared to the first solution, the size and number of the culverts has been globally retained. As the number of ports used is 3 times more, the port size has been reduced in order to achieve a flow distribution as uniform as possible.

Remark : the water intakes and outlets in the Gatun lake and Pacific Ocean have not yet been pre-designed. Nevertheless a singular head loss has been taken into account.

8.8.3 FLOWMASTER MODEL PARAMETERS

The components used in simulations are briefly described hereafter. They are the same as in the first solution:

- **Culvert**: the culvert sizes are given above; the absolute roughness of the inner surface is 0.025 mm, which corresponds to the absolute roughness of a smooth concrete pipe (cf. Internal Flow System from D.S Miller).

- **Valve**: the valves used in the model are valve gates with a section equal to the pipe section.

- **Discrete loss**: in order to take into account the kinetic energy dispersal in every chamber (or component assimilated to a chamber), discrete losses have been introduced downstream the ports with a loss coefficient of 1. The reverse flow coefficient is taken equal to 0.5.

- **T-junctions**: T-junctions are used to model the ports. Loss coefficients in T-junctions are automatically set depending on the two-branch flow and area ratios. The calibration of those components (see annex 3 of the first configuration report) demonstrated that they are suitable to model the ports.

8.8.4 FILLING AND EMPTYING TIMES

About 100 simulations have been run with Flowmaster in order to estimate the filling and emptying times, the flow rate and maximum velocities reached in the culverts. The simulations take into account all the likely Gatun Lake and Pacific Ocean levels.

Two kinds of simulation have been performed:

- Simulation of lockage with water saving basins
- Simulations of lockage without water saving basins

1- Lockage using water saving basins in filling/emptying phases

The chart below gives an overview of filling and emptying times for lockage in convoy mode with water saving basins. It takes into account the minimum and the maximum fall that can be reached between the lock chamber and the pool or between a water saving basin and the lock chamber either during filling or emptying phases.

Those times have been reached with a valve opening time of 2 min. The valve closing operation has not been take into account.

For all those simulations, the velocities in culverts and ports do not exceed 7 m/s, there is consequently no risk of a quick erosion of the culverts and ports.

The total times for the filling operation range from 29'02” to 35'42” with an average time of 32'41”.

The total times for the emptying operation range from 27'46” to 35'49” with an average time of 32'25”.

NB: the valve closing time is not included in the total time given above.

		emptying of lock chamber		filling of lock chamber	
		head in m	time in s	head in m	time in s
WSB n° 1 (upper WSB)	maxi	6.7	251	6.7	251
	mini	5.9	238	5.8	237
	mean	**6.3**	**245**	**6.3**	**245**
WSB n° 2	maxi	6.7	251	6.8	253
	mini	5.8	237	5.7	234
	mean	**6.3**	**245**	**6.3**	**244**
WSB n° 3	maxi	6.8	254	7.0	256
	mini	5.7	234	5.5	230
	mean	**6.3**	**245**	**6.3**	**244**
WSB n° 4	maxi	6.9	256	7.5	265
	mini	5.6	231	5.1	221
	mean	**6.3**	**245**	**6.3**	**244**
WSB n° 5	maxi	7.2	260	8.5	282
	mini	5.4	226	4.1	199
	mean	**6.3**	**245**	**6.3**	**244**
WSB n° 6 (lower WSB)	maxi	7.9	272	10.9	324
	mini	4.8	213	1.9	143
	mean	**6.4**	**246**	**6.4**	**246**
Lake (filling) Ocean (emptying)	maxi	10.2	615	6.7	511
	mini	2.4	287	5.9	478
	mean	**6.3**	**474**	**6.3**	**494**

total time	maximum	2159	35' 59"	2142	35' 42"
	minimum	1666	27' 46"	1742	29' 2"
	mean	**1945**	**32' 25"**	**1961**	**32' 41"**

Graphics representing the flow rate and the water surface elevation in the lock chamber are given in:

- annexes 4-1 and 4-2 for the basin to lock and Lake to lock filling operation of the upper and lower WSB.
- annexes 4-3 and 4-4 for the basin to lock and lock to Ocean emptying operation of the upper and lower WSB

In order to include in the total operation time the valves closing time, a simulation was done on the upper and on the lower saving basin.

The annex 4-3 (3/4) shows the influence of the valves closing times on the total operation time. It demonstrates that without any concealing of the closing time (the closing of the valves starts when the levels in the lock and in the water saving basin are the same), the water surface elevation of the lock when the valve closes largely exceeds the WSB level.

Considering the flow between the lock and the upper water saving basin, starting the valve closure 1 min before the equalization of the levels leads to a level difference between the lock and the WSB superior to 10 cm which is the maximum residual filling depth.

Starting the valve closure 55“ before the equalization of the levels leads to a level difference between the lock and the WSB inferior to 10 cm.

As a result, considering that each valve closing operation could be almost totally concealed (concealing times between 5 and 10 sec.), the total filling time of the lock would be increased up to 33’40”.

The same methodology, applied to the emptying operation, leads to a total emptying time of 33'25”.

Conclusion: The target time of 35’ for any filling or emptying operation is respected.

2- Lockage without using water saving basins during filling and emptying phases

Those simulations only concern the lake -to-lock filling or lock-to-ocean emptying operations, which are the worse configurations from an hydraulical point of view.

The initial head between the levels is far higher than in the first configuration. Consequently, the velocities in the culverts and the ports increase drastically and overshoot the allowable value (calculations give maximum velocities of about 12 m/s). Filling and emptying times are also shortened. A suitable solution to reduce the velocities is to slow down the valve opening rate.

The simulation was made with the maximum head of 30 m between the lake and the lock or between the lock and the Ocean.

The maximum velocity exceeds the value of the design criteria, which would enforce to increase the opening time of the valves.

The filling and emptying times are respectively:

Head in meters	**Filling time**	**Emptying time**
30	18'48"	18'18"

This filling time gives an average raising velocity of the lock water level of 1.6 m/s , superior to the design criteria (1.25 m/s); this shows that from a hydraulical point of view, this solution is more efficient.

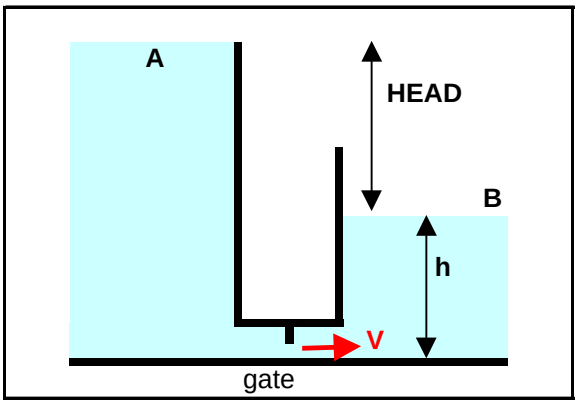
Graphics representing the flow rate and the water surface elevation in the lock chamber are given in annex 4-5.

9 Cavitation and air demand

9.1 GENERAL PRINCIPLE

The scheme hereafter represents a schematic connection between two chambers (or saving basin)

Downstream the valve, the high velocity jet has a capacity of carrying away the water located just



above it. The pressure of the water decreases according to kinetic energy $V^2/2g$ of the jet. So the static pressure 'h' downstream the valve can be reduced for worse of $V^2/2g$.

If the pressure becomes lower than the water vapor pressure, h_v, water begins to boil at room temperature and cavitation appears with production of vapor bubbles. Cavitation produces noise and vibration and implosion of bubbles can damage the structures and especially the valves.

The following no-dimensional number gives the condition of cavitation:

$$s = \frac{P - P_v}{1/2\, r V^2} = \frac{h - h_v}{V^2/2g}$$

Pv = 0.02 bar hv = 20 cm vapor pressure (at 20 °C)

Cavitation can appear if $s < s_v$; s_v given by the literature ($s_v \approx 1$)

Remarks

According to the Bernoulli equation and neglecting head losses, the kinetic energy $V^2/2g$ of the jet is equal to the head between the chambers giving:

$$s = \frac{h - 0.2}{head} \approx \frac{h}{head}$$

So, if the head is less than the water height above the jet, cavitation can not appear.

<u>Head < h ⇔ no cavitation</u>

In case of a head greater than h, more precise calculations of head losses must be done. Flowmaster is able to run simulations making allowance for the cavitation phenomenon.

A solution to avoid cavitation on the valves is to lower their sills (adopted in the Niffer lock case).

9.2 APPLICATION TO THE SINGLE LIFT LOCK

- *Water saving basins to lock*

As the head between the water saving basins and the chamber is always smaller than 7 m and the minimum water height in the chamber is 18.3 m (Head < h), cavitation can not appear.

- *Pool to lock*

In case of not using the water saving basins, the maximum head between would be 30 m. As the minimum water level of water in the chamber is 18.3 m, cavitation could appear at the beginning of the filling, afterwards the head decreases and the cavitation conditions are no longer observed.

10 Strengths on the hawsers

The examination of the strengths' origins has been done in the report of the triple lift lock system. The same methodology will be applied to determine the strengths on the hawsers in the worst configuration of the single lift lock system.

This configuration concerns the two solutions, in the case that no water saving basins would be used and the maximum head corresponding to the filling of the empty lock by the lake.

During emptying and filling operations, oscillating waves and mass movements of water occur in the chamber. These unsteady phenomena are the result of valve operations in the system, which create surges propagating in the chamber and reflecting against the walls and the ship.

The celerity C of the wave is $\sqrt{gh}$, so the period of oscillation T = 2L/C (L = chamber length) is decreasing during the filling.

As a consequence, the water surface in the chamber oscillates around an average level, generally sloping from the upstream to the downstream end of the lock.

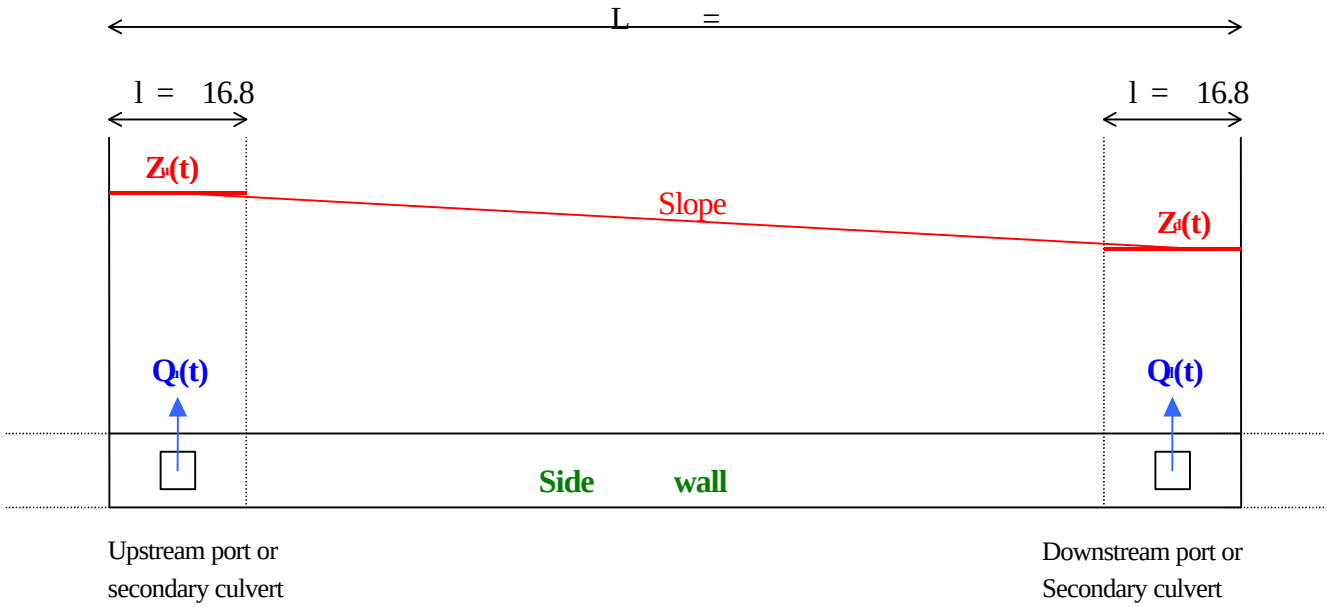
The more the inflow injection is concentrated at one end of the lock, the steeper is the average water surface slope and the higher is the force on the ship.

The main force acting on the ship results from this slope and can be calculated by the expression:

$$F = P \cdot S$$

Where P is the displacement weight of the vessel,
S is the average slope in the chamber (oscillating).

The effects of inertia and friction on the vessel are far smaller. Each force is subject to highly turbulent fluctuations.



For the 1-step lock the maximum slope S_{max} has been assessed thanks to the simple mathematical model, described in the first configuration report.

The water slope is calculated by assessing the upstream water level in the lock chamber, noted $Z_u(t)$ and the downstream water level in the lock chamber, noted $Z_d(t)$. Those levels are calculated considering elementary cells centred on the upstream and the downstream port, 16.8 m long and 61 m large.

Simulations run with Flowmaster give the flow discharge in every port with a 1 s time step, noted Δt. Water levels are given by:

$$Z_u(t) = \frac{Q_u(t) * \Delta t}{S} \qquad \text{with } S = 61 * 16.8 = 1025 \text{ m}^2$$

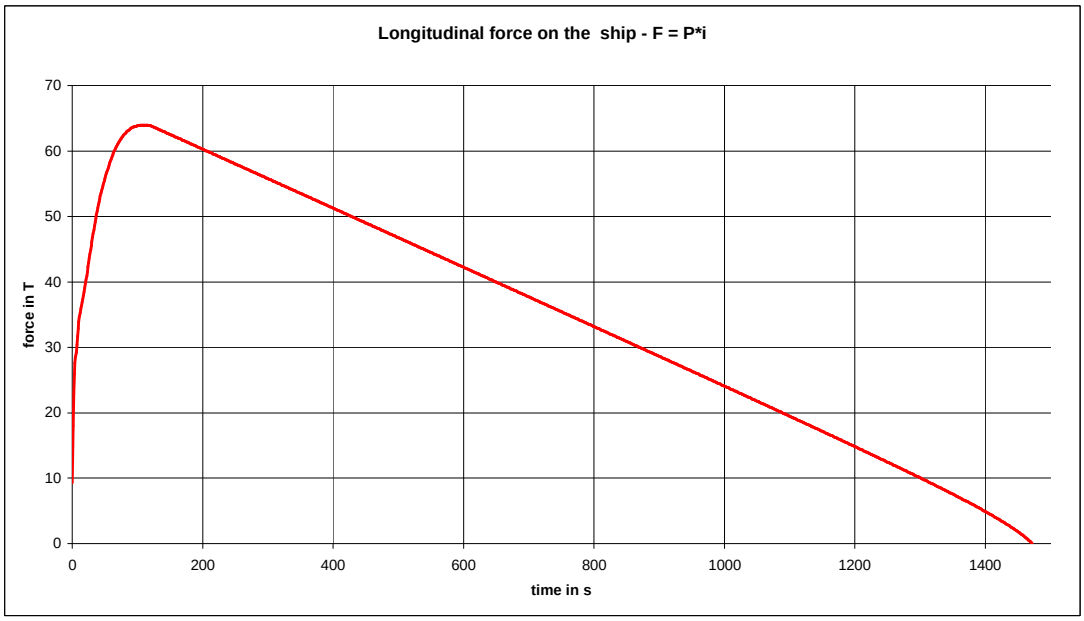
$$Z_d(t) = \frac{Q_d(t) * \Delta t}{S}$$

It is assessed that the water levels equalize in the lock chamber between each time step. The slope is then calculated every 1 s by:

$$S(t) = \frac{Z_u(t) - Z_d(t)}{L}$$

The following graphics give an overview of the strength on the ship, according the total head:

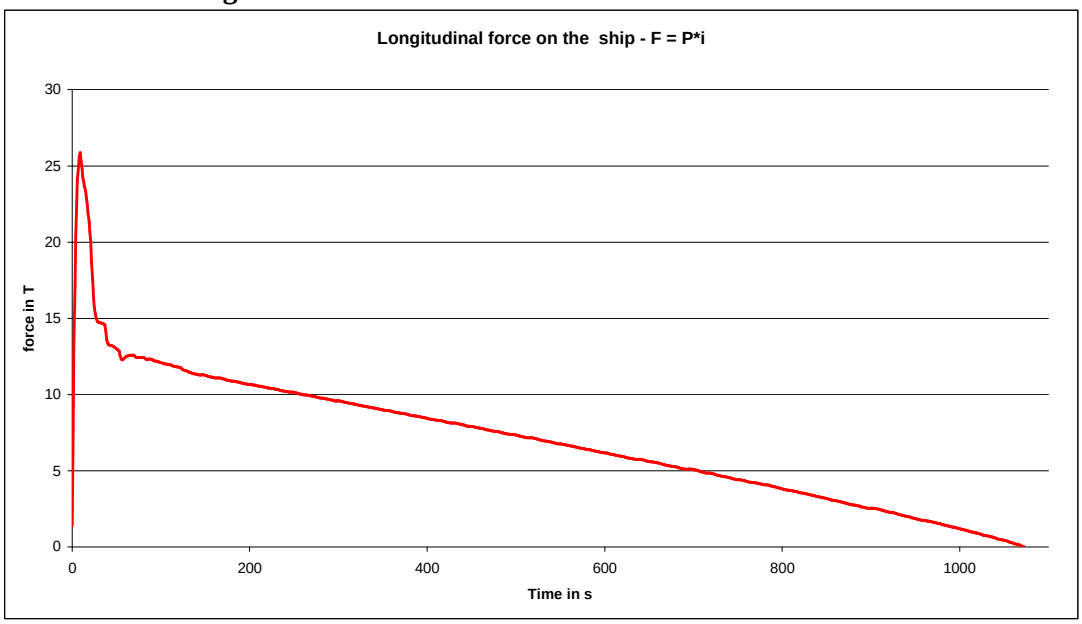
Solution 1:



The maximum strength is observed for the simulation: lock-to-lock filling operation ; head of 30 m.
With P = 316 000 tons (385 m x 54 m x 15.20 m); $S_{max} = 2.5\ 10^{-4}$; $F_{max} = 64$ tons

This maximum strength is reached after 120 s, at the beginning of the filling phase.

Solution 2: bottom filling



The maximum strength is observed for the simulation: lock-to-lock filling operation ; head of 30 m.
With P = 316 000 tons ; $S_{max} = 7.8\ 10^{-5}$; $F_{max} = 26$ tons

This maximum strength is reached after 11 s, at the very beginning of the filling phase.

This solution proves its better ability to reduce the strengths on the hawsers thanks to its better flow distribution.

Conclusion:

<u>Note that these strengths can be much higher due to the oscillation phenomenon mentioned above.</u>

Because of the complexity of the hydraulic phenomena involved, it is impossible to determine with more accuracy the hawser stresses without physical model tests.

At this stage of hydraulic conceptual design, the scope of work is not to calculate the exact values of hawsers stresses, but to select emptying/filling systems able to minimize these stresses and to underline all the means which could be used, in further detailed studies, to reduce hawser stresses under a minimum allowable level.

Nevertheless, the strengths on the hawsers would result lower by using the water saving basins and, if not using them, by increasing the filling times.

11 WATER SAVING BASINS

11.1 GENERAL LAY OUT

Those aspects have already been discussed in § 8.1.

Two dispositions have been studied :

- A classic one, as in the first configuration : all the six basins are disposed side by side
- A disposition with 6 stacked basins, two by two, i.e. 3 piles

11.2 BASIN STRUCTURE

11.2.1 FOUNDATION

The water saving basins will be of one type for each solution, side by side or stacked. For both solutions, the entire structure is located in the basalt formation

11.2.2 SIDE BY SIDE BASINS

The general disposition is the one adopted in the first configuration, but for this one, the lower basin is the nearest to the chamber (to minimize earthworks)

Due to the fact there is only one chamber, the rectangular basins can be more extended in the longitudinal direction

Separation walls, cantilever type, are foreseen, in addition to peripheral walls, all around the basins

11.2.3 STACKED BASINS

The nearest to the chamber basins are 90 m wide and 400 m long, the outer basins are 60 m wide and 600 m long

The support of the upper basins, especially the inner water, is made by the way of floors, constituted by slabs, 1 m thick, and grids of cross beams, approximately 2 m high.

This floor is supported by square posts, 1.80 m x 1.80, every each 15 m. With this disposition, there are 3 rows of posts in the outer basins and 5 rows in the nearest to the chamber basin.

As for the side by side disposition, separation and retaining outer walls are foreseen,

11.3 INNER WALLS AND ANTI-VORTEX DEVICES

Since the water saving basin areas are very large, flushing is expected in the basin. Some inner transverse walls should be added. These walls should not be continuous in order to allow water transfer in the basin in the case a valve is out of order.

In addition, some anti vortex walls could be located at the pipe intakes.

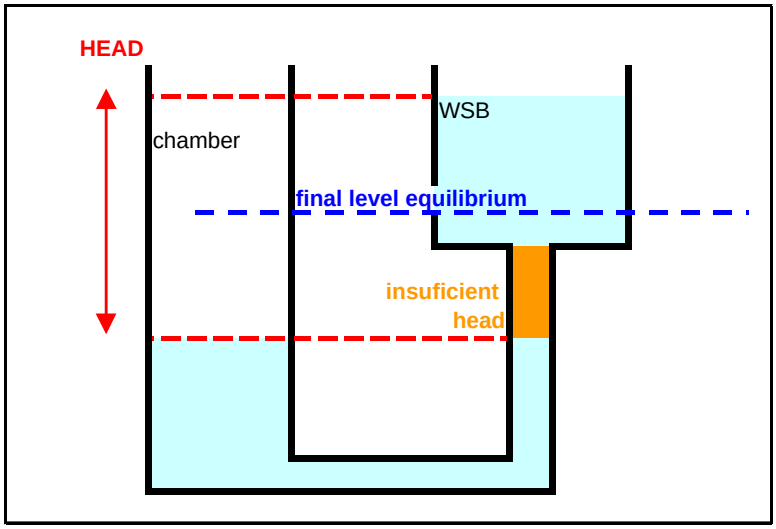
Concerning solution 2, stacking the basins will need numerous piles placed into the lower basins to support the upper ones

The location, number and size of the walls, piles and anti-vortex devices as well, have to be adjusted on a physical model.

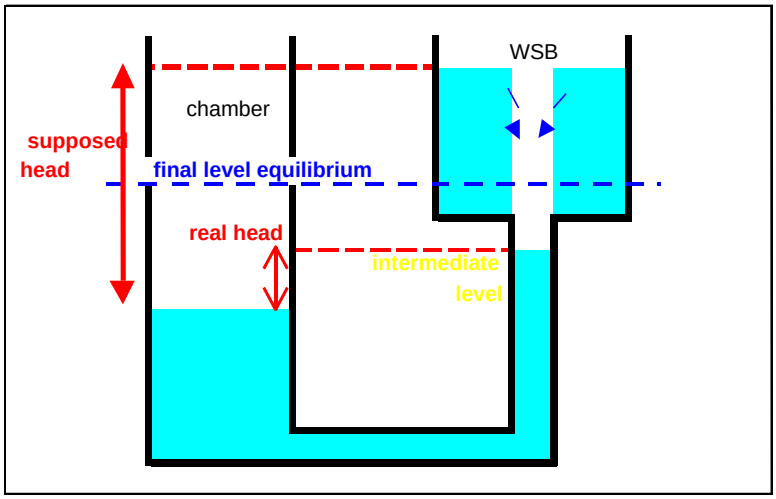
11.4 MINIMUM HEAD IN THE BASINS

Water saving basins must not be emptied until their bottom floor. Two problems must be checked:

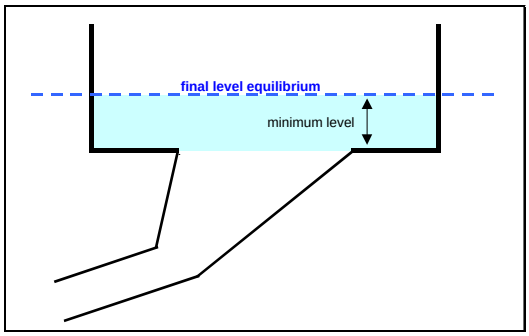
- A minimum head is required to create sufficient kinetic energy in the upper part of the culvert. If the same diameter is designed in the upper part, the head will not be sufficient, and the pressure will decrease. So larger sections are required for this part.



- The entrance of the culvert is similar to a spillway, whose discharge depends on its perimeter. If the discharge of this spillway is not sufficient, an intermediate level will appear in the culvert, controlling and reducing the discharge.



Both problems can be solved by increasing the basin minimum level and by increasing the intake perimeter



A scale model is needed for a precise hydraulic design of the intake.

First assessments given by the Consultant are:

- Minimum water clearance 1 m
- Minimum perimeter length 100 m

12 SPILLED WATER AND RECYCLING

12.1 GENERAL

During the driest seasons, due to the ''El Niño'' phenomenon, the lowest level in the lake Gatun of +23.90 m PLD is expected even with the water saved thanks to the saving basins. Anyway ACP wishes to operate the locks at a full capacity, whatever the season or the year.

In the Terms of Reference, some provisions are required for intakes and outlets in the hydraulic circuits in order to recycle the spilled water in the Pacific Ocean.

The Consultant has to propose specific means in addition to the saving basins, able to spare all the water needed to operate the locks.

The recycling system is expected to save almost all the water usually spilled in the Pacific Ocean, using additional ponds and pumping. The software developed by the Consultant is able to calculate for every lockage the amount of water spilled in the Ocean and thus able to design the required ponds and pumping.

Moreover, the ship pilots reported that the emptying of the lock chamber creates strong currents downstream the locks of Miraflores, disturbing the approach of the ships:

…. It has been observed that when a gate is opened after equalization between waters of different salinity, a heavy current develops from the fresh water to the salty water. Tests were performed to observe currents developed when the gates were opened between Miraflores Lake and the upper level; between upper and lower levels; and between the lower level and sea level. In all cases it was found that strong currents developed on the surface with a reverse current at the bottom. They were measured using telephone poles ….

…. These observations are confirmed with similar observations made with vessels entering the Locks from the sea. This data is important as vessels approaching Miraflores from the sea find that the current tends to push the vessel crosswise to the tailbay. This tendency is so strong that the author considered it unsafe to bring large vessels into the chamber until the fresh-salt water currents cease, which results in a delay of 20 to 30 minutes.

The locomotives can control smaller vessels. Additionally, it was advisable to use the power of the vessel. The danger to the vessel is the possibility of colliding with the corner of the wing wall. The author also questioned whether it would have been advisable to build the wingwall in such a manner that a vessel could be brought up close enough to the gates so that

when the gates are opened, the fresh-water current from the Locks would not expand until after passing the stern of the ship.

At Gatun, the situation is different as the tidal fluctuation is only 2 ft (0,61 m). The relative densities between the lower chamber and the sea are less at Gatun than at Miraflores, as the fresh water is locked down three steps and only two at Miraflores.

The current from the lower chamber to sea also makes it somewhat difficult for a vessel to leave, as there is a very strong tendency to carry the vessel over toward the wing wall and the bank of the canal.

(excerpt from a paper entitled, *Hydraulics of the Locks*, by R.H. Whitehead)

Even with the use of water saving basins, the amount of water spilled downstream the 3rd lane locks will be nearly the same as the amount currently spilled downstream the Miraflores locks. So this problem must be taken into account.

12.2 SPILLED WATER – LOWER POND

The water normally spilled to the Ocean is fresher than the water just downstream the locks.

Pumping brackish water from downstream to upstream is not suitable. So a lower pond is required to store the water usually spilled into the Pacific Ocean.

Designing the lower pond must take into account the high range of the Pacific Ocean tides. The lowest level of the lower pond depends on its surface.

Both sidewall culverts are connected to the pond located on the left bank of the third line, the right Bank culvert passing under the lower chamber.

The pond is connected to the Pacific Ocean in the approach channel of the existing locks of Miraflores: these proposed disposals suppress the formation of currents downstream the 3rd line of locks. Furthermore, the foreseen output in the approach channel is far enough from the Miraflores lock in order not to disturb the Panamax ships manoeuvrability.

The connection between the lower pond and the Pacific Ocean is made by valves and large culverts in order to minimize head losses.

There are two operating schedules:

- Water is not recycled: the valves of the pond are opened, the water is spilled into the Ocean
- Water is recycled: the valves of the pond are closed. The pond fills up during the lock chamber emptying stage. The filling stops when the lock chamber water level is equal to the Pacific Ocean level. Water is continuously pumped up to the upper pond.

12.3 RECYCLING WATER – UPPER POND

Brackish water enters the chamber especially when the ship is getting out. That is why the spilled water from the lower chamber to the lower pond is a little bit brackish. Pumping this water directly in the Gatun Lake could increase the salinity of the upstream channel.

An upper pond is thus required above the lock. This pond could be artificial or use a natural hollow if any. The lowest level of the pond must be at least +23.90 m PLD. The highest level depends on the area of the pond.

According to the layout of the third line, it appears that the upper pond can be realized by building a dam on the Cocoli River. This proposal will be examined more thoroughly in the next step of the studies.

12.4 EXAMPLE

A simulation has been run with the software developed by the Consultant, with the following entry data:

- Duration: 40 320 min = 672 h = 28 days
- Gatun Lake level: 26.67 m PLD
- Pacific Ocean level: ranging from –3.44 m PLD to 3.60 m PLD
- Lower pond area: 50 000 m^2 (almost 2 times the chamber area)
- Upper pond area: 50 000 m^2 (almost 2 times the chamber area)

The results achieved with this simulation allow calculating the main characteristic of the water recycling system:

- Water consumption: 46 040 300 m^3
- Pumping rate: 19.11 m^3/s
- Maximum head between ponds: 36.88 m
- Minimum head between ponds: 31.06 m
- Average head between ponds: 34.33 m
- Maximum power required: 9 200 kW
- Annual average energy consumption: 75.10^6 kWh (for a continuous pumping all year long)
- Total pipe length: 2 500 m
- Pipe diameter: 3 m

It is possible to reduce the head between the ponds by increasing one or both pond areas, thus reducing the power and the consumption of the pumping station.

Remark: the lower pond water level at the equalization between the chamber and the pond must not be higher than the Pacific Ocean level, otherwise the opening of the downstream gate would be impossible.

The consultant proposes the following solutions if this condition is not always fulfilled:

- To increase the pond area
- To lower the bottom floor of the pond
- Exceptionally to open the downstream valves of the pond during the emptying stage
- To install butterfly valves in the downstream gate

12.5 INVESTMENTS

The total amount of the investments is nearly 34 million US $, with the following components :

	total (US $)
lower basin	8 000 000
upper basin an dam	3 000 000
access road	100 000
pumping station	12 500 000
3.00 m diameter pipe	8 000 000
TOTAL	**31 600 000**

12.6 SCHEDULING

The 3rd lane of locks is expected not to be saturated within a couple of years of operating. Water consumption of the locks should be reduced during the first years and the construction of the ponds and the pumping station could be postponed.

13 Conclusion - Comparison BETWEEN solution 1 and solution 2

- Filling or emptying times

  - The time for filling or emptying the lock chamber from the water saving basins is a bit longer for the second solution , because of the superior head losses due to the secondary network of culverts.

  - The time for filling or emptying the chamber from the pools is shorter for the second solution

  - Both former points lead to similar global operating times:

	Average emptying time	Average filling time
Solution 1	**29'54**	**33'39**
Solution 2	**32'25**	**32'41**

NB: hypothesis is made that oscillations in the chamber are admissible, if not, opening time of valves should be increased and consequently filling and emptying time will be higher.

- Filling or emptying speeds of the chamber water level, using the water saving basins:

  - The former times lead to the following speeds of the chamber water level:

	Average emptying speed (m/s)	Average filling speed (m/s)
Solution 1	**1.0**	**0.89**
Solution 2	**0.92**	**0.92**

- The main difference between both solutions is that solution 2 proposes a more balanced filling of the chamber, if no water saving basins would be used. It results in a reduction of the strengths on the hawsers. It must be added that these forces are longitudinal ones and that it is as important to determine the transversal forces on a scale model.

- The flow distribution could be still improved and the maximum velocities reduced in both solutions by a non-uniform ports spacing or adapted port shapes.

The solution 1 is a very good solution when the water saving basins are used, which is likely to be the case and was imposed by the Terms of Reference. The drawbacks, especially the ones due to the operating without using the water saving basins, can be lessened by increasing the opening time of the valves, at the beginning.

The solution 2 would be less constraining for lake-to-lock operations without water saving basins; however, in order to avoid cavitation, the operating times should be increased too. Moreover, as it will be demonstrated in the estimates, this solution is much more costly than the first one.

Consequently, the solution 1 appears to be the best one for the single lift lock configuration.

Concerning the water saving basins disposition, it has been demonstrated that the stacked basins disposition is inadequate technically and economically.

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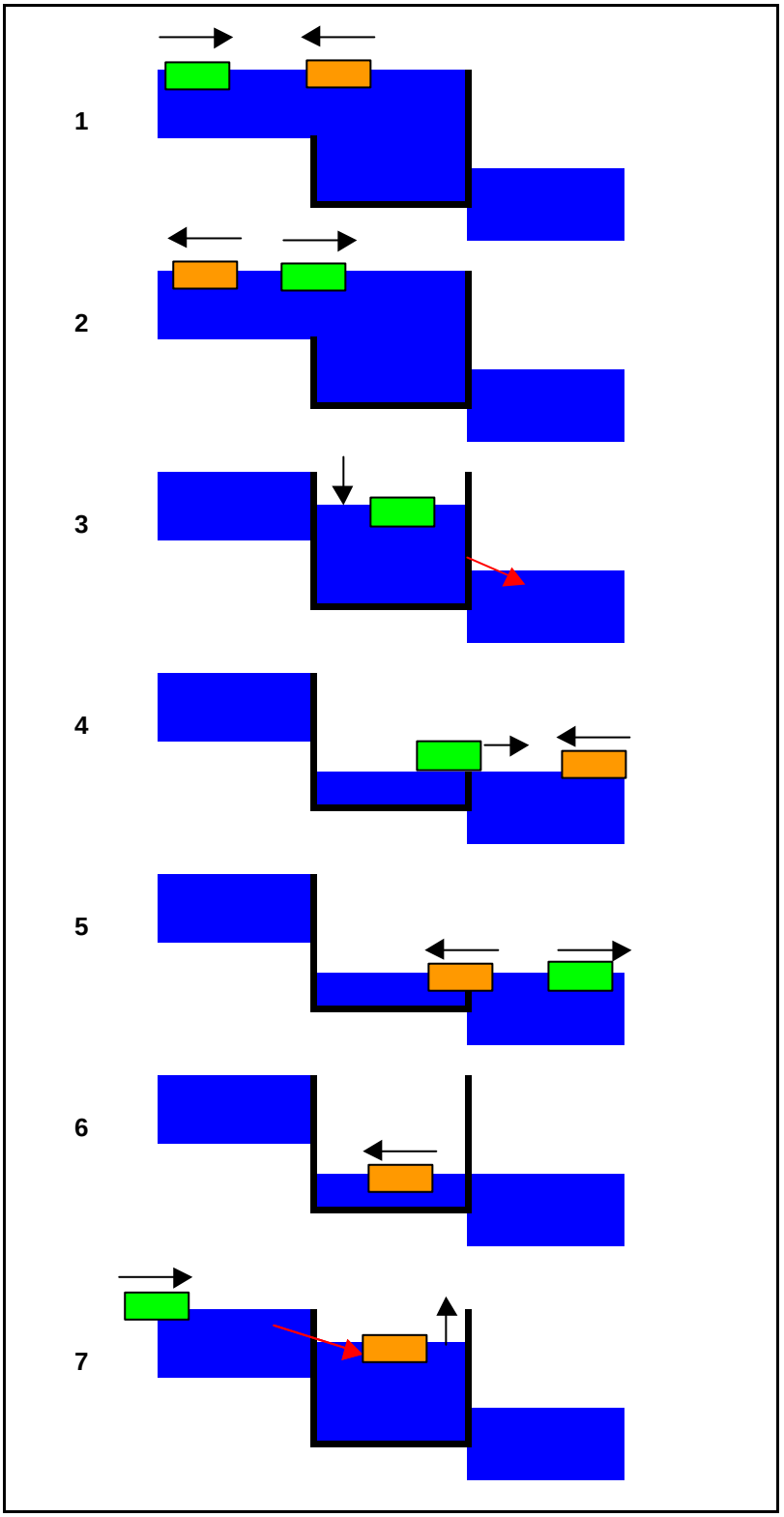
ANNEX 2

Annex 2-1
Scheduling in alternate mode



ANNEX 2.2 (1/2)

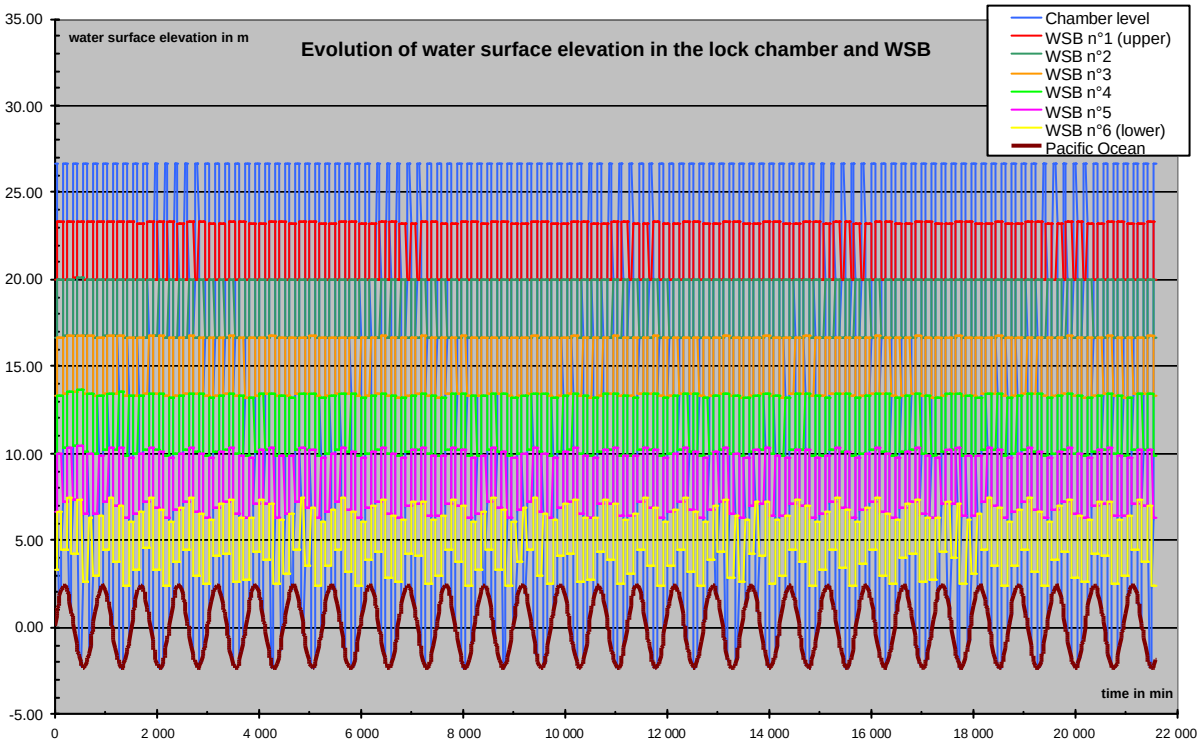
Zlake = 26.67 m
Overview on 15 days

Lake level : 26.67 m
Océan level : Mean Low Water Spring (-3.44 m ; +3.60 m)

Lock surface : 33 800 m^2
m = Lock surface/ WSB surface: 1
Residual level between lock and WSB: 0,1 m

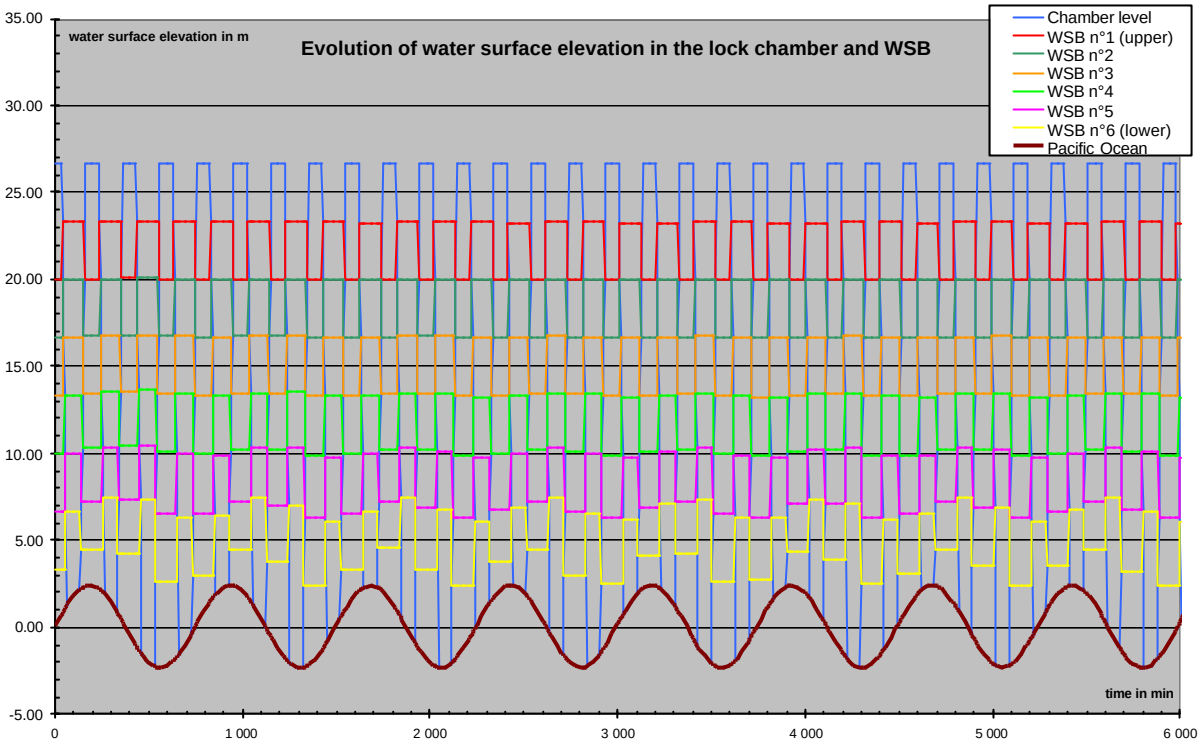
Operating times

Gate opening : 6 min
Gate closing: 6 min
Filling of 1 WSB : 4 min
End of filling time : 5 min
Ship movement (entry or exit) : 30 min



ANNEX 2.2 (2/2)

Zlake = 26.67 m
Zoom on the first 100 hours



ANNEX 2.3 (1/2)

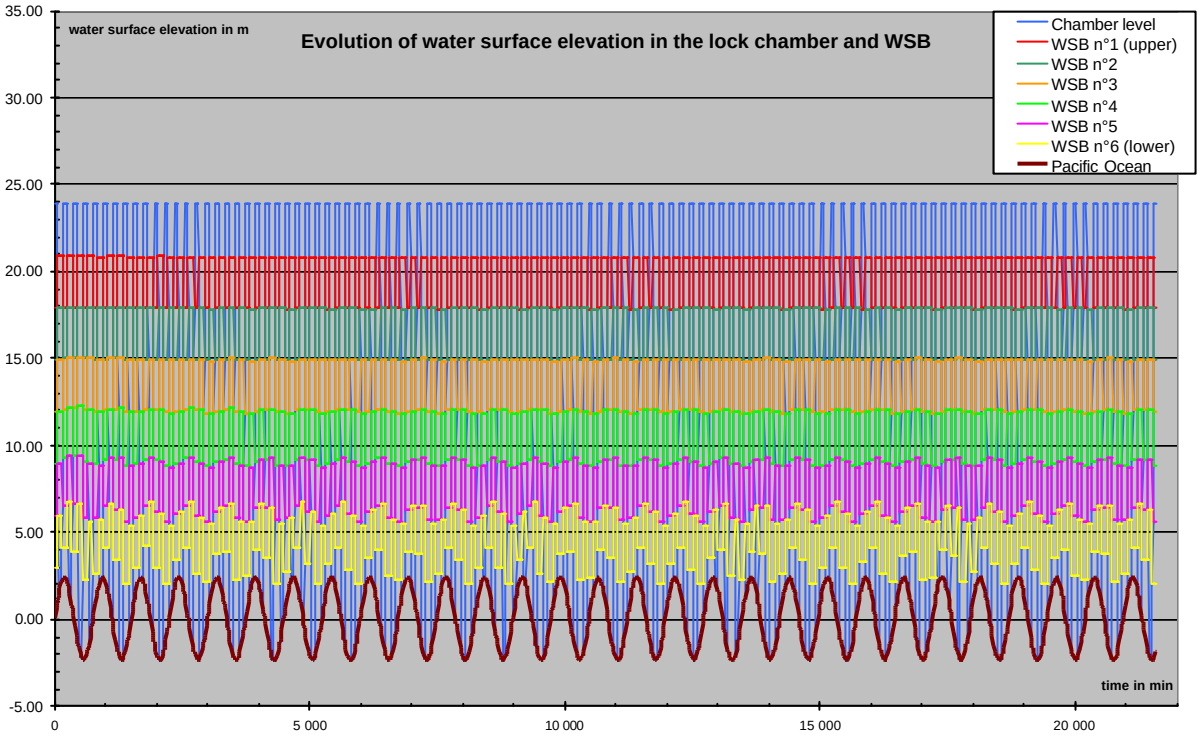
Zlake = 23.90 m
Overview on 15 days

Lake level : 23.90 m
Océan level : Mean Low Water Spring (-3.44 m ; +3.60 m)

Lock surface : 33 800 m^2
m = Lock surface/ WSB surface: 1
Residual level between lock and WSB: 0,1 m

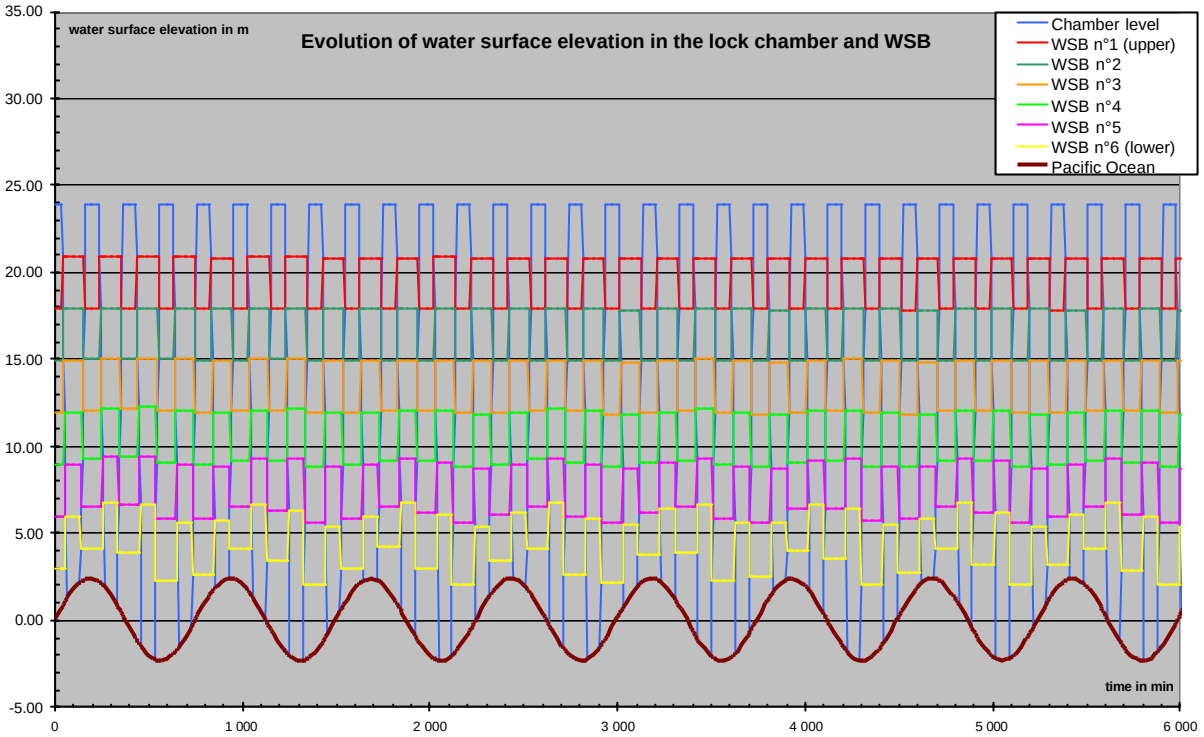
Operating times

Gate opening : 6 min
Gate closing: 6 min
Filling of 1 WSB : 4 min
End of filling time : 5 min
Ship movement (entry or exit) : 30 min



ANNEX 2.3 (2/2)

Zlake = 23.90 m
Zoom on the first 100 hours



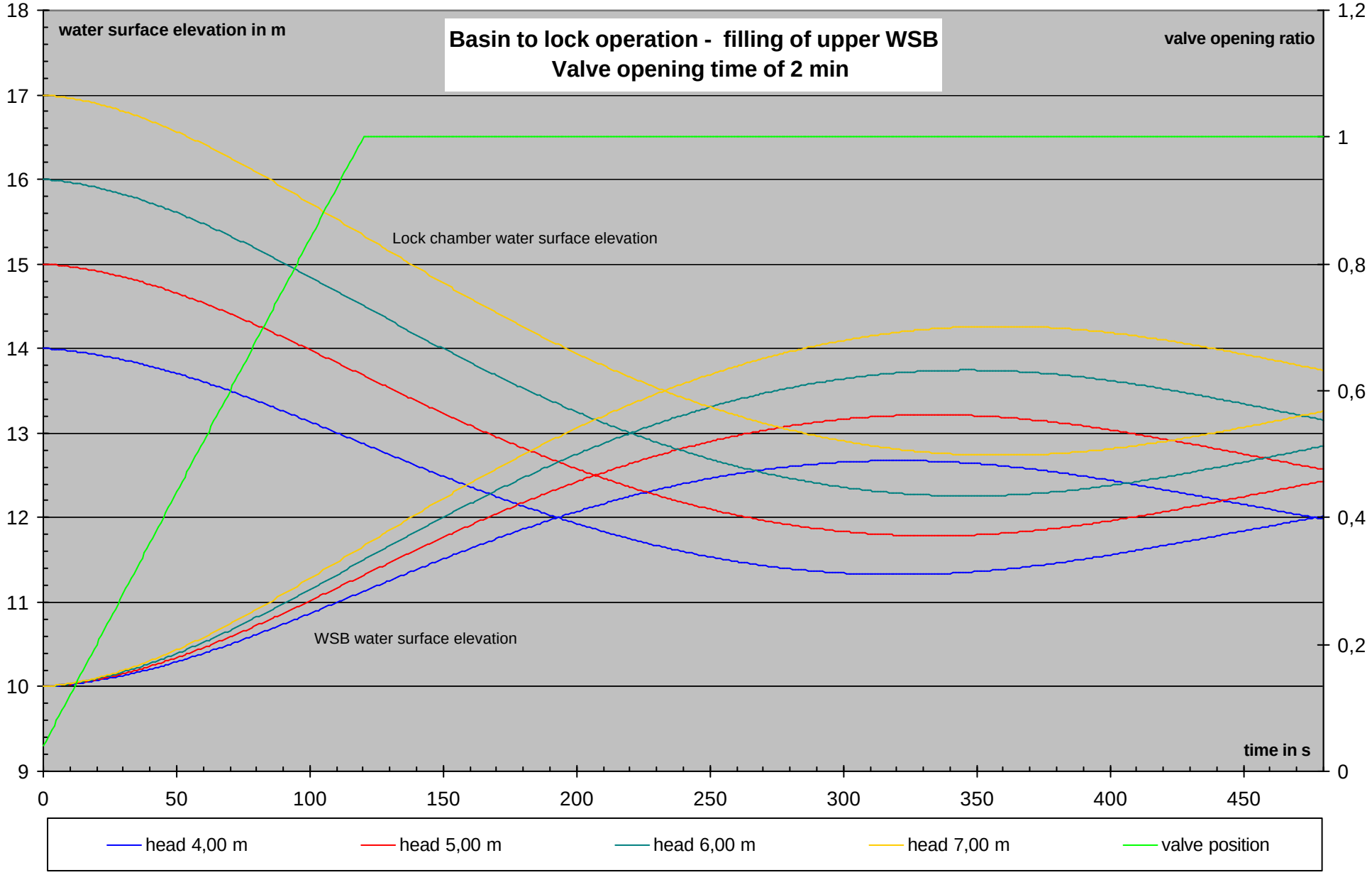
Annex 2.4
Level setting results

Zocean between - 3.44 PLD and + 3.60 PLD

Zlake	Db (Residual filling depth)		Chamber level	Upper WSB (n°1) level	WSB n°2 level	WSB n°3 level	WSB n°4 level	WSB n°5 level	Lower WSB (n°6) level
26,67	0	maxi	26,67	23,40	20,14	16,92	13,76	10,66	7,76
		mini	-3,44	19,99	16,63	13,22	9,72	6,00	1,81
23,9	0	maxi	23,90	20,97	18,07	15,19	12,37	9,62	7,07
		mini	-3,44	17,91	14,90	11,84	8,68	5,31	1,46
26,67	0,1	maxi	26,67	23,33	20,10	16,90	13,75	10,68	7,81
		mini	-3,44	19,94	16,60	13,22	9,75	6,05	1,88
23,9	0,1	maxi	23,90	20,90	18,02	15,17	12,37	9,63	7,12
		mini	-3,44	17,86	14,87	11,84	8,71	5,36	1,53
26,67	0,2	maxi	26,67	23,25	20,05	16,87	13,75	10,69	7,86
		mini	-3,44	19,89	16,58	13,22	9,77	6,10	1,96
23,9	0,2	maxi	23,90	20,83	17,97	15,14	12,36	9,65	7,17
		mini	-3,44	17,81	14,85	11,84	8,73	5,41	1,61

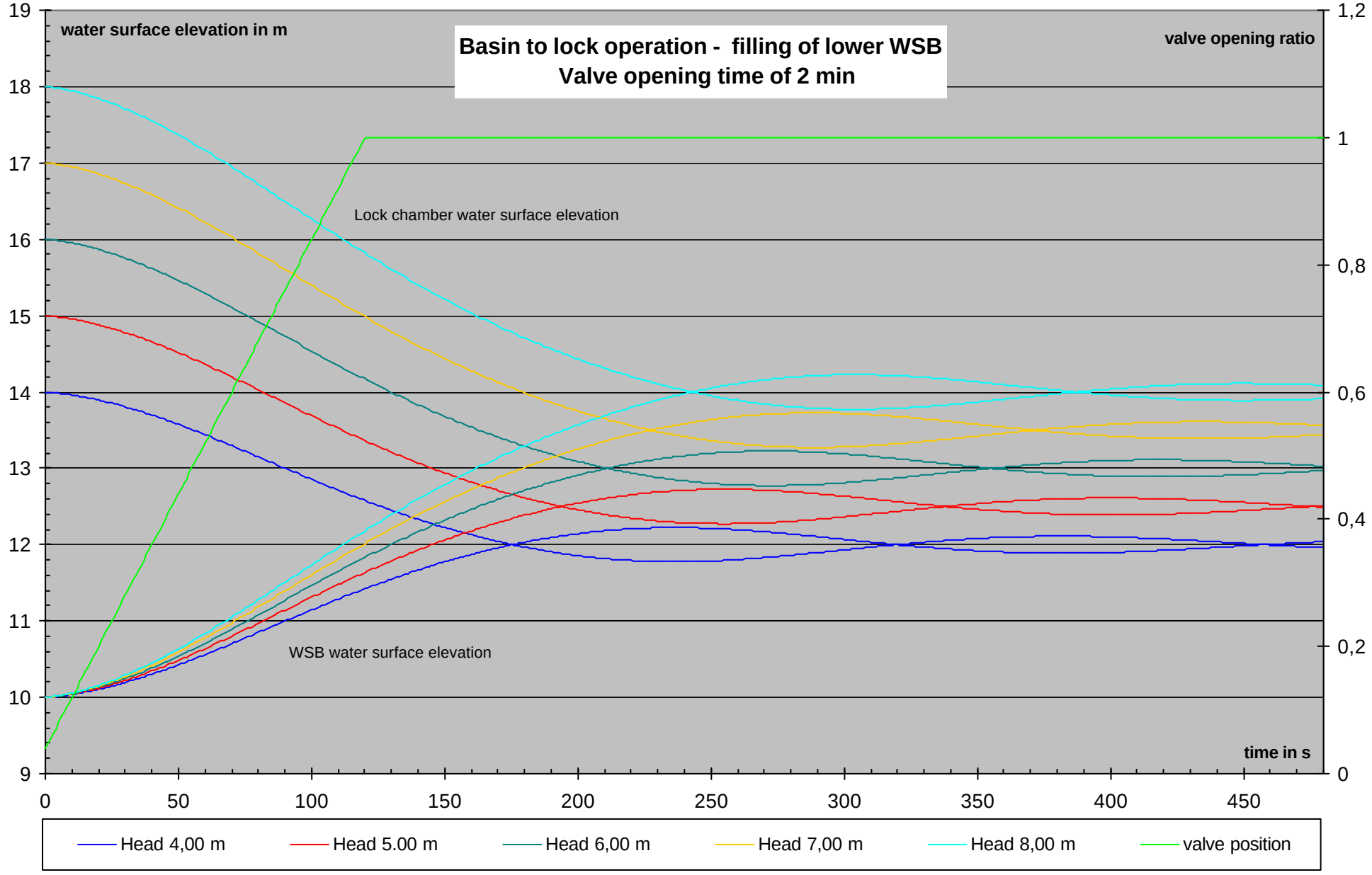
ANNEX 3

Annex 3-1 (1/3)
1st solution - Lateral filling / emptying system
Lockage with WSB

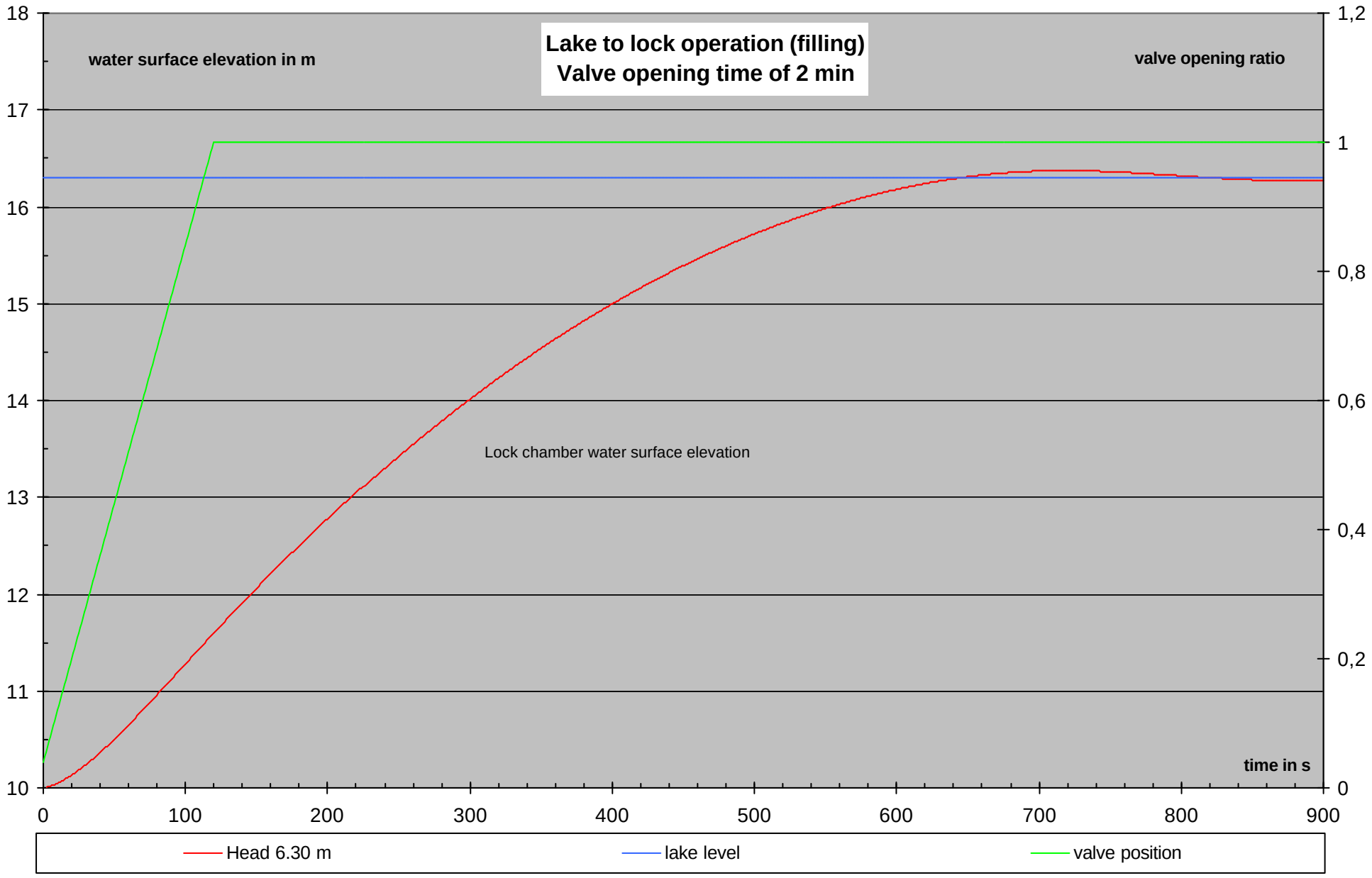


Annex 3-1 (2/3)
Lockage with WSB

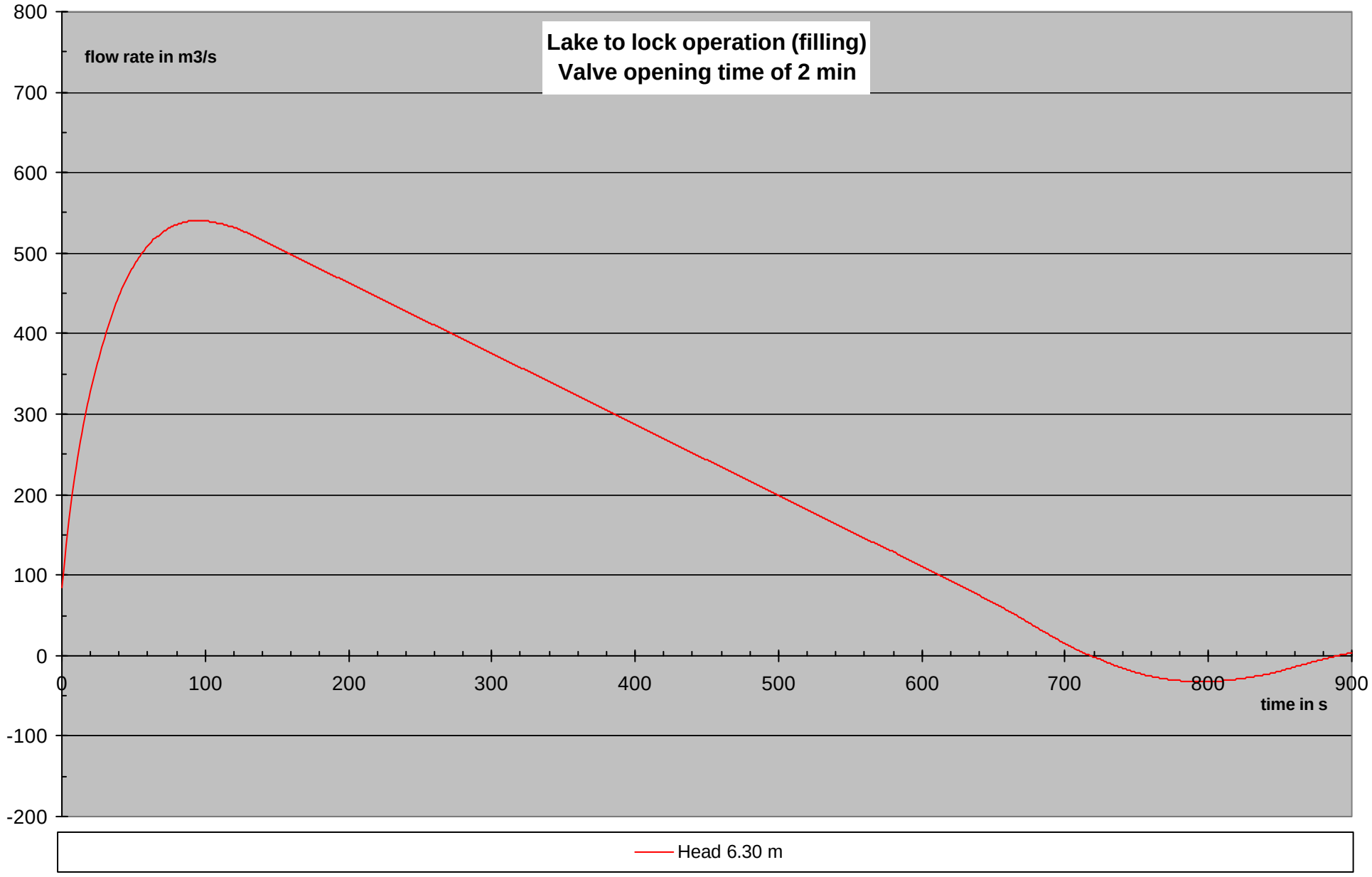
Annex 3-1 (3/3)
Lockage with WSB



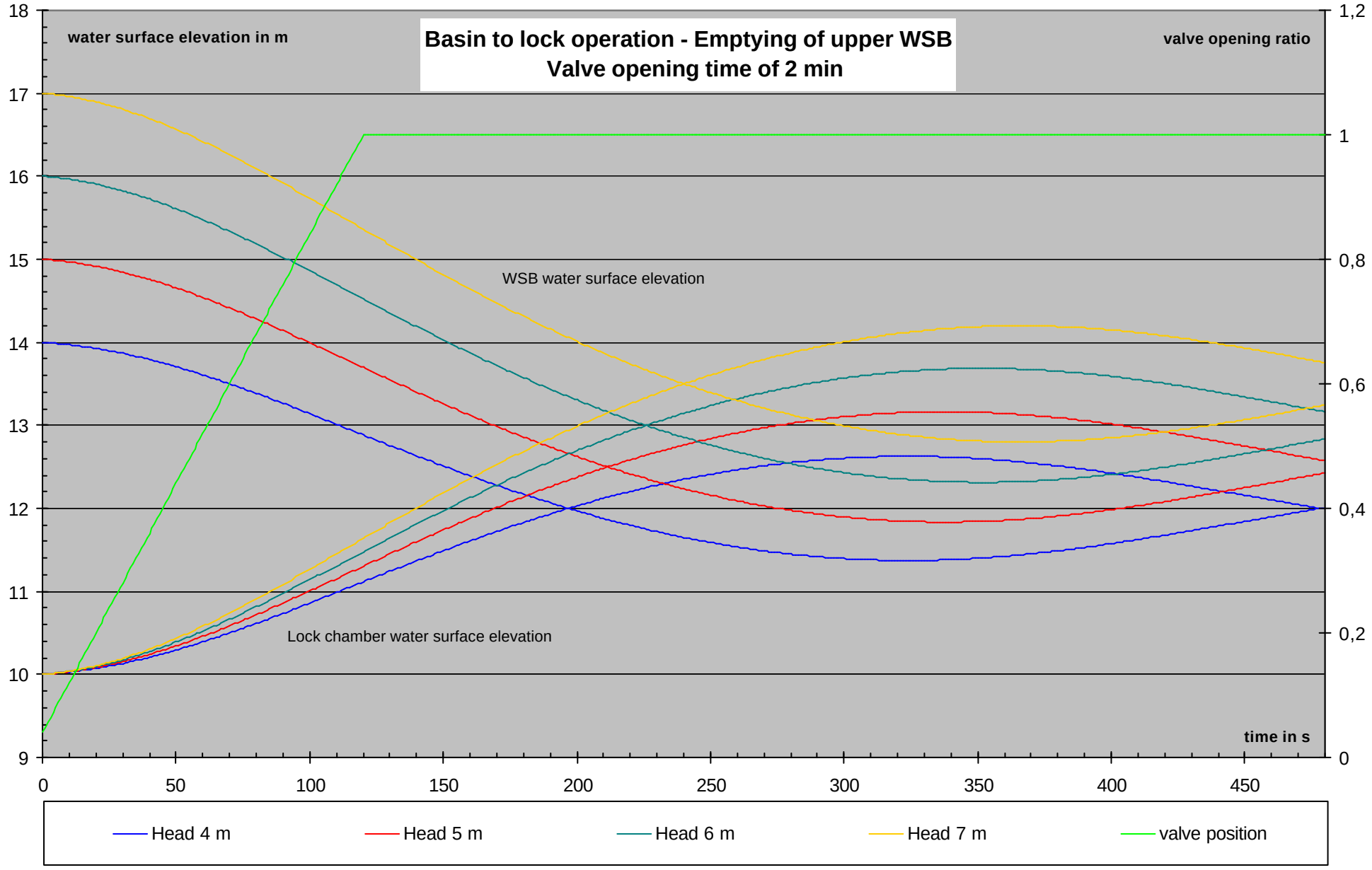
Annex 3-2 (1/2)
Lockage with WSB



Annex 3-2 (2/2)
Lockage with WSB



Annex 3-3 (1/4)
Lockage with WSB



Annex 3-3 (2/4)
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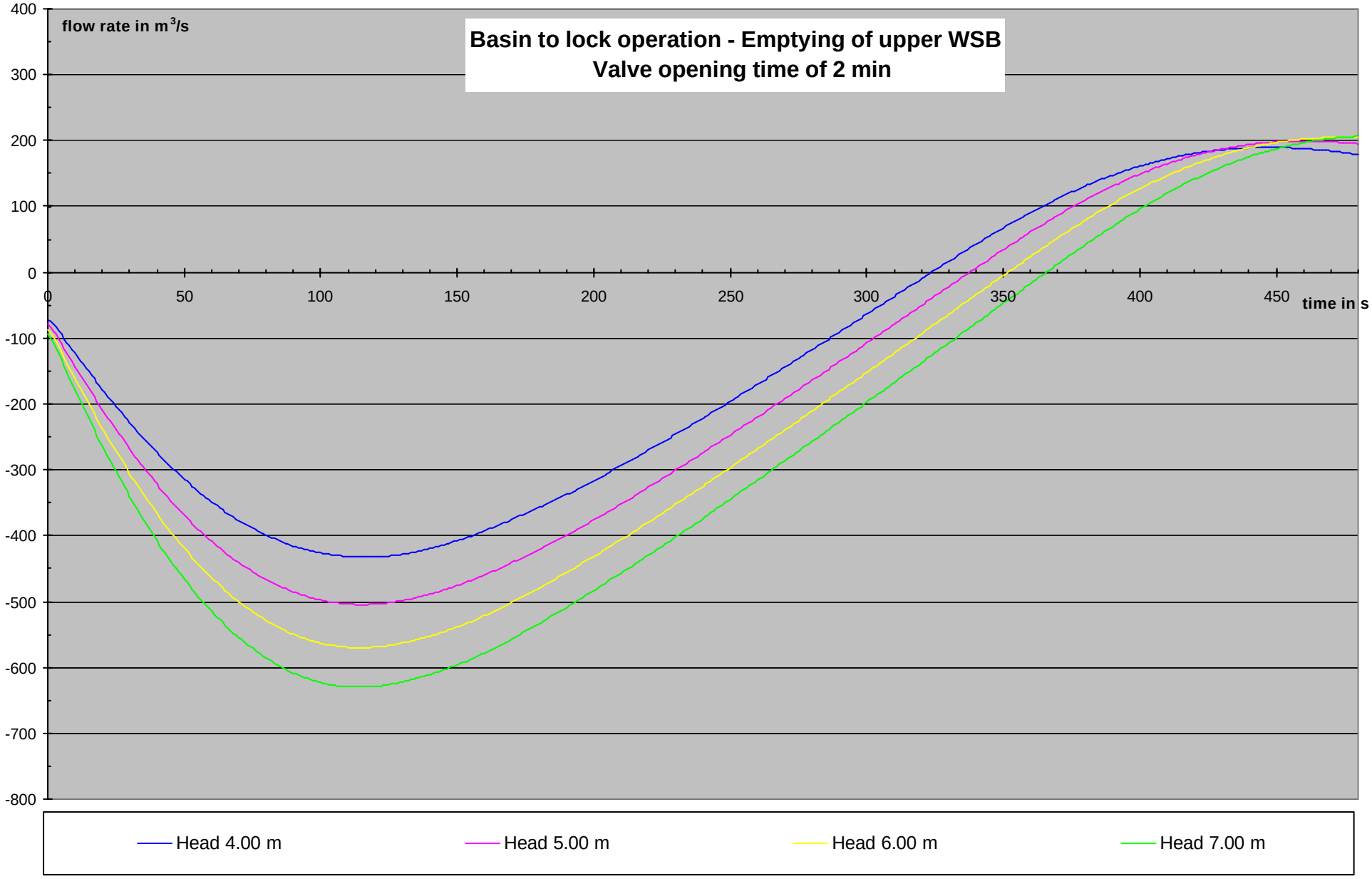
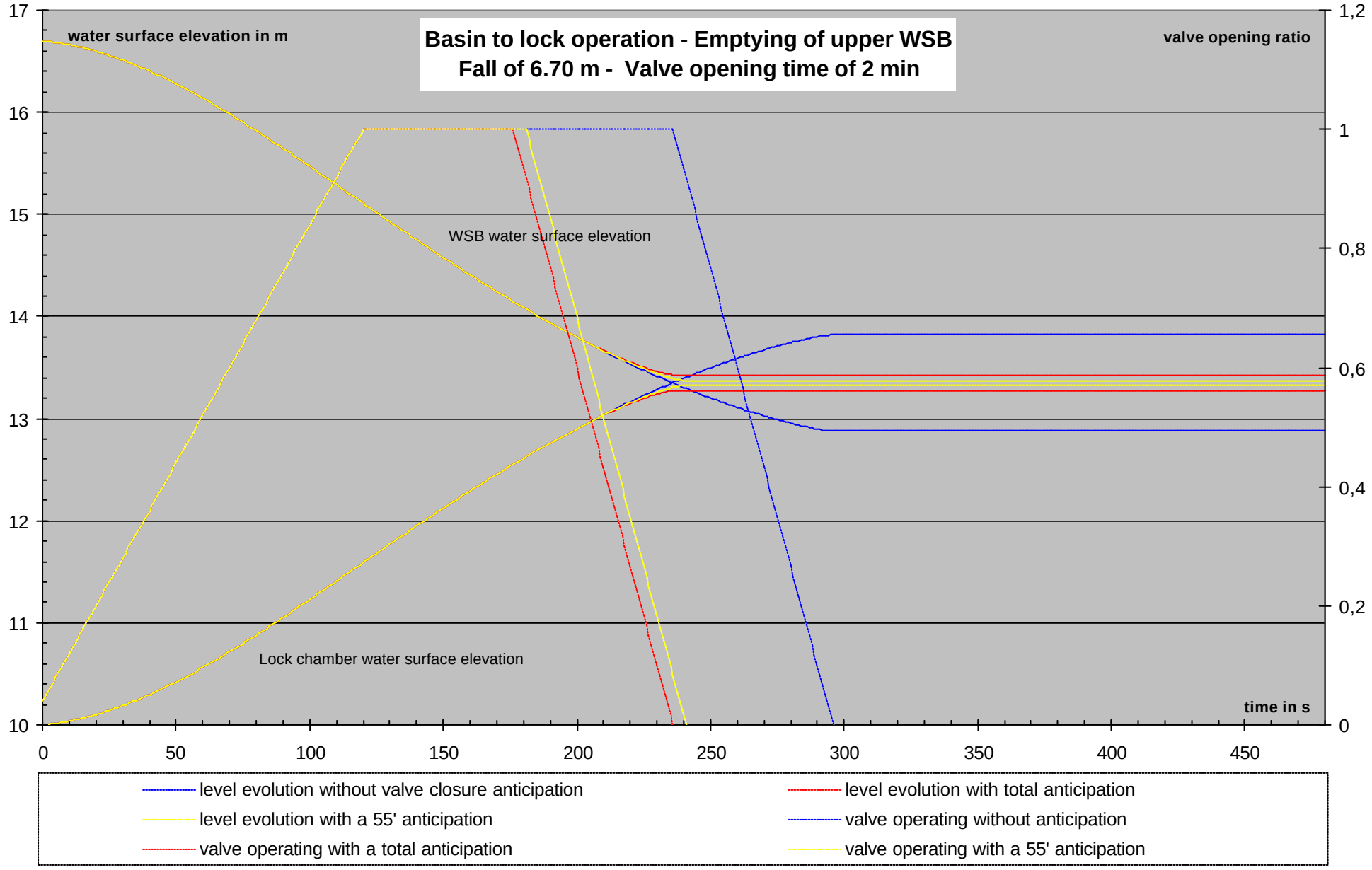
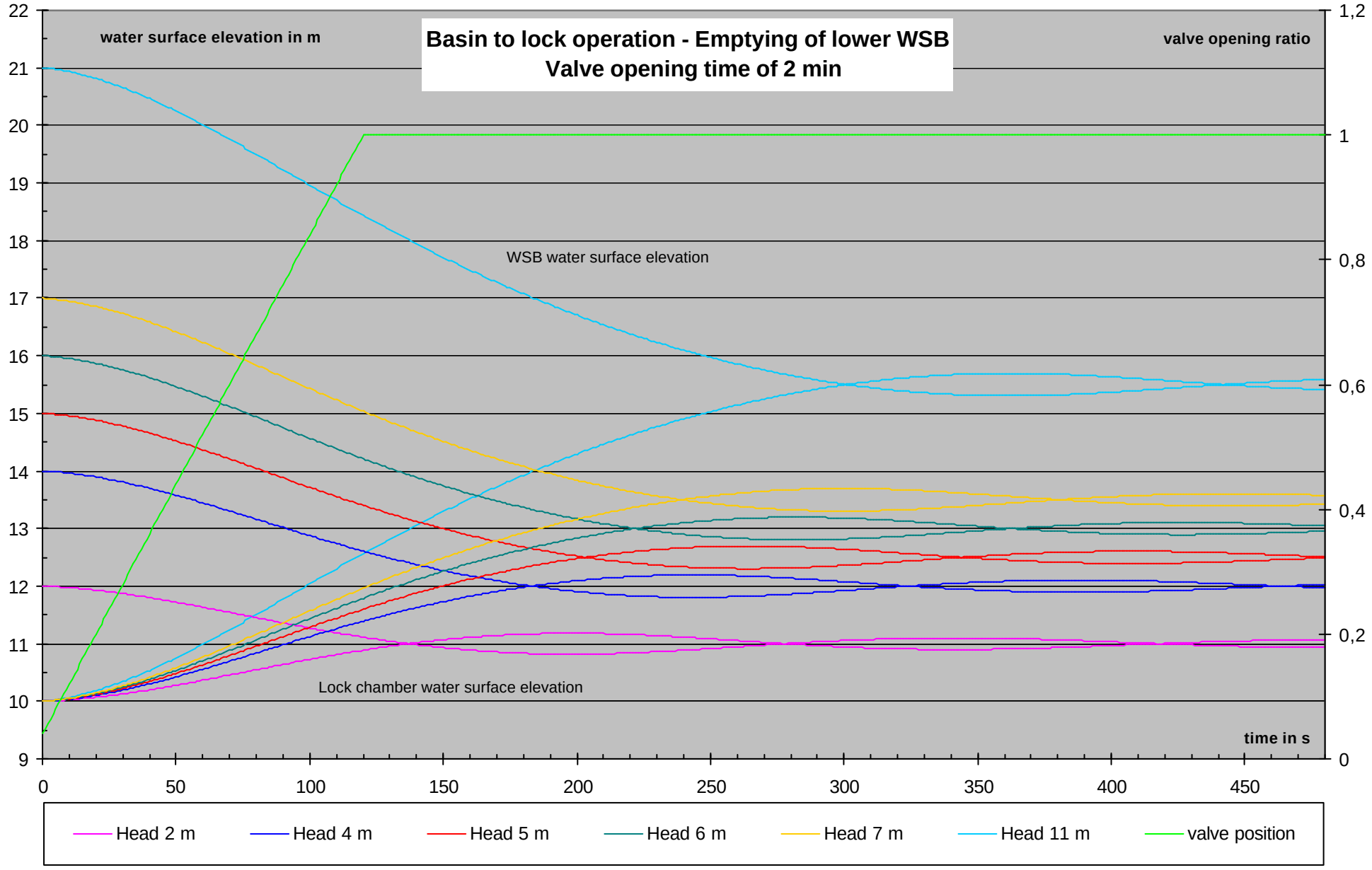


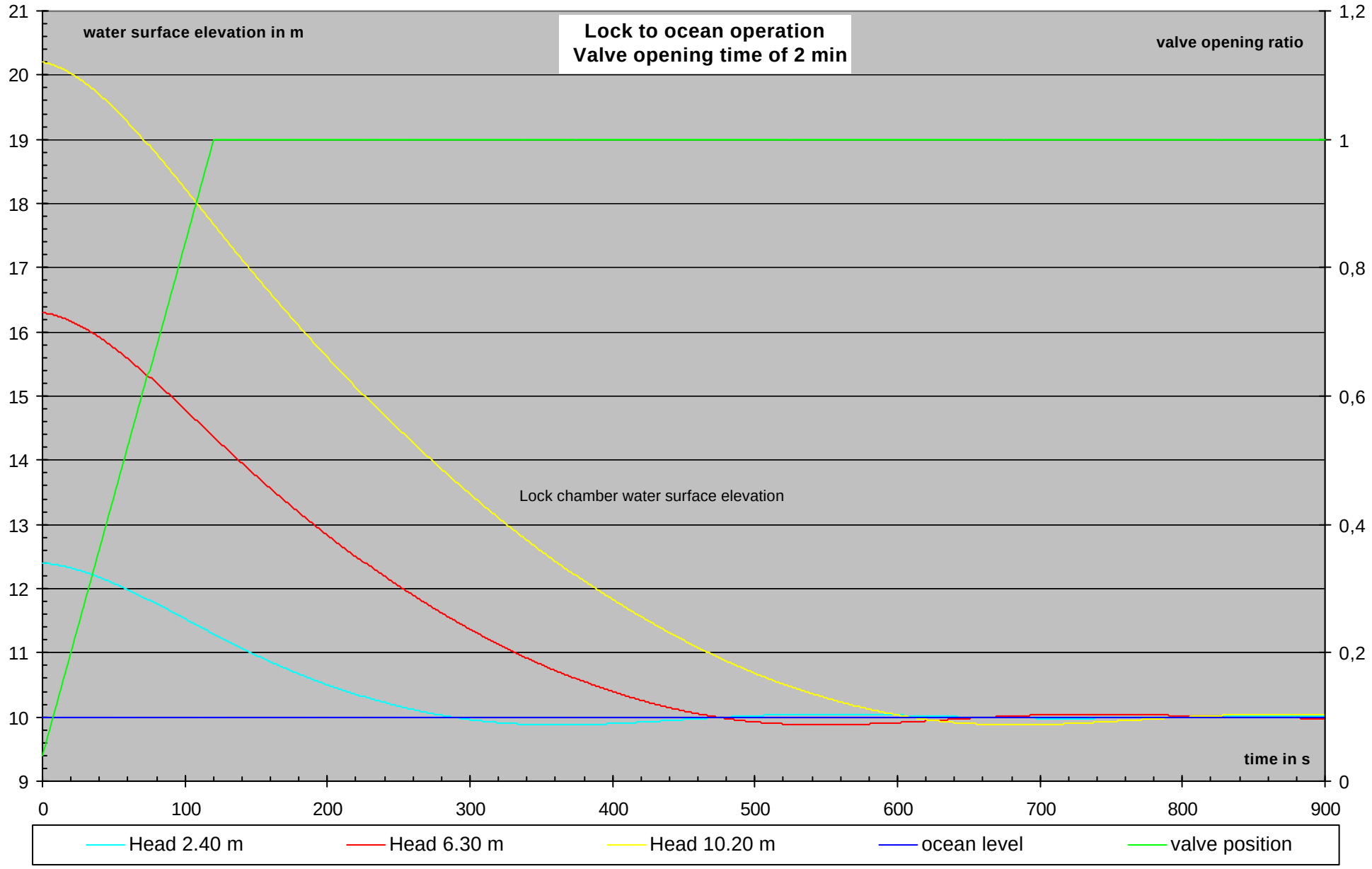
Annex 3-3 (3/4)
Lockage with WSB



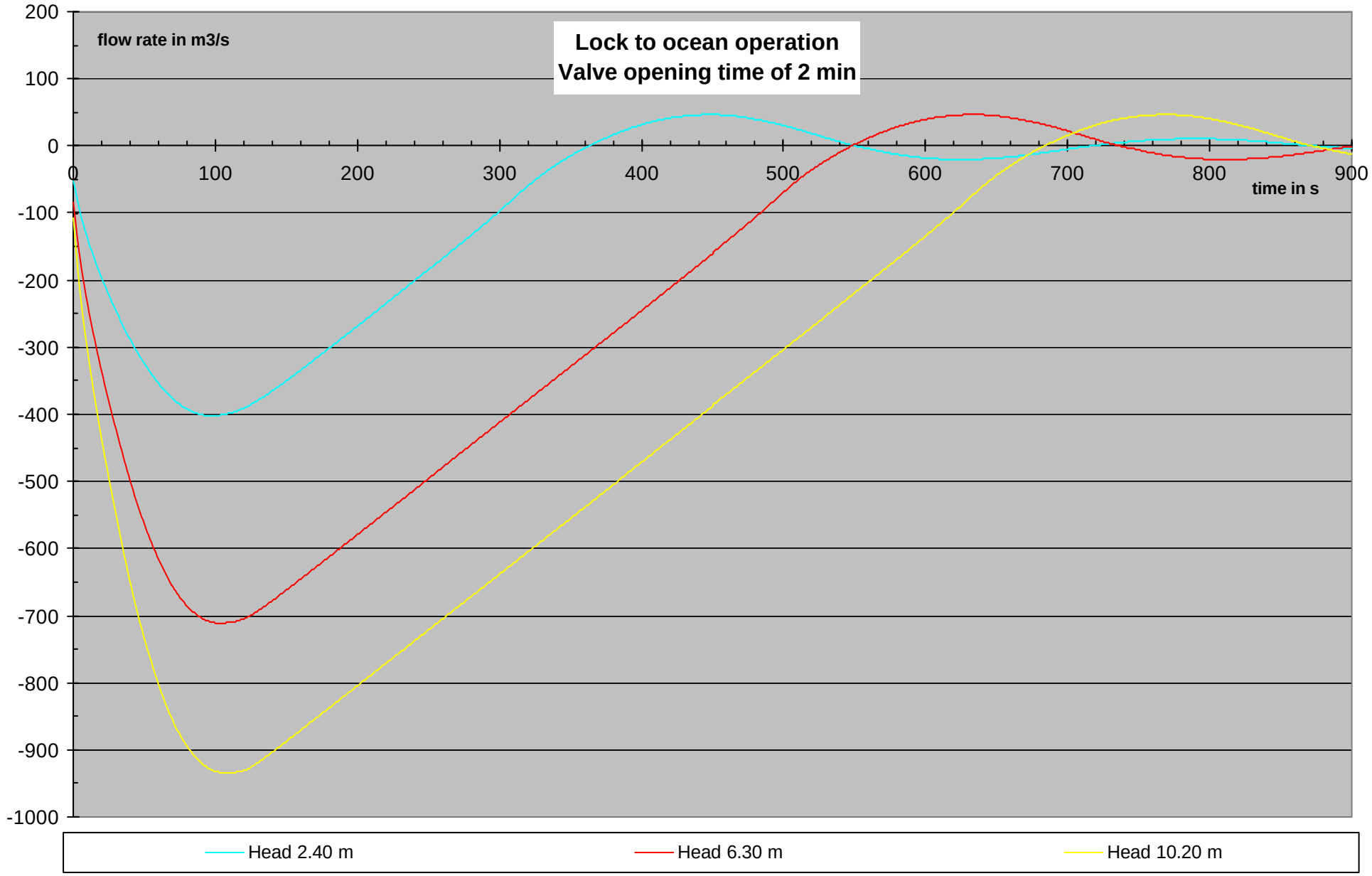
Annex 3-3 (4.4)
Lockage with WSB



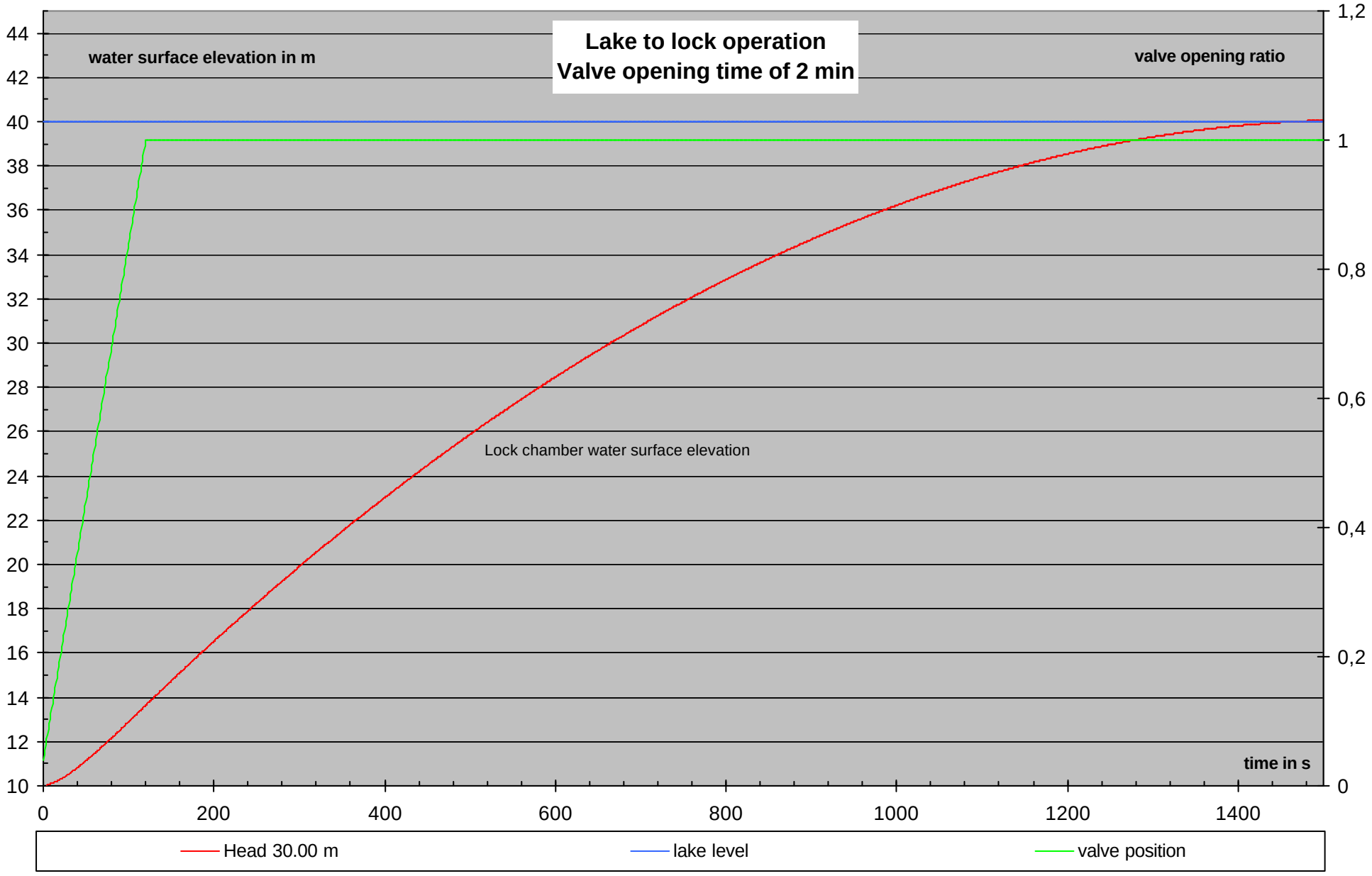
Annex 3-4 (1/2)
Lockage with WSB



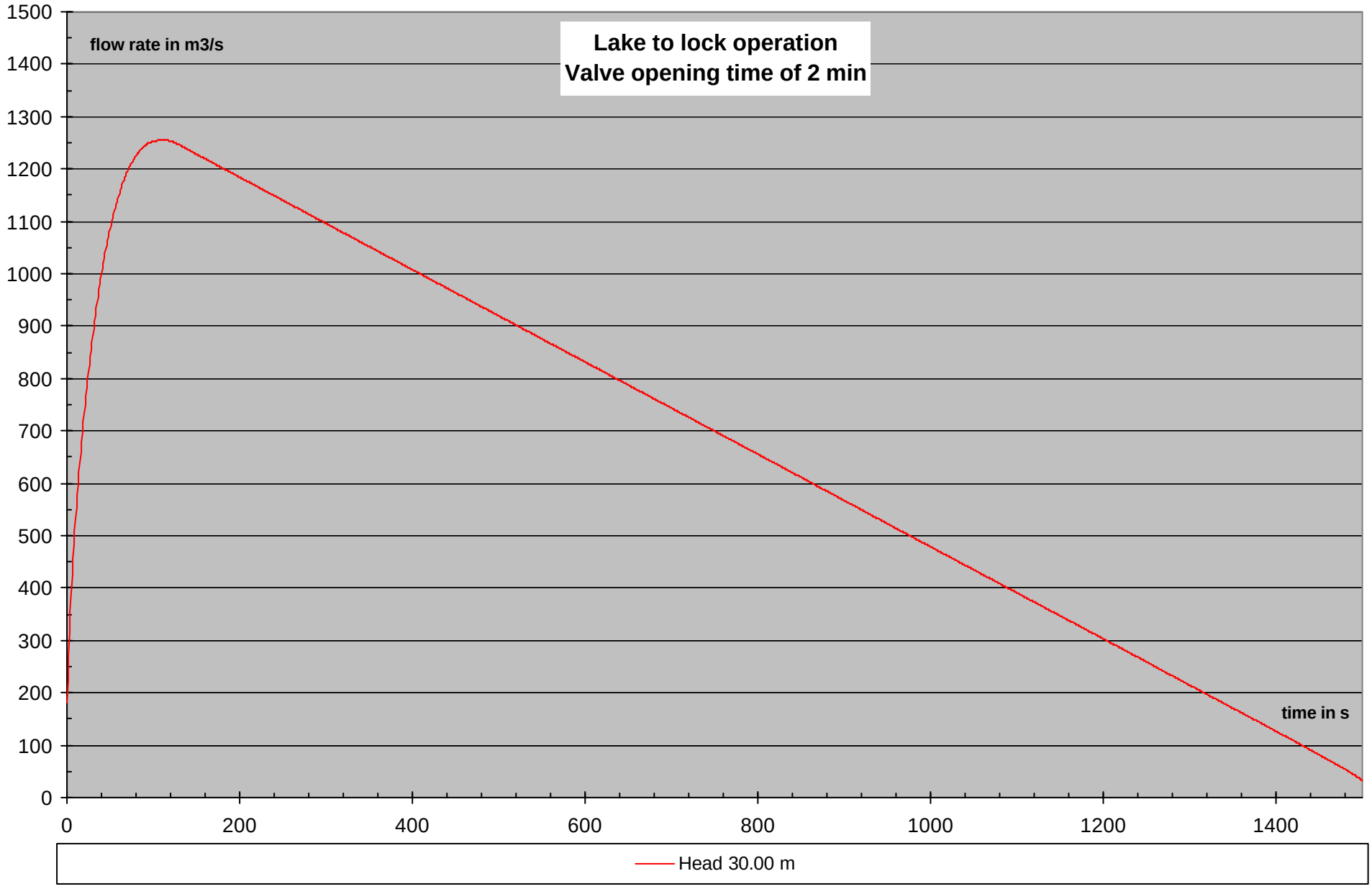
Annex 3-4 (2.2)
Lockage with WSB



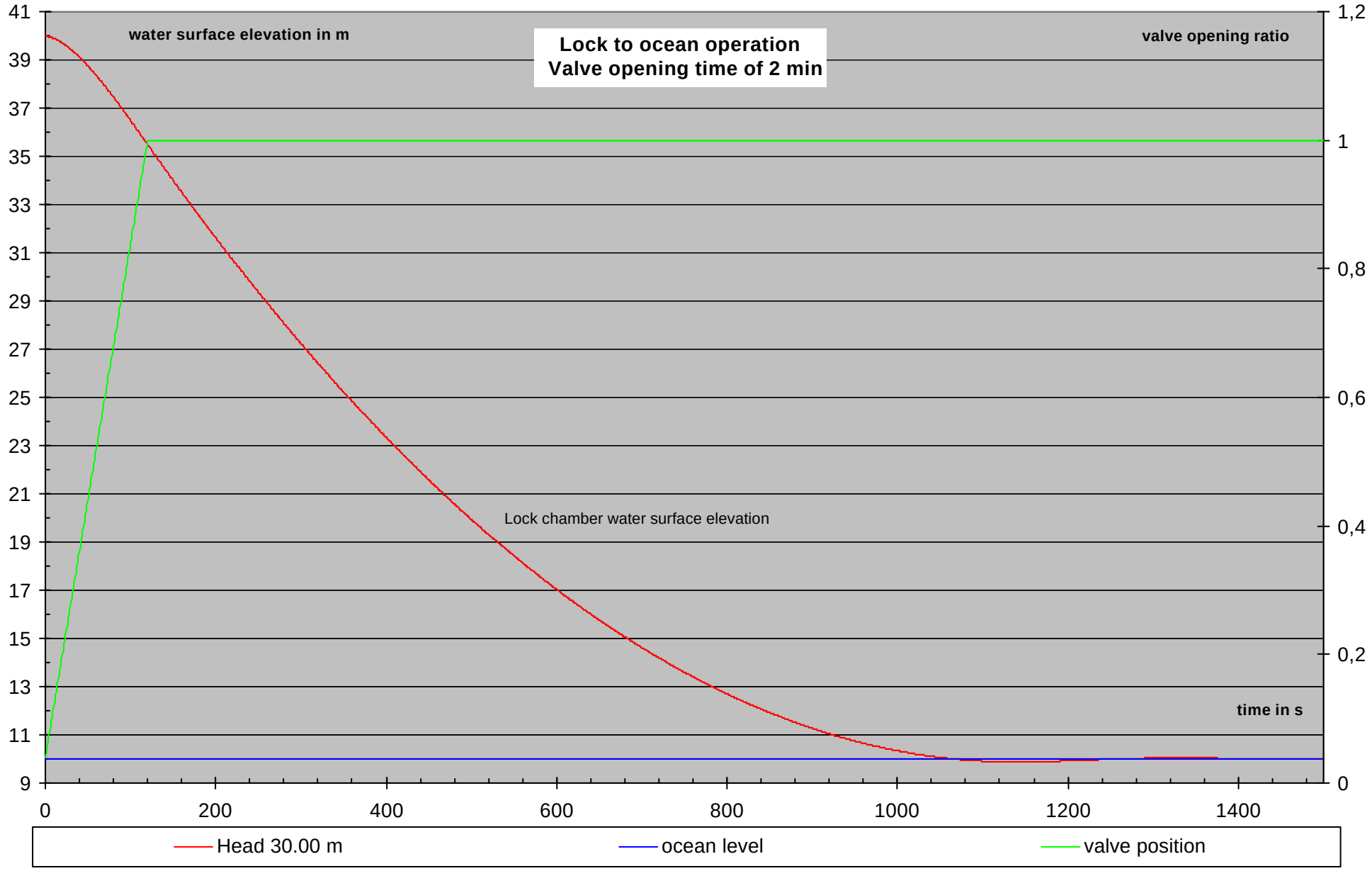
Annex 3-5 (1/4)
Lockage without WSB



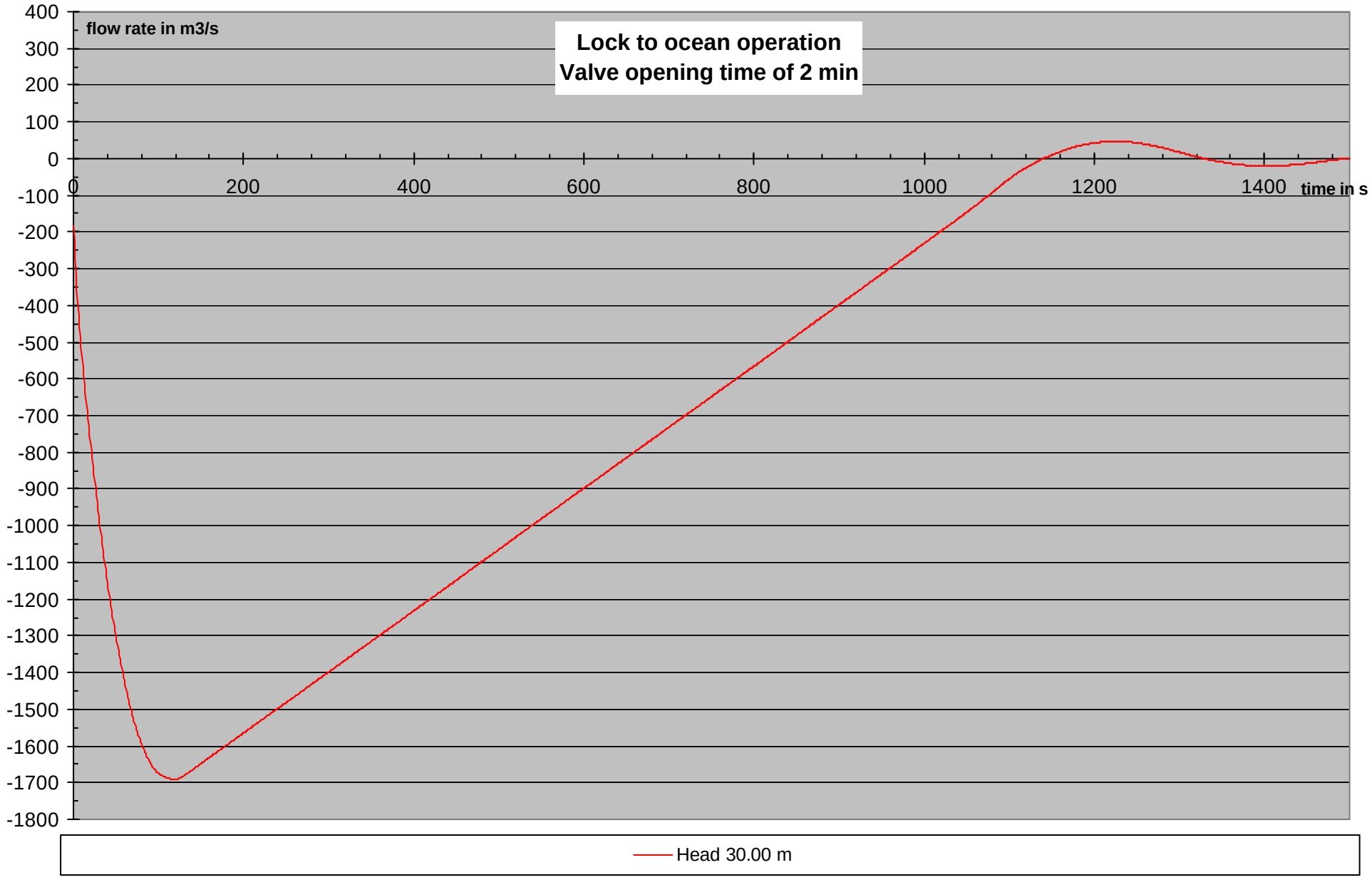
Annex 3-5 (2/4)
Lockage without WSB



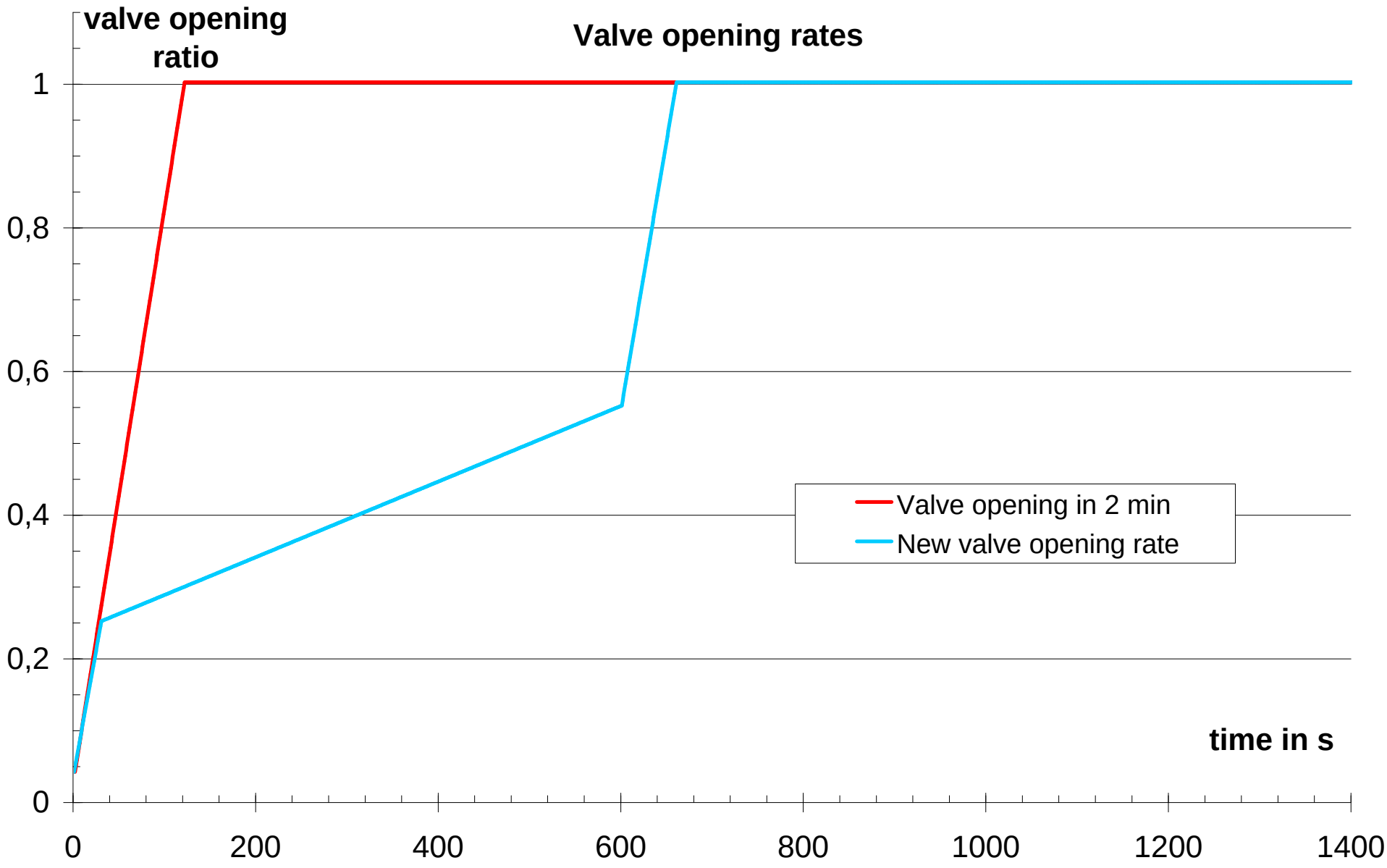
Annex 3-5 (3/4)
Lockage without WSB



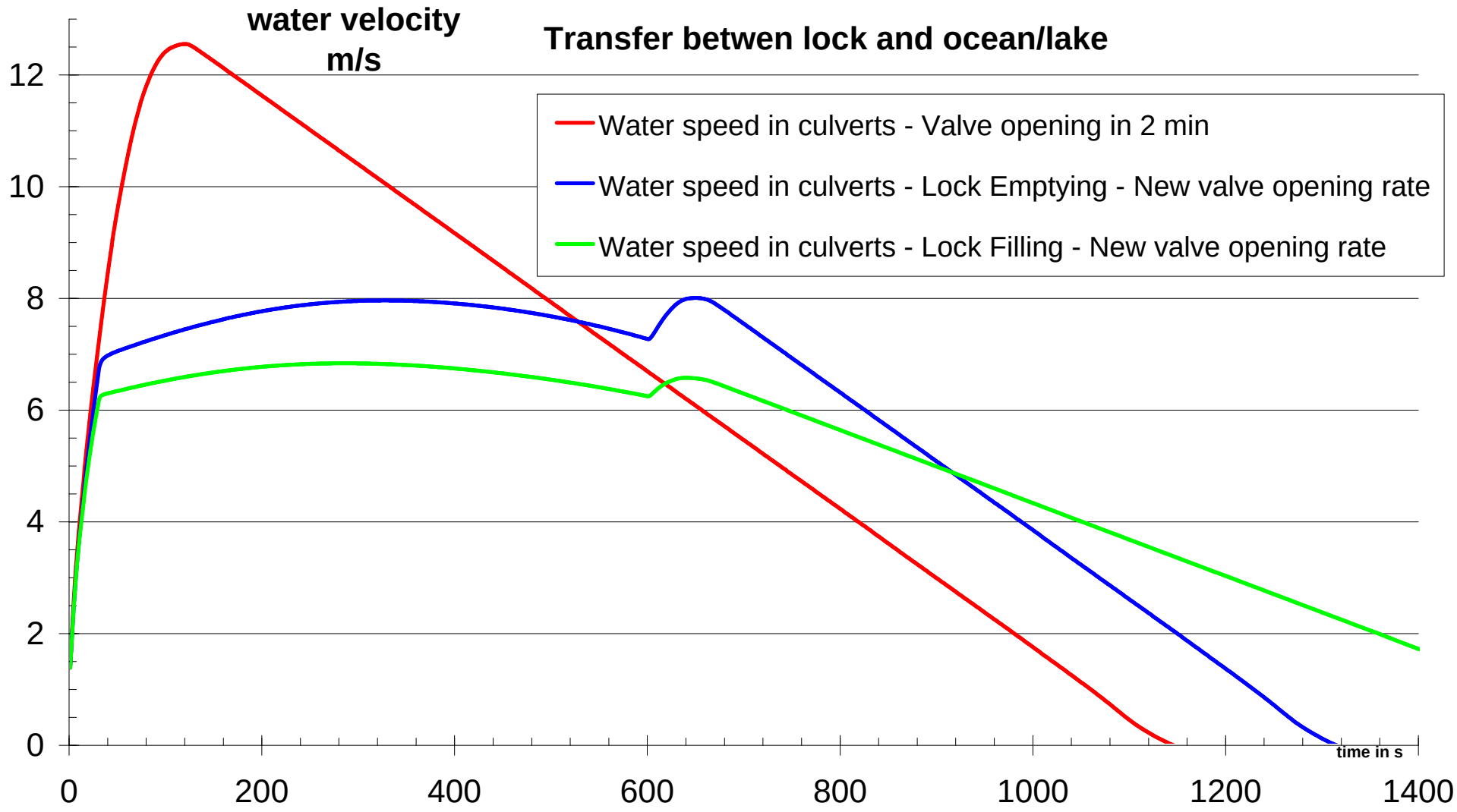
Annex 3-5 4.4
Lockage without WSB



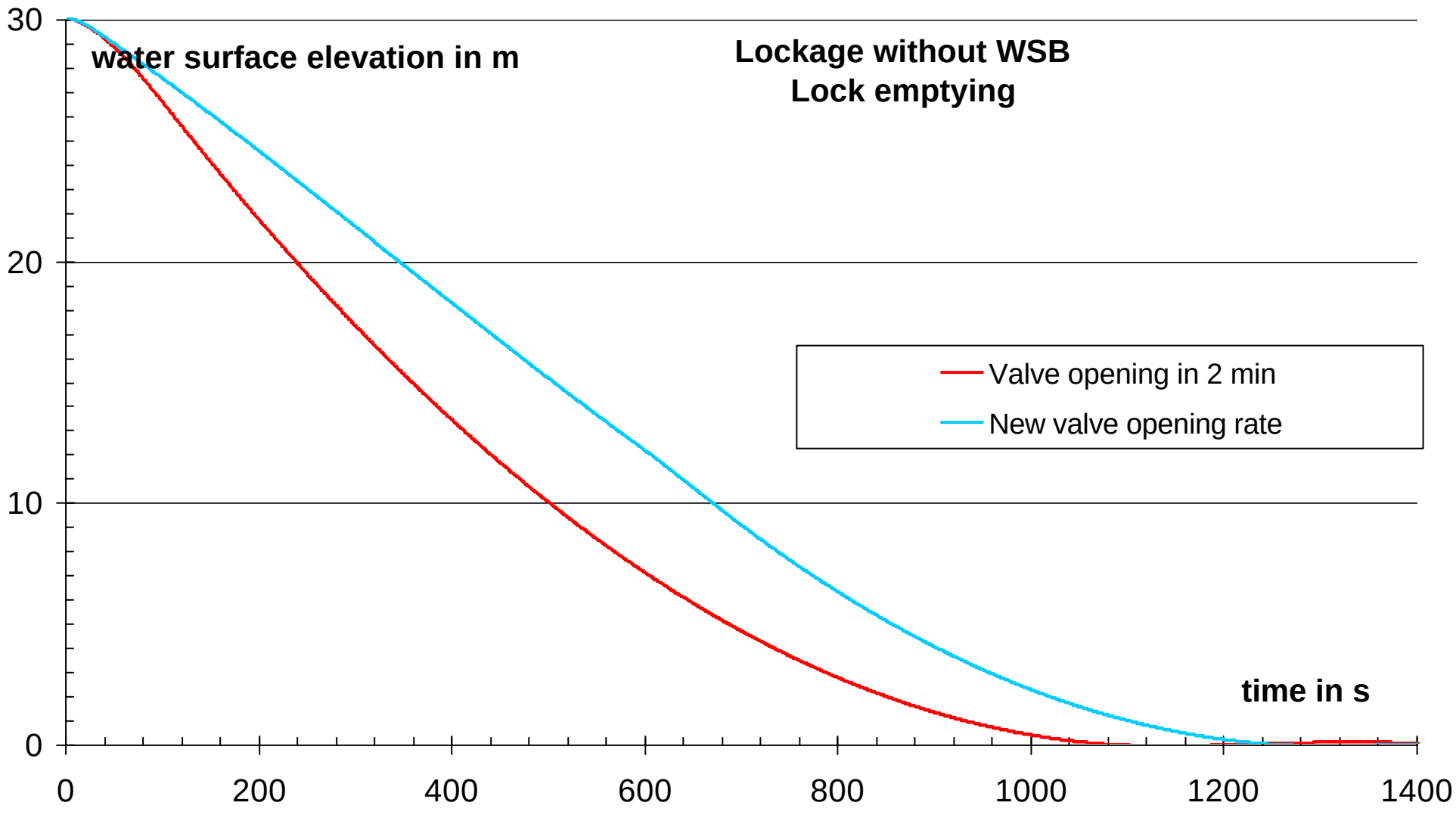
Annex 3-6 1/4
Lockage without WSB



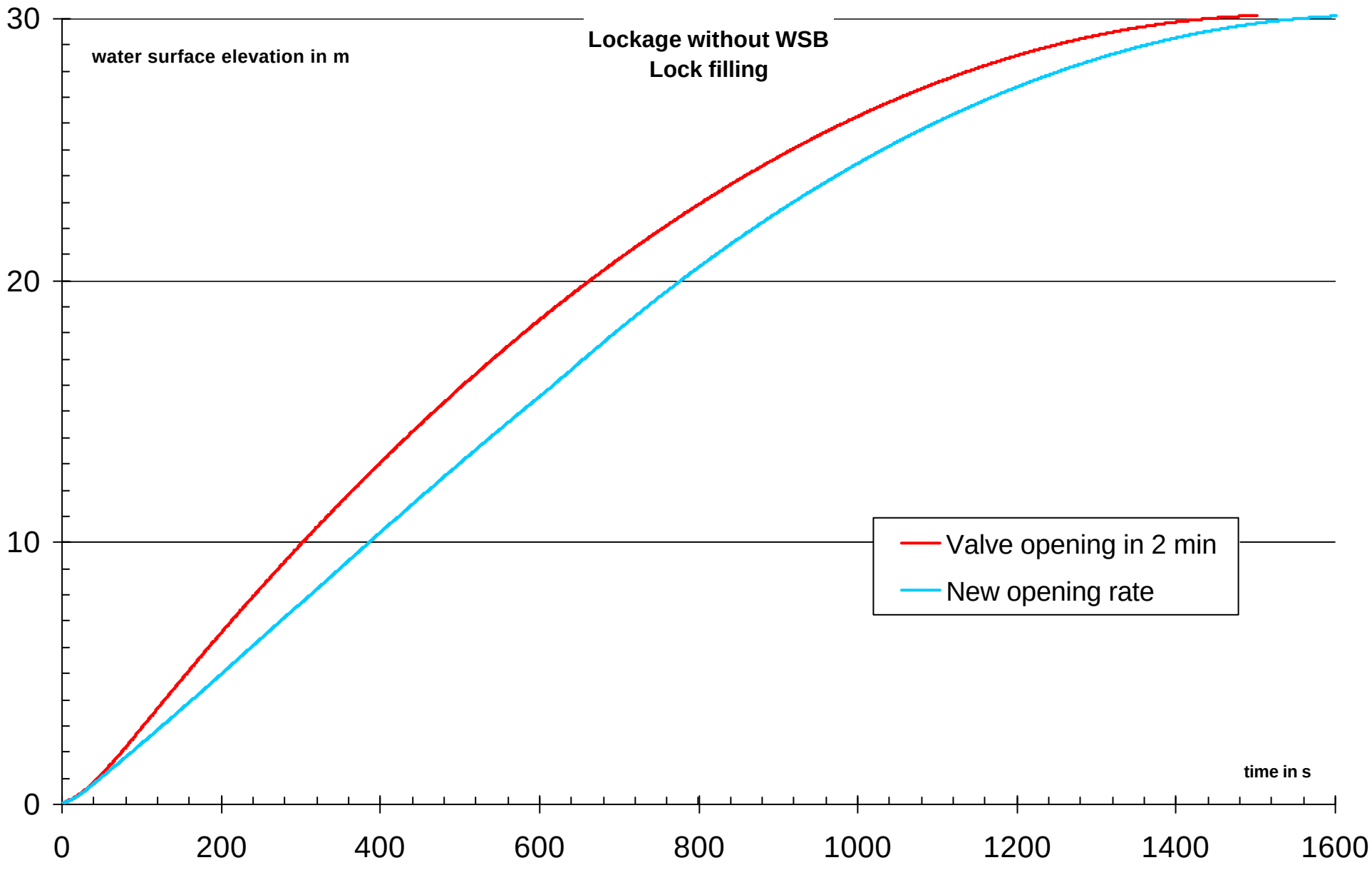
Annex 3-6 2/4
Lockage without WSB



Annex 3-6 3/4
Lockage without WSB

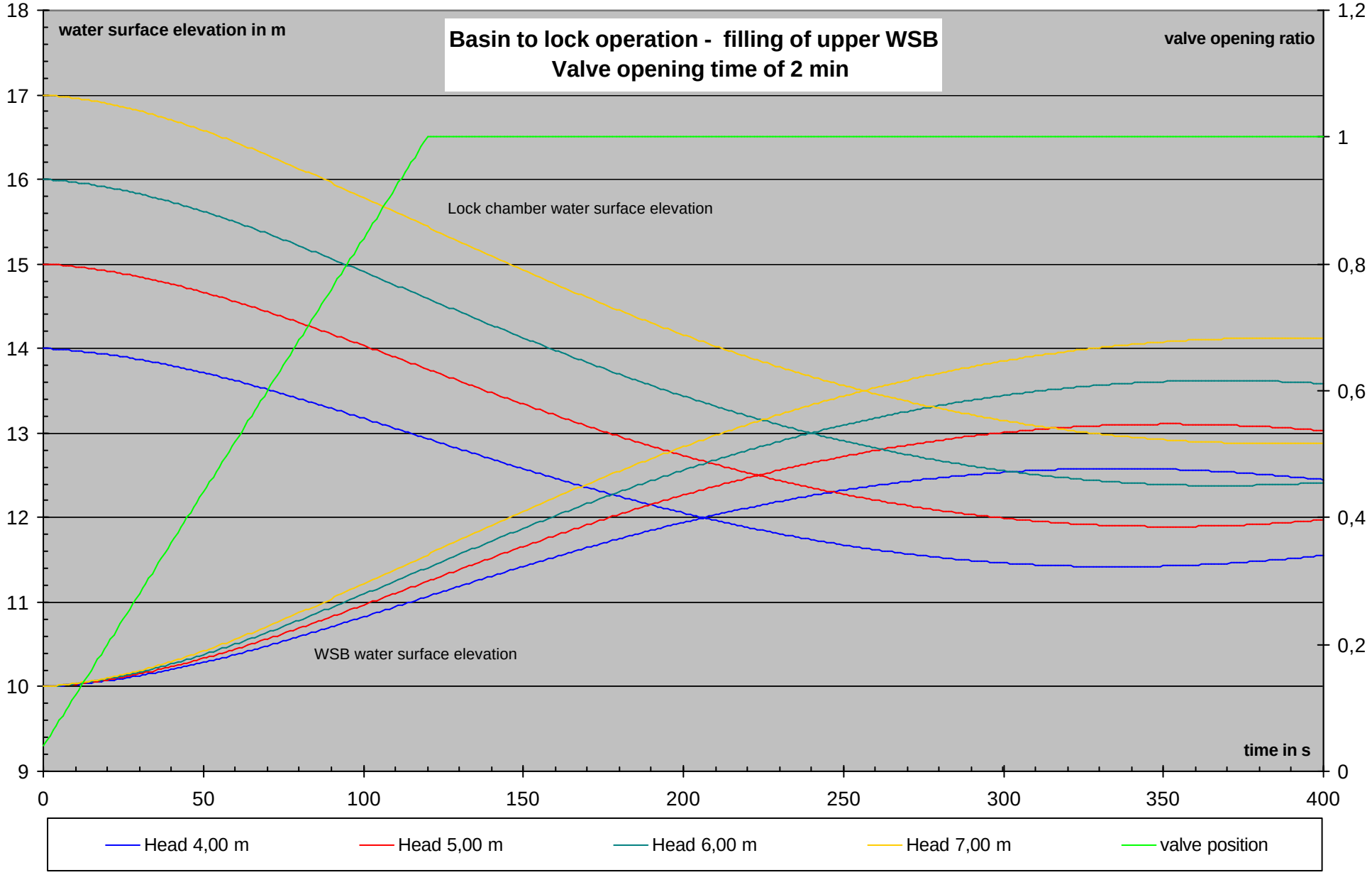


Annex 3-6 4/4
Lockage without WSB

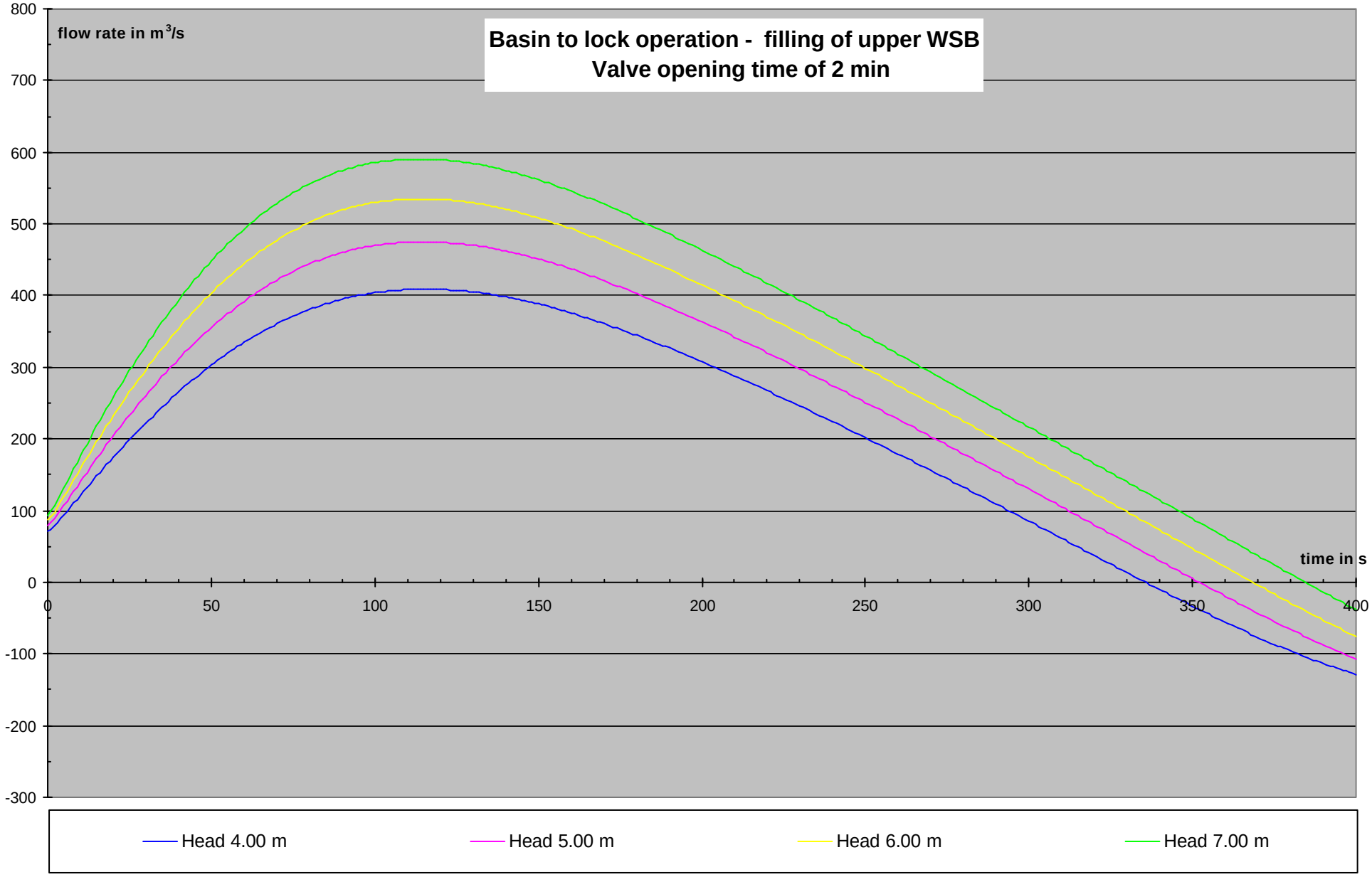


ANNEX 4

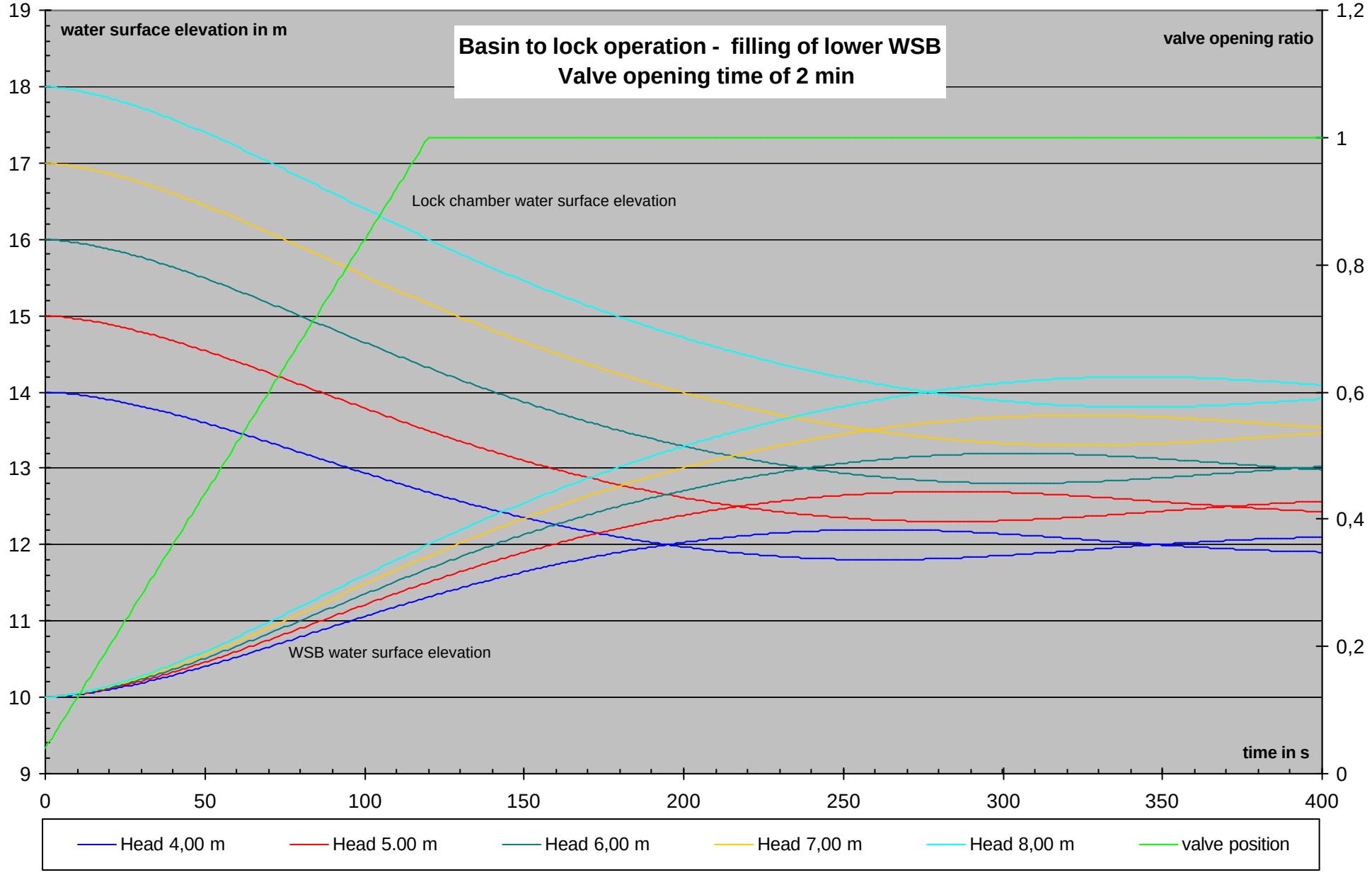
Annex 4-1 (1/3)
Lockage with WSB



Annex 4-1 (2/3)
Lockage with WSB



Annex 4-1 (3/3)
Lockage with WSB



Annex 4-2 (1/2)
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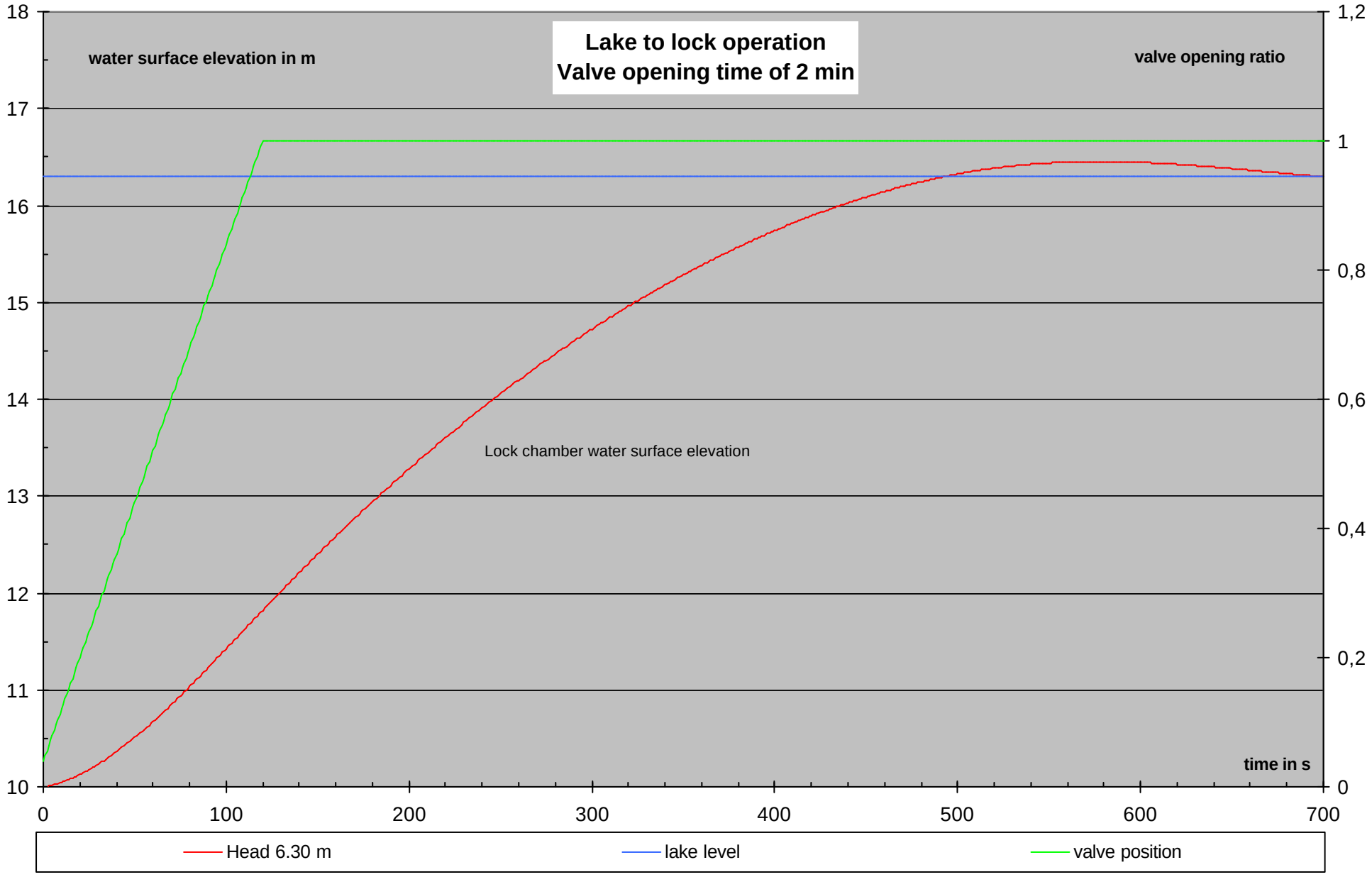
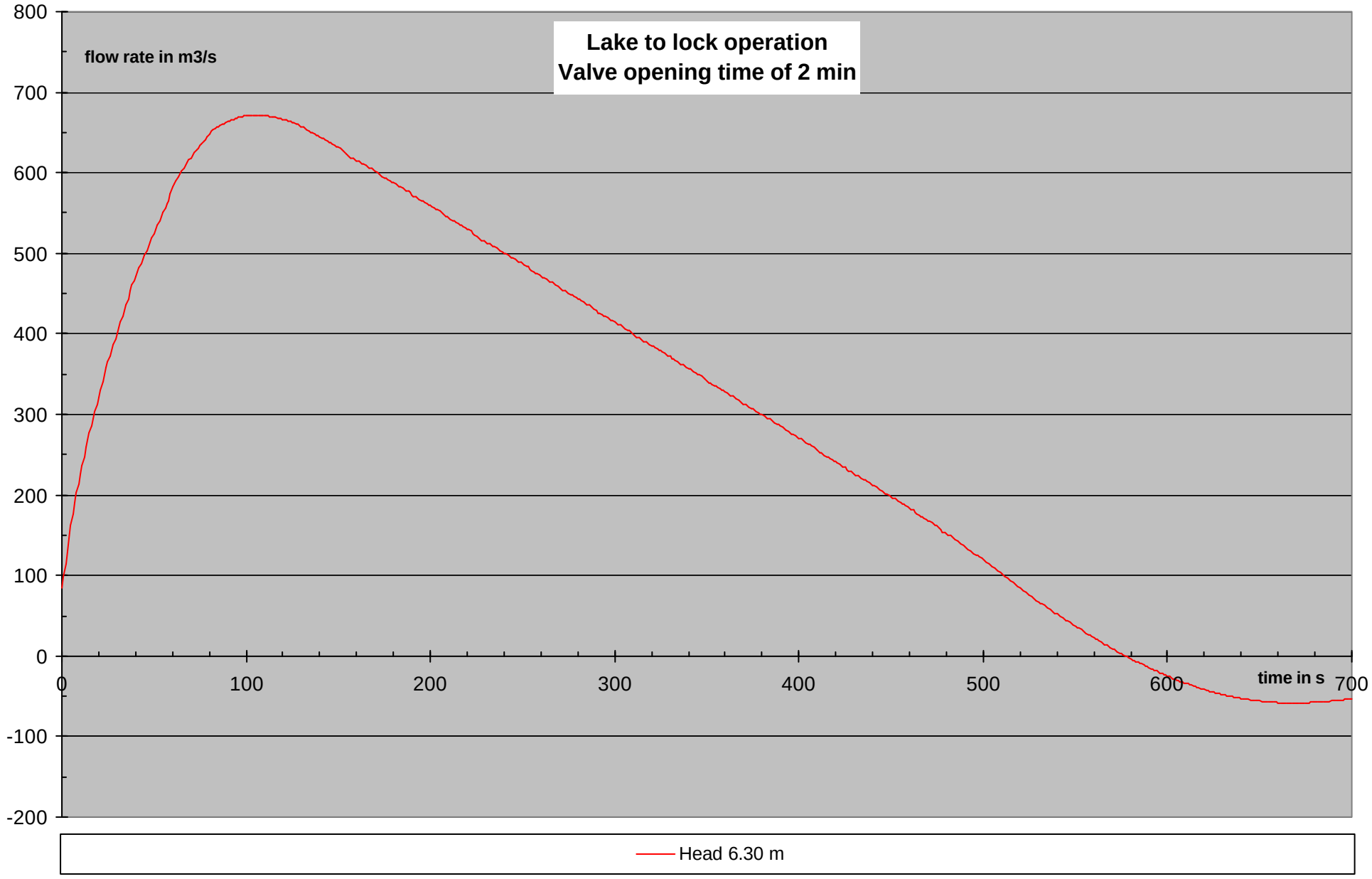


Annex 4-2 (2/2)
Lockage with WSB



Annex 4-3 (1/4)
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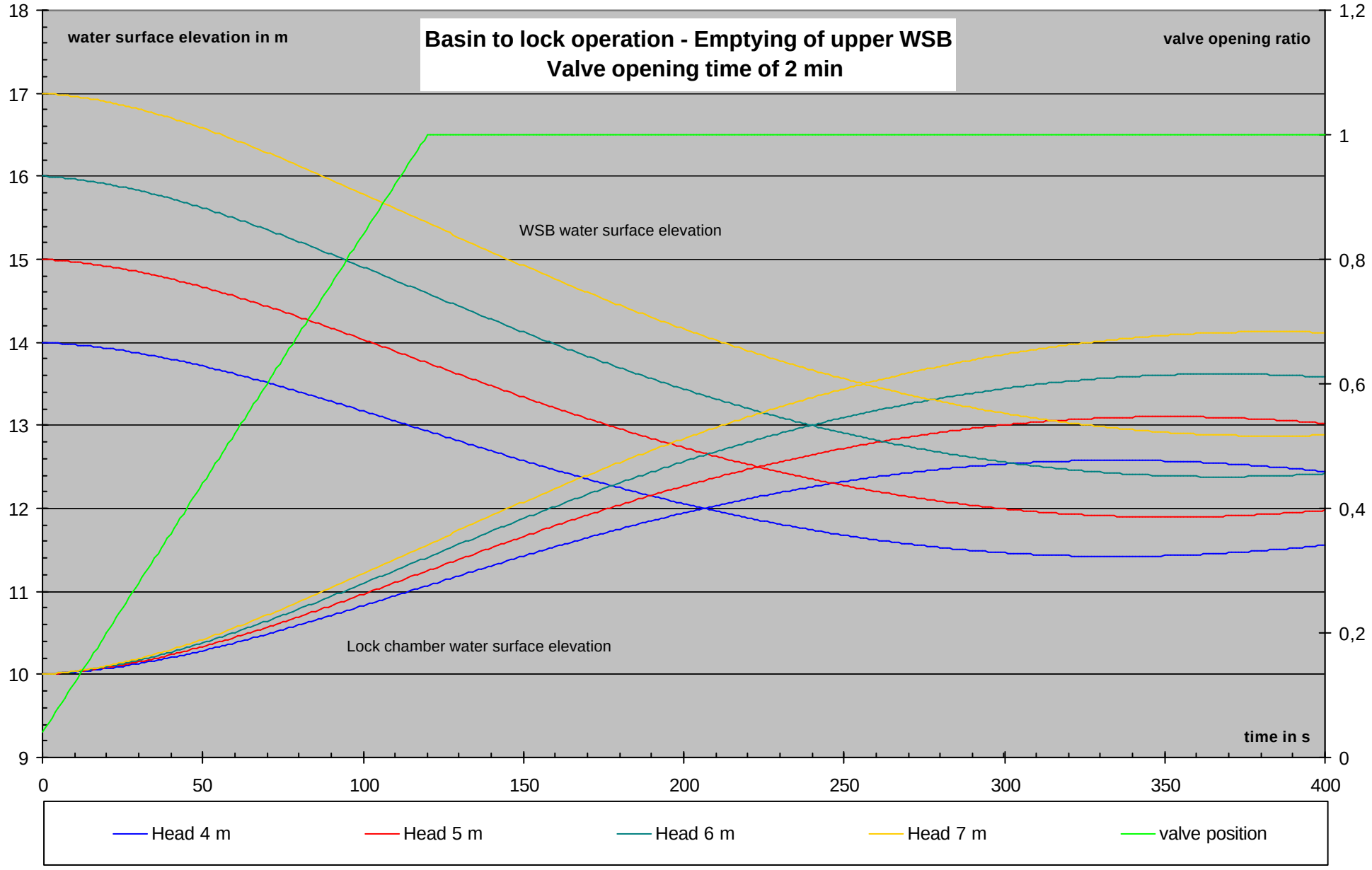

Annex 4-3 (2/4)
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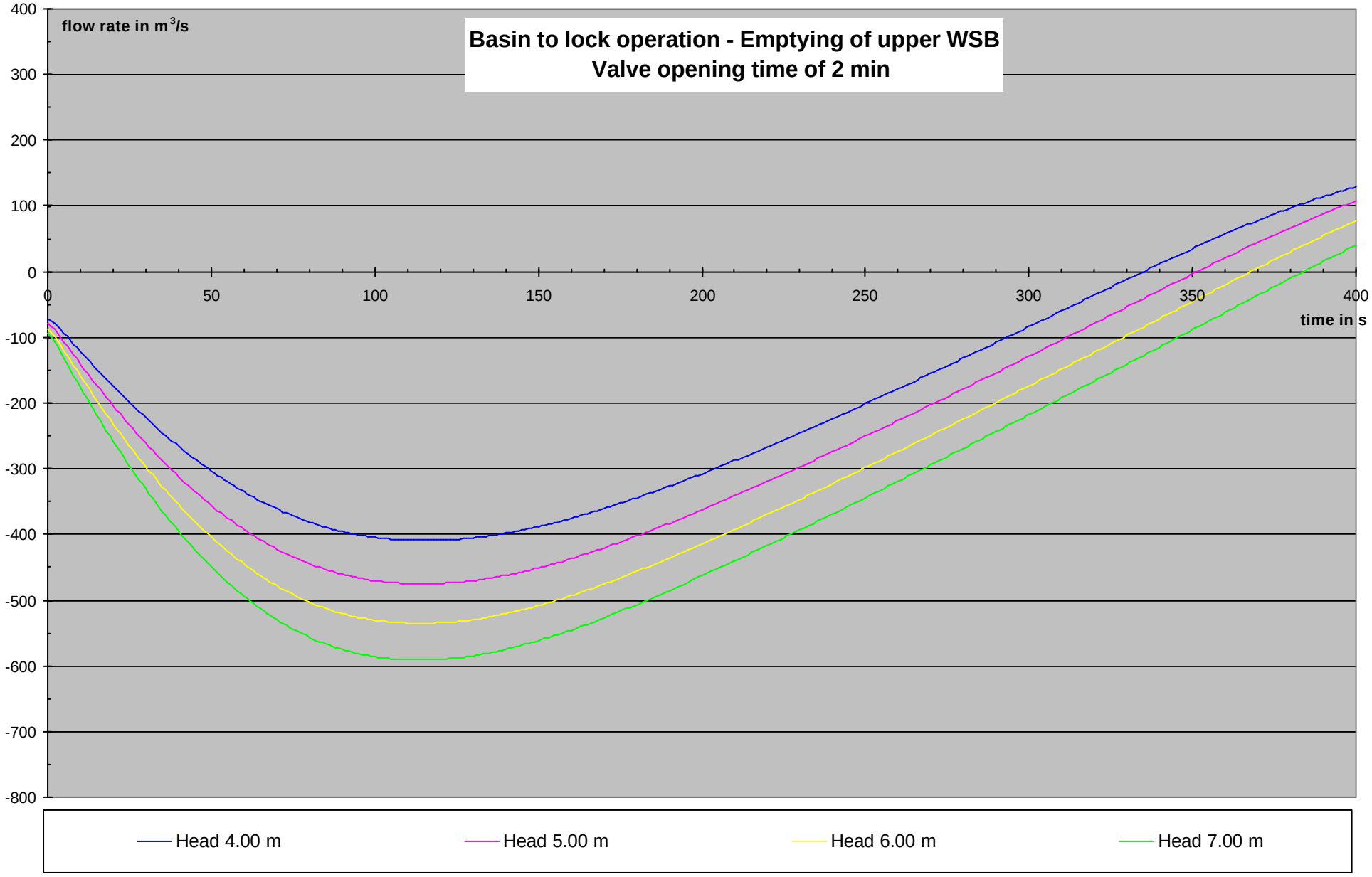
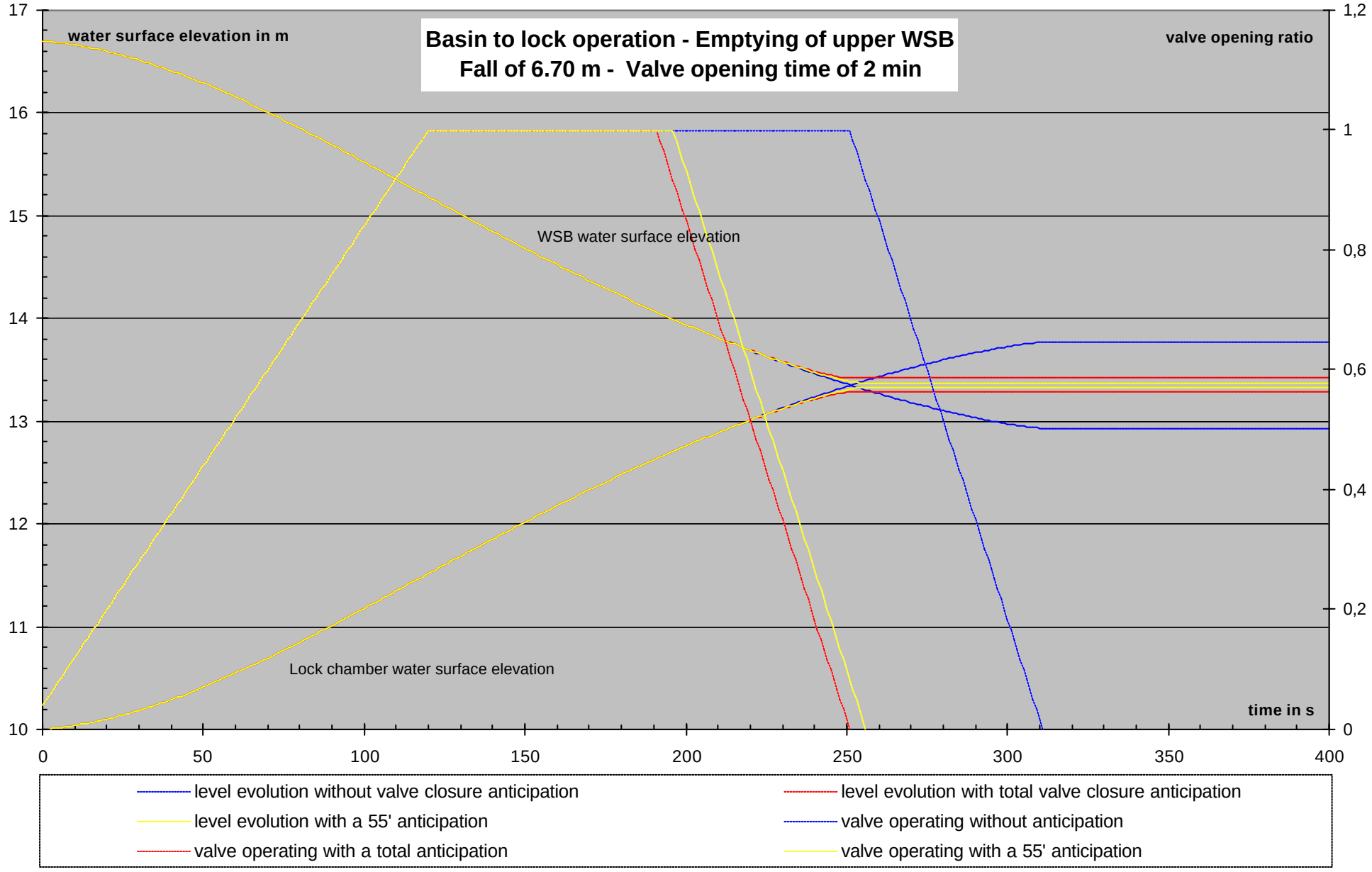
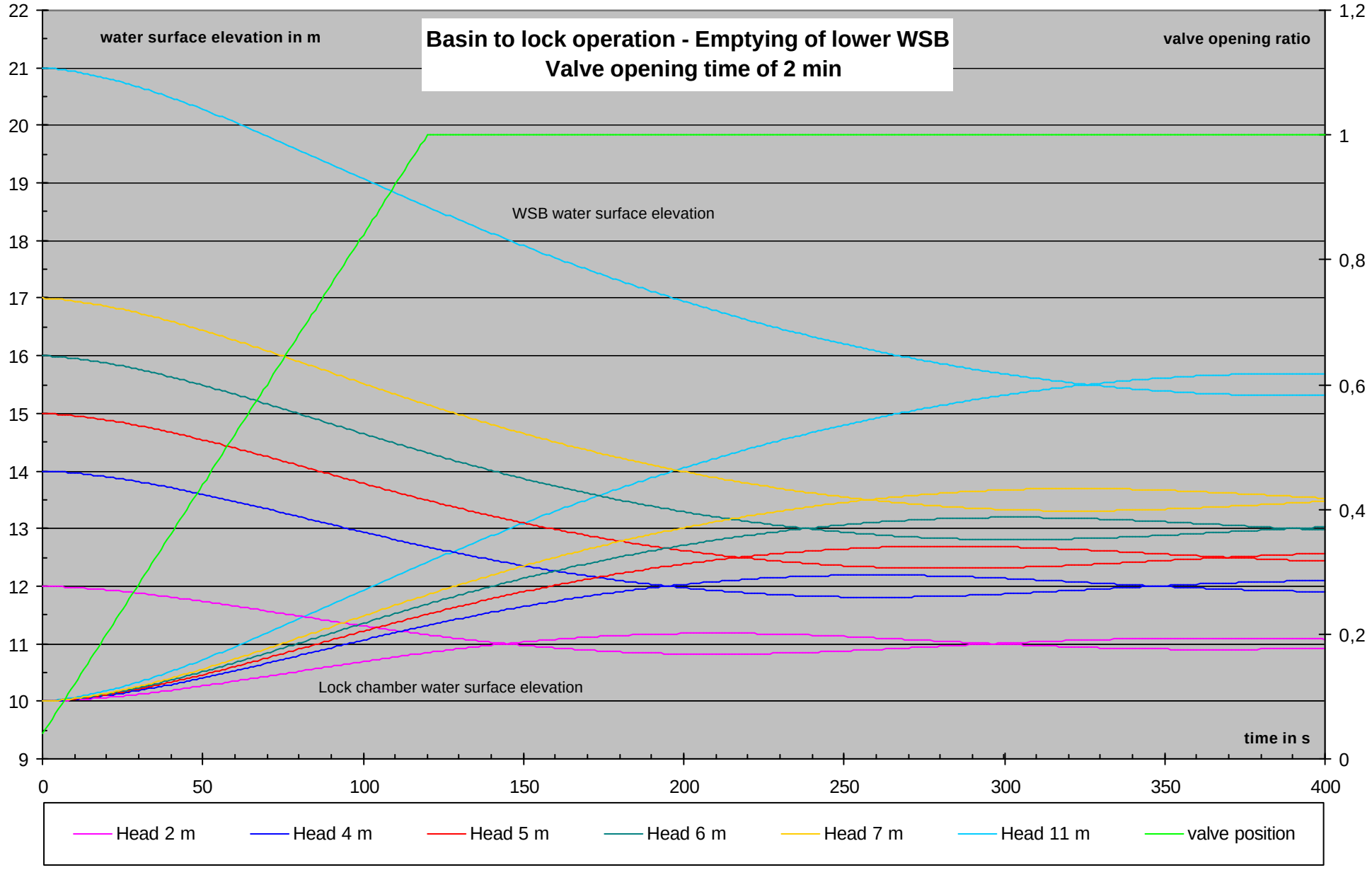


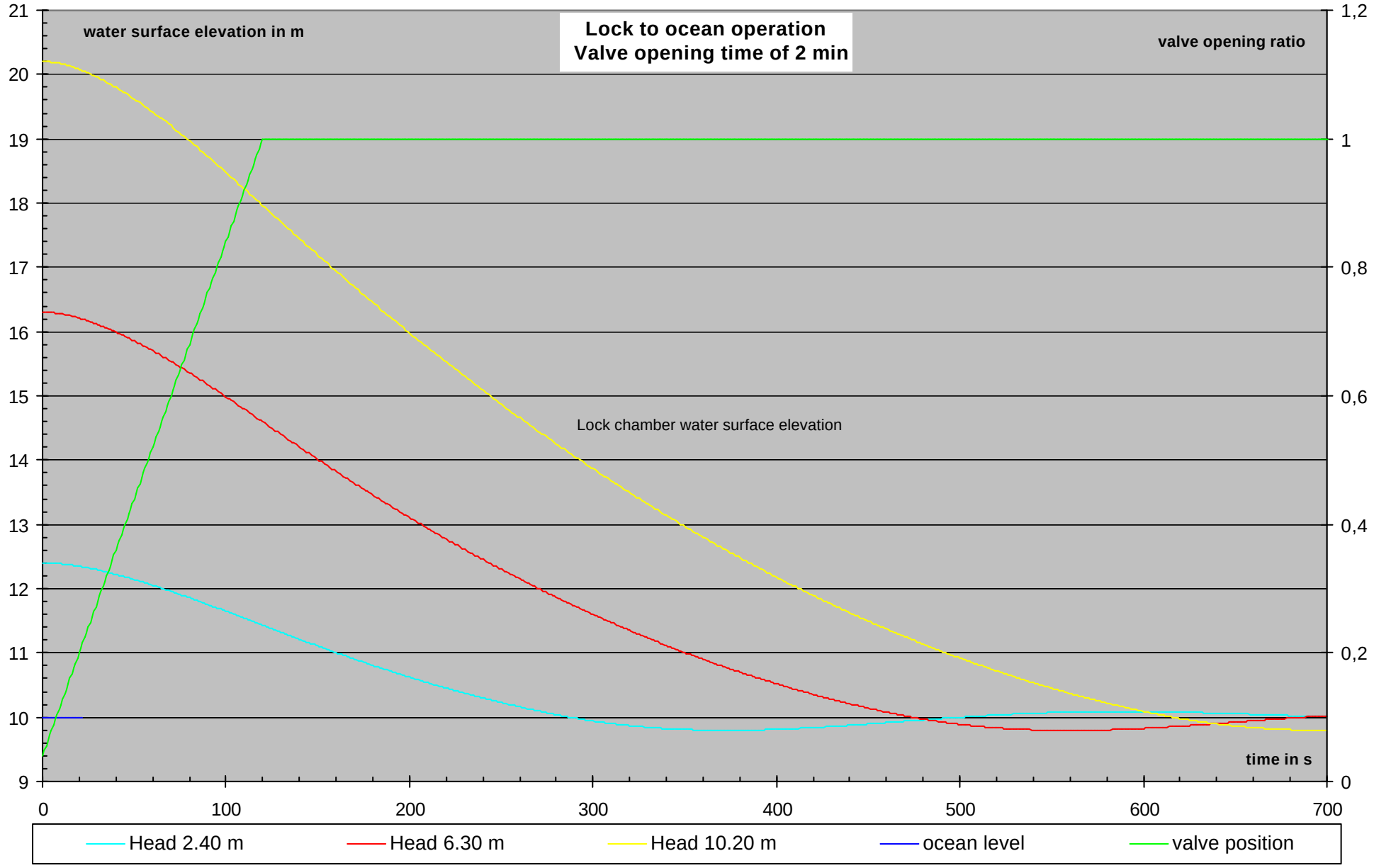
Annex 4-3 (3/4)
Lockage with WSB



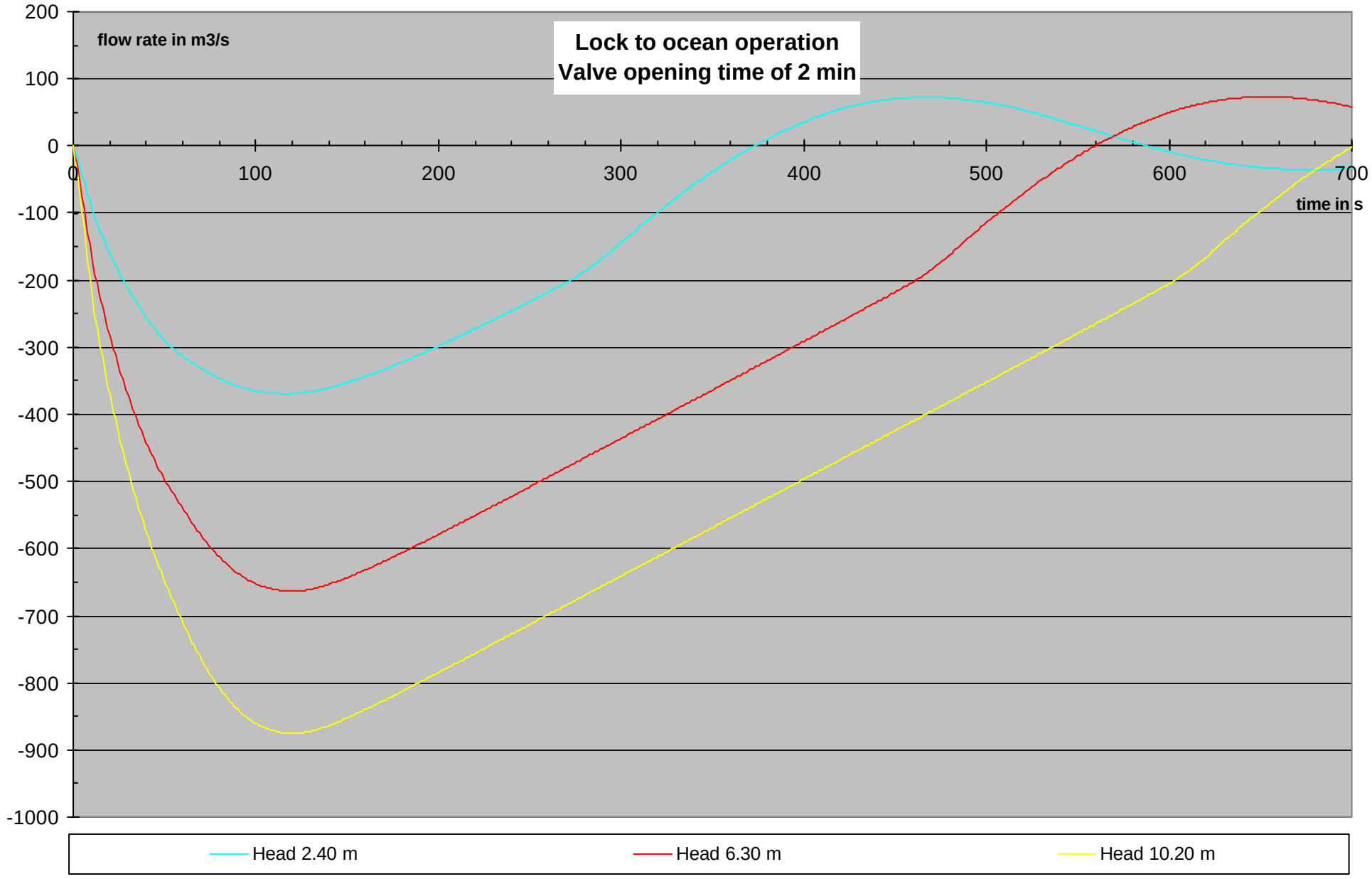
Annex 4-3 (4/4)
Lockage with WSB



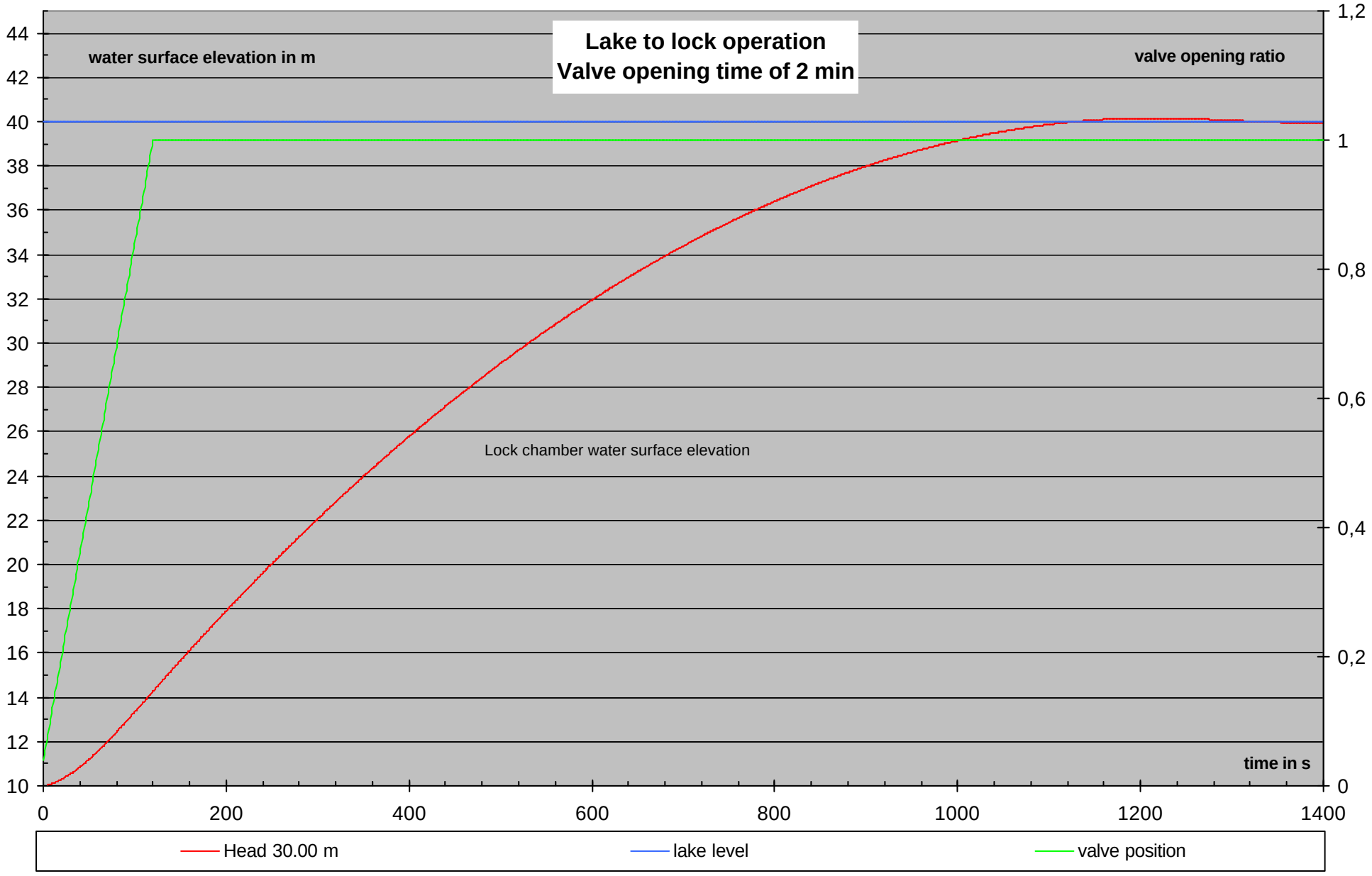
Annex 4-4 (1/2)
Lockage with WSB



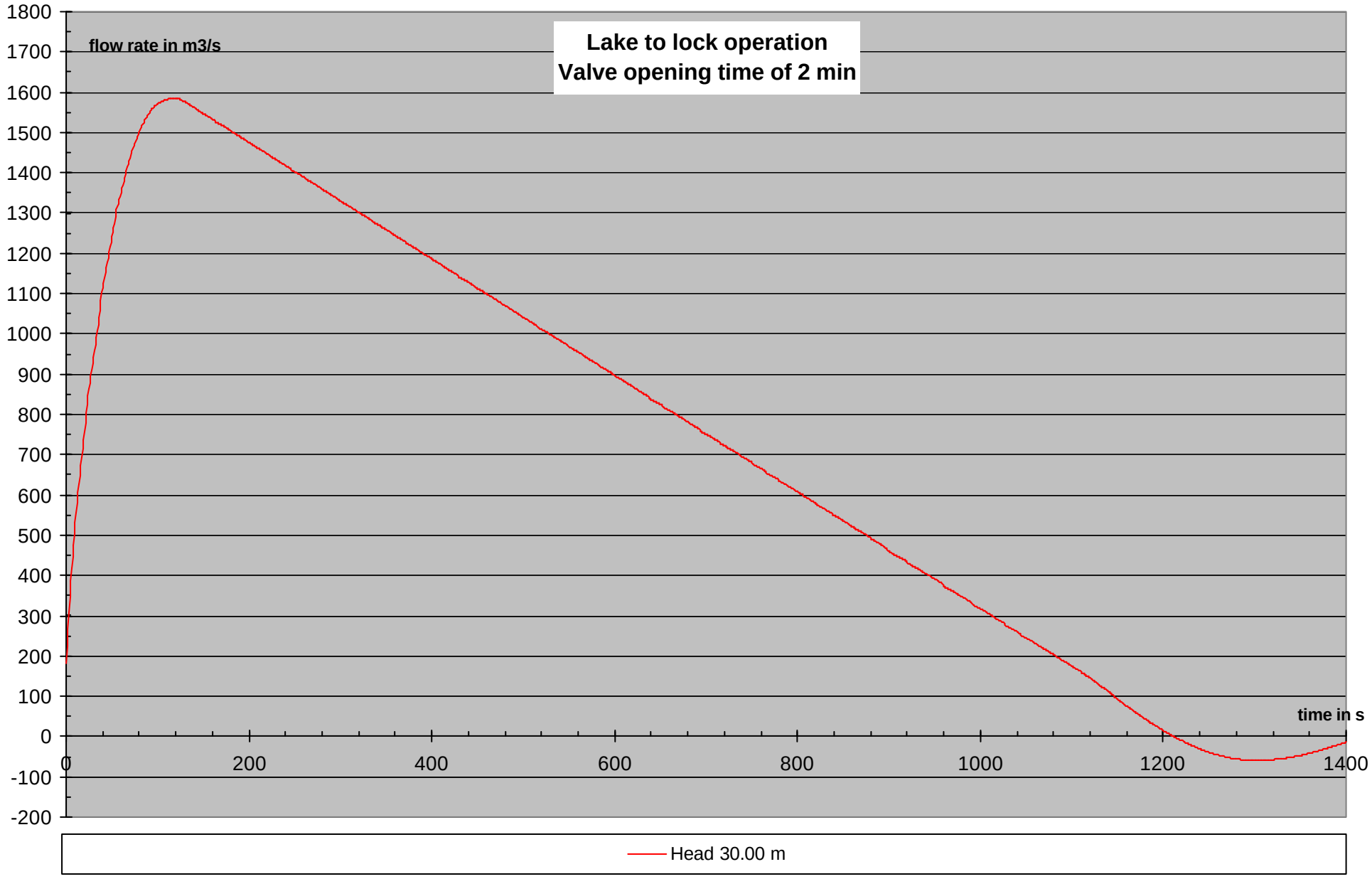
Annex 4-4 (2/2)
Lockage with WSB



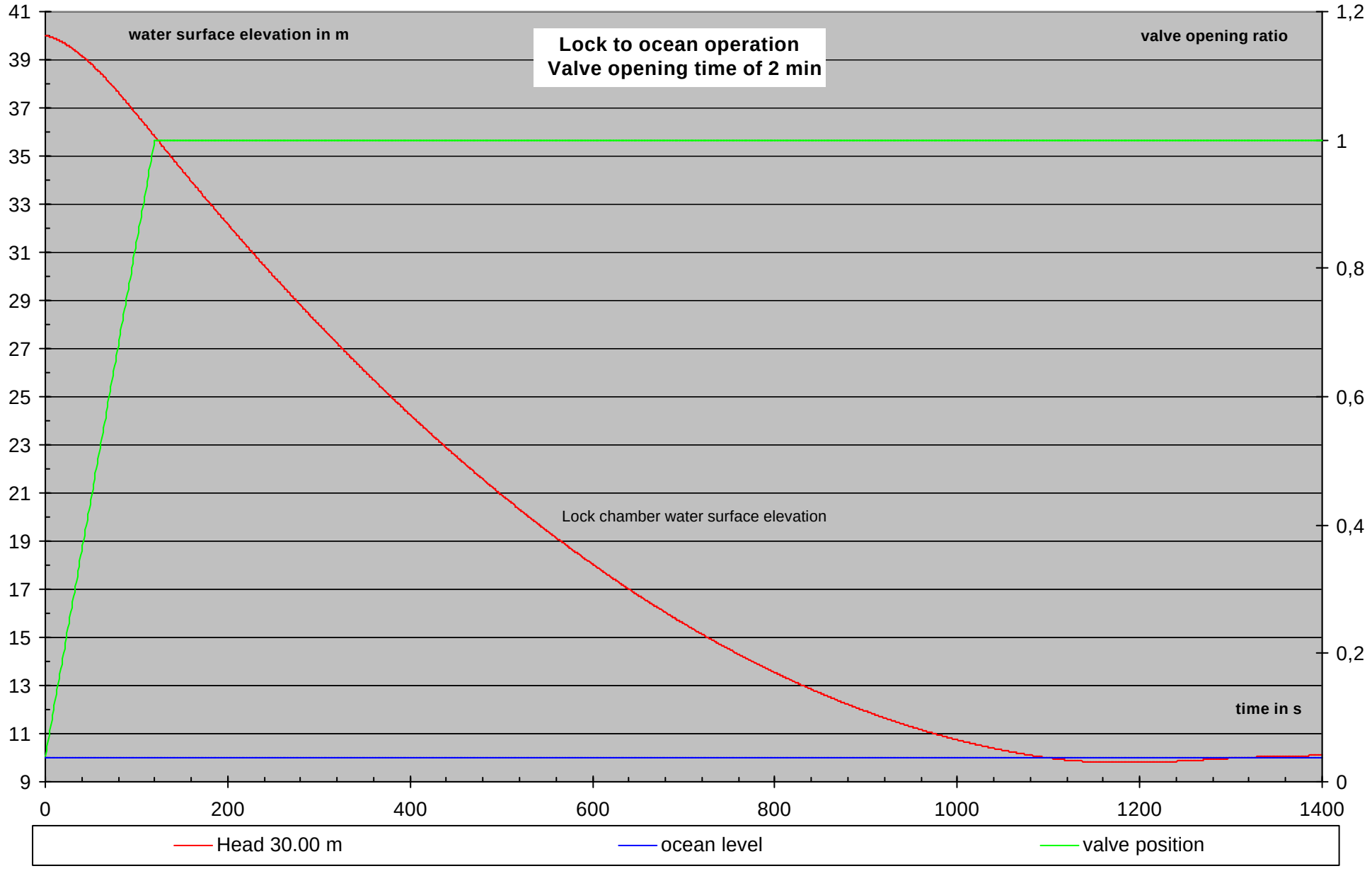
Annex 4-5 (1/4)
Lockage without WSB



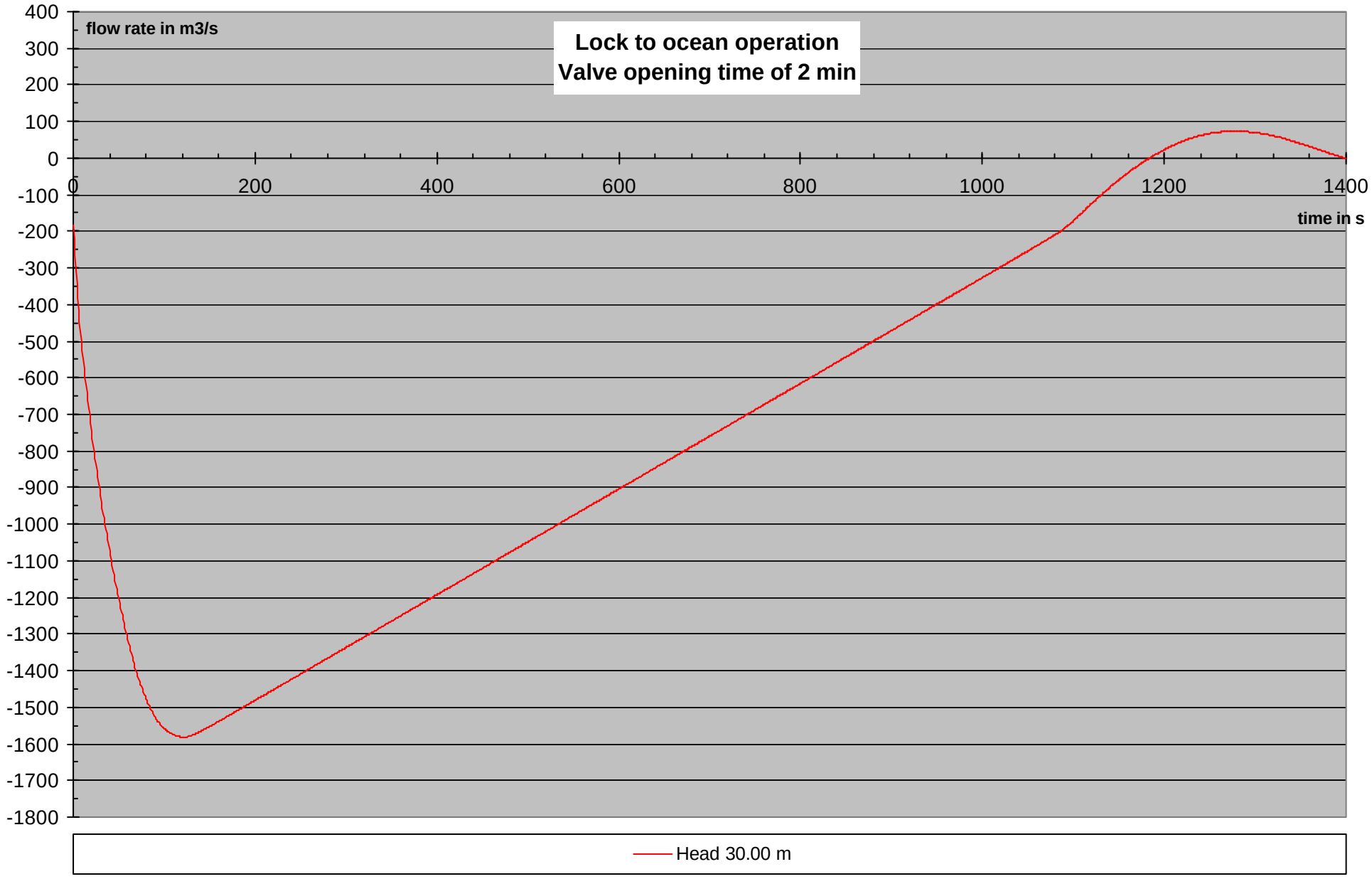
Annex 4-5 (2/4)
Lockage without WSB



Annex 4-5 (3/4)
Lockage without WSB

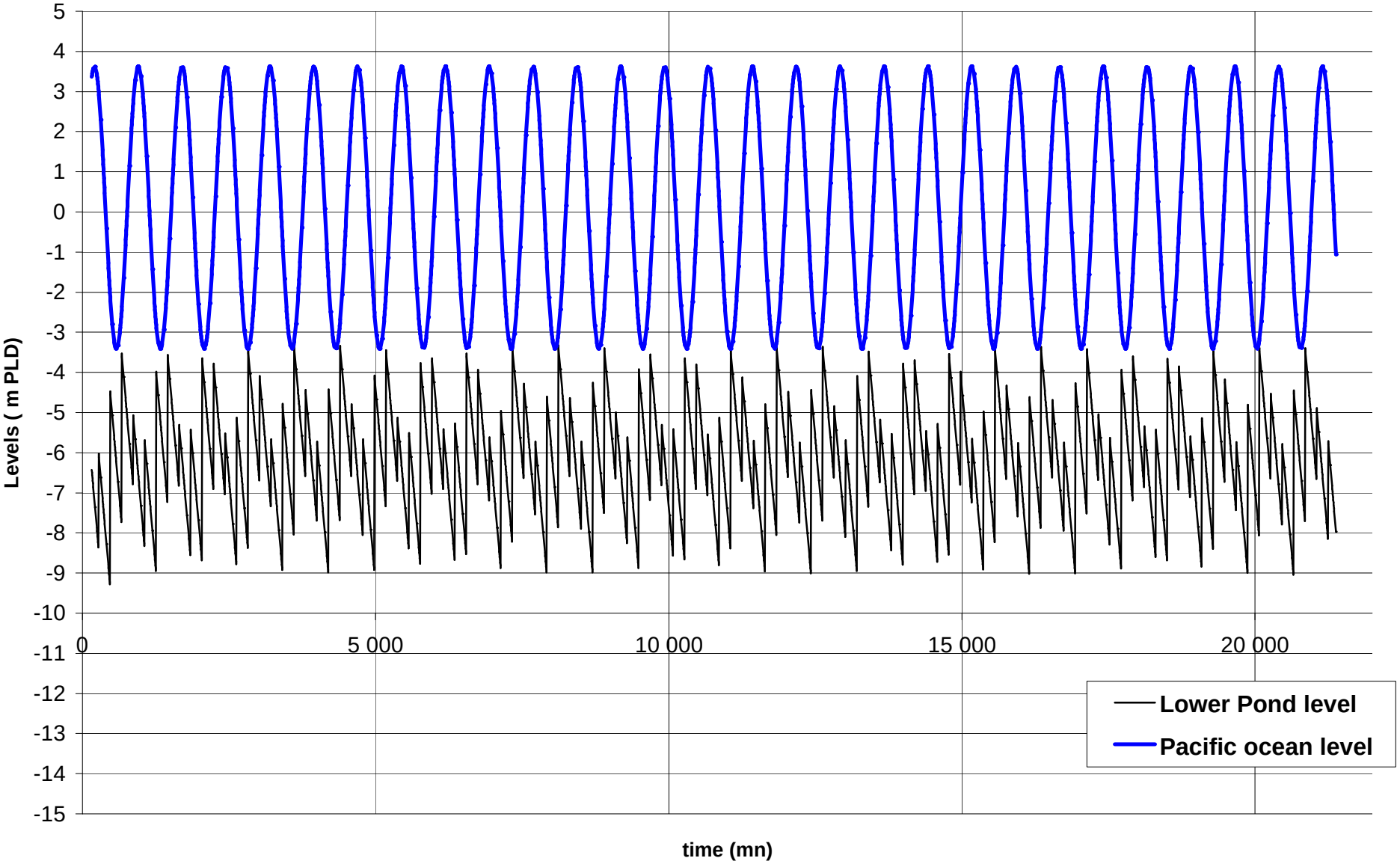


Annex 4-5 (4/4)
Lockage without WSB

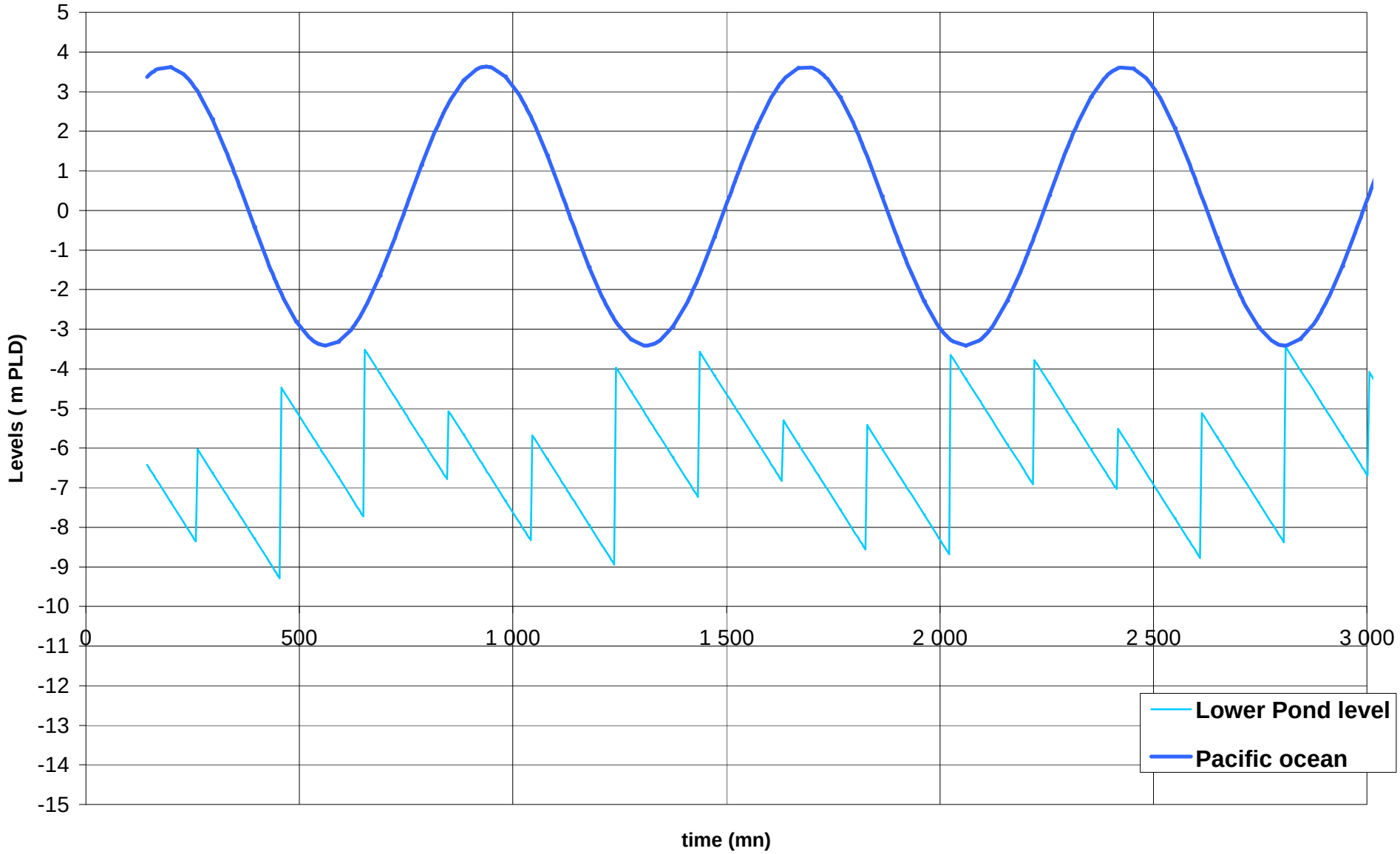


ANNEX 5

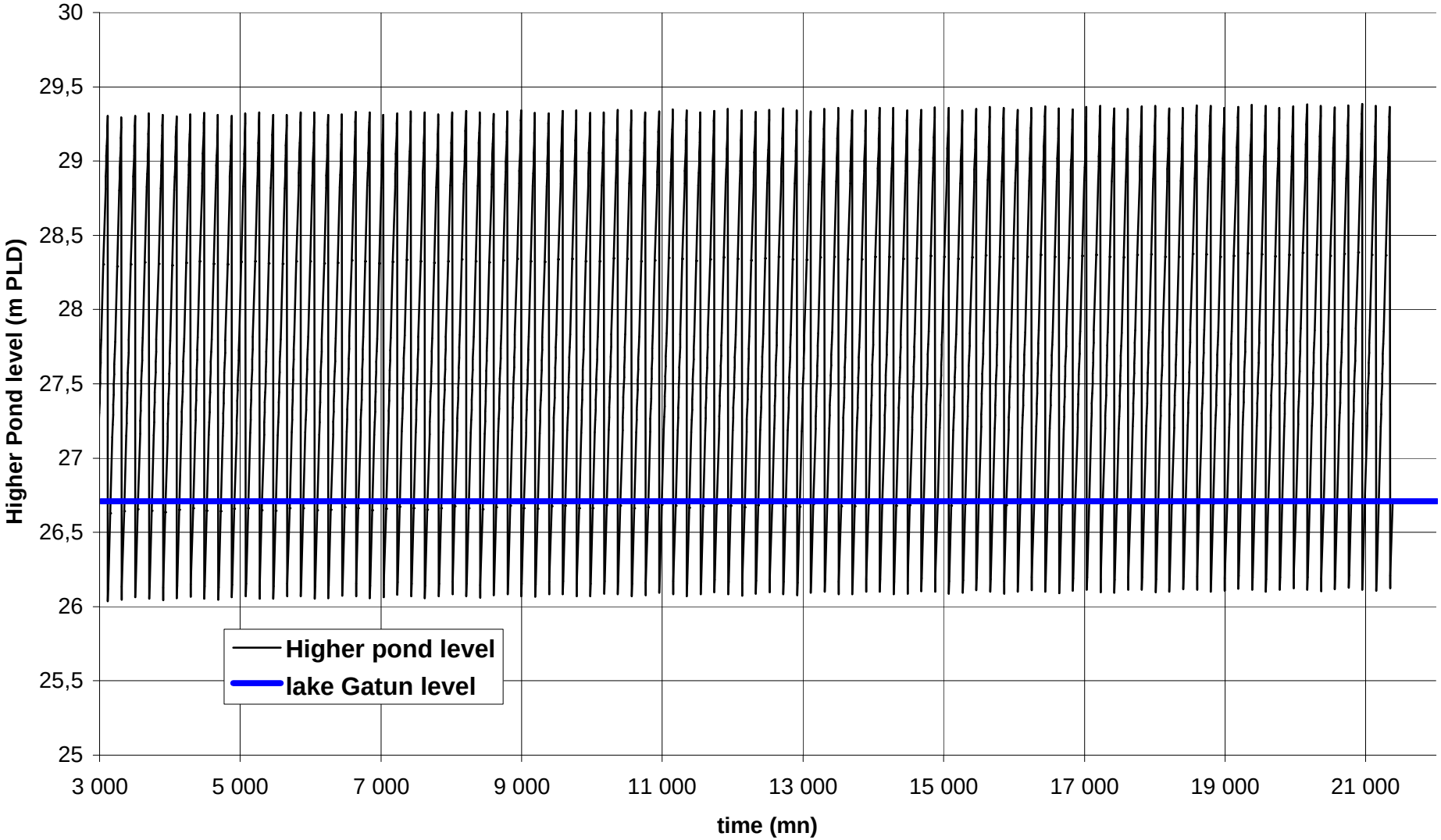
Annex 5 (1/4) - WATER RECYCLING - Lower Pond
(Lower Pond area = 2 x chamber area)



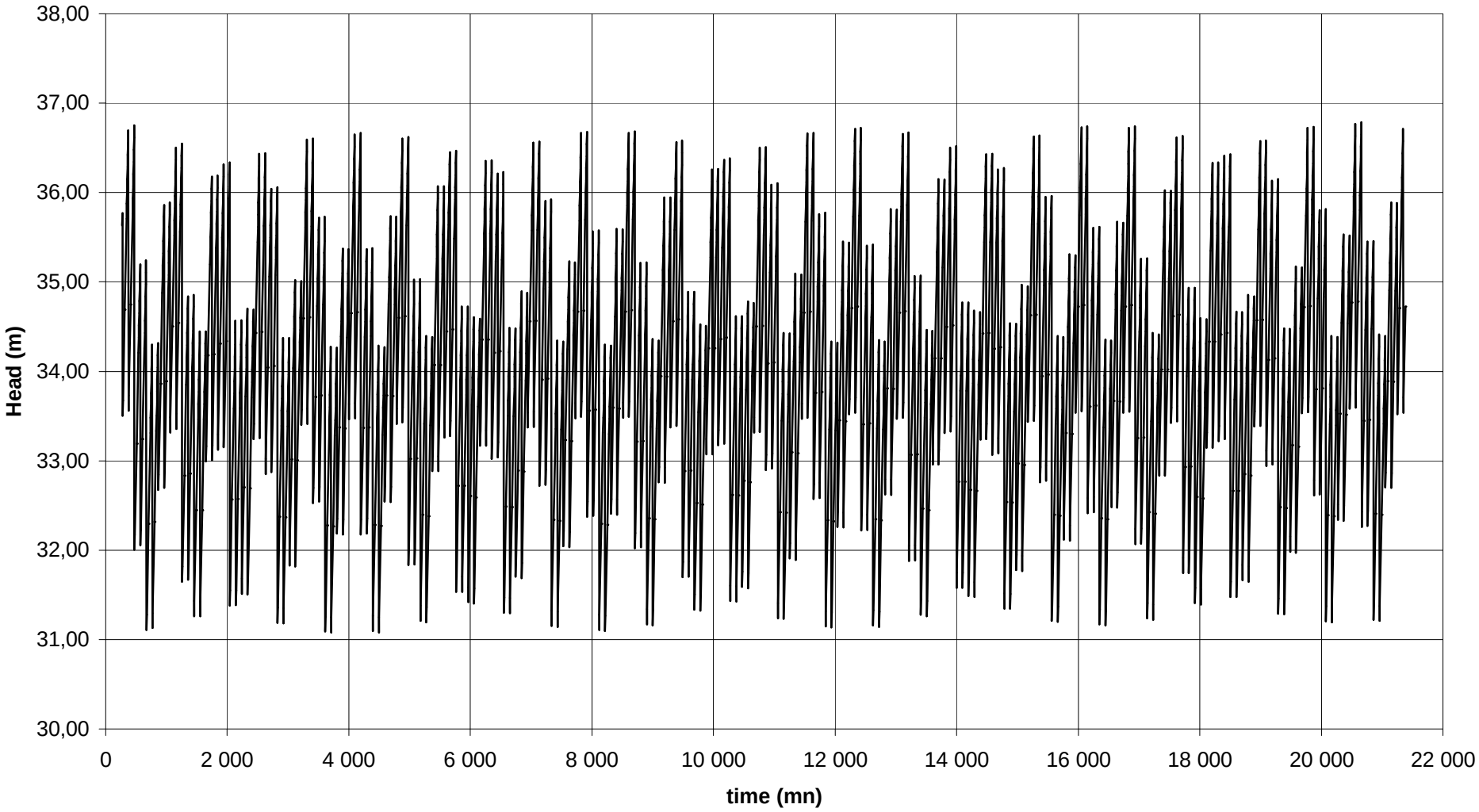
Annex 5 (2/4) - WATER RECYCLING - Lower Pond
(Lower Pond area = 2 x chamber area)



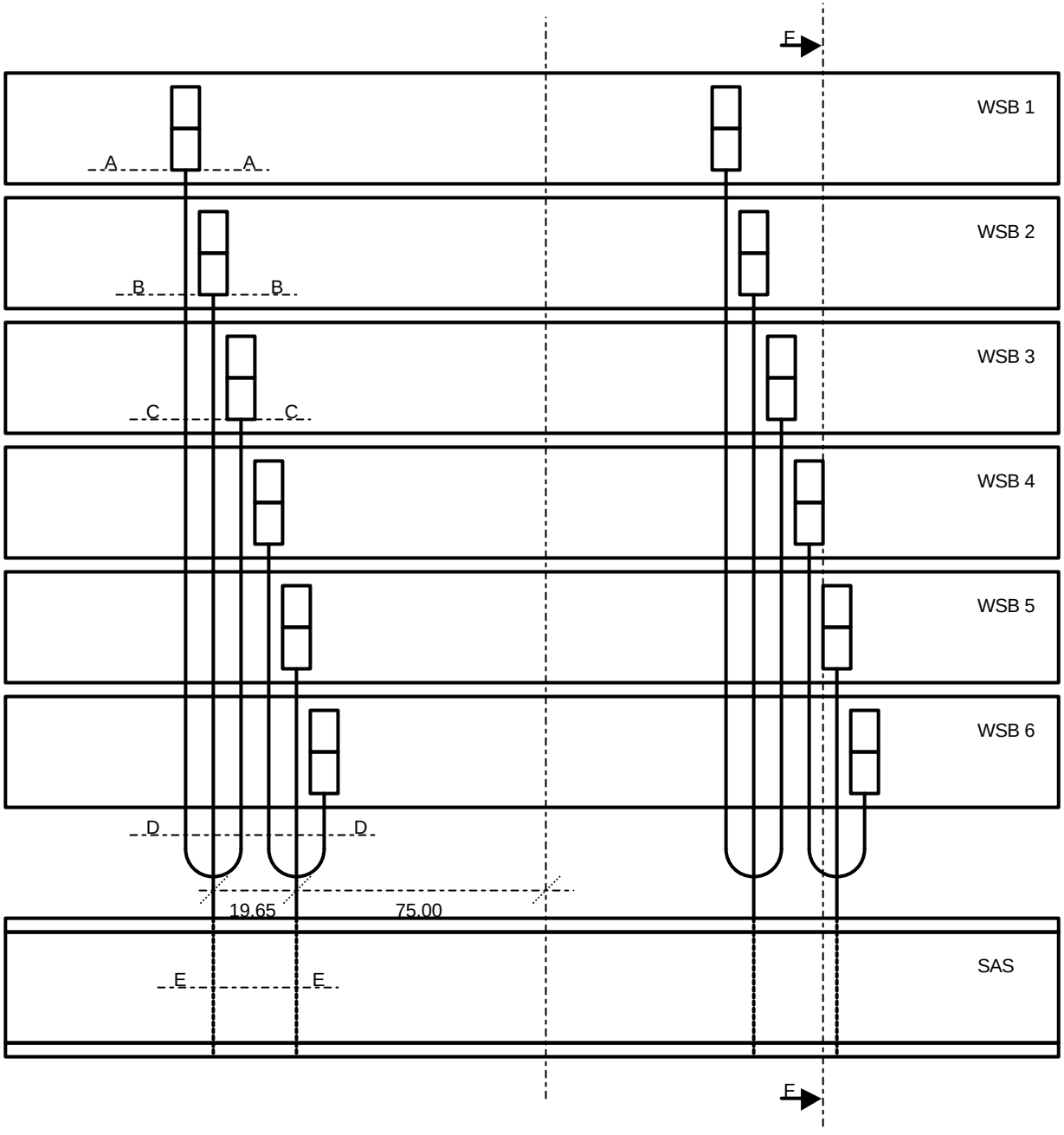
ANNEX 5 (3/4) - WATER RECYCLING - Higher Pond
(Higher Pond area = 2 x chamber area)



Annex 5 (4/4) - DISCHARGE OUTPUT HEAD



ANNEX 6



ANNEX 6.1

Panama
Configuration 2
Solution 1
Lateral culverts

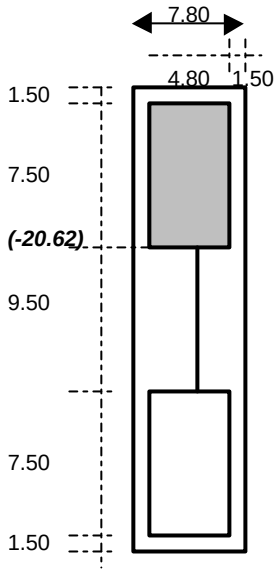
Plan view

ANNEX 6.2

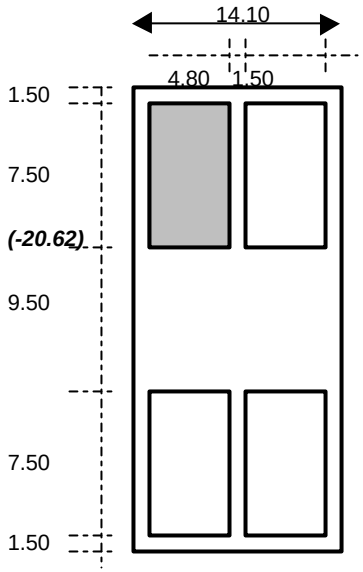
Panama
Configuration 2
Solution 1
Lateral culverts

Cross sections

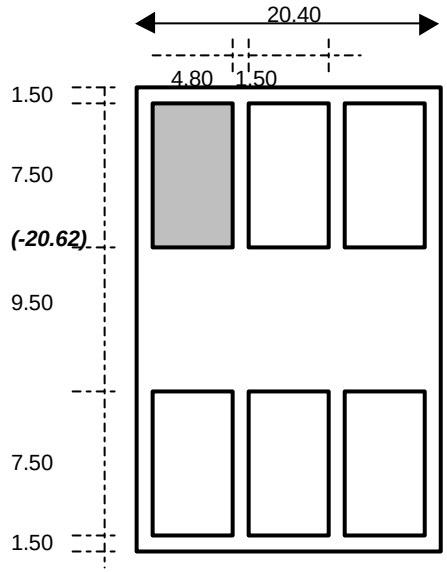
Cross section A-A



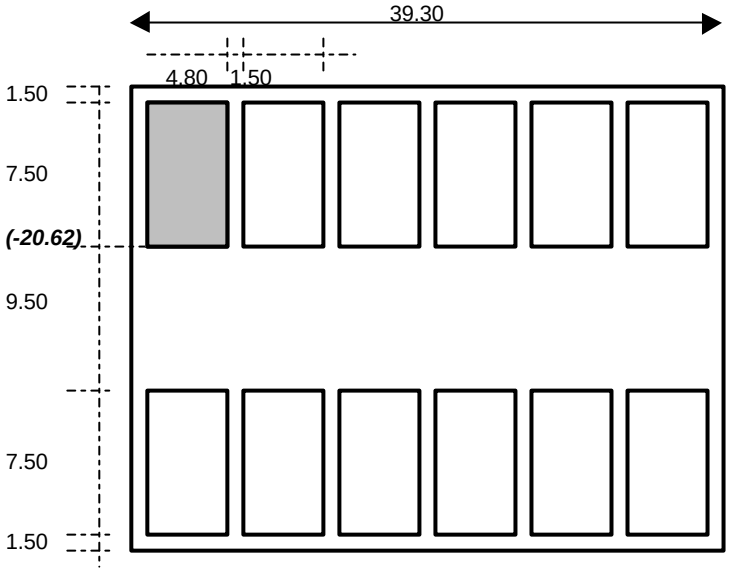
Cross section B-B



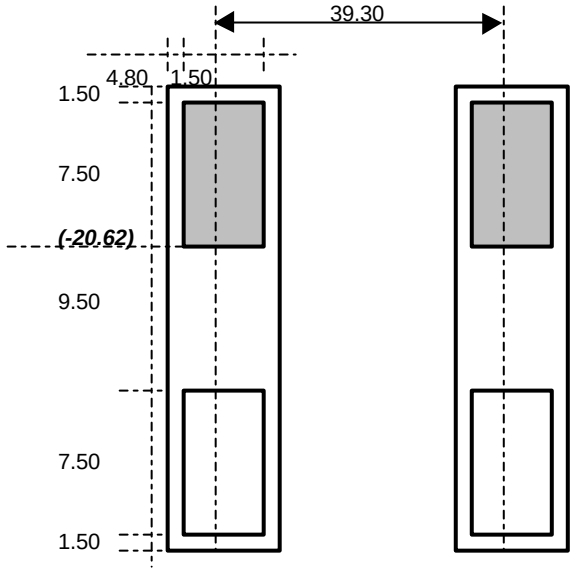
Cross section C-C



Cross section D-D



Cross section E-E

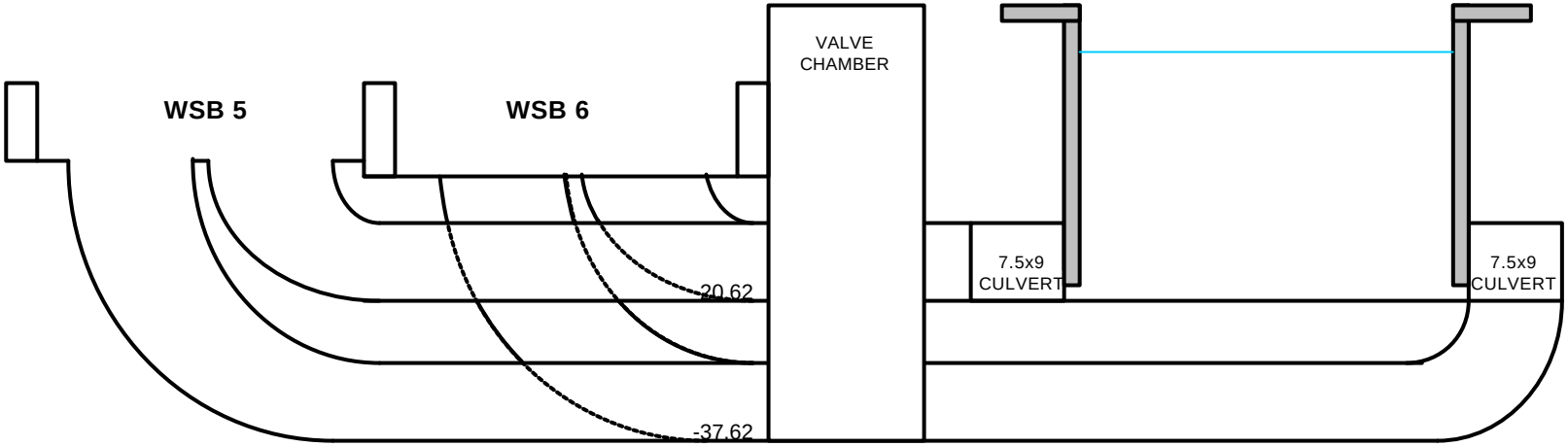


ANNEX 6.3

UPPER WSB - ELEVATIONF-F

Panama
Configuration 2
Solution 1
Lateral culverts

Elevation

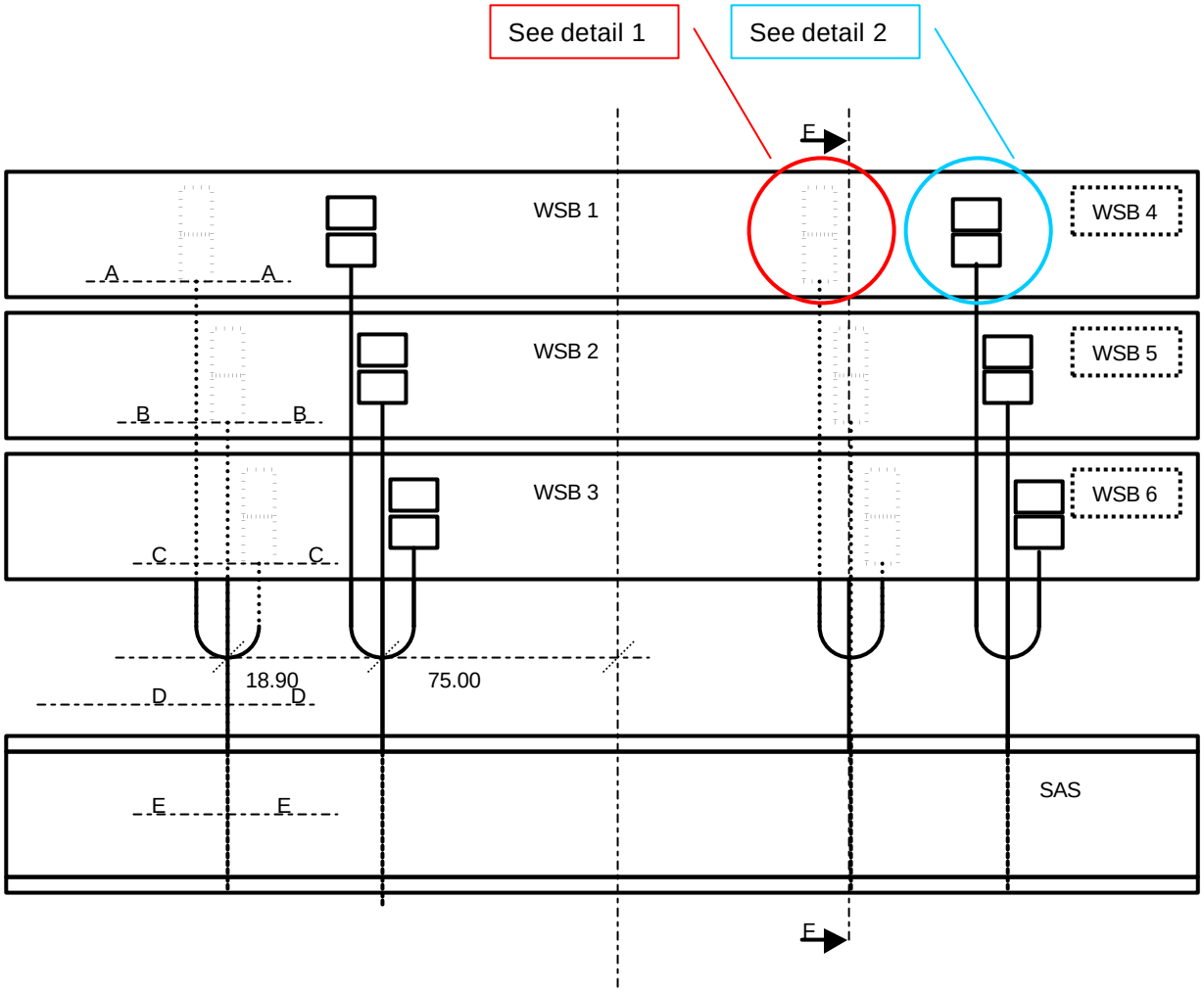


ANNEX 7

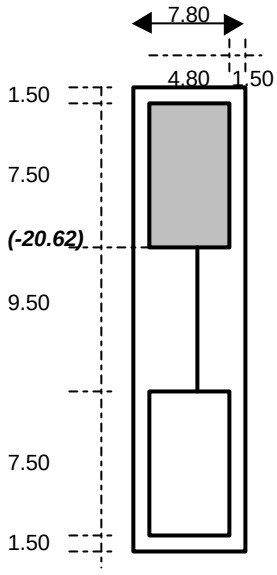
ANNEX 7.1

Panama
Configuration 2
Solution 2
Bottom feeding

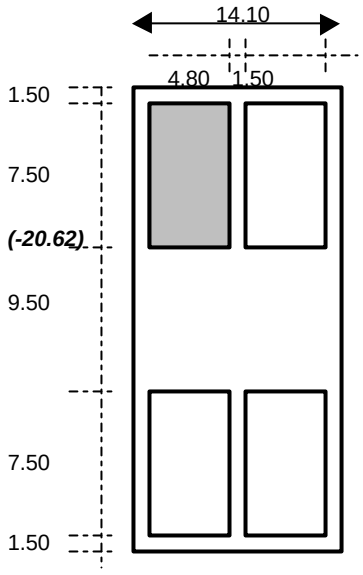
Plan view



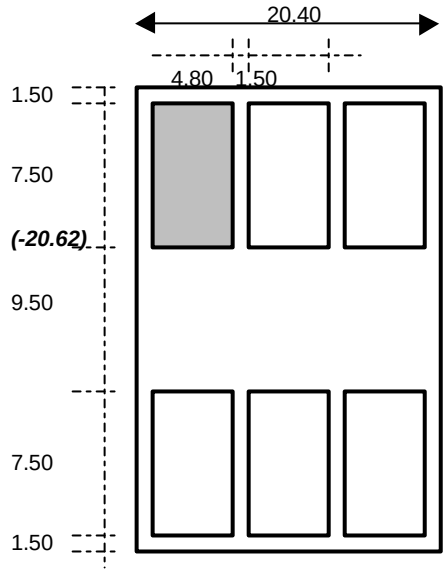
Cross section A-A



Cross section B-B



Cross section C-C

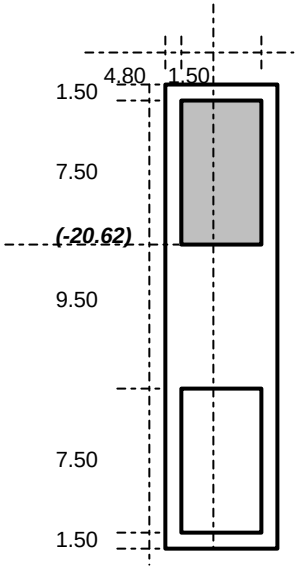


ANNEX 7.2

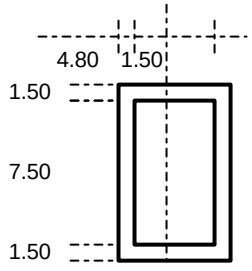
Panama
Configuration 2
Solution 2
Bottom feeding

Cross sections

Cross section D-D



Cross section E-E

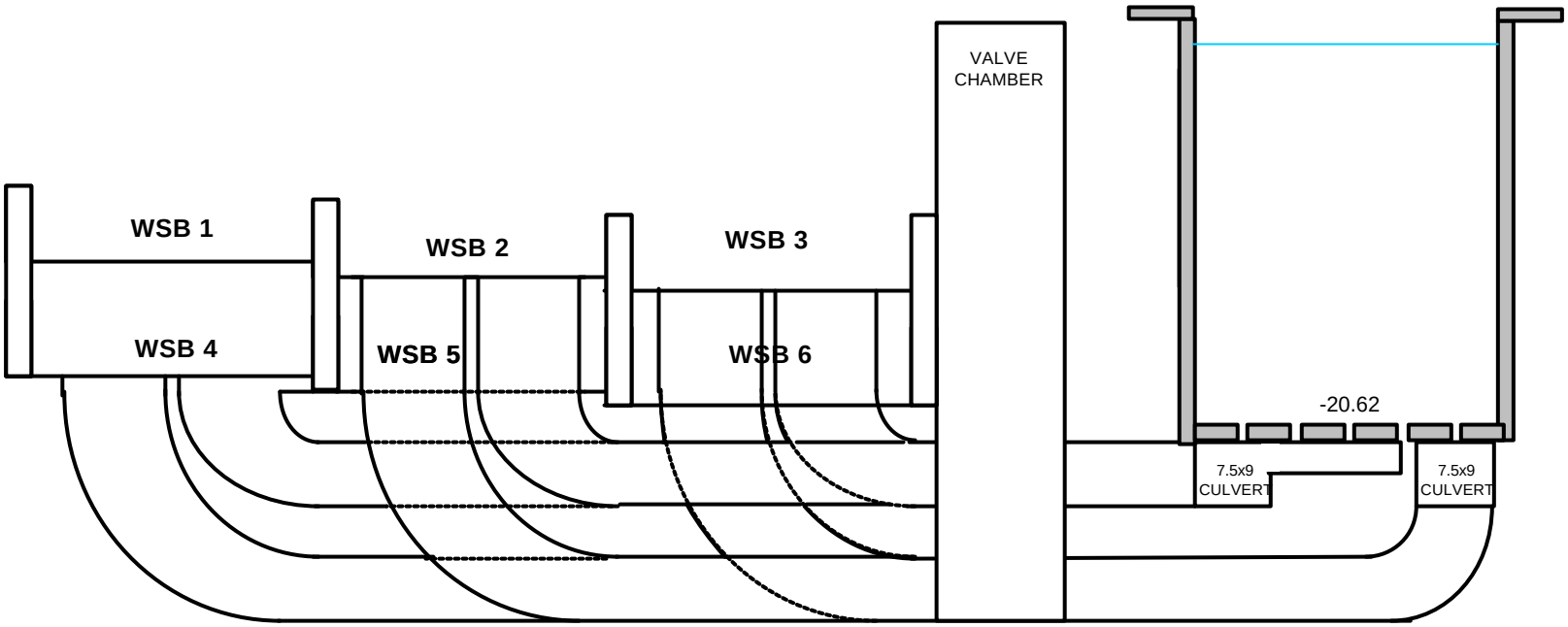


ANNEX 7.3

Panama
Configuration 2
Solution 2
Bottom feeding

Elevation

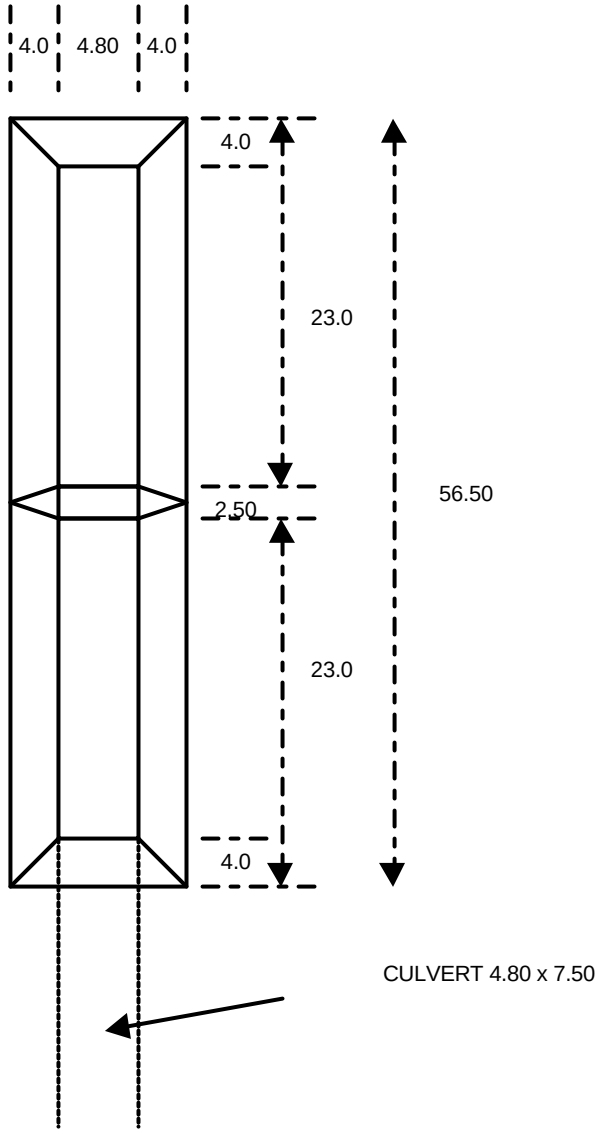
ELEVATIONF-F

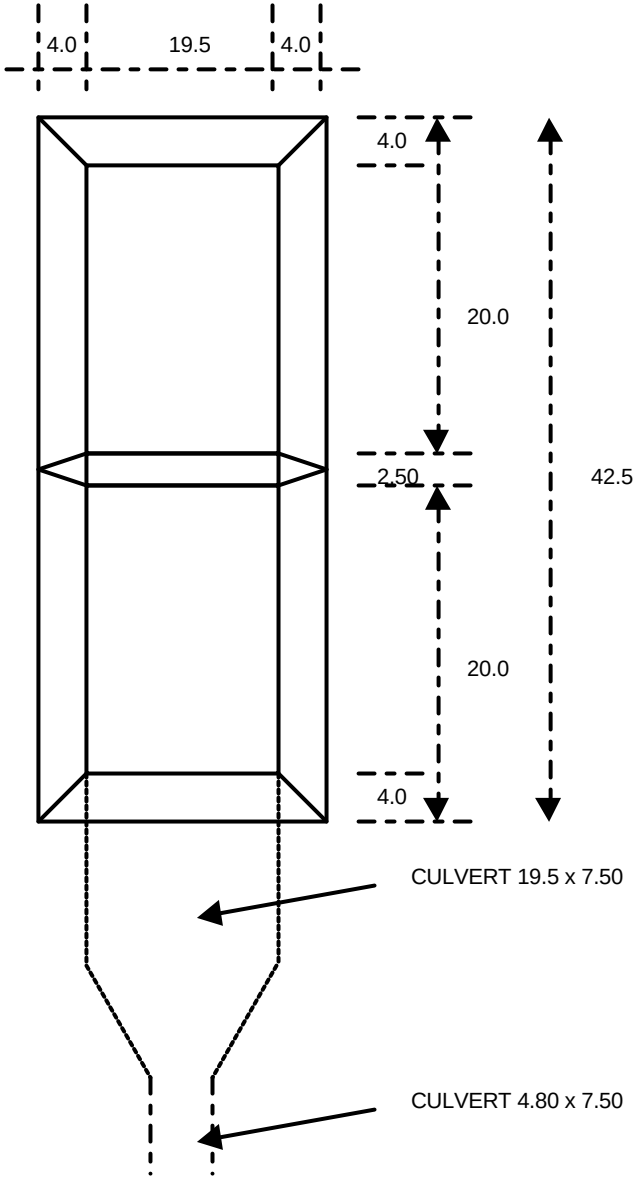


ANNEX 7.4

Panama
Configuration 2
Solution 2
Bottom feeding

DETAIL 1





ANNEX 7.5

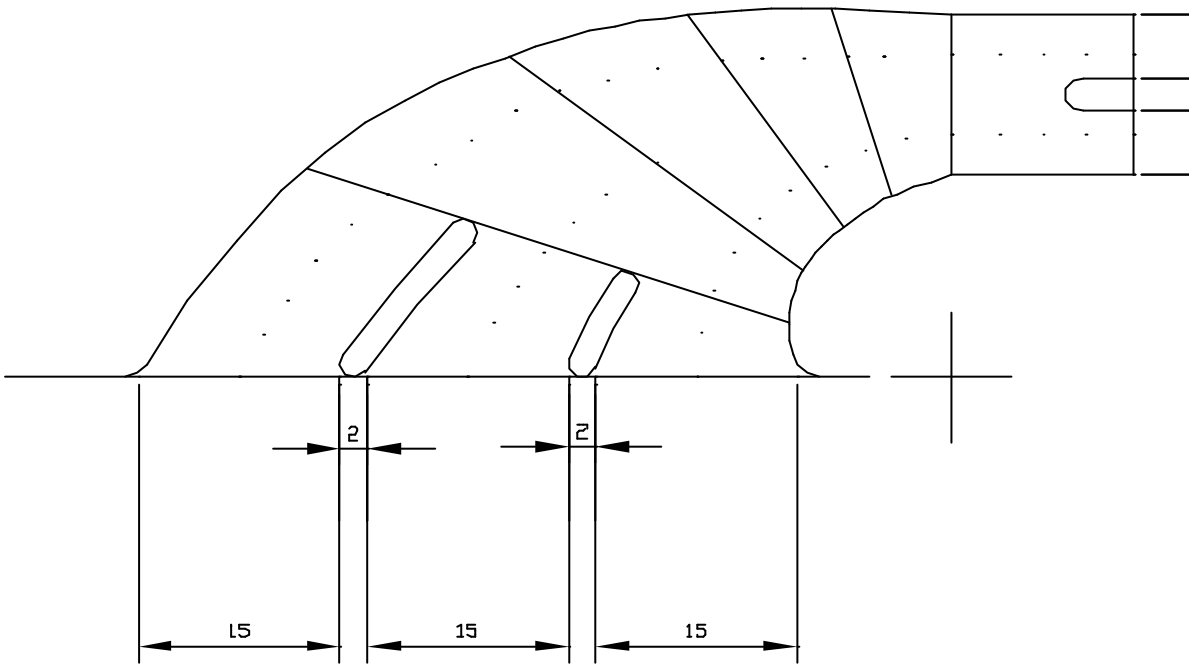
Panama
Configuration 2
Solution 2
Bottom feeding

DETAIL 2

ANNEX 8

Annex 8

Single-lift lock
Water intakes

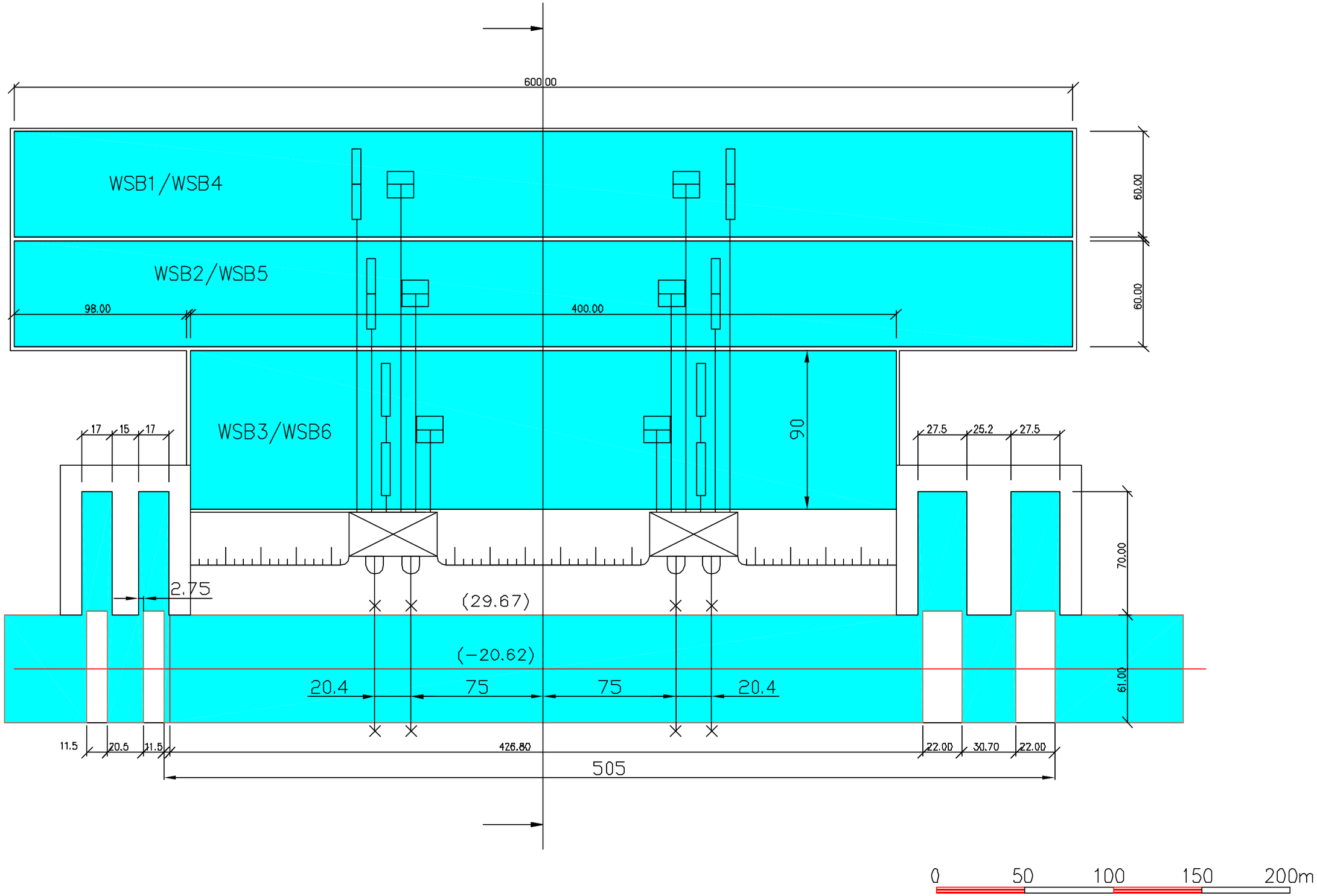


Dimensions in m.

ANNEX 9

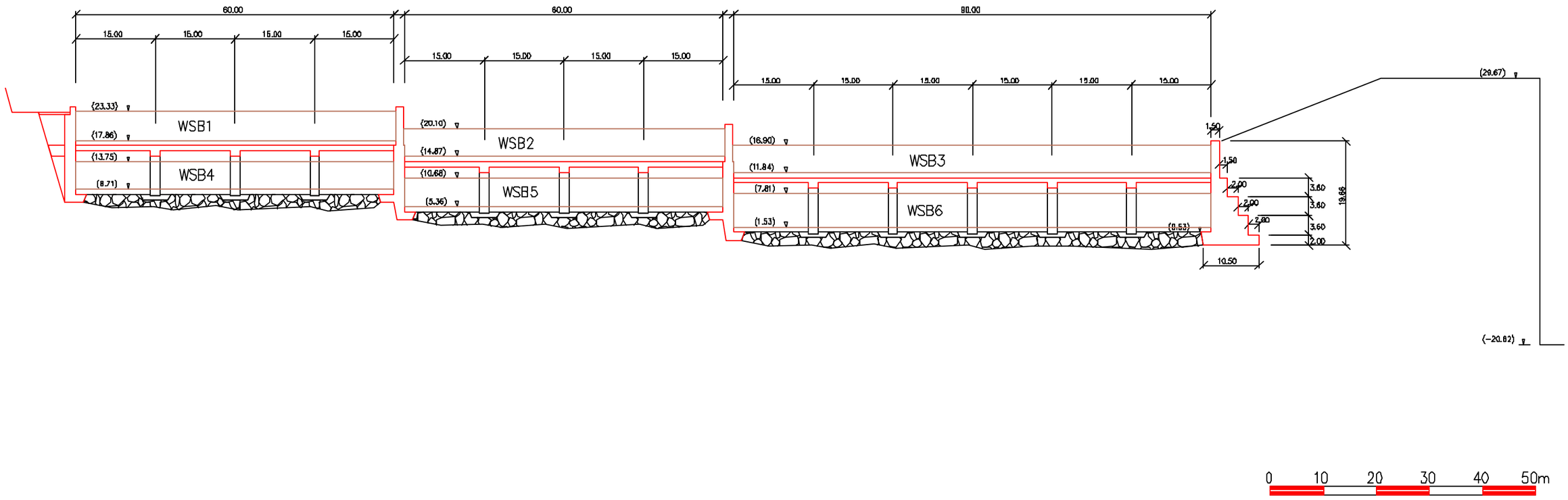
ANNEX 9-1

Plan view



ANNEX 9-2

Transversal cross section



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Diseño Conceptual de las Esclusas Post Panamax

TASK 4

D – LOCK OPERATING GATES

R4-D

Tractebel Development Engineering · TECHNUM · COYNE ET BELLIER · CNR PROJETS

in association with

ZAI · IMDC · SBE · FITA · AOSO

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1 Lay out of rolling gates

1.1 BASIC DATA

1.1.1 WATER AND BOTTOM LEVELS

Following water levels and corresponding bottom levels of the lock chamber are taken in account for the concept design of the gates structures and lay out. All level data are in m and refer to PLD.

	Gate S1	Gate S2
Max. water level upstream	+ 26.67	+ 26.67
Max. water level downstream	+ 26.67	+ 3.60
Min. water level open/close gates	+ 23.92 (*)	- 3.44
Min. water level downstream	below sill level	- 3.44
Sill level (downstream)	+ 5.63	- 20.62

(*) For maintenance operations in the gate recesses a safety allowance is considered: the minimum water level for floating operations of the gates is taken +22.00 m PLD (see 1.2.3).

1.1.2 GEOMETRY

Upstream gates S1
The axis to axis distance between the vertical bearings of the gates at the lock walls is taken 63 m for gates S1 (i.e.: the width of the lock chamber plus an excess length of 1 m at both sides).

The center of the horizontal bearing at the bottom of the gates is positioned 0.40 m below the level of the sill. The axis level of the horizontal bottom frame will be situated 1.27 m above this level in order to facilitate access under the gates during maintenance and repair operations, in particular to replace the lower support wagon.

The skin plating extends over an additional 0.25 m (horizontal and vertical) from the above defined bearing axes. Thus the total horizontal length of the gate skin plating is 63.50 m.

The extremities of the air chamber of each gate will be appropriately shaped in order to reduce the hydrodynamic forces during opening and closing operations at relatively large speeds.

Downstream gates S2
For gates S2 the axis to axis distance between the vertical bearings of the gates at the lock walls is taken 63.6 m. Added to the width of the lock chamber (61 m), gates S2 have an excess length of 1 m at the front end and 1.6 m at the rear end respectively.
The center of the horizontal bearing at the bottom of the gates is positioned 3.40 m below the level of the sill. Therefore a vertical recess will be constructed. The axis level of the horizontal bottom frame will be situated 2.27 m above this level in order to facilitate access under the gates during maintenance and repair operations, in particular to replace the lower support wagon.
The skin plating extends over an additional 0.45 m (horizontal) and 0.25 m (vertical) from the above defined bearing axes. Thus the total horizontal length of the gate skin plating is 64.50 m.

No specific optimum shaping is considered as the hydrodynamic forces almost vanish at the relatively low operating speeds of gates S2 (6 minutes opening and closing time), compared with the inertia forces, simultaneously acting during operations of the gates, due to the acceleration of the relatively heavy lock gate structure (incl. its ballast) and the moving water masses which are exchanged between the gate recesses and the lock chamber.

1.1.3 LOAD CASES ASSUMPTIONS

The following assumptions on load cases are made for the concept design of the gates structures and lay out.

1. Traffic load is considered to be of a moderate level for which normal bridge deck designs apply. This only holds for gates S1; a bridge deck for gates S2 is not considered.
2. The gates resist the water pressures due to the possible differences between the water levels listed in the table sub 1.1.1. An ultimate limit loading case with an increased upstream water level by 1 m is considered. Lock chamber dewatering doesn't impose determinative design load cases.
3. The gates are not subject to back pressures from the downstream side: locking procedures will be designed such that the water level at the downstream side of each gate never exceeds the water level at the upstream side.
4. The stability against rolling over of a floating gate is not considered as a determinative design criterion; however the metacentric height will be checked afterwards to assess the possible need for auxiliary equipment and provisions during floating operations.
5. Floating of the gates is still possible with 4 symmetrical pairs of compartments entirely filled with water, e.g. due to local damage after a ship collision.

1.2 GATE STRUCTURE DESIGN

1.2.1 GENERAL

In what follows the concept design of the structure and lay out is presented for the upstream and downstream rolling gates for a single lift lock configuration.

- The (smaller) upstream gates S1 are of the "wheelbarrow" type, i.e. with *one* submerged lower support wagon running on rails at the bottom of the lock chamber and one upper support wagon on rails above the water.
- The (large) downstream gates S2 are of the "wagon" type, i.e. with *two* submerged lower support wagons running on rails at the bottom of the lock chamber. No upper support wagon is present in this case. On the one hand the width of the gate S2 is sufficiently large to safely resist (through the two lower support wagons) possible lateral loading during opening and closing of the gates. On the other hand the structure of the (maintenance friendly) upper rolling wagon would be too high to fit in the lock structure in combination with the other necessary features and the cantilevering support to which this rolling wagon is fixed would be excessively loaded and consequently very heavy.

From the load cases assumptions mentioned sub 1.1.3 it is concluded that a single skin plating at the downstream side is sufficient for gates S1 to perform the necessary water retaining tasks. Double skin plating is only present to constitute an air chamber with sufficient height to be able to float the gates.

Doing so a considerable construction weight reduction is possible in comparison with similar double plated gate structures, e.g. like for the world largest Berendrecht lock (port of Antwerp). In particular the single plating at the downstream side is not subjected to compression forces and therefore it should not be designed against the risk of buckling instability; only the upstream plating of the air chamber should be designed for this load case. This weight reduction also has a favorable effect on the floating stability of the gates as it leads to a reduction in the necessary volume c.q. height of the air chamber. This (partial) single plating concept has been applied where possible to the gates of the Zandvliet lock (twins with the Berendrecht lock – port of Antwerp).

Instead of plating, appropriate trusses are designed to safely resist the compression forces at the upstream side in the horizontal and vertical members of the proposed structural framework.

For gates S2 a symmetrical structure with double skin plating is proposed in order to achieve a maximum of safety against global collapse in the event of accidental ship collisions. Weight reduction through the use of compact compression members instead of compressed plating is marginal. Through the relatively large width of the gates S2 in order to be able to float them in a stable manner, tension levels tend to be relatively low such that safety against buckling risk is not determinative in this case.

Note on buckling design standards: compressed plating is designed against buckling according to the Belgian standard NBN B 51-002 (August 1988), based on the linear elastic buckling theory (similar to for example DIN 4114) in combination with the safety concept adopted in the present Eurocode 3. The appropriate effective stiffeners are designed according to the technical notes of the CECM.

Observing these options, the design procedure is followed as described sub D1.6 to D1.9 (pages 26-30) in the methodology appendix V of the Quality Plan.
Note on fatigue: the gate structure (and most of the load bearing parts fixed to it) are subjected to cyclic loading and unloading, going along with the locking operations. The number of cycles over a 100 years life time design period is set at N = 25 cycles/day x 36525 days = 9.125 x 10^5 (see section 3.10 of the specific design criteria).

Based on our experience with common material tension levels (below the limit value for fatigue) for the proposed steel grade S355J2G3 and with common overall lay outs of the structural framework of rolling gates, an a priori estimate is made of the total width and weight of the gates and the spacing between the vertical frames.
Thus the necessary height of the air chamber is estimated and a local analysis yields the necessary "equivalent" thickness of the plating (i.e.: taking in account the material consumption for the necessary longitudinal stiffeners – see 1.2.2). The position of the top and bottom of the air chamber is fixed observing the minimum water level at closing and opening operations (see 1.2.3) and an appropriate upper deck is designed for the traffic loads to be considered (1.2.4). Based on the assumption of an equivalent plate thickness of the intermediate horizontal frames, an overall cross section analysis yields an estimate of the torsion stiffness distribution over the horizontal frames, taking in account their contingence.
Then a 2D-beam grid model of the gate structure (integrated over the width) is drawn up. Subsequently the assumed material tension levels are verified, in particular for the design of the compressed parts against buckling and the (local) design of the longitudinal stiffeners. Both elements may have a considerable impact on the final weight distribution of the gate structure, allowing to verify the height of the air chamber, the reaction forces at the support wagons and the floating stability.

Hereafter the concept design of some particular parts of the lock gates is discussed. It will be indicated how a more detailed level of design may lead to optimization of the obtained results.

Finally the main characteristics are listed (1.2.5) for which convergence occurs with the design procedure mentioned above.

1.2.2 SKIN PLATING AND STIFFENERS

The skin plating is divided in different panels between the horizontal structural frames considered. Each panel is designed separately to retain the water pressure (p) that acts upon it. The choice of the thickness (e) of the plating is based on experience, such to limit the material tension for a chosen width of the gates. It is to be confirmed and possibly optimized in a more detailed level of design.

If B denotes the height of a panel, the number n of longitudinal stiffeners is determined such that their spacing l = B/(n+1) satisfies the following:

$$\frac{pl^2}{12} \leq \sigma_{max} \cdot \frac{e^2}{6} \qquad (2.1)$$

If L denotes the horizontal length of a panel between two vertical structural frames, the required stiffener profile (minimum moment of inertia I and bending module W, in combination with an effective strip of plating) results from:

$$\frac{(pl)L^2}{24} \leq \sigma_{max} \cdot W \tag{2.2a}$$

$$\frac{(pl)L^3}{384\,E\,I} \leq \left(f/L \right)_{max} \tag{2.2b}$$

where σ_{max} and $(f/L)_{max}$ are respectively the maximum allowed material stress level (for local load transfer) and (local) displacement of the stiffener profile in combination with an effective strip of plating (taking in account the shear lag effect), which are chosen based on experience with similar structures and taking in account the (global) material stresses derived from the 2D-beam grid model.

Note that the adopted design value of the (local) bending moment (2.2a) holds halfway between two vertical frames. The doubled value locally occurring at the connection with the vertical frames is resisted by additional triangular stiffener plates, which also transfer the corresponding (local) shear forces to the frames. In order to arrive at moderate material stress levels in plating and connecting welds (fatigue!) the σ_{max}-value is chosen appropriately for each panel and each stiffener.

From a catalogue of commercially available standardized steel profiles, the necessary cross sectional area A is derived such that the "equivalent" plate thickness (e_{eq}) for the 2D-beam grid characteristics and the weight estimation of the considered panel becomes:

$$e_{eq} = e + \frac{n \cdot A}{B} \tag{2.3}$$

1.2.3 POSITION OF TOP AIR CHAMBER

In general the top level of the air chamber is to be chosen such that (if possible) the air chamber remains entirely submerged during opening and closing of the gates, thus avoiding excessive loading on the support wagons.

In this case the top level of the air chamber is taken 0.50 m below the lowest water level at which opening and closing of the gates will take place (see basic data sub 1.1.1), allowing for possible water level fluctuations in the lock chambers.

For gate S1 an additional safety margin below the estimated lowest lake Gatun level is considered, with a head allowance to keep the slot bulkhead pressed against the bearings of the gate recess. Thus it is possible in all circumstances to create a sufficient free working space under the floating gates in the gate recess. This consideration does not apply to gate S2, as the water level in their gate recess may be adjusted (elevated) if necessary. The thus lowered position of the air chamber of gate S1 does not

significantly affect its floating stability, as it has a relatively low level of center of gravity (compared to the other gates) and the air chamber remains in a relatively elevated position.

1.2.4 ROAD BRIDGE DECK

For this concept design, the road bridge deck lay out for gates S1 is taken similar to the one of the Berendrecht lock gates, which has more or less similar horizontal dimensions of deck panels between the structural frames and the edges. Furthermore two movable deck panels at the extremities are proposed to bridge the height difference from the top level of the gates to the ground level of the surrounding concrete structure by a ramp of 10% inclination angle. For gates S2 no bridge deck is proposed (note that this has a favourable effect on their floating stability).
These lay outs are subject to further investigation and optimisation in a more detailed level of design.

1.2.5 CONCLUSIONS: MAIN DIMENSIONS AND CHARACTERISTICS

The general cross sectional lay out of the two different gates for the single lift lock configuration is shown on drawing D4-D-201. For gate S2 a lateral and aerial view and section is shown as well.

The proposed inner diameter of the vertical access tubes is 1.0 m and the outer diameter of the horizontal access tube in the air chamber is 2.3 m for gates S1 and 10.0 m for gates S2.
The air chamber of gates S1 has one longitudinal separation wall, constituting *two* adjacent watertight compartments in each cross section.
The air chamber of gates S2 has one longitudinal separation wall over the full height and two separation walls of limited height connecting the bottom of the air chamber with the extremities of the horizontal access tube. Thus *four* adjacent watertight compartments are constituted in each cross section during floating operations in normal conditions, in order to achieve sufficient stability against rolling over.

Below some dimensions and characteristics are listed for the proposed concepts of the gates. Note that these figures are to be confirmed and subject to revision in a more detailed level of design.
E.g.: additional longitudinal separation walls in the air chamber will increase the stability against rolling over of a floating gate, but will complicate the separate accesses of the watertight compartments from the central horizontal access tube. Moreover the weight of the gates will increase substantially and the entire lay out of the gates (below the top level of the air chamber) is subject to revision.

Axis levels (m PLD) of horizontal frames	Gate S1	Gate S2
R1 : top of upper frame = bridge deck	+ 27.67	+ 27.67
R2 : intermediate frame above air chamber	not present	+ 23.16
R3 : intermediate frame above air chamber	not present	+ 15.41
R4 : intermediate frame above air chamber	not present	+ 7.66
R5 : intermediate frame above air chamber	not present	+ 0.06
R6 : top of air chamber	+ 20.65	- 3.94
R7 : bottom of air chamber gate S1 - intermediate frame inside air chamber S2	+ 15.25	- 11.44
R8 : intermediate frame below air chamber S1 - bottom of air chamber gate S2	+ 10.87	- 18.94
R9 : bottom frame	+ 6.49	- 21.75
R10: bottom bearing at the sill	+ 5.22	- 24.02 (*)
R11: bottom edge of skin plating	+ 4.97	- 24.27 (*)

(*) These levels require a lowering by 3 m of the bottom level of the lock heads, compared with the minimum level for the given sill depth.

	Gate S1	Gate S2
Width (outside plating)	8 m	22 m
Spacing between vertical frames	3.15 m	2.65 m
Weight per lateral area (height x length)	1400 kg/m²	3550 kg/m²
Weight of gate structure	2100 tons	11 500 tons
Weight of fixed ballast	none	7000 tons

In general the figures above for gates S1 are considered to be reasonable and very well in line with existing rolling gates. Gates S2 are of an extraordinary size, excluding any possible comparison. In general it is concluded that the proposed solution with rolling gates is well feasible as even the large gates S2 may be operated and handled in a safe and durable way, meeting all the practical criteria set out in the terms of reference.

Both gates S1 and S2 are suitable for dewatering the lock chamber. For gates S1 this is a normal loading case as the gates run dry during normal locking operations when the water level in the lock chamber drops to the downstream level.
In principle gates S2 (double plated but like gates S1 with seals only on the downstream side) might be reversed for this purpose and maneuvered to an appropriately shaped separate bearing. Subsequently the dewatering of the lock constitutes a less severe loading case than the service loading case during normal locking operations (see section 1.3.9). Considering the relatively moderate maximum downstream water level (+3.60 PLD - see section 1.1.1) to retain at the downstream lock head in case of dewatering, an additional smaller type of gate, similar to S1, would be an optimum solution. Doing so the dimensions of the additional bearing details may be kept to a minimum as well.

1.3 LAY OUT OF DETAILS

1.3.1 GENERAL

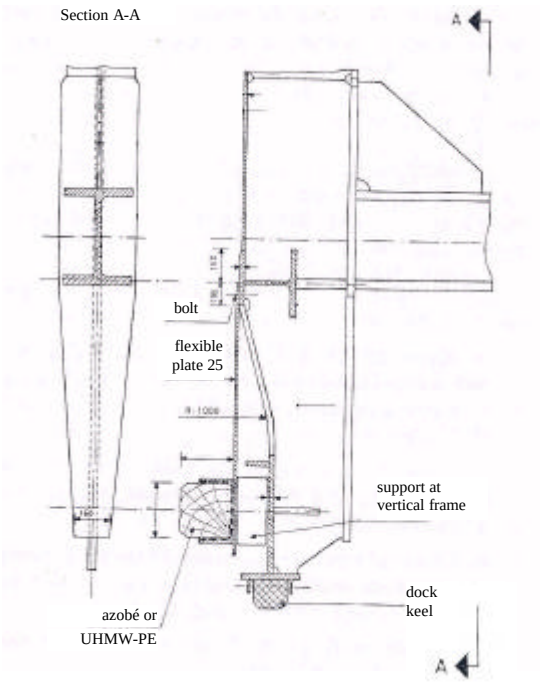
In this section the conceptual lay outs of some operational features and details of the proposed rolling lock gates are presented. As stated sub D1.12 to D1.16 (pages 31-32) in the methodology appendix V of the Quality Plan, similar lay outs of corresponding details of the rolling gates in operation at the large locks in the port of Antwerp (Belgium) are proposed.
Relevant excerpts from archive drawings of the Berendrecht lock gates are included in this report.
The appropriateness of the use of these details or those of the recently designed new rolling gates for the Van Cauwelaert lock (port of Antwerp) in the actual gates in the Panama case is evaluated where necessary, also considering the computations presented in section 1.5.

1.3.2 SEALS AND FENDERS

Both vertical (at the lock walls) as horizontal (at the bottom near the sill) seals are proposed to be massive beams. They have a rectangular cross section of 500 mm width and 250 mm thickness for gates S1 and 500mm (horizontal) to 1000 mm (vertical) width and 500 mm thickness for gates S2. The beams may be of azobé wood (considered in the computations) or a high performance composite material. The beams will be fixed on the skin plating on the downstream side of the gates between plate stiffeners of 100 mm width and 10 mm thickness for gates S1 and 250 mm width and 20 mm thickness for gates S2.
These beams also constitute the supports of the gates against the bearings of the surrounding lock chamber structure (lock walls and sill). In section 1.5 it will be shown that the pressure levels in the beams require sufficient high strength materials, excluding currently available elastomeric materials.

Moreover similar beams serving as fenders will be fixed to the horizontal frames at both sides of gates S1, at the downstream side of gates S2 and at the bottom of the upstream side of gates S2. At the R4-level (+7.66 PLD) at the upstream side of gates S2 a rail will be fixed with a facing in stainless steel to roll along lateral steel guidance wheels serving as fenders fixed to the surrounding gate recess walls, which have to be sufficiently distant to the gates at the connection with the lock chamber to allow for the necessary (dis-)mounting maneuvers (see drawing D4-D-202).

1.3.3 FIXED SUPPORTS

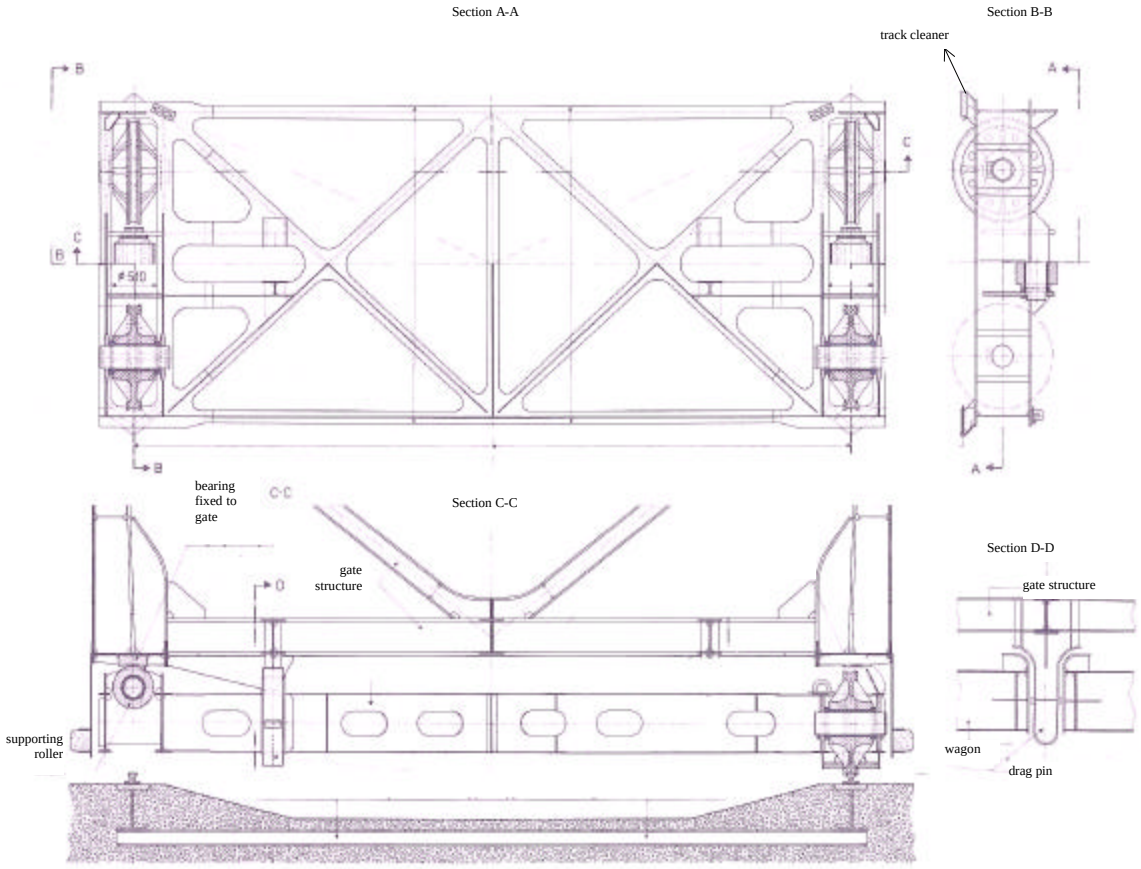


Seals and bottom support

At the sill level the gates have cantilevering extensions of their vertical frames. At the bottom end of these extensions fixed supports are designed such that the gate can rest on the bottom of the lock chamber or a gate recess when the lower support wagon (see 1.3.4) is absent (e.g.: due to maintenance or during mounting).
On the extensions at the downstream side of the gate a steel reinforced elastomeric block is fixed to support a flexible cantilevering extension of the skin plating (see illustration). This system allows to adjust to a certain degree the reaction forces which will be exerted on the gates at the sill. This may be necessary to avoid uplift from the sill bearing of the skin plating at the gate bottom edges due to an inappropriate distribution of stiffness over the gate structure.

1.3.4 LOWER SUPPORT WAGON GATES S1

From the assessment of the maximum vertical reaction forces over the range of operating conditions (see 1.5.2) it is concluded that for gates S1 a design similar to the lower support wagon of the Berendrecht lock is appropriate.

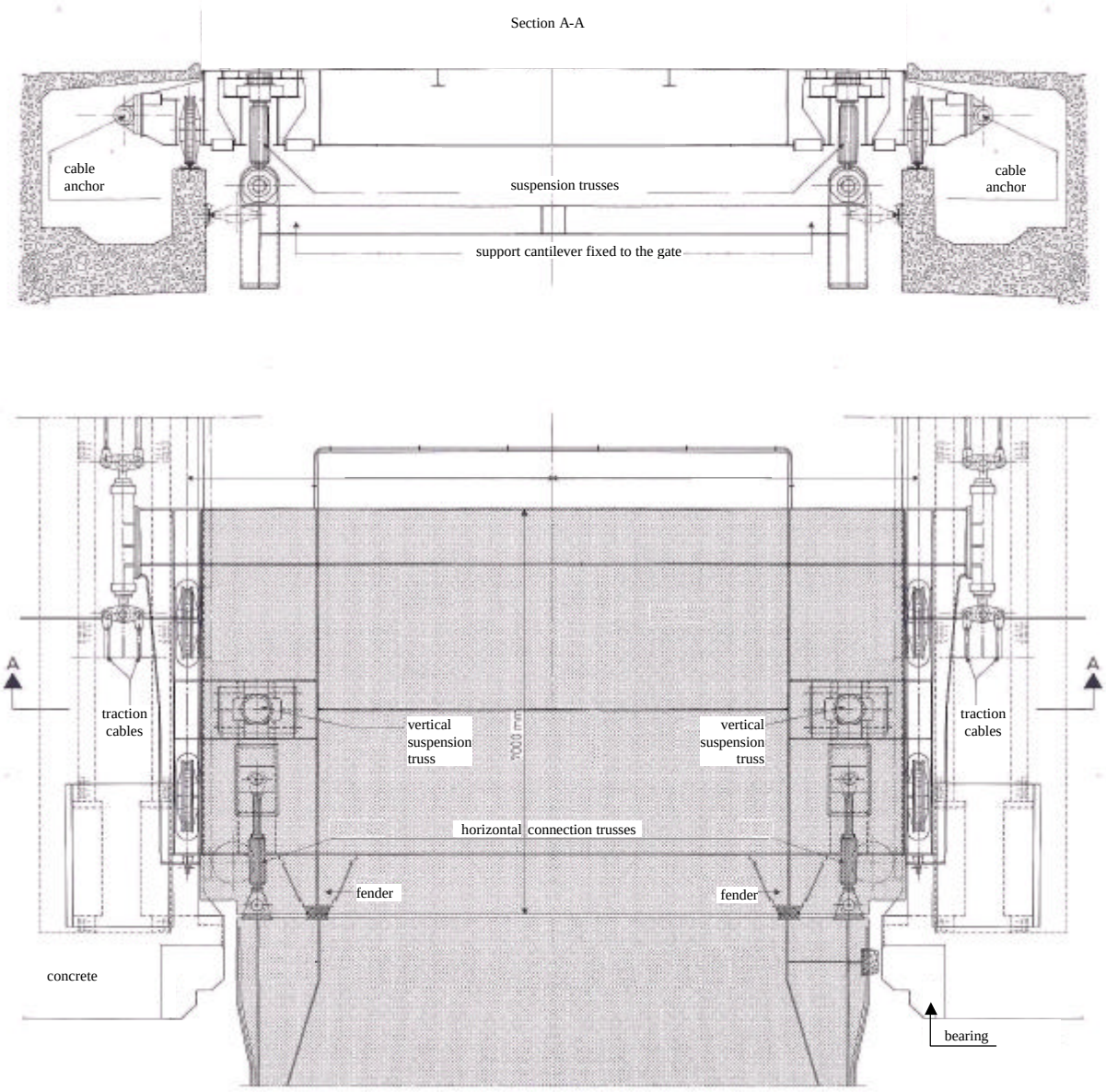


Lower support wagon S1

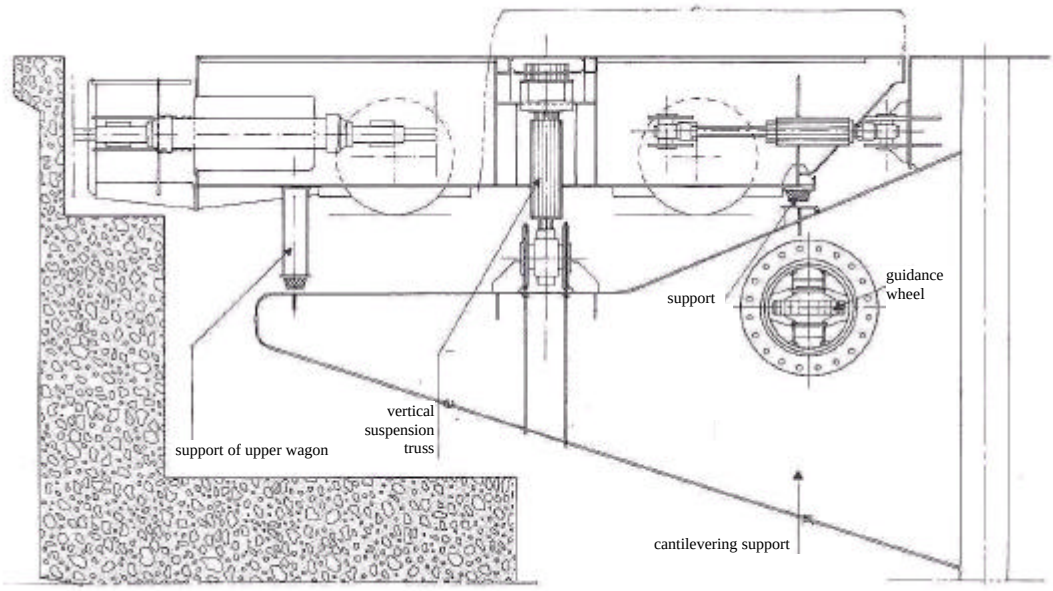
1.3.5 UPPER SUPPORT WAGON GATES S1

From the assessment of the maximum vertical reaction forces over the range of operating conditions (see 1.5.2) it is concluded that a design similar to the upper support wagon of the Berendrecht lock is appropriate. For gate S1 the cantilevering support (by which the upper support wagon connects to the lock gates) can be taken similar to the one of the Berendrecht lock. For gates S2 no cantilevering support is present as both support wagons run on rails at the bottom of the lock. At their rear end gates S2 have two relatively small lateral cantilevers at the top deck level, to which the traction cables of the gearing are connected. Moreover a lateral guidance wheel is built in these cantilevers.

1.3.5.1 General view

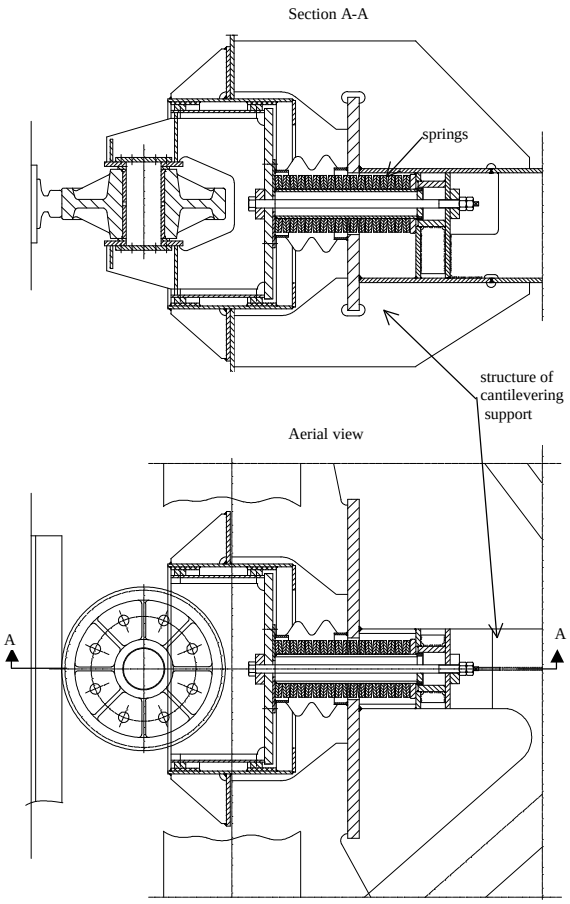


Upper support wagon S1

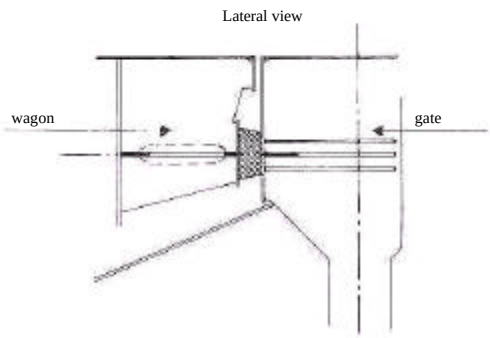


Lateral view of upper support wagon S1 with cantilevering support

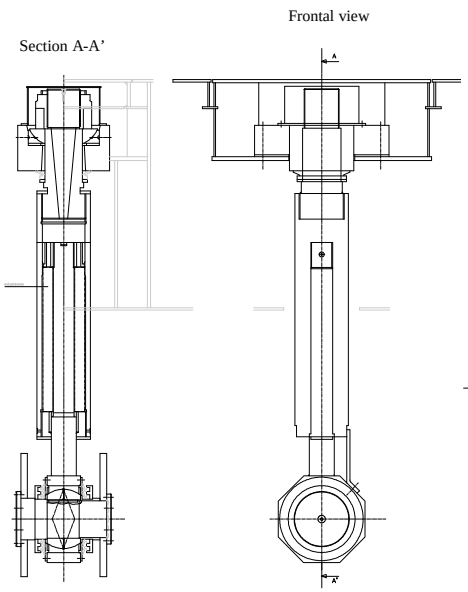
1.3.5.2 Details



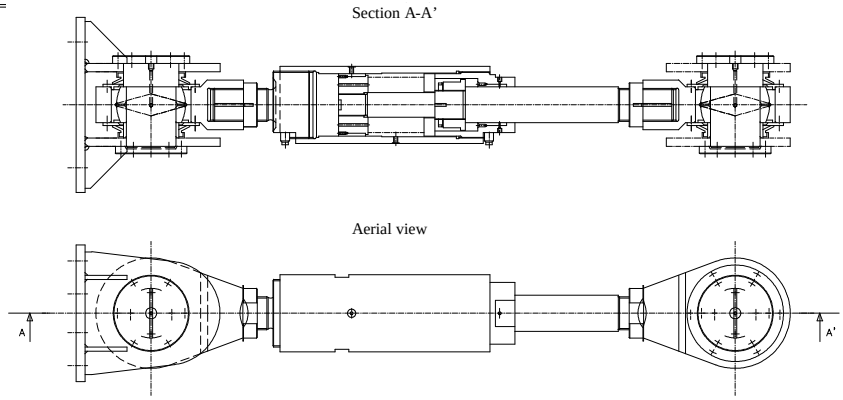
Guidance wheel



Fender between gate and upper support wagon



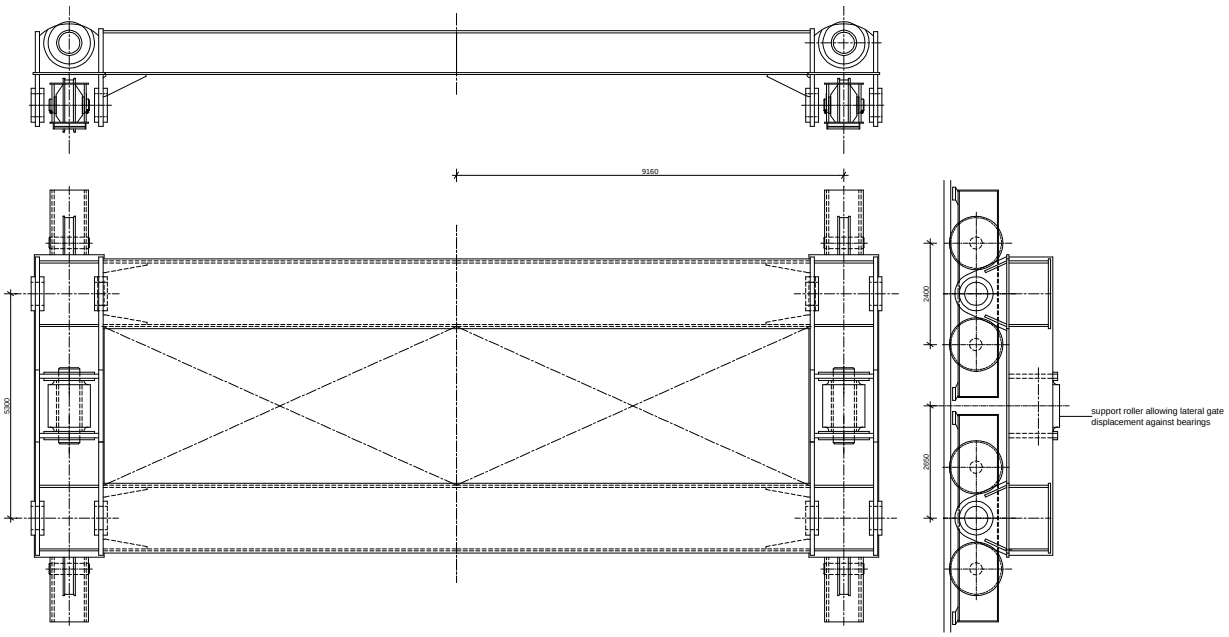
Vertical suspension truss



Horizontal connection truss

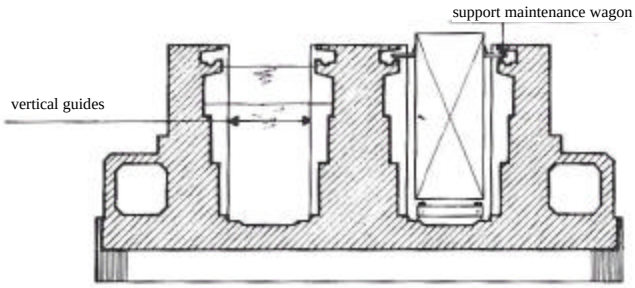
1.3.6 ROLLING SUPPORT WAGONS GATES S2

From the assessment of the maximum vertical reaction forces over the range of operating conditions (see 1.5.2) it is concluded that for the two (lower) rolling support wagons of gates S2 an adapted design with balanced double two-wheel sets is appropriate. The two-wheel sets are similar to the ones used for the lower support wagon of the recently designed rolling gates for the Van Cauwelaert lock (port of Antwerp). The necessary wheel bearing capacity does not exceed 1250 kN.

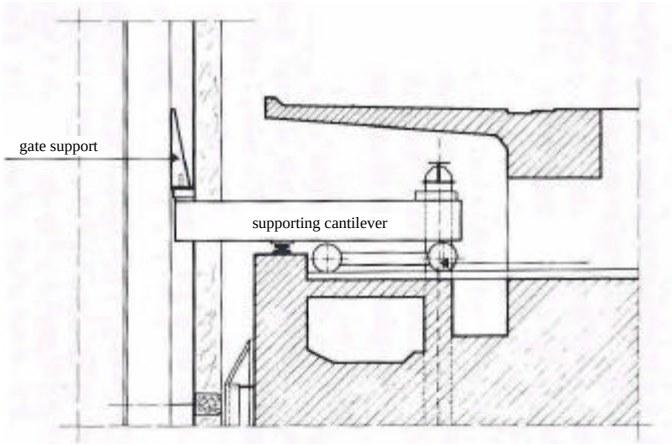


Rolling support wagon S2

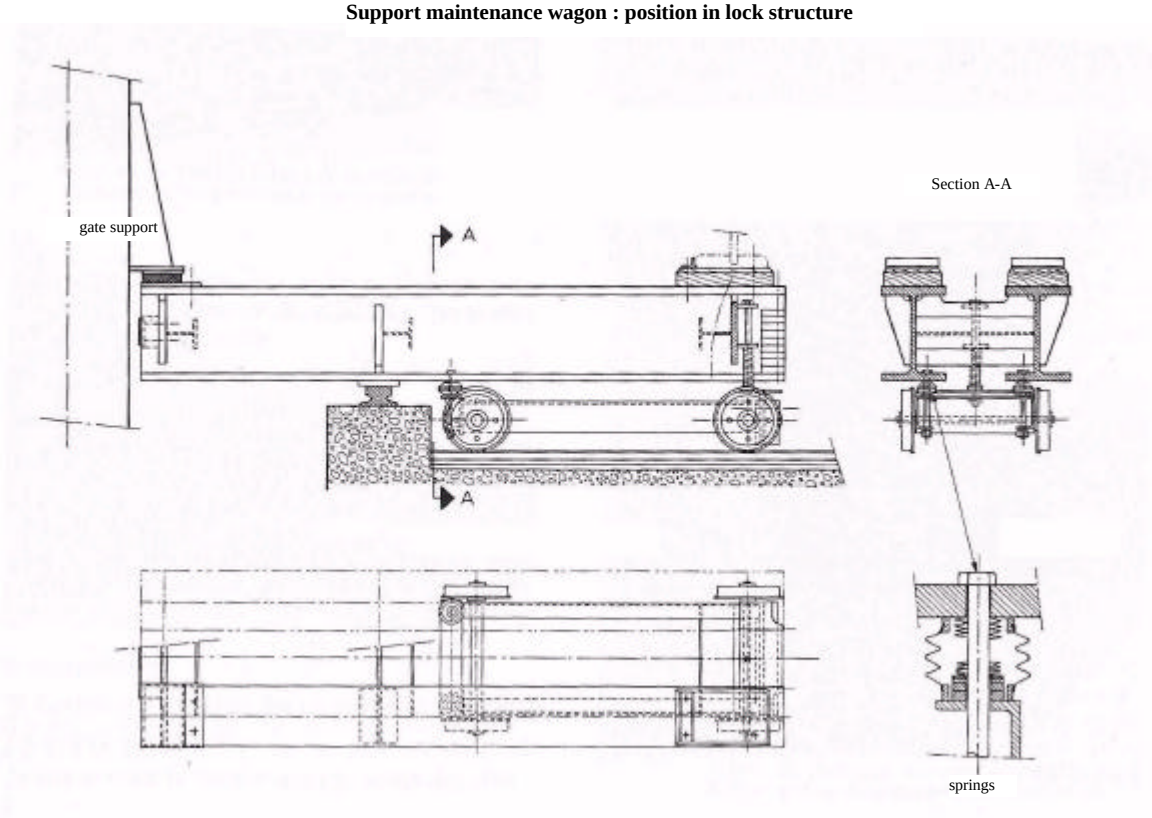
1.3.7 SUPPORT MAINTENANCE WAGON



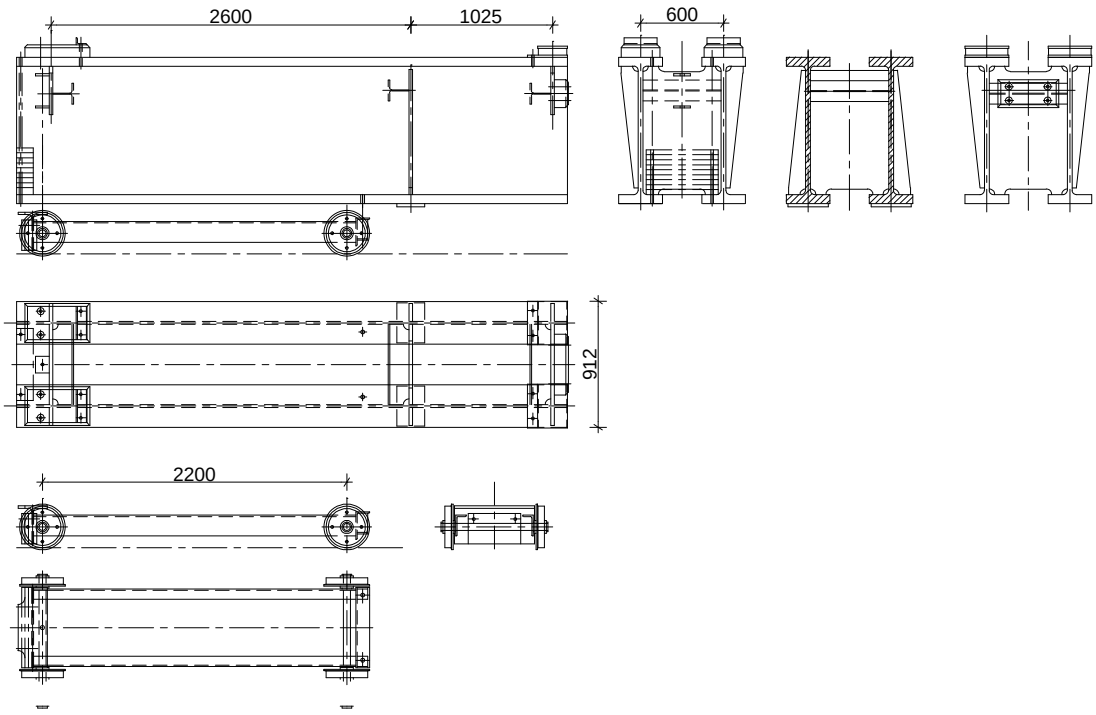
Gate in suspended position



Support maintenance wagon : position in lock structure



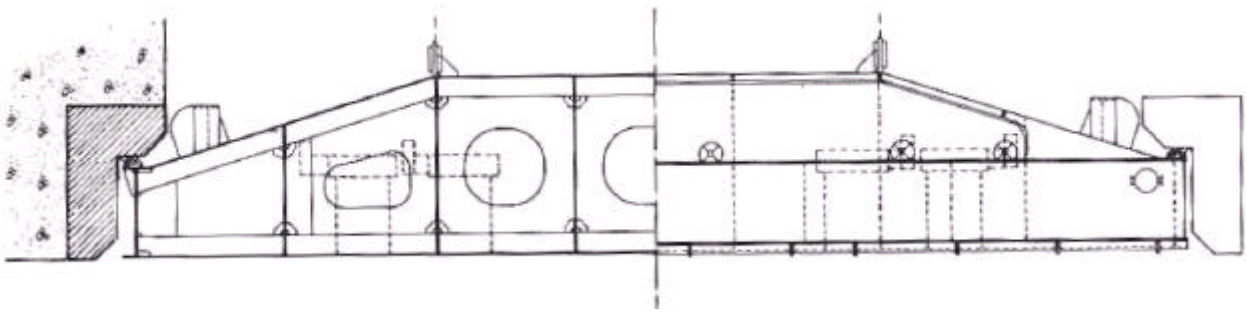
Support maintenance wagon S1 : details



Support maintenance wagon S2

1.3.8 SLOT BULKHEAD

In case of gates S1 the width of the proposed rolling gate structures is comparable to the width of the Berendrecht lock gates. Consequently a design similar to the slot bulkhead of the Berendrecht lock is appropriate (see illustration). Preliminary calculations show that for gates S2 an adapted design based on the same concept is well feasible. This even holds in the case of an additional widening of the gate recess at the connection with the lock chamber to facilitate water exchange during operations of the lock gates to limit the necessary traction forces of the gearing equipment to a reasonable maximum. A sufficient allowance of additional gate recess length is provided to lodge the relatively wide-bodied bulkhead (outside the facings of the lock walls!) together with the retracted lock gate S2 to be maintained and/or repaired in its gate recess.



Slot bulkhead

1.3.9 NOTE ON LOCK DEWATERING PROCEDURE

At the *upstream* lock head the upstream side will be equipped with an additional shaping (among others including an additional sill) to provide an additional bearing. A gate S1 is maneuvered from its gate recess and relocated to constitute a water retaining closure plate against this additional bearing.

At the *downstream* lock head the downstream side will be equipped with an additional shaping (among others including an additional sill) to provide an "inverse" bearing. Against this inverse bearing preferably an appropriate S1-like gate is maneuvered (although in principle a gate S2 might be used for this purpose as well) to constitute a water retaining closure plate. Gates S2 have on only one side (downstream) seals, which have to be positioned relatively close to the bearings. On the other (upstream) side sufficient spacing between the gate and the wall of its gate recess will be provided for maneuvering such that the cumbersome dismounting and remounting of fender beams (at the bottom) is avoided. Lateral guidance of the operating gates at the upstream side will be performed by appropriate wheel fenders, which are fixed to the (upstream) wall of the gate recess. These fenders may be dismounted and remounted relatively easy to provide the necessary lateral space for the gate maneuvers.

Working at the rails of the lower support wagon(s) of both gates S1 and S2 will be performed inside a habitat tunnel, which is accessed through the slot bulkhead (section 1.3.8) from the dewatered corresponding gate recess. Thus it is not necessary to achieve (dry) lock chamber conditions for these maintenance operations and maneuvering of the gates from and back to their gate recesses is avoided.

1.4 SAMPLE COMPUTATIONS FOR GATE S2

1.4.1 GENERAL

In this section sample computations are presented for the case of gate S2. The applied formulae and the corresponding results will be demonstrated as adopted for the concept design of the proposed rolling lock gates.
It should be noted that more thorough procedures can be followed in an advanced level of design and optimization.

1.4.2 LIST OF SYMBOLS

The following symbols will be used (in order of appearance):
H: "width" of the gates, i.e.: distance between outsides of plating (m)

L: spacing between two adjacent vertical structural frames (m)
B: height of a plating panel between two adjacent horizontal structural frames (m)
$e_{(eq)}$: (equivalent) thickness of a plating panel (m)
$p_{w.c}$: characteristic value of the water pressure on a plating panel (N/m^2)
n: number of longitudinal stiffeners over the height B (-)
n_e: number of effective stiffeners against buckling (-)
l: spacing between longitudinal stiffeners (m)
b: spacing between effective stiffeners against buckling (m)
b_e: effective width, allowing for shear lag effect (-)
A: cross section area (m^2)
I: (geometric) moment of inertia (m^4)
W: bending module (I/v) (m^3)
R: subscript referring to (longitudinal) stiffener, in combination with effective plating strip (-)
α: shape factor of plating panel = L/B or L/b or B/L (-)
β: relative width of a plating panel = b/e (-)
δ: relative cross section = A/(B.e) (-)
γ^*: critical relative stiffening factor against buckling (-)
m = 4 for open sections of stiffeners; = 2.5 for closed (e.g.: omega) stiffener profiles
γ^{**} = m . γ^*
ν: Poisson's coefficient = 0.3 for structural steel; $12.(1-\nu^2) = 10.92$
σ: (subscript referring to) normal stress (both tension, compression) (N/m^2)
τ: (subscript referring to) shear stress (N/m^2)
x: (subscript referring to) longitudinal spatial co-ordinate (m)
y: (subscript referring to) transversal spatial co-ordinate (m)
ψ: ratio between minimum and maximum value of longitudinal normal stress at plate edges (-)
ρ: ratio between corrected values of shear stress and longitudinal normal stress (-)
c: correction coefficient (inverse of safety factor) (-)
c*: maximum critical value of correction coefficient c (-)
w: subscript referring to the web of an I-shaped beam (corresponding to a frame) (-)
ac: subscript referring to parts belonging to the air chamber (-)

1.4.3 2D-BEAM GRID MODEL

Both vertical and horizontal structural frames are modeled as I-shaped beams. The skin plating is assigned as flanges to the beams to which it is nearest. The longitudinal compression members of the upstream skin framework of the gates (instead of the plating) also constitute a flange for their corresponding beam. For the webs of the beams corresponding to the intermediate horizontal frames, an assumption is made on the equivalent plate thickness of the horizontal transversal connections.

An overall cross section analysis yields an estimate of the torsion stiffness distribution over the horizontal frames, taking in account their contingence.
Finally the stiffness of the flexible plates at the bottom is tuned to avoid uplift of the bottom corner edges of the skin plating of the gates.

With these geometric characteristics of each beam a 2D-beam grid of the gate structure (integrated over the width) is drawn up.
Doing so the distribution of the section forces and displacements is derived with the (in Europe widely used) ESA-primaWin structural engineering software. Subsequently the material tension levels at the extremities (flanges) of the cross section are computed, in particular for the design of the compressed parts against buckling.

An output document generated by the applied structural engineering software is attached as Appendix A, showing input and output (reaction forces (kN), section forces (kN, kNm), material stresses, deformations (mm)) for the 2D-beam grid model.

Note that the listed reaction forces shown at page 23 can be found as follows:

$$R_{normal} = 1000\frac{kg}{m^3}\cdot 10\frac{m}{s^2}\cdot\frac{(30.11\,m)^2}{2}\cdot 63.6\,m + 1000\frac{kg}{m^3}\cdot 10\frac{m}{s^2}\cdot 30.11\,m\cdot 63.6\,m\cdot 20.58\,m = 682409\,kN$$

$$R_{ultimate} = 1000\frac{kg}{m^3}\cdot 10\frac{m}{s^2}\cdot\frac{(31.11\,m)^2}{2}\cdot 63.6\,m + 1000\frac{kg}{m^3}\cdot 10\frac{m}{s^2}\cdot 31.11\,m\cdot 63.6\,m\cdot 20.58\,m = 714966\,kN$$

The resulting material stresses are shown for each frame in appendix A page 31-33 (load case “water retaining normal”) and page 42-44 (load case “water retaining ultimate”).

1.4.4 DOWNSTREAM AIR CHAMBER PLATING

The plate thickness is chosen corresponding to the tension level derived from the 2D-beam grid model. The longitudinal stiffeners are chosen according to the procedure described in section 1.2.2. For the upper half downstream air chamber plating (panel R6-R7) of gate S2 holds:

L = 2.65 m
B = 7.50m
e = 40 mm
$p_{w.c}$ = 150 kN/m² (15 m water column)

yielding:

n = 9 longitudinal stiffeners type 1/2IPE750-147
l = 0.75 m (= B/10)
b_e = 50.2 cm
I = 67365.5 cm^4
W = 2211.7 cm³ (at flange edge of stiffener)
W = 6019.5 cm³ (at outside plating edge)
e_{eq} = 4.0 cm + 9 x 93.75 cm² / 750 cm = 5.13 cm

For these characteristics the relations (2.1), (2.2a) and (2.2b) of section 1.2.2 hold with σ_{max} = ca. 40 N/mm², leaving sufficient resistance for the characteristic global stress of about 103 N/mm² (see appendix A p. 42) to arrive at a sufficiently moderate total stress, taking in account fatigue.

A similar procedure is followed for the other plating panels, yielding e_{eq}-values that are used to derive characteristics for (the flanges of) the I-shaped members of the 2D-beam grid model (see below).

Gate S2 : Plating panel characteristics					
	Double skin plating both at compression and tension side				
Panel	B	e	profile	n	e_{eq}
R1_top-R2	451	1.4	1/2 IPE500	9	2.55
R2-R3	775	1.4	1/2 IPE500	9	2.07
R3-R4	775	1.6	1/2 IPE600	10	2.61
R4-R5	760	1.6	1/2 IPE600	10	2.63
R5-R6_top ac	400	3.0	1/2 IPE600	5	3.98
R6_top ac-R7_mid_ac	750	4.0	1/2 IPE750-147	9	5.13
R7_mid_ac-R8_bottom_ac	750	4.0	1/2 IPE750-147	10	5.25
R8_bottom_ac-R9_bottom	281	4.0	1/2 IPE600	5	5.39
Flexible plate	227	4.0	none	0	4.00

1.4.5 UPSTREAM AIR CHAMBER PLATING (COMPRESSED)

In order to obtain an appropriately stiffened plating panel to safely resist the longitudinal compression loading, the longitudinal stiffeners are chosen such that the buckling risk of stiffeners doesn't exceed the buckling risk of the separate plating strips between the stiffeners. This is obtained by choosing I_R above a critical value as follows:

$$I_R \;{}^{3}\; \gamma^{**} \frac{Be^3}{12\,(1-\upsilon^2)} \qquad (4.1)$$

where

$$\gamma^{**} = m \cdot MAX\left[\gamma^*_{\sigma_x}\,;\gamma^*_{\sigma_y}\,;\gamma^*_{\tau}\right] \qquad (4.2)$$

The critical relative stiffening factors γ^* for each simple loading case mainly depend on the shape parameter α of each panel. When the number of stiffeners increases, the shear force case is determinative. For three cases a closed formula is published in the technical notes of CECM (n_e = 1, 2 and infinite respectively):

$$\gamma^*_{\tau(1)} = \frac{5.4}{\alpha}\left(\frac{2}{\alpha}+\frac{2.5}{\alpha^2}-\frac{1}{\alpha^3}-1\right) \qquad (4.3.1)$$

$$\gamma^*_{\tau(2)} = \frac{12.1}{\alpha}\left(\frac{4.4}{\alpha}-1\right) \qquad (4.3.2)$$

$$\gamma^*_{\tau(\infty)} = \frac{28}{\alpha} - 20\,\alpha \qquad (4.3.3)$$

For other n_e-values (> 2) an interpolation formula is used.

For the upper half upstream air chamber plating (panel R6-R7) of gate S2, considering again (like the downstream panel, see 1.4.4) e = 40 mm and n_e = 3 effective stiffeners against buckling, holds:

b = B/4 = 1.875 m
$\gamma^*_{t(1)}$ = 0.705, $\gamma^*_{\tau(2)}$ = 2.178, $\gamma^*_{\tau(8)}$ = 8.982
$\gamma^*_{\tau(3)}$ = 2.533 (interpolation)
γ^{**} = 10.21
$I_{R\text{-}min}$ = 44900 cm^4

Choosing profiles 1/2IPE750-147 yields (with b_e = b and n = 9 stiffeners as obtained in 1.4.4):

I_R = 84085 cm^4
e_{eq} = 4.0 cm + 9 x 93.75 cm² / 750 cm = 5.13 cm

Consequently the compressed plating panel safely resists buckling if the separate panels between the (effective) stiffeners have a sufficient safety against buckling. This is evaluated as follows.

The critical resistances against buckling for simple loading cases are respectively:

$$\sigma^o_{x,cr} = k_{\sigma_x}\,\sigma_E \qquad (4.4.1)$$

$$\sigma^o_{y,cr} = k_{\sigma_y}\,\sigma_E \qquad (4.4.2)$$

$$\tau^o_{cr} = k_{\tau}\,\sigma_E \qquad (4.4.3)$$

wherein the Euler stress is defined as: $\sigma_E = \dfrac{\pi^2\ E}{12\,\beta^2\,(1-\nu^2)} = \dfrac{189800 \cdot N/mm^2}{\beta^2}$ (4.5.0)

with β = b/e the relative width of the plating panel

The k-factors follow from linear elastic buckling theory.
For ψ = 1 we have the following formulas:

$$k_{\sigma_x} = \left(\mathrm{MIN}[\alpha;1] + \frac{1}{\mathrm{MIN}[\alpha;1]}\right)^2 \qquad (4.5.1)$$

$$k_{\sigma_y} = \frac{\left(\mathrm{MIN}[\alpha;1] + \frac{1}{\mathrm{MIN}[\alpha;1]}\right)^2}{\alpha^2} \qquad (4.5.2)$$

$$k_\tau = \frac{5.34}{(\mathrm{MIN}[\alpha;1])^2} + \frac{4}{(\mathrm{MAX}[\alpha;1])^2} \tag{4.5.3}$$

Assuming proportionality between the critical resistances for the combined loading case and the actual stresses σ_x, σ_y and τ, the non-reduced ("ideal") combined critical comparison stress level is given by:

$$\sigma_{c,cr}^{id} = \frac{\sigma_c}{\frac{4-\rho}{4}\cdot\frac{\sigma_y}{\sigma_{y,cr}^o} + \sqrt{\left[\frac{\rho}{4}\frac{\sigma_y}{\sigma_{y,cr}^o}\right]^2 + \left[\frac{\sigma_x}{\sigma_{x,cr}^o}\right]^2}} \quad \text{for } \rho \le 1 \tag{4.6.1}$$

$$\sigma_{c,cr}^{id} = \frac{\sigma_c}{\frac{1+2\rho}{4\rho}\cdot\frac{\sigma_y}{\sigma_{y,cr}^o} + \sqrt{\left[\frac{2\rho-1}{4\rho}\frac{\sigma_y}{\sigma_{y,cr}^o}\right]^2 + \left[\frac{\tau}{\tau_{cr}^o}\right]^2}} \quad \text{for } \rho \ge 1 \tag{4.6.2}$$

wherein $\rho = \dfrac{\tau \cdot k_{\sigma x}}{\sigma_x \cdot k_\tau}$ (4.7)

which is reduced if $s_{c,cr}^{id} > 0.8 \cdot f_y$ as follows:

$$\sigma_{c,cr}^{red} = y \cdot f_y \quad \text{with } y = \frac{0.8 + 0.2\cdot\sqrt{1-\frac{0.6}{x^2}}}{1+\frac{0.04}{x^2}} \quad \text{and} \quad x = \frac{\sigma_{c,cr}^{id}}{f_y} > 0.8 \tag{4.8.1}$$

otherwise:

$$\sigma_{c,cr}^{red} = \sigma_{c,cr}^{id} \tag{4.8.2}$$

Finally the actual Von Mises comparison stress σ_c in the compressed plating panel

$$\sigma_c = \sqrt{\sigma_x^{\,2} + \sigma_y^{\,2} - \sigma_x\sigma_y + 3\tau^2} \tag{4.9}$$

is compared with the reduced combined critical comparison stress through a correction factor c defined as:

$$c = \frac{\sigma_c}{\sigma_{c,cr}^{red}} \tag{4.10}$$

Safety against buckling of the plating is guaranteed if this value does not exceed the critical limit value c* = 0.83 which holds for the determinative zone in the middle of the span (case with relatively small shear stress and almost pure compression ψ = 1). In general c* equals a weighted average of the squares of the simple load case critical values:

$$c^* = \sqrt{\frac{\left[\frac{\sigma_x \cdot c_x^*}{\sigma_{x,cr}^o}\right]^2 + \left[\frac{\sigma_y \cdot c_y^*}{\sigma_{y,cr}^o}\right]^2 + \left[\frac{\tau \cdot c_\tau^*}{\tau_{cr}^o}\right]^2}{\left[\frac{\sigma_x}{\sigma_{x,cr}^o}\right]^2 + \left[\frac{\sigma_y}{\sigma_{y,cr}^o}\right]^2 + \left[\frac{\tau}{\tau_{cr}^o}\right]^2}} \qquad (4.11)$$

wherein c^*_x ranges from 0.83 (pure compression) to 1.05 (pure bending), $c^*_y = 0.83$ and $c^*_\tau = 1.05$

The 2D-beam grid model yields the actual design values $\sigma_x = 110$ N/mm², $\sigma_y = 12$ N/mm² and $\tau = 4$ N/mm² (see appendix A p. 42-44) in the middle of the span of the air chamber. The critical resistance values for the simple load cases are respectively: 345.5 N/mm², 194.5 N/mm² and 634.2 N/mm² based on the respective k-factors: 4.00, 2.25 and 7.34.

Using the equations above yields $c = 0.54 < 0.83 = c^*$ showing sufficient safety against plate buckling.

1.4.6 UPSTREAM LONGITUDINAL COMPRESSION MEMBER OF HORIZONTAL FRAME R8 FOR GATES S1

Except from the air chamber zone, no plating is present at the upstream side of the gates to transmit the compression forces at this side due to the water pressure loading. Instead for each horizontal frame profiles are designed against buckling considering a compression force equal to the tension force in the plating at the downstream side (derived from the 2D-beam grid model).

The horizontal framework is assumed to connect only one out of each pair of adjacent vertical frames. The buckling length of the compression members to be considered thus equals 2 x 3.15 m = 6.30 m.

The proposed cross section of the compression member is A = 540 cm² with a minimum geometric moment of inertia I = 108000 cm^4 (this may be acquired by a symmetrical I-shaped beam made of three plates of 600 mm x 30 mm cross section). The characteristic value of the compression stress is 90 N/mm² (obtained from computations for gates S1 similar to those presented in appendix A for gates S2) or $N_{s.c}$ = 4860 kN. For these values a Eurocode 3 unity check for buckling instability (pure compression) results 0.48 < 1.00 OK (see appendix B p. 7).

Note that this A-value is subject to revision in a more detailed level of design, when the connecting framework will be integrated in a full 3D-spatial framework, taking in account the contingence of the different frames.

1.4.7 CONCLUSION: CHARACTERISTICS OF I-SHAPED BEAMS FOR 2D-BEAM GRID MODEL

Following the procedure described above, the characteristics of the I-shaped beams corresponding to the horizontal frames are obtained as listed in the table below (all units in cm).

Gate S2 : Horizontal frame characteristics									
Hor. Frame	A_{comp}	$A_{tension}$	$A_{flanges}$	A_{web}	I_t	I_y	I_z	Wel_y	Wel_z
R1 top	576	576	1151	3639	1,10E+10	2,85E+09	2,44E+06	2,59E+06	2,16E+04
R2	1378	1378	2756	2200	8,81E+09	4,21E+09	4,31E+07	3,83E+06	1,41E+05
R3	1812	1812	3625	2200	7,79E+09	5,26E+09	9,07E+07	4,78E+06	2,34E+05
R4	2008	2008	4016	2200	7,23E+09	5,73E+09	9,86E+07	5,21E+06	2,57E+05
R5	1793	1793	3586	2200	5,60E+09	5,21E+09	5,03E+07	4,73E+06	1,73E+05
R6-top ac	2717	2717	5434	8945	6,43E+09	1,01E+10	1,50E+08	9,19E+06	5,21E+05
R7-mid ac	3891	3891	7781	9418	9,55E+09	1,31E+10	3,65E+08	1,19E+07	9,73E+05
R8-bottom ac	2726	2726	5452	10518	1,46E+10	1,07E+10	6,04E+07	9,77E+06	2,34E+05
R9 bottom	1665	1665	3330	3300	8,23E+09	5,33E+09	1,87E+07	4,84E+06	1,02E+05

The 2-D beam grid model with these characteristics was used to derive the material stresses used in the computations illustrated above. This shows that convergence has been reached. Thus it may be concluded that the proposed structure fulfils the stability rules.

1.4.8 NOTE ON ACCURACY AND MORE DETAILED LEVEL OF DESIGN

The above mentioned results based on the design procedure described in section D1.6 to D1.9 (pages 26-30) in the methodology appendix V of the Quality Plan eventually should be subject to a verification analysis by means of a full 3D Finite Element modeling including plates and frameworks. Thus the spatial contingence of the frames can be assessed more accurately and the design of the beams of the vertical and horizontal frameworks can be optimized.
Based on our experience with such 3D-modeling verification exercises, e.g. with the recently designed new rolling gates for the Van Cauwelaert lock (port of Antwerp), we can state that the accuracy of the above described procedure certainly allows a cost estimate within the limit imposed by the terms of reference.
For the gate S2 structure a preliminary 3D-FEM analysis was carried out, indicating that the model assumptions adopted for this concept design are sufficiently accurate as stated.

1.5 REACTION FORCES

1.5.1 GENERAL

Proceeding according to section D1.7 (pages 27-28) in the methodology appendix V of the Quality Plan, as illustrated in section 1.4 of this report, the distribution of horizontal reaction forces on the water retaining gates is determined. Horizontal reaction forces occur both at the extremities of the gates (vertical lateral bearings on the lock walls) and at the bearing at the sill. Vertical forces occur at the upper and lower support wagons during opening and closing of the gates.

1.5.2 VERTICAL SUPPORTS - ROLLING WAGONS

Maximum vertical forces at the support wagons will occur during operations (closing, opening) of the gates. It is assumed that both the support wagons should remain loaded with a minimum vertical reaction force (ca. 550 kN for gates S1 and ca. 1800 kN for gates S2). Thus a proper functioning of the connections in operational circumstances is guaranteed over a wide range of lateral actions on the gates (wind, waves, currents). The vertical reaction forces increase when the water level decreases, causing the structure to be less submerged and thus its weight to be less relieved.

The rolling wagons are not designed for the vertical reaction forces occurring at water levels lower than the minimum values at opening/closing of the gates listed in section 1.1.1 (e.g. in the event of dewatering the gate recess or even the entire lock chamber). In such cases the lower support wagons will be removed (by pulling them from underneath the floating gates) and subsequently the lock gates will be placed on their fixed bottom supports (see 1.3.3).
The table below shows the total vertical reaction forces on the support wagons at the lowest operating water level of the gates in normal service circumstances (symmetrical distribution of the total vertical reaction force over the wheels of the wagons).

Gate S1	Highest water level	Lowest water level
Upper wagon	560 kN	800 kN
Lower wagon	560 kN	900 kN

Gate S2	Highest water level	Lowest water level
Support wagons	1800 kN	5400 kN

Vertical reaction forces in normal service circumstances

The support wagons are designed taking in account that a single watertight zone (two compartments of the air chamber) may be flooded accidentally, causing an additional possible vertical loading of the support wagons. This additional loading depends on the position of the flooded zone (to be chosen appropriately for each wagon) and the size of the compartment.

Characteristic values of the maximum vertical reactions (at lowest operating water levels) are listed in the table below. For gates S1 the total vertical reaction on the lower support wagon always exceeds the one on the upper support wagon. For both gates S1 and S2 the total vertical reaction on the lower support wagon(s) amounts ca. 7 to 9% of the total weight of the corresponding gate structure.

Gate S1	Side of flooded zone	Other side	Total vert. reaction
Upper wagon	1000 kN	500 kN	1500 kN
Lower wagon	1200 kN	700 kN	1900 kN

Gate S2	Side of flooded zone	Other side	Total vert. reaction
Support wagons	5000 kN	3500 kN	8500 kN

Vertical reaction forces with flooded compartments

The maximum values found for gates S1 are similar to the corresponding ones for gates of the Berendrecht lock. The values for gates S2 are approximately double the values for the lower rolling wagons of the recently designed new rolling gates of the Van Cauwelaert lock (port of Antwerp). They require an adapted design of the two identical lower rolling wagons, which will be equipped with balanced double two-wheel sets (each wheel having a bearing capacity not exceeding 1250 kN) instead of single two-wheel sets at each side of the rolling wagon.

1.5.3 HORIZONTAL FORCES AT THE SILL BEARING

Maximum horizontal reaction forces at the sill bearing occur during retaining of the (maximum) water level difference. They result directly from the 2D-beam grid model computations presented in appendix A after an optimization of the stiffness of the cantilevering bottom ends of the vertical frames. Doing so uplift from the sill bearing of the skin plating at the gate bottom edges is avoided.
To derive the maximum contact stress, the minimum spreading length (along the azobé beams of 500 mm width) is mentioned in the tables below.
.

	Reaction force at frame (3.15 m length)	Max. contact stress (min. 440 mm)
Gate S1	6500 kN	30 N/mm²

	Reaction force at frame (2.65 m length)	Max. contact stress (min. 540 mm)
Gate S2	6000 kN	22 N/mm²

1.5.4 HORIZONTAL FORCES AT THE LATERAL BEARINGS

Maximum horizontal reaction forces at the lateral bearings (on the lock walls) occur during retaining of the (maximum) water level difference. From the 2D-beam grid model computations presented in

appendix A, the reaction forces at the horizontal frames are obtained (corresponding to the same optimized stiffness distribution as mentioned sub 1.5.3). Subsequently the part of the vertical frame structure at the contact with the lock walls is modeled as a continuously elastically supported beam, which is loaded by these reaction forces. The maximum contact stresses (along azobé beams of 500 mm width for gates S1 and 1000 mm width for gates S2) are listed below.

Gate S1	Max. contact stress (at R1)
	45 N/mm²

Gate S2	Max. contact stress at R1	Max. contact stress at R6
	35 N/mm²	42 N/mm² (*)

(*) Based on our experience with 3D-modelling of the recently designed new rolling gates for the Van Cauwelaert lock (port of Antwerp) we expect that the contact stresses at R6 are overestimated at least by 5 N/mm² due to the underestimation of the beam stiffness at the air chamber.

1.5.5 CONCLUSION

The above mentioned computational results show that similar lay outs of the rolling support wagons and bearings of the rolling gates in operation at the large locks in the port of Antwerp (Belgium) are appropriate for use in the actual gates S1 in the Panama case. For gates S2 adapted designs are necessary with balanced double two-wheels sets instead of a single two-wheels sets at each side.
Moreover the pressure levels in the supporting and sealing beams require sufficient high strength materials, like azobé wood or high performance composite materials.

APPENDIX A

Appendix A : 2D-beam grid model gate S2

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1. Input data

Basic data
Structure type : General XYZ

Aantal knopen:	273
Aantal staven:	464
Aantal 1D macro's:	104
Aantal randlijnen:	4
Aantal 2D macro's:	1
Aantal profielen:	25
Aantal belastingsgev.:	4
Aantal materialen:	1

Materials

Naam		
S 355		
	Treksterkte	510.00 MPa
	Vloeigrens	355.00 MPa
	E-modulus	210000.00 MPa
	Poisson coëff.	0.30
	Specifiek gewicht	0.00 kg/mm^3
	Uitzettingscoëff.	1.2e-005 mm/mm.K

List of materials
Beams group:
1/464

nr.	Naam	Kwaliteit	Eenh. gewicht kg/mm	Lengte mm	Massa kg
1	R1 Top (Numeriek)	S 355	3.76	63600	239145
2	R2 (Numeriek)	S 355	3.89	63600	247433
3	R3 (Numeriek)	S 355	4.57	63600	290818
4	R4 (Numeriek)	S 355	4.88	63600	310340
5	R5 (Numeriek)	S 355	4.54	63600	288871
7	R6 Top ac (Numeriek)	S 355	11.29	63600	717836
8	R7 Mid ac (Numeriek)	S 355	13.50	63600	858677
9	R8 Bottom ac (Numeriek)	S 355	12.54	63600	797318
11	R9 Bottom (Numeriek)	S 355	5.20	63600	331009
12	VF R1-R2 (22000,1,2650,14)	S 355	0.75	103730	78310
13	VF R2-R3 (22000,1,2650,14)	S 355	0.75	178250	134569
14	VF R3-R4 (22000,1,2650,16)	S 355	0.84	178250	149396
15	VF R4-R5 (22000,1,2650,16)	S 355	0.84	174800	146504
16	VF R5-R6 (22000,1,2650,30)	S 355	1.42	92000	130674
18	VF ac1 (22000,16,2650,40)	S 355	4.42	172500	761993
19	VF ac2 (22000,16,2650,40)	S 355	4.42	172500	761993
20	VF R8-R9 (22000,1,2650,40)	S 355	1.84	64630	118678
21	Bottom cantilever 1 (1860,40,800,40)	S 355	1.06	26105	27705
22	Bottom cantilever 2 (1685,40,800,40)	S 355	1.01	26105	26271
23	Urand lijf5 (22000,5,1775,16,1300)	S 355	1.31	63220	82699
24	Urand lijf 5 (22000,5,1775,40,1300)	S 355	1.98	40160	79318

List of materials - Macro2D
Beams group:
1/1

nr.	Naam	Kwaliteit	Specifieke massa kgmm^3	Volume mm^3	Massa kg
21	S 355	S 355	0.00	32874840000.00	258067.49

Totaal gewicht van constructie: 6837634.91 kg
Verfoppervlakte: 67714345372.95 mm^2

Section properties, profiles

Doorsnedenr. 1 - R1 Top (Numeriek)
Materiaal : 21 - S 355

A :	4.790000e+003 cm^2		
Ay/A :	0.240	Az/A :	0.760
Iy :	2.850000e+009 cm^4	Iz :	2.440000e+006 cm^4
Iyz :	0.000000e+000 cm^4	It :	1.100000e+010 cm^4
Iw :	1.000000e-006 cm^6		
Wely :	2.590000e+006 cm^3	Welz :	2.160000e+004 cm^3
Wply :	1.000000e-003 cm^3	Wplz :	1.000000e-003 cm^3
cy :	0.00 cm	cz :	0.00 cm
iy :	771.36 cm	iz :	22.57 cm
dy :	0.00 cm	dz :	0.00 cm
Omtrek :		0.00 cm	

Controletype: A-typische doorsnede

Doorsnedenr. 2 - R2 (Numeriek)
Materiaal : 21 - S 355

A :	4.956000e+003 cm^2		
Ay/A :	0.556	Az/A :	0.444
Iy :	4.210000e+009 cm^4	Iz :	4.310000e+007 cm^4
Iyz :	0.000000e+000 cm^4	It :	8.810000e+009 cm^4
Iw :	1.000000e-006 cm^6		
Wely :	3.830000e+006 cm^3	Welz :	1.410000e+005 cm^3
Wply :	1.000000e-003 cm^3	Wplz :	1.000000e-003 cm^3
cy :	0.00 cm	cz :	0.00 cm
iy :	921.67 cm	iz :	93.26 cm
dy :	0.00 cm	dz :	0.00 cm
Omtrek :		0.00 cm	

Controletype: A-typische doorsnede

Doorsnedenr. 3 - R3 (Numeriek)
Materiaal : 21 - S 355

A :	5.825000e+003 cm^2		
Ay/A :	0.622	Az/A :	0.378
Iy :	5.260000e+009 cm^4	Iz :	9.070000e+007 cm^4
Iyz :	0.000000e+000 cm^4	It :	7.790000e+009 cm^4
Iw :	1.000000e-006 cm^6		
Wely :	4.780000e+006 cm^3	Welz :	2.340000e+005 cm^3
Wply :	1.000000e-003 cm^3	Wplz :	1.000000e-003 cm^3
cy :	0.00 cm	cz :	0.00 cm
iy :	950.27 cm	iz :	124.78 cm
dy :	0.00 cm	dz :	0.00 cm
Omtrek :		0.00 cm	

Controletype: A-typische doorsnede

Doorsnedenr. 4 - R4 (Numeriek)
Materiaal : 21 - S 355

A :	6.216000e+003 cm^2		
Ay/A :	0.646	Az/A :	0.354
Iy :	5.730000e+009 cm^4	Iz :	9.860000e+007 cm^4
Iyz :	0.000000e+000 cm^4	It :	7.230000e+009 cm^4
Iw :	1.000000e-006 cm^6		
Wely :	5.210000e+006 cm^3	Welz :	2.570000e+005 cm^3
Wply :	1.000000e-003 cm^3	Wplz :	1.000000e-003 cm^3
cy :	0.00 cm	cz :	0.00 cm
iy :	960.11 cm	iz :	125.95 cm
dy :	0.00 cm	dz :	0.00 cm
Omtrek :		0.00 cm	

Controletype: A-typische doorsnede

Doorsnedenr. 5 - R5 (Numeriek)
Materiaal : 21 - S 355

A :	5.786000e+003 cm^2		
Ay/A :	0.620	Az/A :	0.380
Iy :	5.210000e+009 cm^4	Iz :	5.030000e+007 cm^4
Iyz :	0.000000e+000 cm^4	It :	5.600000e+009 cm^4
Iw :	1.000000e+000 cm^6		
Wely :	4.730000e+006 cm^3	Welz :	1.730000e+005 cm^3
Wply :	1.000000e-003 cm^3	Wplz :	1.000000e-003 cm^3
cy :	0.00 cm	cz :	0.00 cm
iy :	948.92 cm	iz :	93.24 cm
dy :	0.00 cm	dz :	0.00 cm
Omtrek :		0.00 cm	

Controletype: A-typische doorsnede

Doorsnedenr. 7 - R6 Top ac (Numeriek)
Materiaal : 21 - S 355

A :	1.437800e+004 cm^2		
Ay/A :	0.378	Az/A :	0.622
Iy :	1.010000e+010 cm^4	Iz :	1.500000e+008 cm^4
Iyz :	0.000000e+000 cm^4	It :	6.430000e+009 cm^4
Iw :	1.000000e-006 cm^6		
Wely :	9.190000e+006 cm^3	Welz :	5.210000e+005 cm^3
Wply :	1.000000e-003 cm^3	Wplz :	1.000000e-003 cm^3
cy :	0.00 cm	cz :	0.00 cm
iy :	838.13 cm	iz :	102.14 cm
dy :	0.00 cm	dz :	0.00 cm
Omtrek :		0.00 cm	

Controletype: A-typische doorsnede

Doorsnedenr. 8 - R7 Mid ac (Numeriek)
Materiaal : 21 - S 355

A :	1.719900e+004 cm^2		
Ay/A :	0.452	Az/A :	0.548
Iy :	1.310000e+010 cm^4	Iz :	3.650000e+008 cm^4
Iyz :	0.000000e+000 cm^4	It :	9.550000e+009 cm^4
Iw :	1.000000e-006 cm^6		
Wely :	1.190000e+007 cm^3	Welz :	9.730000e+005 cm^3
Wply :	1.000000e-003 cm^3	Wplz :	1.000000e-003 cm^3
cy :	0.00 cm	cz :	0.00 cm
iy :	872.74 cm	iz :	145.68 cm
dy :	0.00 cm	dz :	0.00 cm
Omtrek :		0.00 cm	

Controletype: A-typische doorsnede

Doorsnedenr. 9 - R8 Bottom ac (Numeriek)
Materiaal : 21 - S 355

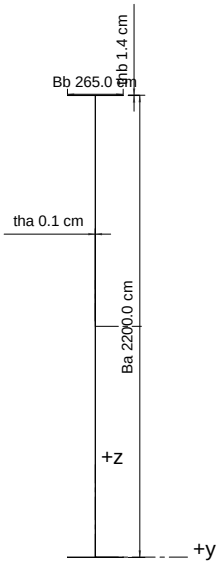
A :	1.597000e+004 cm^2		
Ay/A :	0.341	Az/A :	0.659
Iy :	1.070000e+010 cm^4	Iz :	6.040000e+007 cm^4
Iyz :	0.000000e+000 cm^4	It :	1.460000e+010 cm^4
Iw :	1.000000e-006 cm^6		
Wely :	9.770000e+006 cm^3	Welz :	2.340000e+005 cm^3
Wply :	1.000000e-003 cm^3	Wplz :	1.000000e-003 cm^3
cy :	0.00 cm	cz :	0.00 cm
iy :	818.54 cm	iz :	61.50 cm
dy :	0.00 cm	dz :	0.00 cm
Omtrek :		0.00 cm	

Controletype: A-typische doorsnede

Doorsnedenr. 11 - R9 Bottom (Numeriek)
Materiaal : 21 - S 355

A :	6.630000e+003 cm^2		
Ay/A :	0.502	Az/A :	0.498
Iy :	5.330000e+009 cm^4	Iz :	1.870000e+007 cm^4
Iyz :	0.000000e+000 cm^4	It :	8.230000e+009 cm^4
Iw :	1.000000e-006 cm^6		
Wely :	4.840000e+006 cm^3	Welz :	1.020000e+005 cm^3
Wply :	1.000000e-003 cm^3	Wplz :	1.000000e-003 cm^3
cy :	0.00 cm	cz :	0.00 cm
iy :	896.62 cm	iz :	53.11 cm
dy :	0.00 cm	dz :	0.00 cm
Omtrek :		0.00 cm	

Controletype: A-typische doorsnede



VF R1-R2 (2200.0,0.1,265.0,1.4)

Doorsnedenr. 12 - VF R1-R2 (2200.0,0.1,265.0,1.4)
Materiaal : 21 - S 355

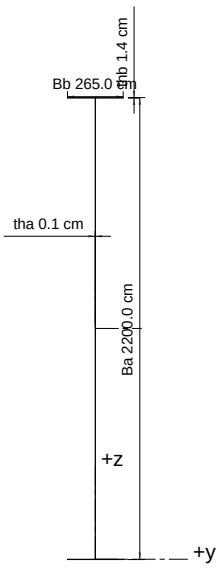
1	P1/21972 - S 355
2	P14/2650 - S 355
3	P14/2650 - S 355

A :	9.617200e+002 cm^2		
Ay/A :	0.817	Az/A :	0.228
Iy :	9.850728e+008 cm^4	Iz :	4.342247e+006 cm^4
Iyz :	8.118303e-009 cm^4	It :	4.855062e+002 cm^4
Iw :	5.903362e+012 cm^6		
Wely :	8.955207e+005 cm^3	Welz :	3.277167e+004 cm^3
Wply :	9.363729e+005 cm^3	Wplz :	4.916300e+004 cm^3

A :	9.617200e+002 cm^2		
cy :	-0.05 cm	cz :	1098.60 cm
iy :	1012.07 cm	iz :	67.19 cm
dy :	0.00 cm	dz :	0.00 cm
Omtrek :		5459.80 cm	

Controletype: I-profiel

Hoogte	2200.00 cm	Breedte	265.00 cm
Flensdikte	1.40 cm	Lijfdikte	0.10 cm
Straal	0.10 cm		



VF R2-R3 (2200.0,0.1,265.0,1.4)

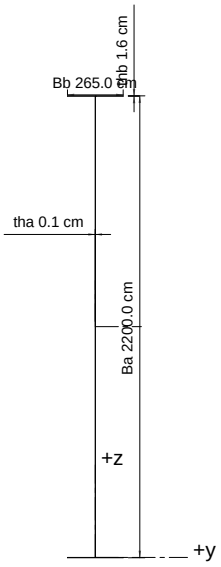
Doorsnedenr. 13 - VF R2-R3 (2200.0,0.1,265.0,1.4)
Materiaal : 21 - S 355

1	P1/21972 - S 355
2	P14/2650 - S 355
3	P14/2650 - S 355

A :	9.617200e+002 cm^2		
Ay/A :	0.817	Az/A :	0.228
Iy :	9.850728e+008 cm^4	Iz :	4.342247e+006 cm^4
Iyz :	8.118303e-009 cm^4	It :	4.855062e+002 cm^4
Iw :	5.903362e+012 cm^6		
Wely :	8.955207e+005 cm^3	Welz :	3.277167e+004 cm^3
Wply :	9.363729e+005 cm^3	Wplz :	4.916300e+004 cm^3
cy :	-0.05 cm	cz :	1098.60 cm
iy :	1012.07 cm	iz :	67.19 cm
dy :	0.00 cm	dz :	0.00 cm
Omtrek :		5459.80 cm	

Controletype: I-profiel

Hoogte	2200.00 cm	Breedte	265.00 cm
Flensdikte	1.40 cm	Lijfdikte	0.10 cm
Straal	0.10 cm		



VF R3-R4 (2200.0,0.1,265.0,1.6)

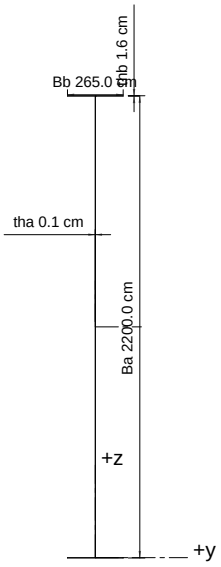
Doorsnedenr. 14 - VF R3-R4 (2200.0,0.1,265.0,1.6)
Materiaal : 21 - S 355

1	P1/21968 - S 355
2	P16/2650 - S 355
3	P16/2650 - S 355

A :	1.067680e+003 cm^2		
Ay/A :	0.841	Az/A :	0.206
Iy :	1.112935e+009 cm^4	Iz :	4.962568e+006 cm^4
Iyz :	8.114237e-009 cm^4	It :	7.243595e+002 cm^4
Iw :	6.745472e+012 cm^6		
Wely :	1.011759e+006 cm^3	Welz :	3.745334e+004 cm^3
Wply :	1.052770e+006 cm^3	Wplz :	5.618550e+004 cm^3
cy :	-0.05 cm	cz :	1098.40 cm
iy :	1020.97 cm	iz :	68.18 cm
dy :	0.00 cm	dz :	0.00 cm
Omtrek :		5459.80 cm	

Controletype: I-profiel

Hoogte	2200.00 cm	Breedte	265.00 cm
Flensdikte	1.60 cm	Lijfdikte	0.10 cm
Straal	0.10 cm		



VF R4-R5 (2200.0,0.1,265.0,1.6)

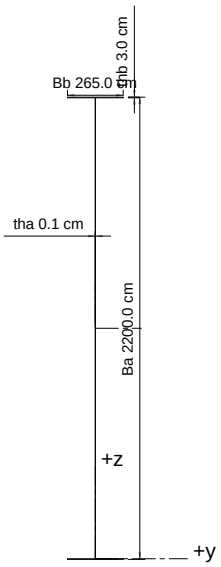
Doorsnedenr. 15 - VF R4-R5 (2200.0,0.1,265.0,1.6)
Materiaal : 21 - S 355

1	P1/21968 - S 355
2	P16/2650 - S 355
3	P16/2650 - S 355

A :	1.067680e+003 cm^2		
Ay/A :	0.841	Az/A :	0.206
Iy :	1.112935e+009 cm^4	Iz :	4.962568e+006 cm^4
Iyz :	8.114237e-009 cm^4	It :	7.243595e+002 cm^4
Iw :	6.745472e+012 cm^6		
Wely :	1.011759e+006 cm^3	Welz :	3.745334e+004 cm^3
Wply :	1.052770e+006 cm^3	Wplz :	5.618550e+004 cm^3
cy :	-0.05 cm	cz :	1098.40 cm
iy :	1020.97 cm	iz :	68.18 cm
dy :	0.00 cm	dz :	0.00 cm
Omtrek :		5459.80 cm	

Controletype: I-profiel

Hoogte	2200.00 cm	Breedte	265.00 cm
Flensdikte	1.60 cm	Lijfdikte	0.10 cm
Straal	0.10 cm		



VF R5-R6 (2200.0,0.1,265.0,3.0)

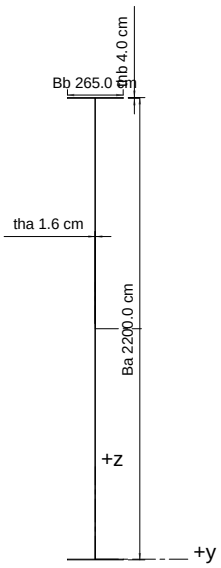
Doorsnedenr. 16 - VF R5-R6 (2200.0,0.1,265.0,3.0)
Materiaal : 21 - S 355

1	P1/21940 - S 355
2	P30/2650 - S 355
3	P30/2650 - S 355

A :	1.809400e+003 cm^2		
Ay/A :	0.930	Az/A :	0.121
Iy :	2.006667e+009 cm^4	Iz :	9.304813e+006 cm^4
Iyz :	8.082727e-009 cm^4	It :	4.770732e+003 cm^4
Iw :	1.263166e+013 cm^6		
Wely :	1.824243e+006 cm^3	Welz :	7.022501e+004 cm^3
Wply :	1.866956e+006 cm^3	Wplz :	1.053430e+005 cm^3
cy :	-0.05 cm	cz :	1097.00 cm
iy :	1053.10 cm	iz :	71.71 cm
dy :	0.00 cm	dz :	-0.00 cm
Omtrek :		5459.80 cm	

Controletype: I-profiel

Hoogte	2200.00 cm	Breedte	265.00 cm
Flensdikte	3.00 cm	Lijfdikte	0.10 cm
Straal	0.10 cm		



VF ac1 (2200.0,1.6,265.0,4.0)

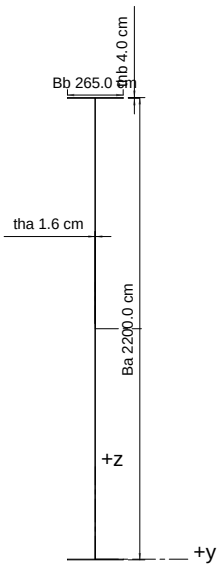
Doorsnedenr. 18 - VF ac1 (2200.0,1.6,265.0,4.0)
Materiaal : 21 - S 355

1	P16/21920 - S 355
2	P40/2650 - S 355
3	P40/2650 - S 355

A :	5.627200e+003 cm^2		
Ay/A :	0.398	Az/A :	0.608
Iy :	3.960185e+009 cm^4	Iz :	1.240717e+007 cm^4
Iyz :	1.291068e-007 cm^4	It :	1.430494e+004 cm^4
Iw :	1.682688e+013 cm^6		
Wely :	3.600168e+006 cm^3	Welz :	9.363899e+004 cm^3
Wply :	4.249706e+006 cm^3	Wplz :	1.418529e+005 cm^3
cy :	-0.80 cm	cz :	1096.00 cm
iy :	838.90 cm	iz :	46.96 cm
dy :	0.00 cm	dz :	0.00 cm
Omtrek :		5456.80 cm	

Controletype: I-profiel

Hoogte	2200.00 cm	Breedte	265.00 cm
Flensdikte	4.00 cm	Lijfdikte	1.60 cm
Straal	1.60 cm		



VF ac2 (2200.0,1.6,265.0,4.0)

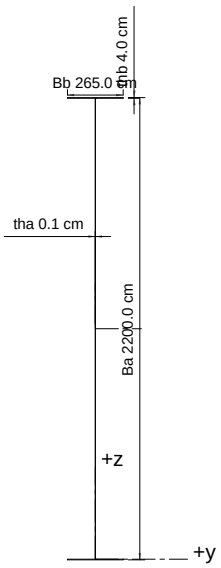
Doorsnedenr. 19 - VF ac2 (2200.0,1.6,265.0,4.0)
Materiaal : 21 - S 355

1	P16/21920 - S 355
2	P40/2650 - S 355
3	P40/2650 - S 355

A :	5.627200e+003 cm^2		
Ay/A :	0.398	Az/A :	0.608
Iy :	3.960185e+009 cm^4	Iz :	1.240717e+007 cm^4
Iyz :	1.291068e-007 cm^4	It :	1.430494e+004 cm^4
Iw :	1.682688e+013 cm^6		
Wely :	3.600168e+006 cm^3	Welz :	9.363899e+004 cm^3
Wply :	4.249706e+006 cm^3	Wplz :	1.418529e+005 cm^3
cy :	-0.80 cm	cz :	1096.00 cm
iy :	838.90 cm	iz :	46.96 cm
dy :	0.00 cm	dz :	0.00 cm
Omtrek :		5456.80 cm	

Controletype: I-profiel

Hoogte	2200.00 cm	Breedte	265.00 cm
Flensdikte	4.00 cm	Lijfdikte	1.60 cm
Straal	1.60 cm		



VF R8-R9 (2200.0,0.1,265.0,4.0)

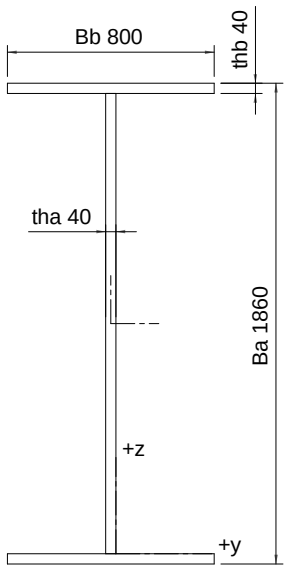
Doorsnedenr. 20 - VF R8-R9 (2200.0,0.1,265.0,4.0)
Materiaal : 21 - S 355

1	P1/21920 - S 355
2	P40/2650 - S 355
3	P40/2650 - S 355

A :	2.339200e+003 cm^2		
Ay/A :	0.959	Az/A :	0.094
Iy :	2.643652e+009 cm^4	Iz :	1.240642e+007 cm^4
Iyz :	8.061551e-009 cm^4	It :	1.130740e+004 cm^4
Iw :	1.682688e+013 cm^6		
Wely :	2.403320e+006 cm^3	Welz :	9.363334e+004 cm^3
Wply :	2.447882e+006 cm^3	Wplz :	1.404555e+005 cm^3
cy :	-0.05 cm	cz :	1096.00 cm
iy :	1063.09 cm	iz :	72.83 cm
dy :	0.00 cm	dz :	0.00 cm
Omtrek :		5459.80 cm	

Controletype: I-profiel

Hoogte	2200.00 cm	Breedte	265.00 cm
Flensdikte	4.00 cm	Lijfdikte	0.10 cm
Straal	0.10 cm		



Bottom cantilever 1 (186.0,4.0,80.0,4.0)

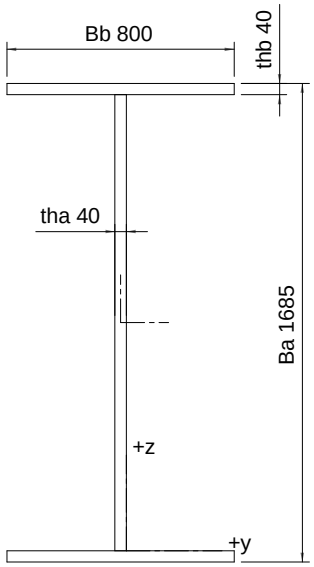
Doorsnedenr. 21 - Bottom cantilever 1 (186.0,4.0,80.0,4.0)
Materiaal : 21 - S 355

1	P40/1780 - S 355
2	P40/800 - S 355
3	P40/800 - S 355

A :	1.352000e+003 cm^2		
Ay/A :	0.401	Az/A :	0.506
Iy :	7.180610e+006 cm^4	Iz :	3.422827e+005 cm^4
Iyz :	1.761829e-010 cm^4	It :	7.296000e+003 cm^4
Iw :	2.865839e+009 cm^6		
Wely :	7.721087e+004 cm^3	Welz :	8.557066e+003 cm^3
Wply :	8.992400e+004 cm^3	Wplz :	1.351200e+004 cm^3
cy :	-2.00 cm	cz :	89.00 cm
iy :	72.88 cm	iz :	15.91 cm
dy :	-0.00 cm	dz :	-0.00 cm
Omtrek :		684.00 cm	

Controletype: I-profiel

Hoogte	186.00 cm	Breedte	80.00 cm
Flensdikte	4.00 cm	Lijfdikte	4.00 cm
Straal	4.00 cm		



Bottom cantilever 2 (168.5,4.0,80.0,4.0)

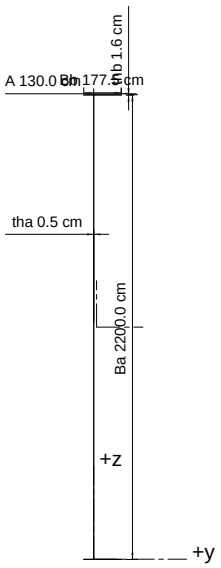
Doorsnedenr. 22 - Bottom cantilever 2 (168.5,4.0,80.0,4.0)
Materiaal : 21 - S 355

1	P40/1605 - S 355
2	P40/800 - S 355
3	P40/800 - S 355

A :	1.282000e+003 cm^2		
Ay/A :	0.419	Az/A :	0.480
Iy :	5.708667e+006 cm^4	Iz :	3.421893e+005 cm^4
Iyz :	8.185726e-010 cm^4	It :	6.922667e+003 cm^4
Iw :	2.332704e+009 cm^6		
Wely :	6.775866e+004 cm^3	Welz :	8.554733e+003 cm^3
Wply :	7.840025e+004 cm^3	Wplz :	1.344200e+004 cm^3
cy :	-2.00 cm	cz :	80.25 cm
iy :	66.73 cm	iz :	16.34 cm
dy :	0.00 cm	dz :	0.00 cm
Omtrek :		649.00 cm	

Controletype: I-profiel

Hoogte	168.50 cm	Breedte	80.00 cm
Flensdikte	4.00 cm	Lijfdikte	4.00 cm
Straal	4.00 cm		



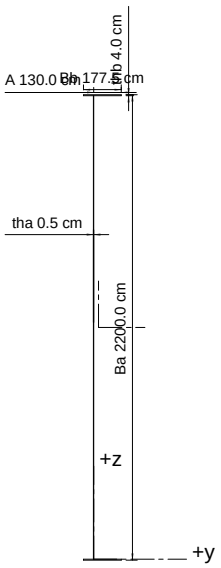
Urand lijf5 (2200.0,0.5,177.5,1.6,130.0)

Doorsnedenr. 23 - Urand lijf5 (2200.0,0.5,177.5,1.6,130.0)
Materiaal : 21 - S 355

1	P5/21968 - S 355
2	P16/1775 - S 355
3	P16/1775 - S 355

A :	1.666400e+003 cm^2		
Ay/A :	0.833	Az/A :	0.640
Iy :	1.128014e+009 cm^4	Iz :	2.136120e+006 cm^4
Iyz :	-7.993606e-007 cm^4	It :	5.762933e+002 cm^4
Iw :	2.690168e+012 cm^6		
Wely :	1.025468e+006 cm^3	Welz :	1.839825e+004 cm^3
Wply :	1.227587e+006 cm^3	Wplz :	3.088161e+004 cm^3
cy :	13.90 cm	cz :	1098.40 cm
iy :	822.75 cm	iz :	35.80 cm
dy :	-39.33 cm	dz :	0.00 cm
Omtrek :		5109.00 cm	

Controletype: A-typische doorsnede



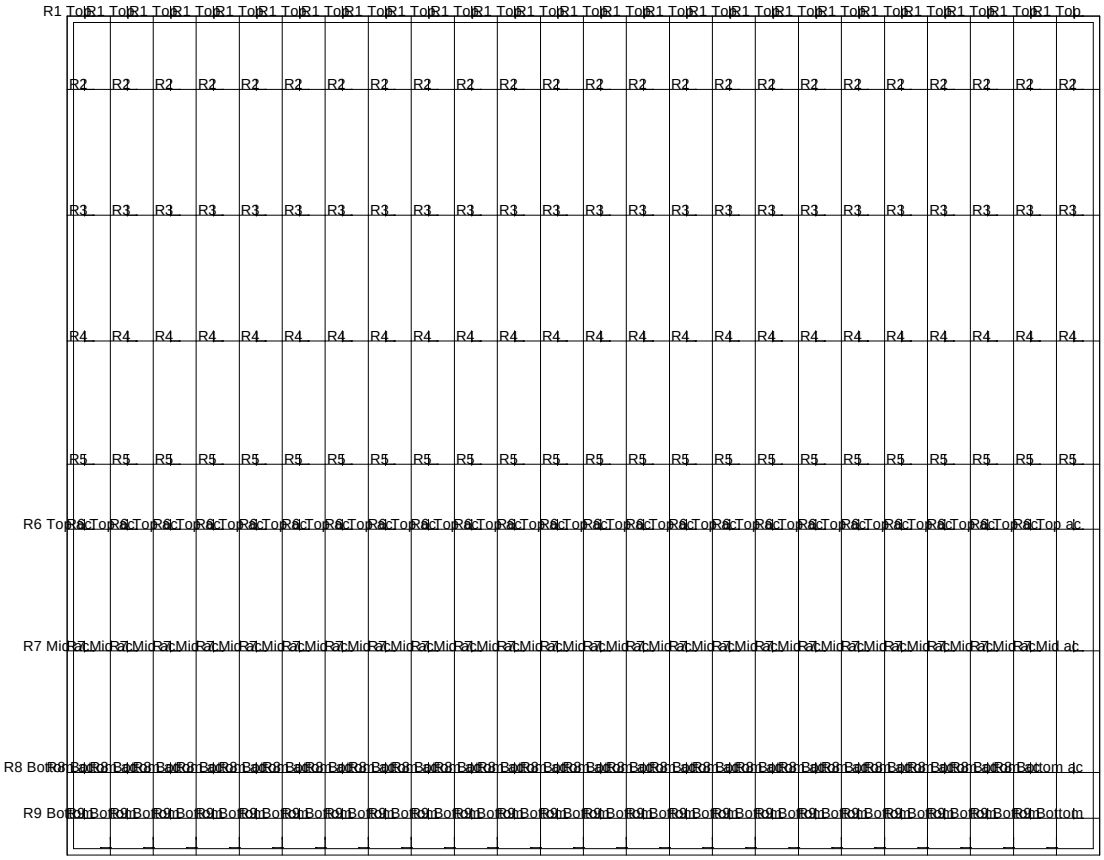
Urand lijf 5 (2200.0,0.5,177.5,4.0,130.0)

Doorsnedenr. 24 - Urand lijf 5 (2200.0,0.5,177.5,4.0,130.0)
Materiaal : 21 - S 355

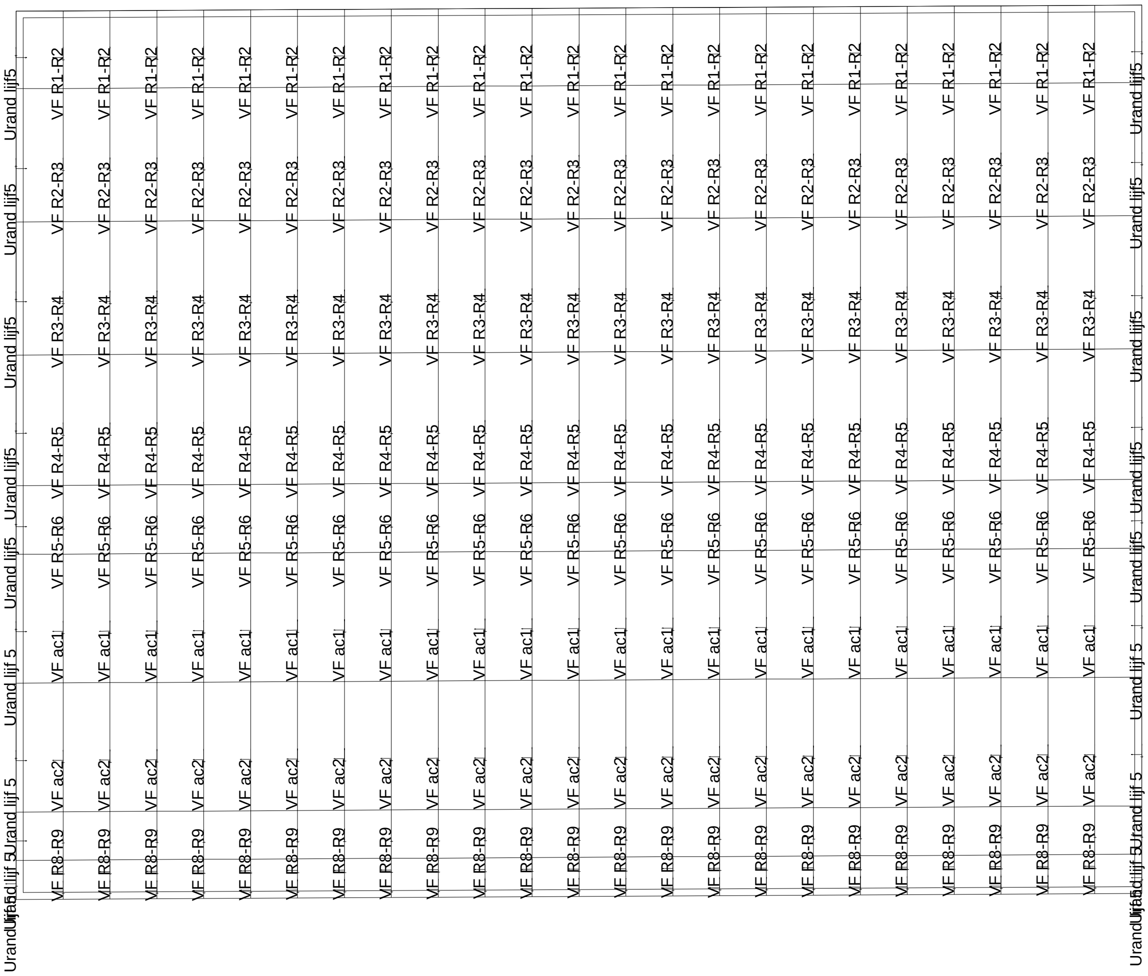
1	P5/21920 - S 355
2	P40/1775 - S 355
3	P40/1775 - S 355

A :	2.516000e+003 cm^2		
Ay/A :	0.833	Az/A :	0.432
Iy :	2.150804e+009 cm^4	Iz :	4.793593e+006 cm^4
Iyz :	-2.442491e-007 cm^4	It :	7.664834e+003 cm^4
Iw :	6.158097e+012 cm^6		
Wely :	1.955276e+006 cm^3	Welz :	4.487211e+004 cm^3
Wply :	2.159768e+006 cm^3	Wplz :	7.654265e+004 cm^3
cy :	23.17 cm	cz :	1096.00 cm
iy :	924.58 cm	iz :	43.65 cm
dy :	-56.38 cm	dz :	0.00 cm
Omtrek :		5109.00 cm	

Controletype: A-typische doorsnede



Horizontal frames



Vertical frames

Support boundary conditions

Support	node	type	flexibility kN/m-kNm/rad	Afmeting mm
1	1	Y		0.00
2	21	Y		0.00
3	22	Y		0.00
4	42	Y		0.00
5	43	Y		0.00
6	63	Y		0.00
7	64	Y		0.00
8	84	Y		0.00
9	85	Y		0.00
10	105	Y		0.00
11	106	Y		0.00
12	126	Y		0.00
13	127	Y		0.00
14	147	Y		0.00
15	148	Z		0.00
16	149	YZ	ky =710000.00	0.00
17	150	YZ	ky =710000.00	0.00
18	151	YZ	ky =710000.00	0.00
19	152	YZ	ky =710000.00	0.00
20	153	YZ	ky =710000.00	0.00
21	154	YZ	ky =710000.00	0.00
22	155	YZ	ky =710000.00	0.00
23	156	YZ	ky =710000.00	0.00
24	157	YZ	ky =710000.00	0.00
25	158	XYZ	ky =710000.00	0.00
26	159	YZ	ky =710000.00	0.00
27	160	YZ	ky =710000.00	0.00
28	161	YZ	ky =710000.00	0.00
29	162	YZ	ky =710000.00	0.00
30	163	YZ	ky =710000.00	0.00
31	164	YZ	ky =710000.00	0.00
32	165	YZ	ky =710000.00	0.00
33	166	YZ	ky =710000.00	0.00
34	167	YZ	ky =710000.00	0.00
35	168	Z		0.00
36	169	Y		0.00
37	170	Y		0.00
38	190	Y		0.00
39	210	Y		0.00
40	211	YZ	ky =710000.00	0.00
41	212	YZ	ky =710000.00	0.00
42	213	YZ	ky =710000.00	0.00
43	214	YZ	ky =710000.00	0.00

Load cases

LC	Naam	Omschrijving
1	WR normal +26.67 -3.44 PLD	Variabel - Water pressure excl.
2	WR ultimate +27.67 -3.44 PLD	Variabel - Water pressure excl.
3	EG	Eigengewicht. Richting -Z
4	Dry water condition -21.02 +3.60 PLD	Variabel - Water pressure excl.

Load case no. 1 – Free load

Rechthoeken

Index	Verdeling	x m	y m	qx kN/m^2	qy kN/m^2	qz kN/m^2	Systeem	Geldigheid	Locatie
1	Uniform	0.00	-24.02	0.00	-301.10	0.00	Globaal	Alles	Lengte
1		63.60	-3.44						
2	Richting Y	0.00	-3.44	0.00	-301.10	0.00	Globaal	Alles	Lengte
2		63.60	26.67	0.00	0.00	0.00			

Load case no. 2 – Free load

Rechthoeken

Index	Verdeling	x m	y m	qx kN/m^2	qy kN/m^2	qz kN/m^2	Systeem	Geldigheid	Locatie
1	Uniform	0.00	-24.02	0.00	-311.10	0.00	Globaal	Alles	Lengte
1		63.60	-3.44						
2	Richting Y	0.00	-3.44	0.00	-311.10	0.00	Globaal	Alles	Lengte
2		63.60	27.67	0.00	0.00	0.00			

Load case no. 4 – Free load

Rechthoeken

Index	Verdeling	x m	y m	qx kN/m^2	qy kN/m^2	qz kN/m^2	Systeem	Geldigheid	Locatie
1	Richting Y	0.00	-24.02	0.00	-288.00	0.00	Globaal	Alles	Lengte
1		63.60	4.60	0.00	0.00	0.00			

Load combinations

Combi	Norm	BG	coëff
1.	EC ULS	1 WR normal +26.67 -3.44 PLD	0.90
1.	EC ULS	2 WR ultimate +27.67 -3.44 PLD	0.90
1.	EC ULS	3 EG	1.00
1.	EC ULS	4 Dry water condition -21.02 +3.60 PLD	0.90
2.	EC SLS	1 WR normal +26.67 -3.44 PLD	1.00
2.	EC SLS	2 WR ultimate +27.67 -3.44 PLD	1.00
2.	EC SLS	3 EG	1.00
2.	EC SLS	4 Dry water condition -21.02 +3.60 PLD	1.00

Ultimate load combination rules:

1 : 1.35*BG3
2 : 1.35*BG1 / 1.35*BG2 / 1.35*BG3 / 1.35*BG4
3 : 1.35*BG1 / 1.35*BG2 / 1.00*BG3 / 1.35*BG4

Servicebility load combination rules:
:
1 : 1.00*BG3
2 : 1.00*BG1 / 1.00*BG2 / 1.00*BG3 / 1.00*BG4

Ultimate load combinations:

1/ 3 : +1.00*BG3
2/ 1 : +1.35*BG3
3/ 3 : +1.35*BG1+1.00*BG3
4/ 3 : +1.35*BG2+1.00*BG3
5/ 3 : +1.00*BG3+1.35*BG4
6/ 2 : +1.35*BG1+1.35*BG3
7/ 2 : +1.35*BG2+1.35*BG3
8/ 2 : +1.35*BG3+1.35*BG4

Servicebility load combinations:
1/ 1 : +1.00*BG3
2/ 2 : +1.00*BG1+1.00*BG3
3/ 2 : +1.00*BG2+1.00*BG3
4/ 2 : +1.00*BG3+1.00*BG4

Report calculations

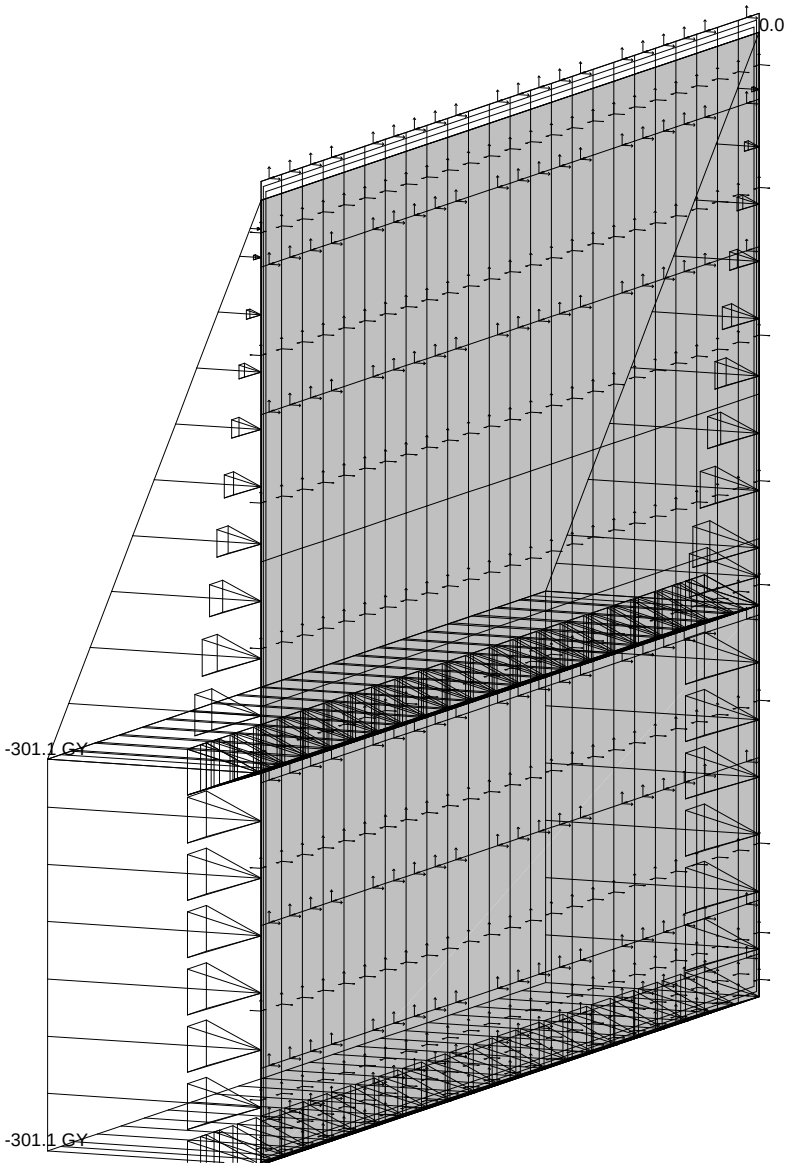
Linear calculation

Aantal 2D elementen	7104
Aantal 1D elementen	666
Aantal netknopen	7298
Aantal vergelijkingen	43788
Belastinggevallen	BG 1 WR normal +26.67 -3.44 PLD
	BG 2 WR ultimate +27.67 -3.44 PLD
	BG 3 EG
	BG 4 Dry water condition -21.02 +3.60 PLD
Buigtheorie	Mindlin
Start berekening	11.12.2002 07:32
Einde berekening	11.12.2002 07:33

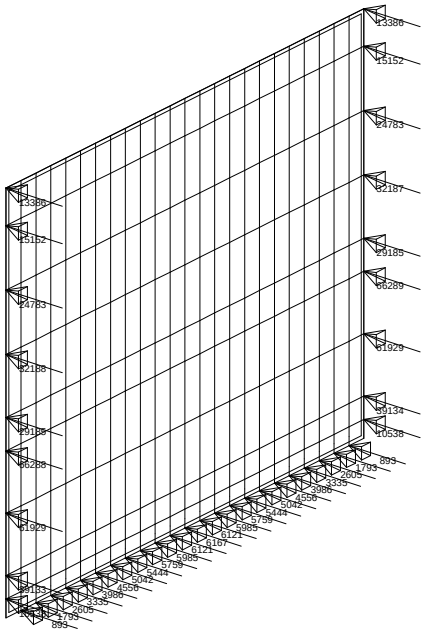
Sum of loads and reaction forces.

		X	Y	Z
belastinggeval 1	last	0.0	-682395.6	0.0
	reactie	0.0	682372.2	-0.0
	contact	0.0	0.0	0.0
belastinggeval 2	last	0.0	-714992.2	0.0
	reactie	-0.0	714970.8	-0.0
	contact	0.0	0.0	0.0
belastinggeval 3	last	-0.0	-0.0	-68376.4
	reactie	0.0	0.0	68376.4
	contact	0.0	0.0	0.0
belastinggeval 4	last	0.0	-262076.0	0.0
	reactie	0.0	262069.4	0.0
	contact	0.0	0.0	0.0

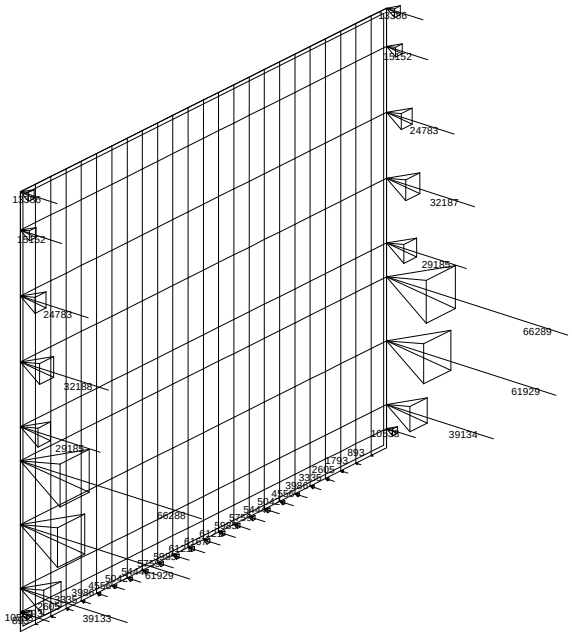
2. Water retaining normal



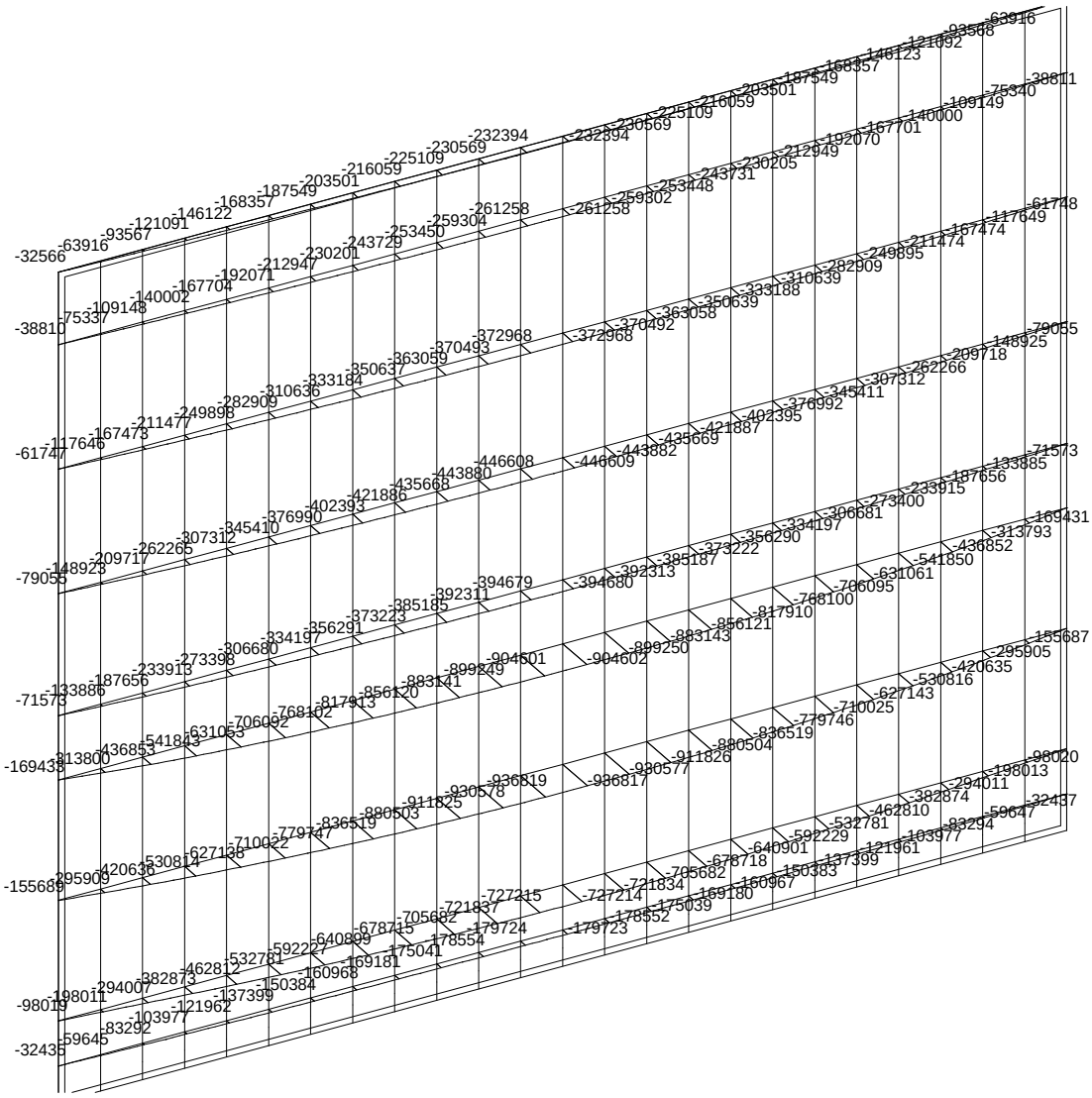
Load case water retaining - normal : +26.67 -3.44 PLD



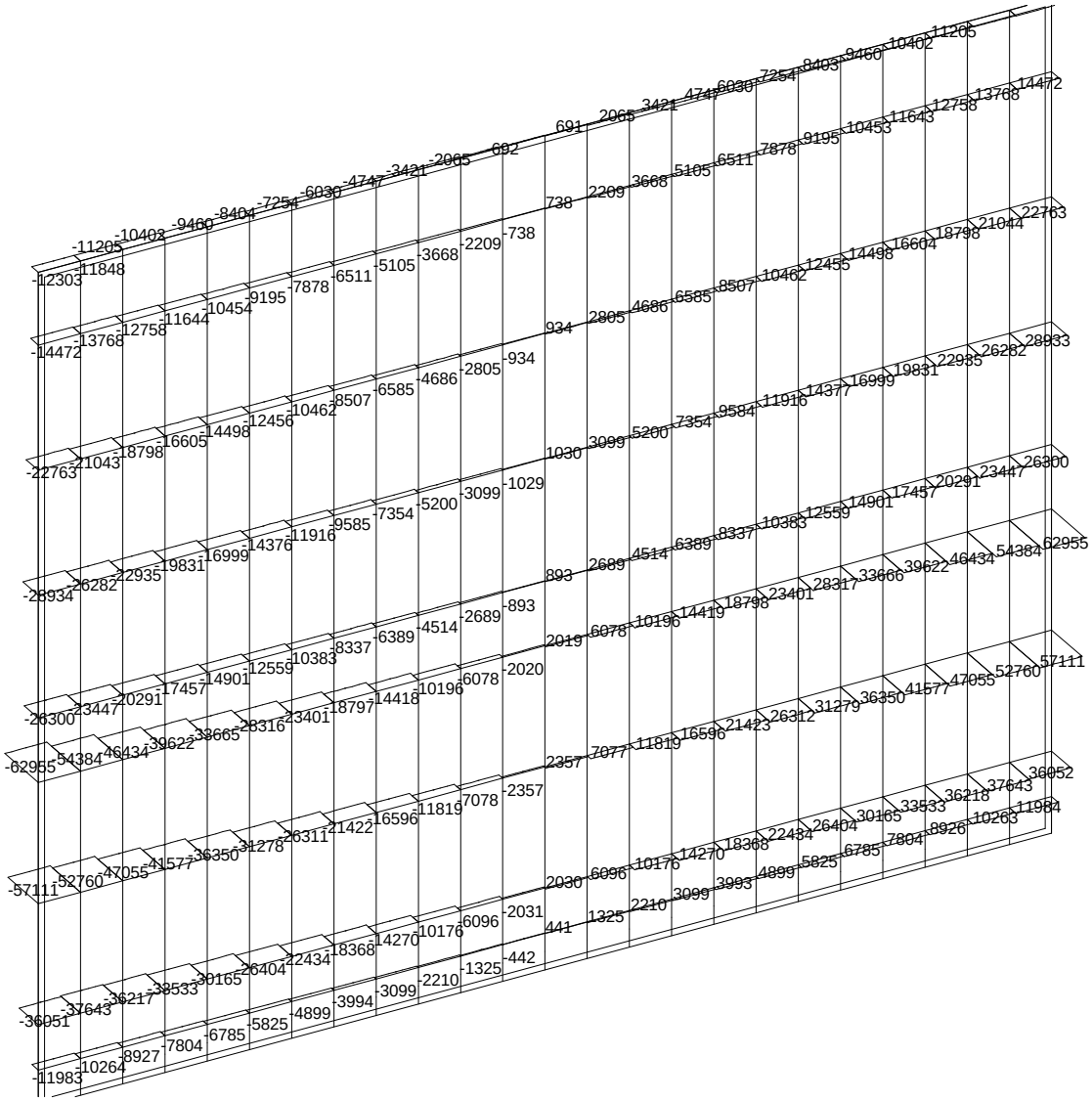
Reaction forces - WR normal +26.67 -3.44 PLD



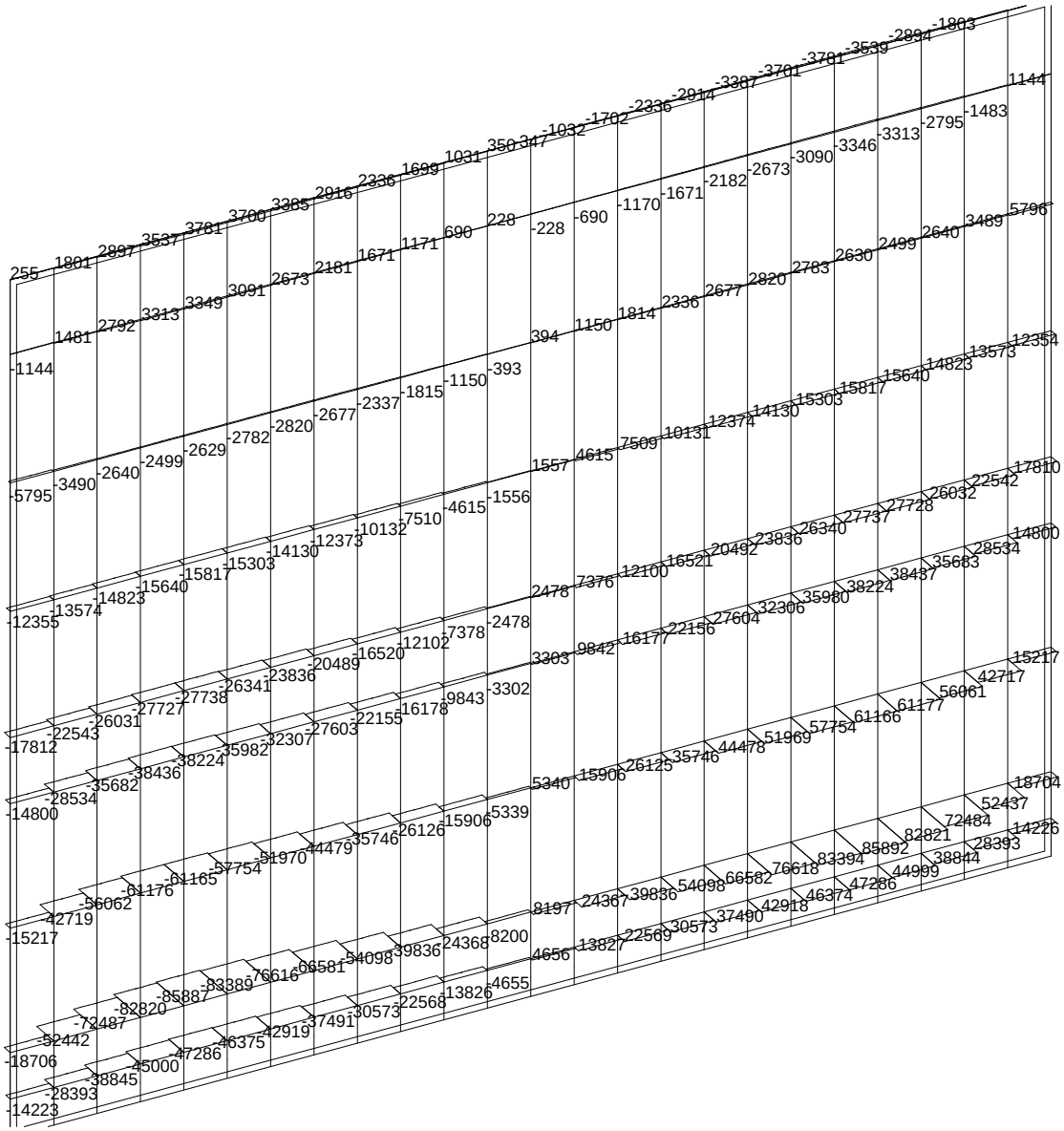
Reaction forces - WR normal +26.67 -3.44 PLD



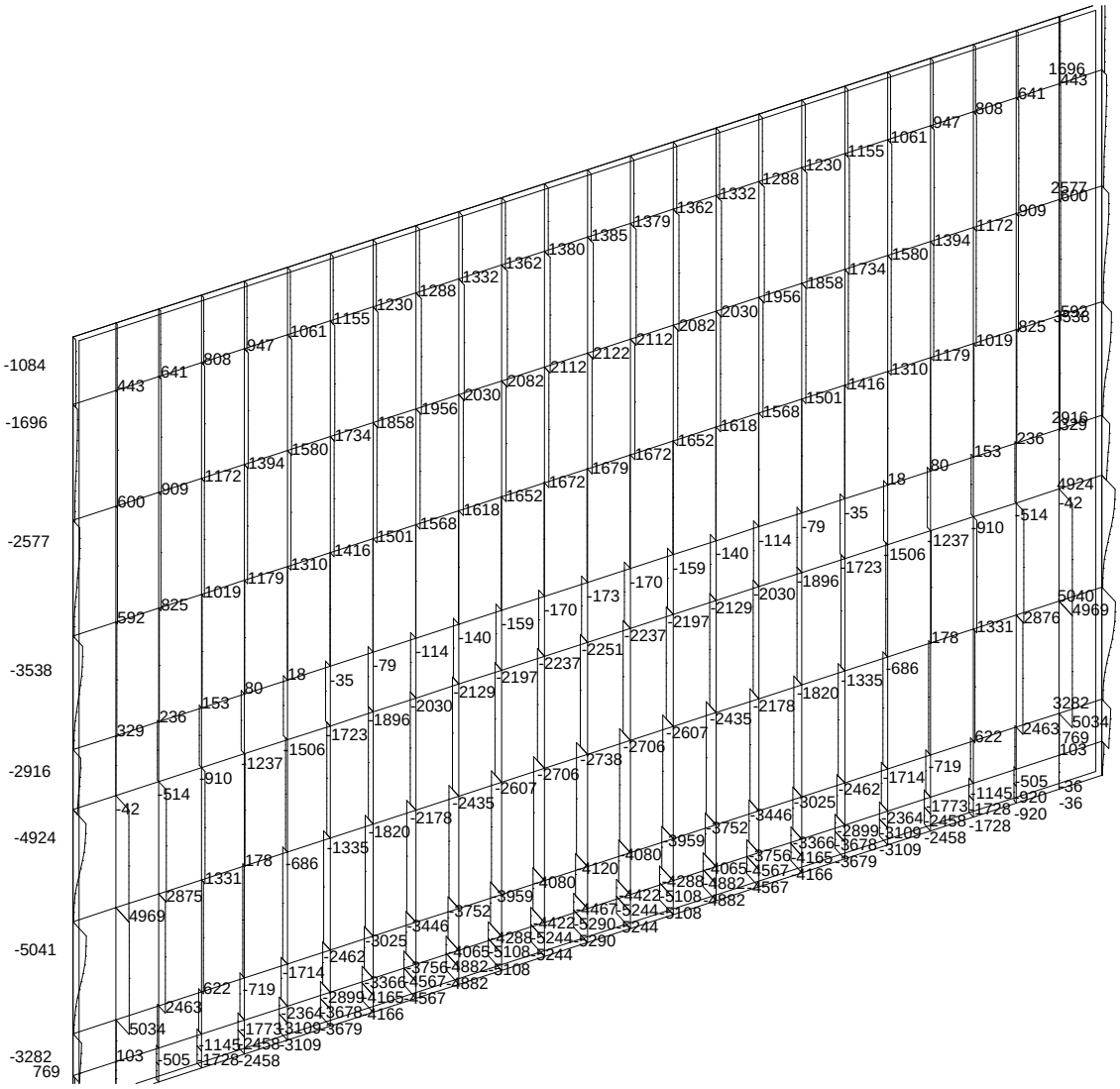
My in beams : WR normal +26.67 -3.44 PLD



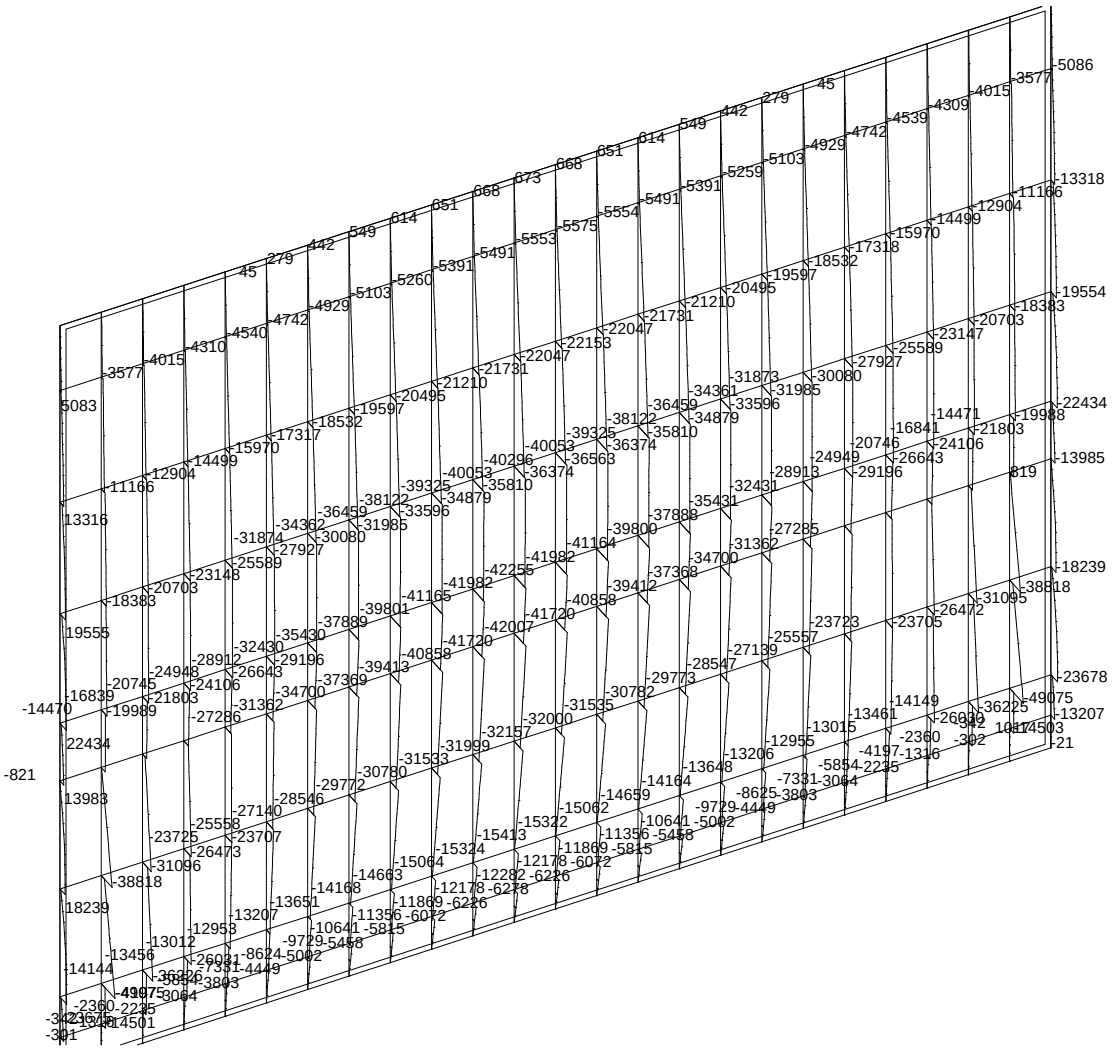
Vz in beams : WR normal +26.67 -3.44 PLD



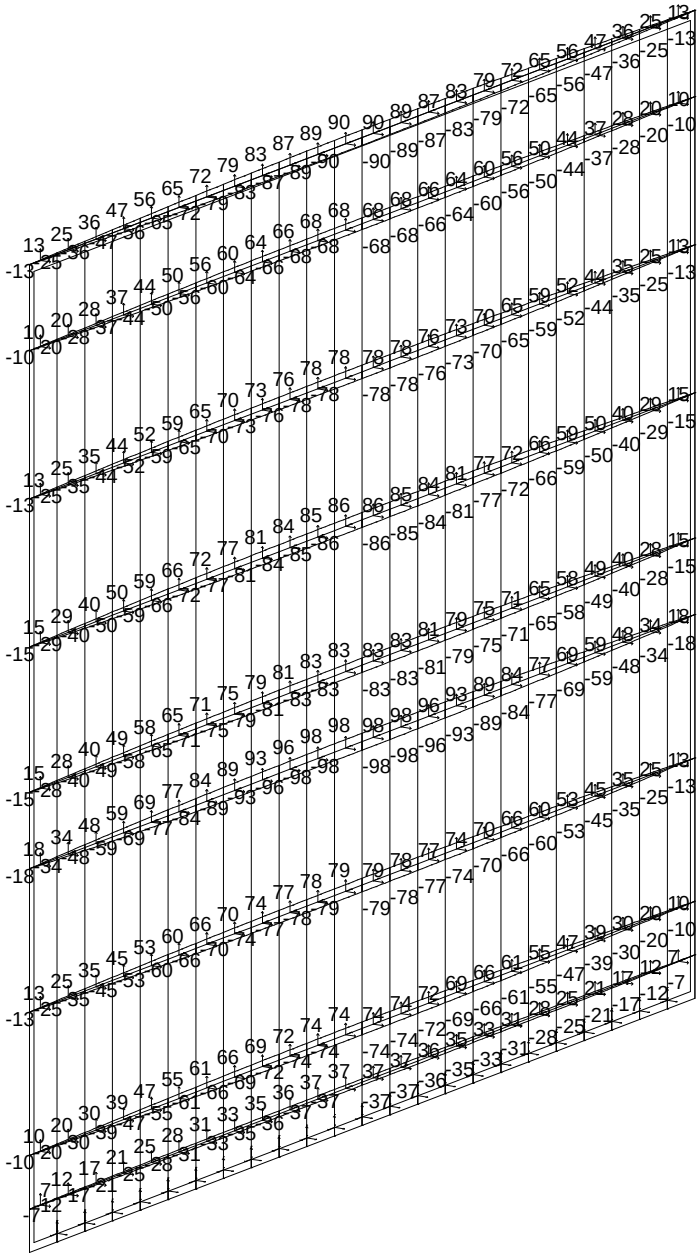
Mx (torsion) in beams : WR normal +26.67 -3.44 PLD



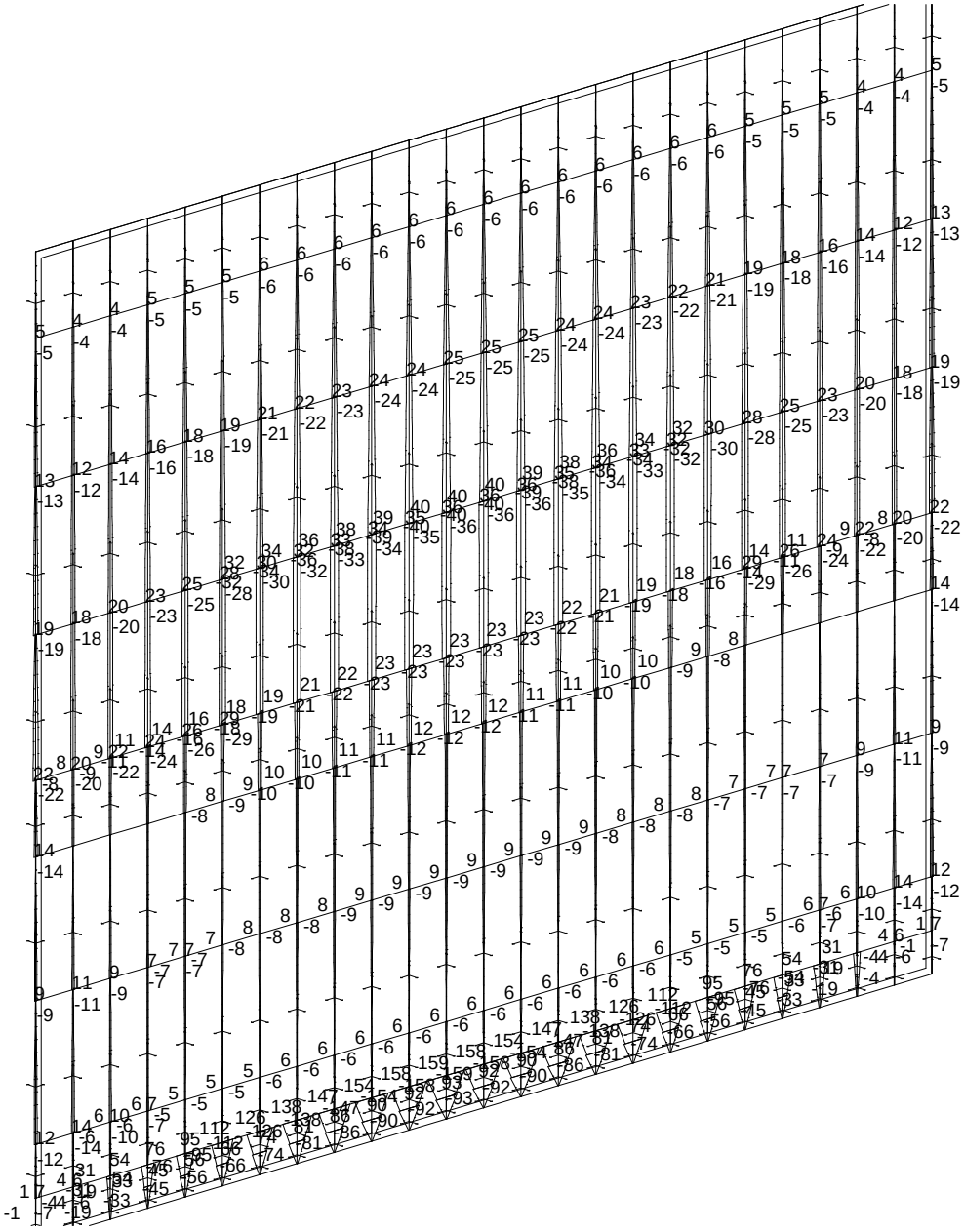
Vz in beams : WR normal +26.67 -3.44 PLD



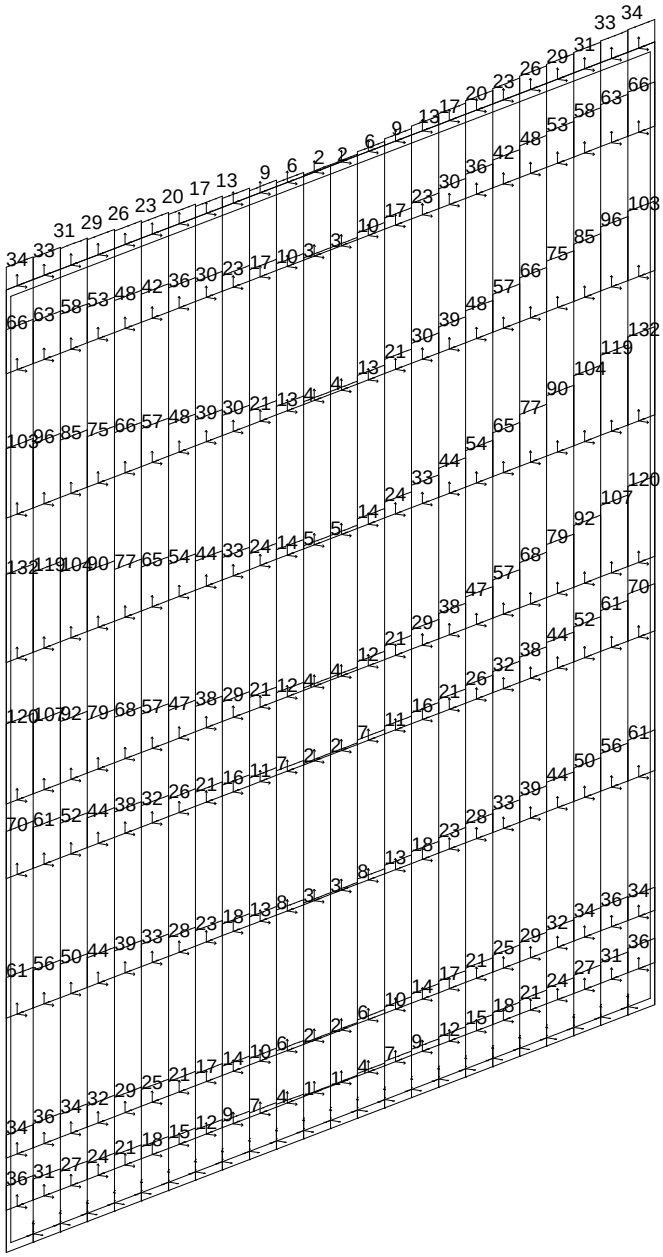
My in beams : WR normal +26.67 -3.44 PLD



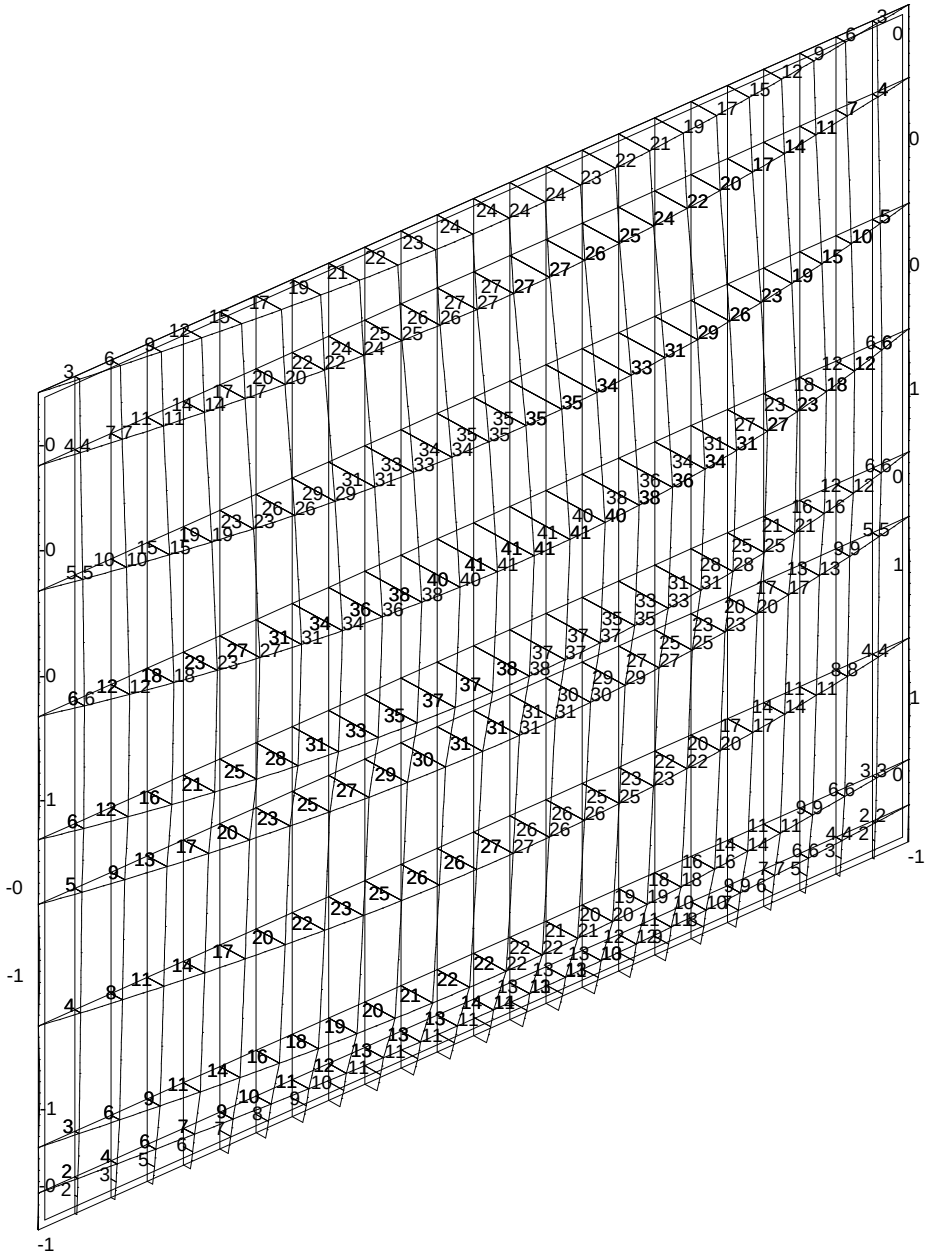
Normal stresses in beams - WR normal +26.67 -3.44 PLD



Normal stresses in beams - WR normal +26.67 -3.44 PLD

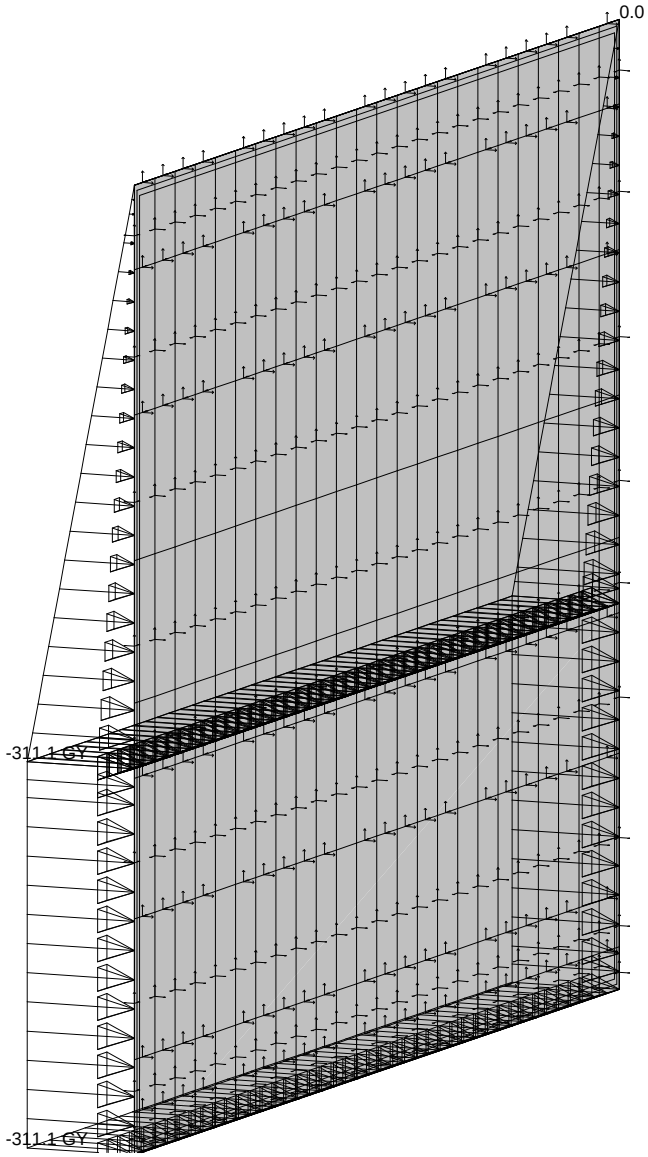


Shear stresses in beams - WR normal +26.67 -3.44 PLD

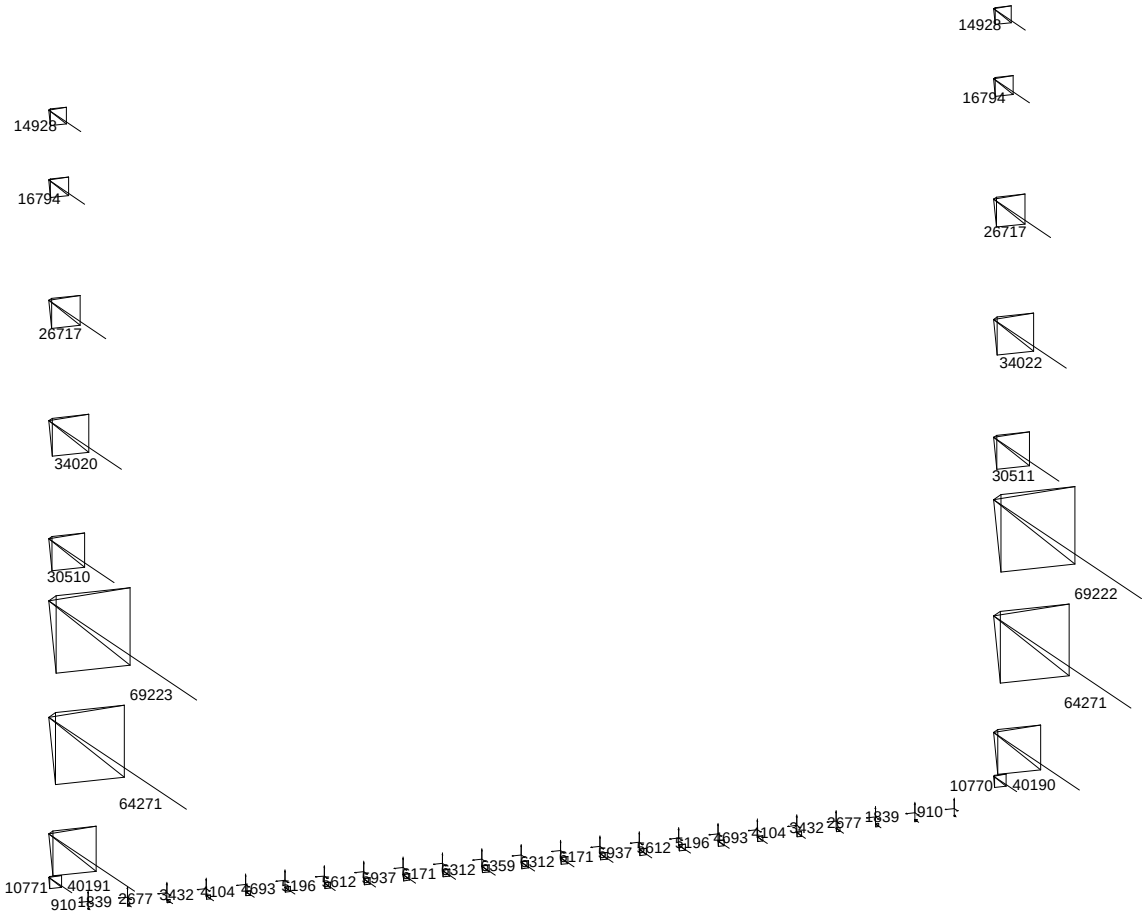


Deformations - uz in beams : WR normal +26.67 -3.44 PLD

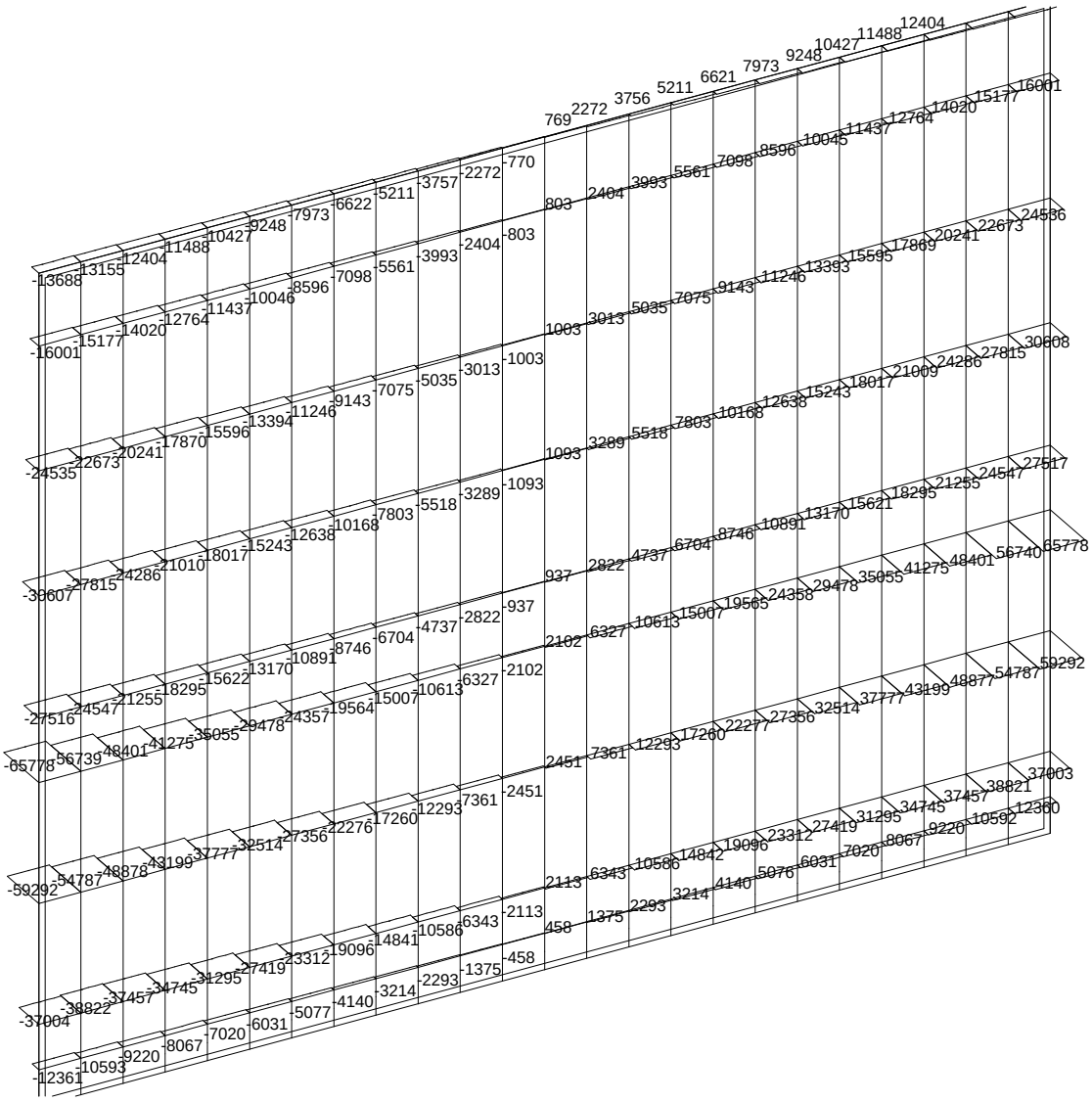
3. Water retaining ultimate



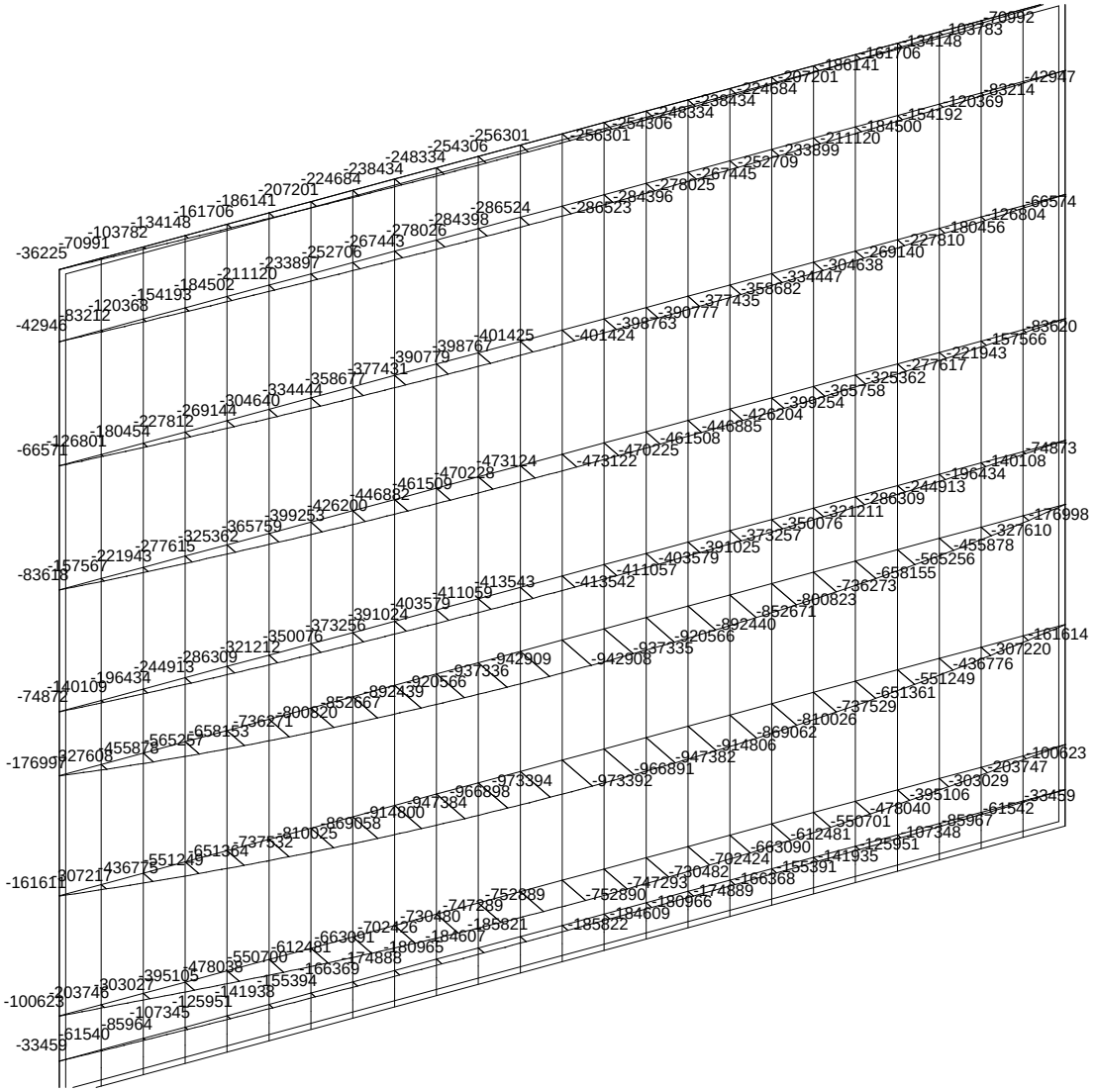
Load case water retaining - ultimate : +27.67 -3.44 PLD



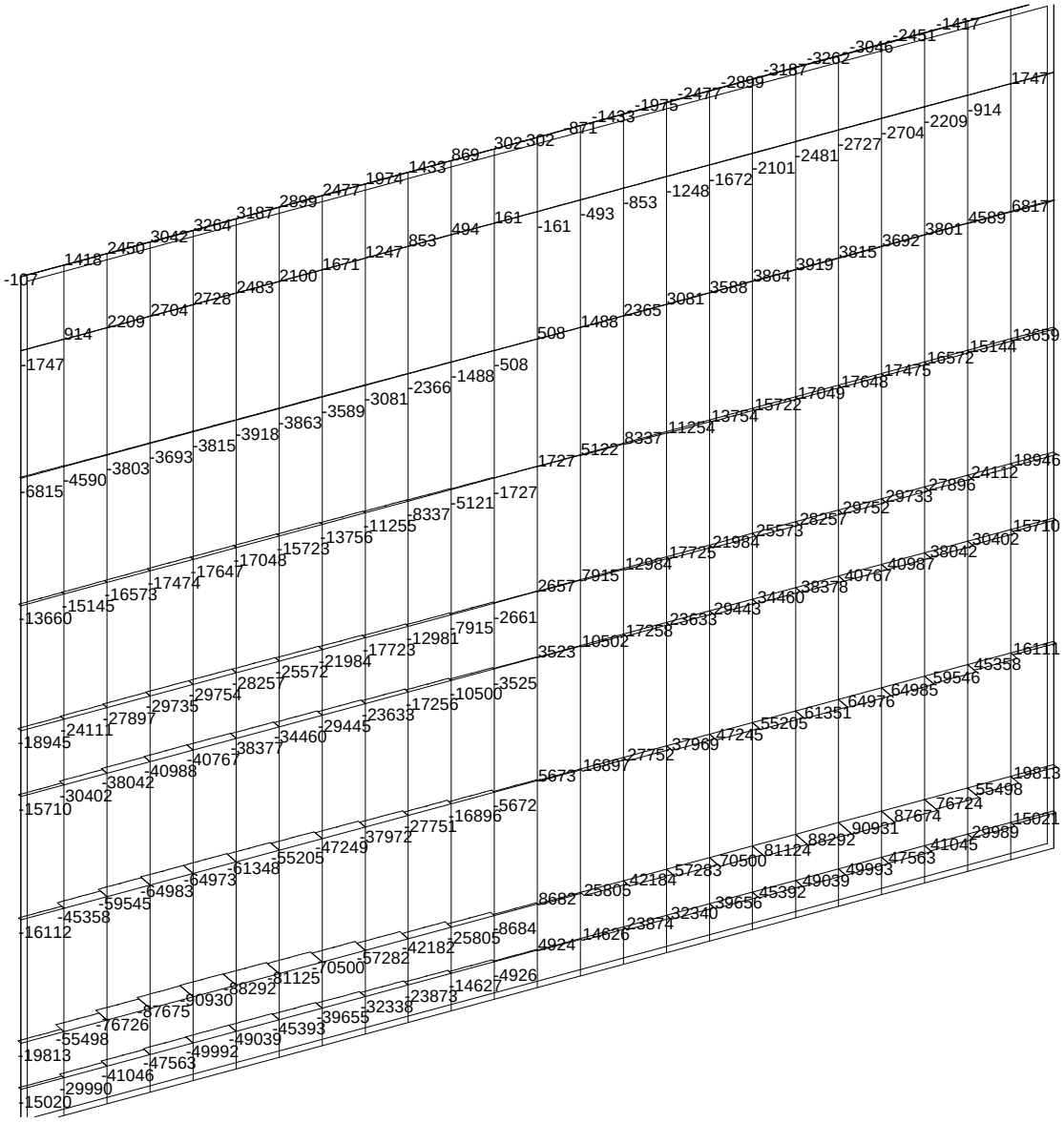
Reaction forces - WR ultimate +27.67 -3.44 PLD



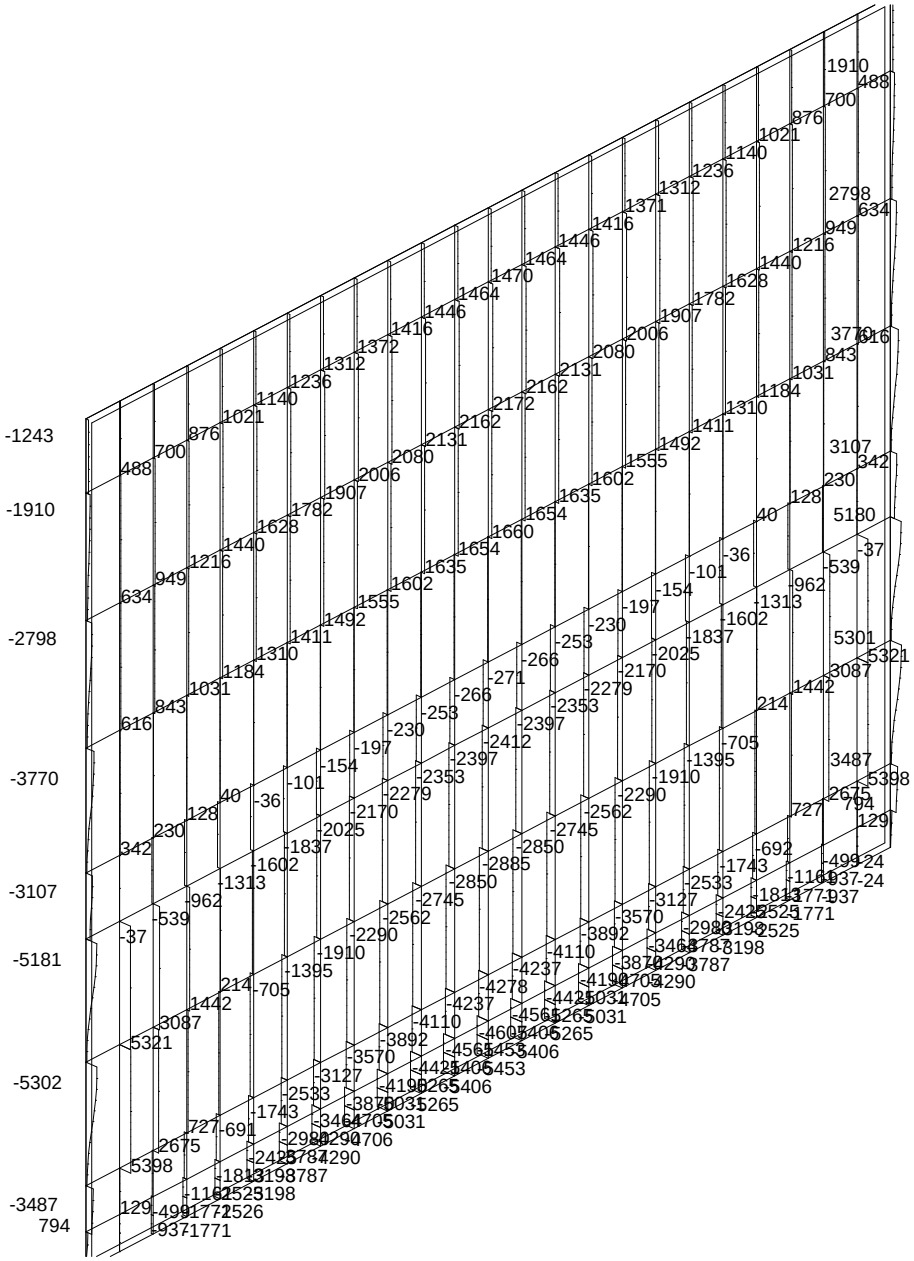
Vz in beams : WR ultimate +27.67 -3.44 PLD



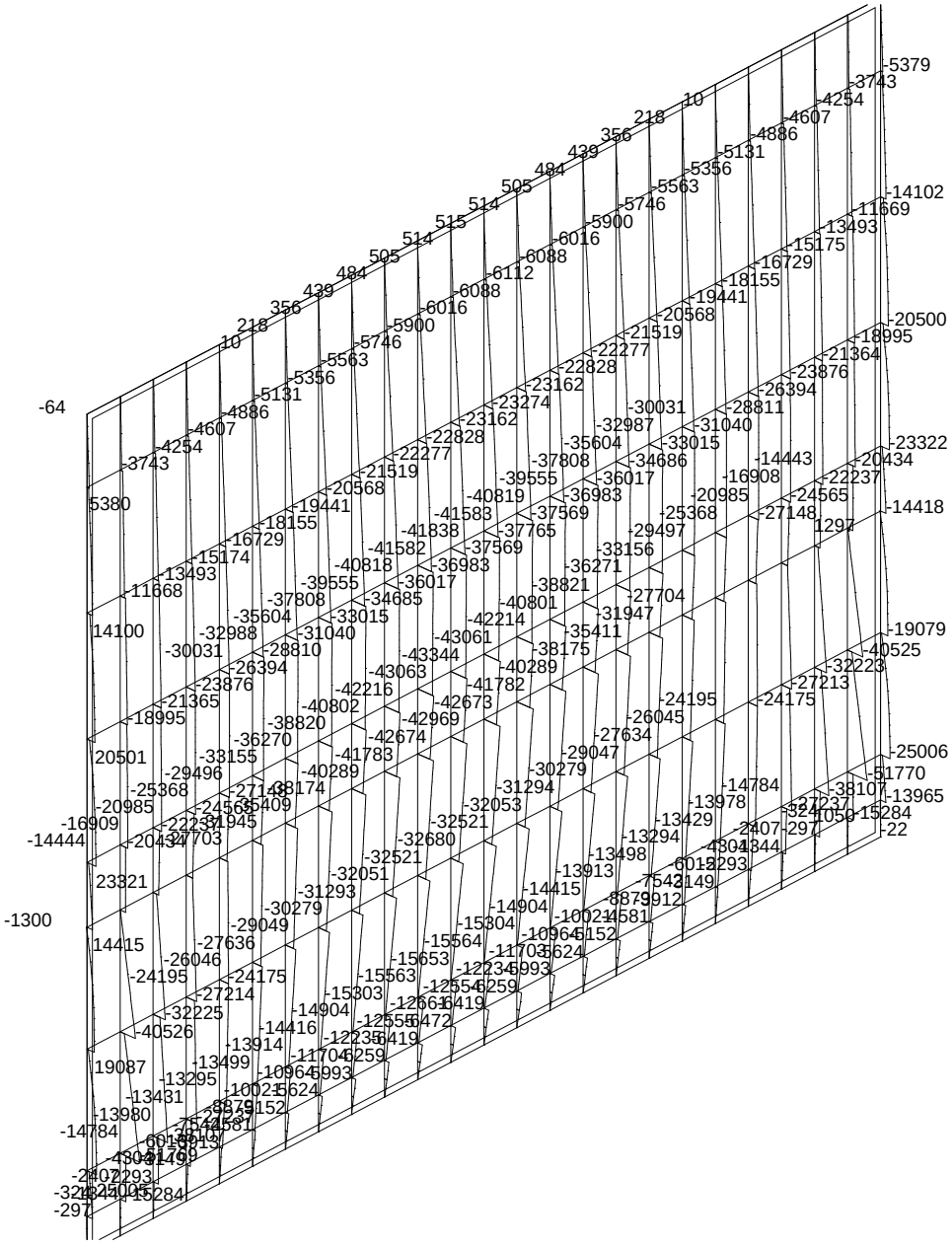
My in beams : WR ultimate +27.67 -3.44 PLD



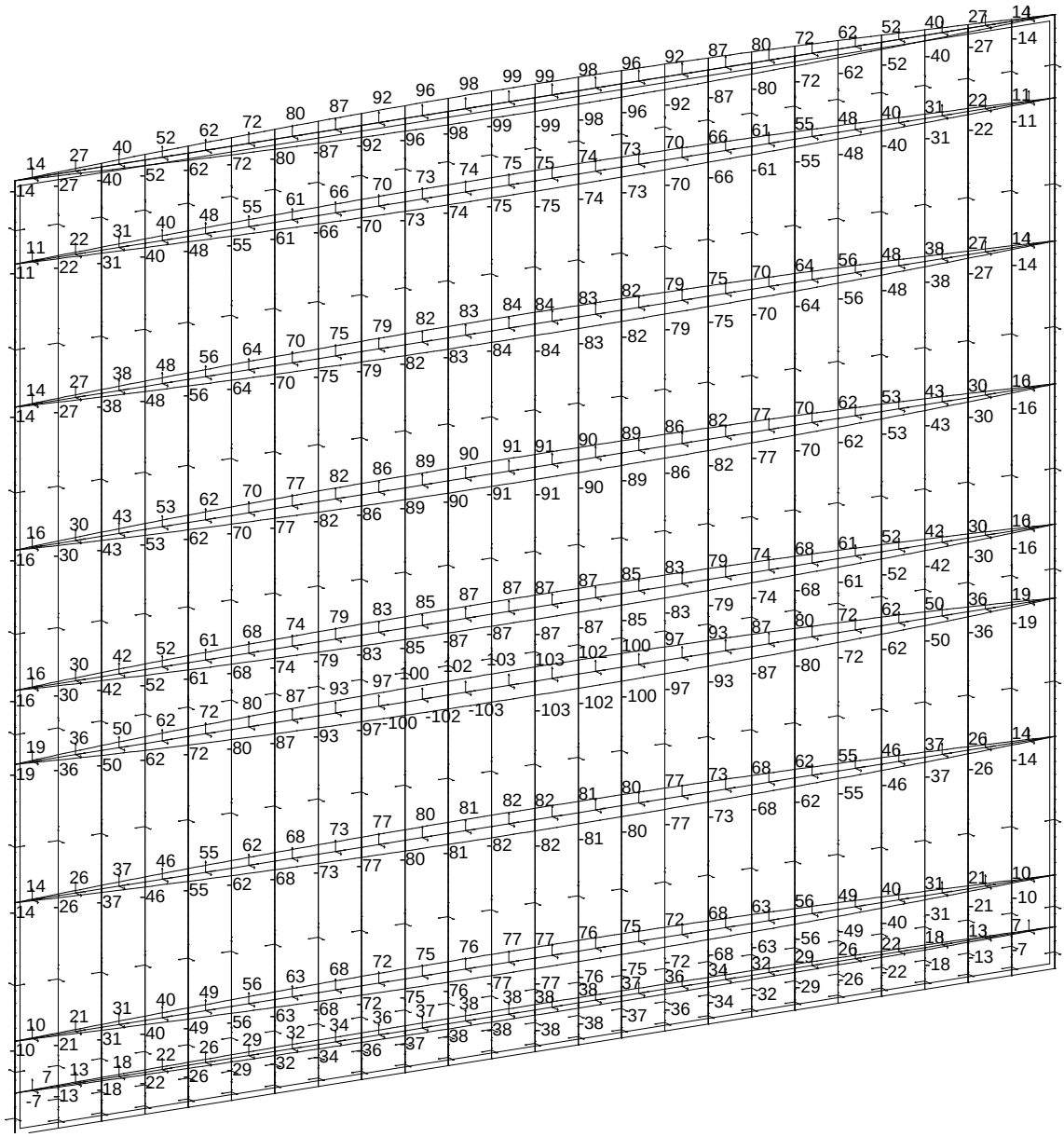
Mx (torsion) in beams : WR ultimate +27.67 -3.44 PLD



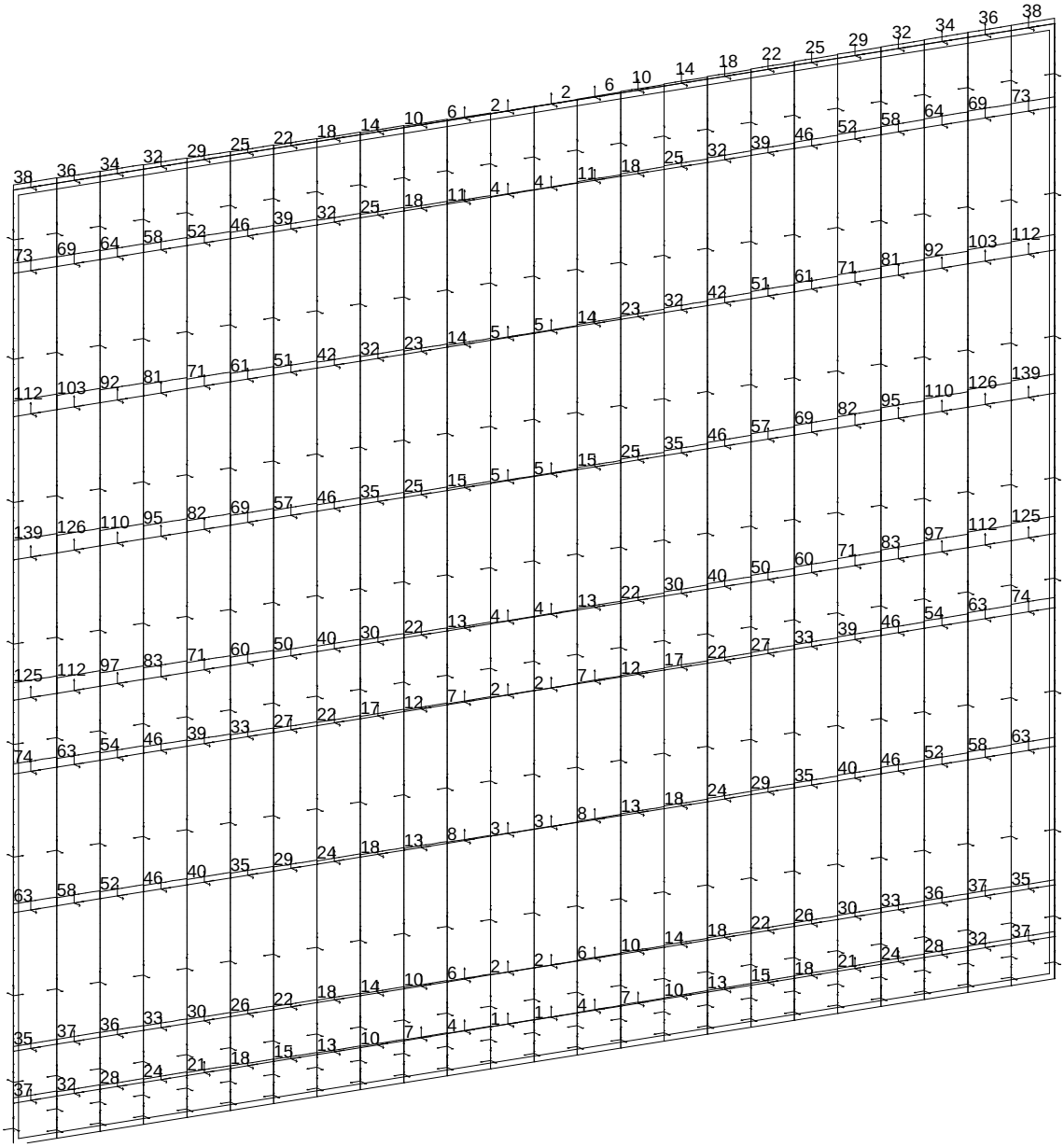
Vz in beams : WR ultimate +27.67 -3.44 PLD



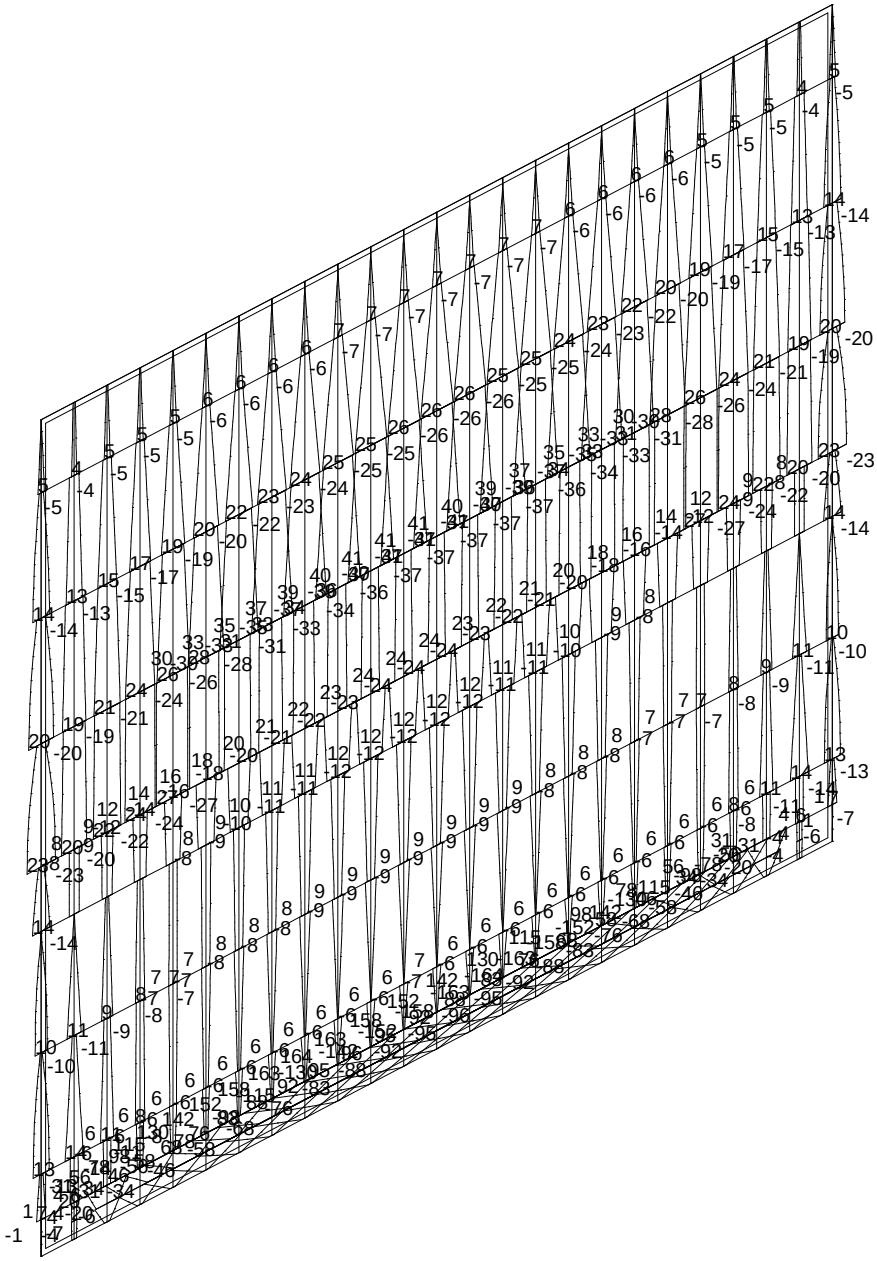
My in beams : WR ultimate +27.67 -3.44 PLD



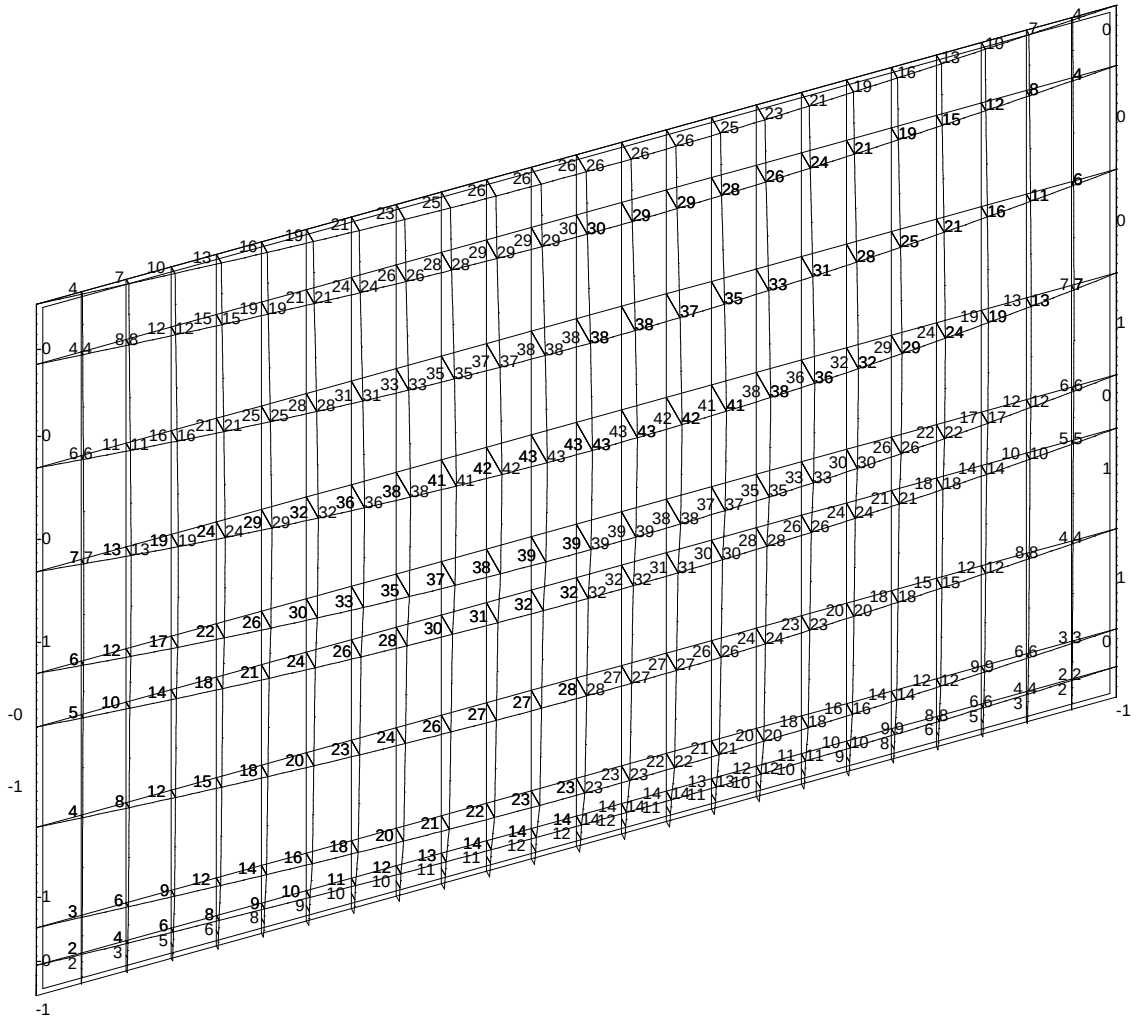
Normal stresses in beams : WR ultimate +27.67 -3.44 PLD



Shear stresses in beams : WR ultimate +27.67 -3.44 PLD



Normal stresses in beams : WR ultimate +27.67 -3.44 PLD



Deformations - uz in beams : WR ultimate +27.67 -3.44 PLD

APPENDIX B

Appendix B : Gate S1 : check compression member R8

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1. Input data

Basic data
Structure type : General XYZ

Aantal knopen:	2
Aantal staven:	1
Aantal 1D macro's:	1
Aantal randlijnen:	0
Aantal 2D macro's:	0
Aantal profielen:	4
Aantal belastingsgev.:	2
Aantal materialen:	1

Material

Naam		
S 355		
	Treksterkte	510.00 MPa

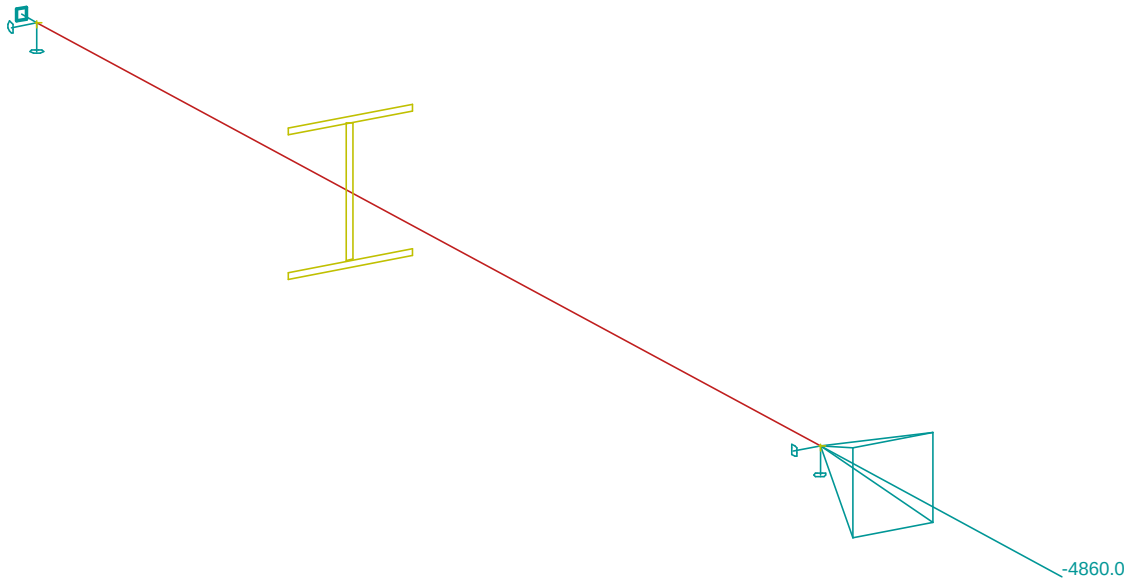
Auteur : WDC

Naam		
	Vloeigrens	355.00 MPa
	E-modulus	210000.00 MPa
	Poisson coëff.	0.30
	Specifiek gewicht	0.00 kg/mm^3
	Uitzettingscoëff.	1.2e-005 mm/mm.K

List of materials
Beams group:
1/1

nr.	Naam	Kwaliteit	Eenh. gewicht kg/mm	Lengte mm	Massa kg
1	Iw gelast (660,30,600,30)	S 355	0.42	6300.00	2670.57

Totaal gewicht van constructie: 2670.57 kg
Verfoppervlakte: 23814000.88 mm^2



Beam geometry

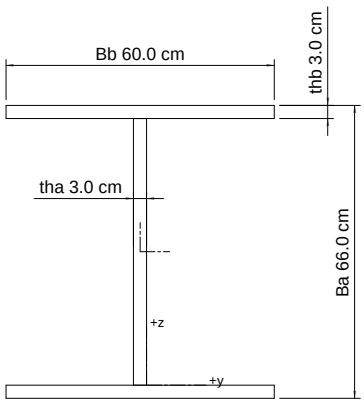
Nodes

knoop	X mm	Y mm	Z mm
1	0	0	0
2	6300	0	0

Beams

macro	staaf	knoop 1	knoop 2	Lengte mm	Rx deg	Profiel	Kwaliteit
1	1	1	2	6300	0.00	1 - Iw gelast (660,30,600,30...	S 355

Profiles



Iw gelast (66.0,3.0,60.0,3.0)

Doorsnedenr. 1 - Iw gelast (66.0,3.0,60.0,3.0)
Materiaal : 12 - S 355

1	P30/600 - S 355
2	P30/600 - S 355
3	P30/600 - S 355

A :	5.400000e+002 cm^2		
Ay/A :	0.550	Az/A :	0.308
Iy :	4.114801e+005 cm^4	Iz :	1.081350e+005 cm^4
Iyz :	5.251604e-012 cm^4	It :	1.647000e+003 cm^4
Iw :	1.075351e+008 cm^6		
Wely :	1.246909e+004 cm^3	Welz :	3.604500e+003 cm^3
Wply :	1.404000e+004 cm^3	Wplz :	5.535000e+003 cm^3
cy :	-1.50 cm	cz :	30.00 cm
iy :	27.60 cm	iz :	14.15 cm
dy :	0.00 cm	dz :	-0.00 cm
Omtrek :		366.00 cm	

Controletype: I-profiel

Hoogte	66.00 cm	Breedte	60.00 cm
Flensdikte	3.00 cm	Lijfdikte	3.00 cm
Straal	3.00 cm		

Support boundary conditions

Steunpunt	knoop	type	Afmeting mm
1	1	XYZRx	0.00
2	2	YZ	0.00

Load cases

LC	Naam	Omschrijving
1	Self weight	Eigengewicht. Richting -Z
2	Normal force	Variabel - Water pressure

Load case no. 2 – Node loads

node	Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
2	-4860.00	0.00	0.00	0.00	0.00	0.00

Load combinations

Combi	Norm	BG	coëff
1.	EC eenv - UGT	1 Self weight	1.00
1.	EC eenv - UGT	2 Normal force	0.90

Ultimate load combination rules:
1 : 1.35*BG1
2 : 1.35*BG1 / 1.35*BG2
3 : 1.00*BG1 / 1.35*BG2

Ultimate load combinations:
1/ 3 : +1.00*BG1
2/ 1 : +1.35*BG1
3/ 2 : +1.35*BG1+1.35*BG2

Buckling length

beam	k yz	k ltb	swayY	swayZ	positie last	k	kw
1	1.00	1.00	0	0	middelpunt	1.0	1.0

Report calculations

Linear computation

Aantal 2D elementen	0
Aantal 1D elementen	1
Aantal netknopen	2
Aantal vergelijkingen	12
Belastinggevallen	BG 1 Self weight

Auteur : WDC

Aantal 2D elementen	0
Aantal 1D elementen	1
Aantal netknopen	2
Aantal vergelijkingen	12
	BG 2 Normal force
Buigtheorie	Mindlin
Start berekening	10.12.2002 16:15
Einde berekening	10.12.2002 16:15

Sum of loads and reaction forces

		X	Y	Z
belastinggeval 1	last	0.0	0.0	-26.7
	reactie	0.0	0.0	26.7
	contact	0.0	0.0	0.0
belastinggeval 2	last	-4860.0	0.0	0.0
	reactie	4860.0	0.0	0.0
	contact	0.0	0.0	0.0

2. Check EC 3 - Ultimate limit state

EC3 : check compression member R8 - ULS

EC3 Controle

Macro 1	**Staaf 1**	**Iw gelast**	**S 355**	**UGT combi 3**	**0.48**

Basisgeg. EC3
Partiële veiligheidsfactor Gamma M0 voor weerstand van doorsnedes 1.10
Partiële veiligheidsfactor Gamma M1 voor weerstand van knik 1.10
Partiële veiligheidsfactor Gamma M2 voor weerstand van netto doorsnede 1.25

Gegevens materiaal		
bezwijksterkte fy	355.00	MPa
treksterkte fu	510.00	MPa
fabrikatie	gelast	

SPANNINGSCONTROLE
b/t verhouding voor lijven (tab.5.3.1. a).
verhouding 18.00 op positie 0.00 m

verhouding		
maximale verhouding	1	26.85
maximale verhouding	2	30.92
maximale verhouding	3	34.17

==> Profiel klasse 1

b/t verhouding voor flenzen (Tab.5.3.1. c).
verhouding 10.00 op positie 0.00 m

verhouding		
maximale verhouding	1	7.32
maximale verhouding	2	8.14
maximale verhouding	3	11.20

==> Profiel klasse 3

Auteur : WDC

Kritische controle op positie 3.15 m

Interne krachten		
NSd	-6561.00	kN
Vy.Sd	0.00	kN
Vz.Sd	0.00	kN
Mt.Sd	0.00	kNm
My.Sd	28.39	kNm
Mz.Sd	0.00	kNm

Controle druk

volgens artikel 5.4.4. en formule (5.16)

Doorsnede classificatie is 3.

Tabel van waarden		
Nc.Rd	17427.27	kN
unity check	0.38	

Gecombineerde controle buiging, normaalkrachten afschuiving

volgens artikel 5.4.9. en formule (5.37)

Doorsnede classificatie is 3.

Tabel van waarden		
sigma N	121.50	MPa
sigma Myy	2.28	MPa
sigma Mzz	0.00	MPa

ro 0.00 plaats 12

unity check 0.38

Staaf voldoet aan spanningscontrole !

STABILITY CHECK

Knikparameters	yy	zz	
type	geschoord	geschoord	
Slankheid	22.82	44.52	
Gereduceerde slankheid	0.30	0.58	
Knikkromme	b	c	
Imperfectie	0.34	0.49	
Reductie factoren	0.96	0.80	
Lengte	6.30	6.30	m
Knik factor	1.00	1.00	
Buckling length	6.30	6.30	m
Kritische Euler belastingen	214886.17	56471.07	kN

Buckling control
volgens artikel 5.5.1. en formule (5.45)

Tabel van waarden		
Nb.Rd	13865.62	kN
Beta A	1.00	
unity check	0.47	

Torsie-buiging knikcontrole
volgens artikel ENV 1993-1-3 : 6.2.3 en formule (6.1) (6.4a-b)(6.5a-b)(6.6)

Tabel van waarden		
Nb.Rd	14737.85	kN
Beta A	1.00	
Gereduceerde slankheid	0.58	
Reductie factoren	0.85	
sigma,cr,T	1336.65	MPa
sigma,cr,TF	1045.76	MPa
Torsieknik lengte	6.30	m
unity check	0.45	

Kipcontrole
volgens artikel 5.5.2. en formule (5.48)

Tabel van waarden		
Mb.Rd	3514.59	kNm
Beta W	0.89	
reductie	0.87	
imperfectie	0.49	
Mcr	22378.05	kNm

LTB		
Kiplengte	6.30	m
k	1.00	
kw	1.00	
C1	1.13	
C2	0.45	
C3	0.53	

last in zwaartepunt
unity check =0.01

Auteur : WDC

Controle druk en buiging

volgens artikel 5.5.4. en formule (5.53)

Tabel van waarden	
ky	1.15
kz	1.10
muy	-0.42
muz	-0.23
BetaMy	1.30
BetaMz	1.80

unity check = 0.39 + 0.01 + 0.00 = 0.40

Controle druk, buiging en kip

volgens artikel 5.5.4. en formule (5.54)

Tabel van waarden	
klt	1.00
kz	1.10
Mmax	-0.04
muz	-0.23
BetaMlt	1.30
BetaMz	1.80

unity check =0.47 + 0.01 + 0.00 = 0.48

Member satisfies stability check !

Diseño Conceptual de las Esclusas Post Panamax

TASK 4

E– CULVERT AND CONDUIT VALVES

R4-E

in association with

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1.2 LAYOUT 1-2

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1.2.2 WSB VALVES 1-4

1.3 DESIGN BASIC DATA 1-5

1.3.1 CULVERT VALVES AND BULKHEADS 1-5
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1.5 CONSTRUCTION DETAILS 1-16

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1 Description and dimensioning

1.1 GENERAL

The analysis of the suitability of different types of valves has concluded that the most suitable type is the fixed-wheel valve.

The section dimensions of the lock culverts and water saving basins conduits have been provided after the hydraulic study of configuration 2 (single lift) has been completed:

- culvert dimensions: W x h = 7.5 x 9.0m
- conduit dimensions: W x h = 4.8 x h = 7.5m.

The above conduit dimensions W x h = 4.8 x 7.5m replace the 6 x 6m as mentioned p. 42 and 49 of the filling and emptying system. That modification has no influence seen from the hydraulic point of view because the section of the conduit remains the same for both cases (36m²) as well as water velocity. However, a 6 x 6m valve would have been heavier than a 4.8 x h = 7.5m valve.

It must be pointed out that there is no fixed ratio h / W (see reference list given at point 1.10.4 of chapter R4-E of the Triple Lift Lock System). Generally however, while keeping the same section, preference is given to ratio >1 (valve height > valve width) because the weight and thus the price of the valve leaf is rapidly decreasing when the width is decreasing.

As it is the case for most of big size locks with rolling gates, the culvert valves are redundant (two valves per culvert).

The basic principle adopted for operation reliability is to work with two valves in parallel so that any incident to any valve will not stop ship transit through the locks.

In case of planned emptying of the lock chamber, it is recommended to lower the bulkhead gates on the Gatun Lake and Pacific side.

Regarding the WSB valves, each of the six basins is connected to the lock by four conduits. No provision has been made for redundancy of the valves. In case of any trouble on a valve, one

conduit will be out of order but the three remaining conduits of the concerned basin will be sufficient to operate almost normally.

1.2 LAYOUT

As required by ACP, each culvert and conduit valve is equipped upstream and downstream with bulkhead gates allowing access to the valve(s) after emptying by pumping of the space on both sides.

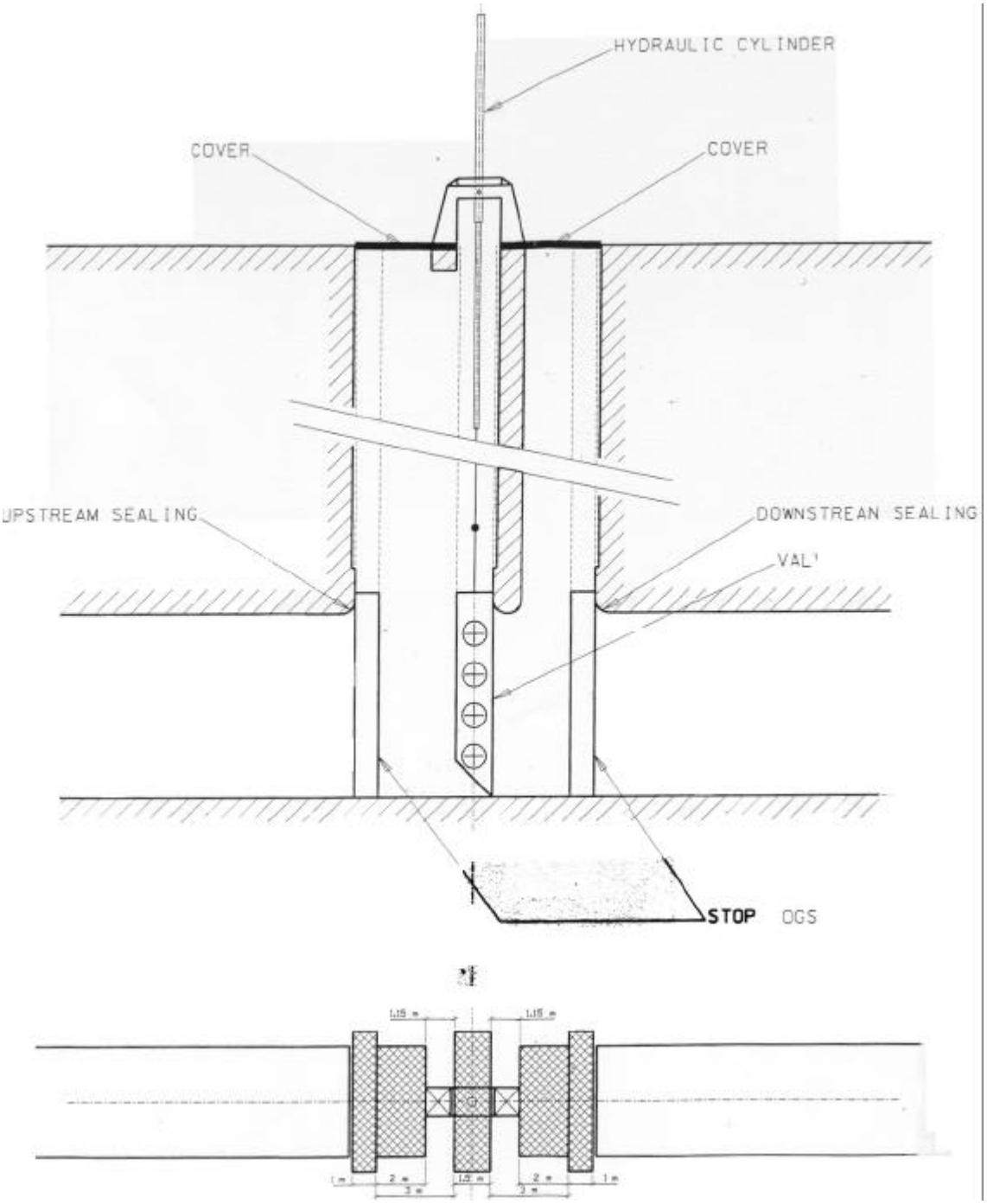
In order to simplify the civil works as for configuration 1 (three lifts), the basins conduits have been arranged two by two. For each pair, one conduit is located on top of the other. This implementation combined with above requirements makes the WSB valves arrangement quite complicated with a big number of slots and separation walls. The upstream /downstream sealing system makes it possible to reduce that number.

1.2.1 CULVERT VALVES

The two side culverts are running along the locks and at the level of the lock chamber bottom. However, the bottom of the rolling gates chambers prevent them to keep a straight way. Moreover, as the culverts are right under the locomotives track space (width: 15m), they can not remain straight either in the plan view along the lock chamber as the valves are operated by external hydraulic cylinders. Both problems have been solved at the same place: the culverts are passing under the rolling gates and the valves are implemented between the gates.

The culvert section of 7.5 x h = 9m has been locally splitted into two sections of 3.75 x h = 9m where valves are to be installed. The total section and thus the mean water velocity remain constant at full opening of the valve.

The next page shows a basic layout for a culvert valve and two isolating bulkheads. There is only one flow direction from the left to the right.



In that case:

- the upstream bulkhead has to be tight on its upstream side for emptying both sides of the valve,
- the upstream bulkhead has to be tight on its downstream side,
- the valve has to be tight on its downstream side.

That design has the advantage regarding civil works to use only one vertical separation wall.

1.2.2 WSB VALVES

The arrangement of the valves and bulkheads is shown on the civil works drawings.
The fixed-wheel valves of the upper and lower conduit are designed with upstream and downstream sealings as Berendrecht.

Their leaf structure is able to support the maximum static pressure on both sides corresponding to following pressure conditions:

- maximum lock chamber level on one side and WSB completely empty on the other side,

- maximum WSB level on one side and lock chamber completely empty on the other side.

However, the hydraulic cylinders operating the valves are dimensioned for normal operation with the locks and basins filled with water and not for this unusual situation.

The bulkhead gate on the basin side is of the sliding type in three elements and is designed with a double sealing system allowing to:

- empty the WSB while keeping the lock in operation,
- empty the space between the two bulkhead gates to give access to the valves and slots for maintenance.

The bulkhead gate on the lock chamber side is also in three pieces and is designed with a sealing system allowing to:

- empty the WSB keeping the locks in operation,
- empty the space between the two bulkhead gates to give access to the valves and slots for maintenance.

The basic data for designing the valves (dimensions and maximum static head) are the same as those of the bulkhead gates.

The bulkhead gates elements can be lowered or removed by means of a mobile gantry crane equipped with an automatic lifting beam.

The alternative to design the fixed-wheel valves and bulkhead gates for the operation head only is not recommended in order to allow lock operations in case of the emptying of a basin.

Moreover, to avoid any possible error, the 12 valves of the upper conduit are dimensioned for the same design head H = 50mWC (Water Column) as well as the 12 valves of the lower conduits are dimensioned for the same design head H = 65mWC.

The 8 culvert valves are also the same. They are dimensioned for the design head H = 40mWC.

1.3 DESIGN BASIC DATA

The tables hereunder are providing for the culvert and WSB valves as well as the bulkhead gates the different maximum and minimum water levels in the locks and basins as well as the valves sill levels and the maximum water pressure to be taken into account for estimating the weight of the moving parts..

The last column of the tables "Valve maximum static Hs" for the WSB valves is used for dimensioning the leaf structure for supporting the maximum pressure when a WSB is empty.

1.3.1 CULVERT VALVES AND BULKHEADS

Number of culvert valves: 8
Number of culvert bulkheads: 4 sets (8 pieces)
Dimensions : W x h = 3.75 x 9.00m (for all valves and bulkheads)

Culvert Valves	Upstream Max./Min Level	Downstr. Max./Min Level	Lowest Valve Sill Level	Valve Max. Static Hs (mWC)
Interface GATUN/ LOCK = (GATES 1) (*)	Gatun Lake : +26.67 / +23.92	Lock : +26.67 / - 3.44	-3.32	26.67 – 3.32 = 29.99m
Interface LOCK (GATES 2) (*)	Lock : +26.67 / - 3.44	Pacific : +3.60 / -3.44	-33.57	37.17 -

(*) 4 valves per interface : 2 on the eastern and 2 on the western side.

1.3.2 WSB VALVES

Number : 24
Dimensions : W x h = 4.80 x 7.50m (all valves have the same size)

WSB / Valves	WSB Max. Level	WSB Min. Level	Lock Max.Level	Lock Min.Level	Upper Valves Sill Level	Lower Valves Sill Level	Max. Static Hs (mWC) (when WSB is empty)
WSB 1 Upper valves 1 & 2	+ 7.86	+1.46	+26.67	-3.44	-20.62		47.29
WSB 1 Lower valves 3 & 4	+7.86	+1.46	+26.67	-3.44		-37.62	64.29
WSB 2 Upper valves 5 & 6	+10.69	+5.31	+26.67	-3.44	-20.62		47.29
WSB 2 Lower valves 7 & 8	+10.69	+5.31	+26.67	-3.44		-37.62	64.29
WSB 3 Upper valves 9 & 10	+13.76	+8.78	+26.67	-3.44	-20.62		47.29
WSB 3 Lower valves 11 & 12	+13.76	+8.78	+26.67	-3.44		-37.62	64.29
WSB 4 Upper valves 13 & 14	+16.92	+11.84	+26.67	-3.44	-20.62		47.29
WSB 4 Lower valves 15 & 16	+16.92	+11.84	+26.67	-3.44		-37.62	64.29
WSB 5 Upper valves 17 & 18	+20.14	+14.85	+26.67	-3.44	-20.62		47.29
WSB 5 Lower valves 19 & 20	+20.14	+14.85	+26.67	-3.44		-37.62	64.29
WSB 6 Upper valves 21 & 22	+23.40	+17.81	+26.67	-3.44	-20.62		47.29
WSB 6 Lower valves 23 & 24	+23.40	+17.81	+26.67	-3.44		-37.62	64.29

1.3.3 WSB BULKHEADS – DESIGN BASIC DATA

Number : 2 sets (12 elements)
Dimensions : bulkheads (8): W x h = 4.80 x 7.50m
Intermediate elements (4): W x h = 4.80 x 9.5m

In order to be able to move any bulkhead in any slot, all bulkheads will be identical i.e.:

- sill level: -37.62m
- water pressure on sill: 26.67 – (-37.62) = 64.29m

With 2 sets of bulkhead, it will be possible to empty 2 WSB with the lock still in operation.

1.4 ESTIMATED WEIGHTS

A precise determination of the moving part of a fixed-wheel gate by a comprehensive study based on preliminary data and admissible stresses is a quite long and difficult exercise. To determine an approximate weight, it is usual to make a comparison with existing valves of the same type.

Estimating the weight based on the main parameters i.e. the dimensions and water pressure on the sill can be developed by a formula based on statistical data. The weight of the slot embedded fixed parts has to be added.

This procedure gives an acceptable approach to the conceptual study stage.

The formula used here (see Water Power and Dam Construction by P.C. Erbiste May 1984) is a function of WhH where W and h are the span and the valve height respectively (in m) and H is the head on the valve sill (in mWC):

$$\text{Weight of a fixed-wheel valve (in kN)}: = 0.706\ (W^2hH)^{0.7}$$

The weight of fixed-wheel valves compared to tainter valves versus W^2hH is given on the next page.

The hereafter table of basic data (dimensions, maximum and minimum lock chambers and WSB water levels, pressure on the sills) for the WSB and culvert valves shows that the water pressure on the sill is respectively about H = 25mWC for the culvert valves and bulkhead, H = 30mWC for the upper WSB valves and H = 50mWC for the lower WSB valves and corresponding bulkheads.

The estimated unit weights of the valves and bulkhead gates are as follows:

- Culvert valve (W x h = 4.5 x 7.5m - H = 40mWC): 31.5 tons
- Culvert bulkhead (W x h = 4.5 x 7.5m - H = 40mWC): 28 tons
- WSB upper valve (W x h = 4.8 x 7.5m - H = 50mWC): 40 tons
- WSB lower valve (W x h = 4.8 x 7.5m - H = 65mWC): 48.5 tons
- WSB lower bulkhead (W x h = 4.8 x 7.5m – H = 65mWC): 45 tons
- WSB upper bulkhead (W x h 4.8 x 7.5m – H = 50mWC): 37 tons
- WSB bulkhead central part (W x h = 4.8 x 9m) – H = 57.5mWC): 50 tons

To check the procedure, a preliminary calculation of a WSB fixed-wheel valve structure (see documents hereafter) has confirmed the results of the above formula.

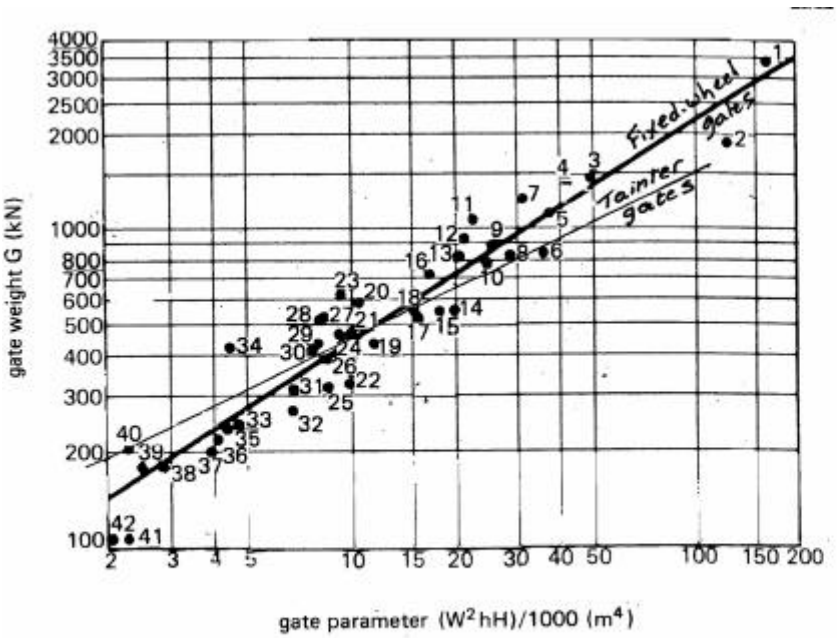
Moreover, the weight of one meter of embedded fixed parts is estimated to:

- Culvert fixed-wheel valves at the bottom of the slot: 800 kg (last 15m)
- Culvert fixed-wheel valves at the upper part of the slot (only for guiding): 200 kg
- Culvert sliding bulkhead at the bottom of the slot: 500 kg (last 10m)
- sliding bulkhead (only for guiding) 200 kg
- WSB bulkhead at the bottom of the slot: 500 kg (last 25m)
- WSB fixed-wheel valves at the bottom of the slot: 1000 kg (last 15m)

- WSB fixed-wheel valves at the upper part of the slot: 200 kg

Note: Lintel and sill embedded parts have been added separately

The table of detailed weights is given p.22.



Weight of large fixed-wheel gates ($W^2hH > 2000\ m^4$).

<u>PRELIMINARY CALCULATION OF A WSB LOWER VALVE (1st configuration)</u>
<u>Dimensions: 5.70 x h = 7.50m - Hs = 50m</u>

SKIN PLATE

The estimated skin plate thickness corresponds to a distance of 1.5m between the horizontal I beams and 1m between the vertical T shape intercostals is 4cm

STEEL PLATE		Mesh 1.00 x 1.50 m		LOAD : 50 t/m2	
		span maximum bending moment (tm) :			3.71333
		edges and corners maximum bending moment (tm) :			5.11170
thickness	I/v	relative displacement		maximum stresses	
		span	corner	span	corner
(m)	(m3)	(mm)	(mm)	(kg/mm2)	(kg/mm2)
0.040	0.0002667	0.880	1.540	12.55	19.17
0.035	0.0002042	1.314	2.300	16.39	25.04
0.030	0.0001500	2.087	3.653	22.30	34.08
0.025	0.0001042	3.605	6.312	32.12	49.07
0.020	0.0000667	7.042	12.328	50.18	76.68

choosen thickness: 4 cm

MAIN BEAMS

The horizontal main beams size depends on the span between them and load. According to the I/v required, alternatives were investigated i.e.:

- HE 1000 A
- W 1100 x 400 x 433

MAIN GIRDERS		length (m) :	5.7	distance (m):	1.5	load (t/m):	75	Moment (tm):	304.59375
		E (t/m2):	21000000						

DISPLACEMENT vs INERTIA		STRESS vs I/v	
I (m4)	f (m)	I/v (m3)	STRESS (t/m2)
0.0005	0.098177093	0.005	60918.75
0.0006	0.081814244	0.007	43513.392857
0.0007	0.070126495	0.009	33843.75
0.0008	0.061360683	0.011	27690.340909
0.0009	0.054542829	0.013	23430.288462
0.001	0.049088546	0.015	20306.25
0.0011	0.044625951	0.017	17917.279412
0.0012	0.040907122	0.019	16031.25
0.0013	0.03776042	0.021	14504.464286
0.0014	0.035063247	0.023	13243.206522
0.0015	0.032726698	0.025	12183.75
0.0016	0.030680341	0.027	11281.25
0.0017	0.028875615	0.029	10503.232759
0.0018	0.027271415	0.031	9825.6048387
0.0019	0.025836077	0.033	9230.1136364
0.002	0.024544273	0.035	8702.6785714
0.0021	0.023375498	0.037	8232.2635135
0.0022	0.022312976	0.039	7810.0961538
0.0023	0.021342846	0.041	7429.1158537
0.0024	0.020453561	0.043	7083.5755814
0.0025	0.019635419	0.045	6768.75
0.0026	0.01888021	0.047	6480.7180851
0.0027	0.018180943	0.049	6216.1989796
0.0028	0.017531624	0.051	5972.4264706
0.0029	0.016927085	0.053	5747.0518868
0.003	0.016362849	0.055	5538.0681818
0.0031	0.015835015	0.057	5343.75
0.0032	0.015340171	0.059	5162.6059322
0.0033	0.014875317	0.061	4993.3401639
0.0034	0.014437808	0.063	4834.8214286
0.0035	0.014025299	0.065	4686.0576923
0.0036	0.013635707	0.067	4546.1753731
0.0037	0.013267175	0.069	4414.4021739
0.0038	0.012918039	0.071	4290.0528169
0.0039	0.012586807	0.073	4172.5171233
0.004	0.012272137	0.075	4061.25
0.0041	0.011972816	0.077	3955.762987
0.0042	0.011687749	0.079	3855.5170886
0.0043	0.011415941	0.081	3760.4166667
0.0044	0.011156488	0.083	3669.8042169
0.0045	0.010908566	0.085	3583.4558824
0.0046	0.010671423	0.087	3501.0775862
0.0047	0.010444372	0.089	3422.4016854
0.0048	0.01022678	0.091	3347.1840659
0.0049	0.010018071	0.093	3275.2016129
0.005	0.009817709	0.095	3206.25
0.0051	0.009625205	0.097	3140.1417526
0.0052	0.009440105	0.099	3076.7045455
0.0053	0.00926199	0.101	3015.779703
0.0054	0.009090472	0.103	2957.2208738
0.0055	0.00892519	0.105	2900.8928571
0.0056	0.008765812	0.107	2846.6705607
0.0057	0.008612026	0.109	2794.4380734
0.0058	0.008463542	0.111	2744.0878378
0.0059	0.008320093	0.113	2695.5199115
0.006	0.008181424	0.115	2648.6413043
0.0061	0.008047303	0.117	2603.3653846
0.0062	0.007917507	0.119	2559.6113445
0.0063	0.007791833	0.121	2517.303719
0.0064	0.007670085	0.123	2476.3719512
0.0065	0.007552084	0.125	2436.75
0.0066	0.007437659	0.127	2398.3759843
0.0067	0.007326649	0.129	2361.1918605
0.0068	0.007218904	0.131	2325.1431298
0.0069	0.007114282	0.133	2290.1785714
0.007	0.007012649	0.135	2256.25
0.0071	0.00691388	0.137	2223.3120438
0.0072	0.006817854	0.139	2191.3219424
0.0073	0.006724458	0.141	2160.2393617
0.0074	0.006633587	0.143	2130.0262238
0.0075	0.00654514	0.145	2100.6466517
0.0076	0.006459019	0.147	2072.0663265
0.0077	0.006375136	0.149	2044.2533557
0.0078	0.006293403	0.151	2017.1771523
0.0079	0.00621374	0.153	1990.8068235
0.008	0.006136068	0.155	1965.1209677
0.0081	0.006060314	0.157	1940.0875796
0.0082	0.005986408	0.159	1915.6839623
0.0083	0.005914283	0.161	1891.886646
0.0084	0.005843875	0.163	1868.6733129
0.0085	0.005775123	0.165	1846.0227273
0.0086	0.005707971	0.167	1823.9146707
0.0087	0.005642362	0.169	1802.3298817
0.0088	0.005578244	0.171	1781.25
0.0089	0.005515567	0.173	1760.5575145
0.009	0.005454283	0.175	1740.5357143
0.0091	0.005394346	0.177	1720.8686441
0.0092	0.005335712	0.179	1701.6410615
0.0093	0.005278338	0.181	1682.8363978

for a deformation =
span/1000 (.0057).
I must be > 860000 cm4

To keep a stress
< 15 kg/mm2, I/v
must be > 20000 cm3

SECONDARY BEAMS

T beams coming from HE 600 A were considered

SECONDARY GIRDERS	length (m):	1.5	distance (m):	1	load (t/m):	50	M (tm):	9.375

DISPLACEMENT vs INERTIA		STRESS vs I/v	
I (m4)	f (m)	I/v (m3)	STRESS (t/m2)
1E-05	0.00313895	0.0002	46875
2E-05	0.00156948	0.00025	37500
3E-05	0.00104632	0.0003	31250
4E-05	0.00078474	0.00035	26785.71429
5E-05	0.00062779	0.0004	23437.5
6E-05	0.00052316	0.00045	20833.33333
7E-05	0.00044842	0.0005	18750
8E-05	0.00039237	0.00055	17045.45455
9E-05	0.00034877	0.0006	15625
0.0001	0.0003139	0.00065	14423.07692
0.00011	0.00028536	0.0007	13392.85714
0.00012	0.00026158	0.00075	12500

I/v should be > 600 cm3

HE600A 1/2

	b	h	S	y	S.y	bh3/12	d	S.d2
base	30	2.5	75	28.25	2118.75	39.0625	-18.0257	24369.573848
wall	1.3	27	35.1	13.5	473.85	2132.325	-3.27575	376.64181104
plate	30	4	120	-2	-240	160	12.22425	17931.875524
			230.1	10.22425033	2352.6	2331.3875		42678.091183

I =	45009.4787			
I/v1=	3164.27774	stress:	2.962761416	kg/mm2
I/v h =	2335.03129	stress:	4.014935487	kg/mm2
f (m)=	6.974E-05			

WEIGHTS:

Steel plate 40 x	7500 x 5700 mm	13.4235 t	
main girder W 1100 x 400 x 433 yield point 24 kg/mm2			
total length 5 x 5.7 m			12.34734
main girder HE1000B yield point 36 kg/mm2			8.96154
secondary girders 1/2 HE600A			
total length 5 x 7.5			4.6725
border plate	5 cm	10.362 t	
suspension		6 t	
axis, wheels		2.4 t	
variante 1	49.20534		
variante 2	45.81954		

CONCLUSION:

The estimated weight by 1st calculation is 46 or 49 tons according to the beam choice (HE 1000 A or W 1100 x 400 x 300 according to the ARBED catalogue (see extract hereunder). These values are to be compared with the 51 tons found by the above statistical formula referring to a 5.7 x h = 7.5m fixed-wheel valve with Hs = 50mWC.

Catalog
ProfilARBED - Beams selection program

PROFILARBED

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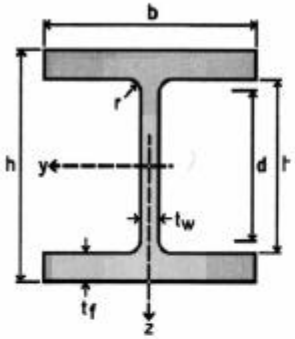

Listing with profiles according to the following rule:
I.y must be between 5000,00 cm4 and 3000000,00 cm4
W.y must be between 9000,00 cm3 and 71000,00 cm3
G ascending
Search in: IPE, IPN, HE, HL, HD, HP, HP(US), W, UB, UBP, UC, H

Profile						G [kg/m]	A [cm2] *A.vz [cm2]*	I.y [cm4] *i.y [cm]*	W.y [cm3] *W.y.pl [cm3]*	I.z [cm4] *i.z [cm]*	W.z [cm3] *W.z.pl [cm3]*	.T [cm4]	I.T [cm] *I.omega [cm6]*
W 1000 X 300 X 249	980,00	300,00	16,50	26,00	30,00	249,04	316,85	481 078,52	9 817,93	11 754,44	783,63	584,40	7,39
	928,00	*868,00*	*103,65*	*3,08*	*12,37*		*180,74*	*38,97*	*11 346,88*	*6,09*	*1 244,71*		*26 620 893*
HE 900 A	890,00	300,00	16,00	30,00	30,00	251,93	320,53	422 074,83	9 484,83	13 547,46	903,16	736,77	7,63
	830,00	*770,00*	*111,15*	*2,90*	*11,51*		*163,33*	*36,29*	*10 811,04*	*6,50*	*1 414,48*		*24 961 500*
UB 914 X 305 X 253	918,40	305,50	17,30	27,90	19,10	253,74	322,83	436 304,46	9 501,40	13 301,11	870,78	630,51	7,71
	862,60	*824,40*	*95,48*	*2,99*	*11,80*		*167,85*	*36,76*	*10 942,00*	*6,42*	*1 370,54*		*26 284 181*
W 920 X 310 X 253	919,00	306,00	17,30	27,90	19,00	254,02	323,18	437 456,16	9 520,26	13 366,25	873,61	630,91	7,72
	863,20	*825,20*	*95,36*	*2,99*	*11,80*		*167,86*	*36,79*	*10 962,73*	*6,43*	*1 374,80*		*26 449 053*
W 920 X 310 X 271	923,00	307,00	18,40	30,00	19,00	272,03	346,09	471 573,42	10 218,26	14 518,01	945,80	775,02	7,76
	863,00	*825,00*	*100,66*	*3,00*	*11,06*		*178,81*	*36,91*	*11 782,87*	*6,48*	*1 490,95*		*28 842 178*
W 1000 X 300 X 272	990,00	300,00	16,50	31,00	30,00	272,62	346,85	553 846,02	11 188,81	14 004,44	933,63	822,41	7,55
	928,00	*868,00*	*113,65*	*3,10*	*11,37*		*184,56*	*39,96*	*12 824,38*	*6,35*	*1 469,71*		*32 073 875*
HE 1000 A	990,00	300,00	16,50	31,00	30,00	272,62	346,85	553 846,02	11 188,81	14 004,44	933,63	822,41	7,55
	928,00	*868,00*	*113,65*	*3,10*	*11,37*		*184,56*	*39,96*	*12 824,38*	*6,35*	*1 469,71*		*32 073 875*
H 900 X 300 X 18 X 34	912,00	302,00	18,00	34,00	18,00	283,01	360,06	491 010,69	10 767,78	15 654,09	1 036,69	980,82	7,77
	844,00	*808,00*	*107,09*	*2,97*	*10,49*		*173,06*	*36,93*	*12 337,07*	*6,59*	*1 622,45*		*30 079 980*

ARBED GROUP

Catalog
ProfilARBED - Beams selection program

PROFIL ARBED

page 1
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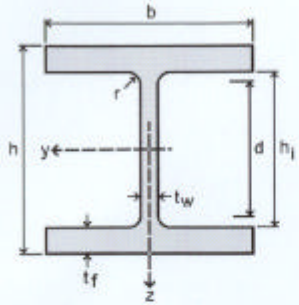


Listing with profiles according to the following rule:
I.y must be between 1125000,00 cm4 and 3000000,00 cm4
W.y must be between 10000,00 cm3 and 100000,00 cm3
G ascending
Search in: IPE, IPN, HE, HL, HD, HP, HP(US), W, UB, UBP, UC, H

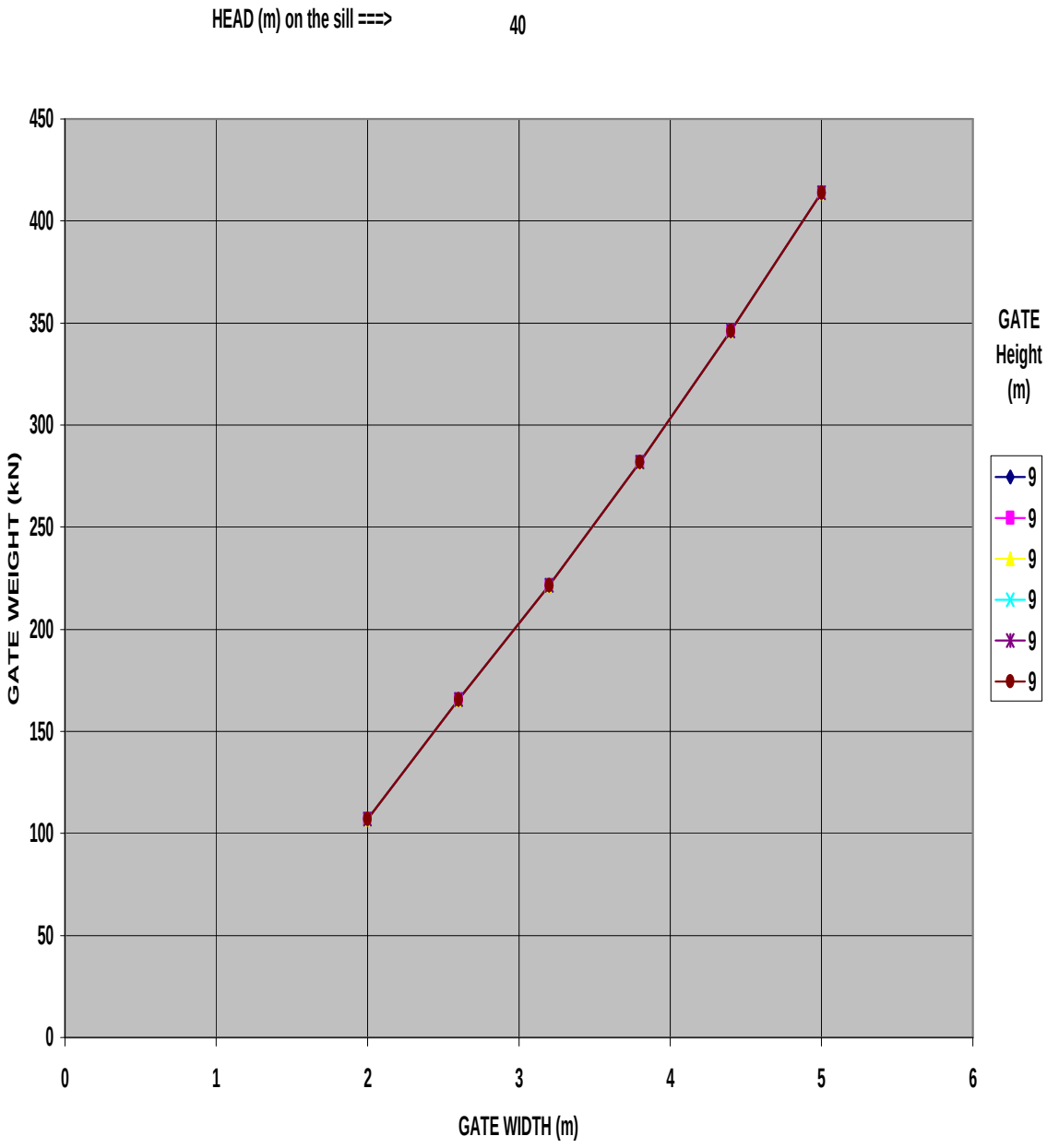
Profile	h [mm] *h.i [mm]*	b [mm] *d [mm]*	t.w [mm] *S.s [mm]*	t.f [mm] *A.L [m2/m]*	r [mm] *A.G [m2/t]*	G [kg/m]	A [cm2] *A.vz [cm2]*	I.y [cm4] *i.y [cm]*	W.y [cm3] *W.y.pl [cm3]*	I.z [cm4] *i.z [cm]*	W.z [cm3] *W.z.pl [cm3]*	I.T [cm4]	i.T [cm] *I.omega [cm6]*
W 1100 X 400 X 433	1 108,00 *1 028,00*	402,00 *988,00*	22,00 *125,43*	40,00 *3,75*	20,00 *8,66*	433,24	551,19 *254,39*	1 125 573,94 *45,19*	20 317,22 *23 160,71*	43 409,79 *8,87*	2 159,69 *3 361,78*	2 129,54	10,40 *123 500 699*
HL 1100 M	1 108,00 *1 028,00*	402,00 *988,00*	22,00 *125,43*	40,00 *3,75*	20,00 *8,66*	433,24	551,19 *254,39*	1 125 573,94 *45,19*	20 317,22 *23 160,71*	43 409,79 *8,87*	2 159,69 *3 361,78*	2 129,54	10,40 *123 500 699*
W 1100 X 400 X 499	1 118,00 *1 028,00*	405,00 *988,00*	26,00 *139,43*	45,00 *3,77*	20,00 *7,56*	499,28	635,21 *300,41*	1 294 059,56 *45,14*	23 149,54 *26 599,48*	49 964,12 *8,87*	2 468,35 *3 870,29*	3 134,95	10,45 *143 405 493*
HL 1100 R	1 118,00 *1 028,00*	405,00 *988,00*	26,00 *139,43*	45,00 *3,77*	20,00 *7,56*	499,28	635,21 *300,41*	1 294 059,56 *45,14*	23 149,54 *26 599,48*	49 964,12 *8,87*	2 468,35 *3 870,29*	3 134,95	10,45 *143 405 493*
W 1000 X 400 X 539	1 030,00 *927,80*	407,00 *867,80*	28,40 *165,75*	51,10 *3,58*	30,00 *6,64*	540,12	687,17 *316,39*	1 202 537,90 *41,83*	23 350,25 *26 823,86*	57 631,92 *9,16*	2 832,04 *4 435,56*	4 546,45	10,60 *137 552 834*
HL 1000 X 554	1 032,00 *928,00*	408,00 *868,00*	29,50 *168,65*	52,00 *3,59*	30,00 *6,47*	554,76	705,81 *328,03*	1 232 371,55 *41,79*	23 883,17 *27 496,21*	59 098,19 *9,15*	2 896,97 *4 546,53*	4 859,98	10,61 *141 326 871*
HE 1000 X 579	1 056,00 *928,00*	316,00 *868,00*	35,00 *198,15*	64,00 *3,25*	30,00 *5,63*	579,29	737,01 *393,33*	1 245 718,26 *41,11*	23 593,15 *27 950,86*	34 037,38 *6,80*	2 154,26 *3 498,29*	7 102,05	8,06 *82 804 383*
W 1000 X 300 X 584	1 056,00 *928,00*	314,00 *868,00*	36,00 *199,15*	64,00 *3,24*	30,00 *5,56*	584,57	743,73 *403,25*	1 246 071,34 *40,93*	23 599,84 *28 039,18*	33 433,46 *6,70*	2 129,52 *3 474,83*	7 230,02	7,98 *81 242 078*

ARBED GROUP

Weight of fixed-wheel gates with following characteristics:

- Width: from 2 to 5m,
- Height: 9m

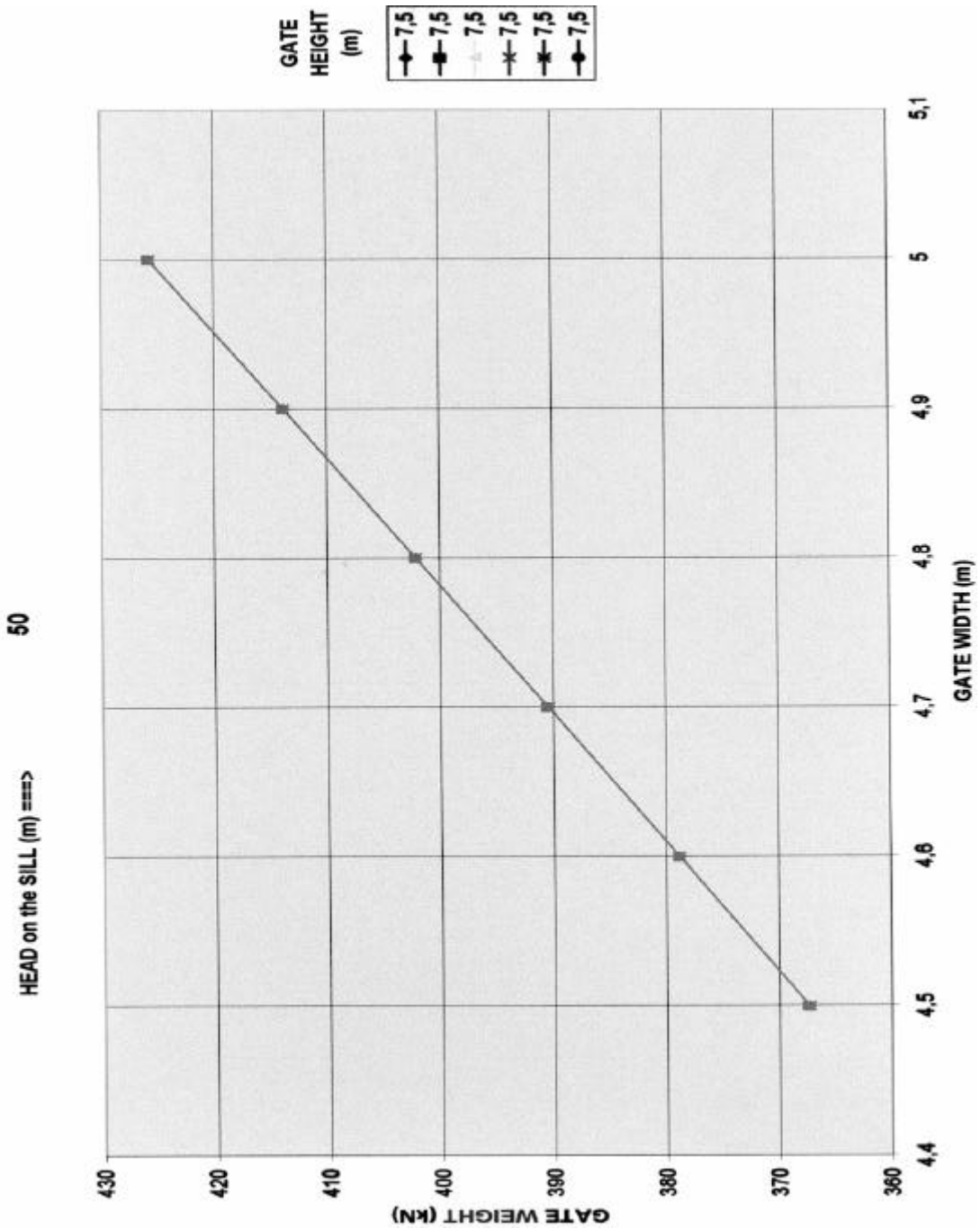
Pressure on the valve sill: 40mWC



Weight of fixed-wheel gates with following characteristics:

- Width: from 4.5 to 5m,
- Height: 7.5m

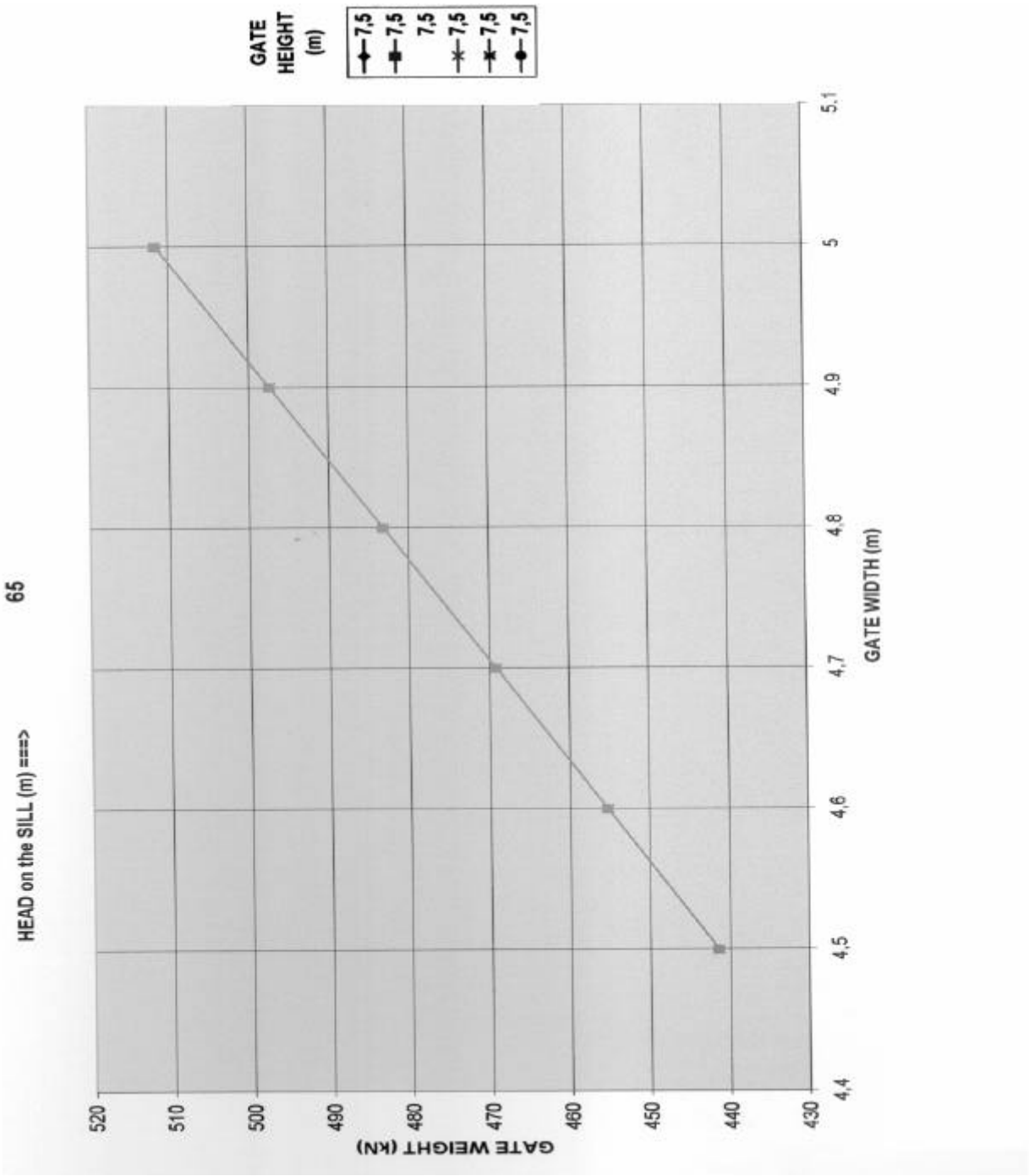
Pressure on the valve sill: 50mWC



Weight of fixed-wheel gates with following characteristics:

- Width: from 4.5 to 5m,
- height: 7.5m

Pressure on the valve sill: 65mWC



ESTIMATED WEIGHTS OF THE CULVERT AND WSB VALVES AND BULKHEADS

	N°	Height of slots (m)	Unit weight (tons)	Total weight (tons)	Remarks
Culvert valves (Hs = 40m)	8	-	27.5	220	
Culvert bulkheads (Hs = 40m)	8	-	24	192	
Culvert valves slots	8	32.99 (4) 24.04 (4)	200 (guiding) 800 (last 15m)	133	Incl.15t for lintels and sills
Culvert bulkhead slots	16	32.99 (4) 24.04 (4)	200 (guiding) 500 (last 10m)	193	Incl.30t for lintels and sills
WSB upper valves (Hs = 50m)	12	-	40	480	
WSB lower valves (Hs = 65m)	12	-	48.5	582	
WSB bulkheads (Hs = 65m)	4	-	131	524	
WSB upper valves slots	12	50.29	200 (guiding) 1000 (last 15m)	288	Incl.23t for lintels and sills
WSB lower valves slots	12	69.29	200 (guiding) 1000 (last 15m)	333	Incl.23t for lintels and sills
WSB bulkhead slots	24	69.29	200 (guiding) 500 (last 25m)	536	Incl.23t for lintels and sills
Miscellaneous (suspension elements, cylinder support and dogging devices)				175	
TOTAL				3656 tons	

This table will be a base for estimating the price of the valves and bulkheads. The price for welded construction is usually estimated by multiplying a weight by a kg price.
It must be pointed out that the total weight could be significantly reduced by optimising the weight of each valve and bulkhead. As said in point 2.1 (General) above, the service would not be the same In particular, no emptying of WSB with ship transit through the locks would be possible.

1.5 CONSTRUCTION DETAILS

Operated by use of hydraulic cylinders, fixed wheel valves are equipped with wheels revolving on fixed axles cantilevered from the valve frame (see next page a sectional view of one wheel of the Berendrecht culvert valves). Wheels can be of the flat rolling type on stainless steel tracks or

flanged type rolling on rails. Tracks must withstand the bearing pressures and distribute them to the concrete structure behind. The number of wheels will be based on the steel characteristics

A typical horizontal sectional view of a valve or bulkhead welded structure is shown hereafter. Horizontal plate girders or standard T or I-shape beams are the main force resisting members of the valve.

The distance between horizontal girders may vary according to the hydrostatic pressure. Diaphragm plates and intercostals are also used as reinforcement to distribute loads more uniformly.

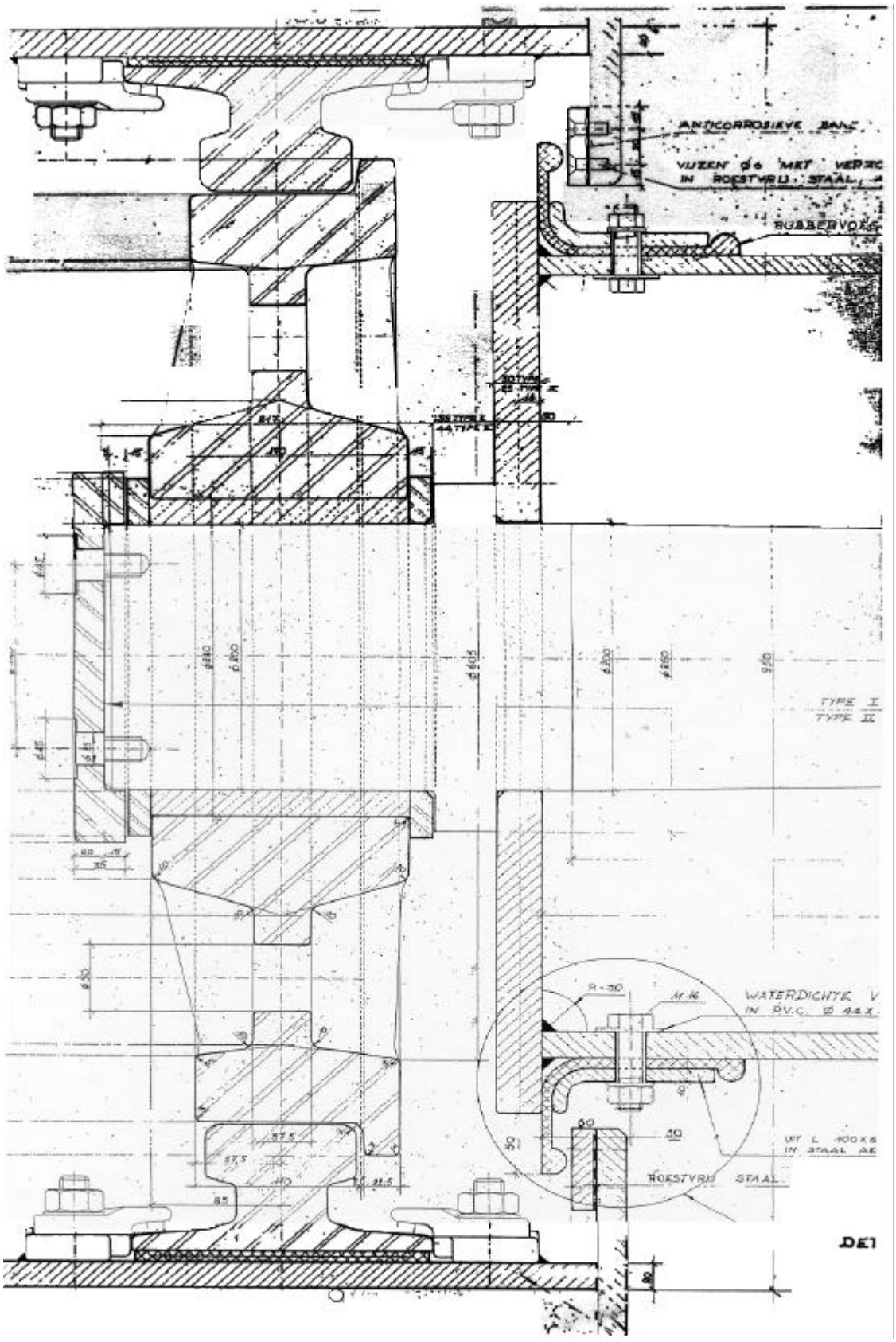
WSB fixed-wheel valves have to resist to water pressure and be tight in both directions as for the maritime locks (tide effect – for example: Berendrecht Lock in Antwerp)

The access shaft for maintenance will be used as surge chambers during operation of the valves.

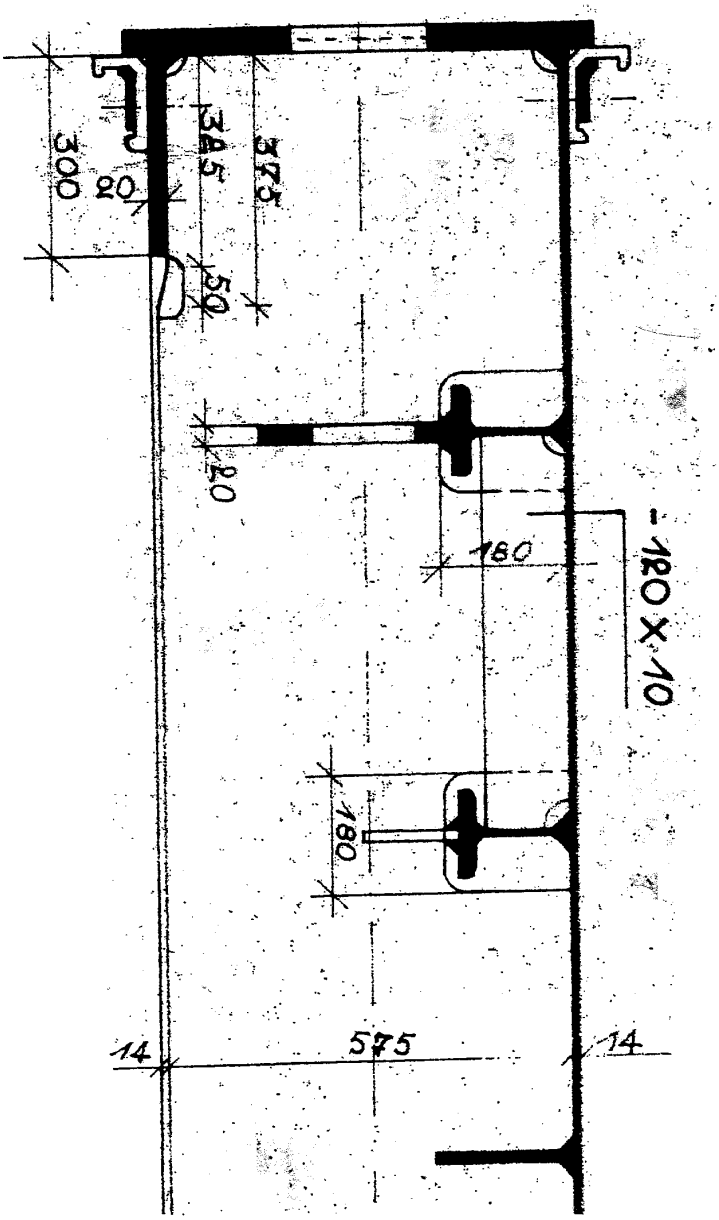
Tolerances must be adequate to assure watertight seals. That is the reason why it is recommended to use very rigid U-shaped steel guiding for the valves to avoid any movement during embedding of the fixed parts.

The valve and wheels are permanently under water. Maintenance of these wheels and bearings is possible by lifting the moving parts out of water. Wear of these elements can be considerably reduced by using convenient material (for example Ertalon used in Berendrecht lock).

SECTIONAL VIEW OF A VALVE WHEEL OF BERENDRECHT LOCK



TYPICAL VALVE STRUCTURE



<u>SEALING SYSTEM</u>

Seals are usually made of rubber with or without a PTFE overlay. The seals are often of J-shape or lip type.

For the WSB valves being tight for water flowing in both directions, the lip seals adopted for Berendrecht (see sectional view of the wheel) are convenient.

Lintel seal and side seals: can be of the upstream or downstream type (see sketch hereafter)

Bottom seal can be flat or also of the J-shaped type.(see Berendrecht type of bottom seals hereunder)

MAINTENANCE OF THE VALVES AND BULKHEADS

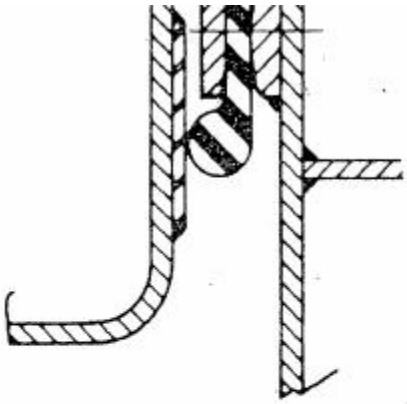
Maintenance work on valves and culverts consists mainly of the replacement of rubber seal and painting.

During normal operation, any trouble with one culvert or WSB valve (blocking or incident on the oil system) will not interfere on the ship transit except concerning the operation time. Every valve can be isolated and maintenance people can reach the upstream or downstream side of the valve by use of bulkheads after emptying of the space in between them.

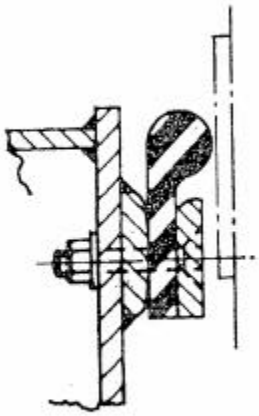
In case of planned replacement of seals or painting, the valve will be lifted out by use of a gantry crane moving on rails of 60 tons capacity. This crane will be provided by truck, assembled and installed on the railway located above the valve slot. After dismantling of the valve, the work will be carried out in good conditions in the maintenance building. Two cranes will be necessary for the 32 valves and 12 bulkheads. Rails will be installed between and outside of all the rows of WSB and culvert slots.

Bulkheads can be stored outside or suspended into the slots (one piece of bulkhead per slot). To remove any bulkhead, the cranes will be equipped wih an automatic lifting beam. Planned maintenance will also be done in the maintenance building.

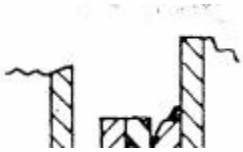
UPSTREAM AND DOWNSTREAM SEALING (J-shape type)



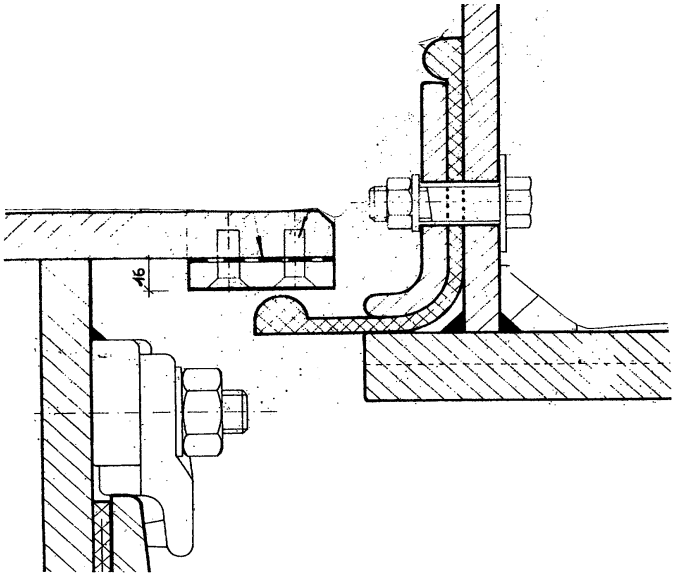
UPSTREAM SEALING

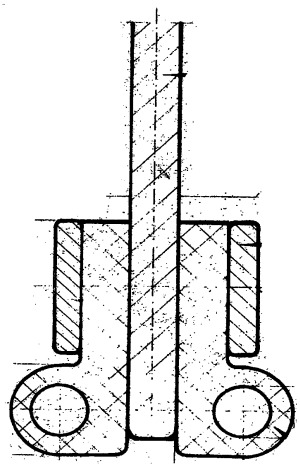


DOWNSTREAM SEALING



SIDE AND BOTTOM SEALS (BERENDRECHT)





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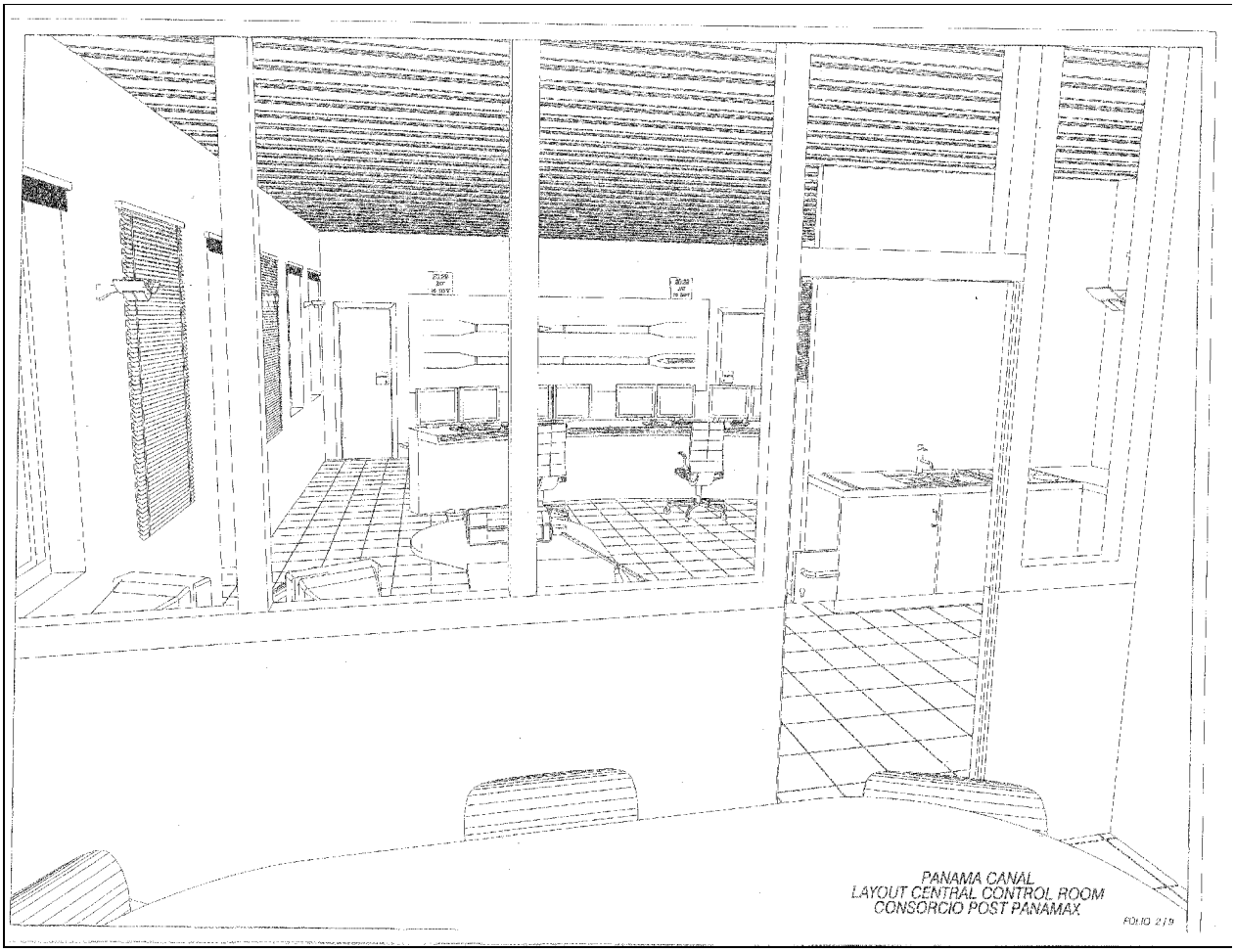

Diseño Conceptual de las Esclusas Post Panamax

TASK 4

F – OPERATING MACHINERY

R4-F

in association with

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1 Gates and Valves Operating Machinary

1.1 INTRODUCTION

1.1.1 PURPOSE OF THE DOCUMENT

The purpose of this document is to present a control system for the 3-rd lane of locks of Panama.

1.1.2 OBJECTIVES OF THE CONTROL SYSTEM

The control system shall be efficient and reliable; it will be designed with the following targets:

- safe operating conditions for the people and for the navigation.
- improvement of the operator interface;
- decrease of the shutdown time for maintenance and repair;
- minimisation of the staffing requirements;

1.2 HARDWIRED OR COMPUTER TECHNOLOGY

A hardwired control system based on electromagnetic relays and classic control panels (push-buttons, lamps (or Led's), switches ...) is reliable and safe. But there are many disadvantages with

this system in comparison with a computer-based system. So the hardwired control system is no more used except in particular safety applications.
Computerised control systems offer a lot of advantages in comparison with electromagnetic relays. They are extremely flexible and can fit with radical changes in control philosophy through simple programming changes. They have pre-developed tools which bring an important help for the diagnosis of defects and malfunctions, for maintenance operations and for automatic reports of activities.
At the supervision level, the computerised control system guarantees to the operating staff a level of control of the installation superior to the level they can get with a classical system based on conventional synoptic panels.
Furthermore, the maintenance staff has a tool of diagnosis allowing him to determine more quickly the origin of a failure.
These improvements are brought mainly by the following elements:

- Clear and accurate indications and this, in real time, of the status of all the installation;
- Auto-diagnosis of the control system equipment (Input/output cards, Central Processing Units, communication cards…);
- Use of sequence with the possibility to get the indications of missing criteria's;
- Mimic displays showing all the equipment as well as all the indications linked with each equipment;
- Use of standard modules for the control of the equipment;
- Records of the analogical values, events and alarms with the possibility of sorting, zooming and archiving.

In this project, the distances between equipment are too long to consider a system with all Programmable Logic Controllers (PLC's) located in the same room with the wires running from the devices in the field to the PLC's.
Remote I/O solution could also be used but the fact that we have two identical technical rooms for the gates leads to install a distributed system with a PLC in each of the technical room.
This solution is more flexible and reliable due to the fact that each PLC can work individually and has to be connected with the central system for display and control purposes but the safety basic functions are always running on the PLC level.
Another advantage consists in the fact that the installation of the 3rd lane of lock of Panama is based on two identical systems (gates): the proposed solution leads to a greater simplicity and contributes also to make the maintenance operations easier.
Then, the proposition for the control system of the 3-rd lane of locks of Panama is a distributed control system with several PLC's and an optical fibre network connecting all the devices.
Operator workstations shall be installed in the central control room and shall allow the control of all the installation. This modern control philosophy is widely used in industry.
This is a very much opened system which allows future PLC's extensions by the simple connection of new devices on the network.

1.3 CONTROL PHILOSOPHY

It must be possible to operate all the various functional equipment dedicated to the third lane of locks with a minimum of human supervision and this only from one location: the central control room.
For safety reasons, it shall be better to provide also a backup control room located in another building. This backup control room allows the same control functions and facilities as from the central control room.
From these control rooms, it shall be then possible to control:

- the preliminary actions for the auxiliary devices;
- the lighting;
- the initialisation of opening and closing sequences.

But for reasons of redundancy and proximity during the test operations, it shall be better to provide also a local control near the concerned equipment. These local controls will be used in case of exceptional maintenance or test operations.

1.3.1 CONTROL LEVELS

The system will be built up with three control levels:

- On the central control station level, the system will carry out the control and supervisory functions for the overall 3rd lane of locks and all its auxiliary devices like the lighting and the water saving basins;
- The local control level will be located either in each technical room linked to each gate, or near the valves of water saving basins or near the HV arrivals;
  On this level, the local control system based on PLC's will be installed for the different equipment. Different computers will be used for each functional group (like a gate and its associated devices), to carry out all the control and supervisory functions. At these local control levels, manual push button system directly connected to the devices will be available to operate the devices if the PLC's fail or during the commissioning phase.
- On the test and maintenance level, manual operation of individual items of equipment could also be possible from local boxes in the field.

The control system will permit to operate the locks in different manners:

- the normal and automatic mode of control of the locks will be achieved from the central control room where the system gets the overall and necessary information to perform a simple and reliable operation of all the equipment of the 3rd lane of locks;
- as a back-up of the normal operation or during special operations, it will be possible to operate the different parts of the installation from the local control system located near the gates either in automatic mode using the PLC's or manually using the push buttons;
- at testing and maintenance level, it will be possible to operate the equipment from the boxes located near the process equipment.

1.3.1.1 Selection modes

For the selection of the control mode, some selector switches will be provided in front of each functional group of equipment; for example in the technical rooms near the gates.
On this local control level, each functional group will have its own control mode selector switch. The switching in local mode will require the agreement of the central control room level.
These switches have three positions: **remote / local_auto / local_ manu.**

- in "remote" position, the control is transferred to the central control station;
- in "local" positions the particular functional group is controlled from a local control screen or panel located in the same room as the switch.
  - in "local_auto" position the functions for automatic control are possible but only locally;
  - in "local_manu", only the manual control is authorised: this last mode is a degraded mode.

1.3.1.2 Interlocking

Whatever is the selected mode, "remote or local"; interlocks prevent always any forbidden operations. Interlocking and safety signals are always hardwired and independent of the control system.

1.3.1.3 Possibilities of the system at each level

A. Central control station level

At this level, all the information is available from the whole installation. It is possible to control all the equipment of the site. All the facilities of the control system are available on this level, with among others:

- automatic control of the complete installation (as well as opening / closing sequences, controls of all the auxiliary systems);
- information about the missing preliminary conditions for the initialisation of an operation;
- supervision of the complete installation via mimic displays, trend-logs, bar-charts, supervision sequences;
- alarm and event management;
- statistic data and reports;
- diagnosis of the system;
- printing out of trends and mimic displays,
- data archiving...

B. Local control level with PLC's

A display monitor is foreseen with each local PLC. The following facilities will be available but limited to the relative functional group.

- automatic control of the relative functional group (as well as opening/closing sequences or controls of the auxiliary systems);
- information about the missing preliminary conditions for the initialisation of an operation;
- supervision of the relative functional group via mimic displays, trend-logs, bar-charts, supervision sequences;
- alarm and event management;
- diagnosis of the system;

C. Local control level with push buttons

A conventional control panel with pushbuttons, switches, indicators and lamps (or Led's) will allow operating the relative functional group in case of PLC failure.
It is an elementary local mode of exploitation: the operator does not get all the information as well as all the diagnosis capabilities of the control system, but it allows nevertheless the normal exploitation of the relative functional group of equipment.

D. Test and maintenance level

This is in fact the equipment level.
Here, there is no automation: it is only a local command on the equipment itself if the "local" control panel is too far away from the equipment. This level will be used only for maintenance and tests purposes.
At this level, interlocking does not exist.

1.3.2 AUTOMATION LEVEL

The installation includes some elementary systems, each of them having a variable level of complexity.
The automation level is defined at the mechanical engineering design level according to the characteristics of each system.
As a general rule, each elementary system is sequentially controlled and operated by the operator from the operator workstation through the selection of choices and start / stop orders.

The following hierarchical control levels may be defined:

a) Equipment level
It is the individual control including only safety interlocking and individual protections dedicated to the controlled equipment. For the control of the equipment, a standard module could be used. This one allows a diagnosis of the equipment: unavailability, abnormal trip, equipment in manual local mode...

b) Group level
The sub-group is an assembly of motors or actuators witch constitutes a given function, for example a culvert valve and its auxiliary devices. This group of equipment is under the control of interlocks witch assures the required function for this set of equipment.

c) Sequential level
The sequences allow the realisation in an automatic mode or in step by step mode of all the functions requested for an operation. For example: the opening of a gate.
The functional equipment will be controlled through a sequential program where the various steps and their related criteria's can be dynamically displayed on the screens.

1.4 MINIMAL REQUIREMENTS

1.4.1 REDUNDANCIES

Redundancies are installed in order to
- avoid any common mode failure;
- increase availability of the main equipment;
- increase safety.

The following redundancies are systematically installed:
- all programmable logic controllers (PLC), using the hot standby principle;
- the operator workstations and their communication couplers;
- the communication networks between PLC's and theirs couplers;
- the power supplies.

All redundant main equipment (like gates) are treated by different PLC's
All redundant equipment (motors, actuators, measurements) managed by the same PLC, and whose loss affects the availability or the performance of the installation, are connected to different Input/Output cards.

1.4.2 PROGRAMMABLE LOGIC CONTROLLER

A Programmable Logic Controller consists of several modular components, which can be extended modularly depending on the scope of the automation tasks.

It consists mainly of central multi-function modules and an adequate number of process interface modules. The main components are:

- The redundant control processor unit (CPU) where all the automation functions algorithms are processed, such as loop control, sequence control, as well a wide range of calculation functions, analogue value corrections and linearization functions, etc;
- - Signal acquisition modules whose functions are the reading, validation, monitoring and conditioning of all the process binary variables as well as analogue variables, making these values available for further use in the process control system (digital input modules, analogue input modules) ;
- - Signal output modules generating the logic or the analogue outputs to the process from orders issued from the multi-function processors (digital output modules and analogue output modules);
- A dual redundant optical network performs the communication between the different automation units.

1.4.3 COMMUNICATION

Signal transfers between the various components of the supervision and automation systems are performed by the way of redundant data highways whose speed is adapted to the required functionality.
Those networks must use an industrial type of optical cable so that they can be routed through the installation without particular precautions.
The networks that are used will guarantee that global performances of the system are met in all circumstances.
The system is open to interface with third party components by providing various interface modules. Classical serial link could be based on Modbus, Profibus or equivalent protocols. Essentials indications or status of locks will be required by the Marine Traffic Control (MTC) and on the upper management's computers. In consequence, the system will be designed to enable the dialogue with third party components through standardized interfaces (RS 232-C, Ethernet…).
All the networks are redundant, so as single failure cannot affect the availability of any communication link.
For the AC motor drive control, principle hereafter could be used: hardwired connections for safety and interlocking related signals and serial links for monitoring and control.

1.4.4 MAN / MACHINE INTERFACE

The Man / Machine Interface consists mainly of operator consoles connected on the site network via operator workstations.
These units are equivalent but could be dedicated an area of the process, to some specific functions... Anyway each operator workstation allows the control of the complete installation. So, those are functionally redundant toward each other.

The operator workstations are installed on standard hardware platforms.
The operation on the operator consoles is based on the window technology, acting on free configurable process displays on one side, and on standardised faceplates on the other side.

The Man/Machine Interface offers the following features on the operator workstations:

- presentation of the data on:
  - mimic displays for operating and monitoring the locks;
  - fixed-format displays such as overview displays, group displays, equipment status displays, etc;
- data archiving which stores the data over a configurable period and offers the various logs as the alarms logs, event logs, trip logs, long term trending of analogue variables automatically or on request. The storage and retrieval of historical data function provides facilities to store up to 30 days without transfer to an external device. One external long-term archiving media (e.g. optical disk) for memorisation of historical data of the plant shall be foreseen;
- on line event recording facilities;
- trending facilities : analogue values can be memorised over 72 hours minimum with a sampling rate of 1 second minimum;
- alarms annunciation and displays (with different priority levels);
- statistic calculations;
- system diagnosis presentation.

The system will be able to memorise chronologically all I/O status changes that appear within the plant or at the interfaces.
Moreover, printing out of analogue trends and data logs will be also possible.
The supervision system is based on hierarchic visualisation concept; this is reflected in the display hierarchy where the graphic elements can be displayed easily and quickly.

Travelling through the displays (mimic displays, alarms displays, control displays, data logging, and functional groups displays) will be also possible:

- either starting from an overview display;
- or by pointing at specific designated areas;

The following display hierarchy shall be applied:

- Site overview level;
- Functional area level;
- Equipment level.

The firmware of the workstations will allow the sequence monitoring of actuators and also the identification of the criteria's which are not fulfilled between two steps of a sequence.
It is also possible to by-pass, with the agreement of the operator supervisor, some steps in "hand" mode and then to come back in "auto" mode for the remaining steps of the sequence;

1.4.5 ENGINEERING STATION

The Engineering Station is an integral part of the control system. It is used through all stages of the project from the configuration based on detailed engineering documents to pre-commissioning and commissioning phases.
Software modifications and updates during the lifetime of the plant are carried out via this engineering station.

During the tests, commissioning and operating of the plant, the engineering stations are connected to the network(s); this allows, among others, the following operations:

- on-line development or modifications of the application software and down-loading of the programs into each element of the control system;
- on-line diagnosis (hardware and software) of any element belonging to the control system's structure.

The Engineering Station provides the tools requested to configure easily the entire process control system, hardware and software.
The application software is designed by the use of function diagrams, which are converted into machine code by a code generator and then "downloaded" to the target systems (PLC's or MMI equipment) via the bus system in a quick and safe manner.

Main functionality of this engineering station

- Programming :
  - - tools are provided for inserting, deleting and duplicating blocks of programs (with automatic renumbering, search functions, . . .);
  - - easy back-up possibilities;
  - - automatic documentation and configuration management tools.
- Diagnosis :
  - - partial visualisation and (controlled and temporary) overwriting of status of inputs, outputs and internal variables (defined in application programs or implicit in functional modules);
  - - display and control of program status progress in a step-by-step mode.

1.4.6 DIAGNOSIS TOOLS

Any internal fault inside the control system activates a detailed error message, which is sent to the operator workstations; external faults (e.g. signal validation) are also covered.
Investigation is available on the engineering workstation or on the operator workstations.
Repairing is to be performed during operation of the system and will consist mainly in easy module replacements (with minimum needs in wiring disconnection).
After detection and localisation of a faulty module, maintenance people can repair without disturbance on overall operation of the process.
All I/O modules and redundant modules may be removed under power.

Theoretical MTBF (Mean Time Between Failure) of the various subsystems that appear on the general architecture scheme are such that the MTBF of the whole system will not be lower than one year.
Practically, reliability criteria will be met only if during normal operation the failure ratio is lower than 1 to 250 pieces of equipment per year spread over a one year period. A piece of equipment is an elementary interchangeable component (for example: a plug-in module, a CPU module, a power supply module, a workstation…).

Remark : A failure does not mean systematically a stop of the navigation but only the replacement of the defective piece of equipment.

1.4.7 INSTRUMENTATION

The level of instrumentation is generally related to the automation level foreseen for the installation, that is, all the remote and local measuring systems are provided to guarantee the supervision, tuning and control of the various parts of the installation.
Where measurements are critical or important, several transmitters or transducers shall be foreseen. The protection criteria are foreseen with 2 out of 3 logic.

1.4.8 EMERGENCY STOP

By action on the different emergency shut-down buttons adequately located in the site, the corresponding part of the installation goes automatically to a secure mode. These push-buttons, are mechanically locked if depressed.

1.5 CONTROL SYSTEM ARCHITECTURE

1.5.1 FUNCTIONAL SPLIT

The high modularity of the control system and an adequate functional distribution between the different PLC's minimise the common failures to a little part of the installation. For that reason, the

following split is proposed; a PLC with redundant CPU is attributed to each group of equipment listed here after.

1. **One redundant PLC in the technical room for gates 1 and 2**: for the control of equipment associated with the gate 1 left side (gate, valves, HV1, LV cabinets, lighting and the emergency diesel set : 250 I/O estimated)
2. **One redundant PLC in the technical room for gates 1 and 2** : for the control of equipment associated with the gate 2 left side (gate, valves, HV1, LV cabinets, lighting: 150 I/O estimated)
3. **One redundant PLC in the control building** : for the control of equipment associated with gates 1 and 2 right side and the control building (valves, HV3, LV cabinets, lighting: 200 I/O estimated)
4. **One redundant PLC in the technical room for gates 3 and 4** : for the control of equipment associated with the gate 3 left side (gate, valves, HV2, LV cabinets, lighting: 150 I/O estimated)
5. **One redundant PLC in the technical room for gates 3 and 4** : for the control of equipment associated with the gate 4 left side (gate, valves, HV2, LV cabinets, lighting: 150 I/O estimated)
6. **One redundant PLC in the HV technical room 4** : for the control of equipment associated with gates 3 and 4 right side (valves, HV, LV cabinets, lighting: 150 I/O estimated)
7. **One redundant PLC in the WSB technical building 1** : for the control of equipment of the water saving basins (100 I/O estimated)
8. **One redundant PLC in the WSB technical Building 2** : for the control of equipment of the water saving basins (100 I/O estimated)

This is a minimal structure of PLC's established in function of a functional split. This solution presents the advantage to have two identical systems of 3 PLC's for each two double gates.
The number of I/O (1250 I/O) and their functional split could be improved according to the definitive design of locks and to the geographical location of the different equipment (for example the valves of the saving basins).

1.5.2 BASIC CONFIGURATION

The minimal configuration for the control system of the 3rd lane of locks of Panama will include:

- The eight (8) PLC's mentioned before with, every time, a redundant CPU associated with not redundant peripheral cards. The power supply of the PLC's are redundant;
- A redundant optical fibre network connecting on one side the PLC's together and on the other side connecting these PLC's to the supervision units. The redundancy is also applicable for communication nodes ;
- Three (3) operating workstations with their associated electronics; each including a 20" colour flat screen with keyboard and mouse. One of the threee operating workstation will be situated in a technical room for safety reasons. In case for example of fire incident into the control room, this third operating workstation will be used as a backup control room of the locks ;

- From each workstation, all the installation can be controlled and every workstation is independent from the others. In practice, every screen will be allocated to the control of a part of the installation: a screen by system of double gates and a screen for the auxiliary devices. This makes the control easier due to the fact that the operators will find easily the equipment on their dedicated screen;
- Three (3) printers for alarm, events, and hardcopy ;
- One (1) Engineering Station with keyboard, mouse, printer and mass storage device shall also be installed. This station shall allow off-line configuration of the control process units and the MMI, on-line downloading of the data's to the selected targets, parameterisation, and automatic generation of as-built documentation of the control system configuration (logic drawings and I/O assignments). This kind of documents is automatically “As-built”.

This basic configuration (see drawing D4-F-201) allows the control of all the installations and contains redundancy at every level: automation with redundant CPU’s, communication with redundant optical fibre network and supervision with the five redundant workstations.

1.5.3 VARIANTS AND IMPROVEMENTS

Some variants could be envisaged. Their advantages or disadvantages are described here after.

1.5.3.1 Large flat screens (rear projection system).

Large flat screens could be provided in supplement to the normal operator workstations. This rear projection system would be connected to the control system and allows the visualisation of the complete set of locks of the 3rd lane of Panama on the same mimic display.
We consider that this variant is an interesting one for the operator; people have immediately an overview of the whole plant.

1.5.3.2 Automatically positioning CCTV

According to the very long distances between the control room and some equipment, it is certainly interesting to foresee a CCTV's system (Circuit Closed TeleVision).
Cameras would be positioned automatically in the adequate position in function of the operations to be realised. It will be done by means of interconnections between the control system and the matrix of the CCTV system.
The installation of a CCTV monitor, close to every workstation, would allow to the operator to see the equipment of the process concerned by each step of the operation.

1.5.3.3 Panel for local manual control

To be in accordance with the control philosophy described in § 3.1, it is necessary to add a conventional local control panel in the technical rooms; this will include push buttons, switches, indicators and lamps (or Led's).
This control panel is directly connected to the equipment and allows the control of equipment in a degraded mode in case of general defect of the main control system.

1.5.3.4 Monitor for local automatic control

To be in accordance with the control philosophy described in § 3.1, it is necessary to add an automatic local control device in each local technical room.
This local control device could be based on a small classic panel connected to the PLC.
However it is better to foresee a local control screen. It allows having locally all the facilities and diagnosis tools of a modern supervision system, for tests and maintenance; it can also be used in case of a general failure in the central control room.

1.5.3.5 Backup control Panel in the central control room

As a supplement to the workstations in the central control room, it is possible to foresee a conventional backup control panel with simplified control which allows, via a PLC linked to the network, the control of the locks from the control room in case of a defect of workstations.
This degraded control mode loses however its interest if we consider that all the installation can be monitored from every workstation of the control room and from every technical room.

1.5.3.6 PLC's dedicated to the lighting, HV and LV cabinets

The split of the auxiliary devices (electric HV & LV distribution cabinets, lighting...) from the process itself (gates, valves...) at the level of the PLC in the technical rooms for gates would bring the following advantages:

- minimize the common failures to a little part of the installation;
- simplify the searches in case of defect (targeted defects);
- guaranty the strictly identical character for the four PLC's at the level of the technical rooms for gates and for the four PLC's at the HV technical rooms;
- ensure the separation of more "static" equipment (very few operations at the level of the electric auxiliary devices) and the functioning of locks.

The variety in the size of the PLC on the market allows indeed finding a type of PLC suited to the best functional split.
We obtain the following functional split:

1. **One redundant PLC in the technical room for gates 1 and 2** : for the control of equipment associated with the gate 1 left side (gate, valves: 100 I/O estimated)

2. **One redundant PLC in the technical room for gates 1 and 2** : for the control of equipment associated with the gate 2 left side (gate, valves: 100 I/O estimated)
3. **One redundant PLC in the control building** : for the control of equipment associated with gates 1 and 2 right side and the control building (valves, HV, LV cabinets, lighting: 150 I/O estimated)
4. **One redundant PLC in the technical room for gates 3 and 4** : for the control of equipment associated with the gate 3 left side (gate, valves: 100 I/O estimated)
5. **One redundant PLC in the technical room for gates 3 and 4** : for the control of equipment associated with the gate 4 left side (gate, valves: 100 I/O estimated)
6. **One redundant PLC in the HV technical room 4** : for the control of equipment associated with gates 3 and 4 right side (valves, HV, LV cabinets, lighting: 150 I/O estimated)
7. **One redundant PLC in the WSB technical building 1** : for the control of equipment of the saving basins (100 I/O estimated)
8. **One redundant PLC in the WSB technical building 2** : for the control of equipment of the saving basins (100 I/O estimated)
9. **One redundant PLC in the HV1 technical room for gates 1 and 2** : for the control of associated electrical equipment (HV, LV cabinets, lighting, emergency diesel set : 250 I/O estimated)
10. **One redundant PLC in the HV2 technical room for gates 3 and 4** : for the control of associated electrical equipment (HV, LV cabinets, lighting: 100 I/O estimated)
11. **One redundant PLC in the control building** : for the management of the internal equipment of this building (HVAC, CCTV...: 50 estimated I/O)

1.5.3.7 Redundant I/O's

A solution with redundant input/output cards leads to a very important additional cost with regard to a system with simple I/O cards.
Systematically use of redundant I/O cards offers few advantages with regard to a non redundant I/O cards system for which redundant equipment are monitored via different I/O cards.
Moreover, the failures of I/O cards are rare, except during the commissioning and, in any case, the replacement of modular cards is easy and fast.

1.5.3.8 Maintenance help system

The operator workstations or the engineering workstation could be loaded with special software which could allow statistic global calculations as well as data logging related to the locks. It is certainly interesting to foresee this maintenance tool in the control system.
The performance functionalities could include:

- electrical auxiliary device consumption calculation (1/4 hour values);
- lock statistic records (number of gate opening or closing, traffic management...);
- on-line data sheets actuators management for maintenance purpose (cumulative operation time, number of starts...).

1.5.3.9 Fieldbus alternative

The fieldbus is especially used in the petrochemical environment where equipment are distributed almost everywhere on the site.
In the case of the locks of Panama, if the distances are important, most of the equipment are grouped together in technical rooms where the PLC'S are installed. In that case a fieldbus solution is not recommended as far as it does not allow great savings of cabling. (To be confirmed in function of the definitive design and equipment layout).

1.5.4 FINAL PROPOSAL

The final proposal takes into account the basic configuration (§ 5.2) with addition of the following variants:

- Large flat screens (rear projection system);
- Automatically positioning CCTV system;
- Panel of local manual control ;
- Monitor of local automatic control ;
- PLC's dedicated to the lighting, HV and LV cabinets...
- Maintenance help system.

The final proposition for the architecture of the system of control consists of following elements (to see also the drawing D4-F-202):

- The eleven (11) PLC's mentioned at §5.3.6 with, every time, a redundant CPU associated with not redundant peripheral cards. The power supplies of the PLC's are also redundant;
- A redundant optical fibre network connecting on one side the PLC's together and on the other side connecting these PLC's to the supervision units. The redundancy is also applicable for communication nodes ;
- Three (3) operating workstations with their associated electronics; each including a 20" colour flat screen with keyboard and mouse. One of the three operating workstation will be situated in the gates (1 & 2) technical room for safety reasons. In case for example of fire incident into the control room, this third operating workstation will be used as a backup control room of the locks ;
- From each workstation, all the installation can be controlled and every workstation is independent from the others. In practice, every screen will be allocated to the control of a part of the installation: a screen by system of double gates and a screen for the auxiliary devices. This makes the control easier due to the fact that the operators will find easily the equipment on their dedicated screen;
- One rear projection system of big dimension (for example 4 times 1 metre) to show in one step the chamber, the 2 double gates and the water saving basins ;
- Three (3) printers for alarm, events, and hardcopy ;
- One (1) Engineering Station with keyboard, mouse, printer and mass storage device shall also be installed. This station shall allow off-line configuration of the control process units and the MMI, on-line downloading of the data's to the selected targets, parameterisation, and automatic generation of as-built documentation of the control system configuration (logic drawings and I/O assignments). This kind of documents

is automatically "As-built". This station shall have maintenance tools here above mentioned.

- Eleven (11) display monitors provided for each PLC. This is the maximum configuration, it can be resume to one display monitor by technical room or may be to a system with touch screens;
- Eleven (11) conventional local panels of command.
- The interface modules required for the communication with the Marine Traffic Control and with the upper management's computers.

1.5.5 DEGRADED MODES

1.5.5.1 Normal situation

In the normal situation, the equipment of the 3-rd lane of locks are controlled from the central control room via the workstation dedicated to these equipment. The operator has also the rear projection system and the CCTV system.

1.5.5.2 Simple failure

The table below resumes the various possibilities of command of equipment in case of one control system element failure.

Faulty element	Control mode
- Operating workstation in the central control room	- Full control: from another operating workstation (for example from this one normally dedicated to electrical auxiliary devices witch is rarely used).
- Optical fibre network cut	- Full control: from the workstation dedicated to these equipment via the redundant network.
- Control Process Unit	- Full control: from the workstation dedicated to these equipment via the redundant Control Process Unit.

1.5.5.3 Double failure

The table below resumes the various possibilities of command of equipment in the extremely rare case of double the control system failure.

Faulty element	Control mode
- Operating workstation in the central control room - Another Operating workstation in the central control room	- Full control: from another operating workstation. The five operating workstations allow the control of every equipment of the locks. In case of unavailability of the main control room (fire incident for example): full control from the backup control room.
- Operating workstation in the central control room - Optical fibre network	- - Full control: from another operating workstation via the redundant network.
- Operating workstation in the central control room - Control Process Unit	- Full control: from another operating workstation via the redundant Control Process Unit.
- Optical fibre network - The redundant network Comment: the fact of having two ring networks makes the complete loss of 2 networks almost impossible.	- Automatically, from the local display monitors. This is a degraded mode because it needs several operators at the different technical rooms.
- Optical fibre network - Control Process Unit	- Full control: via the redundant Control Process Unit and the redundant network.
- Control Process Unit - Another Control Process Unit (not its backup)	- Full control: via the redundant Control Process Units
- Control Process Unit - Another Control Process Unit (the backup of the first one)	- Manually, from the conventional control panel. This is a degraded mode.

1.6 CONTROL ROOM LAYOUT

Drawing D4-F-002 (same as triple lift configuration) shows a proposition for the control room layout. This proposition includes the control room and its equipment with certain annexes such as an office for the supervisor, a conference room, a kitchen area and a sanitary area.
The choose of remote control of the other locks from this control room will lead automatically to a redesign of the proposed layout.

2 Gates and valves operating machinery

2.1 OPERATING MACHINERY FOR THE ROLLING GATES

The gates of the single lift configuration on the Pacific side are much heavier and larger than the gates on the Gatun Lake side. The basic principle of the machinery remains however the same but the power and size of the main motors and gear boxes are different.

Each rolling gate is operated by a winch system that consists mainly of (see drawing N° D4-J-201 and N° D4-J-202):

- two main driving AC motors of 300 kW (on the Gatun Lake side) and 900 kW (on the Pacific side) , one operating and one in standby,
- one smaller emergency AC motor of 30 kW (on the Gatun Lake side) or 100 kW (on the Pacific side) allowing to still move the rolling gate if the main motors are not available or in case of shutdown of the main supply
- one central primary gear box with connection flanges to the motors and to two secondary gear boxes,
- two secondary gear boxes,
- two rope drums of about 2m in diameter (on the Gatun Lake side) and about 3m (on the Pacific side) .

The two steel cables are attached on each side of the upper support wagon of the rolling gate via a set of pulleys and on the other side to the rope drum. The effort in the steel cables is regulated and damped by pre-stressing action and elastic rods.

On each side, one of the two cables is starting from the rope drum to the opposite end of the gate railway and is coming back to the drum. This cable allows to close the rolling gate. The second cable is going straight from the drum to the support wagon of the rolling gate. This cable allows to bring back the rolling gate into its gate chamber.

The above operating machinery is quite similar to the Berendrecht Lock in operation for now 13 years without significant problem.

2.2 GATE MOTORS

As shown in the chapter R4-F of the triple lift configuration, the AC variable solution (VSI drive + synchronous motors) is the most convenient to this application.

For the motors of the gates located on the Gatun Lake side, the solution is the same as for the one studied for the 3-steps configuration (rated power: 300kW).

On the contrary, the rated power (900 kW) of the gate motors on the Pacific side, is quite bigger.

There are two possibilities regarding the voltage to be used for the drive and the motor :

- a low voltage power supply,
- or a medium voltage (V > 1000 kV).

Hydraulic motors were not considered for following reasons:

- that solution has not been used up to now on gate operating machinery of big locks as Post-Panamax ones,
- preference has been given to a solution with a permanent mechanical connection.

2.2.1 BASIC DATA.

2.2.1.1 Redundancy.

The lock can be isolated by two rolling gates at each end of the chamber. There are two couples of gates for the lock.

One main motor is normally operating alone and is designed to move one gate. The other main motor remains in standby.

The two main motors are alternately working in order to keep them in good condition and to reduce the number of working cycles.

In case of failure of one motor, redundancy is ensured.

In case of emergency, a smaller auxiliary motor has been added. This motor has to be able to open or close the gate at reduced speed. This auxiliary motor will be of the asynchronous type.

2.2.1.2 Type of service

The service of the motor can be defined as an intermittent duty type with electrical braking.

A typical operating cycle for one motor is as follows:

Step 1	Opening of the first gate (by use of motor 1)	time: 06 min
Step 2	Movement of ship into the lock chamber	time: 12 min
Step 3	Closing of the first gate (by use of motor 2)	time: 06 min
Step 4	Filling or emptying time (by use of water saving basins)	time: 35 min*
Step 5	Opening of the third gate (by use of motor 3)	time: 06 min
Step 6	Ship going out the lock chamber	time: 12 min
Step 7	Movement of another ship entering into the chamber	time: 12 min
Step 8	Closing of the third gate (by use of motor 4)	time: 06 min
Step 8	Filling or emptying time (by use of water saving basins)	time: 35 min*
Step 9	= Step 1: Opening of the first gate (by use of motor 1)	

* The Hydraulic section mentions a time between 32 and 36 Minutes

The idle time between two operations of one motor is about 130 min
Therefore, the cyclic duration factor equal to the working time / (working time + idle time) is 6/130 = 0,046

In case of failure of one motor, the minimum idle time is 12 min.
The total cyclic duration factor is then equal to 0,33.

Consequently, in both cases, the starting number and the working time can be considered as reduced.

2.2.1.3 Atmospheric condition (Balboa FAA)

Average of the maximum air temperature: 104,4 °F or (104,4 -32)/1,8 = 40,22 °C
Annual average air temperature: 80,9 °F or (80,9 -32)/1,8 = 27,16 °C
Relative Humidity average (during wet season): 80,1 %

According to IEC 34-1, motors are designed to operate in air temperature between -16 and 40° C. Power available when operating at higher temperature than 40°C, decreases of 1 -2 % by degree Celsius. The dimensioning of the motor has to take this fact into account.

The drive contains electronic parts and the maximal temperature cannot exceed 50 °C. A de-rating is also to be applied for temperatures higher than 40 °C. But this problem is not really important because the drive will be placed in the electrical room that will be ventilated with air-conditioning.

2.2.2 VARIABLE SPEED DRIVE + ASYNCHRONOUS MOTOR

2.2.2.1 Preliminary

As detailed and described in the chapter R4-F of the triple lift configuration, the more convenient solution is an asynchronous motor and a variable speed drive.
The variable speed drive is a Voltage Source Inverter Drive allowing an easy regulating of the torque and speed of the asynchronous motor.

The drive is composed of:
- a diode bridge rectifier
- a DC bus with resistor (for electrical braking)
- an IGBT inverter

The regulation is based on the flux vector method in open loop (without “position” encoder)

2.2.2.2 Motor of 900 kW

A. Electrical features

Frequency : the standard frequency ranges from 45 to 65 Hz.

Harmonic current sent to the main: the harmonics are due to the diode rectifier. For a 6-pulse rectifier, the harmonics are multiple of (6±1). The most important harmonic currents correspond to the 5th rank and 7th rank.
The harmonic current can affect the sine wave voltage.
The harmonic magnitude is depending on the impedance of the main.

They can be reduced by using :
- a choke placed before the rectifier. (Price rectifier + choke: 120 %),
- a 12 pulse rectifier.

The 12-pulse rectifier is made by two connected thyristor bridges. A double secondary winding transformer supplies the rectifier. The windings of the first secondary are star connected and the others are delta connected. Each secondary of the transformer supplies one bridge. It allows to eliminate the harmonics from 5th and 7th rank. It leads to an increase in price for the transformer and the rectifier (the 12 pulse rectifier is twice more expensive).

At first approach, the use of a choke could be enough to obtain an acceptable harmonics rate. The final study should take this point into account. The limits for harmonic current are defined in the IEC 1000-3-4.

In the case of an AC supply in Medium Voltage (> 1 kV), the usual voltages are 2,4 kV; 3,3 kV; 4,2 kV; 6,6 kV.
In the case of an AC supply in Low Voltage (< 1 kV), the usual supply voltages are 400 V, 525 V or 660 V.

B. Comparison between a Low Voltage power supply and a Medium Voltage power supply

Preliminary remark : The development in the field of the variable speed drive is important and maybe some conclusion could be different within a few years.

Mechanically (speed range, speed regulation, torque, overload, ...) the performances are quite similar for both cases.

For the harmonics generated and sent to the main, the performances with a filter are also similar.

The main difference between both solutions is economical :

- The current is higher in Low than in Medium Voltage. The size of the cables connecting the transformers, the variable speed drive and the motor are thus much bigger.

- For a Medium Voltage motor of 900 kW, the price of the variable speed drive is higher for several reasons :
  - The need for a higher insulation,
  - The minimum rated power proposed by major manufacturers is about 1500 to 2000 kW so that, for this application, the variable speed is oversized.
  - There are actually more applications in Low Voltage than in Medium Voltage so that products standardization of the latter on the market is less.

- For a supply in Medium Voltage, two transformers and two circuit breakers have to be added to the electrical installation.

<u>Conclusion :</u>
Actually and for this application , the choice of a Low Voltage supply for the variable speed drive and the motor of 900 kW is economically the best solution.

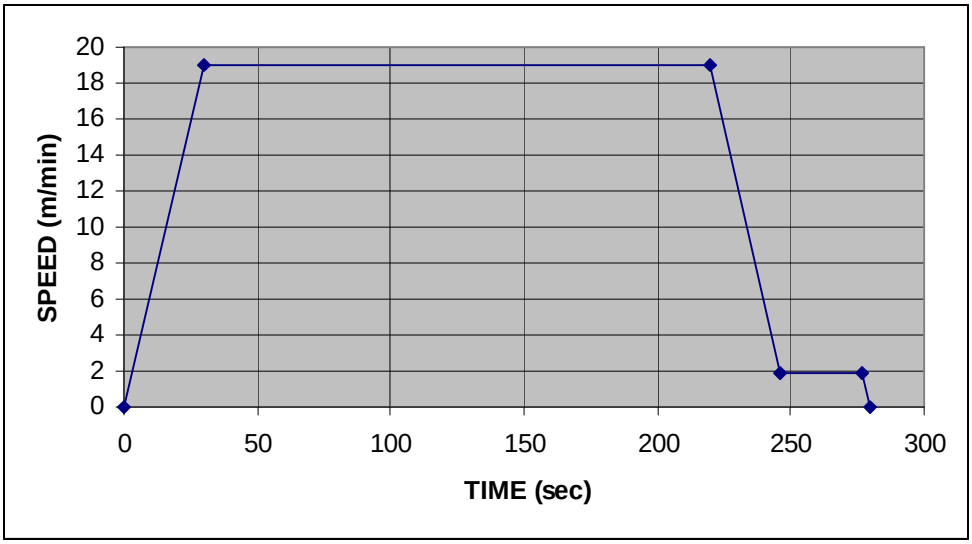
2.2.3 DETERMINATION OF ROLLING GATE OPENING TIME.

2.2.3.1 Gates on the Gatun Lake side

The experience of Berendrecht locks is interesting because the gate dimensions are similar to the Gatun lake side gates.

Actually for the Berendrecht gates, the DC motors are driven to reach the following parameters :
- Max speed of the rolling gate : 19 m / min
- Time to reach the max speed : 30 sec
- Acceleration : 0,011 m/s²
- Approach speed or minimum speed (next the other edge of the chamber) : 1,9 m/min This speed is 10 % of max speed.
- Lock width : 69,6 m
- Total time for closing or opening the gate : 4' 40'' or 280 s

Graphics of speed versus time :



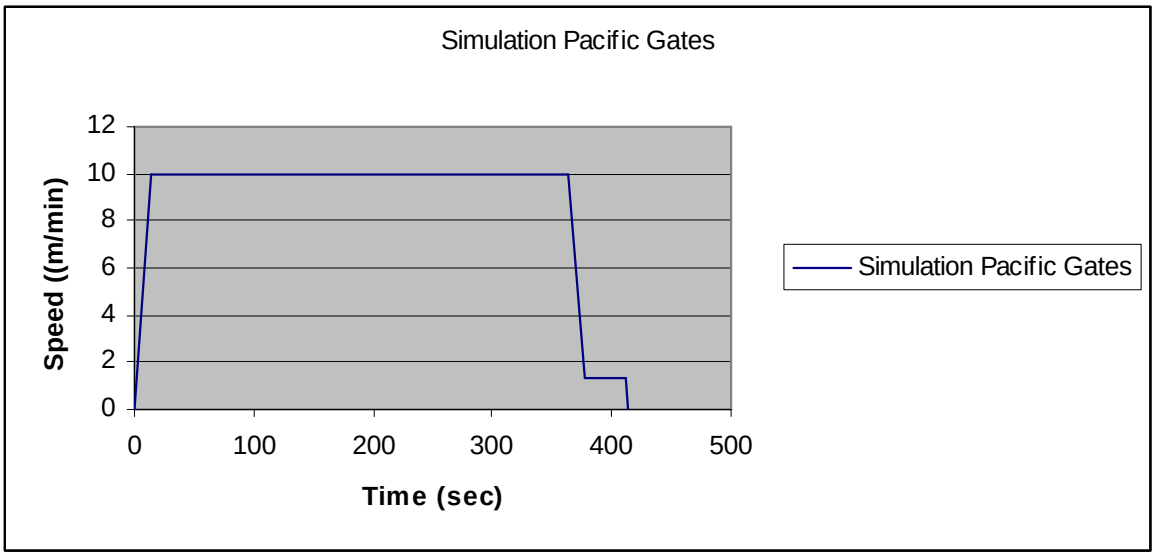
The starting point of the decreasing speed is giving by a limit switch when the gate arrives at 1,5 meter from the end. Other limit switches also control the speed for emergency stop.

Measurements :
- Effort applied to the 4 cables: 280 000 N during the starting time and 140 000 N at normal speed.
- Current consumed by the motor : 200 A during the starting time and 100 A at nominal speed. Sometimes , the rolling gate can knock against some debris. In this case, current peak can occur during a very short time. Circuit breakers are set according to this parameter.

2.2.3.2 Gates on the Pacific side

In order to keep a realistic size for the different equipment (steel driving cable, pulleys, drum, gear boxes and motors), the maximum effort applied to the cable has been fixed to 600 000 N. (during the starting time). A realistic diameter of the steel cables based on their size in Berendrecht (4cm for max. 280 000 N) would be 6cm.
The maximum acceleration for this effort is limited to 0,01 m²/s
Width : 61 m + 1m = 62 m
The maximum speed is reduced to 10 m/min
Approach speed : 1,3 m/min
Approach length : 1m

The time required for closure of the gates on the Pacific side is almost 7 minutes. As there is no existing gate of that size, it will be necessary to study it more in detail during a further stage of the studies in case this configuration would be chosen as the best one.



2.3 POWER ESTIMATE FOR OPERATING THE ROLLING GATES

2.3.1 GATES ON THE GATUN LAKE SIDE

In the chapter R4-F of the triple lift configuration, it has been shown that a rated power of 300 kW is enough (and even oversized) for a gate similar to the Berendrecht gates.

For the gates situated on the Gatun Lake side, a motor of 300 kW will thus be enough.

2.3.2 GATES ON THE PACIFIC SIDE

For the gates on the Pacific side, the basic data shows that the force on the pulling cables is approximately 2x more (600 kN).

The power (in rotation) P is given by the formula :

$P = M \times \omega$	where M is the moment of force (Nm) and ω is the angular speed (rad/s)
$M = F \times d$	where F is the force (N) and d is the distance between the point where is applied F and the axis.
$\omega = 2 \pi \times N/60$	where N is the rotational speed

The formula thus becomes: $P = F \times d \times \omega$

If we compare with Berendrecht, for this application :
F is about 2 x more,
d is 1.5 x more (3m instead of 2 due to the increasing of the cable diameter),
ω is similar (the drum diameter is different)

The approximate power is thus : 3 x P (Berendrecht) = 900 kW
Remark : This rated power is also oversized.

2.4 OPERATING MACHINERY FOR THE CULVERT AND CONDUIT VALVES

Each culvert and conduit valve will be operated by a hydraulic cylinder supported on the upper access platform by a steel support. Each valve will be opened by oil pressure (200bar) and closed by gravity. Both sides of the piston will be filled with oil to avoid corrosion.

Opening time: 2 minutes. Closing time: 1 minute.

Pressure oil will be provided by a separate hydraulic power unit including reservoir, 2 electric motor driven pumps, automatic controls, pressure relief, check valves, flow control and directional control valves, pressure and temperature gages, fluid level switches, filters, piping, wiring and accessories. All the equipment will be mounted on the oil reservoir.

Each valve can be locally operated from a control board with circuit breaker, magnetic contactor, protective relays, volt and ammeter, push-buttons, signal lamps, etc.

HYDRAULIC CYLINDERS FOR CULVERT AND CONDUIT VALVES :

Estimate of the vertical effort :

The hydraulic downpull forms one of the predominant forces in high-head gate installations. It adds to the gate weight and the frictional forces during rising and thus determines the hoist capacity required. When lowering the gate, the hoist has to withstand the sum of the gate weight and the downpull minus the frictional forces. In some instances, negative downpull, which results in an uplift force may prevent gate closure.

Downpull is caused by the difference between the downward force on the top of the gate and the vertical component of the force on the gate bottom under flow conditions (dynamic load). The gate designer is called upon to evolve designs of high-head gates to keep the downpull forces as small as is feasible to economize the gate and hoist costs. As downpull varies with the gate opening, its magnitude must be evaluated at various gate openings to obtain the value which, combined with frictional forces, determine the required hoist capacity.

There are three factors influencing the downpull forces :

- the flow characteristics, operating head or velocity of the contracted jet issuing beneath the gate under free flow conditions and aeration downstream,
- the fluid properties :specific weight w, dynamic viscosity v and acceleration due to gravity g,
- geometry of the gate installation : culvert and gate dimensions.

It is clear that at this stage of conceptual design, the geometry of the valves and in particular of the leaf bottom as well as friction coefficients are not defined yet. However, as a first approach, a rough estimate of forces on the valve leaf for both cases (culvert and lower WSB valves) allows a preliminary dimensioning of the cylinder and oil system.

Preliminary estimate of the forces on the valve leaf :
(for pressures and dimensions see chapter R4- E)

Sealing friction forces Fs:

Fs = f x1.5 x p x A where

f is the friction coefficient = 0.7 (rubber on stainless steel for shore A 65 hardness is 0.7). For PTFE, the friction coefficient can be reduced to 0.15. This is recommended in this case.
p is the hydraulic pressure on the gate,
A is the area of sealing contact

For the WSB valves (rubber) : Fs = 0.7 x 1.5 x 1.09 x (780 x 2 + 510) x 3 = 7107 kg
For the culvert valves(rubber): Fs = 0.7 x 1.5 x 3 x (780 x 2 + 480) x 3 = 19278 kg

For the WSB valves (PTFE): Fs = 0.15 x 1.5 x 1.09 x (780 x 2 + 610) x 3 = 1523 kg
For the culvert valves(PTFE): Fs = 0.15 x 1.5 x 3 x (780 x 2 + 480) x 3 = 4131 kg

Wheel friction Fw:

$$Fw = \frac{Q \times (fd \times d + fr)}{D}$$ where :

Q is the maximum load on the valve
fd : friction coefficient of the wheel bushings : 0.12 (Lubrite or similar)
fr is the friction coefficient of wheels rolling on slot rails : 0.2
d is the diameter of the wheel shaft,
D is the wheel diameter.

For the WSB valves : $Fw = \frac{1.09 \times 510 \times 780\ (0.12 \times 20 + 0.2)}{80} = 14100$ kg
For the culvert valves : $Fw = \frac{3 \times 480 \times 780\ (0.12 \times 20 + 0.2)}{80} = 36500$ kg

Hydraulic load F1 on the top seal of the valve

F1 = p1.A where :

p1 is the pressure on the seal (l supposed to be 8 cm)
A is the area supporting the pressure p1

For the WSB valves, F1 = 1.09 x 8 x 510 = 4550 kg
For the culvert valves, F1 = 3 x 8 x 480 = 11520 kg

Hydraulic load on the top of the valve F2

For the WSB valves, F2 = 1.09 x 100 x 510 = 55590 kg
For the culvert valves, F1 = 3 x 100 x 480 = 144000 kg

Hydraulic load under the valve F3

(the dynamic load coefficient is assumed to be 0.8. In fact, it depends on the shape of the valve leaf bottom)

For the WSB valves, F3 (dynamic load): 0.8 x 55590 kg = 44470 kg
For the culvert valves, F1 (dynamic load): 0.8 x 144000 kg = 115200 kg

Weight (under water)

For the WSB valves, W1 = 48.5 x 6.85 / 7.85 x 1.05 = 45 tons
For the culvert valves, W2 = 31.5 x 6.85 / 7.85 x 1.05 = 29 tons

Max. load opening (cracking)

F = Fs + Fw + F1 + F2 – F3 + G =

For the WSB valves, F = 1.52 + 14.1+ 4.55 + 55.6 – 44.5 + 45 = 76.3 tons
For the culvert valves, F = 4.1 + 36.5 +11.5 +144 – 115 + 29 =110 tons

Critical valve closing position

Before the top load due to the lintel seal can be added to the valve load the valve will be at 20 cm of the bottom sill and the friction forces will be maximum. The dynamic effect gives a positive effect on closing operation.

The condition for closing in critical position is Sum F < G

F1 is supposed to be 0.5 x F1 = 4.55 / 2 = 2.28 tons for the WSB valves and 11.5 / 2 = 5.75 tons for the culvert valves

Sum F = Fs + Fw + F3 – F2 =
For the WSB valves, F = 1.52 + 14.1 + 44.5 – 55.6 = 4.5 tons < 45 tons
For the culvert valves, F = 4.1 + 36.5 + 115 - 144 =11.6 tons < 29 tons

Max. load required when closing
(at about 66% of closing stroke)

Friction forces as well as dynamic load have been reduced and downwards loads have been artificially increased for security.

F*s = 0.1 pA
For the WSB valves, F*s = 0.2 tons
For the culvert valves, F*s = 0.4 tons

For the WSB valves : $F^*w = \frac{1.09 \times 510 \times 780\ (0.08 \times 20 + 0.1)}{80} = 9.2$ tons

For the culvert valves : $F^*w = \frac{3 \times 480 \times 780\ (0.08 \times 20 + 0.1)}{80} = 24$ tons

For the WSB valves, F*2 = 50 tons
For the culvert valves, F*2 = 130 tons

For the WSB valves, F*3 (dynamic load): 0.5 x 44.5 = 22 tons
For the culvert valves, F*3 (dynamic load): 0.5 x115.2 = 57.6 tons

For the WSB valves, G* = 48.5 tons
For the culvert valves, G* = 31.5 tons

For the WSB valves, F*1 = 0.5 pA = 2.3 tons
For the culvert valves, F*1 = 0.5 pA = 5.7 tons

Braking force:
B = G* + F*2 + F*1 – F*3 – F*w – F*s =
For the WSB valves, B = 48.5 +50 + 2.3 – 22 – 9.2 – 0.2 = 69 tons
For the culvert valves, B = 31.5 + 130 + 5.7 – 57.6 – 24 – 0.4 = 85 tons

Estimate of the power of the valve hydraulic units

This rough estimate will be based on a maximum effort of 100tons , an oil pressure of 200bar, a stroke of 7.50m and an opening time of 2 minutes (i.e.).

Cylinder section: about 5 dm²,
Cylinder oil volume: 5 x 75 = 375l.
Oil flow: 375 / 2 = 187.5 l / min
Power:

$$P = \frac{p \times Q}{600 \times ?} \quad \text{where:}$$

P: power in kW,
p: pressure in bar or daN / cm²
Q: flow in l / min
? : mechanical efficiency (0.90 to 0.95)

$$P = \frac{200 \times 187.5}{600 \times 0.90} = 70\text{kW (or 2 x 35kW)}$$

Diseño Conceptual de las Esclusas Post Panamax

TASK 4

G – LIGHTING

R4-G

in association with

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6.3.3 EXAMPLE OF FLOODLIGHT 6-7

1 Introduction

A study of the existing problems and proposals to solve them has already been done in the report R4-G of the triple lift configuration.

In comparison with the three steps configuration, the problem of lighting of the working area and of glare that interferes with the pilot's visibility are quite similar. The high mast equipped with high pressure (HP) sodium floodlight remains also the most convenient solution.
The solution with high mast equipped by metal halide floodlight is not considered in this report because this solution requires more electrical power and is less convenient than the HP sodium floodlight (see report R4-G-409).

For the lock chambers lighting, the problem is more important because the level variation is bigger (29,71 m instead of 12m for the 3 steps configuration).

Following problems are more difficult than in the 3 steps configuration :
- Darkness of the lock chamber in the vicinity of the gates
- Lack of visibility of the water level in the lock chamber and the space between the ship and the chamber walls;

Regarding the lighting system layout, please refer to the plan view D4 – A – 201 and to the sketch at page 4-11.

2 Basic Data

2.1 DEFINITION OF THE DIFFERENT ZONES

Four zones have been considered as follows :

	Zone 1 Working area - loco Eastern side	Zone 2 Eastern side	Zone 3 Central area - loco Western side	Zone 4 Chamber area
Gatun Lake side	90 m + 75 m	75	570 m + 75 m	75 + 70 m (central area) 80 + 70 m (left side)
Gates area	42 m	42 m	42 m	15 m
Single chamber	425 m	425 m	425 m	425 m
Gates area	76 m	76 m	76 m	20 m
Pacific entrance	75 m + 75 m	75	75 m + 570 m	75 + 70 m (central area) 75 + 80 m (left side)

The illuminated area is composed of :

- The working area along the lock walls (zones 1, 2 and 3) to be illuminated with high masts,
- The second area is including the vicinity of the gates technical building, the culvert technical rooms, the maintenance shop, ... and the first part of the water saving basins. The other water saving basins are not lighted (excepted by the remaining light). If necessary, a local lighting system could be added for the others basins.
- The zone 4 of the lock chamber is equipped with floodlights turned down and located in vertical recesses on the top edge of the lock walls and rolling gates.

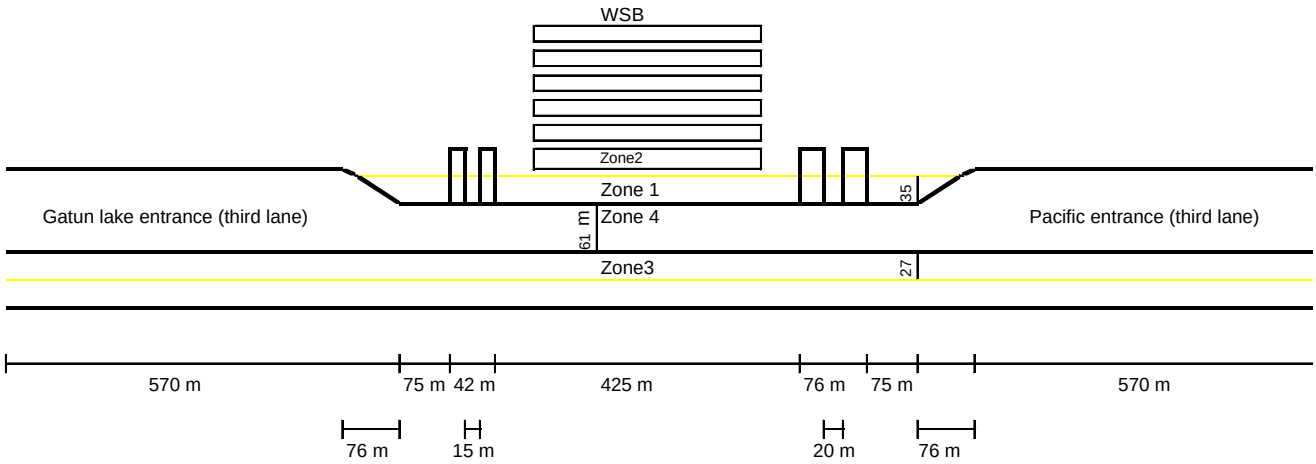
2.2 BASIC ASSUMPTIONS

- Zone 1: 50 m wide including the locomotive tracks
  Illumination level: 100lux

- Zone 2: from the border line of zone 1 to the end of zone 2:
  Illumination level: from 100 to 50 lux

- Zone 3: future central zone between the lanes 3 and 4 (55 m wide)
  Mean illumination level: 100 lux

SINGLE CONFIGURATION



The yellow line is the "high mast line"

3 Lighting Design Proposal

3.1 LIGHTING SYSTEM PROPOSAL FOR WORKING AREA (ZONES 1 TO 3)

Working areas along the lock walls are illuminated with floodlights fixed to high masts.
The mast heights depend mainly on the surface of the zones to be illuminated.

The floodlights are equipped with high pressure sodium lamps and asymetric reflector.

The major advantages of that solution is:
- a maximum photometric efficiency
- a minimum electric power
- no undesirable total reflection
- the glare (in the vicinity of the masts) and the light pollution are eliminated by use of an asymetric deflector.

3.2 LIGHTING SYSTEM PROPOSAL FOR THE LOCK CHAMBER (ZONE 4)

As already shown in the report R4-G of the triple lift configuration, the led module solution is not suitable:
At 7 meters under the platform, the remaining average illumination is only 5lux and there is no remaining light at a a distance of 10 meters under the platform.

Only the alternative with metal halide floodlight has been studied. The floodlights are fixed to hinged plates on the top edge of the lock walls. These plates are covering vertical recesses going down 1meter below the minimum water level of the lock chamber. The recesses were limited in width to 2.4m each so that the bigger portion of the lock walls remained unchanged.

Vertical recesses in the lock walls are equipped on top of a turned-down lighting system fixed under a hinged plate with easy access from the working platform.

To avoid any damage, the recesses of 30 to 35cm would be implemented along one fourth of the wall length. The concrete corners would be cut at 45° of the chamber wall surface.

The height of the recess can be limited to the maximum water level of the lock chamber.

The width of the recesses as well as the lamps wattage have still to be optimised.
Maintenance work on the lighting equipment can easily be done from the platform and should not much interfere with the ship transit.

4 Calculation

4.1 PRELIMINARY CALCULATION

4.1.1 ZONE 1 (EASTERN SIDE) :

First method:
Surface : (90 + 75 + 42 + 425 + 76 +75 +80) x 50 = 863 x 50 = 43.150 m²

With HPS lamps 600W, the specific power is 0.017kW/m²/lux.
Power = 0.017 kW/m²/lux x 43.150m² x 100lux = 73 355 W
I.e. 73 355 / 600 = 122 floodlights, 9 high masts with each 14 floodlights of 600W
Final power installed: 75 600 W (1.75 W / m²)

Second method:
By using the formula: $N = \frac{S \times E}{F \times U \times D}$

where:
N = number of floodlights to be installed,
S = illuminated surface,
E = illumination in lux,
F = flux in lumens,
U = utilization factor in %,
D = depreciation factor in %.

With HPS lamps 600W, N = (43150m² x 100) / (90000 x 0.7 x 0.6) = 114 floodlights
e.g. 114 floodlights, 9 high masts with each 12 floodlights of 600W
Final power installed: 64 800 W (1.5 W / m²)

4.1.2 ZONE 2 (EASTERN SIDE):

First method:
Surface (for 1 lock) : 693 x 100 = 69.300 m²
With HPS lamps 600W, the specific power is 0,017 kW/m²/lux
Power 0,017 x 69.300m² x 50lux = 58.905 W
I.e. 58.905 / 600 = 98 floodlights, 9 high masts with each 11 floodlights of 600W
Final power installed: 59.400 W (0,86 W / m²)

Second method:
By using the formula: $N = \frac{S \times E}{F \times U \times D}$
where:
N = number of floodlights to be installed,
S = illuminated surface,
E = illumination in lux,
F = flux in lumens,
U = utilization factor in %,
D = depreciation factor in %.

With HPS lamps 600W, N = (69.300 x 50) / (90000 x 0.7 x 0.6) = 92 floodlights
e.g. 66 floodlights, 9 high masts with each 10 floodlights of 600W
Final power installed: 54.000W (0.78 W / m²)

4.1.3 ZONE 3 (WESTERN SIDE)

Surface: (645 + 42+ 426 + 76 + 645) x 55 = 100.870 m²
Illumination level: 100lux

First method
Power 0,017 x 100.870 m² x 100 lux = 171.479 W
I.e. 171.479 / 600 = 286 floodlights, 36 high masts with each 8 floodlights of 600W
Final power installed: 172.800 W (1,71 W / m²)

Second method
By using the formula: $N = \frac{S \times E}{F \times U \times D}$
With HPS lamps 600W,
N = (100.870 m² x 50) / (90000 x 0.7 x 0.6) = 267 floodlights
e.g. 267 floodlights, 33 high masts with each 8 floodlights of 600W
Final power installed: 158.400W (1.57 W / m²)

4.2 FINAL STUDY

4.2.1 ZONES 1 AND 2 (EASTERN SIDE)

The same masts are used for the zones 1 and 2.

Mast height: 35m
The mast are placed along the locomotives track way. In order to avoid the glare effect, the lighting power has to be reduced.
Distance between 2 masts: 94m
The distance of 94 m is chosen in order to have a symmetric distribution of the masts.

Results:
- Illumination level for zone 1:
E average. = 80lux
- Illumination level for zone 2:
Decreasing illumination level from 50 lux to 10 lux (remaining illumination at a distance of 150 m from the lock chamber).
- Glare effect of the masts in the lock chambers has been controlled at 10m below platform level and is very acceptable (index of glare for the whole installation: GR-max 35.8)

Electrical Power :
- Power floodlight : 1000 W + 57 W (ballast) = 1057 W
- Number of masts : 9 (2 for Gatun lake entrance and 2 for the Pacific entrance)
- Number of floodlights: 8 per mast of 1000W = 40 + 32 (entrances)
- Power installed zone 1: (40 x 1057 W) + (32 x 1057 W)
= 42, 3 kW + 33, 8 kW = 76.1 kW (including ballasts)

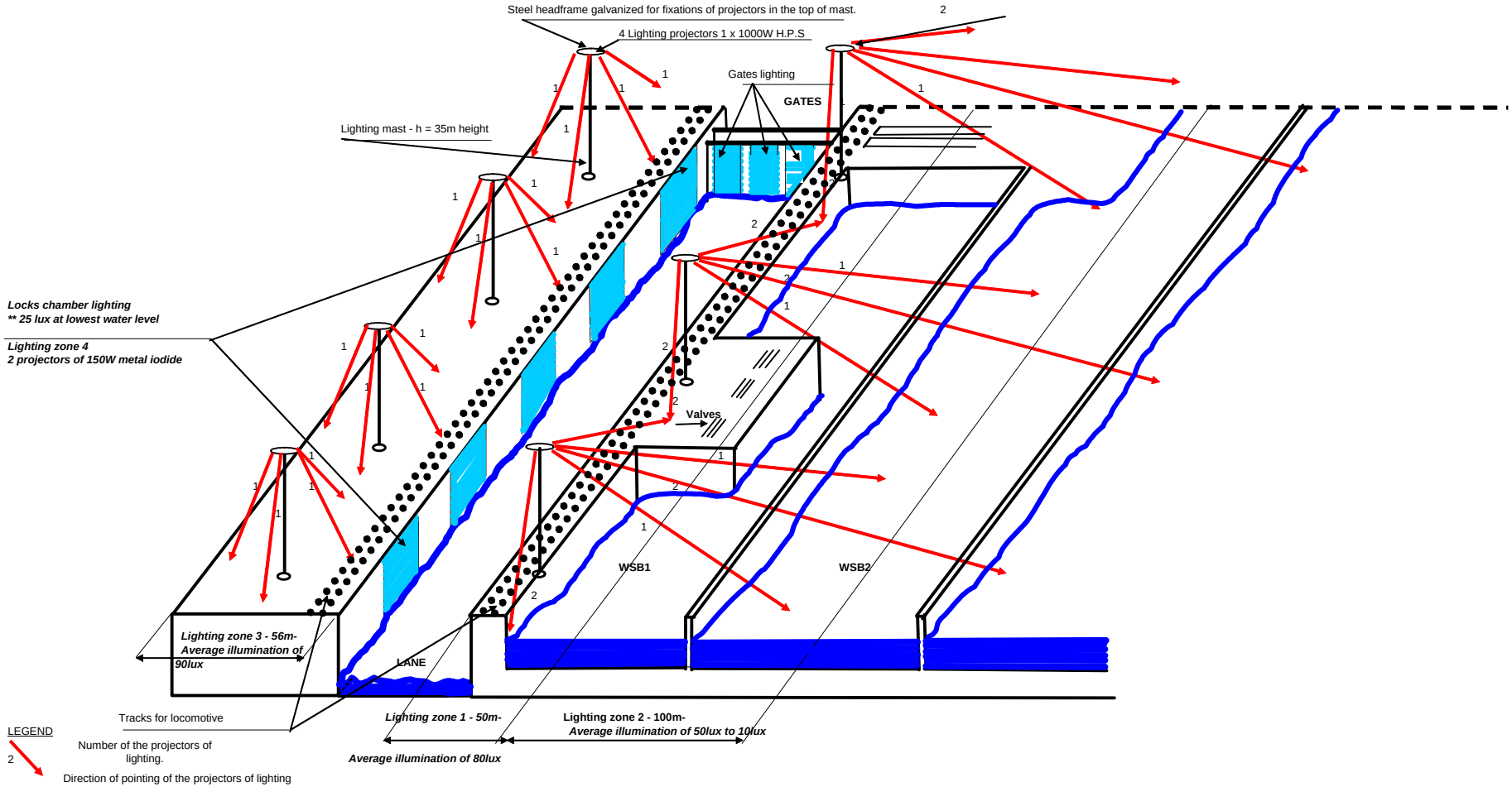
4.2.2 ZONE 3 (WESTERN SIDE)

Distance between 2 masts: 60m
Width of zone 3: 55.4m
Mast height: 35 m
Compared with the three lift configuration, the width of the zone 3 is smaller, so that we have reduced the number of floodlights from six to four per mast. The illumination level is lower but more uniform.

Illumination level:
Eav. = 90lux
Power Floodlight : 1000 W + 57 W (ballast)

Number of masts : 30 (11 for the Gatun lake entrance and 11 for the Pacific entrance)
Number of floodlights: 4 per mast of 1000W = 32 + 88 (entrances)

Power installed zone 3 : (32 x 1057) + (88 x 1057)
= 126,84 kW (including ballasts)



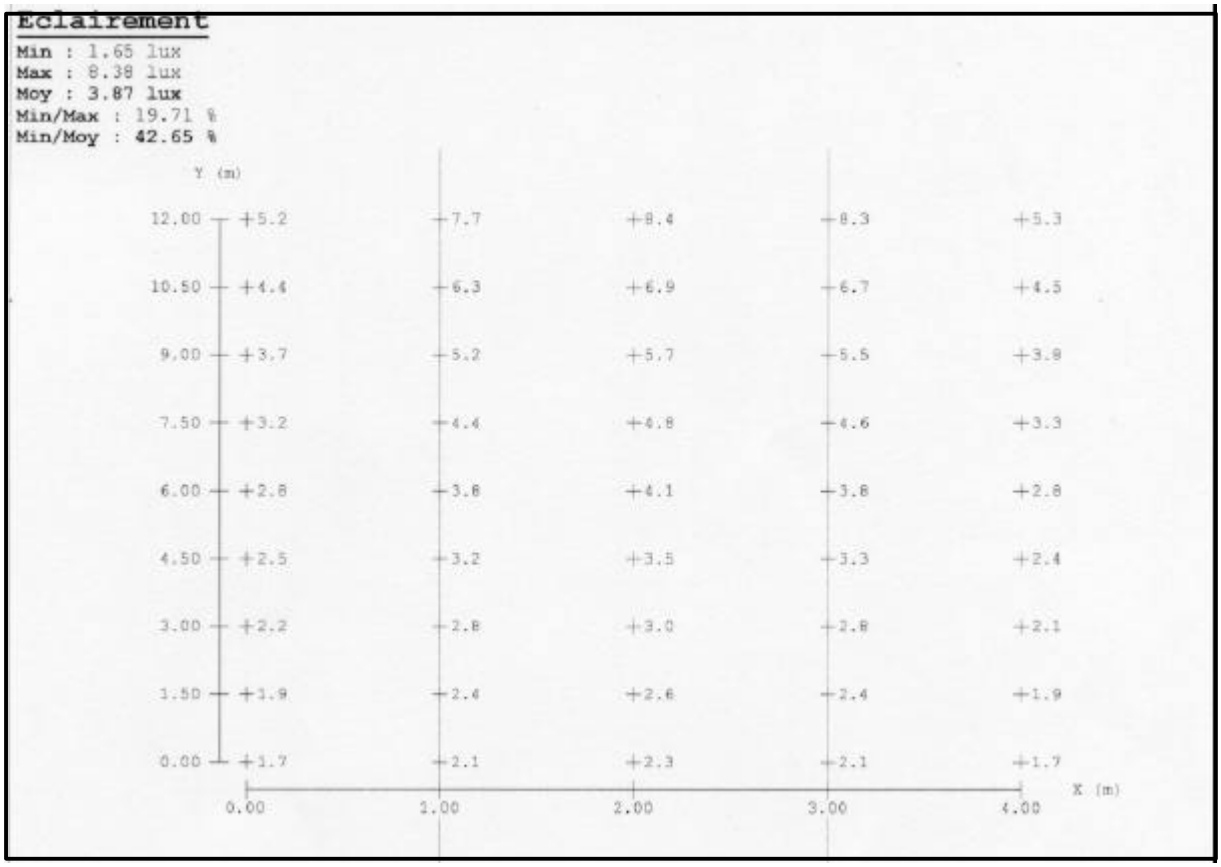
Solution With floodlights of 1000 W

4.2.3 ZONE 4

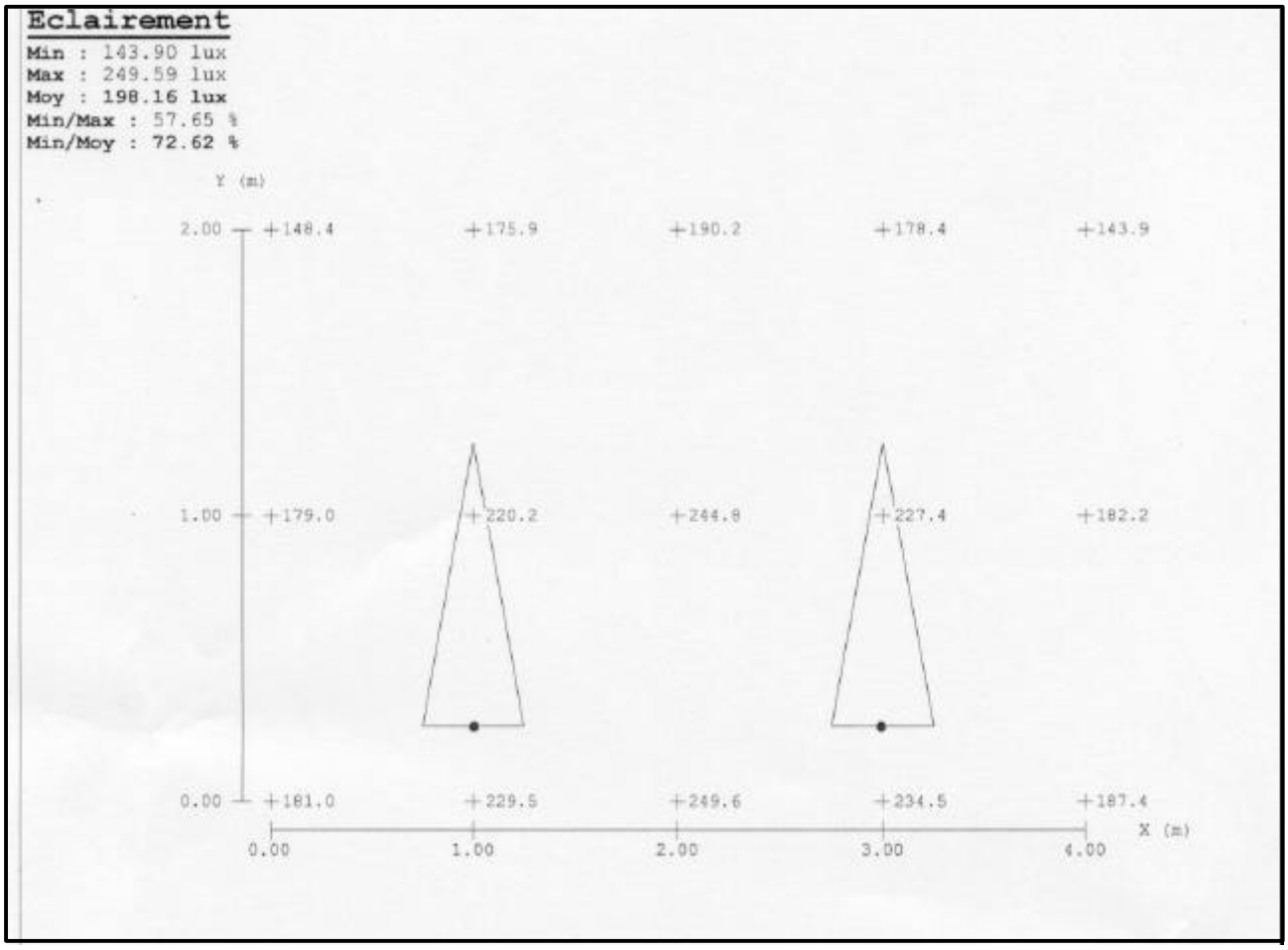
Two Metal halide floodlights of 150 W are placed every 10 meters.

Results:

In the zone where the floodlights are installed**,** the calculation has provided following results:
- On the vertical wall at 18m under the platform, the average illumination level is about 8 lux
- On the vertical wall at 30m under the platform, the average illumination level is about 2 lux.



At a water level located 30m under the working platform, the average illumination on a surface of 4m long x 2m is 198 lux with a maximum illumination (situated in the middle of the two floodlights) of 249 lux.



5 Conclusion

Based on the Panama Canal past experience of ACP, CPP is proposing following lighting system and recommendations:

- The working areas around the locks will be illuminated by two rows of high masts equipped with floodlights of 600W or 1000W. The glare produced by lights will no more affect the visibility of pilots by using deflectors fixed to the floodlights.

  The floodlight will be of the HP sodium type.
  The yellow hue of the lights has proven to be advantageous.

  The maintenance of light fixtures remains a concern (falling down or blocking of the clusters). One solution would be to use a top platform and a secured access by ladder or to re-consider the choice of cluster mechanism and material to be used,

  The effects of corrosion of lighting equipment can be reduced by improving protection level of the floodlights and choosing the best material quality,

- The lock chambers and rolling gates will be illuminated by use of small 150W floodlights turned down and inlighting vertical recesses in order to solve the problem of lack of visibility of the water level in the lock chamber and the space between the ship and the chamber walls. It will also provide to the pilot a clear cut reference. The vicinity of the miter gates will also be visible as the ship advances towards the lock approach wall.

- We recommend to test locally some turned down floodlights in the existing lock chambers

- The existing locomotive boom lights remain useful but should be improved.

- If tugs as the SPS (Ship Positioning System) are used, the use of reflector to shine at the water surface should be studied. At first, we think the inconveniences of shine effect at the water surface should be negligible. However, it would be interesting to proceed to some tests in one existing lock chamber.

6 Lighting Equipment

6.1 GENERAL

All the lamps will be able to start at ambient temperatures between + 5°C and + 40°C.

The average useful life of the lamp shall be that of the number of hours of operation in a laboratory at standardised ageing conditions at the end of which 50 % of the lamps of the tested batch have failed. Any lamp which in the course of this test produces less than 70 % of the rated luminous flux is considered failed.

The operational life with 15 % failure of a batch of lamps is the number of hours of operation in the operational conditions after which 15 % of the lamps of the batch have failed.
The flux and operational life values specified in the tables below shall be taken as the design bases for the lighting and for calculation of the operation costs, and these values shall be guaranteed by the contractor as being minimum values.

6.2 HP SODIUM FLOODLIGHT (FOR HIGH MAST IN THE ZONE 1,2,3)

6.2.1 DESCRIPTION

HP sodium floodlight are more convenient than the metal halide:
- The life time of HP sodium floodlight is better.
- Metal halide do not reach the minimal required flood.
- HP sodium has a better efficiency.
- Metal halide floodlight has some problems with thermal stress.

The HP sodium floodlights are typically composed of :
- a cast aluminium body painted or not,
- a reflector made from polished anodized aluminium,
- a protector made from hardened glass with gasket,
- one or two HPS compact tubular lamps,
- a deflector to reduce light pollution,
- a galvanized steel bracket for mounting the floodlight on the mast with adjustment device for controlling the tilting angle,
- two lampholders support plugs with gasket,
- a connexion box and cabling system.

Characteristics (typical):
- lamps: 1 x 1000w or 2 x 600W
- tightness rating of the housing with optical system: IP 65 minimum or IP 66 according to EN 60598
- tightness rating of the connection box: housing: IP 65
- mechanical strength of the housing: IK08 at 35°C according to EN 50 102.

Electrical auxiliaries compartment is located at the bottom of the mast.

6.2.2 AUXILIARY DEVICES

Ballast, starting device, condenser

The auxiliary devices is compliant to the IEC 922/923 and VDE 0712 standards.
Ballast shall be of the electromagnetic type.
The starting device will be of the electronic self-blocking type to avoid flashing (pumping) in the event of a lamp defect, and is in accordance with the selected type of ballast.
The compensation condenser is equipped with a discharge resistance.

6.2.3 ELECTRICAL AND PHOTOMETRIC FEATURES

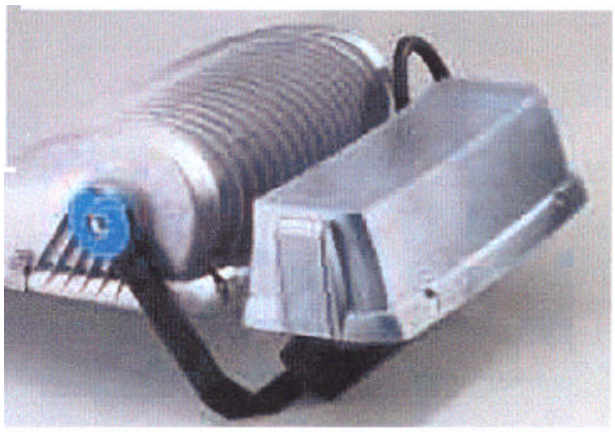
The tube-type HP sodium vapor lamps is compliant to the requirements of NBN C72-662 and satisfy the stipulations below :

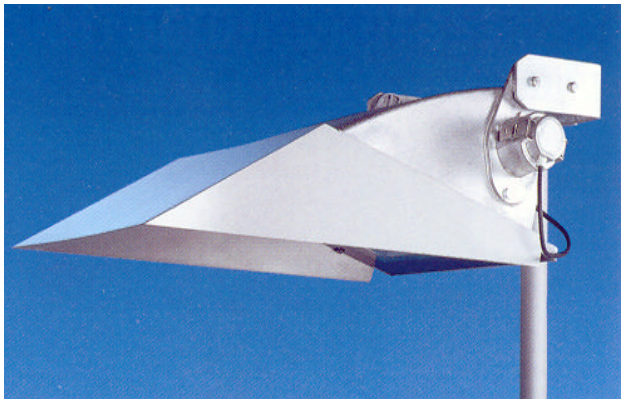
After a 12-hour operation cycle the characteristics are the following :

Rated wattage of the lamp (W)	Colour temperature (K)	Colour rendition index	Flux (Lm)	Power absorbed with auxiliary devices (W)	Average useful life (h)	Operational life with 15 % failure (h)
400	1950	25	53.000	442	15.000	10.000
600	1950	25	90.000	634	15.000	10.000
1000	1950	25	130.000	1056	15.000	6.000

Note : The re-ignition time after voltage interruption is 60 seconds for a 600 W HP sodium floodlight and 240 seconds for a 1000 W HP sodium floodlight. A good stability of the electrical power supply is required. In order to avoid being completely in the dark in case of a short breakdown, a solution could be to supply (a part of) the lighting system through a UPS. The autonomy of this UPS is calculated to ensure the supply during the starting of the diesel emergency set.
Voltage variation should be very low because the locomotive and the lighting are supplied by separate transformers.

6.2.4 EXAMPLES OF FLOODLIGHTS

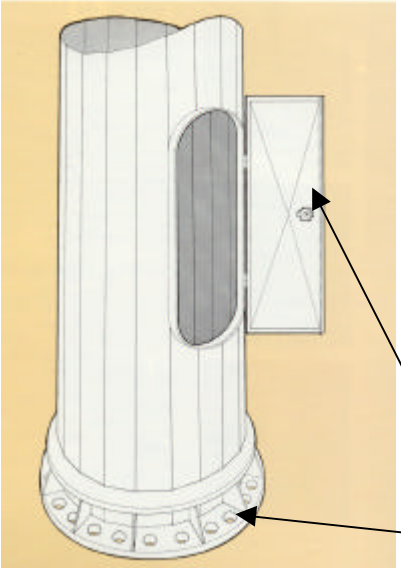




6.3 HIGH MASTS

The floodlights of the zones 1, 2 and 3 are supported by high masts. The height has been defined to provide the required performances and to reduce the light pollution.

The base of the mast is composed of a welded flange to be fixed by anchor bolts in the foundations.



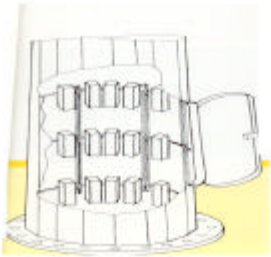
Door Flange plate

Door :

The door dimensions depend on the mast diameter.
The aperture is reinforced by means of a thick flat steel bar.
This framing guarantees tightness against penetration of rainwater and at the same time allows inside ventilation of the mast.

Fixing arrangement for Control Gear :

Circular bars fixed to vertical rails for adjustable spacing enable control gear back plates to be fixed around the mast internally at one or more levels.



The earth connection will be realized through a cable with a minimal section of 16mm².

One mast can support up to 12 high-power spotlights.

The access to the spotlights for maintenance can either be done by lowering and rising the light clusters (actual system)or by use of a ladder with security harness and a top platform as shown on the picture below. For that last option, special attention will be paid to the mast rigidity and foundation block.

6.3 METAL HALIDE FLOODLIGHTS (FOR CHAMBER WALLS)

6.3.1 DESCRIPTION

The small metal halide floodlight with ceramic burner is installed in a box made of aluminium (see pictures hereafter).

An easy access to the lamp and electrical auxiliaries, facilitates the maintenance.

Level of tightness: IP66.

The length of the box can vary from minimum 200mm to 6000mm. (800mm in our case to allow access at both ends). Width: 180mm, height: 90mm.

Protector in thermally hardened glass (Mechanical strength: IK08).

Reflector with narrow beam for long range made from anodized aluminium.

Lamp 150W type UV-block (example: Type : MASTER colour CDM-T 150W/830 Culot G12 – Philips or similar). Minimum power factor: 0.9

Auxiliary equipment (according to IEC 922/ 923 and VDE 0712):

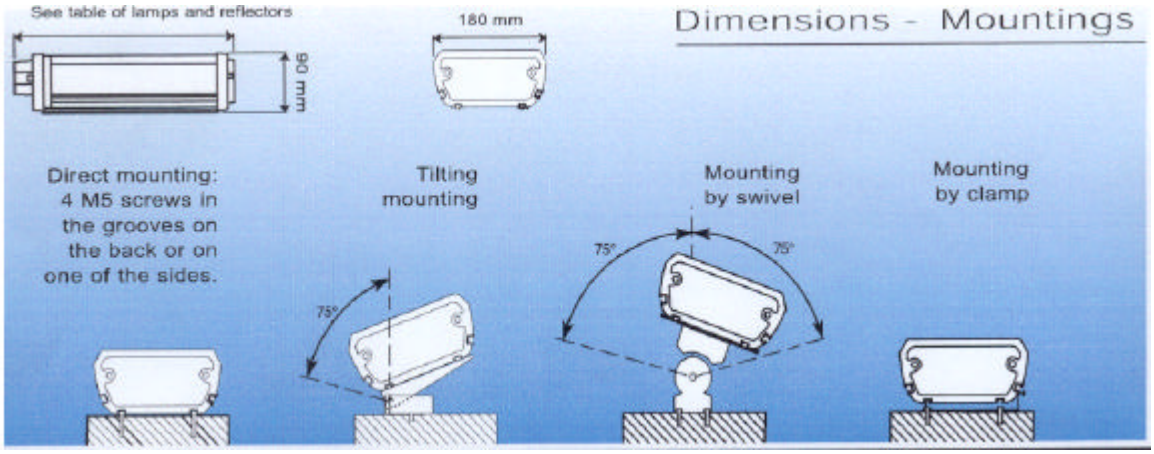
Ballast,
Muffler,
Anti-flickering device,
Stabilization of the characteristics of the lamp with regard to voltage fluctuations

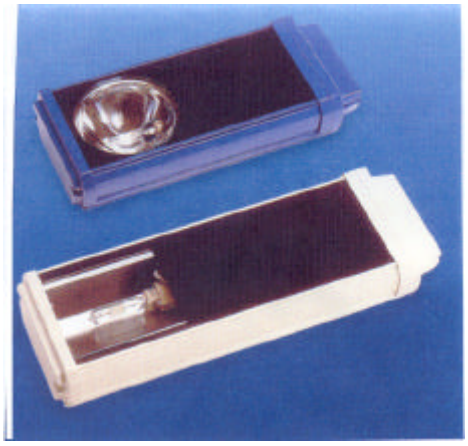
6.3.2 ELECTRICAL AND PHOTOMETRICS FEATURES

After a 12-hour operation cycle the characteristics shall be the following :

Rated wattage of the lamp (W)	Colour temperature (K)	Colour rendition index	Flux (Lm)	Power absorbed with auxiliary devices (W)	Average useful life (h)	Operational life with 15 % failure (h)
70	3000	81	6.600	80	10.000	7.000
150	3000	85	14.000	1 63	10.000	8.000

6.3.3 EXAMPLE OF FLOODLIGHT





Diseño Conceptual de las Esclusas Post Panamax

TASK 4

H – ELECTRICAL POWER AND POWER REQUIREMENTS

R4-H

Tractebel Development Engineering · TECHNUM · COYNE ET BELLIER · CNR PROJETS

in association with

IMDC · SBE · FITA AOSO

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6 Electrical Equipment 6-1

6.1 EXTERNAL INFLUENCES 6-1

6.2 MAIN ELECTRICAL EQUIPMENT 6-1

1 Introduction – Basic data

The dimensioning of the electrical network of the new locks has taken into account as well as the present existing network (see one line diagram of ACP N° HD JA 00) and the power requirements of the future fourth lane to be built along the third one.

It has been assumed that the starting point of the power grid will be the Miraflores substation (12 kV).

The first estimate of detailed power consumption has been based on the one hand on the existing major locks in Antwerp (in particular Berendrecht lock quite similar in size to the Gatun lake locks) as far as the rolling gate type is concerned and on the other hand on the existing Panama locks for the general auxiliaries (extrapolation of the power needed for locos, fire pumps, Pacific locks...).

As described in the chapter R4-H of the triple lift configuration, a low voltage distribution for the whole site is not technically acceptable for this application

In order to have a redundant system and to avoid a large number of transformer, an high voltage loop including four HV substations situated next the main loads has been considered.

Two alternatives (1 and 2) have been studied.
See hereafter, drawings showing the distribution system and the main high voltage substation, in the alternatives 1 and 2.

See also the drawings:
D4-H-204 High voltage one-line diagram - alternative 1
D4-H-206 High Voltage one-line diagram - alternative 2

Details of alternative 1

Two feeders (redundancy) coming from the 12 kV Miraflores substation, arrive at the High Voltage substation HV1 and in the High Voltage substation HV5.

These substations supply the internal high voltage loop of the 3rd lane.
The level of voltage of this HV loop is 12 000 V.

There are two main substations (HV1, HV2) on the left side situated next the technical room of the gates. It is there that the main loads (motors, cicuits for locomotive, valve, ...) are situated.

On the right side which is the central area between the 3rd and 4th lane, there are two main substations (HV3 and HV4) situated at the extremity of the lock.

The principle of loop between the different substations allows a complete redundancy of the power supply system.
This loop will be sized in order to supply the four others substations of the future 4th lane.

Details of Alternative 2

One feeder coming from the 12 kV Miraflores substation, arrive at the High Voltage substation HV1.
Another feeder coming from the 12 kV Miraflores substation, arrive at the High Voltage substation HV3.
The level of voltage is 12 000 V.

At the left side of the 3rd lane, the high voltage substation HV1 is supplying the following substation HV2 by two feeders..

At the right side of the 3rd lane, the high voltage substation HV3 is supplying the following substation HV4 by two feeders.

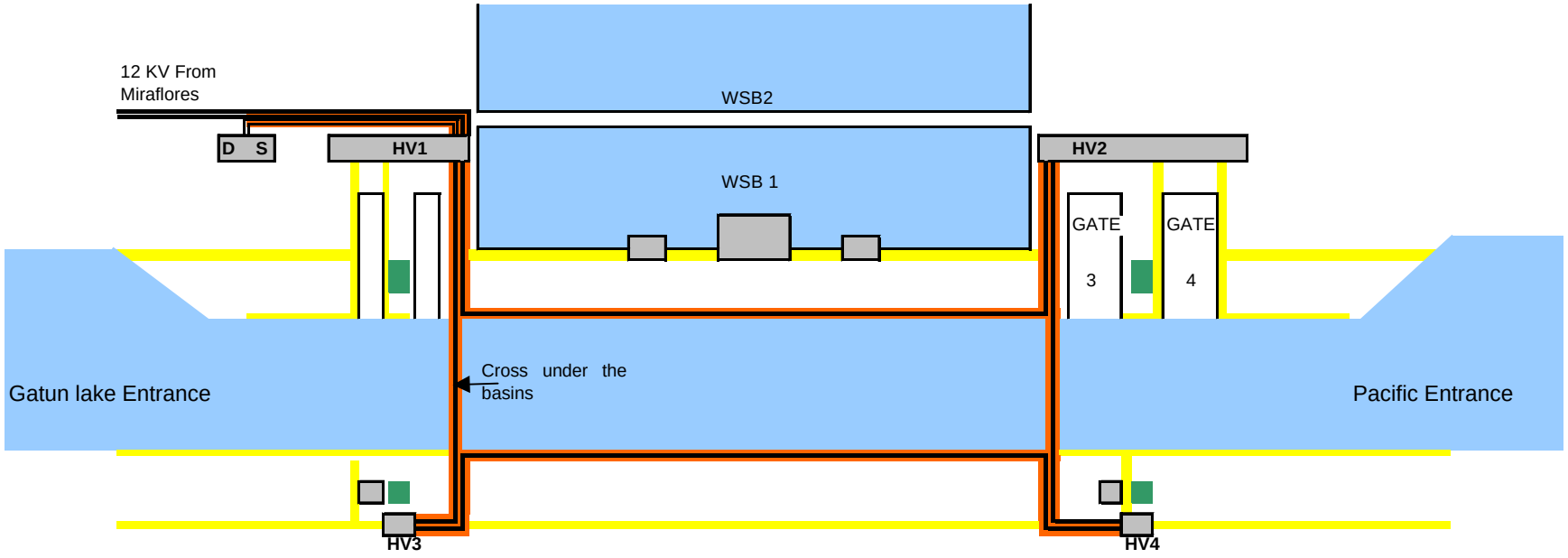
HV1 and HV3 are connected by one feeder that can be used in case of failure.
HV2 and HV4 are also connected by one feeder.

Comparison between alternative 1 and 2

Technically :
In the alternative 4, we have a simple redundancy. In case of failure of a feeder, we can supply through the other part of the loop.
The alternative 5 is more secure because with the power liaison between HV1 and HV3 and between HV2 and HV4, each substation can be supplied by three different feeders. It is then possible to supply all the substations in case of a double failure.
Remark : In the alternative 5, during normal operation, the two sides of the locks are independent

Economically:
In the alternative 2, the cable total length is approximately multiplied by 2.
In this alternative, it is also necessary to have additional circuit breaker in the different switchboards.

Alternative 1



: High Voltage cables gallery

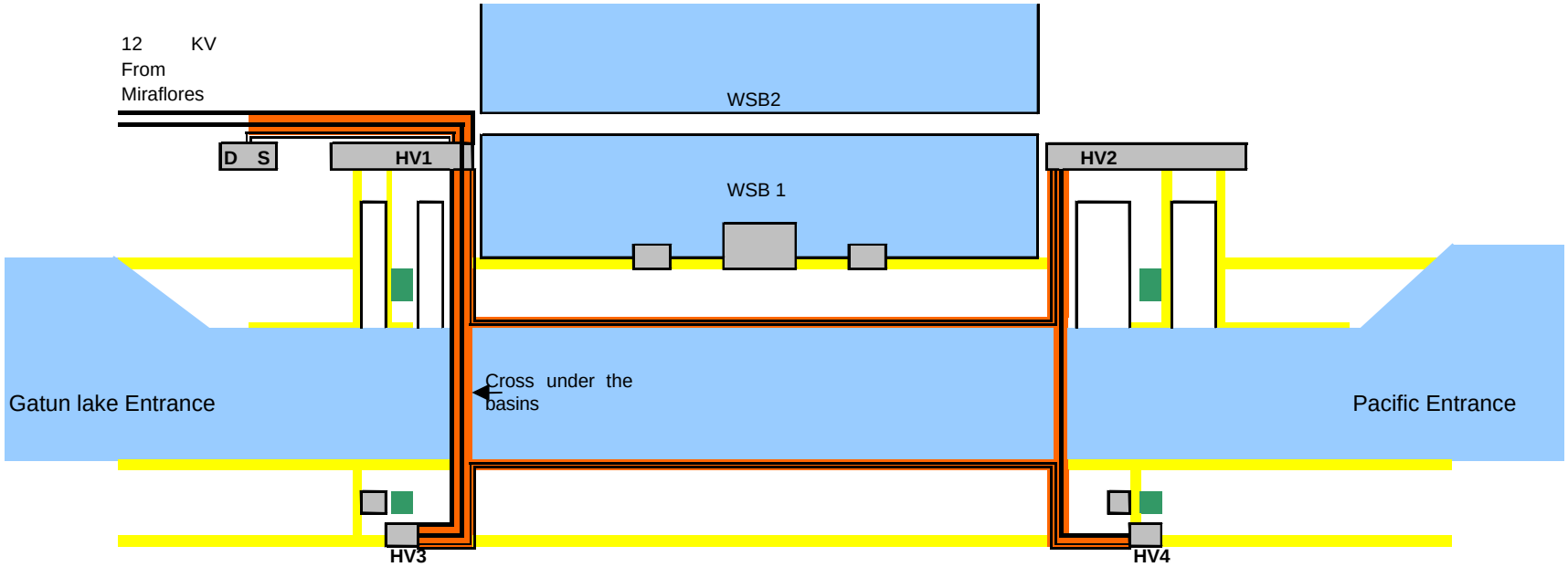
: Underground Low Voltage cables

: single or double HV feeder

HV : High Voltage technical building

DS : Diesel set generator

Alternative 2



: High Voltage cables gallery
: Underground Low Voltage cables

HV : High Voltage technical building
DS : Diesel set generator

: single or double HV feeder

2 Estimate of power consumptions

Definitions:
Simultaneity coefficient or coincidence factor: All the electrical loads (motor, valve ...) do not work together at the same time.
—
Utilization coefficient: All the electrical loads do not work at their maximum power. Only a part of the maximum power is used.

Reserve coefficient: In the future, some equipment can be added to the installation. At this stage, a reserve coefficient of 25 % is generally used.

These three coefficients allow to realize a balance of the installed power and then to estimate for each substation, the electrical power consumptions

2.1 MAIN POWER CONSUMPTIONS

POSITIONING SYSTEM - LOCOMOTIVE CIRCUITS
The size and capacity of existing locos will not be sufficient to control the Post-Panamax ships.

The information given by ACP for the new locomotive are the following :
Voltage : 480 V, 3-phases, Main Circuit breaker : 800 A
The maximum power is : 666 kVA
With an utilization coefficient of 0,9 (when the locos are pulling on the boat).
The necessary power is 600 kVA by locomotive (to be confirmed by ACP)

Note: “The track lines” will be supplied by specific transformers of 630 kVA (12000 V / 480V), in order to reduce voltage transient effect on other power consumers.
The size of these transformers will be modified according to the real track power required.

ROLLING GATES MOTORS

The motors are supplied by the HV1, HV2 substations situated near the technical room foreseen for the gate machinery.

Each gate is normally operated by one of the two main AC motors, one in operation and one in standby (redundancy). In normal operation, there is only one gate moving. For the power estimation of the substation, the simultaneity ratio of the main motors is thus 1 / 4 = 25% .

Utilization coefficient: 1
NB: The maximum overload admitted during transient by the driver is 150% during 60sec. Circuit breaker will be adjusted with this overload.
The power factor of the driving system including motor is 0.83.
The gates 3 and 4 cannot operate in the same time then the gates 1 of 2.

For all gates, we consider for the simultaneity coefficient that only one big motor is running.

Note: In fact, three gates could be in operation: one gate in operation is opening or closing together with the nearest one. This case will be not considered for the design.
Moreover, four gates could even be operated theoretically at the same time without a major trouble (for example, gates 1, 3, 5 and 7 could be closed when the 4 other gates are already closed). This case will not be considered either.

The size and the weight of the gates are different. The rated power of the motors is also different:
- Rated power for one motor of the Gatun lake side gate : 300 kW. For the Gate side lake Gatun This power is supposed to be similar to the Berendrecht main motors as the Post-Panamax rolling gates have almost the same size and weight as the Berendrecht ones. Moreover, the 13 years experience has shown that these motors have been over dimensioned.
- Rated power for one motor of the Pacific side gate: 900 kW. (See report Operating Machinery)

EMERGENCY MOTOR OF THE ROLLING GATES

In case of failure of the main motors, there is a small asynchronous motor. The power of this motor is 30 kW (Gatun lake side gates) and 100 kW (Pacific side gates)
This motor does not operate at the same time than the main motor. Thus, this is not taken into account in the power calculations.

In case of failure of the power supply, the emergency diesel set is dimensioned to supply only this motor.

ROLLING GATE AUXILIARIES

The 8 rolling gates auxiliaries are including:
- the lubrication system of the gear boxes,
- the braking system,
- the fans of the motors (if necessary),
- the oil lubrication pumps,...

The estimated power for above auxiliary equipment is 50 kW for the couple of gates 1 & 2 and 75 kW for the couple of gates 3 & 4.

The auxiliaries are supplied by the HV1, HV2 substations

MAINTENANCE EQUIPMENT FOR ROLLING GATES

The maintenance equipment dedicated to the rolling gates is including:

- an air compressor for the cleaning of the submerged railway,
- submersible drain pumps
- electrical plug ins (for lighting inside the gate)

The estimated power for this equipment is 100 kW for a couple of gates.
The compressor may be mobile and common to all gates.

Regarding simultaneity, it takes into account that the maintenance of one gate can be made while the second gate remains in operation. But for the whole lock there is only one gate in maintenance period.

The maintenance equipment are supplied from the HV1, HV2 substations

FIRE FIGHTING

The number and power of the fire pumps has been based on the single-line diagrams of the existing locks: for two lanes, there are 6 vertical water pumps with a unit power of 800 HP. These pumps are situated at each end of the locks. These pumps are supplied by the HV1, HV2 substations.

For the third lane: 4 x 800 x 0.746 = 2387 kW (1 HP = 746 W)
Power factor: 0,8.

Simultaneity factor: in case of fire, “normal operation” must be able to go on at the same time.

At this stage (third lane only), the required power for fire fighting will be 2387kW (2 fire pumps on each side of the lock).

CULVERT VALVES
The hydraulic valves are vertical-lift valves of the fixed wheel type operated by hydraulic cylinders.

Number of culvert valves:

Four culvert valves are required per couple of rolling gates. Two valves in parallel on the same culvert are implemented on each upstream side of each lock chamber.
Total number of culvert valves: 4 x 2 = 8.

The HV1 and HV2 substations supply 2 culvert valves. The HV3 and, HV4 substations supply two culvert valves for the 3rd lane and will supply two other culvert valves for the 4 rd lane.

It takes about two minutes to open a valve.

The valves do not work at the same time than the rolling gates of the lock.
Utilization coefficient: 0,8

CONDUIT VALVES

There are six water saving basins (WSB) and four conduit valves by WSB. Total number of conduit valves: 6 x 4 = 24.

The conduit valves are supplied by the specific low voltage board situated in the water saving basins technical room. There are two WSB technical room, one fed by HV1 and the other by HV2.
Simultaneity coefficient: Only four culvert valves are working in the same time.

The power for one valve is estimated to 70 kW.

It takes about two minutes to open a valve.

The valves do not work at the same time than the rolling gates of the lock.
Utilization coefficient: 0,8

OUTDOOR LIGHTING – HIGH MAST SYSTEM

The hereafter power requirements are based on a preliminary study of the lighting system for the three locks. (See Lighting Chapter R4-G).

Central area (Western side):

The different area covered by high mast are the Gatun Lake side entrance, the area between gate 1 and gate 4 and the Pacific side entrance

Power of one floodlight : 1000 W
Power per ballast: 56 W
There are 4 floodlights by high mast.
The power for one high mast is 4 x (1000 + 56) = 4224 W or 4.2 kW
The lighting electrical supply of the central zone (Western side) will be shared between 2 electrical boards supplied by the HV3 and HV4 substations

LV Board 3 : 11 + 4 = 15 high masts to supply
LV Board 4 : 4 + 11 = 15 high masts to supply

The total power installed for the central area is: (15 + 15) x 4.2 = 127 kW.

Area on the Eastern side (near the rolling gates chambers):

For the area between gates 2 and 3 (425 m), 5 masts with 8 lamps are required.
The areas before the first gate (on the Gatun Lake side of the locks) and after the last gate (on the Pacific side of the locks), will be equipped with 2 masts.

Power for one lamp: 1000 W
Power for one ballast: 56 W
Power for one high mast: 8 x (1000 +56) = 8448 W or 8.45 kW
The electrical supply of the gate chambers area will be shared between 2 electrical boards supplied by the HV1 and HV2 substations

Board 1 : 2 + 3 = 5 high masts to supply
Board 2 : 2 + 2 = 4 high masts to supply

The total power for this area is: (5 + 4) x 8.45 = 76 kW.
There is a starting current of 1.5 times the rated power during ten seconds. This current peak has to be considered for the sizing of the low voltage cable and for the adjusting of the circuit breakers. But, in order to avoid over-dimensioning of the transformer, the switch on of the different circuits has to be fitted with a time delay system.

The power factor is 0.9
Simultaneity and utilization coefficients are 1.

OUTDOOR LIGHTING – LOCK WALLS AND GATE LIGHTING.

The top edges of the lock chamber walls as well as the rolling gates will be equipped with lamps or with floodlights.

The first estimate is based on the installation of 2 lamps of 150 W (+ 15 W for ballast) every 10 meters.

<u>On the right side</u> (central part between third and fourth lane), the lighted area is supposed to start 165 m before the upper gate down to 155 m after the bottom gate.
Regarding the right side, the electrical supply of the wall's edge lighting is shared in 2 electrical board supplied by the HV3 and HV4 substations:

LV Board 3 : for supplying 38 x 2 lamps + ballasts (L = 145 m for the Gatun side entrance + 15 m between the gate 1 and 2 + 425/2 m)
LV Board 4 : for supplying 38 x 2 lamps + ballasts (L = 425 /2 m + 20 m between the gate 3 and 4 + 145 m for the Pacific entrance)

Total power: 25,08 kW

<u>On the left side</u> (rolling gates chambers), the lighted area the lighted area is supposed to start 130m before the first upper gate down to 130m after the last bottom gate.
Regarding the left side, the electrical supply of the wall's edge lighting is shared in 4 electrical board supplied by the HV 1, HV2, HV3 and HV4 substations:

LV Board 1 : for supplying 39 x 2 lamps + ballasts (L = 155 m for the Gatun side entrance + 15 m between the gate 1 and 2 + 425/2 m)
LV Board 2 : for supplying 39 x 2 lamps + ballasts (L = 425 /2 m + 20 m between the gate 3 and 4 + 155 m for the Pacific entrance)
Total power: 25,74 kW

The total for the wall's edge lighting is 46 kW
The same power has to be added for the fourth lane.

Each rolling gate will be lighted by 6 x 2 = 12 lamps + ballasts (L = 61m) i.e. 48 lamps for the 4 rolling gates.
The edge lighting of each couple of gates will be supplied by the nearest board. On the left side of the locks (gates 1 and 2 by LV board 1, gates 3 and 4 by LV board 2).
Total power for the rolling gates: 7,92 kW

UPS / RECTIFIER

For each technical room, a small UPS and rectifier is needed for the auxiliary voltage and to supply the computerized control systems.
Power: 15 kVA per technical room.
For the control room, the estimated power is 40 kVA
Total power required : (15 x 4) + 40 = 100 kVA
With the fourth lane the total power is (15 x 6) + 40 = 130 kVA

VENTILATION / AIR CONDITIONING

In order to assure good operation conditions to the electrical and control systems equipment, the electrical room and control room have to be ventilated.
Power estimate: 30 kVA per technical room and 40 kVA for the control room

The simultaneity coefficient is 0,8
Total: (30 x 4) + 40 = 160 kVA

With the fourth lane, the total for the ventilation has been estimated to 220 kVA

INSIDE LIGHTING AND PLUGS

A secondary board supply the lighting and plugs inside all buildings (technical and control rooms)

As a first approach, following assumptions have been made :
For the technical rooms: 10 W/m²
For the control room: 40 W/m²

Technical area:

There are two Gate technical rooms.
For the Gatun lake Gates : The technical room has an area of 600 m² (50 m x 12 m)
For the Pacific Gates : The technical room has an area of 1008 m² (84 m x 12 m)

There are 4 conduit valves technical building of 100 m² (10 m x 10m) supplied by HV1, HV2,HV3 and HV4.
There are two water saving basins building of 250 m² (23 m x 11 m) supplied by HV1 and HV2.

There are 2 HV technical rooms (HV3 + HV4) in the central area of 120 m².
There are 2 HV technical room (HV1 and HV2) next the gates technical room of 108 m².
There are one diesel set generator building of 150 m² (150 m x 100 m) supplied by HV1

There are one maintenance buildings of 1040 m² (52 * 20 m²) are previous for spare parts, ... The low voltage switchboard situated in the maintenance building will be supplied by the HV1 substation.
Note: The power consumption for the separate maintenance workshops has not been taken into account.

For each technical room, an estimated power of 10 W/m² is taken in consideration
The simultaneity coefficient is 0,6 (low use)
The using coefficient is 0,9

Control room:

The control building is combining the main control room located on the second floor and a technical room (HV3) is installed on the first floor.
We propose to implement the control building in the central area between the third and fourth lane at the highest level i.e. next to the upper lock. In this case the control room is supplied by HV 3 substation.
The estimated area of the control room and offices on the second floor is 120 m².
Power installed for the control room and offices : 5kW

The simultaneity coefficient is 0,9
The utilization coefficient is 0,9

INSIDE LIGHTING - CABLE GALLERY (+/- 1100 m)

The cable gallery is lighted by means of neon tube of 58 W.
The estimated power is 25 kW.
This lighting is only used during maintenance.

Simultaneity coefficient : 0,2.
Utilization factor : 1

2.2 POWER CONSUMPTION OF THE ELECTRICAL SUBSTATIONS

2.2.1 SUBSTATION HV1

Loads	Power	Power	Power	Utilization	Simult.	Number	Total
	kW	Factor	kVA	coefficient	coefficient		kVA
Motors (1 to 4) for gates 1 & 2	300	0.83	361.4	1	0.25	4	361.4
Culvert Valve (1,2)	70	0.85	82.4	0.8	0.4	2	52.7
Conduit valves (1 to 12)	70	0.85	82.4	0.8	0.2	12	158.2
Lock Walls and gate lighting (Eastern side - Gatun lake entrance + 1/2 chamber)	0.33	0.9	0.4	1	1	51	20.4
High mast (Gatun lake entrance + 1/2 area between gates 2 and 3)	8.5	0.9	9.4	1	1	5	47
Maintenance equipment gates 1&2	100	0.85	117.6	0.7	0.9	1	74.1
Auxiliary Gates 1 & 2	50	0.8	62.5	0.8	0.5	1	25
Inside lighting and plugs. (LV board of the different technical buidings)	22.5	0.87	25.9	0.9	0.5	1	11.7
Cable gallery lighting	6.25	0.9	6.9	1	0.2	1	1.4
Ventilation / Air conditionning	30	0.85	35.3	0.8	1	1	28.2
UPS / Rectifier	15	0.82	18.3	0.8	1	1	14.6
Fire fighting - vertical turbine water pump	596.8	0.8	746	1	0.6	1	447.6
						Total	1242.3
				With a reserve of 25 %			1553

Loads	Power	Power	Power	Utilization	Simult.	Number	Total
	kW	Factor	kVA	coefficient	coefficient		kVA
Positioning systems - locomotive Eastern side - track and return track (parts 1 & 2)	-	-	600	1	1	1	600

Proposal :
Two transformers of 800 kVA with a third transformer in standby in order to ensure redundancy in case of maintenance.
One transformer of 630 kVA for the positioning system.

2.2.2 SUBSTATION HV2

Loads	Power	Power	Power	using	Simult.	Number	Total
	kW	Factor	kVA	coefficient	coefficient		kVA
Motors (5 to 8) for gates 3 & 4	900	0.83	1084.3	1	0.25	4	1084.3
Culvert Valve (3, 4)	70	0.85	82.4	0.8	0.4	2	52.7
Conduit valves (13 to 24)	70	0.85	82.4	0.8	0.2	12	158.2
Lock Walls and gate lighting (Eastern side - 1/2 chamber + Pacific entrance)	0.33	0.9	0.4	1	1	51	20.4
High mast Lighting (1/2 area between gates 2 and 3 + Pacific entrance)	8.5	0.9	9.4	1	1	4	37.6
Maintenance equipment gates 3 & 4	100	0.85	117.6	0.7	0.9	1	74.1
Auxiliary Gates 3 & 4	75	0.8	93.8	0.8	0.5	1	37.5
Inside lighting and plugs. (LV board of the different technical buidings)	14.68	0.87	16.9	0.9	0.5	1	7.6
Cable ducts lighting	6.25	0.9	6.9	1	0.2	1	1.4
Ventilation / Air conditionning	30	0.85	35.3	0.8	1	1	28.2
UPS / Rectifier	15	0.82	18.3	0.8	1	1	14.6
Fire fighting - vertical turbine water pump	596.8	0.8	746	1	0.6	1	447.6
						Total	1964.2
				With a reserve of 25 %			2455

Loads	Power	Power	Power	utilization	Simult.	Number	Total
	kW	Factor	kVA	coefficient	coefficient		kVA
Positioning systems - locomotive Eastern side - track and return track (parts 4 and 5)	-	-	600	1	1	1	600
						Total	600

Proposal :
Two transformers of 1250 kVA with a third transformer in standby in order to ensure redundancy in case of maintenance.
One transformer of 630 kVA for the positioning system.

2.2.3 SUBSTATION HV3

Loads	Power kW	Power Factor	Power kVA	using coefficient	Simult. coefficient	Number	Total kVA
Technical room :							
Culvert Valve (5,6)	70	0.85	82.4	0.8	0.9	2	118.7
Lock Walls lighting (Gatun lake entrance + Western side - 1/2chamber)	0.33	0.9	0.4	1	1	38	15.2
High mast Lighting (Central area - Gatun lake entrance + 1/2 lock)	4.2	0.9	4.7	1	1	15	70.5
Inside lighting and plugs. (LV board of the different technical buildings)	2.2	0.87	2.5	0.9	0.5	1	1.1
Cable ducts lighting	6.25	0.9	6.9	1	0.2	1	1.4
UPS / Rectifier	15	0.82	18.3	0.8	1	1	14.6
Fire fighting - vertical turbine water pump	596.8	0.8	746	1	1	1	746
Ventilation	20	0.85	23.5	0.8	1	1	18.8
Control room :							
LV board of the control room	4.8	0.87	5.5	0.9	0.9	1	4.5
Air conditionning for control room	30	0.85	35.3	0.8	1	1	28.2
UPS / Rectifier for control room	40	0.82	48.8	0.8	1	1	39
For the fourth lane:							
Cable ducts lighting	6.25	0.9	6.9	1	0.2	1	1.4
Lock Walls lighting	0.34	0.9	0.4	1	1	48	19.2
Culvert Valve	70	0.85	82.4	0.8	0.5	2	65.9
						Total	1144.5
				With a reserve of 25 %			1431

Loads	Power kW	Power Factor	Power kVA	utilization coefficient	Simult. coefficient	Number	Total kVA
Positioning systems - locomotive Western side - track and return track (parts 2 & 3)	-	-	600	1	1	1	600
						Total	600
Provision for the fourth lane :							
Positioning systems - locomotive Eastern side for the future fourth lane - track (parts 2 &3)	-	-	600	1	1	1	600
						Total	600

Proposal :
Two transformers of 800 kVA with a third transformer in standby in order to ensure redundancy in case of maintenance
One transformer of 630 kVA for the positioning system.

2.2.4 SUBSTATION HV4

Loads	Power	Power	Power	using	Simult.	Number	Total
	kW	Factor	kVA	coefficient	coefficient		kVA
Culvert Valve (7,8)	70	0.85	82.4	0.8	0.9	2	118.7
Lock Walls lighting (Western side - 1/2 chamber + Pacific entrance)	0.33	0.9	0.4	1	1	38	15.2
High mast Lighting (Central area - 1/2 lock + Pacific entrance)	4.2	0.9	4.7	1	1	15	70.5
Inside lighting and plugs. (LV board of the different technical buildings)	2.2	0.87	2.5	0.9	0.5	1	1.1
Cable ducts lighting	6.25	0.9	6.9	1	0.2	1	1.4
Ventilation / Air conditionning	30	0.85	35.3	0.8	1	1	28.2
UPS / Rectifier	15	0.82	18.3	0.8	1	1	14.6
Fire fighting - vertical turbine water pump	596.8	0.8	746	1	1	1	746
For the fourth lane:							
Cable ducts lighting	5	0.9	5.6	1	0.2	1	1.1
Lock Walls lighting	0.34	0.9	0.4	1	0.25	76	7.6
Culvert Valve	70	0.85	82.4	0.8	0.5	2	65.9
						Total	1070.3
				With a reserve of 25 %			1338

Loads	Power	Power	Power	utilization	Simult.	Number	Total
	kW	Factor	kVA	coefficient	coefficient		kVA
Positioning systems - locomotive Western side - track and return track (parts 4 & 5)	-	-	600	1	1	1	600
						Total	600
Provision for the fourth lane :							
Positioning systems - locomotive Eastern side for the future third lane - track (parts 4 &5)	-	-	600	1	1	1	600
						Total	600

Proposal
Two transformers of 800 kVA with a third transformer in standby in order to ensure redundancy in case of maintenance.
One transformer of 630 kVA for the positioning system.

2.3 ESTIMATION OF TOTAL POWER CONSUMPTION OF THE HIGH VOLTAGE LOOP

The total power (without reserve) for the eight substations is the following:

- Substation HV1	1 242 +	600	kVA	
- Substation HV2	1 964 +	600	kVA	
- Substation HV3	1 144 +	600	kVA	
- Substation HV4	1 070 +	600	kVA	
Total	5 420 +	2.400	kVA =	7 820 kVA

In order to take into account the 4ft lane of lock, the same power than the substations HV1 and HV2 and 1200 kVA (for the positioning system) has to be added.

Total power for the 3rd and 4ft lanes together: 12.226 kVA

As already mentioned, all equipment do not work at the same time. The main equipment are the motors of gates, the locomotives and the fire fighting systems. A global coefficient of 0,6 can be applied to the total power.

Moreover, for future possible extension by ACP, be taken, a reserve coefficient of 1.15 (+15%) has been supposed to be sufficient.

The power to take into consideration for the design of the high voltage network is :
12.226 kVA x 0.6 x 1.15 = 8 436 kVA

A first estimation shows that the high voltage network would have two systems of single core cable (XLPE insulation, copper conductor) of 150 mm² (metric conductor size).
Note : 150 mm² is approximately corresponding to 300 AWG.
This first estimation has taken into account:
- the rating factor for variation of the air temperature. (Temperature of air of 40°C)
- the group rating factors for cables. (The single core cables are laid in air on perforated cable trays).

3 Choice of earthing system type

3.1 MEANING OF CODES USED

The codes used have the following meaning (according to IEC 364 –1):

First letter: relationship of the power system to earth

T: direct connection of one point to earth
I: All live parts isolated from earth or one point connected to earth through an impedance

Second letter : *relationship of exposed conductive parts to earth*

T: direct electrical connexion of the exposed conductive parts to earth, independently the earthing of any point of the power system
N: direct electrical connection of the exposed conductive parts to the earthed point of the power system.

Third letter: arrangement of neutral and protective conductors

S: neutral and protective functions provided by separate conductors (N and PE)
C: same combined in a single conductor (PEN conductor)

3.2 POST PANAMAX APPLICATION

In this application, two types of system earthing are possible:
- The IT system
- The TN system

3.2.1 IT SYSTEM

Main advantage of the IT system
- operation can still go on after first earth fault has appeared.

Main disadvantage of the IT system:
- this system is not suitable for wide installations as it is the case here
- earthing fault detection is difficult and requires complementary equipment (insulation controller,..) in different places of the installation.
- it is not possible to use filters to eliminate harmonics generated by the variable speed drive (for the rolling gate motors)
- important risk in case of appearance of a second fault.
- not suitable for applications such as control room or computer loads.
- requires qualified personnel for maintenance.

3.2.2 TN SYSTEM

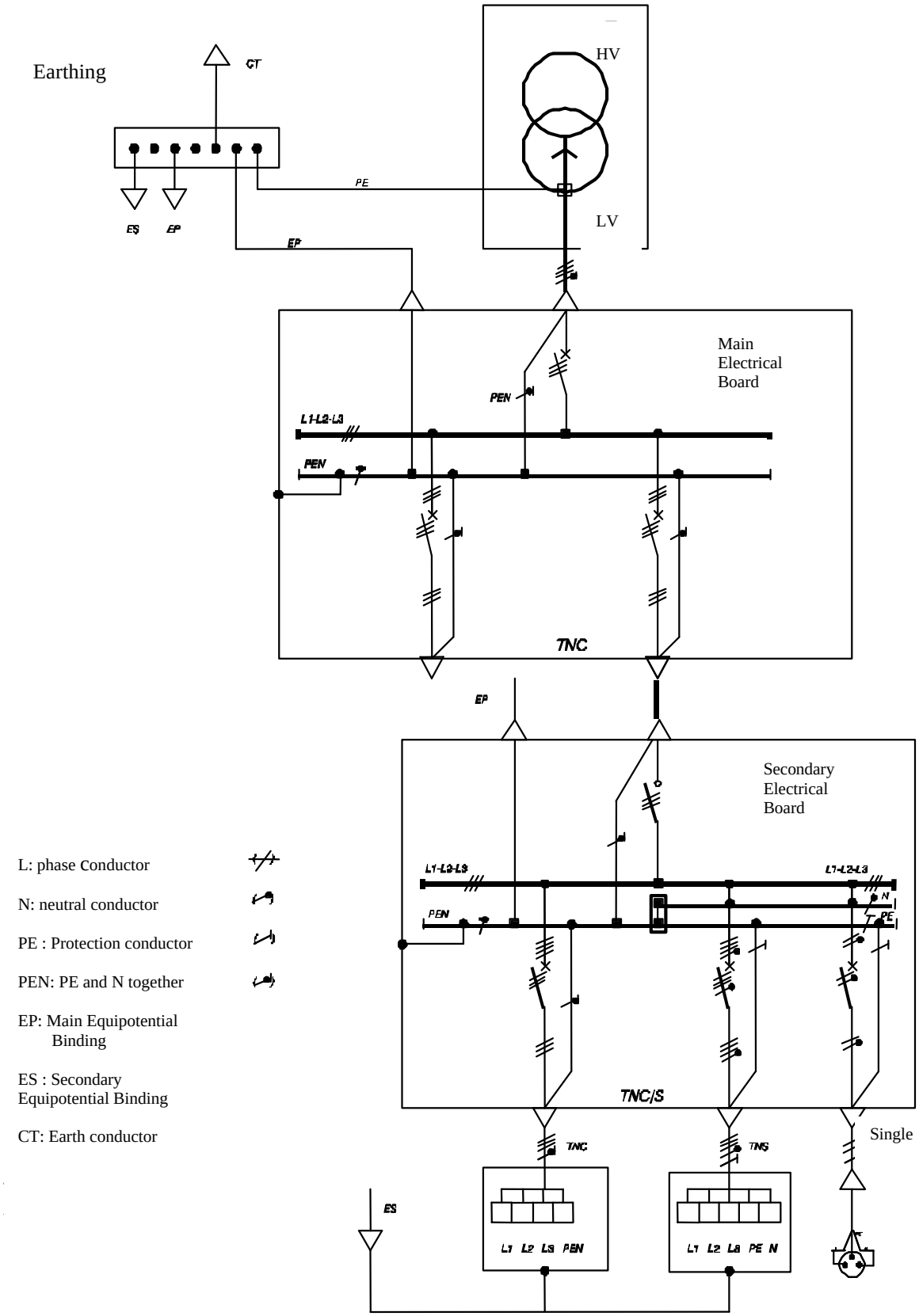
Main advantages of the TN system:
- does not require additional equipment.
- harmonics filters associated to the variable speed drive are allowed
- suitable system for computer applications (with TNS system)

Main disadvantages of the TN system:
- does not allow the operation to go on after a first fault has happened. However, the redundancy of the main electric equipment reduces the effect of this disadvantage.
- requires a protection conductor of sufficient section.
- requires qualified personnel for maintenance.

See hereafter the TN system basic diagram.

3.3 CONCLUSION

The recommended earthing system for the Post-Panamax locks based on above advantages and disadvantages is the TN system.


Earthing
CT
ES
EP
PE
HV
LV
EP
Main
Electrical
Board
PEN
L1-L2-L3
PEN
TNC
EP
Secondary
Electrical
Board
L1-L2-L3
L1-L2-L3
PEN
N
PE
TNC/S
TNC
TNS
Single
ES
L1 L2 L3 PEN
L1 L2 L3 PE N
L: phase Conductor
N: neutral conductor
PE : Protection conductor
PEN: PE and N together
EP: Main Equipotential Binding
ES : Secondary Equipotential Binding
CT: Earth conductor

.

4 Distribution of the power supply (low voltage)

4.1 OUTDOORS LIGHTING

Two complementary types of lighting are installed :
- the lock wall and gate lighting.
- the high mast system lighting.

4.1.1 DISTRIBUTION FOR LOCK WALL AND GATE LIGHTING

Metal halide lamps is used for the lock wall and gate lighting.

Principle :
- Lighting are supplied by the nearest low voltage (400 V ac) electrical board.

- For each circuit, the cable is a four cores cable (3phase + PEN) in order to minimize the cable size. The loads (1phase) are balanced on the 3phase.

- For each area, two circuits are necessary. Each circuit supplies one load (lamp or transformer) on two. This method is frequently used in the lighting for tunnel.

Advantage : with this distribution system, there is no large “black area”, in case of failure of one circuit.

Disadvantage : The necessary length of cable is more important.

- The different areas are :
Left side - Gatun Lake Entrance
Left side - The first ½ length of chamber
Left side - The second ½ length of the chamber
Left side - Pacific Entrance

For the right side: same areas

And for the gates lighting:
Left side - Gate 1
Left side - Gate 2
Left side - Gate 3
Left side - Gate 4

Total: 32 circuits for the walls and gate lighting

Metal halide lamps
The rated voltage of the lamps is 230 V 1-phase.
Power : 150 W + ballast

4.1.2 DISTRIBUTION FOR HIGH MAST SYSTEM - LIGHTING.

Different alternative are described for the distribution

Alternative 1 :
Each high mast is supplied by one circuit breaker situated in the nearest low Voltage board (LV1, LV2, LV3, LV4) .
This simple technique is also proposed in the electrical drawings of the American document EM 1110-22-2703.
In case of failure in the circuit, the lighting of one high mast is lost and there is a shadowed area.

Alternative 2 :
Redundancy for each high mast : two separate circuits supply one high mast. In case of loss of one circuit, the lighting decrease only of an half.
The disadvantage in comparison with the first proposal, is that the number (and thus the length) of cables is the double.

Alternative 3 (A separate network for the lighting supply):
This alternative described in the chapter R4-H of the triple lift lock configuration is not applicable for this project.

Conclusion:
The first alternative is the more economical proposal.
The second alternative is more secure than the first but more expensive

4.1.3 SWITCH-ON OF THE LAMPS OF THE HIGH MAST

As written in the "estimate of power consumptions" paragraph, during the ten first seconds of the switch-on, there is a peak current of 1,5 x the rated current.
Thus, the switch -on of all the lamps is realised in two steps:
- In a first step, an half of the circuit is switched on.
- In a second step, the second half of circuits is switched on.

4.2 INDOOR LIGHTING .

The different indoor lighting of the technical room or control room are supplied by an secondary low voltage board.
Switches are used for the switch on and switch off.

4.3 DISTRIBUTION FOR LOCOMOTIVE

The distribution system is based on the distribution system of the existing lock

For the left side of the third lane lock, the track and the return track are shared in 3 parts :
- Part 1 : Before the gates 1
- Part 2 : Between gates 1 & 3
- Part 3 : After gates 3

The part 1 is supplied by only one low voltage switchboard (LV TT 1).
The parts 2 can be supplied by two different low voltage switchboards (LV TT 1 and LV TT2)
The parts 3 is supplied by only one low voltage switchboard (LV TT 2)
The distribution system is then only redundant for the central part.

The principle is the same for the right side of the lock.

4.4 CONDUIT VALVES

The conduit valves are supplied by a specific low voltage switchboard situated in "the water saving basins building".

5 Emergency power supply

5.1 ESTIMATION OF THE LOADS TO BE SUPPLIED BY THE EMERGENCY DIESEL SET

Lighting lock walls:	100 %
Lighting high masts	100 %
Rolling gate lighting	100 %
Gate motors (Pacific side)	One emergency motor of 100 kW
Gate auxiliaries (Pacific Side)	Auxiliaries for one gate at 100%
Fire fighting	One pump at 100 %
Control Room	100 %
UPS / Rectifier	100 %
Ventilation	100 %
Four Culvert valves and conduit valves	100 %

Note:
No provision for positioning system.
The culvert valves do not work at the same time than the motors of the rolling gates

Loads	Power	Power	Power	using	Simult.	Total
	kW	Factor	kVA	coefficient	coefficient	kVA
Lighting Lock walls	54	0.9	60	1	1	60
Lighting High mast systems	304	0.9	337.8	1	1	337.8
Conduit & culvert valves	280	0.85	329.4	1	0.25	82.4
Motor Gate	100	0.83	120.5	1	1	120.5
Auxiliary	75	0.8	93.8	0.8	0.5	37.5
Fire fighting - vertical turbine water pump	596.8	0.8	746	1	1	746
Control room	5	0.85	5.9	1	0.8	4.7
UPS / Rectifier	130	0.82	158.5	0.8	1	126.8
Ventilation - Air conditioning	160	0.85	188.2	0.5	1	94.1
Secondary board	43	0.87	49.4	0.9	0.25	11.1
						1620.9
				With a reserve of 20 %		1945

Two diesel emergency sets of 1000 kVA are necessary

5.2 DEFINITION OF THE NEED OF AN EMERGENCY POWER SUPPLY

The emergency diesel set is foreseen in case of failure of the main supply (feeders from Miraflores substation).

Because :
In case of failure in the high voltage loop, there is always a second way to supply all substations.
In case of failure in the substation itself:
- the transformers are redundant,
- the high voltage electrical board has two arrivals and a double busbar

5.3 DISTRIBUTION SYSTEM

First solution:

The cheapest solution consists to have a centralized emergency power supply.

In this case, the high voltage network is used to supply the different substations (HV1 to HV4).

Second solution:

Each technical room has its own emergency diesel set. Economically: that solution is more expensive than the first one. In that case, a bigger number of diesel sets and technical rooms makes it more expensive.

Security: That solution is better in case of double failure.

In the first solution, two options are possible:

- a diesel group with a 12 kV generator is an expensive solution due mainly to the generator price and higher maintenance costs to be realized by specialists
- a diesel set with a 400V generator followed by a step-up transformer 400 V / 12.000 V

5.4 PROPOSAL

We recommend two low voltage diesel sets (rated power: 1000 kVA) with step -up transformer in order to supply the high voltage loop of the new lock.

6 Electrical Equipment

For the description of the electrical equipment reference is made to the chapter R4-H of the triple lift lock configuration

6.1 EXTERNAL INFLUENCES

The equipment has to be chosen in function of the external influences. These influences are described in the IEC 364-3

In this application, the main criteria are the following:

Environment:

- Ambient temperature: AA5: + 5°C to + 40°C
- Presence of water: AD2 for the technical room (possibility of vertically falling drops).
- Presence of foreign solid bodies:
  AE1 in electrical room (negligible)
  AE4 in gates technical room (presence of dust in significant quantity)
- Mechanical stresses: AG2 (usual industrial conditions)

Utilization:

- BA4 The electrical room are only accessible by persons adequately advised or supervised by skilled persons to enable them to avoid dangers which electricity may create

6.2 MAIN ELECTRICAL EQUIPMENT

<u>High Voltage Switchgear</u>

Features:

Metal enclosed providing protection against dirt, animals and humidity IP 44.

The metal enclosed cubicle is composed of four compartments:

- A busbar compartment with a double busbar for maintenance reason.
- A switching compartment with (vacuum insulation) withdrawable circuit breaker.
- A cable compartment
- A low voltage compartment that contains the interlocking and the protection equipment. This equipment is full automated and has got a communication port.

Design according to:

- IEC 60694: Common specifications for high-voltage switchgear and controlgear standards,
- IEC 60298: AC metal-enclosed switchgear and controlgear for rated voltages above 1kV and up to and including 52kV,
- IEC 60056: AC High Voltage alternating current circuit breakers,
- IEC 60265-1: High Voltage switches (> 1kV, < 52kV)

Transformers

Windings :

- 12.000 V/ 400V : Dyn (Delta/star with neutral earthed) for transformers that supply 400 V or 230 V loads such lighting, ...
- 12.000 V / 480 V : Ddn (Delta/delta with one corner of the secondary windings earthed) for positioning system transformers.

Use of dry dielectric transformers (better in case of fire) or mineral oil transformers (cheaper).
Rated power: 400 kVA, 630 kVA, 800 kVA.
Transformers shall be placed in a ventilated protection enclosure.

Step-up transformer: 400 V / 12000 V with a rated power of 1000 kVA

Design according to:
IEC 60076 Power transformers

Low Voltage switchgear 400V AC

Design according to:
IEC 60439 -1 / EN60439-1: low voltage assemblies

Features:
In order to limit he hazard during the maintenance, screen and compartments will be implemented in the low voltage board.
The recommended form of the board is the form 3b (see the standard IEC439-1) which provide:
- A separation between the busbars and the functional units
- A separation between the busbars and the terminals.

Board with a sealed enclosure providing protection against dirt, animals and humidity.
Modern digital control and protection equipment with full automation and communication capability.

Cables:

High Voltage 12 kV (8,7 to 15 kV):
Construction:
- Single core cable
- Copper or Aluminium conductor (maximum temperature (steady state): 90°C)
- Inner and outer semi-conducting layer
- Polythene (XLPE) insulation
- Copper wire screen
- PVC outer sheath

Design according to IEC 60 502 -2.

Low voltage (up to 1 kV):

Construction:
- Multicores (three, four or five cores) cable
- Copper or aluminium conductor (minimum sections 2.5 mm²)
- Double steel tape armour (in some application) or no armour
- PVC outer sheath*

Design according to IEC 502

* For the control room, we propose to use halogen free material: a halogen free thermoplastic outer sheath replaces the PVC outer sheath.

Design according to:
- IEC 61034-1 + 2 (Smoke density)
- IEC 60754-2: Test of gases evolved during the combustion of materials taken from electric cables.

Safety cables: For more security, the cables supplying safety equipment, shall be fire resistant with insulation integrity 3 h under impact of fire and mechanical chock according to IEC 60331.

Data cables
Construction:
- XLPE or PVC insulation
- Copper core (single or multicores)
- Metallic screen.

Diseño Conceptual de las Esclusas Post Panamax

TASK 4

I – ENTRANCE WALLS

R4-I

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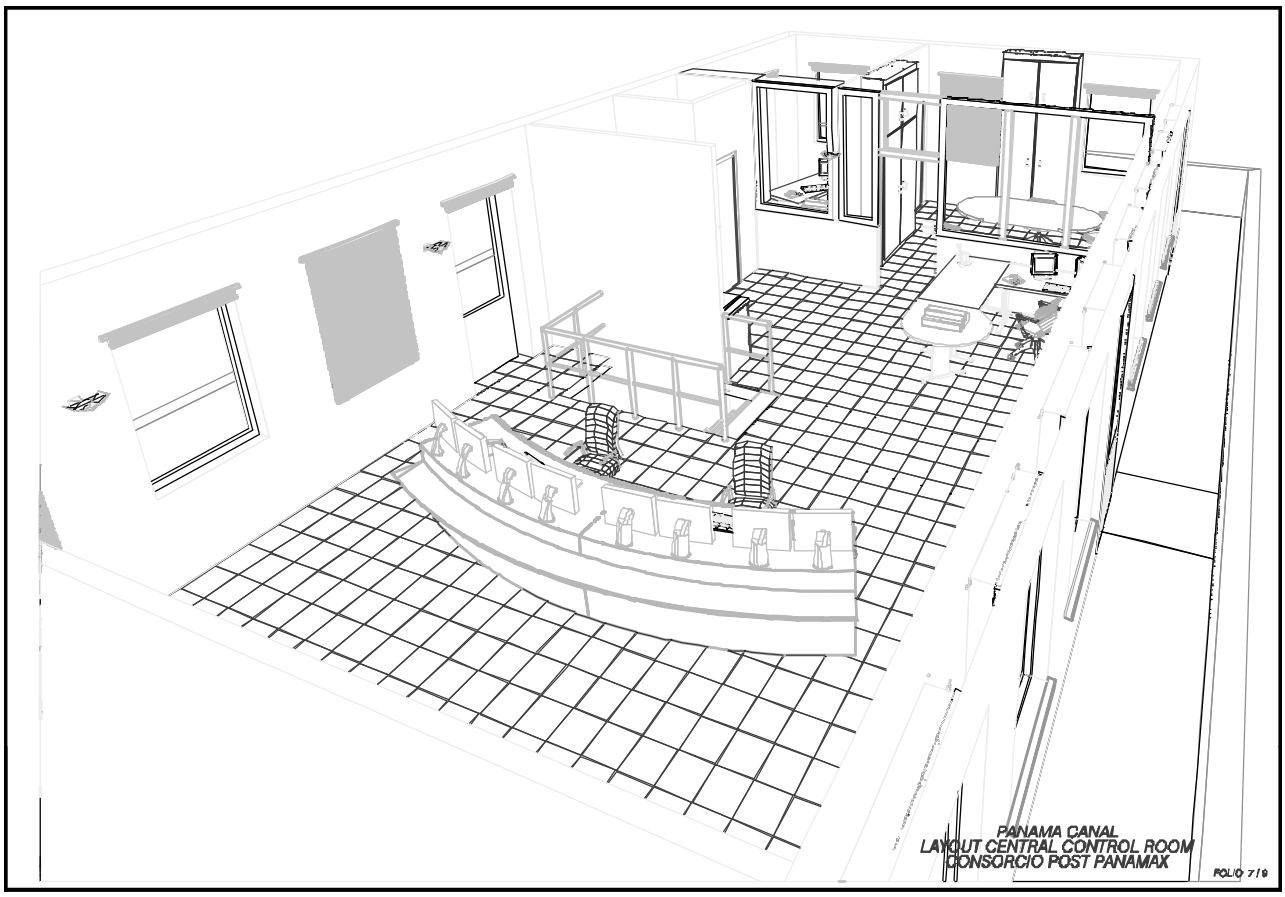
We refer to the Entrance Walls of the Triple Lift Lock System



Diseño Conceptual de las Esclusas Post Panamax

TASK 4

J – OPERATING STRUCTURES

R4-J

in association with

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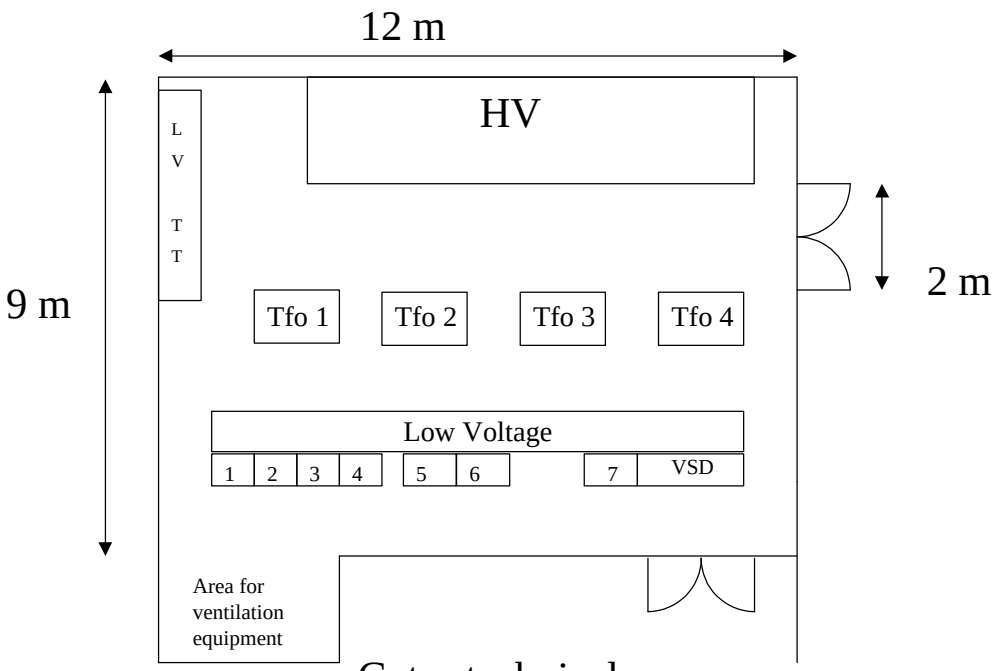
1 General

This report is providing a conceptual proposal for operating structures including following technical or electrical rooms:

- HV1 & HV2 ELECTRICAL ROOMS
- HV3 & HV4 ELECTRICAL ROOMS
- MAINTENANCE BUILDING
- ROLLING GATES TECHNICAL ROOMS (Gatun lake side)
- ROLLING GATES TECHNICAL ROOMS (Pacific side)
- WSB TECHNICAL BUILDING
- CULVERT TECHNICAL BUILDING
- EMERGENCY DIESEL SET ROOM
- CONTROL ROOM

For a general overview of the different buildings, see civil works drawings and in particular the plan view D4 – A – 201.

2 HV1 & HV 2 Electrical Rooms



Gates technical Room

1 to 4 : automats and fibre optics equipment,

5 : Ventilation switchboard

6: “Plugs and inside lighting” switchboard

7 : UPS / Rectifier / battery

The HV technical rooms are located at the end of the gates technical rooms where the operating machinery of two lock gates are implemented.

The equipment of each HV technical room is composed of:

- High Voltage (HV) boards (12kV)
- Four HV transformers
- Low Voltage (LV) boards
- LV TT (Positioning),
- automats and fibre optics equipment,
- UPS / Rectifier / Battery
- Ventilation system

The HV1 and HV2 substations will supply (see report R4 – H – 429)

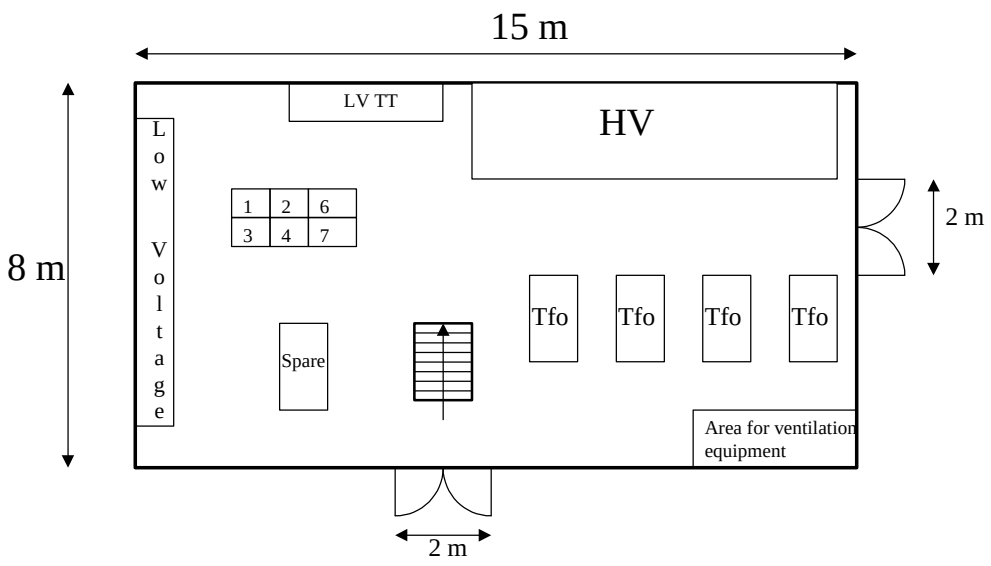
the motors of the rolling gates,
the auxiliaries and maintenance equipment of the rolling gates,
the fire pumps,
the culvert valves and conduit valves,
the lighting,
the positioning system,
etc.

Substation HV1:
Two transformers of 800 kVA with a third transformer in standby in order to ensure redundancy in case of maintenance and one transformer of 630 kVA for the positioning system.

Substation HV2:
Two transformers of 1250 kVA with a third transformer in standby in order to ensure redundancy in case of maintenance and one transformer of 630 kVA for the positioning system.

3 HV3 & HV4 Electrical Rooms

Electrical Room : HV3



1 to 4 : automats and fibre optics equipment, 6 : UPS / Rectifier / battery

7: “Plugs and inside lighting” switchboard ,

The electrical rooms HV3 to HV4 are implemented on the central area between lane 3 and lane 4 in separate building of 15 x 8 m.
HV 3 will be located on the first floor and combined with the control room building.

The equipment of each HV technical room is composed of:

- HV boards (12kV)
- Four HV transformers
- LV boards
- LV TT,
- automats and fibre optics equipment,
- UPS / Rectifier / Battery
- Ventilation system.

The HV3 & HV4 substations will supply (see report R4 – H – 429)

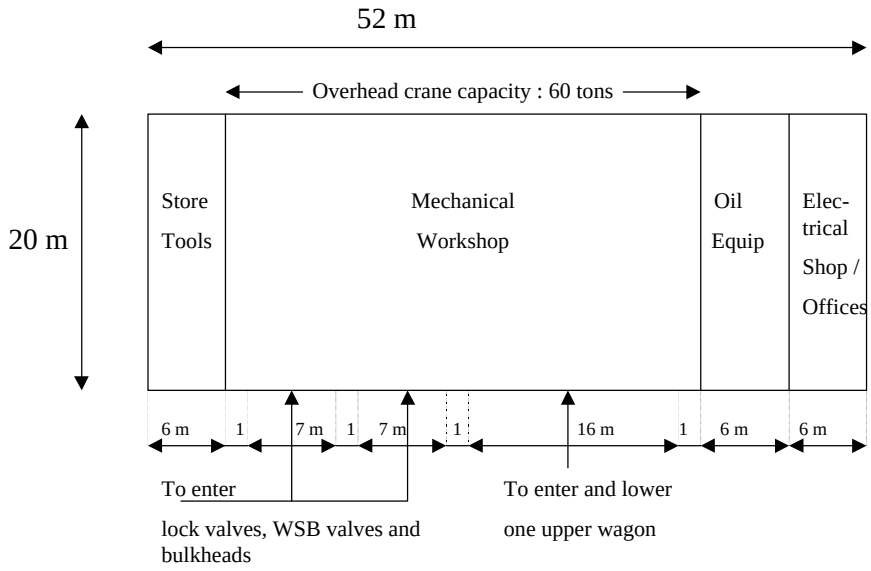
the auxiliaries and maintenance equipment of the rolling gates,
the fire pumps,
the culvert valves,
the lighting,
the positioning system,
etc.

Substation HV3:
Two transformers of 800 kVA with a third transformer in standby in order to ensure redundancy in case of maintenance and one transformers of 630kVA for the positioning system. A spare place is previous for the transformer of the positioning system of the fourth lane.

Substation HV4:
Two transformers of 800 kVA with a third transformer in standby in order to ensure redundancy in case of maintenance and one transformers of 630kVA for the positioning system. A spare place is provided for the transformer of the positioning system of the fourth lane.

4 Maintenance Buildings

Maintenance Building



Note : No space for locomotive maintenance has been included

The maintenance building will be implemented between gate 1 and the service road with access to existing road (Miraflores). See Drawing D4 - A -201

A building is composed of:

a mechanical workshop of 34m x 20m for the maintenance work of culvert and conduit valves.

Four valve leafs and / or bulkhead elements can be maintained together.

Next to the two openings of 7m wide, a third one of 16m allows to enter one top or low support wagon of a gate.

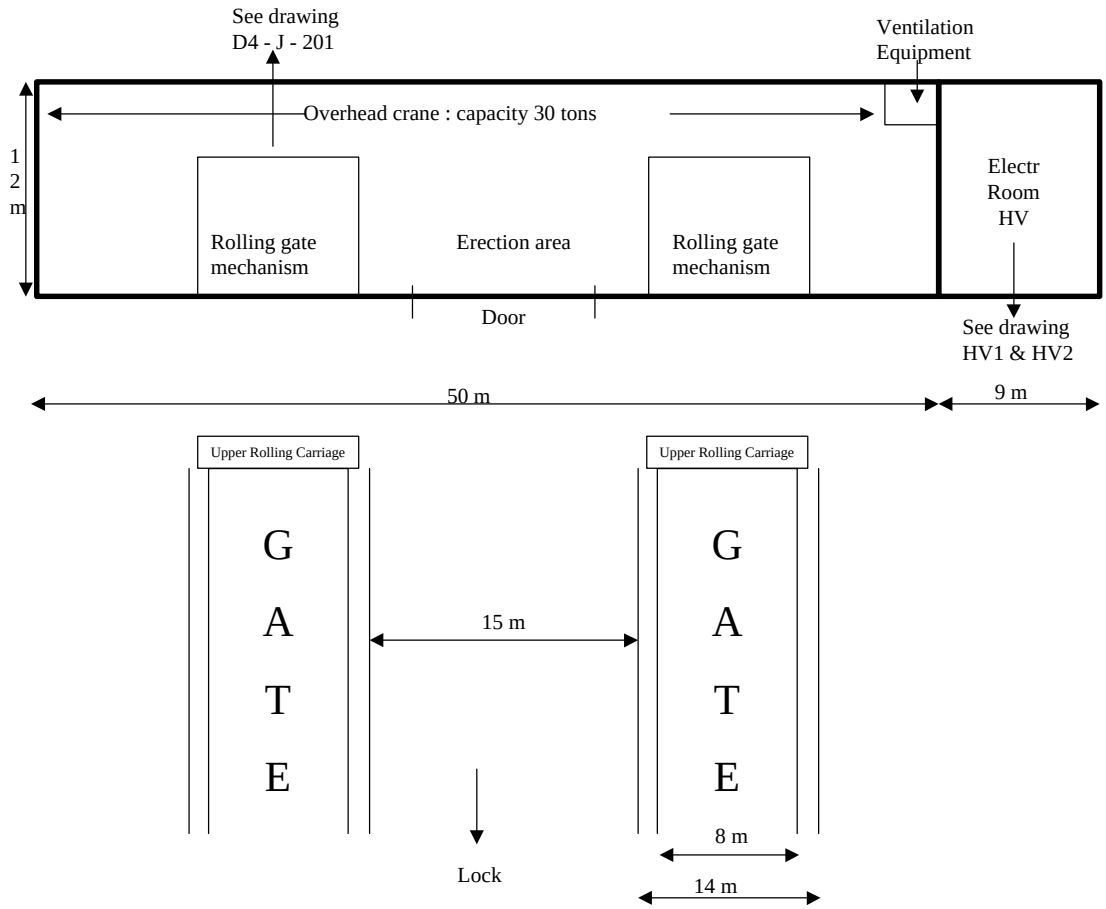
The mechanical workshop is equipped with an overhead crane of 60 tons,

an electrical shop (6 x 20m) including some offices (for technical building staff, meetings,…),

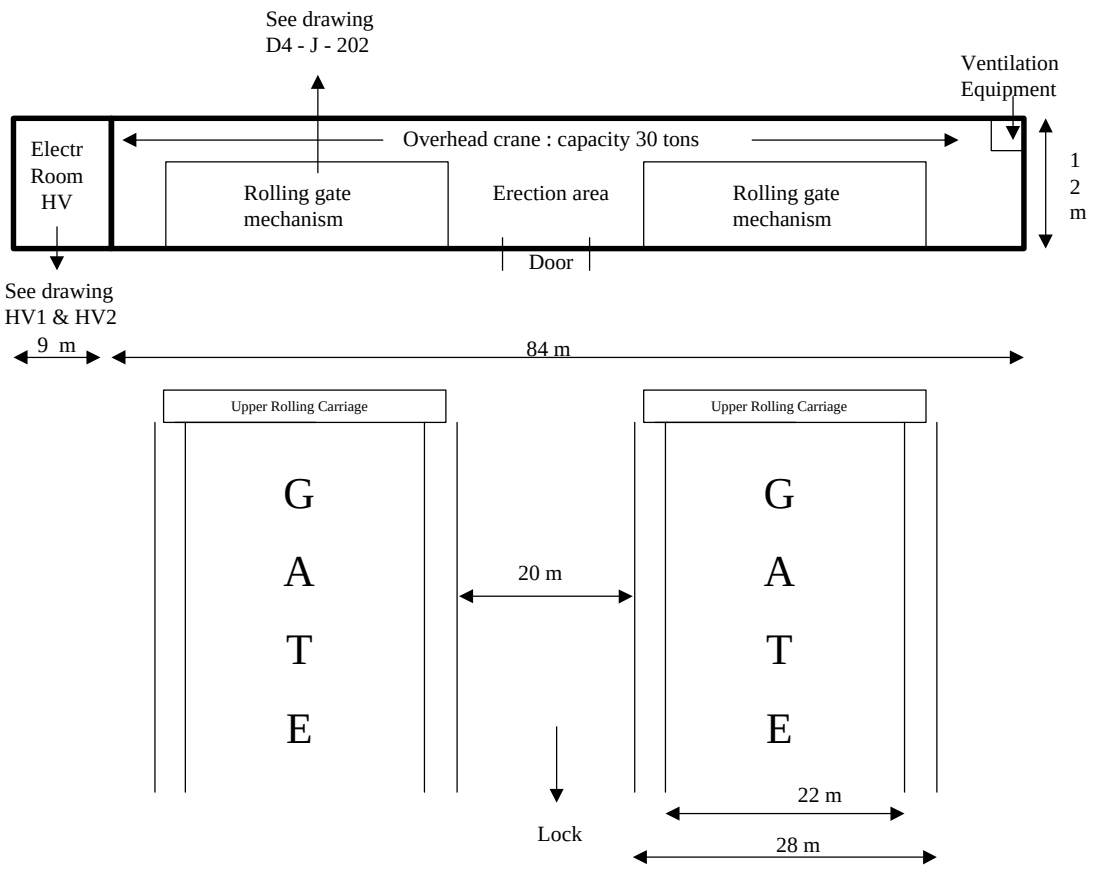
a workshop for maintenance (6 x 20m) and repair of oil pumps, distributors, etc related to the oil systems of culvert and conduit valves,

- a store (6 x 20m) for small spare parts and maintenance tooling.

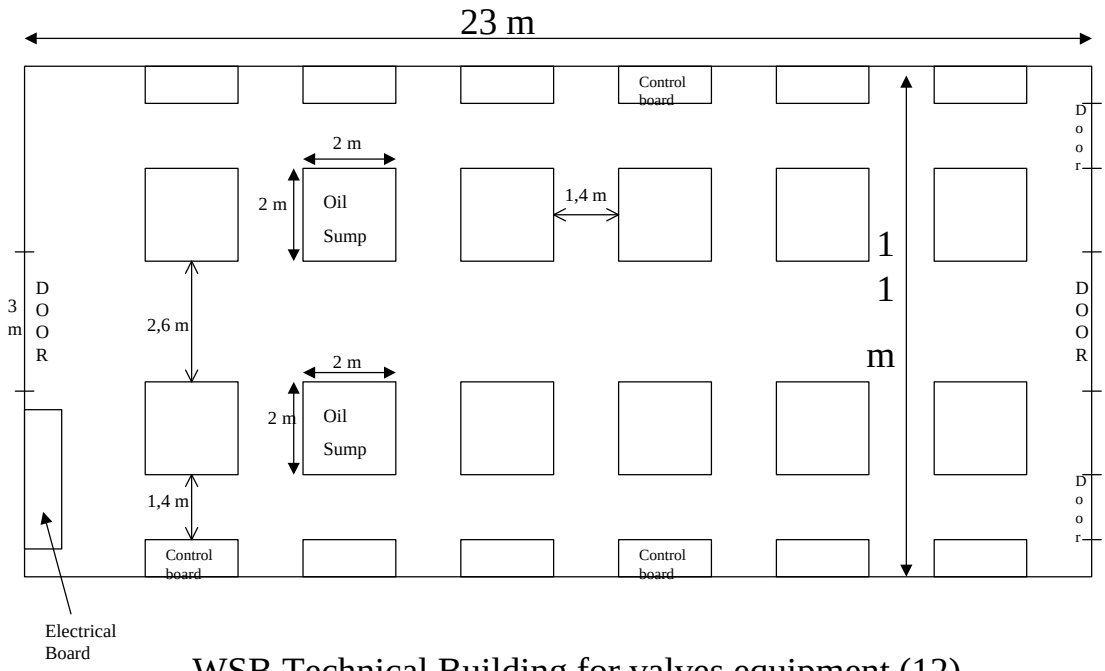
5 Rolling Gates Technical Building Gatun lake side)



6 Rolling Gates Technical Building (Pacific Side)



7 WSB Technical Building



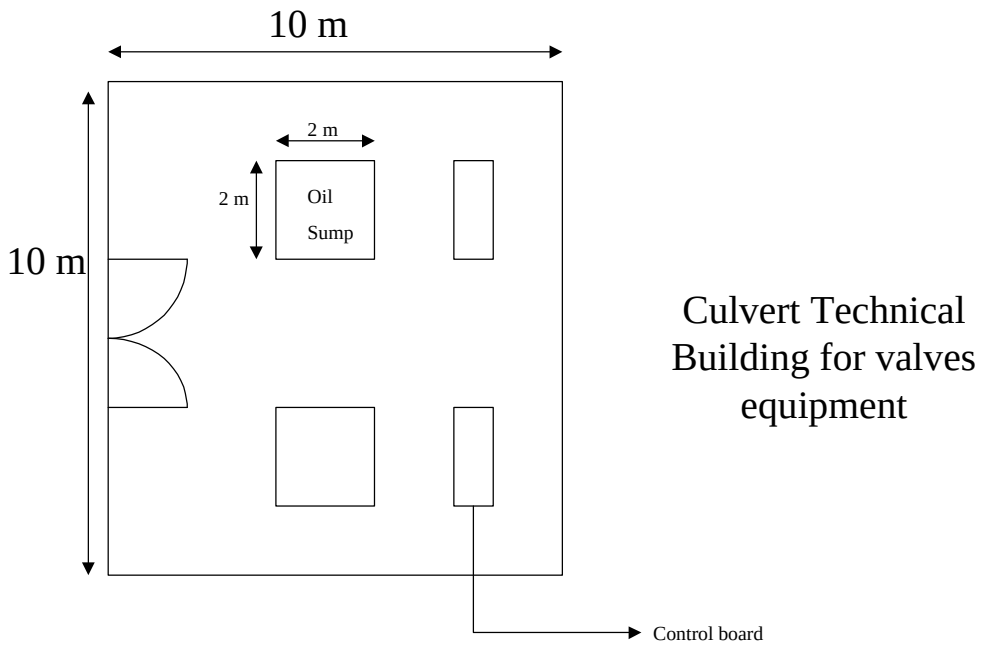
WSB Technical Building for valves equipment (12)

There are two WSB technical buildings of 11 x 23m including valves oil control system and local control equipment. The two buildings will be installed in the vicinity of the 12 valves blocks and are all identical.

Every conduit valve is totally independent and has its own oil sump equipped with pumps and auxiliaries and its own control board.

A free area around the building is provided for a truck crossing.

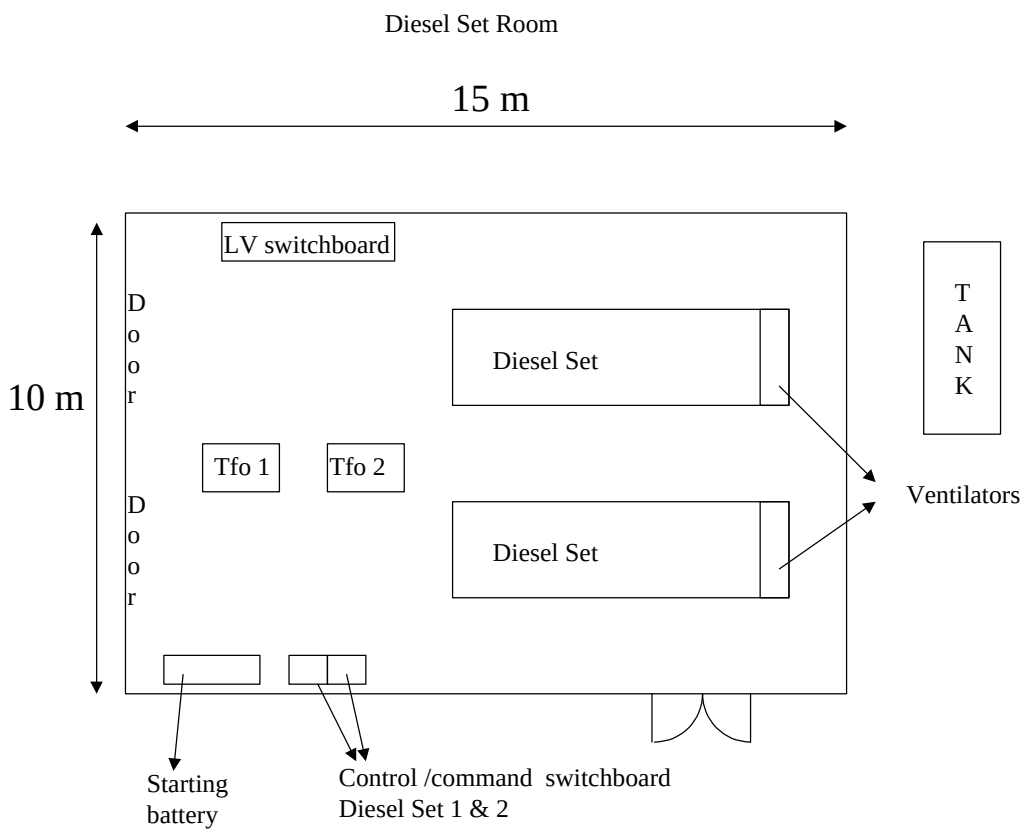
8 Culvert Technical Building



There are four Culvert technical buildings of 10 x 10m including valves oil control system and local control equipment. The four buildings will be installed in the vicinity of the culvert valves blocks and are all identical.

Every culvert valve is totally independent and has its own oil sump equipped with pumps and auxiliaries and its own control board.

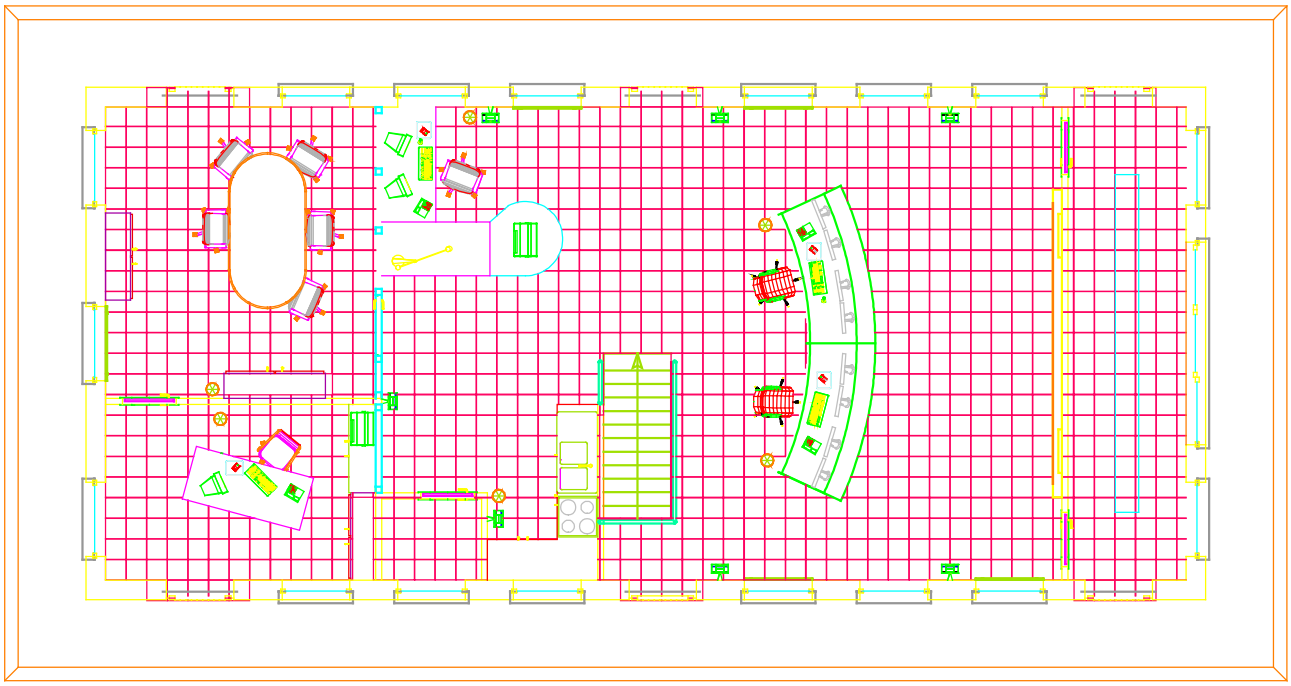
9 Emergency Diesel Sets



NB : Tank is underground.

In order to reduce the risk of damage by a possible flooding, we propose to implement that small building at the top level in the vicinity of the HV1 substation.

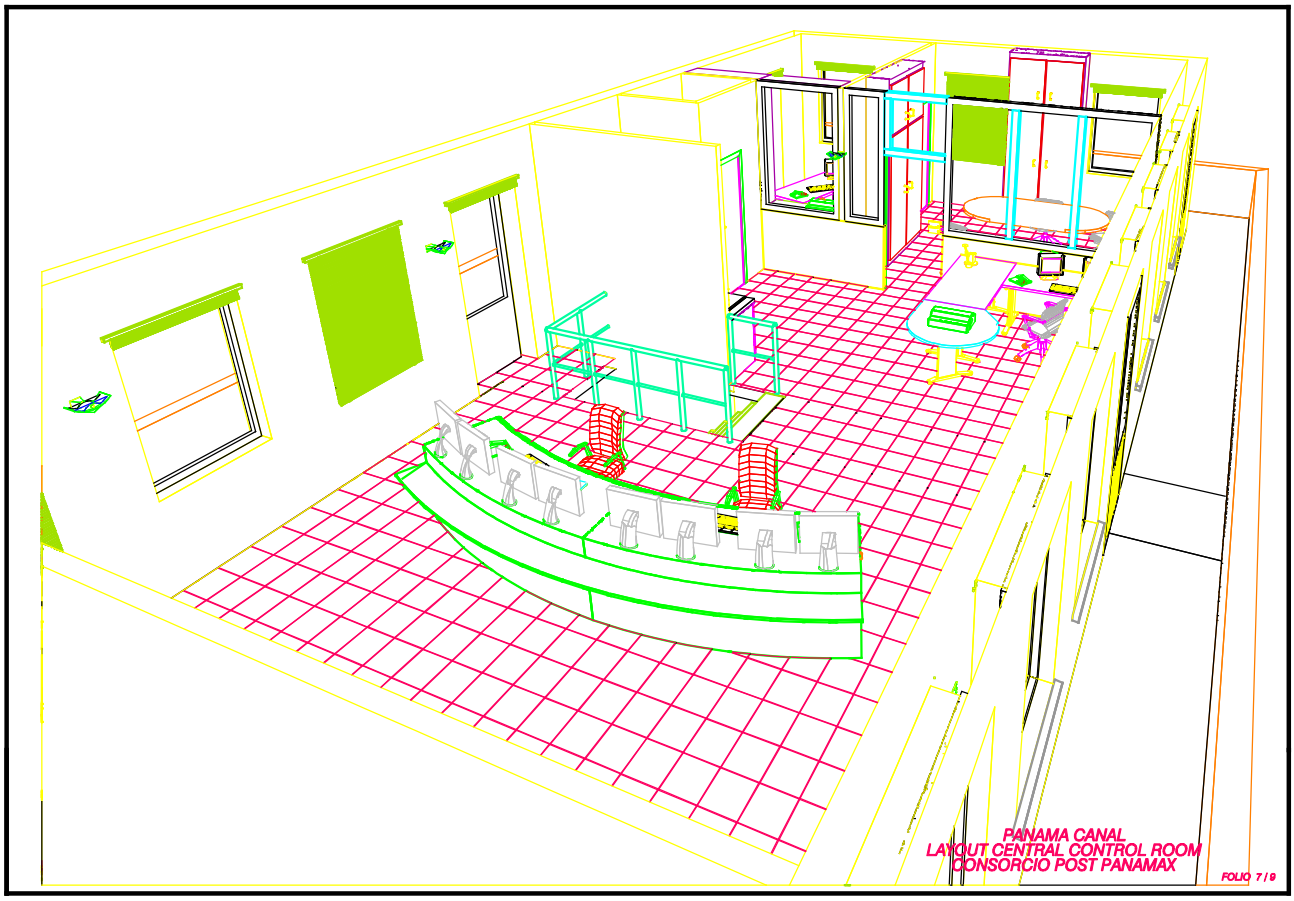
10 Control Room



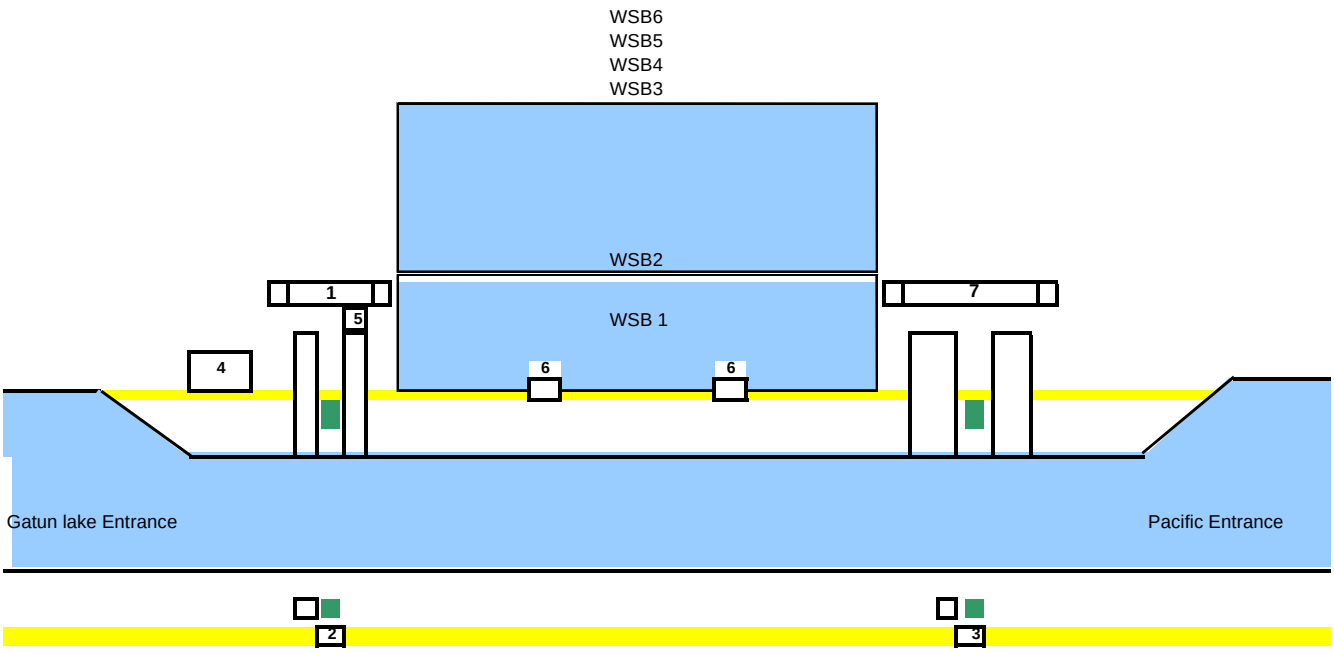
The control building is located next to the lock chamber on the central area between lane 3 and future lane 4 (see drawing D4 – A – 201).

The building (dimensions min: 15 x 8m) has two floors:

- the control room is installed on the second floor
- the substation HV3 (surface required: 15 x 8 m) is implemented on the first floor. The balance can be dedicated to some social rooms (offices and rest-room).


PANAMA CANAL
LAYOUT CENTRAL CONTROL ROOM
CONSORCIO POST PANAMAX
FOLIO 7/9

11 General View

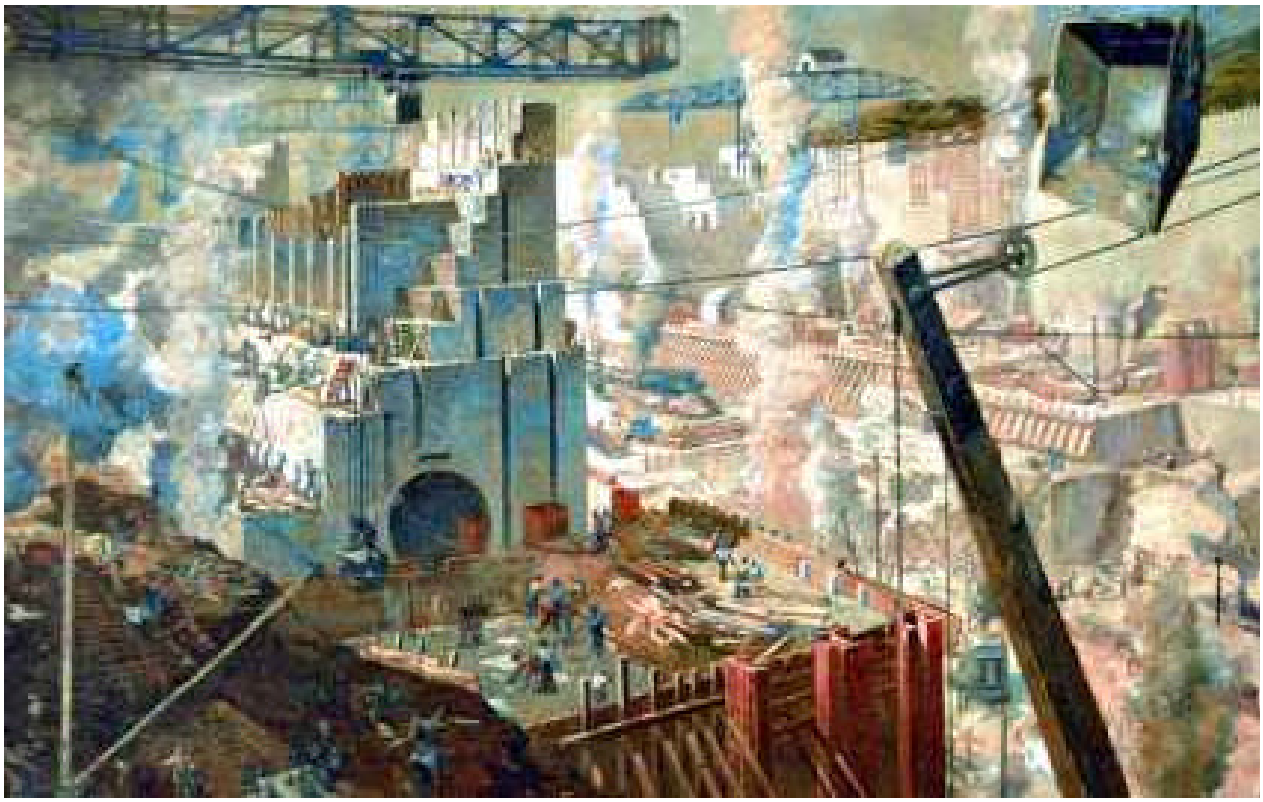


: area for high mast

: 2 culvert valves

1 : Culvert technical building + Gate technical building + HV 1
3 : HV 4 (electrical room - 15 x 8 m)
5 : Diesel set room (15 x 10m)
7 : HV 2 + Gate technical building + Culvert technical building

2 : Control building (15 x 8 m) + HV 3 (electrical room)
4 : Maintenance Building (52 x 20 m)
6 : WSB technical building (23 x 11 m)



Diseño Conceptual de las Esclusas Post Panamax

TASK 4

L – Construction Plan and Scedule

R4-L

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PORT OF ANTWERP
FITA AOSO

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0 Introduction

This Chapter aims to detail how the Pacific Post Panamax Locks will be constructed and put into operation. There is probably much more than one unique solution to reach that objective; however the purpose of this document is to show a feasible construction plan and schedule, compatible with today's modern construction techniques.
The following paragraphs will therefore describe the Construction Plan together with a general organization of the Works, distribution of main construction features within the project area, and the corresponding Construction Schedule.
As far as the Construction Schedule is concerned, only the Combination 2A presented in the Paragraph 2.2 of the Report R4-L-431 Single lift Lock System-Quantities and Cost Estimation will be analyzed.
The Construction Works analyzed in the present chapter are limited on the North by the extremity of the side-approach-wall from Gatun Lake , and on the South by the extremity of the Pacific side-approach-wall. Furthermore, works related to the excess excavation material transport and deposit are not considered here.

1 Construction Plan

1.1 GENERAL

Construction planning is an essential activity during the design of the Project. Therefore, we have developed a Construction Plan foreseeing the use of the most effective construction techniques. Access space as well as availability of resources has been taken into account in the selection of procedures and equipment. The Project considers three alternatives, but at the present stage of development, the Construction Plan for these three alternatives is basically the same. The alternatives are described in the Report R4-L-431 (see ref. here above):

- Combination 1B (Structures with RC)
- Combination 2A (Structures combining RC and RCC)
- Combination 3B (provision for the 4th lane in the western wall)

The Construction Plan does the following:

- Defines the work tasks.
- Maps a layout of the project site showing the location of all activities, access roads and space requirements for the main construction tasks that must be performed to build the project.
- Describes the technology and resources required to perform the work and the manner in which these must be handled to ensure their availability in a timely manner.
- Identifies any interactions among the different work tasks.

1.2 DESCRIPTION OF WORK TO BE PERFORMED

1.2.1 ACTIVITIES

Land Clearing
- Equipment
- Disposal

Excavation
- Rock
  - Drilling
  - Blasting
  - Use for fill
  - Pile for use in aggregate production
  - Haul away to deposit site
  - Stabilization
- Soil
  - Use for fill
  - Haul away to deposit site
  - Stabilization

Tunnels and Trenches

Drainage Ditching and Dewatering

Fill and Compaction
- Rock
  - Transportation and Depositing
  - Compaction
- Soil
  - Transportation and Depositing
  - Compaction

Access Roads and Structures
- Permanent
- Temporary
- Bridges and Culverts

Forms
- Production
  - Wood
  - Steel
- Transportation
- Storage
- Placement

Concrete Production
  - Cement handling and storage
  - Aggregate production and stockpiling
  - Additives
  - Batching plant

- Temperature control
  - Aggregates
  - Ice
- Transportation
- Placement
- Transit mixers and transportation vehicles
- Pumping
  - Pipelines and conduits
  - Pumps

Shotcrete

- Cement handling and storage
- Aggregate production and stockpiling
- Additives
- Transportation
- Equipment storage and maintenance facility

Utilities

- Power supply and distribution system
- Water supply and distribution system
- Sewerage and waste disposal
- Communications
- Lighting

Offices

- Project management and engineering

Shops

- Machine
- Electrical
- Vehicle
- Welding
- Pipe
- Carpentry

Warehousing and Storage

- Materials
- Parts
- Explosives
- Fuel and lubricants

Personnel Facilities

- Dressing rooms
- Sanitary Facilities
- Dining Facilities
- Security

Construction Equipment

- Storage
- Servicing and repair

Firefighting facilities

1.2.2 FACILITIES

1. Concrete

It is foreseen that the bulk of the concrete will be transported by conveyor belt, although other alternatives may also be used for transporting concrete to special areas. . A decision whether to pump or to transport concrete in buckets will directly affect the cost and duration of tasks involved in building construction. A decision between these two alternatives should consider the relative costs, reliability, and availability of equipment for the two transport methods. Unfortunately, the exact implications of different methods depend upon numerous considerations for which information may be sketchy during the planning phase. These are:

Quality Control laboratory
Cement storage silos
Loading and conveying equipment
Water storage tanks
Aggregate handling and stockpiling facilities
Batching Plant
Concrete transportation equipment
Transportation equipment cleaning facilities
Concrete temperature control equipment and facilities

2. Aggregate Processing Plant

Rock crushing and classification equipment, including crushers, screens, conveyors, water pumps, fuel storage tanks, hoppers and stockpiles
Crushers, screens, washers and their feeding and discharge mechanisms
Loading, moving and hauling equipment
Emission Control Equipment

3. Sand

The production of about 3,000,000 m3 of concrete will require a huge quantity of sand (1,500,000 m3) that is not easily available nearby the Lock. The sand may be fabricated from the crushed basalt with probably a high associated cost of production. Another alternative would be to transport the sand from natural sand quarries situated in San Carlos at about 100 km from the Lock site. The maritime transport by barge loaded directly by rolling belt and mechanically unloaded at the site quay dock, might offer an economic solution to be further investigated.

4. Metal and Reinforcing Steel Shop

Deliveries of structural and reinforcing steel will be scheduled in accordance with the execution of the work in order to reduce on-site storage to a minimum. Fabrication of rebar will be performed at this location whenever feasible and transported for placement at the worksite when required. Pre-assembly of structural steel sections will also be done here and transported to the location when required.

Unloading, classification and storage of steel sections and reinforcement bars

Welding area
Fabricating area
Transportation and handling equipment
Bridge crane

5. Concrete Form Shop

Unloading, classification and storage of metal and wood materials
Fabrication facility
Repair facility
Form storage and assembly area
Handling, loading, and transportation equipment

6. Shotcrete Facilities

Equipment storage and repair facility
Cement storage and transportation equipment
Aggregate stockpiling, loading and transportation equipment

7. Drilling and Blasting Facility

Drill and bit storage and repair shop

8. Powder Magazine (located and managed in coordination with Canal Protection and Safety Department).

Equipment storage warehouse
Loading, handling and transportation equipment

9. Pipe Shop

Receiving and storage facilities
Handling equipment
Shop equipment

10. Fuel and Lubricants Facilities

Storage tanks and warehouses
Service stations
Lubricant disposal

11. Compressed Air

Compressors
Storage
Distribution

The work production capacity for the different activities required to build the Post Panamax Locks Project can be established using information obtained from similar projects, as shown in the following Table:

REQUIRED WORK PRODUCTION CAPACITY*

Type of Activity	Production Adopted for the Locks m³/month	Factor	Production Capacity Required m³-month
Rock Excavation	200,000	2	400,000
Soil Excavation	500,000	2	1,000,000
Fill	200,000	1.5	300,000
Conventional Concrete	40,000	1.5	60,000
Roller Compacted Concrete	80,000	1.5	120,000

*See Table 3.1, Paragraph 3.2.
See also comment in Paragraph 3.1. General, regarding the quantity of excavation works required to link the channel to Gatun Lake.

1.2.3 LOCATION (SEE DRAWING D4-L-201 REVA)

Area 1

Project Management and Engineering Offices
Main Toilets, Showers, Changing Facilities and Clothing Storage Lockers
Main Dining Facilities
Health Clinic, First Aid Station, and Ambulance
Environmental Protection, Air Pollution Control and Pest Control Office
Equipment Storage Facilities – indoor and outdoor
Temperature-controlled Storage Warehouse
Main Material and Parts Warehouse
Heavy Equipment Maintenance and Repair Shops
Light Equipment and Vehicles Maintenance and Repair Shops
Fuel Dispensing Facility
Metal and Reinforcement Steel Shops
Concrete Forms Shop
Outdoors Parking and Staging Area for heavy and light construction equipment and vehicles

The principal access to the Project is located on a road that branches from the Interamerican Highway. The only other access by land is over the Miraflores Bridge, which is not in regular operation due to interference with Canal traffic. The main activities have been placed in Area 1, a large level area located at the entrance to the Project. Here are the offices for the Project Management and Engineering staff, as well as facilities that provide services to personnel working in the area. Because of the ease of access to the entrance road as well as to the Project area, the main warehouses and shops have been

placed here. There is a facility that provides fuel to light equipment and vehicles, although the fuel storage tanks are located elsewhere for safety reasons. The area is also used for parking and storing heavy equipment and vehicles when they are idle for extended periods.

Area 2

Compressed Air Facility
Shotcrete Facilities
First Aid Station
Tool room
Area 2, at a central location close to the work area has been selected to house the compressors for producing compressed air for the site. A central Shotcrete Equipment and Materials Facility will be located here to service the entire Project. It also contains one of several tool rooms and First Aid stations.

Area 3

Concrete Production Facility - Batching Plant
Fuel and Lubricants Dispensing Facility
Toilets, showers, changing facilities , clothing storage lockers and Dining Facilities
Field Office
Quality Control Laboratory
Area 3, a smaller area also located at the main entrance to the Project but distant from the main offices and storage areas, has been selected to house the concrete production facilities, an activity that produces considerable noise and pollution.

Area 4

Tool room
Toilets, showers, changing facilities and clothing storage lockers
Dining Facilities
Firefighting Equipment
Branch Warehouse
Auxiliary Repair Facility
Fuel Dispensing Station
First Aid Station
Area 4, located east of the Locks and Water Saving Basins, contains personnel facilities similar to those located in Area 1, but only for the use of the construction workforce. Because it is on the opposite side of the Locks excavation, it also houses correspondingly smaller warehouses, repair, firefighting and health facilities.

Area 5

Aggregate Processing Plant
Fuel and Lubricants Storage Facility
Area 5 is considered the most convenient location for the Aggregate Processing Plant whose production will be used for making reinforced and roller compacted concrete, as well as for backfill, because of the ease of access to the excavation area and to the Concrete Production Facility. Because

this activity produces considerable noise and pollution, an additional advantage is that the site is distant from the offices, shops and work area.

Area 6

Powder Magazine
The Powder Magazine has been located at a remote site for safety reasons.

2 Construction Schedule

2.1 GENERAL

As already mentioned in Paragraph 1. Introduction, only the Construction Schedule corresponding to the most economical Combination 2A is presented in the following paragraphs. Additionally, it can be stated that the construction of the lock walls for the Combination 1B would be more time consuming, considering the complication produced by the concept of the buttresses and heavier reinforcement needs. However, in comparing the two Options, the introduction of RCC technique used to create a continuous gravity mass behind the lock walls in Combination 2A does not significantly change the works scheduling and the total duration of the works, because the critical activity continues to be the excavation works and the conventional concrete works.

In that context, it is worth mentioning that the excavation activity and, especially, the production rate do not take into consideration the huge excavation works to be done in connection with linking the channel to Gatun Lake.

In order to establish realistic Schedules based on feasible work production capacities, an analysis of large construction Projects carried out in different countries has been carried out. The analysis is presented below.

2.2 WORK PRODUCTION CAPACITY

The Table 3.1 presented subsequently, sums up the information gathered from various large Construction Projects undertaken during the last ten years.

The different Projects are presented in columns. The top line summarizes the main characteristics and dimensions of each Project

The left column lists the different types of work considered. Each project column details the corresponding total quantity of work, the monthly peak and mean production capacities (highlighting with a red circle the relevant specific work of each project), and the extreme right column gives the selected production capacity for the Post Panamax Locks.
The following comments can be made:

- The ACP Cut-Widening Project shows a mean production for rock excavation in the range of 100.000 m3/month. It has been verified (source: ACP) that the Contractors involved in those works were not working at full capacity. The Consultant considers that double that production capacity is a perfectly achievable target, for the works entailed. This production capacity can easily be increased if the Project Works are considered in their entirety, i.e. together with the Gatun channel link.

- The concrete placement capacity of the Birecik and Katze projects, reaching roughly 70.000 m3/month, are quite high because of the project type involving mainly large mass concrete structures without any significant reinforcement constraints. For the Post Panamax Locks, it is considered that the geometry is to some extent more complicated than for a gravity dam, which justifies the chosen monthly mean production capacity for concrete placement of 40.000 m3/month

- The same comment made above applies for RCC placement. As a matter of fact, the working area of Tha Dan dam is wide and long and, above all, the RCC placement is continuous; whereas, for the Post Panamax Locks the areas where RCC is required are of smaller dimensions, and the rhythm of placement is governed by the conventional concrete construction progress. An RCC monthly mean capacity placement of 80.000 m3/month seems more appropriate at this stage for the Post Panamax Locks.

WORKS PRODUCTION CAPACITY

References in large Construction Projects
and recommendation for the Post Panamax Locks project

PROJECT		Garafiri	Al Wahda	Birecik	Katze	Tha Dan	ACP Cut Widening	ACP Cut Widening	Other Sources	Production adopted for the LOCKS
Description Type		Earth dam	Earth dam	Composite dam Earth & concrete	Arch dam	RCC gravity dam	Cartagena Soil Excavations	Gold Hill Rock excavations	Boskalis dredging	
Height		75m	90m	62m	185m	95m				
Length		725m	2700m	2507m	710m	2600m				m3/month
Year of construction		1994-1998	1992-1996	1997-1999	1991-1997	1996-1998	1999-2001	1997-1999		
Country		Guinea	Morocco	Turkey	Lesotho	Thailand	Panama	Panama		
Excavation	**Unit**									
Rock										
Total Volume	m3				975,300			1,485,000		**Exc. Rock 200,000**
Monthly Mean Production	m3/month				80,000			**100,000**		
Monthly Peak Production	m3/month							170,000		
Soil										
Total Volume	m3	4,805,132		11,000,000	278,000		2,250,000			**Exc. Soil 500,000**
Monthly Mean Production	m3/month	190,000		**500,000**			125,000			
Monthly Peak Production	m3/month	400,000								
Dredging										
Total Volume	m3									**Dredging 400,000**
Monthly Mean Production	m3/month								**380,000**	
Monthly Peak Production	m3/month									
Fill										
Total Volume	m3	5,275,757	27,000,000	9,000,000						**Fill 200,000**
Monthly Mean Production	m3/month	290,000	**482,000**	**500,000**						
Monthly Peak Production	m3/month	575,000	1,500,000	750,000						
Concrete										
Conventional Concrete										**Conventional Concrete 40,000**
Total Volume	m3	108,528	600,000	1,660,000	2,360,000					
Monthly Mean Production	m3/month	4,930	13,000	**70,000**	**75,000**					
Monthly Peak Production	m3/month	9,000	28,000	104,000	115,000					
Roller Compacted Concrete										
Total Volume	m3					5,000,000				**RCC 80,000**
Monthly Mean Production	m3/month					**130,000**				
Monthly Peak Production	m3/month					170,000				
Source of information				*Coyne et Bellier*			*ACP*		*Boskalis*	

2.3 DESCRIPTION OF THE CONSTRUCTION SCHEDULE

2.3.1 CONSTRUCTION HYPOTHESIS

The construction schedule presented below is based on a certain construction sequence. The sequence of work adopted supposes that:

- The work starts from Lockhead 2 located on the Pacific side, and progresses northward, except for the Pacific side-approach-wall which progresses southward.

- Only a single Lockhead can be built at a time.

- The largest volumes of concrete being in the Lockhead 2 on the Pacific side, the excavation works start in that area to make it ready for concreting works as soon as possible

- In order to avoid obvious interferences, the concreting of the Lockheads and the Lockwalls can start only if all the blasting and excavation works are completed in the area, including the adjacent WSB´s and culverts excavation close to the Lockwall (about 50%) or below the Chamber itself. That is why, for instance, the Single Chamber excavations is divided in two parts to allow the Lockhead 2 concreting activity to start sooner when the excavations of southern part of the Single Chamber and the WSB 1,2, and 3 are completed.

- The WSB´s culvert excavation (balance 50%) and the excavation of WSB 4, 5, and 6 will be done after Single Chamber and Lockhead 1 excavations are completed. This allows starting the concreting works of Lockhead 1 at the earliest.

- The filling of the Lock from the Pacific side can only start when all the civil works and electromechanical equipment erection of the Lock is completed. Of course the valves of the WSB shall also be erected tested and dry commissioned before to fill the Lock with the Pacific waters.

- Once the Lock is open on the Pacific side, and filled up to the Pacific level, all the rolling gates erected in a shipyard will be transported by flotation up to the Locks and stored in the Single Chamber.

- The two large downstream rolling gates are then shifted by flotation and positioned in the Lockhead 2 recesses. The recesses will be sealed with bulkhead gates and pumped dry. The

rolling gates will then be fitted with wooden seals, wagons, etc. (finishing operations). Once ready for operation, the gates will be then shifted into the closed position in the Lock to allow filling the Chamber and raising the upper 2 rolling gates to the Gatun Lake level. The chamber will be filled by introducing water through a temporary pipe connecting Gatun Lake with the chamber, or by pumping water from the Pacific Ocean. The same procedure of placing the gates into the recesses and performing the finishing works will then be repeated in Lockhead 1.

2.3.2 KEY DATES

The Construction Schedule details the following Key Dates:

- Completion of the Civil Work of each Lockhead
- Connection of the Locks to the Pacific and filling the Single Chamber up to the Pacific level
- Connection of the Locks to the Gatun lake
- Locks and WSB starting date for commercial operation

2.3.3 CRITICAL PATH

The critical path has been highlighted with a red line in the Construction Schedule. It can be observed that the excavation works during the first 16 months are on this Critical Path. Of course if the excavation production rate would be increased to a much higher level as required for the works of the connection channel to Gatun Lake, then the critical path would certainly be shifted into the concreting activities.
The concreting activities have been scheduled assuming a mean rate of concrete placement of 40,000 m3 per month, increasing to 50,000 m3 for a period of 8 months, when the Lockhead 1 concreting is done together with the two approach walls. The limitation in the concrete placement rate clearly places the concreting works on the Critical path.

3 Conclusion

The Construction Schedule shows that the total construction time for the Locks and associated WSB´s is near five years and three months. It is certainly possible to reduce the Construction Schedule slightly, however, the Consultant considers that at the present Conceptual Design Stage the rates of production should be maintained on the safe side.
The construction plan presented in the drawing D4-L-201 shows one possible arrangement of the different Construction areas. The main access to the works being the existing road on the South East of the Project Area, a maritime access is possible on the Pacific extremity of the Locks site. It is likely that other arrangements may be considered by the Civil Contractor(s) according to the available construction equipments or to the source of construction material (for instance for the cement and the sand).

*****

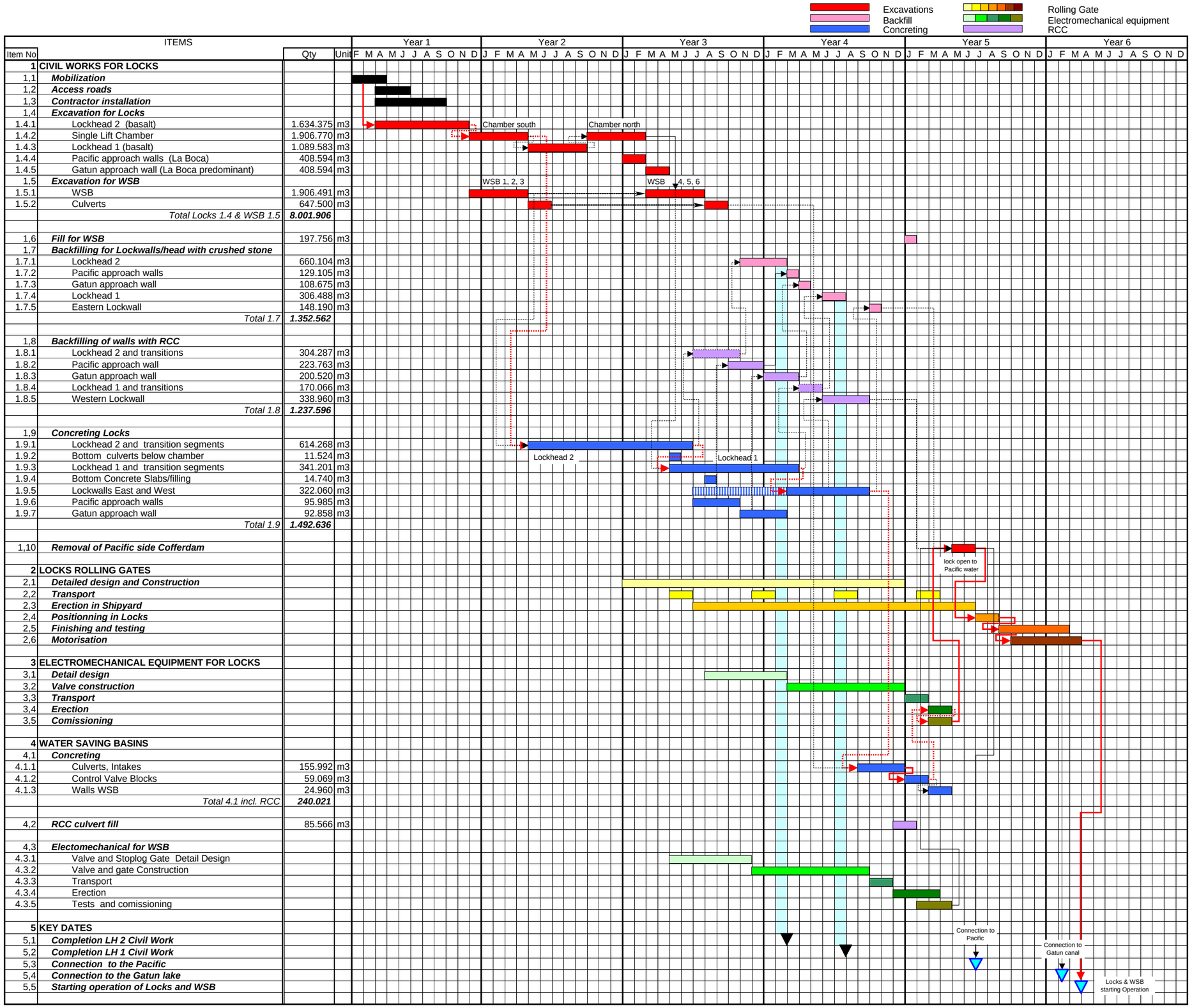
APPENDIX A

CONSTRUCTION PLANNING

CONSTRUCTION SCHEDULE

Combination 2 A with WSB

Item No	ITEMS	Qty	Unit
1	**CIVIL WORKS FOR LOCKS**		
1,1	***Mobilization***		
1,2	***Access roads***		
1,3	***Contractor installation***		
1,4	***Excavation for Locks***		
1.4.1	Lockhead 2 (basalt)	1.634.375	m3
1.4.2	Single Lift Chamber	1.906.770	m3
1.4.3	Lockhead 1 (basalt)	1.089.583	m3
1.4.4	Pacific approach walls (La Boca)	408.594	m3
1.4.5	Gatun approach wall (La Boca predominant)	408.594	m3
1,5	***Excavation for WSB***		
1.5.1	WSB	1.906.491	m3
1.5.2	Culverts	647.500	m3
	Total Locks 1.4 & WSB 1.5	***8.001.906***	
1,6	***Fill for WSB***	197.756	m3
1,7	***Backfilling for Lockwalls/head with crushed stone***		
1.7.1	Lockhead 2	660.104	m3
1.7.2	Pacific approach walls	129.105	m3
1.7.3	Gatun approach wall	108.675	m3
1.7.4	Lockhead 1	306.488	m3
1.7.5	Eastern Lockwall	148.190	m3
	Total 1.7	***1.352.562***	
1,8	***Backfilling of walls with RCC***		
1.8.1	Lockhead 2 and transitions	304.287	m3
1.8.2	Pacific approach wall	223.763	m3
1.8.3	Gatun approach wall	200.520	m3
1.8.4	Lockhead 1 and transitions	170.066	m3
1.8.5	Western Lockwall	338.960	m3
	Total 1.8	***1.237.596***	
1,9	***Concreting Locks***		
1.9.1	Lockhead 2 and transition segments	614.268	m3
1.9.2	Bottom culverts below chamber	11.524	m3
1.9.3	Lockhead 1 and transition segments	341.201	m3
1.9.4	Bottom Concrete Slabs/filling	14.740	m3
1.9.5	Lockwalls East and West	322.060	m3
1.9.6	Pacific approach walls	95.985	m3
1.9.7	Gatun approach wall	92.858	m3
	Total 1.9	***1.492.636***	
1,10	***Removal of Pacific side Cofferdam***		
2	**LOCKS ROLLING GATES**		
2,1	***Detailed design and Construction***		
2,2	***Transport***		
2,3	***Erection in Shipyard***		
2,4	***Positionning in Locks***		
2,5	***Finishing and testing***		
2,6	***Motorisation***		
3	**ELECTROMECHANICAL EQUIPMENT FOR LOCKS**		
3,1	***Detail design***		
3,2	***Valve construction***		
3,3	***Transport***		
3,4	***Erection***		
3,5	***Comissioning***		
4	**WATER SAVING BASINS**		
4,1	***Concreting***		
4.1.1	Culverts, Intakes	155.992	m3
4.1.2	Control Valve Blocks	59.069	m3
4.1.3	Walls WSB	24.960	m3
	Total 4.1 incl. RCC	***240.021***	
4,2	***RCC culvert fill***	85.566	m3
4,3	***Electomechanical for WSB***		
4.3.1	Valve and Stoplog Gate Detail Design		
4.3.2	Valve and gate Construction		
4.3.3	Transport		
4.3.4	Erection		
4.3.5	Tests and comissioning		
5	**KEY DATES**		
5,1	***Completion LH 2 Civil Work***		
5,2	***Completion LH 1 Civil Work***		
5,3	***Connection to the Pacific***		
5,4	***Connection to the Gatun lake***		
5,5	***Starting operation of Locks and WSB***		



Diseño Conceptual de las Esclusas Post Panamax

TASK 4

M – COST ESTIMATION

R4-M

Tractebel Development Engineering · TECHNUM · COYNE ET BELLIER · CNR PROJETS

in association with

IMDC · SBE · FITA AOSO

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0 Preamble

The Single Lift Lock configuration for the new Post Panamax Locks at the Pacific side of the Panama Canal is a huge construction project, probably one of the largest that are going to be built during the forthcoming decades.

A total construction cost for the Pacific Locks has already been quantified for the Triple Lift Lock Configuration and presented by CPP in November 2002 in the Final Report Chapter R4-M titled 3 Steps Lock System Task 4 Cost Estimation.

The present Report contains quantities and cost estimates as of the Year 2002 of the Civil Works and Electromechanical Equipment required to build the Post Panamax Pacific Locks of the Panama Canal in its single Lift configuration. The costs are based on the same aggregated unit price list prepared and justified in the above mentioned Report. However, as the aggregated costs are related to the global quantities involved in the project, it will be demonstrated that the changes in the quantities with respect to the triple lift lock configuration are not of such magnitude that an adjustment in unit prices would be needed.

The present Report consolidates individual reports prepared by the different firms that constitute the Post Panamax Consortium, each in accordance with their particular field of know-how. It groups the information provided in four Chapters: Quantities, Cost Estimates, Total Project Cost and Sensibility Analysis. It considers the cost of building the Water Savings Basins separate from the Locks at a later time. In addition, the Report Includes six Appendices that contain detailed information on quantities of construction items, aggregate unit prices and trend graphs, project cost estimates, postponement of the construction of the Water Saving Basins and sensibility Analysis.

1 Quantities

1.1 GENERAL

According to the different tasks that have been undertaken during the concept design, it was possible to identify all required design criteria, optimize the future third and fourth lane alignment, and determine the most suitable Lock siting and layout. Subsequently, the concept studies of the numerous elements of the new Locks were undertaken, as there are:

- Lock walls;
- Filling and Emptying System, including Water Saving Basins;
- Lock Operating Gates;
- Culvert and Conduit Valves;
- Electromechanical Devices;
- Technical & Control Buildings; etc.

For each of these elements, studies and analysis results have been included in the preceding chapters of this final report. They have been sufficiently worked out by means of proper modern engineering design tools, shown on drawings with all required dimensions on a conceptual level of design, in order to allow calculating the quantities of materials involved. The Terms of Reference require an accuracy of 25% for the cost estimation; therefore it is necessary that the quantities are determined at a higher level of precision, which is most certainly being obtained.

All Quantities are summarized in a series of Tables presented in the Appendix A of the present report.

1.2 LOCK WALLS & ENTRANCE WALLS

Lock walls and entrance walls are gravity type retaining walls, which have to be constructed in an open excavation. Due to the enormous dimensions, especially in depth, they require very large excavations, mainly in very hard rock and partly in soft rock.

In the Task 3 Report on excavation volumes for the new canal by-pass, an estimation of $607,000,000 USD (based on unit prices communicated by ACP as to year 2000) has been put forward as a construction cost for the excavation of the new by-pass including the Locks excavations. The Locks excavation represents only a part of this amount, but it is clear that excavation costs will be a very important factor in determining the total construction cost.

The excavation and backfill volumes have been determined using the digital map "*Curvas nivel*", the plan view D4-A 203 the lock Profile Drawing D4-B-201, and the Cross Section Drawing D4-A-202. Generation of cross sections was done with the AutoCAD 2000 ldd software tool, which also calculates the volumes of excavation and backfill. *Excavation and backfill volumes are calculated in cubic meters [m³]*.

As far as the entrance walls are concerned, the excavation include the entrance channel up to the outer corner of the east wall; from that point on the excavation for the west wall is restricted to the minimum profile required for the construction of the single wall, and does not include the volume of the canal situated in between the entrance wall and the eastern canal embankment, these volumes have to be considered in the total excavation required for the by-pass canal.

An attempt was also made to determine the type of excavation volumes [rock and common (overburden) excavation. Common excavation refers to boulders of less than 1 m³ or to material that can be excavated using a maximum of three passes of a ripper. These assumptions have been based on the available information, which is in our opinion not sufficient to determine the quantities of the different materials with sufficient accuracy. However, the total calculated excavation volume is to be considered as a reliable estimation.

Nevertheless, it was noticed during the analysis of the geo-technical longitudinal profiles that the top levels of the overburden do not correspond with the data from the topographic survey "*Curvas nivel*". It is recommended that these profiles be modified as soon as possible, for instance, as a subject during further design.

The following assumptions were made for quantity estimates:

- Percentages of sound rock, weathered rock and overburden in different types of excavation:

Sound rock	75%
Weathered rock	5%
Overburden	20%

During excavation, and afterwards during construction of the Lock and entrance walls, the excavated area will have to be dewatered to allow concrete works. As the Lock site is enclosed in a nearly impervious rock formation, the contractor will probably only have to inject some cracks to prevent too much water infiltration. However, care has to be exercised, especially with the many faults which were identified and which could be important in the hydrological context. This problem might need further investigation; however, provision has been made by including lump sums to cover foundation treatment, such as grouting and drainage. As excavations in La Boca Formation cause the exposed surfaces of this material to deteriorate rapidly, provision has been made to cover the entire exposed surfaces immediately with a shotcrete protection layer of 5-cm thickness.

The construction of the walls and also the lock heads are to be considered as rather ordinary concrete works, although the applied volumes are rather gigantic and require concrete batching plants with a very high capacity.

In order to determine the concrete volumes with sufficient accuracy, it was necessary to make drawings for each lock partition, i.e. the 2 Lock heads, the Lock walls and the entrance walls.

Reference is made to drawings D4-B-201 to 213, and D4-I-201.

These drawings contain the design details of the following:

- East Lockwall - Single Option (RC – reinforced concrete gravity wall and counterforts. Crushed stone backfill.).
- West Lockwall
  - Option 1 (RC – reinforced concrete gravity wall and counterforts. Separate construction of the 4th lane lock wall. Crushed stone backfill.);
  - Option 2 (RC + RCC – reinforced concrete gravity wall. Roller compacted concrete backfill. Separate construction of the 4th lane lock wall.); and
  - Option 3 (RC Caisson - Reinforced Concrete Caisson that includes the 4th lane lock wall. Crushed stone backfill.);
- Entrance Walls - Option A (RC + RCC – Reinforced concrete gravity wall. Roller compacted concrete backfill) and Option B (RC – Reinforced concrete gravity wall and counterforts. Crushed stone backfill.).

The design details shown in the Drawings were used to calculate concrete volumes for three alternative combinations:

- Combination 1-B includes the single option East Lockwall, Option 1 West Lockwall and Option B Entrance Wall, with and without the Water Savings Basins;
- Combination 2-A includes the single option East Lockwall, Option 2 West Lockwall and Option A Entrance Wall, with and without the Water Savings Basins; and
- Combination 3-B includes the single option East Lockwall, Option 3 West Lockwall and Option B Entrance Wall, with and without the Water Savings Basins;

The cost estimation will indicate which of the three combinations is the most economical one.

The concrete structures are in reinforced concrete, which requires a large amount of steel reinforcement.

The quantities (tons) of steel reinforcement have been determined as a fixed weight per m³ of concrete, based on the engineer's judgment and experience with similar constructions (Lock walls at Berendrecht which are also of reinforced concrete, quay walls). *Steel reinforcement is measured in tons [tons]*.

The following assumptions were made for quantity estimates:

- Quantity of reinforcement steel in reinforced concrete (RC) used estimating purposes in the Post Panamax Pacific Locks Project:
  50 or 75 kg/m³,according to the structure type, its role,
  and, of course, as required by the design

The longitudinal culverts at both sides of the Locks are integrated in the Lock walls and Lock heads; as such they do not appear separately in the quantity list.

The Lock walls and Lock heads, as well as the entrance walls are exposed to temperature variations, curing and shrinkage, and therefore they have to be subdivided in independent parts (segments). In this conceptual design the segments are 30 m in length, with some exceptions, for example, in the transition between Lock walls and Lock heads. Each joint between the wall segments is made water and soil tight by means of a rubber joint which is anchored in the concrete at both sides. *Rubber joints are measured in meters [m]*.

At the corner edge of the top of the Lock walls, a steel corner protection profile is provided to protect the concrete against damage from the locomotive's towing cables. *The protective steel profile is measured in meters [m]*.

After construction the walls that require backfill, as shown on the drawings, are filled at the rear with crushed stone that can be recovered from the rock excavations, but the rock has to be crushed properly in a dedicated installation to obtain an acceptable size, suitable for backfilling and compaction in order to avoid settlements afterwards. *Backfilling in crushed stone is measured in cubic meters [m³]*.

As the Lock chamber bottom is without structural floor (as there is no bottom filling system in the project), and the foundation is in Basalt rock, layer of equalization concrete is provided (*expressed in [m³]*)

A reinforced concrete slab (*expressed in [m³]*) is placed at the culvert and conduit outlets to prevent erosion and weakening of the fractured rock bottom due to currents and exposure (see drawing D4-B-201 and 203). The layer is permeable to prevent uplift pressures caused by lockages. A gravel layer *[m³]* is spread beneath the slabs and covered by a geo-textile *[m²]*

The sills and the vertical bearings in the Lock heads that make the sealing surface of the gate are constructed with basalt or granite prefabricated blocks. They have to be anchored in the concrete by means of steel anchors. *The blocks are measured in [m³]*.

The gates move with the carriage wagons over rails anchored in the bottom floor of the Lock heads and the sidewall recesses of the recess chamber. Other rails are fixed on the recess walls to guide the gate when moving. *The rails are measured in meter [m]*.

Drawing D4-A-201 shows a general plan view of the Locks. It has been used to indicate a number of accessories, such as bollards, fenders, light poles, cable-ducts equipped with steel cover (not indicated), etc… *Such items are always expressed in pieces [PCs]*.

The result of quantity estimates for different items is given in Appendix A.

1.3 LOCK OPERATING GATES.

The rolling gate type has been selected for use in the single lift configuration. The layout of the rolling gate is shown on drawings D4-D 201 to 203. Chapter R4-D on Lock gate design gives unit weight of Lock gates for the different sizes according to the Lock head position.

The unit weight allows determining the total weight of each gate, and an additional weight has to be taken into account for wheelbarrow wagons and steel auxiliaries. For Lock Gate 2, fixed ballast is added for stability purposes and the upper wagon is replaced by a lower wagon. *The steel weight of the total gate structure is expressed in [tons]*.

The sealing of the gate against the basalt or granite blocks is obtained with exotic wooden (azobé) beams that are fixed by bolting to the Lock gate. *These wooden beams are expressed in [m³]*.

In order to use the Lock gate chambers as a place to maintain the gates, a slot bulkhead is required. The *bulkhead is a steel construction, expressed in tons [tons]*.

1.4 ELECTROMECHANICAL EQUIPMENT

Quantities of mechanical equipment, expressed in tons, were based on the experience of the Consultants in large hydropower projects, using graphs and charts relating the weight of equipment with the size and the pressures handled by the proposed equipment. Electrical and power equipment quantities have been based on the conceptual design projects and on the experience provided by the existing Panama Canal Locks.

2 Cost Estimates

2.1 INTRODUCTION

Reference is made to Configuration 1 Chapter R4-M "**3 Lift Lock System".** For this Configuration, the cost estimation for the Civil Works was based on the **aggregation method** in which a cost database is created by analyzing the price/costs of similar work (type/volumes) obtained from international past and present market prices, and adjusting them to obtain current prices. These prices, called aggregate prices, include direct and indirect construction costs. The aggregate prices as of the Year 2002 thus obtained are then applied to the Post Panamax Locks Project to establish its cost. This aggregation method is normally applied by the firms constituting the Consortium, and is of common use in Europe to estimate the cost of projects at a conceptual design stage and even in more detailed study stages. The same unit prices from chapter R4-M Table 2.1 – *Aggregate Unit Price*, used for estimating the cost of the Configuration 1 Triple Lift Lock System have been used to establish costs for Configuration 2, the present Single Step Lock system. The reasons for justifying it are developed in Paragraph 2.2.

2.2 COST ESTIMATE FOR CIVIL WORKS

As explained in Paragraph 1.2, alternative designs have been performed for the Lock walls and entrance walls in order to arrive at the most economical alternative. The different options are shown in drawings D4-B-201 to 220 and D4-I-201.

The single option for the East Lockwall is a reinforced concrete gravity wall and counterforts with crushed stone backfill.

There are three options for the West Lockwall structure:

- Option 1 is a reinforced concrete gravity wall and counterforts with crushed stone backfill.
- Option 2 is a reinforced concrete gravity wall and roller compacted concrete backfill.
- Option 3 is a reinforced concrete caisson-type structure with crushed stone backfill that includes the 4th lane centerwall.

There are two optional designs for the Entrance Walls:

- Option A is a reinforced concrete gravity wall with roller compacted concrete backfill.
- Option B is reinforced concrete gravity wall and counterforts with crushed stone backfill.

The Water Savings Basins design consists of two alternative schemes:

- In the first scheme, there are six adjacent basins on the same level, the same as in Configuration 1, except that the lower basin is the one nearest to the chamber instead of farthest from the chamber. Since there is only one chamber in Configuration 2, the rectangular Basins can be extended further in the longitudinal direction. There are cantilever type separation walls around the outside of the Basins in addition to peripheral walls.

- In the second scheme, the basins are stacked: 3 piles of 2 basins each. Columns support the upper Basins. The bottoms of the upper Basins are reinforced concrete slabs 1 m thick, on grids of cross beams approximately 2 m high. This structure is supported on square columns 1.80 m x 1.80 m every 15 m, resulting in 3 rows of columns in the outer Basin, and 5 rows in the Basin closest to the chamber. Paragraph 2.2.3 details how the cost of both Water Saving Basin schemes were compared.

When compared, the results showed that the cost of the Stacked Water Basin scheme was higher. Therefore, the adjacent Water Basin Scheme was adopted and the Stacked Water Basin scheme was eliminated from further consideration in the elaboration of the Total Project Cost. (See Par. 2.2.3)

The cost of the adjacent Water Savings Basins scheme was then added to each of the three combinations, so that there are two costs for each combination: one including the Water Savings Basins, and one without the cost of the Basins.

The cost of three combinations of these options has been calculated in order to compare the different alternatives.

These combinations are:

- Combination 1-B includes the single option East Lockwall, Option 1 West Lockwall and Option B Entrance Wall, with and without the Water Savings Basins;

- Combination 2-A includes the single option East Lockwall, Option 2 West Lockwall and Option A Entrance Wall, with and without the Water Savings Basins; and

- Combination 3-B includes the single option East Lockwall, Option 3 West Lockwall and Option B Entrance Wall, with and without the Water Savings Basins.

	Combination 1-B	Combination 2-A	Combination 3-B
Eastern Lockwall	Single Option (RC)	Single Option (RC)	Single Option (RC)
Western Lockwall	Option 1 (RC)	Option 2 (RC+RCC)	Option 3 (RC) Caisson
Entrance Wall	Option B (RC)	Option A (RC+RCC)	Option B (RC)
WSB	with and without WSB	with and without WSB	with and without WSB

As it has been shown in the previous Cost Estimation Chapter R4-M for the triple Lift Configuration, the Aggregated Unit Prices are related to the global quantities involved in the Project for each of those items. This relation between prices and volumes has been represented by trend graphs. Appendix B of the present report again shows again the same trend graphs, but with the difference that the vertical lines plotted on those graphs correspond to the total quantities required for both the construction of the Triple lift and the Single lift Lock Configurations. The position of the resulting lines with respect to the trend curves indicate that the difference in volumes between the two configurations is not significant enough to justify a revision of the formerly selected unit prices. Exception is the case of Overburden Excavation which indicates a larger separation between the lines. However, it was decided to maintain the value selected previously since more relative weight has been put on the projects accomplished by the ACP that are of the same order of magnitude at similar prices. Finally it can be concluded that, the same selected prices are valid for calculating the cost of both the Triple lifts and Single lift Lock Configurations.

The following Table 2.1 presents the complete list of Aggregate Unit Prices used to estimate the cost of the Project. The prices for Rails of LSW for the heavier lower rolling gate 2, the Fixed Ballast for Gate Stability of the same gate 2, and the cost of Control and Operation Buildings have been adjusted respectively added in that list.

Table 2.1

Conceptual Design
Post-Panamax Lock Structure (Pacific)

Aggregate Unit Price

Item	Description	Unit	Selected Unit Price USD 2002		
			Maximum	Selected	Minimum
1	**Excavations**				
1.1	Overburden	m³	4.30	3.50	2.70
1.2	Weathered	m³	5.90	4.75	3.60
1.3	Rock	m³	7.50	6.00	4.50
1.4	Overhaul of spoil (10 km)	M³km	0.40	0.30	0.25
2	**Fill**				
2.1	Backfill	m³	4.00	3.00	2.00
2.2	Gravel layer	m³	6.50	6.00	5.50
2.3	Bank protection WSB	m²	15.65	13.00	8.60
3	**Concrete**				
3.1	RC	m³	150.00	120.00	90.00
3.2	RCC	m³	33.00	28.00	23.00
3.3	Concrete slab	m³	150.00	120.00	90.00
3.4	Lean Concrete	m²	11.00	9.00	6.80
3.5	Pavement	m²	30.00	24.00	18.00
3.6	Concrete layer chamber bottom	m³	110.00	90.00	68.00
3.7	Shotcrete (Temporary protection in La Boca)	m²	31.25	25.00	18.75
4	**Reinforcement**				
4.1	Steel reinforcement	tons	1,000.00	875.00	750.00
5	**Other**				
5.1	Steel corner protection	m	78.00	73.00	68.00
5.2	Rubber joint	m	112.00	71.00	30.00
5.3	Geotextile	m²	2.25	1.80	1.50
5.4	Liner HDPE (WSB)	m²	16.63	13.31	10.00
5.5	Underlying protective geotextile (WSB)	m²	2.35	1.88	1.45
5.6	Geotextile for drainage (WSB)	m²	5.90	4.71	3.55
5.7	Rails	m	350.00	280.00	210.00
5.8	Rails LSW	m	1,250.00	1,000.00	750.00
5.9	Wooden vertical guides	m	500.00	400.00	300.00
5.10	Steel for support rail and frames	ton	3,000.00	2,400.00	1,800.00
5.11	Vertical element for seals east/recesses	m³	3,812.50	3,050.00	2,287.50
5.12	Vertical element for seals west	m³	3,375.00	2,700.00	2,025.00
5.13	Horizontal elements for seals lock chamber	m³	3,375.00	2,700.00	2,025.00
5.14	Elements for placement habitat	m³	343.75	275.00	206.25
5.15	Horizontal elements for seals gate recesses	m³	1,900.00	1,520.00	1,140.00
5.16	Bridge over recesses	pcs	625,000	500,000	375,000
5.17	Fixed ballast for gate stability	ton	625.00	500.00	375.00
5.18	Control building	m²	375.00	300.00	225.00
6	**Accessories**				
6.1	Bollards 1500kN	pcs	6,125.00	4,900.00	3,675.00
6.2	Fenders	pcs	675,000	540,000	405,000
6.3	Ladders	m	125.00	100.00	75.00
6.4	Mooring bits	pcs	1,187.50	950.00	712.50

2.2.1 COST ESTIMATE FOR CIVIL WORKS INCLUDING WATER SAVING BASINS

Cost Estimates of Civil Works are summarized in the following Table. Detailed information is presented in Appendix C.

Costs of the Civil Works
Summary

Item	Description	Combination 1-B		
		Low Cost USD - 2002	Selected Cost USD - 2002	High Cost USD - 2002
1	Lock only	289,909,853	370,595,250	452,064,609
2	Water Savings Basin only	53,674,937	68,627,901	84,415,604
3	Lock and WSB`s	343,584,790	439,223,151	536,480,213
4	Percentage of Selected Cost for the Locks & WSB`s	78.2%	100.0%	122.1%

Item	Description	Combination 2-A		
		Low Cost USD - 2002	Selected Cost USD - 2002	High Cost USD - 2002
1	Lock only	284,350,138	362,747,600	442,121,945
2	Water Savings Basin only	53,674,937	68,627,901	84,415,604
3	Lock and WSB`s	338,025,075	431,375,501	526,537,549
4	Percentage of Selected Cost for the Locks & WSB`s	78.4%	100.0%	122.1%

Item	Description	Combination 3-B		
		Low Cost USD - 2002	Selected Cost USD - 2002	High Cost USD - 2002
1	Lock only	378,119,662	482,771,907	588,317,618
2	Water Savings Basin only	53,674,937	68,627,901	84,415,604
3	Lock and WSB`s	431,794,599	551,399,808	672,733,222
4	Percentage of Selected Cost for the Locks & WSB`s	78.3%	100.0%	122.0%

2.2.2 COST ESTIMATES FOR POSTPONED WATER SAVING BASINS CONSTRUCTION

Water Saving Basins (WSB's)—to recycle water by gravity for re-use in lockages—are located behind the East Wall of the Post Panamax Pacific Locks. In the event the ACP opts for postponing the construction of the WSB's to a future and unknown date, a separate estimate of their construction cost, using prices to the Year 2002, is included in this Report. Although this alternative reduces the construction quantities of the Locks, the CPP Project Team consider that the effect on the unit price applicable to the Locks is negligible. The cost of the components that are part of the WSB's located within the Locks wall, such as the conduits and valve structures, would be built as part of the initial phase, and their cost is included in that estimate.

However, if the WSB's are built separately, the construction quantities involved are smaller. In addition, other factors that affect the cost of building the WSB's separately are:

- If built after completion of the Locks, the WSB's are on an island located between the Post Panamax Locks and Pedro Miguel Locks, Miraflores Lake and Miraflores Locks. The project site would require transporting equipment and materials, as well as the removal of spoil material, either through the existing Miraflores Bridge, a new bridge crossing the Post Panamax Locks channel or by water across Miraflores Lake.
- Separate construction requires renewed provision of facilities, such as a concrete plant, aggregate processing and storing facilities, equipment and materials for earthmoving operations, as well as provision of public services required for construction operations.
- More stringent and costly safety measures would be required to protect construction and Locks operations personnel, in addition to Canal traffic during the construction phase.
- Construction time is increased because work must be performed without interfering with Canal Operations. This would produce an adverse impact on movement of equipment, materials and access of personnel to the construction site.

Therefore, the unit prices for estimating the cost of postponing the construction of the WSB's increase. The Civil Works are increased by a factor of 1.5 and the Electromechanical Equipment by a factor of 1.3. The increase is due to the smaller quantities of work and material required which are considered to increase their price. Other factors involved are difficult working conditions and restricted access to the site.

Appendix D contains the Tables and Trend Curves which justify the cost of the WSB's assuming that their construction is postponed. In the trend curves, the corresponding quantities for the WSB's have been plotted, making it possible to determine a new Selected Price, obviously higher than the one selected in Paragraph 2.2, Table 2.1. Table D1 summarizes the new selected prices, the adjustment factor applied, the quantities of the Water Saving Basins and the Total Cost for the Civil Works as well as for the Electromechanical Equipment. These total costs are repeated in Paragraph 3, **Total Project Cost**, here below.

2.2.3 COMPARISON OF STACKED WATER SAVINGS BASINS VS. ADJACENT WATER BASINS

An estimate was made to compare the cost of both schemes and select the least costly one. The construction costs of both schemes are shown in Tables C.15.1 and C.15.2. These indicate that the cost of the adjacent Water Savings Basins is $68,627,901, while that of the stacked Water Savings Basins is $131,054,938, or 191% of the cost of the stacked Basins. Consequently, the stacked Water Savings Basin alternative was eliminated from further consideration in the Total project Cost estimate. Notwithstanding, the same analysis was made for postponing the construction of the Water Savings Basins. Obviously, the results shown in Appendix D conduct to the same tendency as concluded here above.

The adjacent Water Savings Basins scheme was then used to calculate the cost of the 3 combinations and of the postponed construction of the Water Savings Basins detailed in Appendix D.

2.3 COST ESTIMATE OF THE ELECTROMECHANICAL EQUIPMENT

2.3.1 CULVERT AND CONDUIT VALVES

Estimate Weights of the Culvert and WSB Valves and Bulkheads

The Table hereafter (extract from the Chapter R4–E) is the base for estimating the price of the valves and bulkheads. The price for welded construction is usually estimated by multiplying a weight by a kg price. That kg price has been estimated at 5 USD/kg, all-inclusive.

	Number	Height of slots (m)	Unit weight (tons)	Total weight (tons)	Remarks
Culvert valves (Hs = 40m)	8	-	27.5	247.5	Incl. 1 spare part
Culvert bulkheads (Hs = 40m)	8	-	24	192	
Culvert valves slots	8	32.99 (4) 24.04 (4)	200 (guiding) 800 (last 15m)	133	Incl. l5t for lintels and sills
Culvert bulkhead slots	16	32.09 (4) 24.04 (4)	200 (guiding) 500 (last 10m)	193	Incl.30t for lintels and sills
WSB upper valves (Hs = 50m)	12	-	40	520	Incl. 1 spare part
WSB lower valves (Hs = 65m)	12	-	48.5	630.5	Incl. 1 spare part
WSB bulkheads (Hs = 65m)	4	-	131	524	
WSB upper valve slots	12	50.29	200 (guiding) 1000 (last 15m)	288	Incl.23t for lintels and sills
WSB lower valve slots	12	69.29	200 (guiding) 1000 (last 15m)	333	Incl.23t for lintels and sills
WSB bulkhead slots	24	69.29	200 (guiding) 500 (last 25m)	536	Incl. 23t for lintels and sills
Miscellaneous (suspension elements, cylinder support and dogging devices)				175	
TOTAL				**3,772 tons**	

The total price for the **32 fixed-wheel valves** and related bulkheads and slots is estimated at:

3,772,000 x 5 = ***USD 18.86 Million***

That price is including transport, erection and commissioning. It does not include either the operating machinery (cylinders, oil hydraulic unit, etc) and the maintenance cranes or the control boards.

$5/kg is an usual price "all included" considered for similar valves of welded construction in the hydro field. Welded construction kg price ex-works is considered to be normally in a range of $3 to $3.5. Transportation and erection are estimated to vary between 30 and 40%. The top of the range has been preferred for the valves due to some machining and stainless material (wheels, sealing systems).

Valves operating machinery and local control boards: ***USD 6.40 Million***

The valves operating machinery price has been based on a preliminary budget price given by an important supplier (Bosch Rexroth) for 52 hydraulic cylinders all identical with oil sumps and control boards. A rough comparison was also made with the cost of the refurbishment of hydraulic cylinders for 40 pairs of miter gates at the Panama Canal (for 80 hydraulic cylinders).

Maintenance tools, cranes and railways: ***USD 0.90 Million***

This price is including 2 maintenance gantry cranes of 70-ton capacity, span about 6.5m, 590m of rails and maintenance tooling as handling beam to lower and remove valves and bulkhead from the slots.
Weight of cranes has been estimated to 2 x 37 tons, price: 2 x 300,000 = $600,000 (kg price: $8) - Rails: 800m x 100kg/m x $3/m =$240,000 – Maintenance tools: $60,000.

Rolling gate operating machinery: ***USD 7.40 Million***

Is composed of:

- 2 main AC motors of 300kW with variable speed (according to a preliminary budget price of a manufacturer): 2 x 90,000 = $0.20 Million
- 2 main AC motors of 900kW with variable speed (according to a preliminary budget price of a manufacturer): 2 x 130,000 = $0.30 Million
- 2 primary gear boxes (300kW): 2 x 200,000 = $0.4 Million
- 2 primary gear boxes (900kW): 2 x 500,000 = $1.0 Million
- 4 secondary gear boxes (300kW): 4 x300,000 = $1.2 Million
- 4 secondary gear boxes (900kW): 4 x700,000 = $2.8 Million

The prices of gearboxes have been based on hydro gearboxes prices.

- balance of equipment (auxiliary AC motors, cable drums, pulleys, cables, bearings,..) : $.1.5 Million

2.3.2 OPERATING MACHINERY: CONTROL SYSTEM

Estimated budget price: ***USD 1.70 Million***

The budget price is based on the description given in the Chapter R4–F.
It includes the control equipment, installation, cabling and commissioning.

CPU 1 to 20 (Panboard, Rack 19", I/O)	1,190,000
Main Control room	250,000
Backup control Room	50,000
CCTV	210,000
Total	$1,700,000

Prices have been based on unit prices of a similar control system.

2.3.3 LIGHTING

Estimated budget price for 39 high masts, 228 floodlights of 1000W, 308 floodlights for the lock chamber and rolling gates lighting: ***USD 1.20 Million***

2.3.4 ELECTRICAL AND POWER REQUIREMENTS

		Alternative 1	Alternative 2
1	High Voltage		
1.1	Cables	376,200	554,100
1.2	HV Switchgear	885,000	985,000
2	Transformers	198,500	198,500
3	Emergency power supply		
	Diesel set 1000 kVA + transformers + ...	532,500	532,500
4	Low Voltage		
4.1	Low Voltage switchboard	990,000	990,000
4.2	Low Voltage Cables	706,800	706,800
4.3	Low Voltage equipment	161,600	161,600
5	Cable Trays and Supports	840,000	840,500
6	Miscellaneous	500,000	500,000
	Total Including transportation and erection	5,191,100 **USD 6.75 Million**	5,469,000 **USD 7.1 Million**

Note: No provision has been made either for the operating structures (overhead crane of the maintenance building or for HVAC necessary for control room and HV technical rooms).

The Alternative 2, which offers more security, has been selected (see Chapter R4-H, *Electrical Power and Power Requirement*). Therefore, the corresponding prices of Alternative 2 will be used in the present Cost Estimation.

2.4 COST ESTIMATE FOR LOCK GATES

2.4.1 PRICE - BERENDRECHT LOCK GATES

The cost of the Berendrecht Lock gates including equipment:

0	General working costs	363,000 USD
1	Detailed calculation and construction drawings	310,000 USD
2	Metal construction + equipment	
	Lock gates (4)	19,288,000 USD
	Lower support wagon (4 + 1)	177,000 USD
	Upper support wagon (4)	544,000 USD
	Maintenance support wagons (24)	186,000 USD
	Bulkhead	575,000 USD
3	Mechanical parts	958,000 USD
4	Positioning and testing	455,000 USD
5	Temporary storage and additional works	198,000 USD
	Total	23,054,000 USD

These costs were accurate in 1983.

The costs include the 4 gates, 5 lower support wagons (1 spare one), 4 upper support wagons, 4 maintenance support wagons (2 gates can be maintained simultaneously) and 1 bulkhead.

When we divide this total sum by the total weight of the 4 gates + equipment:

23,054,000 USD / 6,800,000 kg = 3.390 USD/kg

Knowing that this price was made in 1983, it has to be multiplied with a factor to take into account the price evolution:

3.390 USD/kg x 1.75 = 5.933 USD/kg

We add to this price the transport of the gates from the workshop to the site:

5.933 USD/kg + 0.24 USD/kg = 6.173 USD/kg

We extrapolated this for the complete single-lift situation:

4,000 tons (2 x gate1) + 23,000 tons (2 x gate2) + 7,162 tons (equipment) = 34,162 tons

6.173 USD/kg x 34,200,000 kg = 211,116,600 USD

We need to add the weight of the ballast required for the stability of the lower rolling gates. This ballast can be taken into account at a low price, 0.5 USD/kg.

0.5 USD/kg x 14,000,000 kg = 7,000,000 USD

The total cost then is:

211,116,600 USD + 7,000,000 USD = 218,116,600 USD

2.4.2 FENDERING

We have foreseen 2 sets of wheel fenders (1 set = 5 wheels), one on each side of the single lift configuration.

Based on recent information the cost of one wheel with casing is 90,000 USD (2002).

The cost of two sets of fenders + positioning on site:

(10 x 90,000 USD) x 1.2 = 1,080,000 USD

This is much cheaper (factor 2) than an extrapolation of the costs of the fendering of the Berendrecht Lock. Based on the evolution during the last years, these materials are less expensive.

3 Total Project Cost

The Total Project Cost is detailed in the following four Tables:

- Table 3.1 contains the Total Lock Cost for Combinations 1-B, 2-A and 3-B.
- Table 3.2 contains the Total Water Savings Basins cost if they are constructed together with the Locks. The WSB's cost is the same for all combinations.
- Table 3.3 contains a summary of the WSB´s Cost if their construction is postponed. The corresponding cost is given as to the year 2002.
- Table 3.4 contains a summary (rounded numbers) of the Total Project Cost showing the three combinations.

The total costs of the Civil Works and of the Electromechanical Equipment have been incremented by lump sum percentages corresponding to items not quantified in terms of volume of work but, nevertheless, required for the completion of the project. These items are the following:

- **Detailed Studies and Supervision**

This item includes all the engineering service to be performed after awarding the Civil Work construction contract(s), the detailed execution studies (shop drawings) and the cost of complete works supervision. Excluded from this item are the basic design, final design, preparation of Tender documents, hydraulic model studies, and the geological and geotechnical investigations (except those related directly to the construction).

Based on the FIDIC recommendations, the estimated percentage covering the above Item 1 comes to 7%. This value is applicable to both the Civil Works and the Electromechanical total costs.

- **Instrumentation**

This Item covers purchase, installation and activation of all permanent instruments dedicated to record the physical behavior of the Civil structures. It covers as well the monitoring and reporting during the construction period. It is estimated that 2% of the total cost of the Civil Works is sufficient to cover this Item 2.

- **Grouting and Consolidation**

It is very unlikely that a project of the size of the Post Panamax Lock will not require grouting, drainage and consolidation of the foundation. At the present stage, the geological and geotechnical local characteristics of the Locks foundation are not known in detail but it is likely that some zones might require special foundation treatment, such as impermeabilization grouting, drainage or consolidation grouting. The Item 3 grouting and consolidation aims to cover the costs related to these

works. It is estimated that 3% applicable to the total Civil Works cost is sufficient provision to cover this item.

- **Contingencies**

This item covers all the works, services and equipment that cannot be precisely identified and quantified at the present stage of the studies. It is commonly accepted that these contingencies amount to from 15 to 20 percent of the total cost of the Civil Works at a conceptual design stage. Considering that the Civil Works have been defined for the Pacific Post Panamax Lock Project with quite a high level of precision for a conceptual study stage, the CPP estimate that a contingencies Item amounting to 15% of the total civil works cost is a sufficient provision.

Of course, with the increasing information gained regarding the geological and geotechnical features of the foundation, and with the increased level of detail achieved in the design of the Civil Work, the amount of this contingencies provision will progressively decrease.

Regarding the contingencies for Electromechanical Equipment, it is again commonly accepted that these works are generally quantified with a quite good level of precision, mainly because the geological and geotechnical uncertainties do not affect the cost estimates. At a Conceptual Design stage, a provision of 10% of the total cost of Electromechanical Equipment is considered perfectly adequate to cover the contingencies. However, considering that even if the technological jump from Berendrecht experience to the projected Gate 2 seems reasonable from a design extrapolation point of view, no Lock Gate of the size of Lock Gate 2 has ever been built in the world, therefore a contingency provision of 20% of the estimated construction cost of the Lock Gate 2, has been included in the total cost estimate.

- **Administrative Costs**

This Item includes all the management, communications and various other expenses incurred by the Owner to control the execution of the project. It does *not* include the financial costs. The Administrative Costs are estimated at 2% of the total cost of Civil Works and Electromechanical Equipment.

Table 3.1
Conceptual Design
Post-Panamax Lock Structure (Pacific)
TOTAL LOCK COST

Item	Description	%	Combination 1-B Total USD - 2002	Combination 2-A Total USD - 2002	Combination 3-B Total USD - 2002
	LOCK				
1	**Civil Works**		**478,067,872**	**467,944,404**	**622,775,760**
1.1	Civil works		370,595,250	362,747,600	482,771,907
1.2	Detailed studies and supervision	7%	25,941,667	25,392,332	33,794,033
1.3	Instrumentation	2%	7,411,905	7,254,952	9,655,438
1.4	Grouting and consolidation	3%	11,117,857	10,882,428	14,483,157
1.5	Contingencies	15%	55,589,287	54,412,140	72,415,786
1.6	Administrative costs	2%	7,411,905	7,254,952	9,655,438
2	**Electromechanical equipment**		**312,529,918**	**312,529,918**	**312,529,918**
2.1	Electromechanical equipment		246,631,754	246,631,754	246,631,754
2.1.1	*EM equipment Lock Head 1*		*27,722,943*	*27,722,943*	*27,722,943*
2.1.2	*EM equipment Lock Head 2*		*190,381,311*	*190,381,311*	*190,381,311*
2.1.3	*EM other equipment and system*		*28,527,500*	*28,527,500*	*28,527,500*
2.2	Detailed studies and supervision	7%	17,264,223	17,264,223	17,264,223
2.3	Contingencies		43,701,307	43,701,307	43,701,307
2.3.1	*Lock Head 1*	*10%*	*2,772,294*	*2,772,294*	*2,772,294*
2.3.2	*Lock Head 2*	*20%*	*38,076,262*	*38,076,262*	*38,076,262*
2.3.3	*Other equipment and system*	*10%*	*2,852,750*	*2,852,750*	*2,852,750*
2.4	Administrative costs	2%	4,932,635	4,932,635	4,932,635
	TOTAL LOCK COST		**790,597,790**	**780,474,323**	**935,305,678**

Table 3.2
Conceptual Design
Post-Panamax Lock Structure (Pacific)
TOTAL WSB´S COST
(If constructed together with the Locks)

Item	Description	%	Combination 1-B Total USD - 2002	Combination 2-A Total USD - 2002	Combination 3-B Total USD - 2002
	WSB				
1	**Civil Works**		**88,529,992**	**88,529,992**	**88,529,992**
1.1	Civil works		68,627,901	68,627,901	68,627,901
1.2	Detailed studies and supervision	7%	4,803,953	4,803,953	4,803,953
1.3	Instrumentation	2%	1,372,558	1,372,558	1,372,558
1.4	Grouting and consolidation	3%	2,058,837	2,058,837	2,058,837
1.5	Contingencies	15%	10,294,185	10,294,185	10,294,185
1.6	Administrative costs	2%	1,372,558	1,372,558	1,372,558
2	**Electromechanical equipment**		**17,888,675**	**17,888,675**	**17,888,675**
2.1	Electromechanical equipment		15,032,500	15,032,500	15,032,500
2.2	Detailed studies and supervision	7%	1,052,275	1,052,275	1,052,275
2.3	Contingencies	10%	1,503,250	1,503,250	1,503,250
2.4	Administrative costs	2%	300,650	300,650	300,650
	TOTAL WSB COST		**106,418,667**	**106,418,667**	**106,418,667**

Table 3.3
Conceptual Design
Post-Panamax Lock Structure (Pacific)
TOTAL WSB COST
(Postponed construction)

Item	Description	%	Total USD - 2002
	WSB		
1	**Civil Works**		**155,669,268**
1.1	Civil works		120,673,851
1.2	Detailed studies and supervision	7%	8,447,170
1.3	Instrumentation	2%	2,413,477
1.4	Grouting and consolidation	3%	3,620,216
1.5	Contingencies	15%	18,101,078
1.6	Administrative costs	2%	2,413,477
2	**Electromechanical equipment**		**23,259,145**
2.1	Electromechanical equipment		19,545,500
2.2	Detailed studies and supervision	7%	1,368,185
2.3	Contingencies	10%	1,954,550
2.4	Administrative costs	2%	390,910
	TOTAL WSB COST		**178,928,413**

Table 3.4
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Summary of the Total Project Cost

Item	Description		Combination 1-B	Combination 2-A	Combination 3-B
			Total USD - 2002	Total USD - 2002	Total USD - 2002
1	Total project cost without WSB		791,000,000	780,000,000	935,000,000
2	Total project cost with WSB		897,000,000	887,000,000	1,042,000,000
3	Cost of WSB´s alone (postponed construction value as to year 2002)		179,000,000	179,000,000	179,000,000

4 Sensitivity Analysis

4.1 GENERAL

The Sensitivity Analysis on the Project Cost has been performed for the two cases as defined in the Terms of References, ie:

- a reduction of 20 feet in the Lock Width,
- a reduction of 5 feet in the water depth over the sills.

Using the same inter-connected spreadsheets which have been prepared to calculate the Total Project Cost in the paragraph 3., the Tables detailing the quantities have been modified for each of the two cases contemplated in the sensitivity analysis

A complete edition of these Tables is given in the Appendices E and F, in which the modified quantities appear in italics.

4.2 REDUCTION OF 20' IN THE LOCK WIDTH

The reduction of 20' in the Lock Width implicates the following changes in the Locks: see the following paragraphs.

Reference is made to the corresponding Tables from appendices A (basic configuration) and E (sensitivity analysis –20').

- Quantities : Tables E18 to E28
- Costs: Table E1 to E17

4.2.1 EXCAVATION AND FILL QUANTITIES

The excavation in Table E18 items 1 is proportionally reduced by a factor of 55/61.

4.2.2 ENTRANCE WALLS

There are no consequences for the quantities.

4.2.3 LOCK WALLS

- The quantities for the conduit under the locks (In Table E21 item10) change by taking out a conduit segment of 6 m in length.

The quantities for chamber layer bottom (in Table E21 item 5) change by taking out a segment of 3 m in length for both the eastern and western lockwall.

4.2.4 WSB´S AND CONDUITS

The quantities concerning the conduit, the RCC and the backfill around it (In Table E22 items 3, 4, and 7, 8) change proportionally by a factor of 55/61.

The same applies to the excavations and backfill. (In Table E22 items 15, 16 and 17)

4.2.5 LOCK HEAD GATES

The quantities for the reinforced concrete, the steel reinforcement, the concrete layer chamber bottom and the lean concrete change by taking out a bottom segment of 6 m width. (In Table E23)

4.2.6 TRANSITION SEGMENT

The same as for the lock head gates.(In Table E24)

4.2.7 EQUIPMENT

The rails USW and LSW and their steel supports, the horizontal elements for seals-lock chamber and the elements for placement habitat (Table E25) are reduced by taking out a segment of 6 m.

4.2.8 ELECTROMECHANICAL EQUIPMENT

The lock gates weights are reduced in a quadratic ratio [factor $(55/61)^2$], because the width is directly related to the length between the supports which is predominant for determining the weight of the rolling gates.

4.2.9 TOTAL PROJECT COSTS

In the configuration with minus 20 feet in the Width of the Lock, the Project Costs are detailed in the following Table E 1:

Table E.1
Conceptual Design
Post-Panamax Lock Structure (Pacific)
TOTAL PROJECT COST
with minus 20 feet in the Width of the Lock

Item	Description	%	Combination 1-B Total USD - 2002	Combination 2-A Total USD - 2002	Combination 3-B Total USD - 2002
	LOCK				
1	**Civil Works**		**461,293,382**	**451,433,014**	**604,807,832**
1.1	Civil works		357,591,769	349,948,073	468,843,281
1.2	Detailed studies and supervision	7%	25,031,424	24,496,365	32,819,030
1.3	Instrumentation	2%	7,151,835	6,998,961	9,376,866
1.4	Grouting and consolidation	3%	10,727,753	10,498,442	14,065,298
1.5	Contingencies	15%	53,638,765	52,492,211	70,326,492
1.6	Administrative costs	2%	7,151,835	6,998,961	9,376,866
2	**Electromechanical equipment**		**270,671,476**	**270,671,476**	**270,671,476**
2.1	Electromechanical equipment		213,824,454	213,824,454	213,824,454
2.1.1	*EM equipment Lock Head 1*		*23,093,193*	*23,093,193*	*23,093,193*
2.1.2	*EM equipment Lock Head 2*		*162,203,761*	*162,203,761*	*162,203,761*
2.1.3	*EM other equipment and system*		*28,527,500*	*28,527,500*	*28,527,500*
2.2	Detailed studies and supervision	7%	14,967,712	14,967,712	14,967,712
2.3	Contingencies		37,602,822	37,602,822	37,602,822
2.3.1	*Lock Head 1*	*10%*	*2,309,319*	*2,309,319*	*2,309,319*
2.3.2	*Lock Head 2*	*20%*	*32,440,752*	*32,440,752*	*32,440,752*
2.3.3	*Other equipment and system*	*10%*	*2,852,750*	*2,852,750*	*2,852,750*
2.4	Administrative costs	2%	4,276,489	4,276,489	4,276,489
	TOTAL LOCK COST		**731,964,858**	**722,104,491**	**875,479,308**
	WSB				
1	**Civil Works**		**84,829,947**	**84,829,947**	**84,829,947**
1.1	Civil works		65,759,649	65,759,649	65,759,649
1.2	Detailed studies and supervision	7%	4,603,175	4,603,175	4,603,175
1.3	Instrumentation	2%	1,315,193	1,315,193	1,315,193
1.4	Grouting and consolidation	3%	1,972,789	1,972,789	1,972,789
1.5	Contingencies	15%	9,863,947	9,863,947	9,863,947
1.6	Administrative costs	2%	1,315,193	1,315,193	1,315,193
2	**Electromechanical equipment**		**17,888,675**	**17,888,675**	**17,888,675**
2.1	Electromechanical equipment		15,032,500	15,032,500	15,032,500
2.2	Detailed studies and supervision	7%	1,052,275	1,052,275	1,052,275
2.3	Contingencies	10%	1,503,250	1,503,250	1,503,250
2.4	Administrative costs	2%	300,650	300,650	300,650
	TOTAL WSB COST		**102,718,622**	**102,718,622**	**102,718,622**
	Summary				
	Total project cost without WSB		**732,000,000**	**722,000,000**	**875,000,000**
	Total project cost with WSB		**835,000,000**	**825,000,000**	**978,000,000**

The reduction of 20' in the width of the Lock generates therefore a reduction in the Project Cost of 7.46% for Combination 1-B, 7.44% for Combination 2-A and 6.42% for Combination 3-B

without the WSB´s and 6.91% for Combination 1-B, 6.99% for Combination 2-A and 6.14% for Combination 3-B with the WSB´s.

4.3 REDUCTION OF 5' IN THE WATER DEPTH OVER THE SILLS

The reduction of 5' in the water depth over the sills implicates the following changes in the Locks: see the following paragraphs.

Reference is made to the corresponding Tables from appendices A (basic configuration) and F (sensitivity analysis –5').

- Quantities : Tables F18 to F28
- Costs: Table F1 to F17

4.3.1 EXCAVATION AND FILL QUANTITIES

The excavations in Table F18, items 1, 2 and 3 are changed by taking out a horizontal segment 1.52m in height.

4.3.2 ENTRANCE WALLS

The reinforced concrete, the steel reinforcement, the backfill with crushed stone and the RCC (Table F19 and F20) are changed by taking out a horizontal segment of 1.52 m in height.

4.3.3 LOCK WALLS

The reinforced concrete, the steel reinforcement, the backfill with crushed stone, the rubber joint and the RCC (Table F21) are changed by taking out an horizontal segment of 1.52 m in height.

4.3.4 WSB AND CONDUITS

The reinforced concrete for intakes WSB, its steel reinforcement, the RCC and the backfill with crushed stone (in Table F22) are reduced by taking out a horizontal segment of 1.52 m height.

4.3.5 LOCK HEAD GATES

The quantities for the reinforced concrete, the steel reinforcement and the backfill crushed stone (in Table F23) are changed by taking out a horizontal segment of 1.52 m height.

4.3.6 TRANSITION SEGMENT

The same method as for the lockhead gates applies. (in Table F24)

4.3.7 EQUIPMENT

The wooden vertical guides and the vertical elements for seals are reduced by taking out a horizontal segment 1.52 m height. (in Table F25)

4.3.8 ELECTROMECHANICAL EQUIPMENT

The weights of the lock rolling gates are proportionally reduced (with ratios of 21.175/22.7 for Lock Gates S1, and 50.415/51.94 for Lock Gates S2), because the changes affects the height of the gate only, and not the span which is predominant for the calculation of weight of the rolling gate.

4.3.9 TOTAL PROJECT COSTS

In the configuration with minus 5 feet in the Water Depth over the sills the Project Costs are detailed in the following Table F 1

Table F.1
Conceptual Design
Post-Panamax Lock Structure (Pacific)
TOTAL PROJECT COST
with minus 5 feet in the Water Depth over the sills

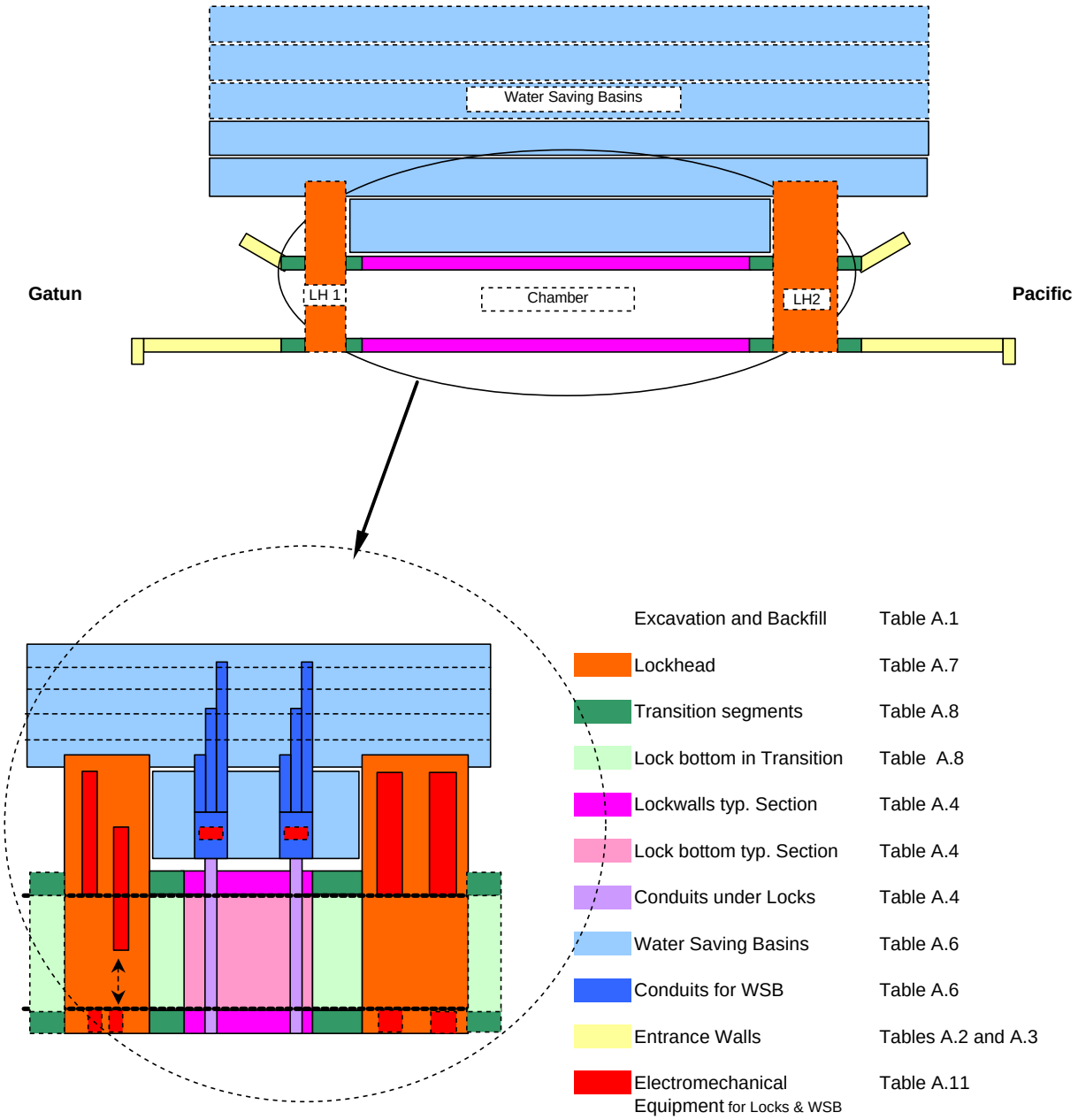
Item	Description	%	Combination 1-B Total USD - 2002	Combination 2-A Total USD - 2002	Combination 3-B Total USD - 2002
	LOCK				
1	**Civil Works**		**468,071,422**	**457,857,676**	**612,960,683**
1.1	Civil works		362,846,063	354,928,431	475,163,320
1.2	Detailed studies and supervision	7%	25,399,224	24,844,990	33,261,432
1.3	Instrumentation	2%	7,256,921	7,098,569	9,503,266
1.4	Grouting and consolidation	3%	10,885,382	10,647,853	14,254,900
1.5	Contingencies	15%	54,426,910	53,239,265	71,274,498
1.6	Administrative costs	2%	7,256,921	7,098,569	9,503,266
2	**Electromechanical equipment**		**305,026,668**	**305,026,668**	**305,026,668**
2.1	Electromechanical equipment		240,690,864	240,690,864	240,690,864
2.1.1	*EM equipment Lock Head 1*		*26,117,963*	*26,117,963*	*26,117,963*
2.1.2	*EM equipment Lock Head 2*		*186,045,401*	*186,045,401*	*186,045,401*
2.1.3	*EM other equipment and system*		*28,527,500*	*28,527,500*	*28,527,500*
2.2	Detailed studies and supervision	7%	16,848,360	16,848,360	16,848,360
2.3	Contingencies		42,673,627	42,673,627	42,673,627
2.3.1	*Lock Head 1*	*10%*	*2,611,796*	*2,611,796*	*2,611,796*
2.3.2	*Lock Head 2*	*20%*	*37,209,080*	*37,209,080*	*37,209,080*
2.3.3	*Other equipment and system*	*10%*	*2,852,750*	*2,852,750*	*2,852,750*
2.4	Administrative costs	2%	4,813,817	4,813,817	4,813,817
	TOTAL LOCK COST		**773,098,090**	**762,884,344**	**917,987,351**
	WSB				
1	**Civil Works**		**87,885,777**	**87,885,777**	**87,885,777**
1.1	Civil works		68,128,509	68,128,509	68,128,509
1.2	Detailed studies and supervision	7%	4,768,996	4,768,996	4,768,996
1.3	Instrumentation	2%	1,362,570	1,362,570	1,362,570
1.4	Grouting and consolidation	3%	2,043,855	2,043,855	2,043,855
1.5	Contingencies	15%	10,219,276	10,219,276	10,219,276
1.6	Administrative costs	2%	1,362,570	1,362,570	1,362,570
2	**Electromechanical equipment**		**17,888,675**	**17,888,675**	**17,888,675**
2.1	Electromechanical equipment		15,032,500	15,032,500	15,032,500
2.2	Detailed studies and supervision	7%	1,052,275	1,052,275	1,052,275
2.3	Contingencies	10%	1,503,250	1,503,250	1,503,250
2.4	Administrative costs	2%	300,650	300,650	300,650
	TOTAL WSB COST		**105,774,452**	**105,774,452**	**105,774,452**
	Summary				
	Total project cost without WSB		**773,000,000**	**763,000,000**	**918,000,000**
	Total project cost with WSB		**879,000,000**	**869,000,000**	**1,024,000,000**

The reduction of 5' in the water depth over the sills generates therefore a reduction in the Project Cost of 2.28% for Combination 1-B, 2.18% for Combination 2-A and 1.85% for Combination 3-B without the WSB´s and 2.01% for Combination 1-B, 2.03% for Combination 2-A and 1.73% for Combination 3-B with the WSB´s.

APPENDIX A

QUANTITIES

Table A.0
Quantities-General information
Key Plan



Excavation and Backfill	Table A.1
Lockhead	Table A.7
Transition segments	Table A.8
Lock bottom in Transition	Table A.8
Lockwalls typ. Section	Table A.4
Lock bottom typ. Section	Table A.4
Conduits under Locks	Table A.4
Water Saving Basins	Table A.6
Conduits for WSB	Table A.6
Entrance Walls	Tables A.2 and A.3
Electromechanical Equipment for Locks & WSB	Table A.11
Accessories	Table A.10
Summary for CW of Locks	Table A.12

TASK 4 - CONFIGURATION 2

Useful Information

1- The Excavation and Fill volumes presented in the Table A.1 are computed for the Total Lock (without the WSB) from the extreme end of the Gatun entrance Wall to the extreme end of the Pacific entrance wall.

2- An Overhaul quantity has been computed for all the material excavated which cannot be re-used in the Locks backfill and in the Lock concrete material. It has been assumed that the spoil will be transported at 10 km outside the Project Area

3- Excavation and Backfill volumes for the WSB are computed separately in the Table A.6.

4- Entrance wall quantities are computed for one typical segment of 30 m and for both the Options A and B The quantities shown in the Table A.2 and A.3 are for one segment , the number of segments is indicated at the bottom of the end of the Tables (there are 23 segments on each side: Pacific and Gatun).

5- Same comment 4- applies for the Lockwall typical sections. The Chamber has 2x10 typical segments of 30 m.

6- To each lockwall segment or lockwall transition element is associated the corresponding quantities for one half of the lock bottom treatment, whatever it is made of concrete slabs (in front of culvert intakes and outlets) or concrete levelling layer (in Basalt).

7- To each structure, Lockhead, lockwall, transition, entrance wall is associated a quantity of Backfill and /or RCC. The corresponding quantities appears in the different Tables. The Table A.12 sums up the quantities for each type of work.

8- The part of WSB conduits which is located below the locks chambers is to be constructed together with the Lock. The corresponding quantities appear with the Table A.4 related to Lockwall. To be noted that the quantities 10. from Table A.4 shall not be multiplied by the number of segments.

9- A systematic temporary protection of La Boca formation with a 5 cm Shotcrete has been considered The total area amounts to 57263 m² asociated with the entrance walls.

10- The ladders are quantified in number of pieces but are evaluated per meter length. The height of each ladder is 50 m.

11- There is no Table A.5 is in this report because it does not apply to Configuration 2.

Table A.1
Excavation and Fill Quantities

Item	Description	Unit	Combination 1-B		Combination 2-A		Combination 3-B	
			Excavation	Backfill	Excavation	Backfill	Excavation	Backfill
1	Lock from edge east wall Gatun side up to edge east wall Pacific side	m³	5.067.908		5.067.908		5.352.908	
2	Entrance wall Pacific side	m³	314.940	341.865	314.940	129.105	657.940	442.962
3	Entrance wall Gatun side	m³	200.000	280.643	200.000	108.675	480.000	399.555
4	Lock walls [1]	m³		660.720		148.190		501.970
5	Lock head gate [1]	m³		852.296		852.296		852.296
6	Transition segment [1]	m³		114.296		114.296		171.444
7	Overhaul for spoil (10 km) Combination 1-B	m³km	16.835.226					
8	Overhaul for spoil (10 km) Combination 2-A	m³km			20.658.561			
9	Overhaul for spoil (10 km) Combination 3-B	m³km					19.234.752	
	Total Volume Excavation / Backfill	m³	5.582.848	2.249.819	5.582.848	1.352.562	6.490.848	2.368.227

[1] Excavation include in item 1
[2] For WSB`s Excavation and Backfill quantities, see Table A6

TASK 4 - CONFIGURATION 2

Table A.2
Entrance Walls
Option A : RCC + RC
Quantities Summary

Item	Description	Unit	Combination 2-A	
			Pacific Side	Gatun Side
			Quantity	Quantity
1	Reinforced Concrete	m³	4.266	4.127
1.1	Footing	m³	1.920	1.920
1,2	Front Wall	m³	1.581	1.442
1,3	Top Structure	m³	765	765
2	Steel Reinforcement BE500	tons	213	206
3	Backfill Crushed Stone	m³	5.738	4.830
4	Steel Corner Protection	m	30	30
5	Rubber Joint	m	42	40
6	Lean Concrete	m²	450	450
7	RCC	m³	9.945	8.912
8	Pavement	m²	600	600
9	Shotcrete (Temporary protection in La Boca)	m²	1.660	885
	Quantities for one 30 m-segment:			
	Number of segments of 30 m:		22,5	22,5

TASK 4 - CONFIGURATION 2

Table A.3
Entrance Walls
Option B : RC
Quantities Summary

Item	Description	Unit	Combination 1-B		Combination 3-B	
			Pacific Side	Gatun Side	Pacific Side	Gatun Side
			Quantity	Quantity	Quantity	Quantity
1	Reinforced Concrete	m³	5.998	5.739	12.641	12.062
1.1	Footing	m³	1.920	1.920	4.320	4.320
1,2	Front Wall	m³	1.581	1.442	2.682	2.400
1,3	Top Structure	m³	1.335	1.335	2.610	2.610
1,4	Buttresses	m³	1.162	1.042	3.029	2.732
2	Steel Reinforcement BE500	tons	450	430	908	905
3	Backfill Crushed Stone	m³	15.194	12.473	19.687	17.758
4	Steel Corner Protection	m	30	30	60	60
5	Rubber Joint	m	42	40	92	88
6	Lean Concrete	m²	450	450	1.080	1.080
7	Pavement	m²	600	600	0	0
8	Shotcrete (Temporary protection in La Boca)	m²	1.660	885	1.660	885
	Quantities for one 30 m-segment:					
	Number of segments of 30 m:		22,5	22,5	22,5	22,5

TASK 4 - CONFIGURATION 2

Table A.4
Lock Walls
Quantities Summary

Item	Description	Unit	Eastern Lock Wall	Western Lock Wall		
				Combination 1-B	Combination 2-A	Combination 3-B
			Quantity	Quantity	Quantity	Quantity
1	Reinforced Concrete	m³	19.541	16.225	12.665	24.716
1.1	Bottom Part with Culvert	m³	2.517	2.517	2.742	5.483
1.2	Toe	m³	6.729	6.729	5.850	6.750
1.3	Front Wall	m³	3.311	2.207	2.117	4.235
1.4	Top Structure	m³	1.911	1.575	1.956	4.710
1.5	Counterforts	m³	5.073	3.197	0	3.538
2	Steel Reinforcement BE500	tons	1.466	1.217	633	1.854
3	Backfill Crushed Stone	m³	14.819	51.253	0	35.378
4	RCC	m³	0	0	33.896	0
5	Concrete Layer Chamber Bottom	m³	248	248	188	368
6	Steel Corner Protection	m	30	30	30	60
7	Rubber joint	m	92	92	92	184
8	Pavement	m²	0	450	0	0
9	Lean Concrete	m²	1.280	1.280	1.003	1.500
	Quantities for one 30 m-segment:					
	Number of segments of 30 m:		10	10	10	10
10	Conduits under lock		Lock			
10.1	Reinforced Concrete (for all chamber)	m³	11.524			
10.2	Steel Reinforcement BE500 (for all chamber)	tons	864			

TASK 4 - CONFIGURATION 2

Table A.6
WSB and Conduits (Civil Works)
Quantities Summary

Item	Description	Unit	Quantity
1	Reinforced concrete for valve chambers and valve connection	m³	59.069
2	Steel reinforcement BE500	tons	4.430
3	Reinforced concrete for conduits	m³	59.253
4	Steel reinforcement BE500	tons	4.444
5	Reinforced concrete for intakes WSB	m³	96.739
6	Steel reinforcement BE500	tons	7.255
7	Roller compacted concrete	m³	85.566
8	Backfill Crushed Stone	m³	497.340
9	Reinforced concrete for walls between WSB	m³	24.960
10	Steel reinforcement BE500	tons	2.496
11	Liner HDPE (WSB1)	m²	0
12	Underlaying protective geotextile (WSB1)	m²	0
13	Geotextile for drainage (WSB1)	m²	0
14	Bank protection WSB1	m²	0
15	Excavations		
15,1	WSB 1 to 6	m³	1.906.491
15,2	Extra conduits	m³	647.500
16	Backfill WSB 1 to 6	m³	197.556
17	Overhaul for spoil (10 km)	m³km	16.694.783
18	Technical building	m²	506

Quantities Summary

Item	Description	Unit	Quantity
1	Reinforced concrete	m³	240.021
2	Steel reinforcement BE500	tons	18.625
3	Roller compacted concrete	m³	85.566
4	Backfill Crushed Stone	m³	497.340
5	Liner HDPE (WSB1)	m²	0
6	Underlaying protective geotextile (WSB1)	m²	0
7	Geotextile for drainage (WSB1)	m²	0
8	Bank protection WSB1	m²	0
9	Excavations	m³	2.553.991
10	Backfill WSB 1 to 6	m³	197.556
11	Overhaul for spoil (10 km)	m³km	16.694.783
12	Technical building	m²	506

TASK 4 - CONFIGURATION 2

Table A.7
Lock Head Gate
Quantities Summary

Item	Description	Unit	Combinations 1-B / 2-A	Combination 3-B
			Quantity	Quantity
1	**Lock Head Gate 1**			
1,1	Reinforced Concrete	m³	188.134	202.244
1,2	Steel Reinforcement BE500	ton	14.110	15.168
1,3	Backfill crushed stone	m³	137.084	137.084
1,4	Backfill RCC	m³	22.086	22.086
1,5	Concrete layer chamber bottom	m³	1.861	1.861
1,6	Steel corner protection	m	428	428
1,7	Rubber joint	m	324	324
1,8	Lean concrete	m²	8.078	8.078
1,9	Pavement	m²	10.500	10.500
2	**Lock Head Gate 2**			
2,1	Reinforced Concrete	m³	447.626	481.198
2,2	Steel Reinforcement BE500	ton	33.572	36.090
2,3	Backfill crushed stone	m³	465.212	465.212
2,4	Backfill RCC	m³	171.753	171.753
2,5	Concrete layer chamber bottom	m³	2.913	2.913
2,6	Steel corner protection	m	540	540
2,7	Rubber joint	m	368	368
2,8	Lean concrete	m²	14.302	14.302
2,9	Pavement	m²	15.730	15.730
3	**Concrete L-shaped walls behind lock heads 1 and 2**			
3,1	Reinforced Concrete	m³	55.000	55.000
3,2	Steel Reinforcement BE500	ton	4.125	4.125
3,3	Backfill crushed stone	m³	250.000	250.000
4	**Operation and maintenance buildings**			
4,1	Technical building	m²	3.654	3.654

TASK 4 - CONFIGURATION 2

Table A.8
Transition Segment
Quantities Summary

Item	Description	Unit	Combinations 1-B / 2-A Quantity	Combination 3-B Quantity
1	**Lock Head Gate 1**			
1,1	Transition segment side Gatún			
1,11	Reinforced concrete	m³	37.135	55.702
1,12	Steel reinforcement BE500	ton	2.785	4.178
1,13	Backfill crushed stone	m³	22.846	34.270
1,14	Backfill RCC	m³	18.164	27.245
1,15	Concrete slabs	m³	4.284	4.284
1,16	Gravel layer	m³	1.428	1.428
1,17	Steel corner protection	m	112	168
1,18	Rubber joint	m	368	552
1,19	Lean concrete	m²	4.032	6.048
1,20	Pavement	m²	3.360	3.360
1,2	Transition segment side lock chamber			
1,21	Reinforced concrete	m³	95.738	143.607
1,22	Steel reinforcement BE500	ton	7.180	10.771
1,23	Backfill crushed stone	m³	21.558	32.337
1,24	Backfill RCC	m³	129.816	194.723
1,25	Concrete layer chamber bottom	m³	2.135	2.135
1,26	Steel corner protection	m	150	225
1,27	Rubber joint	m	380	570
1,28	Lean concrete	m²	6.160	9.240
1,29	Pavement	m²	4.200	4.200

TASK 4 - CONFIGURATION 2

Table A.8
Transition Segment
Quantities Summary

Item	Description	Unit	Combinations 1-B / 2-A Quantity	Combination 3-B Quantity
2	**Lock Head Gate 2**			
2,1	Transition segment side Pacific			
2,11	Reinforced concrete	m³	61.348	92.022
2,12	Steel reinforcement BE500	ton	4.601	6.902
2,13	Backfill crushed stone	m³	46.086	69.129
2,14	Backfill RCC	m³	39.809	59.713
2,15	Concrete slabs	m³	2.436	2.436
2,16	Gravel layer	m³	812	812
2,17	Steel corner protection	m	112	168
2,18	Rubber joint	m	380	570
2,19	Lean concrete	m²	5.040	7.560
2,20	Pavement	m²	3.360	3.360
2,2	Transition segment side lock chamber			
2,21	Reinforced concrete	m³	65.714	98.571
2,22	Steel reinforcement BE500	ton	4.929	7.393
2,23	Backfill crushed stone	m³	23.806	35.709
2,24	Backfill RCC	m³	92.725	139.088
2,25	Concrete layer chamber bottom	m³	1.525	1.525
2,26	Steel corner protection	m	110	165
2,27	Rubber joint	m	380	570
2,28	Lean concrete	m²	4.400	6.600
2,29	Pavement	m²	3.000	3.000

TASK 4 - CONFIGURATION 2

Table A.9

Lock Head Gate

Quantities Summary
Equipment (Civil Part)

Item	Description	Unit	Quantity
1	**Lock Head Gate 1**		
1,1	Equipment lock gate (civil part)		
1.1.1	Rails USW	m	320
1.1.2	Rails LSW	m	320
1.1.3	Rails MSW	m	340
1.1.4	Rails horizontale guidances in recesses	m	320
1.1.5	Wooden vertical guidance in recesses	m	148
1.1.6	Steel for support rails USW	tons	128
1.1.7	Steel for support rails LSW	tons	128
1.1.8	Steel for support rails guidance	tons	48
1.1.9	Maintenance support frames	tons	60
1,2	Equipment lock head (civil part)		
1.2.1	Vertical elements for seals - east/recesses	m^3	147
1.2.2	Vertical elements for seals - west	m^3	193
1.2.3	Horizontal elements for seals- lock chamber	m^3	247
1.2.4	Elements for placement habitat	m^3	258
1.2.5	Horizontal elements for seals- gate recesses	m^3	44
1.2.6	Bridges over recesses	pcs	2

TASK 4 - CONFIGURATION 2

Table A.9

Lock Head Gate

Quantities Summary
Equipment (Civil Part)

Item	Description	Unit	Quantity
2	**Lock Head Gate 2**		
2,1	Equipment lock gate (civil part)		
2.1.1	Rails USW	m	0
2.1.2	Rails LSW	m	560
2.1.3	Rails MSW	m	2.024
2.1.4	Rails horizontal guides in recesses	m	680
2.1.5	Wooden vertical guidance in recesses	m	360
2.1.6	Steel for support rails USW	tons	0
2.1.7	Steel for support rails LSW	tons	336
2.1.8	Steel for support rails guidance	tons	170
2.1.9	Maintenance support frames	tons	0
2,2	Equipment lock head (civil part)		
2.2.1	Vertical elements for seals - east/recesses	m^3	454
2.2.2	Vertical elements for seals - west	m^3	497
2.2.3	Horizontal elements for seals- lock chamber	m^3	65
2.2.4	Elements for placement habitat	m^3	258
2.2.5	Horizontal elements for seals- gate recesses	m^3	50
2.2.6	Bridges over recesses	pcs	2

TASK 4 - CONFIGURATION 2

Table A.10
ACCESSORIES
Quantities Summary

Item	Description	Unit	Quantity
1	**Accessories**		
1,1	Bollards 1500kN	pcs	36
1,2	Fenders	pcs	2
1,3	Ladders	pcs	36
1,4	Mooring Bits	pcs	72

TASK 4 - CONFIGURATION 2

Table A.11
ELECTROMECHANICAL EQUIPMENT
Quantities Summary

Item	Description	Unit	Quantity (pcs)	Unit Weight (t)	Total Weight (t)
1	**EM Equipment Lock**				
1,1	Lock gates				
1.1.1	Lock head 1			*Total 1.1.1:*	**4.491**
	Lock gates (2)	tons	2	2.000	4.000
	Fixed ballast for gate stability (2)	tons	0	0	0
	Bulkheads (1)	tons	1	250	250
	Upper support wagon (2)	tons	2	50	100
	Lower support wagon (3)	tons	3	35	105
	Maintenance suport wagons (12)	tons	12	3	36
1.1.2	Lock head 2			*Total 1.1.2:*	**43.707**
	Lock gates (2)	tons	2	11.500	23.000
	Fixed ballast for gate stability (2)	tons	2	7.000	14.000
	Bulkheads (1)	tons	1	2.000	2.000
	Upper support wagon (2)	tons	2	0	0
	Lower support wagon (5)	tons	5	900	4.500
	Maintenance suport wagons (46)	tons	46	4,5	207
1,2	Culvert valves and bulkheads			*Total 1.2:*	**766**
1.2.1	Culvert valves (incl. 1 spare)	tons	9	28	248
1.2.2	Culvert bulkheads	tons	8	24	192
1.2.3	Culvert valves slot	tons	8	17	133
1.2.4	Culvert bulkhead slots	tons	16	12	193
1,3	Miscellaneous (culverts)	tons	0	0	0
1,4	Support equipment		1		
1,5	Control system		1		
1,6	Lighting System		1		
1,7	Electrical and Power System		1		
2	**EM Equipment WSB**			*Total 2.:*	**3.007**
2,1	WSB upper valves (incl. 1 spare)	tons	13	40	520
2,2	WSB lower valves (incl. 1 spare)	tons	13	49	631
2,3	WSB bulkheads	tons	4	131	524
2,4	WSB upper valves slots	tons	12		288
2,5	WSB lower valves slots	tons	12		333
2,6	WSB bulkheads slots	tons	24		536
2,7	Miscellaneous	tons	1		175

TASK 4 - CONFIGURATION 2

Table A.12

Conceptual Design

Post-Panamax Lock Structure (Pacific)

Quantities Summary (Lock)

Item	Description	Unit	Combination 1-B	Combination 2-A	Combination 3-B
1	**Excavation**				
1,1	Overburden	m³	1.116.570	1.116.570	1.298.170
1,2	Weathered	m³	279.142	279.142	324.542
1,3	Rock	m³	4.187.136	4.187.136	4.868.136
1,4	Overhaul for spoil (10 km)	m³km	16.835.226	20.658.561	19.234.752
2	**Fill**				
2,1	Backfill	m³	2.249.819	1.352.562	2.368.227
2,2	Gravel layer	m³	2.240	2.240	2.240
2,3	Bank protection WSB	m²	0	0	0
3	**Concrete**				
3,1	RC	m³	1.583.961	1.473.121	2.138.251
3,2	RCC	m³	474.352	1.237.595	614.609
3,3	Concrete slab	m³	6.720	6.720	6.720
3,4	Lean Concrete	m²	87.862	85.092	128.228
3,5	Pavement	m²	71.650	67.150	40.150
3,6	Concrete layer chamber bottom	m³	20.113	19.513	21.313
3,7	Shotcrete (Temporary protection in La Boca)	m²	57.263	57.263	57.263
4	**Reinforcement**				
4,1	Steel reinforcement	tons	118.796	102.584	159.474
5	**Other**				
5,1	Steel corner protection	m	3.402	3.402	5.294
5,2	Rubber joint	m	5.885	5.885	9.764
5,3	Geotextile	m²	0	0	0
5,4	Liner HDPE (WSB)	m²	0	0	0
5,5	Underlaying protective geotextile (WSB)	m²	0	0	0
5,6	Geotextile for drainage (WSB)	m²	0	0	0
5,7	Rails	m	4.004	4.004	4.004
5,8	Rails LSW	m	560	560	560
5,9	Wooden vertical guidances	m	508	508	508
5,10	Steel for support rail and frames	ton	870	870	870
5,11	Vertical element for seals east/recesses	m³	601	601	601
5,12	Vertical element for seals west	m³	690	690	690
5,13	Horizontal elements for seals lock chamber	m³	312	312	312
5,14	Elements for placement habitat	m³	516	516	516

TASK 4 - CONFIGURATION 2

Table A.12
Conceptual Design
Post-Panamax Lock Structure (Pacific)

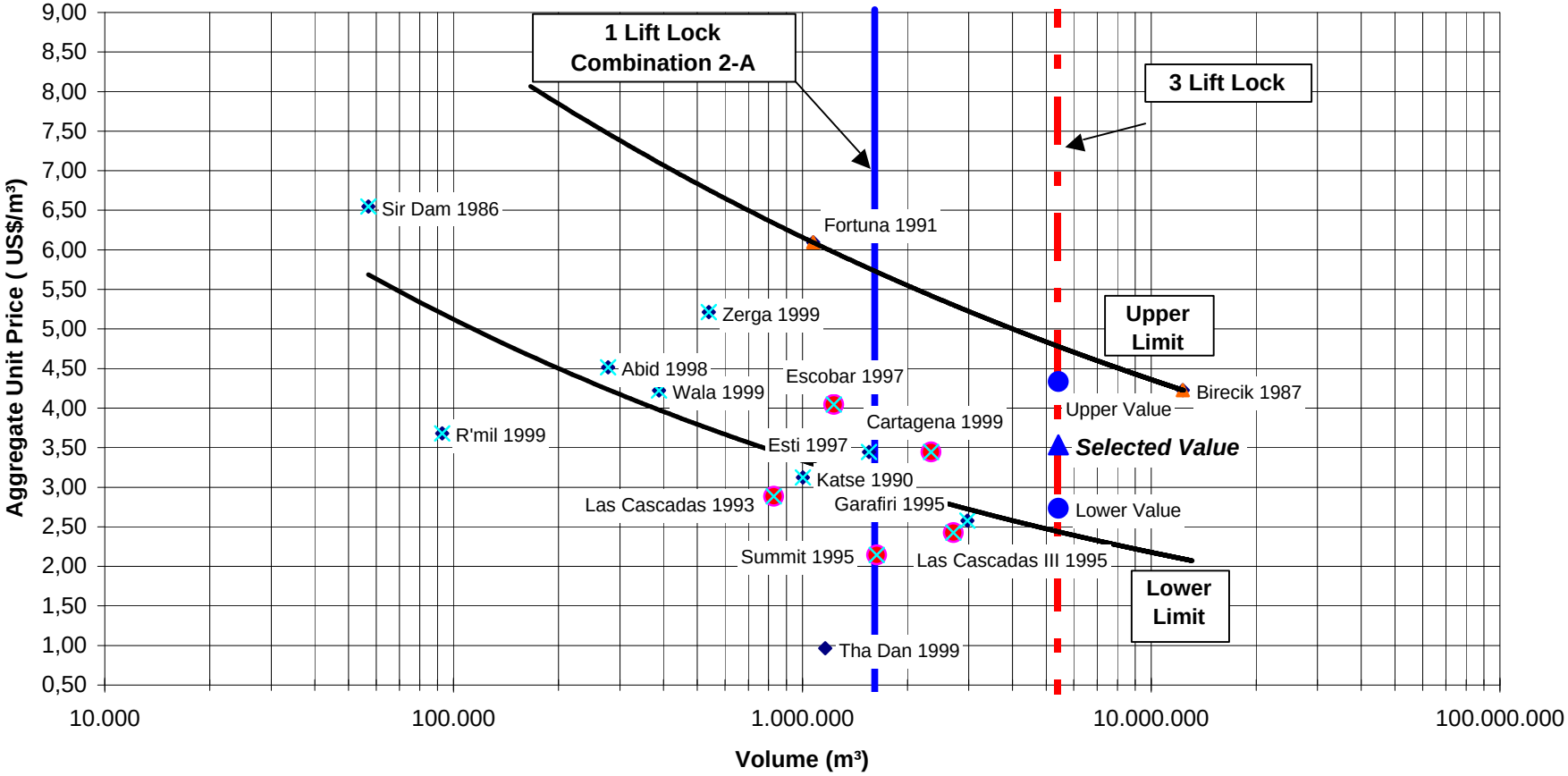
Quantities Summary (Lock)

Item	Description	Unit	Combination 1-B	Combination 2-A	Combination 3-B
5,15	Horizontal elements for seals gate recesses	m³	94	94	94
5.16.1	Bridge over recesses LHG 1	pcs	2	2	2
5.16.2	Bridge over recesses LHG 2	pcs	2	2	2
5,17	Technical building	m²	3.654	3.654	3.654
6	**Accessories**				
6,1	Bollards 1500kN	pcs	36	36	36
6,2	Fenders	pcs	2	2	2
6,3	Ladders	m	1.800	1.800	1.800
6,4	Mooring bits	pcs	72	72	72

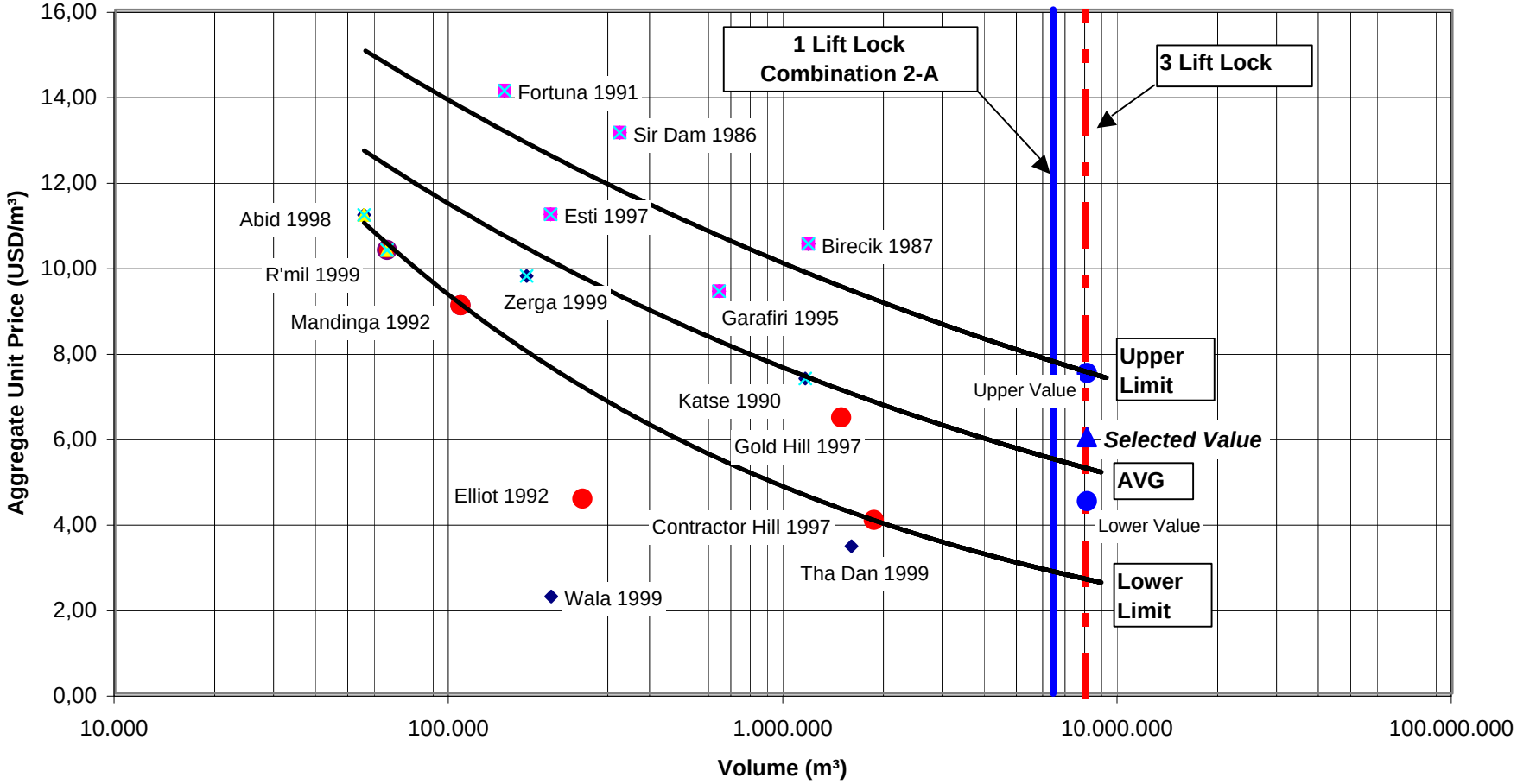
APPENDIX B

TREND GRAPHS
OF
AGGREGATE UNIT PRICES

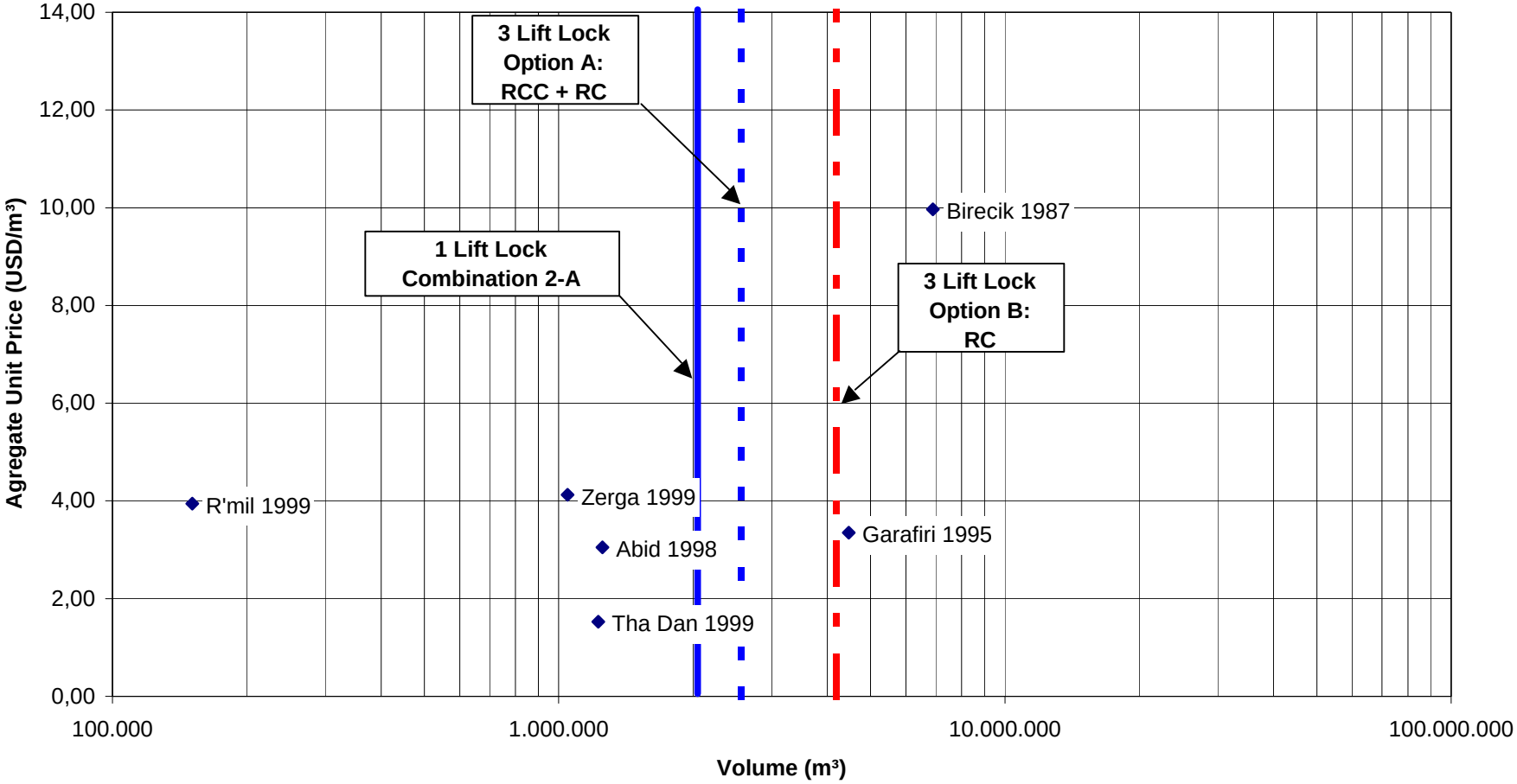
Graph B.1
Conceptual Design
Post-Panamax Lock Structures (Pacific)
Overburden Excavation Aggregate Unit Prices



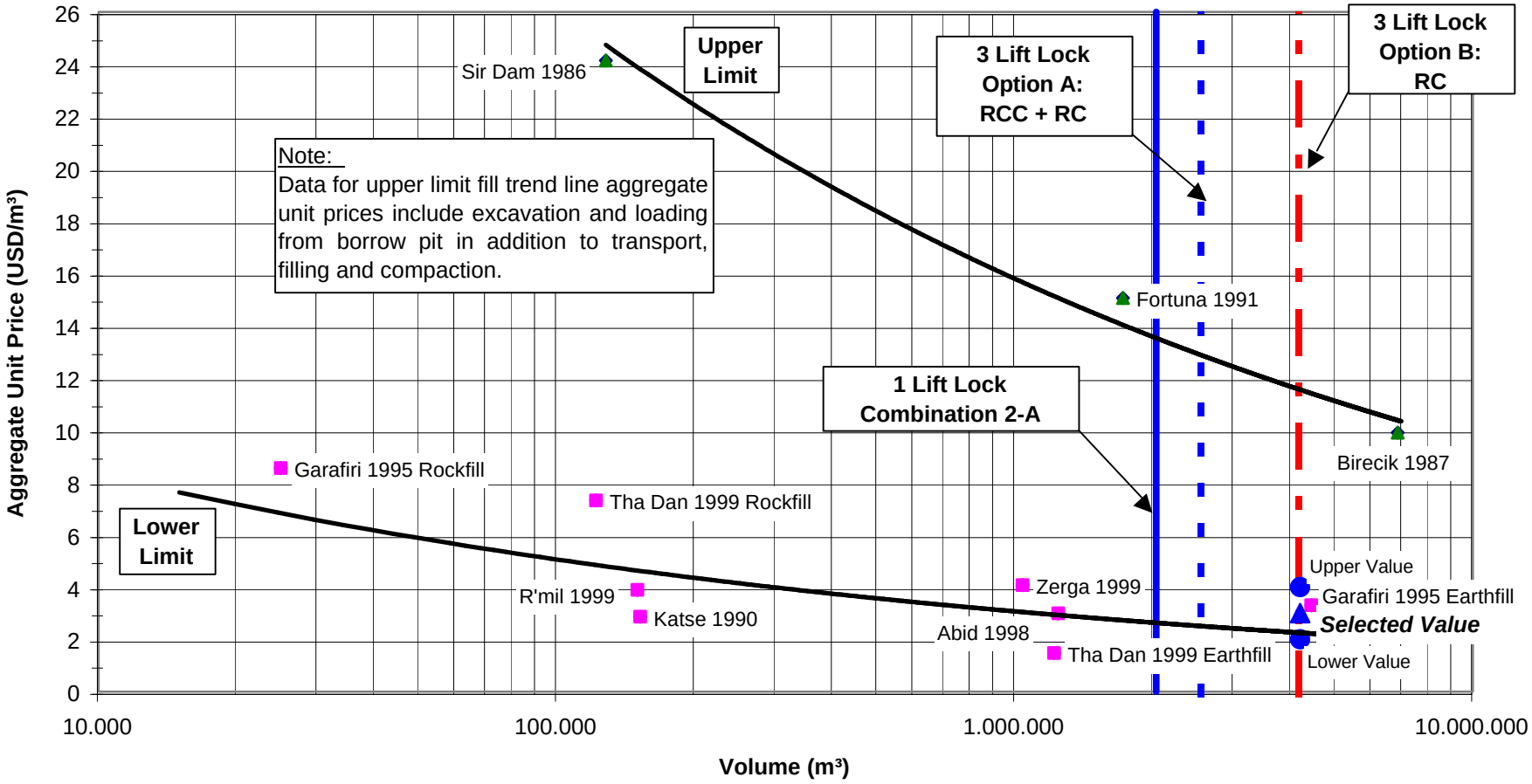
Graph B.2
Conceptual Design
Post-Panamax Lock Structures (Pacific)
Rock Excavation Aggregate Unit Prices



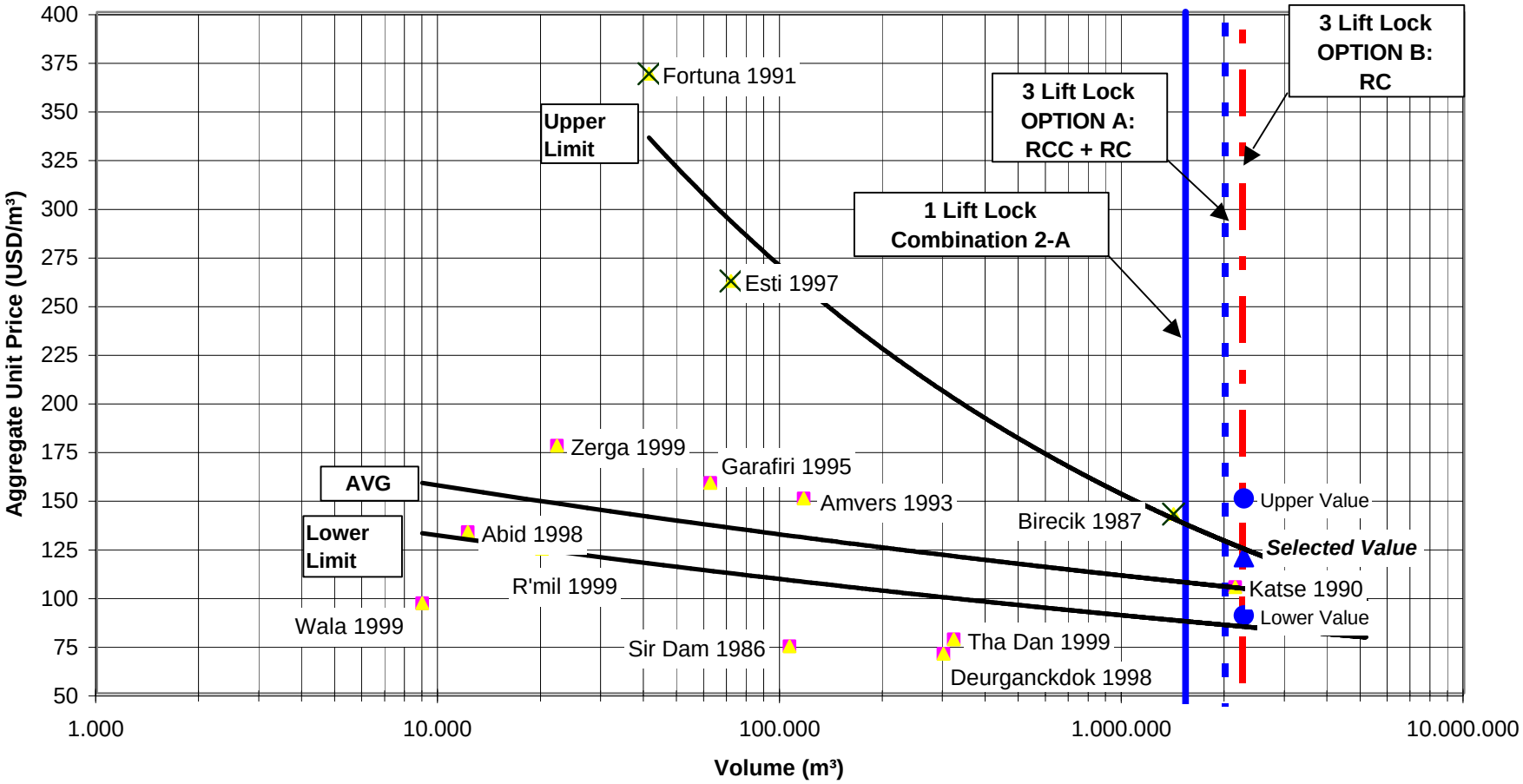
Graph B.3
Conceptual Design
Post - Panamax Lock Structure (Pacific)
Earthfill Agregate Unit Price



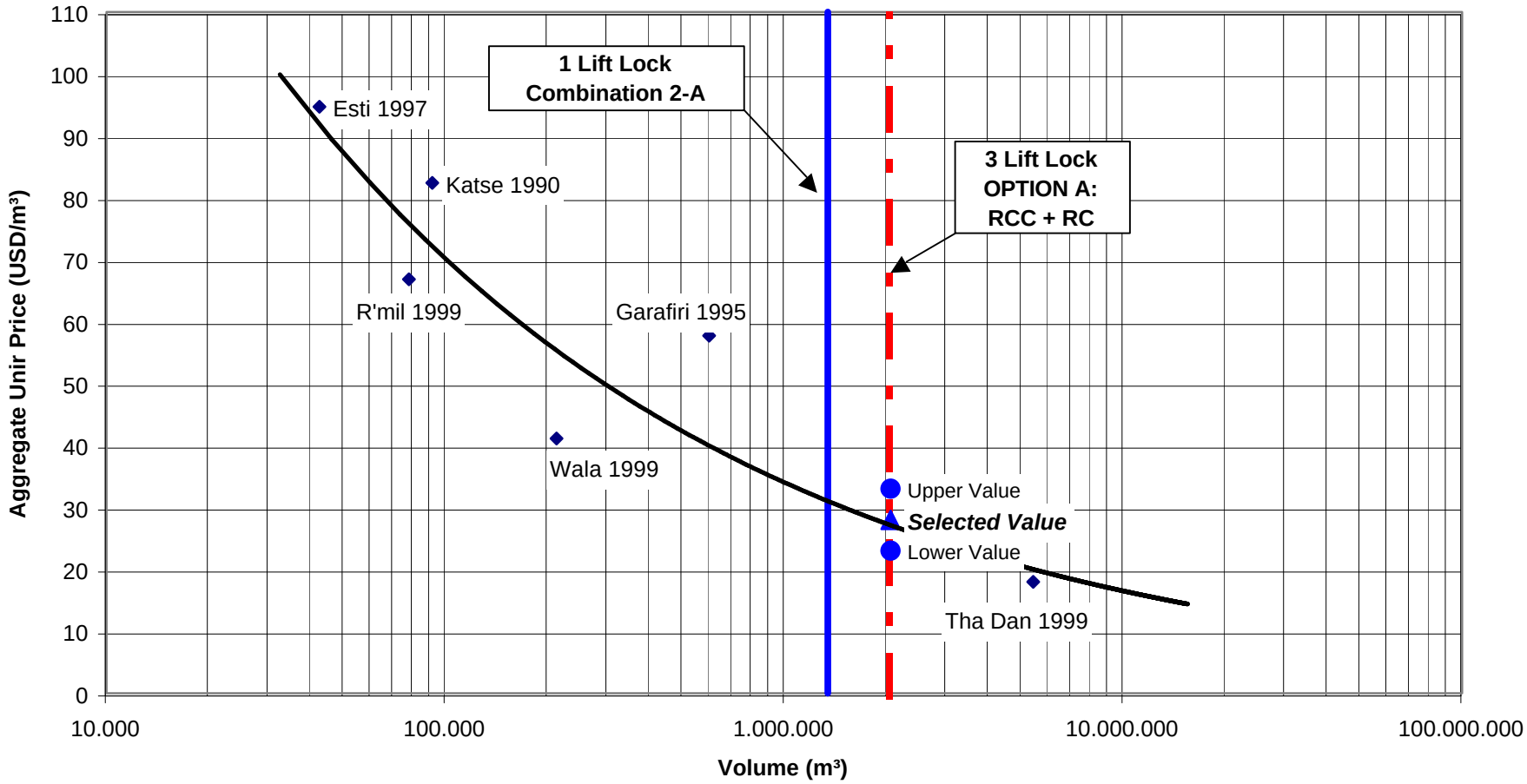
Graph B.4
Conceptual Design
Post-Panamax Lock Structures (Pacific)
Fill Aggregate Unit Price



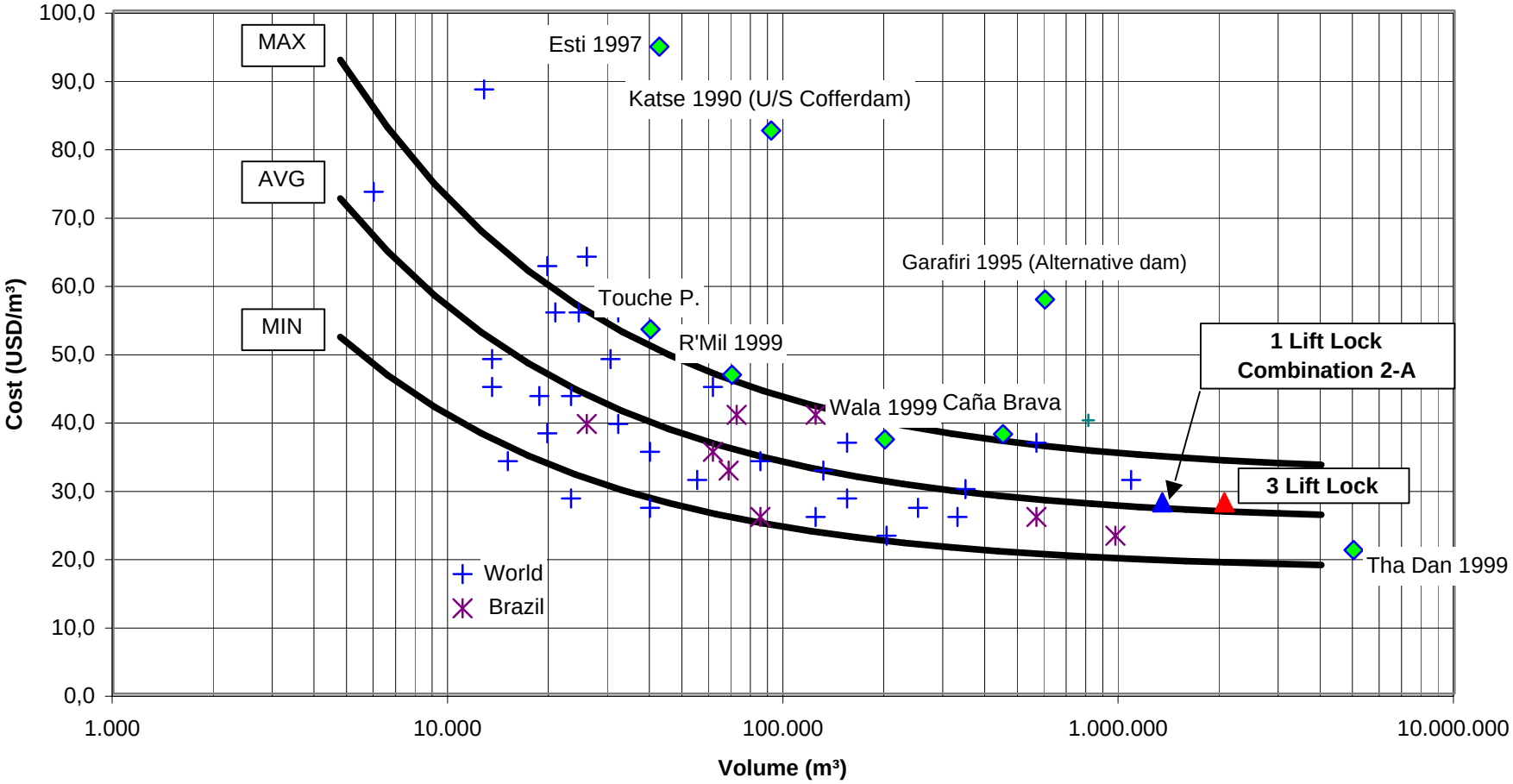
Graph B.5
Conceptual Design
Post-Panamax Lock Structures (Pacific)
Concrete Aggregate Unit Prices



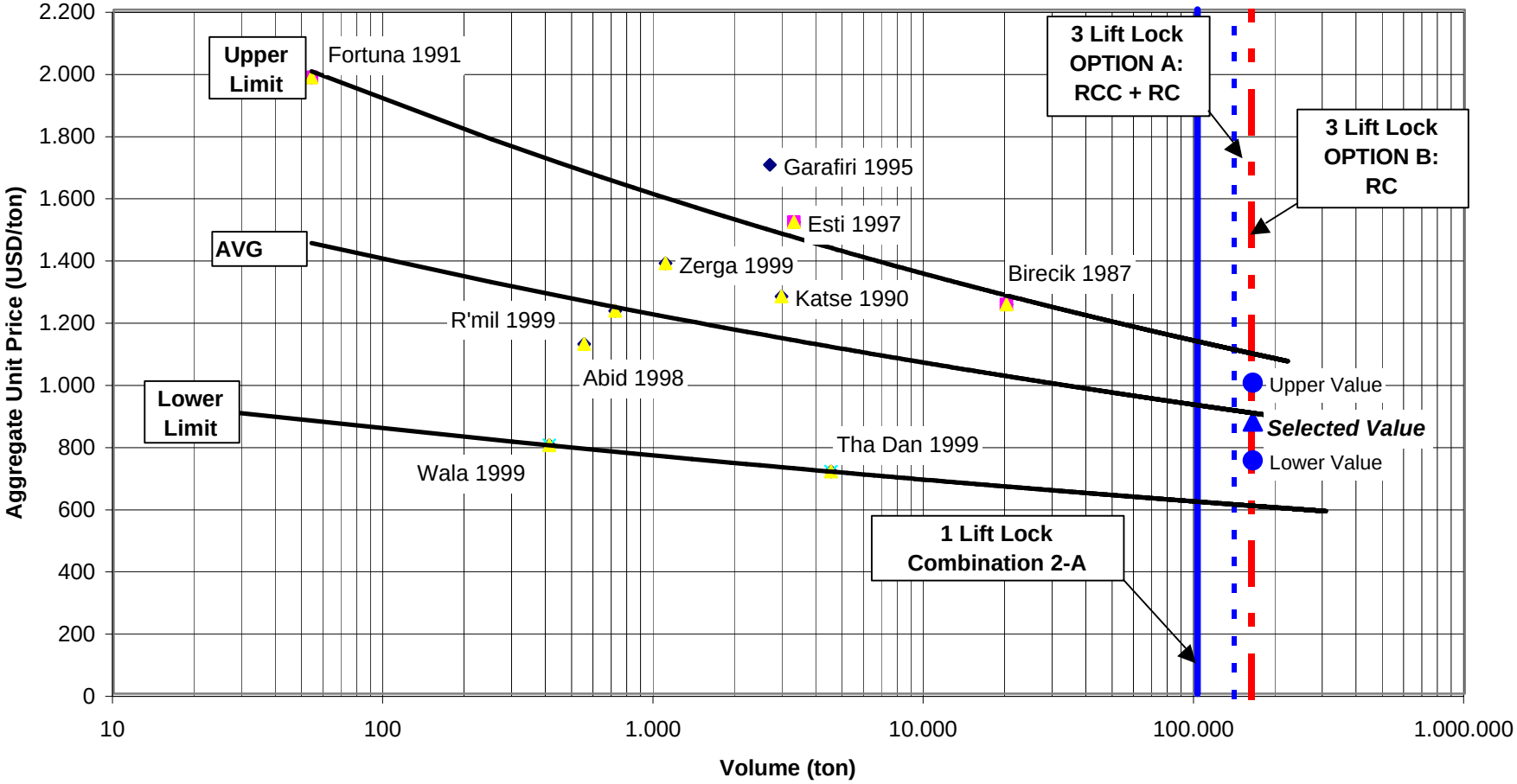
Graph B.6
Conceptual Design
Post-Panamax Lock Structures (Pacific)
Roller Compacted Concrete Aggregate Unit Prices



Graph B.7
Conceptual Design
Post-Panamax Lock Structure (Pacific)
RCC World Price



Graph B.8
Conceptual Design
Post-Panamax Lock Structures (Pacific)
Reinforcement Steel Aggregate Prices



APPENDIX C

COST ESTIMATES

TASK 4 - CONFIGURATION 2

Table C.1
Cost Estimate
Excavation and Fill

Item	Description	Unit	Unit Price	Combination 1-B		Combination 2-A		Combination 3-B	
				Quantity	Total USD - 2002	Quantity	Total USD - 2002	Quantity	Total USD - 2002
1	**Excavation**								
1,1	Overburden excavation	m³	3,50	1.116.570	3.907.994	1.116.570	3.907.994	1.298.170	4.543.594
1,2	La Boca / weathered rock excavation	m³	4,75	279.142	1.325.926	279.142	1.325.926	324.542	1.541.576
1,3	Rock excavation	m³	6,00	4.187.136	25.122.816	4.187.136	25.122.816	4.868.136	29.208.816
1,4	Overhaul for spoil (10 km) Combination 1-B	m³km	0,30	16.835.226	5.050.568				
1,5	Overhaul for spoil (10 km) Combination 2-A	m³km	0,30			20.658.561	6.197.568		
1,6	Overhaul for spoil (10 km) Combination 3-B	m³km	0,30					19.234.752	5.770.425
2	**Fill**								
2,1	Backfill Combination 1-B	m³	3,00	2.249.819	6.749.458				
2,2	Backfill Combination 2-A	m³	3,00			1.352.562	4.057.686		
2,3	Backfill Combination 3-B	m³	3,00					2.368.227	7.104.681
	Total Cost Combination 1-B				**42.156.762**				
	Total Cost Combination 2-A						**40.611.990**		
	Total Cost Combination 3-B								**48.169.093**

TASK 4 - CONFIGURATION 2

Table C.2

Cost Estimate
Entrance Walls

Option A : RCC + RC

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	Reinforced Concrete	m³	120,00	188.843	22.661.100
2	Steel Reinforcement BE500	tons	875,00	9.428	8.249.063
3	Backfill Crushed Stone	m³	3,00	237.780	713.340
4	Steel Corner Protection	m	73,00	1.350	98.550
5	Rubber Joint	m	71,00	1.845	130.995
6	Lean Concrete	m²	9,00	20.250	182.250
7	RCC	m³	28,00	424.283	11.879.910
8	Pavement	m²	24,00	27.000	648.000
9	Shotcrete (Temporary protection in La Boca)	m²	25,00	57.263	1.431.563
	Total Cost				**45.994.770**

TASK 4 - CONFIGURATION 2

Table C.3
Cost Estimate
Entrance Walls
Option B : RC

Item	Description	Unit	Unit Price	Combination 1-B		Combination 3-B	
				Quantity	Total USD - 2002	Quantity	Total USD - 2002
1	Reinforced Concrete	m³	120,00	264.083	31.689.900	555.813	66.697.560
2	Steel Reinforcement BE500	tons	875,00	19.800	17.325.000	40.785	35.686.547
3	Backfill Crushed Stone	m³	3,00	622.508	1.867.523	842.517	2.527.551
4	Steel Corner Protection	m	73,00	1.350	98.550	2.700	197.100
5	Rubber Joint	m	71,00	1.845	130.995	4.050	287.550
6	Lean Concrete	m²	9,00	20.250	182.250	48.600	437.400
7	Pavement	m²	24,00	27.000	648.000	0	0
8	Shotcrete (Temporary protection in La Boca)	m²	25,00	57.263	1.431.563	57.263	1.431.563
	Total Cost				**53.373.780**		**107.265.270**

TASK 4 - CONFIGURATION 2

Table C.4.1
Cost Estimate
Lock Walls
Option 1

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	Reinforced Concrete	m³	120,00	357.660	42.919.200
2	Steel Reinforcement BE500	tons	875,00	26.830	23.476.250
3	Backfill Crushed Stone	m³	3,00	660.720	1.982.160
4	RCC	m³	28,00	0	0
5	Concrete Layer Chamber Bottom	m³	90,00	4.960	446.400
6	Steel Corner Protection	m	73,00	600	43.800
7	Rubber joint	m	71,00	1.840	130.640
8	Pavement	m²	24,00	4.500	108.000
9	Lean Concrete	m²	9,00	25.600	230.400
10	Conduit under locks				
10,1	Reinforced Concrete (for all chambers)	m³	120,00	11.524	1.382.880
10,2	Steel Reinforcement BE500	tons	875,00	864	756.000
	Total Cost				**71.475.730**

Table C.4.2
Cost Estimate
Lock Walls
Option 2

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	Reinforced Concrete	m³	120,00	322.060	38.647.200
2	Steel Reinforcement BE500	tons	875,00	20.990	18.366.250
3	Backfill Crushed Stone	m³	3,00	148.190	444.570
4	RCC	m³	28,00	338.960	9.490.880
5	Concrete Layer Chamber Bottom	m³	90,00	4.360	392.400
6	Steel Corner Protection	m	73,00	600	43.800
7	Rubber joint	m	71,00	1.840	130.640
8	Pavement	m²	24,00	0	0
9	Lean Concrete	m²	9,00	22.830	205.470
10	Conduit under locks				
10,1	Reinforced Concrete (for all chambers)	m³	120,00	11.524	1.382.880
10,2	Steel Reinforcement BE500	tons	875,00	864	756.000
	Total Cost				**69.860.090**

TASK 4 - CONFIGURATION 2

Table C.4.3

Cost Estimate
Lock Walls

Option 3

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	Reinforced Concrete	m³	120,00	442.570	53.108.400
2	Steel Reinforcement BE500	tons	875,00	33.200	29.050.000
3	Backfill Crushed Stone	m³	3,00	501.970	1.505.910
4	RCC	m³	28,00	0	0
5	Concrete Layer Chamber Bottom	m³	90,00	6.160	554.400
6	Steel Corner Protection	m	73,00	900	65.700
7	Rubber joint	m	71,00	2.760	195.960
8	Pavement	m²	24,00	0	0
9	Lean Concrete	m²	9,00	27.800	250.200
10	Conduit under locks				
10,1	Reinforced Concrete (for all chambers)	m³	120,00	11.524	1.382.880
10,2	Steel Reinforcement BE500	tons	875,00	864	756.000
	Total Cost				**86.869.450**

TASK 4 - CONFIGURATION 2

Table C.6

Cost Estimate
WSB and Conduits (Civil Works)

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	Reinforced concrete	m³	120,00	240.021	28.802.544
2	Steel reinforcement BE500	tons	875,00	18.625	16.297.260
3	Roller compact concrete over conduits	m³	28,00	85.566	2.395.848
4	Backfill crushed stone over conduits	m³	3,00	497.340	1.492.020
5	Liner HDPE (WSB)	m²	13,31	0	0
6	Underlaying protective geotextile (WSB)	m²	1,88	0	0
7	Geotextile for drainage (WSB)	m²	4,71	0	0
8	Bank protection WSB	m²	13,00	0	0
10	Excavation				
10,1	Overburden excavation	m³	3,50	510.798	1.787.794
10,2	La Boca / weathered rock excavation	m³	4,75	127.700	606.573
10,3	Rock excavation	m³	6,00	1.915.493	11.492.960
11	Backfill WSB 1 to 6	m³	3,00	197.556	592.668
12	Overhaul for spoil (10 km)	m³km	0,30	16.694.783	5.008.435
13	Technical building	m²	300,00	506	151.800
	Total Cost				**68.627.901**

TASK 4 - CONFIGURATION 2

Table C.7
Cost Estimate
Lock Head Gate

Item	Description	Unit	Unit Price	Combination 1-B / 2-A		Combination 3-B	
				Quantity	Total USD - 2002	Quantity	Total USD - 2002
1	Reinforced Concrete	m³	120,00	690.760	82.891.200	738.442	88.613.040
2	Steel Reinforcement BE500	ton	875,00	51.807	45.331.125	55.383	48.460.256
3	Backfill crushed stone	m³	3,00	852.296	2.556.887	852.296	2.556.887
4	Backfill RCC	m³	28,00	193.839	5.427.492	193.839	5.427.492
5	Concrete layer chamber bottom	m³	90,00	4.773	429.593	4.773	429.593
6	Steel corner protection	m	73,00	968	70.664	968	70.664
7	Rubber joint	m	71,00	692	49.132	692	49.132
8	Lean concrete	m²	9,00	22.380	201.417	22.380	201.417
9	Pavement	m²	24,00	26.230	629.520	26.230	629.520
10	Technical building	m²	300,00	3.654	1.096.200	3.654	1.096.200
	Total Cost				**138.683.230**		**147.534.201**

TASK 4 - CONFIGURATION 2

Table C.8
Cost Estimate
Transition Segment

Item	Description	Unit	Unit Price	Combinations 1-B / 2-A		Combination 3-B	
				Quantity	Total USD - 2002	Quantity	Total USD - 2002
1	Reinforced concrete	m³	120,00	259.935	31.192.168	389.902	46.788.253
2	Steel reinforcement BE500	ton	875,00	19.495	17.058.217	29.243	25.587.326
3	Backfill crushed stone	m³	3,00	114.296	342.889	171.444	514.333
4	Backfil RCC	m³	28,00	280.513	7.854.374	420.770	11.781.561
5	Concrete layer chamber bottom	m³	90,00	10.380	934.200	10.380	934.200
6	Concrete slabs	m³	120,00	6.720	806.400	6.720	806.400
7	Gravel layer	m³	6,00	2.240	13.440	2.240	13.440
8	Steel corner protection	m	73,00	484	35.332	726	52.998
9	Rubber joint	m	71,00	1.508	107.068	2.262	160.602
10	Lean concrete	m²	9,00	19.632	176.688	29.448	265.032
11	Pavement	m²	24,00	13.920	334.080	13.920	334.080
	Total Cost				**58.854.856**		**87.238.224**

TASK 4 - CONFIGURATION 2

Table C.9

Cost Estimate
Lock Head Gate

Equipment (Civil Part)

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	Equipment lock gate (civil part)				3.972.320
1,1	Rails	m	280,00	4.004	1.121.120
1,2	Rails LSW Lock Head 2	m	1.000,00	560	560.000
1,3	Wooden vertical guidances	m	400,00	508	203.200
1,4	Steel for support rails and frames	tons	2.400,00	870	2.088.000
2	Equipment lock head (civil part)				7.323.230
2,1	Vertical elements for seals - east/recesses	m³	3.050,00	601	1.833.050
2,2	Vertical elements for seals - west	m³	2.700,00	690	1.863.000
2,3	Horizontal elements for seals- lock chamber	m³	2.700,00	312	842.400
2,4	Elements for placement habitat	m³	275,00	516	141.900
2,5	Horizontal elements for seals- gate recesses	m³	1.520,00	94	142.880
2,6	Bridges over recesses				
2.6.1	Bridges over recesses LHG 1	pcs	500.000	2	1.000.000
2.6.2	Bridges over recesses LHG 2	pcs	750.000	2	1.500.000
	Total Cost				**11.295.550**

TASK 4 - CONFIGURATION 2

Table C.10
Cost Estimate
Accessories

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	**Accessories**				
1,1	Bollards 1500kN	pcs	4.900	36	176.400
1,2	Fenders	pcs	540.000	2	1.080.000
1,3	Ladders	m	100	1.800	180.000
1,4	Mooring Bits	pcs	950	72	68.400
	Total Cost				**1.504.800**

TASK 4 - CONFIGURATION 2

Table C.11
Cost Estimate
ELECTROMECHANICAL EQUIPMENT

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	**EM Equipment lock**				**246.631.754**
1,1	EM Equipment Lock (gates and bulkheads)	tons		34.198	218.104.254
1.1.1	*EM Equipment Lock Head 1 (gates and bulkheads)*	*tons*	*6.173*	*4.491*	*27.722.943*
1.1.2	*EM Equipment Lock Head 2 (gates and bulkheads)*	*tons*	*6.173*	*29.707*	*183.381.311*
	Fixed ballast for gate stability (2)	*tons*	*500*	*14.000*	*7.000.000*
1,2	EM Equipment Lock (culvert valves and bulkheads)	tons	5.000	766	3.827.500
1,4	Support equipment		14.700.000	1	14.700.000
1,5	Control system		1.700.000	1	1.700.000
1,6	Lighting System		1.200.000	1	1.200.000
1,7	Electrical and Power System		7.100.000	1	7.100.000
2	**EM Equipment WSB (Support and control system**	tons	5.000	3.007	**15.032.500**
	Total Cost				**261.664.254**

TASK 4 - CONFIGURATION 2

Table C.12
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total Cost Combination 1-B

Lock without WSB'

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
1	**Excavation**				**35.407.304**		**44.585.800**		**27.070.569**
1,1	Overburden	m³	1.116.570	3,50	3.907.994	4,30	4.801.249	2,70	3.014.738
1,2	Weathered	m³	279.142	4,75	1.325.926	5,90	1.646.940	3,60	1.004.913
1,3	Rock	m³	4.187.136	6,00	25.122.816	7,50	31.403.520	4,50	18.842.112
1,4	Overhaul of spoil (10 km)	m³km	16.835.226	0,30	5.050.568	0,40	6.734.090	0,25	4.208.806
2	**Fill**				**6.762.898**		**9.013.838**		**4.511.959**
2,1	Backfill	m³	2.249.819	3,00	6.749.458	4,00	8.999.278	2,00	4.499.639
2,2	Gravel layer	m³	2.240	6,00	13.440	6,50	14.560	5,50	12.320
2,3	Bank protection WSB	m²	0	13,00	0	15,65	0	8,60	0
3	**Concrete**				**209.915.724**		**261.373.702**		**158.399.948**
3,1	RC	m³	1.583.961	120,00	190.075.348	150,00	237.594.186	90,00	142.556.511
3,2	RCC	m³	474.352	28,00	13.281.866	33,00	15.653.627	23,00	10.910.104
3,3	Concrete slab	m³	6.720	120,00	806.400	150,00	1.008.000	90,00	604.800
3,4	Lean Concrete	m²	87.862	9,00	790.755	11,00	966.479	6,80	597.460
3,5	Pavement	m²	71.650	24,00	1.719.600	30,00	2.149.500	18,00	1.289.700
3,6	Concrete layer chamber bottom	m³	20.113	90,00	1.810.193	110,00	2.212.458	68,00	1.367.701
3,7	Shotcrete (Temporary protection in La Boca)	m²	57.263	25,00	1.431.563	31,25	1.789.453	18,75	1.073.672
4	**Reinforcement**				**103.946.592**		**118.796.105**		**89.097.079**
4,1	Steel reinforcement	tons	118.796	875,00	103.946.592	1.000,00	118.796.105	750,00	89.097.079

TASK 4 - CONFIGURATION 2

Table C.12
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total Cost Combination 1-B

Lock without WSB'

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
5	**Other**				**13.057.931**		**16.414.164**		**9.701.699**
5,1	Steel corner protection	m	3.402	73,00	248.346	78,00	265.356	68,00	231.336
5,2	Rubber joint	m	5.885	71,00	417.835	112,00	659.120	30,00	176.550
5,3	Geotextile	m²	0	1,80	0	2,25	0	1,50	0
5,4	Liner HDPE (WSB1)	m²	0	13,31	0	16,63	0	10,00	0
5,5	Underlaying protective geotextile (WSB1)	m²	0	1,88	0	2,35	0	1,45	0
5,6	Geotextile for drainage (WSB1)	m²	0	4,71	0	5,90	0	3,55	0
5,7	Rails	m	4.004	280,00	1.121.120	350,00	1.401.400	210,00	840.840
5,8	Rails LSW	m	560	1.000,00	560.000	1.250,00	700.000	750,00	420.000
5,9	Wooden vertical guidances	m	508	400,00	203.200	500,00	254.000	300,00	152.400
5,10	Steel for support rail and frames	ton	870	2.400,00	2.088.000	3.000,00	2.610.000	1.800,00	1.566.000
5,11	Vertical element for seals east/recesses	m³	601	3.050,00	1.833.050	3.812,50	2.291.313	2.287,50	1.374.788
5,12	Vertical element for seals west	m³	690	2.700,00	1.863.000	3.375,00	2.328.750	2.025,00	1.397.250
5,13	Horizontal elements for seals lock chamber	m³	312	2.700,00	842.400	3.375,00	1.053.000	2.025,00	631.800
5,14	Elements for placement habitat	m³	516	275,00	141.900	343,75	177.375	206,25	106.425
5,15	Horizontal elements for seals gate recesses	m³	94	1.520,00	142.880	1.900,00	178.600	1.140,00	107.160
5.16.1	Bridge over recesses LHG 1	pcs	2	500.000,00	1.000.000	625.000,00	1.250.000	375.000,00	750.000
5.16.2	Bridge over recesses LHG 2	pcs	2	750.000,00	1.500.000	937.500,00	1.875.000	562.500,00	1.125.000
5,17	Technical building	m²	3.654	300,00	1.096.200	375,00	1.370.250	225,00	822.150
6	**Accessories**				**1.504.800**		**1.881.000**		**1.128.600**
6,1	Bollards 1500kN	pcs	36	4.900,00	176.400	6.125,00	220.500	3.675,00	132.300
6,2	Fenders	pcs	2	540.000,00	1.080.000	675.000,00	1.350.000	405.000,00	810.000
6,3	Ladders	m	1.800	100,00	180.000	125,00	225.000	75,00	135.000
6,4	Mooring bits	pcs	72	950,00	68.400	1.187,50	85.500	712,50	51.300
	Total Cost				**370.595.250**		**452.064.609**		**289.909.853**

TASK 4 - CONFIGURATION 2

Table C.13
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total Cost Combination 2-A

Lock without WSB'

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
1	**Excavation**				**36.554.304**		**46.115.134**		**28.026.403**
1,1	Overburden	m³	1.116.570	3,50	3.907.994	4,30	4.801.249	2,70	3.014.738
1,2	Weathered	m³	279.142	4,75	1.325.926	5,90	1.646.940	3,60	1.004.913
1,3	Rock	m³	4.187.136	6,00	25.122.816	7,50	31.403.520	4,50	18.842.112
1,4	Overhaul of spoil (10 km)	m³km	20.658.561	0,30	6.197.568	0,40	8.263.424	0,25	5.164.640
2	**Fill**				**4.071.126**		**5.424.808**		**2.717.444**
2,1	Backfill	m³	1.352.562	3,00	4.057.686	4,00	5.410.248	2,00	2.705.124
2,2	Gravel layer	m³	2.240	6,00	13.440	6,50	14.560	5,50	12.320
2,3	Bank protection WSB	m²	0	13,00	0	15,65	0	8,60	0
3	**Concrete**				**217.798.784**		**269.703.235**		**165.838.289**
3,1	RC	m³	1.473.121	120,00	176.774.548	150,00	220.968.186	90,00	132.580.911
3,2	RCC	m³	1.237.595	28,00	34.652.656	33,00	40.840.630	23,00	28.464.682
3,3	Concrete slab	m³	6.720	120,00	806.400	150,00	1.008.000	90,00	604.800
3,4	Lean Concrete	m²	85.092	9,00	765.825	11,00	936.009	6,80	578.624
3,5	Pavement	m²	67.150	24,00	1.611.600	30,00	2.014.500	18,00	1.208.700
3,6	Concrete layer chamber bottom	m³	19.513	90,00	1.756.193	110,00	2.146.458	68,00	1.326.901
3,7	Shotcrete (Temporary protection in La Boca)	m²	57.263	25,00	1.431.563	31,25	1.789.453	18,75	1.073.672
4	**Reinforcement**				**89.760.655**		**102.583.605**		**76.937.704**
4,1	Steel reinforcement	tons	102.584	875,00	89.760.655	1.000,00	102.583.605	750,00	76.937.704

TASK 4 - CONFIGURATION 2

Table C.13
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total Cost Combination 2-A

Lock without WSB'

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
5	**Other**				**13.057.931**		**16.414.164**		**9.701.699**
5,1	Steel corner protection	m	3.402	73,00	248.346	78,00	265.356	68,00	231.336
5,2	Rubber joint	m	5.885	71,00	417.835	112,00	659.120	30,00	176.550
5,3	Geotextile	m²	0	1,80	0	2,25	0	1,50	0
5,4	Liner HDPE (WSB1)	m²	0	13,31	0	16,63	0	10,00	0
5,5	Underlaying protective geotextile (WSB1)	m²	0	1,88	0	2,35	0	1,45	0
5,6	Geotextile for drainage (WSB1)	m²	0	4,71	0	5,90	0	3,55	0
5,7	Rails	m	4.004	280,00	1.121.120	350,00	1.401.400	210,00	840.840
5,8	Rails LSW	m	560	1.000,00	560.000	1.250,00	700.000	750,00	420.000
5,9	Wooden vertical guidances	m	508	400,00	203.200	500,00	254.000	300,00	152.400
5,10	Steel for support rail and frames	ton	870	2.400,00	2.088.000	3.000,00	2.610.000	1.800,00	1.566.000
5,11	Vertical element for seals east/recesses	m³	601	3.050,00	1.833.050	3.812,50	2.291.313	2.287,50	1.374.788
5,12	Vertical element for seals west	m³	690	2.700,00	1.863.000	3.375,00	2.328.750	2.025,00	1.397.250
5,13	Horizontal elements for seals lock chamber	m³	312	2.700,00	842.400	3.375,00	1.053.000	2.025,00	631.800
5,14	Elements for placement habitat	m³	516	275,00	141.900	343,75	177.375	206,25	106.425
5,15	Horizontal elements for seals gate recesses	m³	94	1.520,00	142.880	1.900,00	178.600	1.140,00	107.160
5.16.1	Bridge over recesses LHG 1	pcs	2	500.000,00	1.000.000	625.000,00	1.250.000	375.000,00	750.000
5.16.2	Bridge over recesses LHG 2	pcs	2	750.000,00	1.500.000	937.500,00	1.875.000	562.500,00	1.125.000
5,17	Technical building	m²	3.654	300,00	1.096.200	375,00	1.370.250	225,00	822.150
6	**Accessories**				**1.504.800**		**1.881.000**		**1.128.600**
6,1	Bollards 1500kN	pcs	36	4.900,00	176.400	6.125,00	220.500	3.675,00	132.300
6,2	Fenders	pcs	2	540.000,00	1.080.000	675.000,00	1.350.000	405.000,00	810.000
6,3	Ladders	m	1.800	100,00	180.000	125,00	225.000	75,00	135.000
6,4	Mooring bits	pcs	72	950,00	68.400	1.187,50	85.500	712,50	51.300
	Total Cost				**362.747.600**		**442.121.945**		**284.350.138**

TASK 4 - CONFIGURATION 2

Table C.14
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total Cost Combination 3-B

Lock without WSB'

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
1	**Excavation**				**41.064.411**		**51.701.850**		**31.388.710**
1,1	Overburden	m³	1.298.170	3,50	4.543.594	4,30	5.582.129	2,70	3.505.058
1,2	Weathered	m³	324.542	4,75	1.541.576	5,90	1.914.800	3,60	1.168.353
1,3	Rock	m³	4.868.136	6,00	29.208.816	7,50	36.511.020	4,50	21.906.612
1,4	Overhaul of spoil (10 km)	m³km	19.234.752	0,30	5.770.425	0,40	7.693.901	0,25	4.808.688
2	**Fill**				**7.118.121**		**9.487.468**		**4.748.774**
2,1	Backfill	m³	2.368.227	3,00	7.104.681	4,00	9.472.908	2,00	4.736.454
2,2	Gravel layer	m³	2.240	6,00	13.440	6,50	14.560	5,50	12.320
2,3	Bank protection WSB	m²	0	13,00	0	15,65	0	8,60	0
3	**Concrete**				**280.072.990**		**348.776.679**		**211.301.028**
3,1	RC	m³	2.138.251	120,00	256.590.133	150,00	320.737.666	90,00	192.442.599
3,2	RCC	m³	614.609	28,00	17.209.053	33,00	20.282.098	23,00	14.136.008
3,3	Concrete slab	m³	6.720	120,00	806.400	150,00	1.008.000	90,00	604.800
3,4	Lean Concrete	m²	128.228	9,00	1.154.049	11,00	1.410.505	6,80	871.948
3,5	Pavement	m²	40.150	24,00	963.600	30,00	1.204.500	18,00	722.700
3,6	Concrete layer chamber bottom	m³	21.313	90,00	1.918.193	110,00	2.344.458	68,00	1.449.301
3,7	Shotcrete (Temporary protection in La Boca)	m²	57.263	25,00	1.431.563	31,25	1.789.453	18,75	1.073.672
4	**Reinforcement**				**139.540.129**		**159.474.433**		**119.605.825**
4,1	Steel reinforcement	tons	159.474	875,00	139.540.129	1.000,00	159.474.433	750,00	119.605.825

TASK 4 - CONFIGURATION 2

Table C.14
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total Cost Combination 3-B

Lock without WSB'

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
5	**Other**				**13.471.456**		**16.996.188**		**9.946.725**
5,1	Steel corner protection	m	5.294	73,00	386.462	78,00	412.932	68,00	359.992
5,2	Rubber joint	m	9.764	71,00	693.244	112,00	1.093.568	30,00	292.920
5,3	Geotextile	m²	0	1,80	0	2,25	0	1,50	0
5,4	Liner HDPE (WSB1)	m²	0	13,31	0	16,63	0	10,00	0
5,5	Underlaying protective geotextile (WSB1)	m²	0	1,88	0	2,35	0	1,45	0
5,6	Geotextile for drainage (WSB1)	m²	0	4,71	0	5,90	0	3,55	0
5,7	Rails	m	4.004	280,00	1.121.120	350,00	1.401.400	210,00	840.840
5,8	Rails LSW	m	560	1.000,00	560.000	1.250,00	700.000	750,00	420.000
5,9	Wooden vertical guidances	m	508	400,00	203.200	500,00	254.000	300,00	152.400
5,10	Steel for support rail and frames	ton	870	2.400,00	2.088.000	3.000,00	2.610.000	1.800,00	1.566.000
5,11	Vertical element for seals east/recesses	m³	601	3.050,00	1.833.050	3.812,50	2.291.313	2.287,50	1.374.788
5,12	Vertical element for seals west	m³	690	2.700,00	1.863.000	3.375,00	2.328.750	2.025,00	1.397.250
5,13	Horizontal elements for seals lock chamber	m³	312	2.700,00	842.400	3.375,00	1.053.000	2.025,00	631.800
5,14	Elements for placement habitat	m³	516	275,00	141.900	343,75	177.375	206,25	106.425
5,15	Horizontal elements for seals gate recesses	m³	94	1.520,00	142.880	1.900,00	178.600	1.140,00	107.160
5.16.1	Bridge over recesses LHG 1	pcs	2	500.000,00	1.000.000	625.000,00	1.250.000	375.000,00	750.000
5.16.2	Bridge over recesses LHG 2	pcs	2	750.000,00	1.500.000	937.500,00	1.875.000	562.500,00	1.125.000
5,17	Technical building	m²	3.654	300,00	1.096.200	375,00	1.370.250	225,00	822.150
6	**Accessories**				**1.504.800**		**1.881.000**		**1.128.600**
6,1	Bollards 1500kN	pcs	36	4.900,00	176.400	6.125,00	220.500	3.675,00	132.300
6,2	Fenders	pcs	2	540.000,00	1.080.000	675.000,00	1.350.000	405.000,00	810.000
6,3	Ladders	m	1.800	100,00	180.000	125,00	225.000	75,00	135.000
6,4	Mooring bits	pcs	72	950,00	68.400	1.187,50	85.500	712,50	51.300
	Total Cost				**482.771.907**		**588.317.618**		**378.119.662**

TASK 4 - CONFIGURATION 2

Table C.15.1
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total WSB Cost

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
1	Reinforced concrete	m³	240.021	120,00	28.802.544	150,00	36.003.180	90,00	21.601.908
2	Steel reinforcement BE500	tons	18.625	875,00	16.297.260	1.000,00	18.625.440	750,00	13.969.080
3	Roller compact concrete over conduits	m³	85.566	28,00	2.395.848	33,00	2.823.678	23,00	1.968.018
4	Backfill crushed stone over conduits	m³	497.340	3,00	1.492.020	4,00	1.989.360	2,00	994.680
5	Liner HDPE (WSB)	m²	0	13,31	0	16,63	0	10,00	0
6	Underlaying protective geotextile (WSB)	m²	0	1,88	0	2,35	0	1,45	0
7	Geotextile for drainage (WSB)	m²	0	4,71	0	5,90	0	3,55	0
8	Bank protection WSB	m²	0	13,00	0	15,65	0	8,60	0
10	Excavation								0
10,1	Overburden excavation	m³	510.798	3,50	1.787.794	4,30	2.196.432	2,70	1.379.155
10,2	La Boca / weathered rock excavation	m³	127.700	4,75	606.573	5,90	753.427	3,60	459.718
10,3	Rock excavation	m³	1.915.493	6,00	11.492.960	7,50	14.366.199	4,50	8.619.720
11	Backfill WSB 1 to 6	m³	197.556	3,00	592.668	4,00	790.224	2,00	395.112
12	Overhaul for spoil (10 km)	m³km	16.694.783	0,30	5.008.435	0,40	6.677.913	0,25	4.173.696
13	Technical building	m²	506	300,00	151.800	375,00	189.750	225,00	113.850
	Total Cost				68.627.901		84.415.604		53.674.937

TASK 4 - CONFIGURATION 2

Table C.15.2
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total Stacked WSB Cost

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
1	Reinforced concrete	m³	679.069	120,00	81.488.280	150,00	101.860.350	90,00	61.116.210
2	Steel reinforcement BE500	tons	51.430	875,00	45.001.250	1.000,00	51.430.000	750,00	38.572.500
3	Roller compact concrete over conduits	m³	0	28,00	0	33,00	0	23,00	0
4	Backfill crushed stone over conduits	m³	0	3,00	0	4,00	0	2,00	0
5	Liner HDPE (WSB)	m²	0	13,31	0	16,63	0	10,00	0
6	Underlaying protective geotextile (WSB)	m²	0	1,88	0	2,35	0	1,45	0
7	Geotextile for drainage (WSB)	m²	0	4,71	0	5,90	0	3,55	0
8	Bank protection WSB	m²	0	13,00	0	15,65	0	8,60	0
10	Excavation								0
10,1	Overburden excavation	m³	108.476	3,50	379.666	4,30	466.447	2,70	292.885
10,2	La Boca / weathered rock excavation	m³	27.119	4,75	128.815	5,90	160.002	3,60	97.628
10,3	Rock excavation	m³	379.665	6,00	2.277.990	7,50	2.847.488	4,50	1.708.493
11	Backfill WSB 1 to 6	m³	0	3,00	0	4,00	0	2,00	0
12	Overhaul for spoil (10 km)	m³km	5.423.790	0,30	1.627.137	0,40	2.169.516	0,25	1.355.948
13	Technical building	m²	506	300,00	151.800	375,00	189.750	225,00	113.850
	Total Cost				131.054.938		159.123.552		103.257.514

TASK 4 - CONFIGURATION 2

Table C.16
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Cost Estimate

CIVIL WORKS SUMMARY

Item	Description	Combination 1-B Total USD - 2002	Combination 2-A Total USD - 2002	Combination 3-B Total USD - 2002
1	**Excavation for lock**	35.407.304	36.554.304	41.064.411
2	**Entrance walls [1]**	53.373.780	45.994.770	107.265.270
3	**Lock walls [1]**	71.475.730	69.860.090	86.869.450
4	**Lock heads [1]**	208.833.636	208.833.636	246.067.975
5	**Accessories**	1.504.800	1.504.800	1.504.800
	LOCK TOTAL COST	**370.595.250**	**362.747.600**	**482.771.907**
6	**WSB and conduits (excavation and fill included)**	68.627.901	68.627.901	68.627.901

[1] Include cost for backfill crushed stone

APPENDIX D

WATER SAVING BASINS
POSTPONED CONSTRUCTION
OR
STACKED CONSTRUCTION

TASK 4 - CONFIGURATION 2

Table D.1
Cost Estimate
WSB (Postponed construction)

Item	Description	Unit	Unit Price Based in Qty	Adjustment Factor	Adjusted Unit Price	Quantity	Total USD - 2002
	Civil Works						
1	Reinforced concrete	m³	140,00	1,50	210,00	240.021	50.404.452
2	Steel reinforcement BE500	tons	1.000,00	1,50	1.500,00	18.625	27.938.160
3	Roller compact concrete over conduits	m³	40,00	1,50	60,00	85.566	5.133.960
4	Backfill crushed stone over conduits	m³	4,00	1,50	6,00	497.340	2.984.040
5	Liner HDPE (WSB)	m²	13,31	1,50	19,97	0	0
6	Underlaying protective geotextile (WSB)	m²	1,88	1,50	2,82	0	0
7	Geotextile for drainage (WSB)	m²	4,71	1,50	7,07	0	0
8	Bank protection WSB	m²	13,00	1,50	19,50	0	0
10	Excavation						
10,1	Overburden excavation	m³	4,50	1,50	6,75	510.798	3.447.888
10,2	La Boca / weathered rock excavation	m³	5,75	1,50	8,63	127.700	1.101.409
10,3	Rock excavation	m³	7,00	1,50	10,50	1.915.493	20.112.679
11	Backfill WSB 1 to 6	m³km	4,00	1,50	6,00	197.556	1.185.336
12	Overhaul for spoil (10 km)	m³km	0,30	1,50	0,45	18.590.950	8.365.928
	Total Civil Works Cost						**120.673.851**
	Electromechanical Equipment						
1	EM Equipment WSB (Support and control system)	tons	5.000	1,30	6.500,00	3.007	19.545.500
	Total EM Cost						**19.545.500**

TASK 4 - CONFIGURATION 2

Table D.2
Conceptual Design
Post-Panamax Lock Structure (Pacific)

TOTAL WSB COST

(Postponed construction)

Item	Description	%	Total USD - 2002
	WSB		
1	**Civil Works**		**155.669.268**
1,1	Civil works		120.673.851
1,2	Detailed studies and supervision	7%	8.447.170
1,3	Instrumentation	2%	2.413.477
1,4	Grouting and consolidation	3%	3.620.216
1,5	Contingencies	15%	18.101.078
1,6	Administrative costs	2%	2.413.477
2	**Electromechanical equipment**		**23.259.145**
2,1	Electromechanical equipment		19.545.500
2,2	Detailed studies and supervision	7%	1.368.185
2,3	Contingencies	10%	1.954.550
2,4	Administrative costs	2%	390.910
	TOTAL WSB COST		**178.928.413**

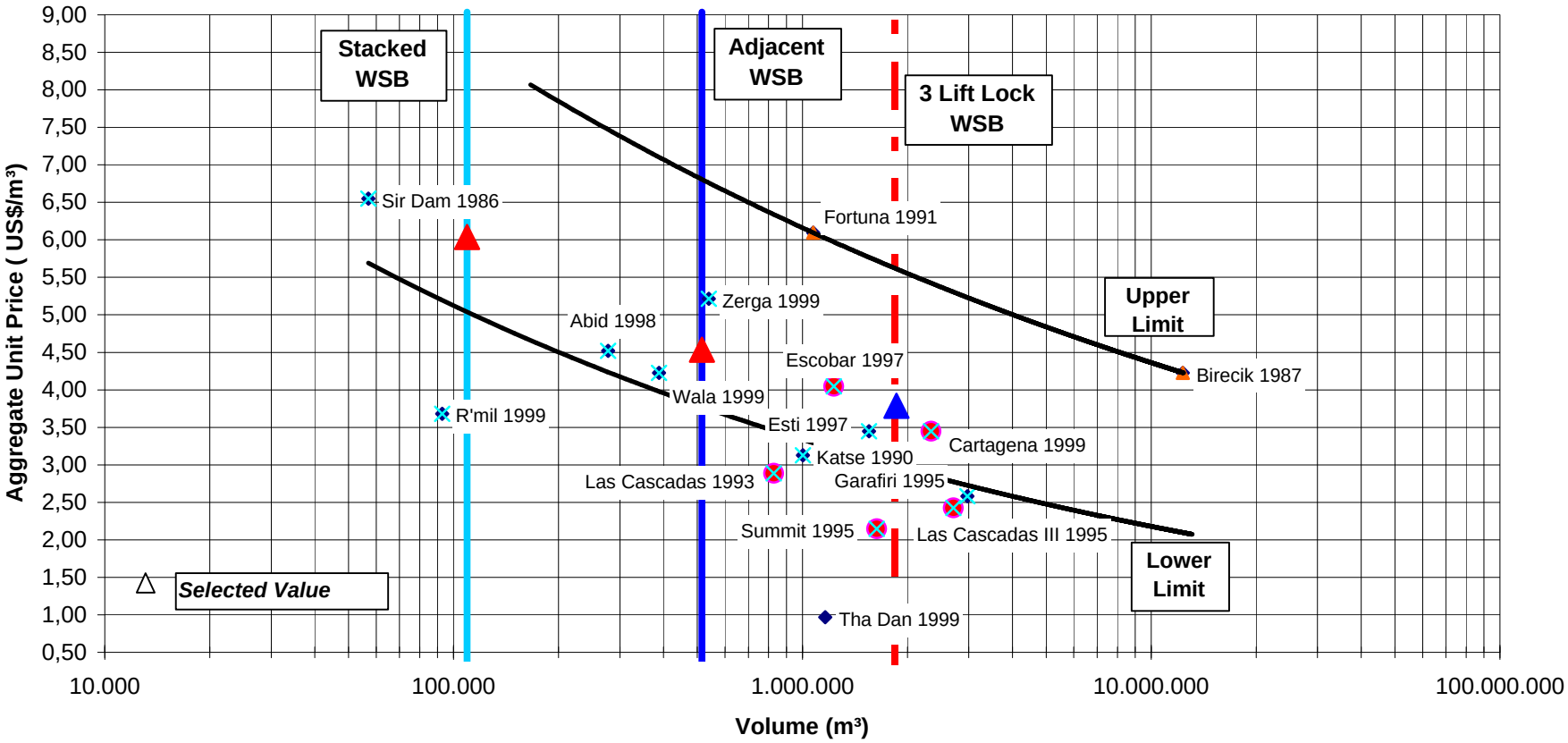
TASK 4 - CONFIGURATION 2

Table D.3
Cost Estimate
Stacked WSB (Postponed construction)

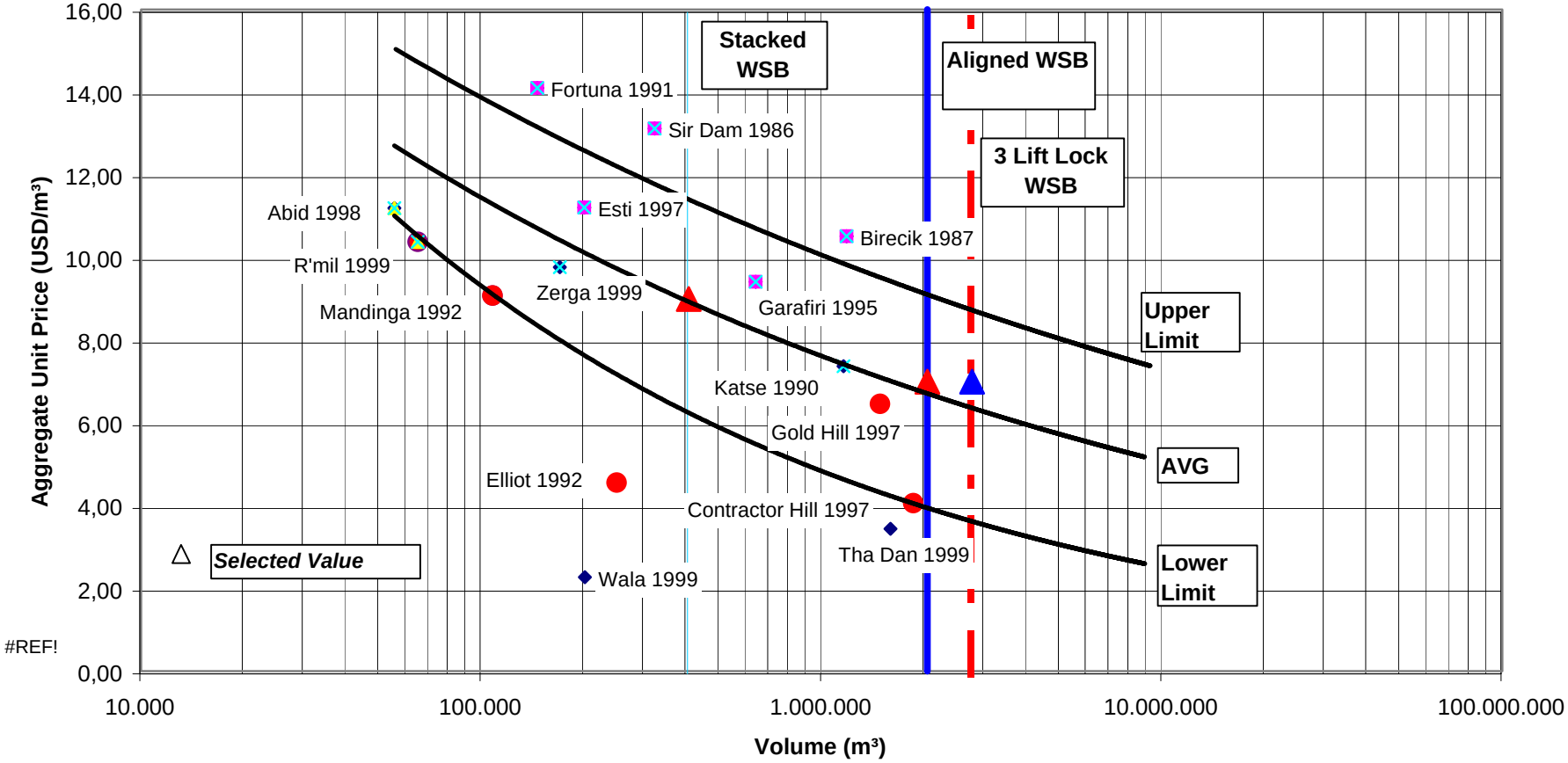
Item	Description	Unit	Unit Price Based in Qty	Adjustment Factor	Adjusted Unit Price	Quantity	Total USD - 2002
	Civil Works						
1	Reinforced concrete	m³	125,00	1,50	187,50	679.069	127.325.438
2	Steel reinforcement BE500	tons	1.000,00	1,50	1.500,00	51.430	77.145.000
3	Roller compact concrete over conduits	m³	40,00	1,50	60,00	0	0
4	Backfill crushed stone over conduits	m³	4,00	1,50	6,00	0	0
5	Liner HDPE (WSB)	m²	13,31	1,50	19,97	0	0
6	Underlaying protective geotextile (WSB)	m²	1,88	1,50	2,82	0	0
7	Geotextile for drainage (WSB)	m²	4,71	1,50	7,07	0	0
8	Bank protection WSB	m²	13,00	1,50	19,50	0	0
10	Excavation						
10,1	Overburden excavation	m³	6,00	1,50	9,00	108.476	976.284
10,2	La Boca / weathered rock excavation	m³	7,50	1,50	11,25	27.119	305.089
10,3	Rock excavation	m³	9,00	1,50	13,50	379.665	5.125.478
11	Backfill WSB 1 to 6	m³km	4,00	1,50	6,00	0	0
12	Overhaul for spoil (10 km)	m³km	0,30	1,50	0,45	5.423.790	2.440.706
	Total Civil Works Cost						**213.317.993**
	Electromechanical Equipment						
1	EM Equipment WSB (Support and control system)	tons	5.000	1,30	6.500,00	3.007	19.545.500
	Total EM Cost						**19.545.500**

Graph D.1
Conceptual Design
Post-Panamax Lock Structures (Pacific)
Water Saving Basin

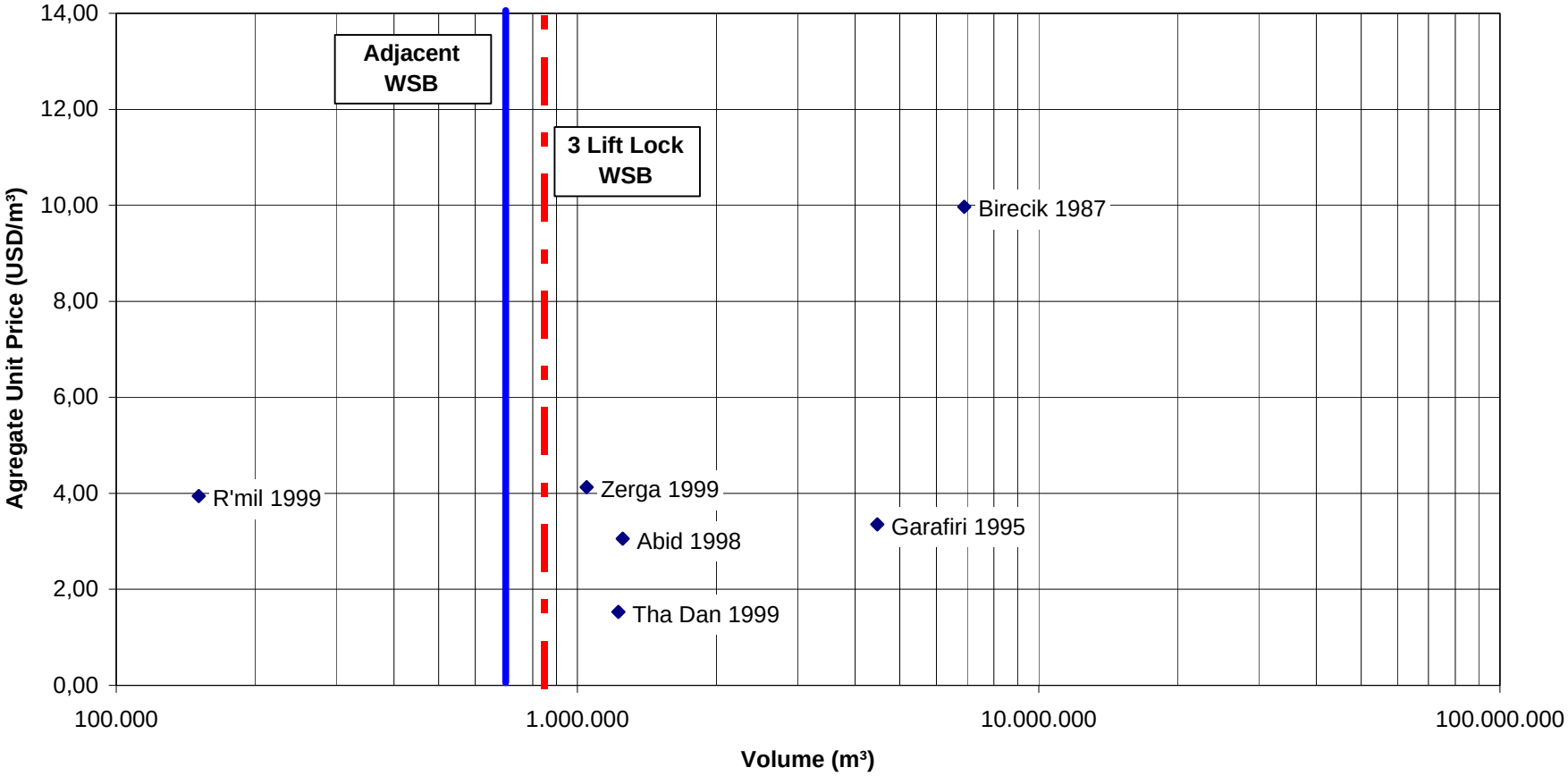
Overburden Excavation Aggregate Unit Prices



Graph D.2
Conceptual Design
Post-Panamax Lock Structures (Pacific)
Water Saving Basin
Rock Excavation Aggregate Unit Prices

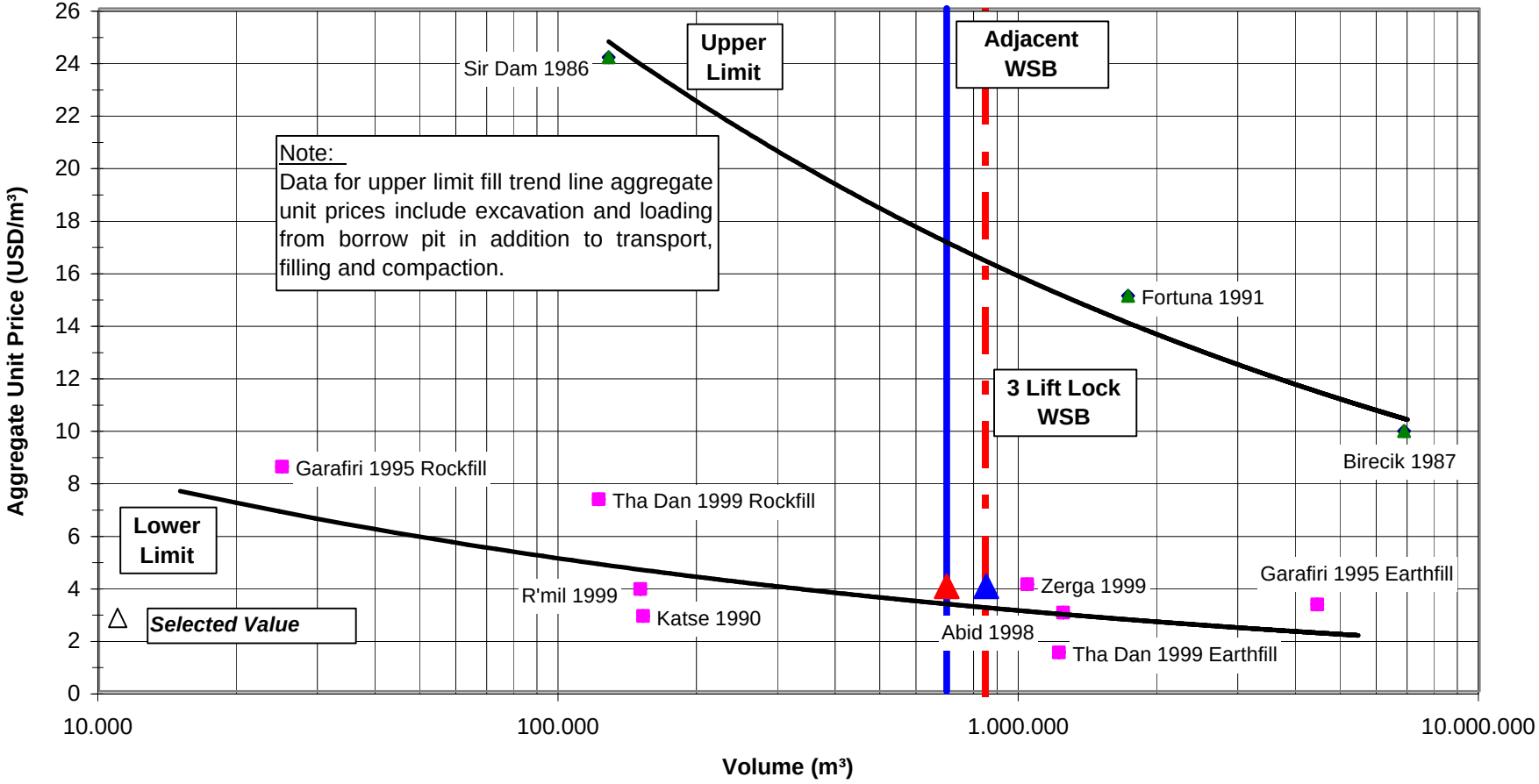


Graph D.3
Conceptual Design
Post - Panamax Lock Structure (Pacific)
Water Saving Basin
Earthfill Agregate Unit Price



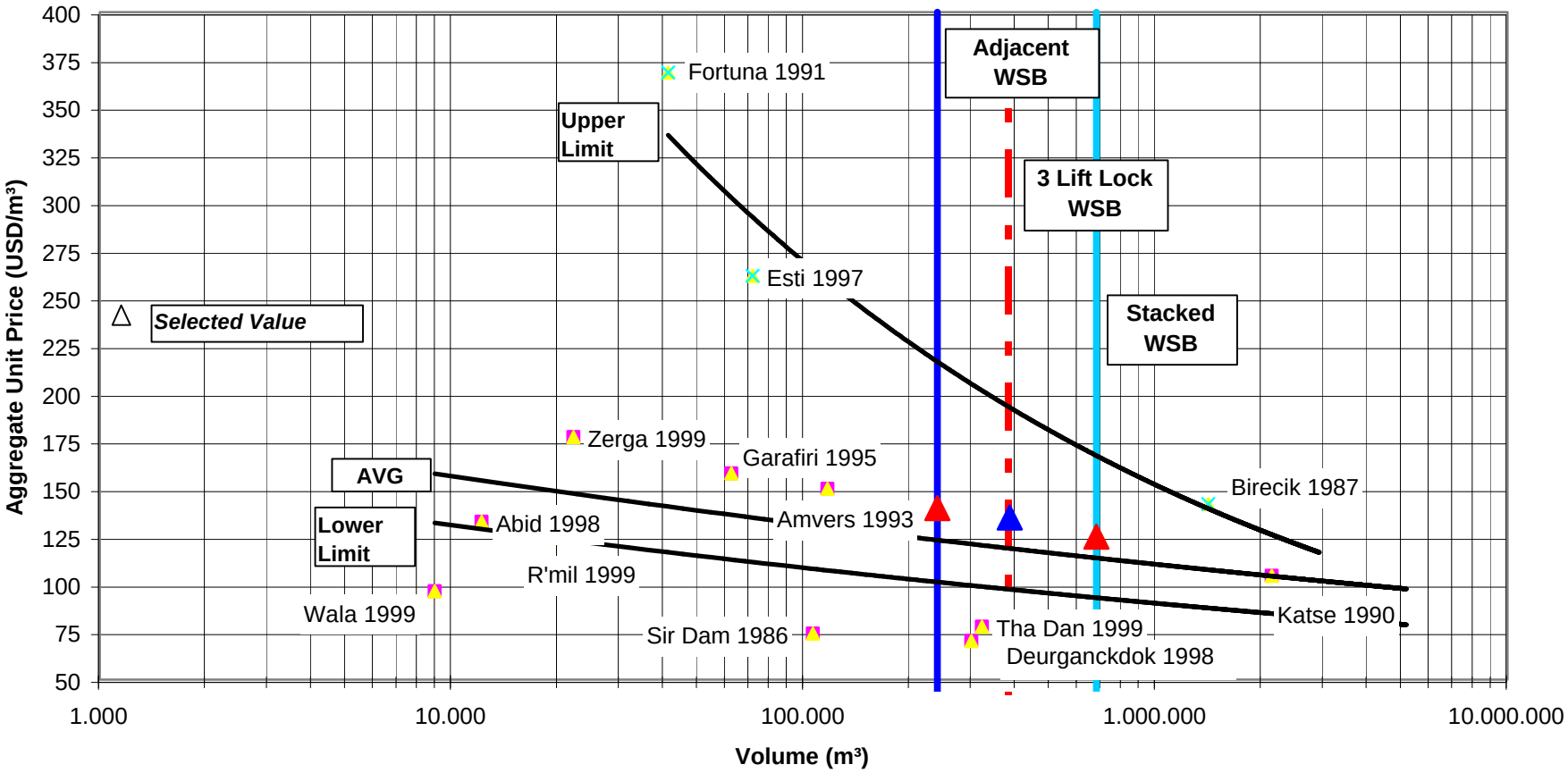
Graph D.4
Conceptual Design
Post-Panamax Lock Structures (Pacific)
Water Saving Basin

Fill Aggregate Unit Price



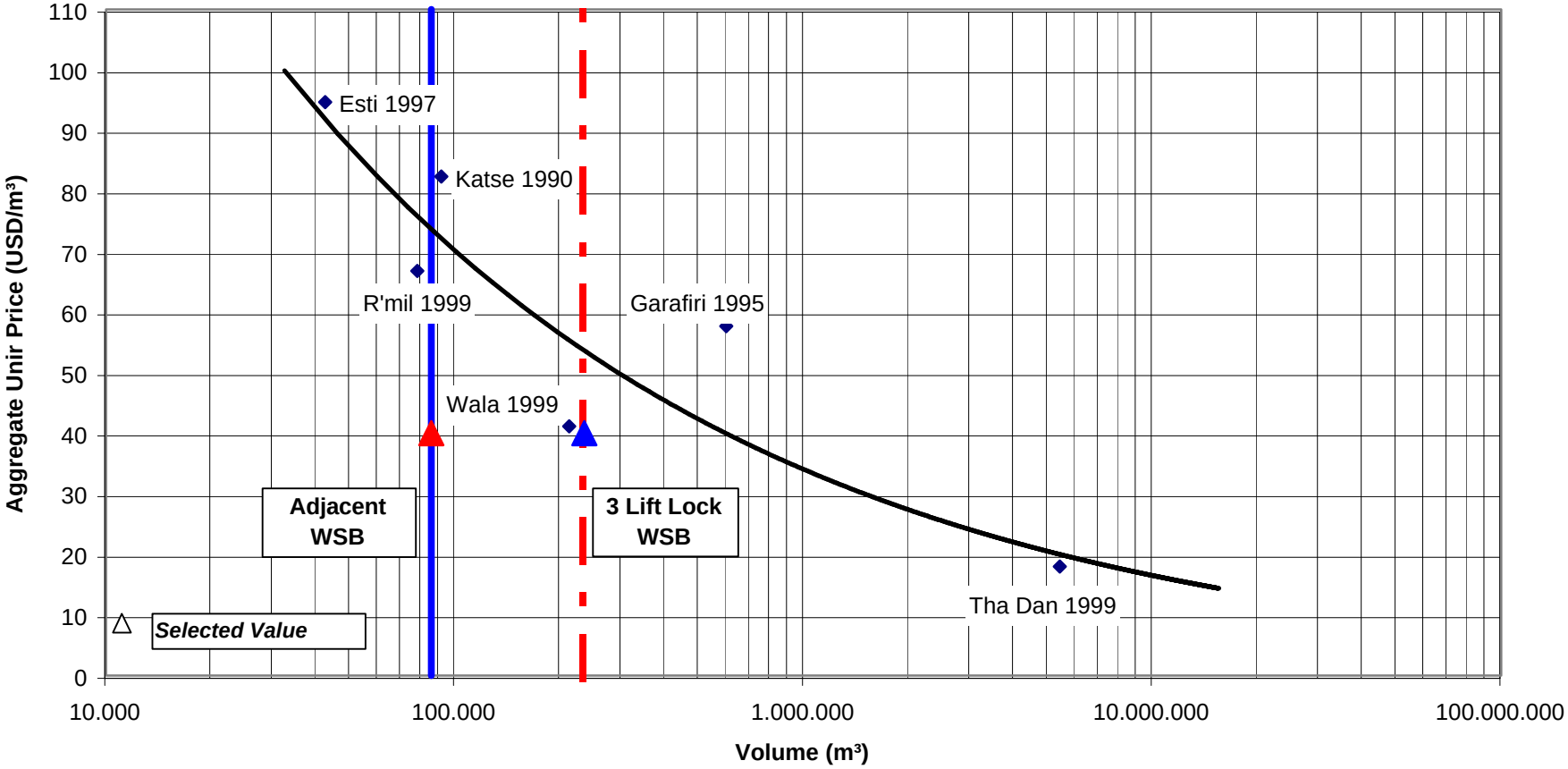
Graph D.5
Conceptual Design
Post-Panamax Lock Structures (Pacific)
Water Saving Basin

Concrete Aggregate Unit Prices

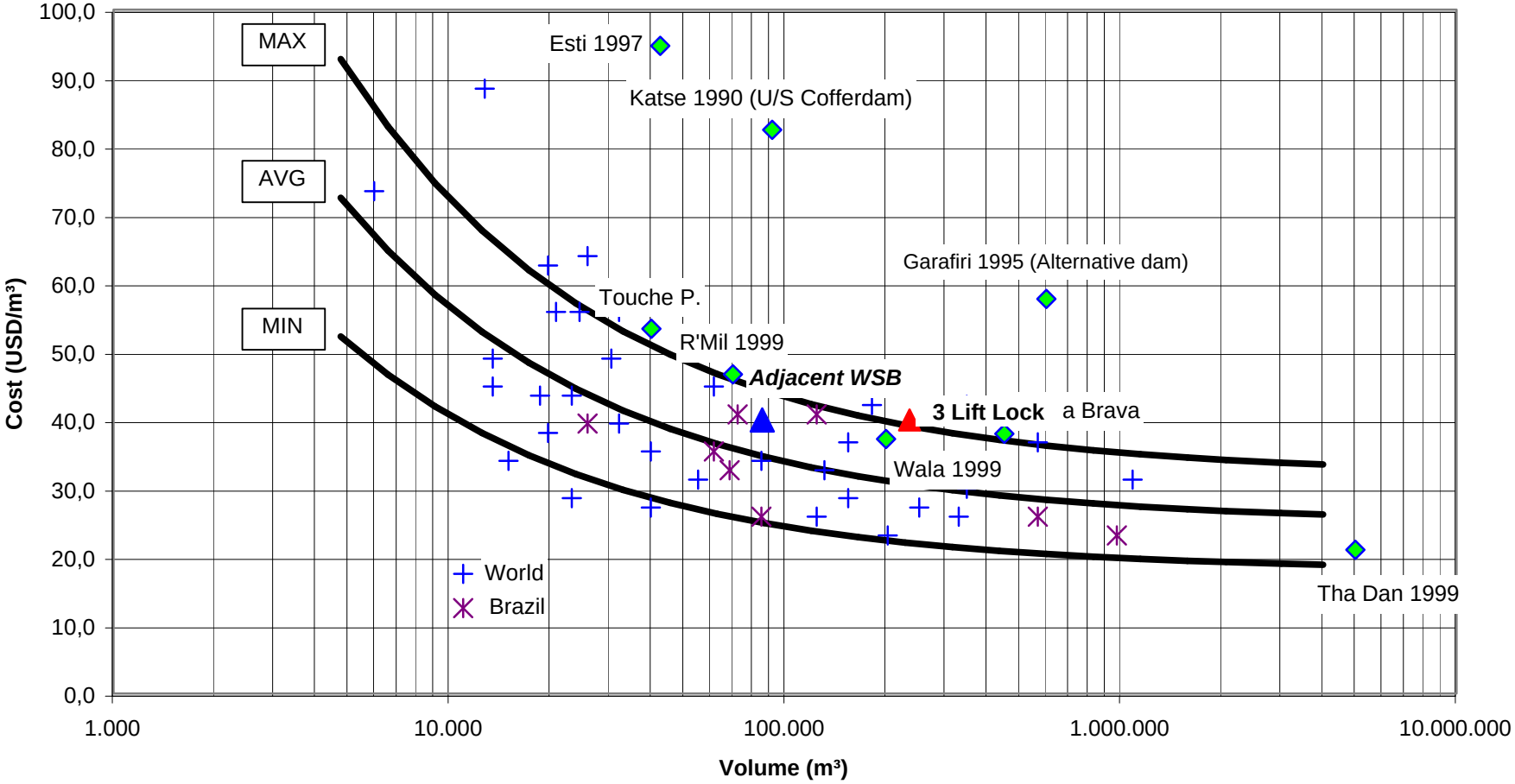


Graph D.6
Conceptual Design
Post-Panamax Lock Structures (Pacific)
Water Saving Basin

Roller Compacted Concrete Aggregate Unit Prices

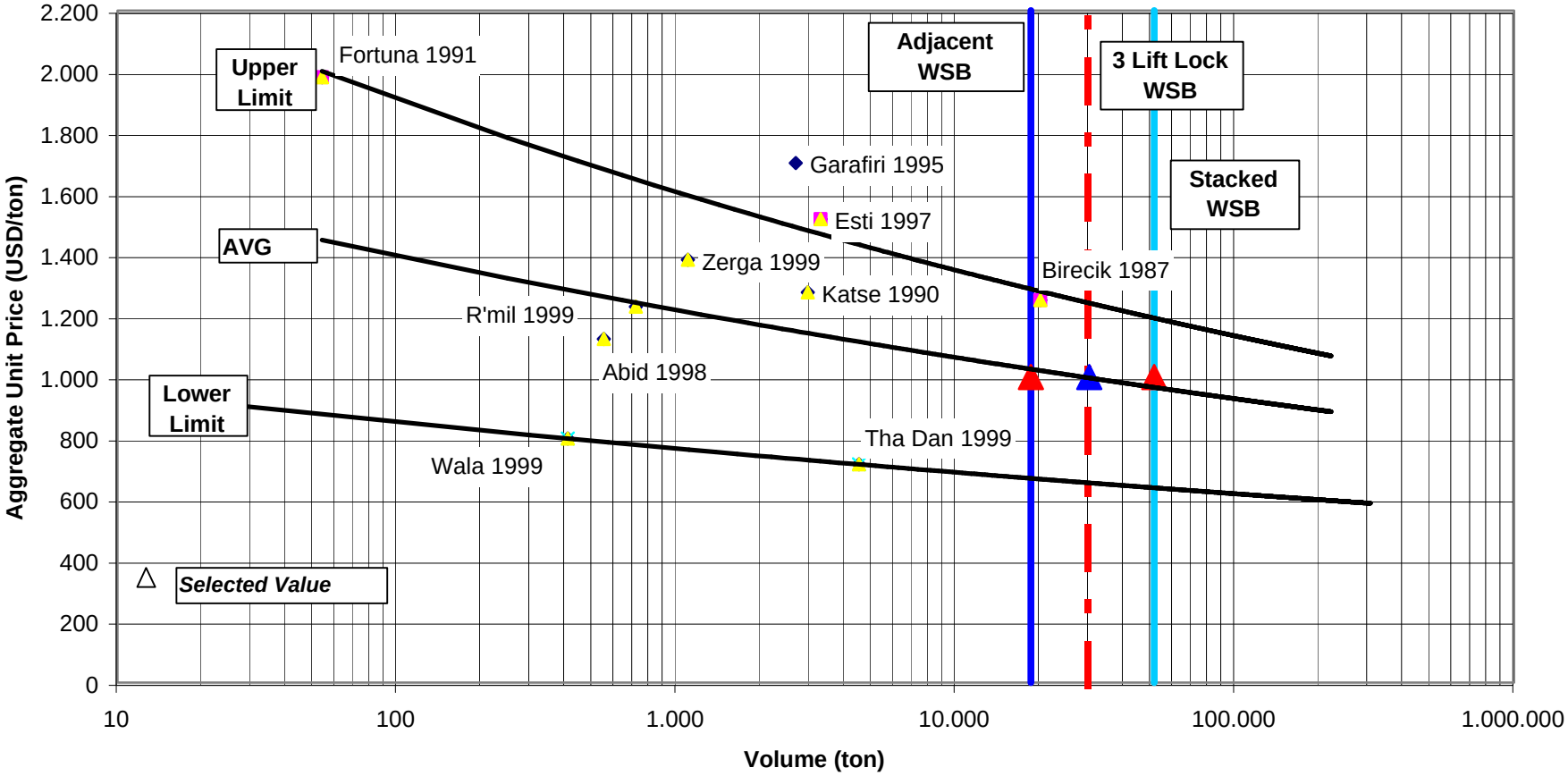


Graph D.7
Conceptual Design
Post-Panamax Lock Structure (Pacific)
RCC World Price



Graph D.8
Conceptual Design
Post-Panamax Lock Structures (Pacific)
Water Saving Basin

Reinforcement Steel Aggregate Prices



APPENDIX E

SENSIBILITY ANALYSIS
WIDTH OF LOCK MINUS 20'

TASK 4 - CONFIGURATION 2

Table E.1
Conceptual Design
Post-Panamax Lock Structure (Pacific)

TOTAL PROJECT COST

Item	Description	%	Combination 1-B Total USD - 2002	Combination 2-A Total USD - 2002	Combination 3-B Total USD - 2002
	LOCK				
1	**Civil Works**		**461.293.382**	**451.433.014**	**604.807.832**
1,1	Civil works		357.591.769	349.948.073	468.843.281
1,2	Detailed studies and supervision	7%	25.031.424	24.496.365	32.819.030
1,3	Instrumentation	2%	7.151.835	6.998.961	9.376.866
1,4	Grouting and consolidation	3%	10.727.753	10.498.442	14.065.298
1,5	Contingencies	15%	53.638.765	52.492.211	70.326.492
1,6	Administrative costs	2%	7.151.835	6.998.961	9.376.866
2	**Electromechanical equipment**		**270.671.476**	**270.671.476**	**270.671.476**
2,1	Electromechanical equipment		213.824.454	213.824.454	213.824.454
2.1.1	*EM equipment Lock Head 1*		*23.093.193*	*23.093.193*	*23.093.193*
2.1.2	*EM equipment Lock Head 2*		*162.203.761*	*162.203.761*	*162.203.761*
2.1.3	*EM other equipment and system*		*28.527.500*	*28.527.500*	*28.527.500*
2,2	Detailed studies and supervision	7%	14.967.712	14.967.712	14.967.712
2,3	Contingencies		37.602.822	37.602.822	37.602.822
2.3.1	*Lock Head 1*	*10%*	*2.309.319*	*2.309.319*	*2.309.319*
2.3.2	*Lock Head 2*	*20%*	*32.440.752*	*32.440.752*	*32.440.752*
2.3.3	*Other equipment and system*	*10%*	*2.852.750*	*2.852.750*	*2.852.750*
2,4	Administrative costs	2%	4.276.489	4.276.489	4.276.489
	TOTAL LOCK COST		**731.964.858**	**722.104.491**	**875.479.308**
	WSB				
1	**Civil Works**		**84.829.947**	**84.829.947**	**84.829.947**
1,1	Civil works		65.759.649	65.759.649	65.759.649
1,2	Detailed studies and supervision	7%	4.603.175	4.603.175	4.603.175
1,3	Instrumentation	2%	1.315.193	1.315.193	1.315.193
1,4	Grouting and consolidation	3%	1.972.789	1.972.789	1.972.789
1,5	Contingencies	15%	9.863.947	9.863.947	9.863.947
1,6	Administrative costs	2%	1.315.193	1.315.193	1.315.193

TASK 4 - CONFIGURATION 2

Table E.1
Conceptual Design
Post-Panamax Lock Structure (Pacific)

TOTAL PROJECT COST

Item	Description	%	Combination 1-B Total USD - 2002	Combination 2-A Total USD - 2002	Combination 3-B Total USD - 2002
2	**Electromechanical equipment**		**17.888.675**	**17.888.675**	**17.888.675**
2,1	Electromechanical equipment		15.032.500	15.032.500	15.032.500
2,2	Detailed studies and supervision	7%	1.052.275	1.052.275	1.052.275
2,3	Contingencies	10%	1.503.250	1.503.250	1.503.250
2,4	Administrative costs	2%	300.650	300.650	300.650
	TOTAL WSB COST		**102.718.622**	**102.718.622**	**102.718.622**
	Summary				
	Total project cost without WSB		**732.000.000**	**722.000.000**	**875.000.000**
	Total project cost with WSB		**835.000.000**	**825.000.000**	**978.000.000**

TASK 4 - CONFIGURATION 2

Table E.2
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total Cost Combination 1-B

Lock without WSB'

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
1	**Excavation**				**31.433.728**		**39.521.985**		**23.976.719**
1,1	Overburden	m³	1.016.873	3,50	3.559.056	4,30	4.372.554	2,70	2.745.557
1,2	Weathered	m³	254.218	4,75	1.207.537	5,90	1.499.888	3,60	915.186
1,3	Rock	m³	3.813.274	6,00	22.879.643	7,50	28.599.553	4,50	17.159.732
1,4	Overhaul of spoil (10 km)	m³km	12.624.976	0,30	3.787.493	0,40	5.049.991	0,25	3.156.244
2	**Fill**				**6.648.917**		**8.862.375**		**4.435.458**
2,1	Backfill	m³	2.212.509	3,00	6.637.527	4,00	8.850.036	2,00	4.425.018
2,2	Gravel layer	m³	1.898	6,00	11.389	6,50	12.338	5,50	10.440
2,3	Bank protection WSB	m²	0	13,00	0	15,65	0	8,60	0
3	**Concrete**				**204.255.801**		**254.315.863**		**154.147.315**
3,1	RC	m³	1.541.959	120,00	185.035.093	150,00	231.293.866	90,00	138.776.320
3,2	RCC	m³	471.679	28,00	13.207.020	33,00	15.565.417	23,00	10.848.624
3,3	Concrete slab	m³	5.696	120,00	683.472	150,00	854.340	90,00	512.604
3,4	Lean Concrete	m²	87.862	9,00	790.755	11,00	966.479	6,80	597.460
3,5	Pavement	m²	71.650	24,00	1.719.600	30,00	2.149.500	18,00	1.289.700
3,6	Concrete layer chamber bottom	m³	15.426	90,00	1.388.297	110,00	1.696.808	68,00	1.048.936
3,7	Shotcrete (Temporary protection in La Boca)	m²	57.263	25,00	1.431.563	31,25	1.789.453	18,75	1.073.672
4	**Reinforcement**				**101.187.840**		**115.643.246**		**86.732.434**
4,1	Steel reinforcement	tons	115.643	875,00	101.187.840	1.000,00	115.643.246	750,00	86.732.434

TASK 4 - CONFIGURATION 2

Table E.2
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total Cost Combination 1-B

Lock without WSB'

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
5	**Other**				**12.560.684**		**15.791.907**		**9.329.461**
5,1	Steel corner protection	m	3.402	73,00	248.346	78,00	265.356	68,00	231.336
5,2	Rubber joint	m	5.855	71,00	415.705	112,00	655.760	30,00	175.650
5,3	Geotextile	m²	0	1,80	0	2,25	0	1,50	0
5,4	Liner HDPE (WSB1)	m²	0	13,31	0	16,63	0	10,00	0
5,5	Underlaying protective geotextile (WSB1)	m²	0	1,88	0	2,35	0	1,45	0
5,6	Geotextile for drainage (WSB1)	m²	0	4,71	0	5,90	0	3,55	0
5,7	Rails	m	3.882	280,00	1.086.960	350,00	1.358.700	210,00	815.220
5,8	Rails LSW	m	510	1.000,00	510.000	1.250,00	637.500	750,00	382.500
5,9	Wooden vertical guidances	m	484	400,00	193.600	500,00	242.000	300,00	145.200
5,10	Steel for support rail and frames	ton	804	2.400,00	1.929.552	3.000,00	2.411.940	1.800,00	1.447.164
5,11	Vertical element for seals east/recesses	m³	579	3.050,00	1.765.950	3.812,50	2.207.438	2.287,50	1.324.463
5,12	Vertical element for seals west	m³	664	2.700,00	1.792.800	3.375,00	2.241.000	2.025,00	1.344.600
5,13	Horizontal elements for seals lock chamber	m³	282	2.700,00	762.480	3.375,00	953.100	2.025,00	571.860
5,14	Elements for placement habitat	m³	457	275,00	125.565	343,75	156.956	206,25	94.174
5,15	Horizontal elements for seals gate recesses	m³	88	1.520,00	133.526	1.900,00	166.907	1.140,00	100.144
5.16.1	Bridge over recesses LHG 1	pcs	2	500.000,00	1.000.000	625.000,00	1.250.000	375.000,00	750.000
5.16.2	Bridge over recesses LHG 2	pcs	2	750.000,00	1.500.000	937.500,00	1.875.000	562.500,00	1.125.000
5,17	Technical building	m²	3.654	300,00	1.096.200	375,00	1.370.250	225,00	822.150
6	**Accessories**				**1.504.800**		**1.881.000**		**1.128.600**
6,1	Bollards 1500kN	pcs	36	4.900,00	176.400	6.125,00	220.500	3.675,00	132.300
6,2	Fenders	pcs	2	540.000,00	1.080.000	675.000,00	1.350.000	405.000,00	810.000
6,3	Ladders	m	1.800	100,00	180.000	125,00	225.000	75,00	135.000
6,4	Mooring bits	pcs	72	950,00	68.400	1.187,50	85.500	712,50	51.300
	Total Cost				**357.591.769**		**436.016.376**		**279.749.987**

TASK 4 - CONFIGURATION 2

Table E.3
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total Cost Combination 2-A

Lock without WSB'

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
1	**Excavation**				**32.514.332**		**40.962.791**		**24.877.222**
1,1	Overburden	m³	1.016.873	3,50	3.559.056	4,30	4.372.554	2,70	2.745.557
1,2	Weathered	m³	254.218	4,75	1.207.537	5,90	1.499.888	3,60	915.186
1,3	Rock	m³	3.813.274	6,00	22.879.643	7,50	28.599.553	4,50	17.159.732
1,4	Overhaul of spoil (10 km)	m³km	16.226.991	0,30	4.868.097	0,40	6.490.796	0,25	4.056.748
2	**Fill**				**4.021.194**		**5.358.745**		**2.683.643**
2,1	Backfill	m³	1.336.602	3,00	4.009.805	4,00	5.346.406	2,00	2.673.203
2,2	Gravel layer	m³	1.898	6,00	11.389	6,50	12.338	5,50	10.440
2,3	Bank protection WSB	m²	0	13,00	0	15,65	0	8,60	0
3	**Concrete**				**212.257.661**		**262.793.895**		**161.674.756**
3,1	RC	m³	1.432.109	120,00	171.853.093	150,00	214.816.366	90,00	128.889.820
3,2	RCC	m³	1.234.922	28,00	34.577.810	33,00	40.752.419	23,00	28.403.201
3,3	Concrete slab	m³	5.696	120,00	683.472	150,00	854.340	90,00	512.604
3,4	Lean Concrete	m²	85.092	9,00	765.825	11,00	936.009	6,80	578.624
3,5	Pavement	m²	67.150	24,00	1.611.600	30,00	2.014.500	18,00	1.208.700
3,6	Concrete layer chamber bottom	m³	14.826	90,00	1.334.297	110,00	1.630.808	68,00	1.008.136
3,7	Shotcrete (Temporary protection in La Boca)	m²	57.263	25,00	1.431.563	31,25	1.789.453	18,75	1.073.672
4	**Reinforcement**				**87.089.403**		**99.530.746**		**74.648.059**
4,1	Steel reinforcement	tons	99.531	875,00	87.089.403	1.000,00	99.530.746	750,00	74.648.059

TASK 4 - CONFIGURATION 2

Table E.3
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total Cost Combination 2-A

Lock without WSB'

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
5	**Other**				**12.560.684**		**15.791.907**		**9.329.461**
5,1	Steel corner protection	m	3.402	73,00	248.346	78,00	265.356	68,00	231.336
5,2	Rubber joint	m	5.855	71,00	415.705	112,00	655.760	30,00	175.650
5,3	Geotextile	m²	0	1,80	0	2,25	0	1,50	0
5,4	Liner HDPE (WSB1)	m²	0	13,31	0	16,63	0	10,00	0
5,5	Underlaying protective geotextile (WSB1)	m²	0	1,88	0	2,35	0	1,45	0
5,6	Geotextile for drainage (WSB1)	m²	0	4,71	0	5,90	0	3,55	0
5,7	Rails	m	3.882	280,00	1.086.960	350,00	1.358.700	210,00	815.220
5,8	Rails LSW	m	510	1.000,00	510.000	1.250,00	637.500	750,00	382.500
5,9	Wooden vertical guidances	m	484	400,00	193.600	500,00	242.000	300,00	145.200
5,10	Steel for support rail and frames	ton	804	2.400,00	1.929.552	3.000,00	2.411.940	1.800,00	1.447.164
5,11	Vertical element for seals east/recesses	m³	579	3.050,00	1.765.950	3.812,50	2.207.438	2.287,50	1.324.463
5,12	Vertical element for seals west	m³	664	2.700,00	1.792.800	3.375,00	2.241.000	2.025,00	1.344.600
5,13	Horizontal elements for seals lock chamber	m³	282	2.700,00	762.480	3.375,00	953.100	2.025,00	571.860
5,14	Elements for placement habitat	m³	457	275,00	125.565	343,75	156.956	206,25	94.174
5,15	Horizontal elements for seals gate recesses	m³	88	1.520,00	133.526	1.900,00	166.907	1.140,00	100.144
5.16.1	Bridge over recesses LHG 1	pcs	2	500.000,00	1.000.000	625.000,00	1.250.000	375.000,00	750.000
5.16.2	Bridge over recesses LHG 2	pcs	2	750.000,00	1.500.000	937.500,00	1.875.000	562.500,00	1.125.000
5,17	Technical building	m²	3.654	300,00	1.096.200	375,00	1.370.250	225,00	822.150
6	**Accessories**				**1.504.800**		**1.881.000**		**1.128.600**
6,1	Bollards 1500kN	pcs	36	4.900,00	176.400	6.125,00	220.500	3.675,00	132.300
6,2	Fenders	pcs	2	540.000,00	1.080.000	675.000,00	1.350.000	405.000,00	810.000
6,3	Ladders	m	1.800	100,00	180.000	125,00	225.000	75,00	135.000
6,4	Mooring bits	pcs	72	950,00	68.400	1.187,50	85.500	712,50	51.300
	Total Cost				**349.948.073**		**426.319.084**		**274.341.742**

TASK 4 - CONFIGURATION 2

Table E.4
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total Cost Combination 3-B

Lock without WSB'

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
1	**Excavation**				**36.837.402**		**46.313.300**		**28.095.895**
1,1	Overburden	m³	1.192.866	3,50	4.175.032	4,30	5.129.326	2,70	3.220.739
1,2	Weathered	m³	298.217	4,75	1.416.529	5,90	1.759.478	3,60	1.073.580
1,3	Rock	m³	4.473.249	6,00	26.839.494	7,50	33.549.368	4,50	20.129.621
1,4	Overhaul of spoil (10 km)	m³km	14.687.824	0,30	4.406.347	0,40	5.875.129	0,25	3.671.956
2	**Fill**				**7.024.419**		**9.363.045**		**4.685.793**
2,1	Backfill	m³	2.337.677	3,00	7.013.031	4,00	9.350.708	2,00	4.675.354
2,2	Gravel layer	m³	1.898	6,00	11.388	6,50	12.337	5,50	10.439
2,3	Bank protection WSB	m²	0	13,00	0	15,65	0	8,60	0
3	**Concrete**				**273.996.180**		**341.192.383**		**206.741.078**
3,1	RC	m³	2.092.150	120,00	251.057.972	150,00	313.822.465	90,00	188.293.479
3,2	RCC	m³	614.609	28,00	17.209.053	33,00	20.282.098	23,00	14.136.008
3,3	Concrete slab	m³	5.696	120,00	683.520	150,00	854.400	90,00	512.640
3,4	Lean Concrete	m²	128.228	9,00	1.154.049	11,00	1.410.505	6,80	871.948
3,5	Pavement	m²	40.150	24,00	963.600	30,00	1.204.500	18,00	722.700
3,6	Concrete layer chamber bottom	m³	16.627	90,00	1.496.423	110,00	1.828.962	68,00	1.130.631
3,7	Shotcrete (Temporary protection in La Boca)	m²	57.263	25,00	1.431.563	31,25	1.789.453	18,75	1.073.672
4	**Reinforcement**				**136.507.335**		**156.008.383**		**117.006.287**
4,1	Steel reinforcement	tons	156.008	875,00	136.507.335	1.000,00	156.008.383	750,00	117.006.287

TASK 4 - CONFIGURATION 2

Table E.4
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total Cost Combination 3-B

Lock without WSB'

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
5	**Other**				**12.973.144**		**16.372.251**		**9.574.037**
5,1	Steel corner protection	m	5.294	73,00	386.462	78,00	412.932	68,00	359.992
5,2	Rubber joint	m	9.719	71,00	690.049	112,00	1.088.528	30,00	291.570
5,3	Geotextile	m²	0	1,80	0	2,25	0	1,50	0
5,4	Liner HDPE (WSB1)	m²	0	13,31	0	16,63	0	10,00	0
5,5	Underlaying protective geotextile (WSB1)	m²	0	1,88	0	2,35	0	1,45	0
5,6	Geotextile for drainage (WSB1)	m²	0	4,71	0	5,90	0	3,55	0
5,7	Rails	m	3.882	280,00	1.086.960	350,00	1.358.700	210,00	815.220
5,8	Rails LSW	m	510	1.000,00	510.000	1.250,00	637.500	750,00	382.500
5,9	Wooden vertical guidances	m	484	400,00	193.600	500,00	242.000	300,00	145.200
5,10	Steel for support rail and frames	ton	804	2.400,00	1.929.552	3.000,00	2.411.940	1.800,00	1.447.164
5,11	Vertical element for seals east/recesses	m³	579	3.050,00	1.765.950	3.812,50	2.207.438	2.287,50	1.324.463
5,12	Vertical element for seals west	m³	664	2.700,00	1.792.800	3.375,00	2.241.000	2.025,00	1.344.600
5,13	Horizontal elements for seals lock chamber	m³	282	2.700,00	762.480	3.375,00	953.100	2.025,00	571.860
5,14	Elements for placement habitat	m³	457	275,00	125.565	343,75	156.956	206,25	94.174
5,15	Horizontal elements for seals gate recesses	m³	88	1.520,00	133.526	1.900,00	166.907	1.140,00	100.144
5.16.1	Bridge over recesses LHG 1	pcs	2	500.000,00	1.000.000	625.000,00	1.250.000	375.000,00	750.000
5.16.2	Bridge over recesses LHG 2	pcs	2	750.000,00	1.500.000	937.500,00	1.875.000	562.500,00	1.125.000
5,17	Technical building	m²	3.654	300,00	1.096.200	375,00	1.370.250	225,00	822.150
6	**Accessories**				**1.504.800**		**1.881.000**		**1.128.600**
6,1	Bollards 1500kN	pcs	36	4.900,00	176.400	6.125,00	220.500	3.675,00	132.300
6,2	Fenders	pcs	2	540.000,00	1.080.000	675.000,00	1.350.000	405.000,00	810.000
6,3	Ladders	m	1.800	100,00	180.000	125,00	225.000	75,00	135.000
6,4	Mooring bits	pcs	72	950,00	68.400	1.187,50	85.500	712,50	51.300
	Total Cost				**468.843.281**		**571.130.363**		**367.231.690**

TASK 4 - CONFIGURATION 2

Table E.5
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total WSB Cost

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
1	Reinforced concrete	m³	234.193	120,00	28.103.184	150,00	35.128.980	90,00	21.077.388
2	Steel reinforcement BE500	tons	18.188	875,00	15.914.776	1.000,00	18.188.315	750,00	13.641.236
3	Roller compact concrete over conduits	m³	77.150	28,00	2.160.200	33,00	2.545.950	23,00	1.774.450
4	Backfill crushed stone over conduits	m³	448.421	3,00	1.345.263	4,00	1.793.684	2,00	896.842
5	Liner HDPE (WSB)	m²	0	13,31	0	16,63	0	10,00	0
6	Underlaying protective geotextile (WSB)	m²	0	1,88	0	2,35	0	1,45	0
7	Geotextile for drainage (WSB)	m²	0	4,71	0	5,90	0	3,55	0
8	Bank protection WSB	m²	0	13,00	0	15,65	0	8,60	0
10	Excavation								0
10,1	Overburden excavation	m³	460.556	3,50	1.611.945	4,30	1.980.389	2,70	1.243.500
10,2	La Boca / weathered rock excavation	m³	115.139	4,75	546.910	5,90	679.320	3,60	414.500
10,3	Rock excavation	m³	1.727.084	6,00	10.362.501	7,50	12.953.126	4,50	7.771.876
11	Backfill WSB 1 to 6	m³	178.124	3,00	534.372	4,00	712.496	2,00	356.248
12	Overhaul for spoil (10 km)	m³km	16.762.330	0,30	5.028.699	0,40	6.704.932	0,25	4.190.583
13	Technical building	m²	506	300,00	151.800	375,00	189.750	225,00	113.850
	Total Cost				65.759.649		80.876.942		51.480.473

TASK 4 - CONFIGURATION 2

Table E.6
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Cost Estimate

CIVIL WORKS SUMMARY

Item	Description	Combination 1-B Total USD - 2002	Combination 2-A Total USD - 2002	Combination 3-B Total USD - 2002
1	**Excavation for lock**	31.433.728	32.514.332	36.837.402
2	**Entrance walls [1]**	53.373.780	45.994.770	107.265.270
3	**Lock walls [1]**	70.223.215	68.877.925	85.373.100
4	**Lock heads [1]**	201.056.246	201.056.246	237.862.708
5	**Accessories**	1.504.800	1.504.800	1.504.800
	LOCK TOTAL COST	**357.591.769**	**349.948.073**	**468.843.281**
6	**WSB and conduits (excavation and fill included)**	65.759.649	65.759.649	65.759.649

[1] Include cost for backfill crushed stone

TASK 4 - CONFIGURATION 2

Table E.7
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Aggregate Unit Price

Item	Description	Unit	Selected Unit Price USD 2002		
			Maximun	Selected	Minimum
1	**Excavations**				
1,1	Overburden	m³	4,30	3,50	2,70
1,2	Weathered	m³	5,90	4,75	3,60
1,3	Rock	m³	7,50	6,00	4,50
1,4	Overhaul of spoil (10 km)	m³km	0,40	0,30	0,25
2	**Fill**				
2,1	Backfill	m³	4,00	3,00	2,00
2,2	Gravel layer	m³	6,50	6,00	5,50
2,3	Bank protection WSB1	m²	15,65	13,00	8,60
3	**Concrete**				
3,1	RC	m³	150,00	120,00	90,00
3,2	RCC	m³	33,00	28,00	23,00
3,3	Concrete slab	m³	150,00	120,00	90,00
3,4	Lean Concrete	m²	11,00	9,00	6,80
3,5	Pavement	m²	30,00	24,00	18,00
3,6	Concrete layer chamber bottom	m³	110,00	90,00	68,00
3,7	Shotcrete (Temporary protection in La Boca)	m²	31,25	25,00	18,75
4	**Reinforcement**				
4,1	Steel reinforcement	tons	1.000,00	875,00	750,00
5	**Other**				
5,1	Steel corner protection	m	78,00	73,00	68,00
5,2	Rubber joint	m	112,00	71,00	30,00
5,3	Geotextile	m²	2,25	1,80	1,50
5,4	Liner HDPE (WSB1)	m²	16,63	13,31	10,00
5,5	Underlaying protective geotextile (WSB1)	m²	2,35	1,88	1,45
5,6	Geotextile for drainage (WSB1)	m²	5,90	4,71	3,55
5,7	Rails	m	350,00	280,00	210,00
5,8	Rails LSW	m	1.250,00	1.000,00	750,00
5,9	Wooden vertical guides	m	500,00	400,00	300,00
5,10	Steel for support rail and frames	ton	3.000,00	2.400,00	1.800,00
5,11	Vertical element for seals east/recesses	m³	3.812,50	3.050,00	2.287,50
5,12	Vertical element for seals west	m³	3.375,00	2.700,00	2.025,00
5,13	Horizontal elements for seals lock chamber	m³	3.375,00	2.700,00	2.025,00
5,14	Elements for placement habitat	m³	343,75	275,00	206,25

TASK 4 - CONFIGURATION 2

Table E.7
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Aggregate Unit Price

Item	Description	Unit	Selected Unit Price USD 2002		
			Maximun	Selected	Minimum
5,15	Horizontal elements for seals gate recesses	m³	1.900,00	1.520,00	1.140,00
5,16	Bridge over recesses	pcs	625.000	500.000	375.000
5,17	Fixed ballast for gate stability	ton	625,00	500,00	375,00
5,18	Technical building	m²	375,00	300,00	225,00
6	**Accessories**				
6,1	Bollards 1500kN	pcs	6.125,00	4.900,00	3.675,00
6,2	Fenders	pcs	675.000	540.000	405.000
6,3	Ladders	m	125,00	100,00	75,00
6,4	Mooring bits	pcs	1.187,50	950,00	712,50

Table E.8
Cost Estimate
Excavation and Fill

Item	Description	Unit	Unit Price	Combination 1-B		Combination 2-A		Combination 3-B	
				Quantity	Total USD - 2002	Quantity	Total USD - 2002	Quantity	Total USD - 2002
1	**Excavation**								
1,1	Overburden excavation	m³	3,50	1.016.873	3.559.056	1.016.873	3.559.056	1.192.866	4.175.032
1,2	La Boca / weathered rock excavation	m³	4,75	254.218	1.207.537	254.218	1.207.537	298.217	1.416.529
1,3	Rock excavation	m³	6,00	3.813.274	22.879.643	3.813.274	22.879.643	4.473.249	26.839.494
1,4	Overhaul for spoil (10 km) Combination 1-B	m³km	0,30	12.624.976	3.787.493				
1,5	Overhaul for spoil (10 km) Combination 2-A	m³km	0,30			16.226.991	4.868.097		
1,6	Overhaul for spoil (10 km) Combination 3-B	m³km	0,30					14.687.824	4.406.347
2	**Fill**								
2,1	Backfill Combination 1-B	m³	3,00	2.212.509	6.637.527				
2,2	Backfill Combination 2-A	m³	3,00			1.336.602	4.009.805		
2,3	Backfill Combination 3-B	m³	3,00					2.337.677	7.013.031
	Total Cost Combination 1-B				**38.071.255**				
	Total Cost Combination 2-A						**36.524.137**		
	Total Cost Combination 3-B								**43.850.434**

TASK 4 - CONFIGURATION 2

Table E.9

Cost Estimate
Entrance Walls

Option A : RCC + RC

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	Reinforced Concrete	m³	120,00	188.843	22.661.100
2	Steel Reinforcement BE500	tons	875,00	9.428	8.249.063
3	Backfill Crushed Stone	m³	3,00	237.780	713.340
4	Steel Corner Protection	m	73,00	1.350	98.550
5	Rubber Joint	m	71,00	1.845	130.995
6	Lean Concrete	m²	9,00	20.250	182.250
7	RCC	m³	28,00	424.283	11.879.910
8	Pavement	m²	24,00	27.000	648.000
9	Shotcrete (Temporary protection in La Boca)	m²	25,00	57.263	1.431.563
	Total Cost				**45.994.770**

TASK 4 - CONFIGURATION 2

Table E.10
Cost Estimate
Entrance Walls
Option B : RC

Item	Description	Unit	Unit Price	Combination 1-B		Combination 3-B	
				Quantity	Total USD - 2002	Quantity	Total USD - 2002
1	Reinforced Concrete	m³	120,00	264.083	31.689.900	555.813	66.697.560
2	Steel Reinforcement BE500	tons	875,00	19.800	17.325.000	40.785	35.686.547
3	Backfill Crushed Stone	m³	3,00	622.508	1.867.523	842.517	2.527.551
4	Steel Corner Protection	m	73,00	1.350	98.550	2.700	197.100
5	Rubber Joint	m	71,00	1.845	130.995	4.050	287.550
6	Lean Concrete	m²	9,00	20.250	182.250	48.600	437.400
7	Pavement	m²	24,00	27.000	648.000	0	0
8	Shotcrete (Temporary protection in La Boca)	m²	25,00	57.263	1.431.563	57.263	1.431.563
	Total Cost				**53.373.780**		**107.265.270**

TASK 4 - CONFIGURATION 2

Table E.11.1
Cost Estimate
Lock Walls
Option 1

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	Reinforced Concrete	m³	120,00	352.630	42.315.600
2	Steel Reinforcement BE500	tons	875,00	26.450	23.143.750
3	Backfill Crushed Stone	m³	3,00	623.410	1.870.230
4	RCC	m³	28,00	0	0
5	Concrete Layer Chamber Bottom	m³	90,00	4.060	365.400
6	Steel Corner Protection	m	73,00	600	43.800
7	Rubber joint	m	71,00	1.810	128.510
8	Pavement	m²	24,00	4.500	108.000
9	Lean Concrete	m²	9,00	25.600	230.400
10	Conduit under locks				
10,1	Reinforced Concrete (for all chambers)	m³	120,00	10.870	1.304.400
10,2	Steel Reinforcement BE500	tons	875,00	815	713.125
	Total Cost				**70.223.215**

Table E.11.2
Cost Estimate
Lock Walls
Option 2

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	Reinforced Concrete	m³	120,00	318.020	38.162.400
2	Steel Reinforcement BE500	tons	875,00	20.710	18.121.250
3	Backfill Crushed Stone	m³	3,00	132.230	396.690
4	RCC	m³	28,00	338.960	9.490.880
5	Concrete Layer Chamber Bottom	m³	90,00	3.460	311.400
6	Steel Corner Protection	m	73,00	600	43.800
7	Rubber joint	m	71,00	1.810	128.510
8	Pavement	m²	24,00	0	0
9	Lean Concrete	m²	9,00	22.830	205.470
10	Conduit under locks				
10,1	Reinforced Concrete (for all chambers)	m³	120,00	10.870	1.304.400
10,2	Steel Reinforcement BE500	tons	875,00	815	713.125
	Total Cost				**68.877.925**

TASK 4 - CONFIGURATION 2

Table E.11.3

Cost Estimate
Lock Walls

Option 3

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	Reinforced Concrete	m³	120,00	436.150	52.338.000
2	Steel Reinforcement BE500	tons	875,00	32.710	28.621.250
3	Backfill Crushed Stone	m³	3,00	471.420	1.414.260
4	RCC	m³	28,00	0	0
5	Concrete Layer Chamber Bottom	m³	90,00	5.260	473.400
6	Steel Corner Protection	m	73,00	900	65.700
7	Rubber joint	m	71,00	2.715	192.765
8	Pavement	m²	24,00	0	0
9	Lean Concrete	m²	9,00	27.800	250.200
10	Conduit under locks				
10,1	Reinforced Concrete (for all chambers)	m³	120,00	10.870	1.304.400
10,2	Steel Reinforcement BE500	tons	875,00	815	713.125
	Total Cost				**85.373.100**

TASK 4 - CONFIGURATION 2

Table E.12

Cost Estimate
WSB and Conduits (Civil Works)

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	Reinforced concrete	m³	120,00	234.193	28.103.184
2	Steel reinforcement BE500	tons	875,00	18.188	15.914.776
3	Roller compact concrete over conduits	m³	28,00	77.150	2.160.200
4	Backfill crushed stone over conduits	m³	3,00	448.421	1.345.263
5	Liner HDPE (WSB)	m²	13,31	0	0
6	Underlaying protective geotextile (WSB)	m²	1,88	0	0
7	Geotextile for drainage (WSB)	m²	4,71	0	0
8	Bank protection WSB	m²	13,00	0	0
10	Excavation				
10,1	Overburden excavation	m³	3,50	460.556	1.611.945
10,2	La Boca / weathered rock excavation	m³	4,75	115.139	546.910
10,3	Rock excavation	m³	6,00	1.727.084	10.362.501
11	Backfill WSB 1 to 6	m³	3,00	178.124	534.372
12	Overhaul for spoil (10 km)	m³km	0,30	16.762.330	5.028.699
13	Technical building	m²	300,00	506	151.800
	Total Cost				**65.759.649**

Table E.13

Cost Estimate
Lock Head Gate

Item	Description	Unit	Unit Price	Combination 1-B / 2-A		Combination 3-B	
				Quantity	Total USD - 2002	Quantity	Total USD - 2002
1	Reinforced Concrete	m³	120,00	654.442	78.532.993	699.415	83.929.760
2	Steel Reinforcement BE500	ton	875,00	49.083	42.947.840	52.456	45.899.088
3	Backfill crushed stone	m³	3,00	852.296	2.556.887	852.296	2.556.887
4	Backfill RCC	m³	28,00	193.839	5.427.492	193.839	5.427.492
5	Concrete layer chamber bottom	m³	90,00	4.296	386.633	4.296	386.633
6	Steel corner protection	m	73,00	968	70.664	968	70.664
7	Rubber joint	m	71,00	692	49.132	692	49.132
8	Lean concrete	m²	9,00	22.380	201.417	22.380	201.417
9	Pavement	m²	24,00	26.230	629.520	26.230	629.520
10	Technical building	m²	300,00	3.654	1.096.200	3.654	1.096.200
	Total Cost				**131.898.779**		**140.246.793**

TASK 4 - CONFIGURATION 2

Table E.14
Cost Estimate
Transition Segment

Item	Description	Unit	Unit Price	Combinations 1-B / 2-A		Combination 3-B	
				Quantity	Total USD - 2002	Quantity	Total USD - 2002
1	Reinforced concrete	m³	120,00	259.935	31.192.200	389.902	46.788.253
2	Steel reinforcement BE500	ton	875,00	19.495	17.058.125	29.243	25.587.326
3	Backfill crushed stone	m³	3,00	114.296	342.888	171.444	514.333
4	Backfil RCC	m³	28,00	277.840	7.779.528	420.770	11.781.561
5	Concrete layer chamber bottom	m³	90,00	7.070	636.264	7.071	636.390
6	Concrete slabs	m³	120,00	5.696	683.472	5.696	683.520
7	Gravel layer	m³	6,00	1.898	11.389	1.898	11.388
8	Steel corner protection	m	73,00	484	35.332	726	52.998
9	Rubber joint	m	71,00	1.508	107.068	2.262	160.602
10	Lean concrete	m²	9,00	19.632	176.688	29.448	265.032
11	Pavement	m²	24,00	13.920	334.080	13.920	334.080
	Total Cost				**58.357.035**		**86.815.482**

TASK 4 - CONFIGURATION 2

Table E.15

Cost Estimate
Lock Head Gate
Equipment (Civil Part)

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	Equipment lock gate (civil part)				3.720.112
1,1	Rails	m	280,00	3.882	1.086.960
1,2	Rails LSW Lock Head 2	m	1.000,00	510	510.000
1,3	Wooden vertical guidances	m	400,00	484	193.600
1,4	Steel for support rails and frames	tons	2.400,00	804	1.929.552
2	Equipment lock head (civil part)				7.080.321
2,1	Vertical elements for seals - east/recesses	m^3	3.050,00	579	1.765.950
2,2	Vertical elements for seals - west	m^3	2.700,00	664	1.792.800
2,3	Horizontal elements for seals- lock chamber	m^3	2.700,00	282	762.480
2,4	Elements for placement habitat	m^3	275,00	457	125.565
2,5	Horizontal elements for seals- gate recesses	m^3	1.520,00	88	133.526
2,6	Bridges over recesses	pcs			
2.6.1	Bridges over recesses LHG 1	pcs	500.000	2	1.000.000
2.6.2	Bridges over recesses LHG 2	pcs	750.000	2	1.500.000
	Total Cost				**10.800.433**

TASK 4 - CONFIGURATION 2

Table E.16
Cost Estimate
Accessories

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	**Accessories**				
1,1	Bollards 1500kN	pcs	4.900	36	176.400
1,2	Fenders	pcs	540.000	2	1.080.000
1,3	Ladders	m	100	1.800	180.000
1,4	Mooring Bits	pcs	950	72	68.400
	Total Cost				**1.504.800**

TASK 4 - CONFIGURATION 2

Table E.17
Cost Estimate
ELECTROMECHANICAL EQUIPMENT

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	**EM Equipment lock**				**213.824.454**
1,1	EM Equipment Lock (gates and bulkheads)	tons		29.098	185.296.954
1.1.1	*EM Equipment Lock Head 1 (gates and bulkheads)*	*tons*	*6.173*	*3.741*	*23.093.193*
1.1.2	*EM Equipment Lock Head 2 (gates and bulkheads)*	*tons*	*6.173*	*25.357*	*156.528.761*
	Fixed ballast for gate stability (2)	*tons*	*500*	*11.350*	*5.675.000*
1,2	EM Equipment Lock (culvert valves and bulkheads)	tons	5.000	766	3.827.500
1,4	Support equipment		14.700.000	1	14.700.000
1,5	Control system		1.700.000	1	1.700.000
1,6	Lighting System		1.200.000	1	1.200.000
1,7	Electrical and Power System		7.100.000	1	7.100.000
2	**EM Equipment WSB (Support and control system**	tons	5.000	3.007	**15.032.500**
	Total Cost				**228.856.954**

Table E.18
Excavation and Fill Quantities

Item	Description	Unit	Combination 1-B		Combination 2-A		Combination 3-B	
			Excavation	Backfill	Excavation	Backfill	Excavation	Backfill
1	Lock from edge east wall Gatun side up to edge east wall Pacific side	m³	*4.569.425*		*4.569.425*		*4.826.392*	
2	Entrance wall Pacific side	m³	314.940	341.865	314.940	129.105	657.940	442.962
3	Entrance wall Gatun side	m³	200.000	280.643	200.000	108.675	480.000	399.555
4	Lock walls [1]	m³		623.410		132.230		471.420
5	Lock head gate [1]	m³		852.296		852.296		852.296
6	Transition segment [1]	m³		114.296		114.296		171.444
7	Overhaul for spoil (10 km) Combination 1-B	m³km	12.624.976					
8	Overhaul for spoil (10 km) Combination 2-A	m³km			16.226.991			
9	Overhaul for spoil (10 km) Combination 3-B	m³km					14.687.824	

[1] Excavation include in item 1

[2] For WSB´s Excavation and Backfill quantities, see Table E.22

TASK 4 - CONFIGURATION 2

Table E.19
Entrance Walls
Option A : RCC + RC
Quantities Summary

Item	Description	Unit	Combination 2-A	
			Pacific Side	Gatun Side
			Quantity	Quantity
1	Reinforced Concrete	m³	4.266	4.127
2	Steel Reinforcement BE500	tons	213	206
3	Backfill Crushed Stone	m³	5.738	4.830
4	Steel Corner Protection	m	30	30
5	Rubber Joint	m	42	40
6	Lean Concrete	m²	450	450
7	RCC	m³	9.945	8.912
8	Pavement	m²	600	600
9	Shotcrete (Temporary protection in La Boca)	m²	1.660	885
	Quantities for one 30 m-segment:			
	Number of segments of 30 m:		22,5	22,5

TASK 4 - CONFIGURATION 2

Table E.20
Entrance Walls
Option B : RC
Quantities Summary

Item	Description	Unit	Combination 1-B		Combination 3-B	
			Pacific Side	Gatun Side	Pacific Side	Gatun Side
			Quantity	Quantity	Quantity	Quantity
1	Reinforced Concrete	m³	5.998	5.739	12.641	12.062
2	Steel Reinforcement BE500	tons	450	430	908	905
3	Backfill Crushed Stone	m³	15.194	12.473	19.687	17.758
4	Steel Corner Protection	m	30	30	60	60
5	Rubber Joint	m	42	40	92	88
6	Lean Concrete	m²	450	450	1.080	1.080
7	Pavement	m²	600	600	0	0
8	Shotcrete (Temporary protection in La Boca)	m²	1.660	885	1.660	885
	Quantities for one 30 m-segment:					
	Number of segments of 30 m:		22,5	22,5	22,5	22,5

TASK 4 - CONFIGURATION 2

Table E.21
Lock Walls
Quantities Summary

Item	Description	Unit	Eastern Lock Wall	Western Lock Wall		
				Combination 1-B	Combination 2-A	Combination 3-B
			Quantity	Quantity	Quantity	Quantity
1	Reinforced Concrete	m³	*19.228*	*16.035*	*12.574*	*24.387*
1.1	Bottom Part with Culvert	m³	2.517	2.517	2.742	5.483
1.2	Toe	m³	6.729	6.729	5.850	6.750
1.3	Front Wall	m³	*3.174*	*2.116*	*2.026*	*4.052*
1.4	Top Structure	m³	1.911	1.575	1.956	4.710
1.5	Counterforts	m³	*4.897*	*3.098*	*0*	*3.392*
2	Steel Reinforcement BE500	tons	*1.442*	*1.203*	*629*	*1.829*
3	Backfill Crushed Stone	m³	*13.223*	*49.118*	*0*	*33.919*
4	RCC	m³	0	0	33.896	0
5	Concrete Layer Chamber Bottom	m³	*203*	*203*	*143*	*323*
6	Steel Corner Protection	m	30	30	30	60
7	Rubber joint	m	91	91	91	181
8	Pavement	m²	0	450	0	0
9	Lean Concrete	m²	1.280	1.280	1.003	1.500
	Quantities for one 30 m-segment:					
	Number of segments of 30 m:		10	10	10	10
10	Conduits under lock		Lock			
10.1	Reinforced Concrete (for all chamber)	m³	*10.870*			
10.2	Steel Reinforcement BE500 (for all chamber)	tons	*815*			

TASK 4 - CONFIGURATION 2

Table E.22
WSB and Conduits (Civil Works)
Quantities Summary

Item	Description	Unit	Quantity
1	Reinforced concrete for valve chambers and valve connection	m³	59.069
2	Steel reinforcement BE500	tons	4.430
3	Reinforced concrete for conduits	m³	*53.425*
4	Steel reinforcement BE500	tons	*4.007*
5	Reinforced concrete for intakes WSB	m³	96.739
6	Steel reinforcement BE500	tons	7.255
7	Roller compacted concrete	m³	*77.150*
8	Backfill Crushed Stone	m³	*448.421*
9	Reinforced concrete for walls between WSB	m³	24.960
10	Steel reinforcement BE500	tons	2.496
11	Liner HDPE (WSB1)	m²	0
12	Underlaying protective geotextile (WSB1)	m²	0
13	Geotextile for drainage (WSB1)	m²	0
14	Bank protection WSB1	m²	0
15	Excavations		
15,1	WSB 1 to 6	m³	*1.718.967*
15,2	Extra conduits	m³	*583.811*
16	Backfill WSB 1 to 6	m³	*178.124*
17	Overhaul for spoil (10 km)	m³km	*16.762.330*
18	Technical building	m²	506

Quantities Summary

Item	Description	Unit	Quantity
1	Reinforced concrete	m³	234.193
2	Steel reinforcement BE500	tons	18.188
3	Roller compacted concrete	m³	77.150
4	Backfill Crushed Stone	m³	448.421
5	Liner HDPE (WSB1)	m²	0
6	Underlaying protective geotextile (WSB1)	m²	0
7	Geotextile for drainage (WSB1)	m²	0
8	Bank protection WSB1	m²	0
9	Excavations	m³	2.302.778
10	Backfill WSB 1 to 6	m³	178.124
11	Overhaul for spoil (10 km)	m³km	16.762.330
12	Technical building	m²	506

TASK 4 - CONFIGURATION 2

Table E.23
Lock Head Gate
Quantities Summary

Item	Description	Unit	Combinations 1-B / 2-A	Combination 3-B
			Quantity	Quantity
1	**Lock Head Gate 1**			
1,1	Reinforced Concrete	m³	*176.225*	*189.442*
1,2	Steel Reinforcement BE500	ton	*13.217*	*14.208*
1,3	Backfill crushed stone	m³	137.084	137.084
1,4	Backfill RCC	m³	22.086	22.086
1,5	Concrete layer chamber bottom	m³	*1.674*	*1.674*
1,6	Steel corner protection	m	428	428
1,7	Rubber joint	m	324	324
1,8	Lean concrete	m²	8.078	8.078
1,9	Pavement	m²	10.500	10.500
2	**Lock Head Gate 2**			
2,1	Reinforced Concrete	m³	*423.217*	*454.973*
2,2	Steel Reinforcement BE500	ton	*31.741*	*34.123*
2,3	Backfill crushed stone	m³	465.212	465.212
2,4	Backfill RCC	m³	171.753	171.753
2,5	Concrete layer chamber bottom	m³	*2.621*	*2.621*
2,6	Steel corner protection	m	540	540
2,7	Rubber joint	m	368	368
2,8	Lean concrete	m²	14.302	14.302
2,9	Pavement	m²	15.730	15.730
3	**Concrete L-shaped walls behind lock heads 1 and 2**			
3,1	Reinforced Concrete	m³	*55.000*	*55.000*
3,2	Steel Reinforcement BE500	ton	*4.125*	*4.125*
3,3	Backfill crushed stone	m³	*250.000*	*250.000*
4	**Operation and maintenance buildings**			
4,1	Technical building	m²	3.654	3.654

TASK 4 - CONFIGURATION 2

Table E.24
Transition Segment
Quantities Summary

Item	Description	Unit	Combinations 1-B / 2-A	Combination 3-B
			Quantity	Quantity
1	**Lock Head Gate 1**			
1,1	Transition segment side Gatún			
1,11	Reinforced concrete	m³	37.135	*55.702*
1,12	Steel reinforcement BE500	ton	2.785	*4.178*
1,13	Backfill crushed stone	m³	22.846	34.270
1,14	Backfill RCC	m³	15.490	27.245
1,15	Concrete slabs	m³	*3.772*	*3.772*
1,16	Gravel layer	m³	*1.257*	*1.257*
1,17	Steel corner protection	m	112	168
1,18	Rubber joint	m	368	552
1,19	Lean concrete	m²	4.032	6.048
1,20	Pavement	m²	3.360	3.360
1,2	Transition segment side lock chamber			
1,21	Reinforced concrete	m³	95.738	143.607
1,22	Steel reinforcement BE500	ton	7.180	10.771
1,23	Backfill crushed stone	m³	21.558	32.337
1,24	Backfill RCC	m³	129.816	194.723
1,25	Concrete layer chamber bottom	m³	*802*	*802*
1,26	Steel corner protection	m	150	225
1,27	Rubber joint	m	380	570
1,28	Lean concrete	m²	6.160	9.240
1,29	Pavement	m²	4.200	4.200

TASK 4 - CONFIGURATION 2

Table E.24
Transition Segment
Quantities Summary

Item	Description	Unit	Combinations 1-B / 2-A Quantity	Combination 3-B Quantity
2	**Lock Head Gate 2**			
2,1	Transition segment side Pacific			
2,11	Reinforced concrete	m³	61.348	92.022
2,12	Steel reinforcement BE500	ton	4.601	6.902
2,13	Backfill crushed stone	m³	46.086	69.129
2,14	Backfill RCC	m³	39.809	59.713
2,15	Concrete slabs	m³	*1.924*	*1.924*
2,16	Gravel layer	m³	*641*	*641*
2,17	Steel corner protection	m	112	168
2,18	Rubber joint	m	380	570
2,19	Lean concrete	m²	5.040	7.560
2,20	Pavement	m²	3.360	3.360
2,2	Transition segment side lock chamber			
2,21	Reinforced concrete	m³	65.714	98.571
2,22	Steel reinforcement BE500	ton	4.929	7.393
2,23	Backfill crushed stone	m³	23.806	35.709
2,24	Backfill RCC	m³	92.725	139.088
2,25	Concrete layer chamber bottom	m³	*573*	*573*
2,26	Steel corner protection	m	110	165
2,27	Rubber joint	m	380	570
2,28	Lean concrete	m²	4.400	6.600
2,29	Pavement	m²	3.000	3.000

TASK 4 - CONFIGURATION 2

Table E.25

Lock Head Gate

Quantities Summary
Equipment (Civil Part)

Item	Description	Unit	Quantity
1	**Lock Head Gate 1**		
1,1	Equipment lock gate (civil part)		
1.1.1	Rails USW	m	*296*
1.1.2	Rails LSW	m	*296*
1.1.3	Rails MSW	m	340
1.1.4	Rails horizontale guidances in recesses	m	*296*
1.1.5	Wooden vertical guidance in recesses	m	136
1.1.6	Steel for support rails USW	tons	*118*
1.1.7	Steel for support rails LSW	tons	*118*
1.1.8	Steel for support rails guidance	tons	*44*
1.1.9	Maintenance support frames	tons	60
1,2	Equipment lock head (civil part)		
1.2.1	Vertical elements for seals - east/recesses	m^3	138
1.2.2	Vertical elements for seals - west	m^3	181
1.2.3	Horizontal elements for seals- lock chamber	m^3	*224*
1.2.4	Elements for placement habitat	m^3	*223*
1.2.5	Horizontal elements for seals- gate recesses	m^3	*41*
1.2.6	Bridges over recesses	pcs	2

TASK 4 - CONFIGURATION 2

Table E.25
Lock Head Gate
Quantities Summary
Equipment (Civil Part)

Item	Description	Unit	Quantity
2	**Lock Head Gate 2**		
2,1	Equipment lock gate (civil part)		
2.1.1	Rails USW	m	0
2.1.2	Rails LSW	m	*510*
2.1.3	Rails MSW	m	2.024
2.1.4	Rails horizontal guides in recesses	m	*630*
2.1.5	Wooden vertical guidance in recesses	m	348
2.1.6	Steel for support rails USW	tons	0
2.1.7	Steel for support rails LSW	tons	*306*
2.1.8	Steel for support rails guidance	tons	*158*
2.1.9	Maintenance support frames	tons	0
2,2	Equipment lock head (civil part)		
2.2.1	Vertical elements for seals - east/recesses	m^3	441
2.2.2	Vertical elements for seals - west	m^3	483
2.2.3	Horizontal elements for seals- lock chamber	m^3	*58*
2.2.4	Elements for placement habitat	m^3	*234*
2.2.5	Horizontal elements for seals- gate recesses	m^3	*47*
2.2.6	Bridges over recesses	pcs	2

TASK 4 - CONFIGURATION 2

Table E.26
ACCESSORIES
Quantities Summary

Item	Description	Unit	Quantity
1	**Accessories**		
1,1	Bollards 1500kN	pcs	36
1,2	Fenders	pcs	2
1,3	Ladders	pcs	36
1,4	Mooring Bits	pcs	72

TASK 4 - CONFIGURATION 2

Table E.27
ELECTROMECHANICAL EQUIPMENT
Quantities Summary

Item	Description	Unit	Quantity (pcs)	Unit Weight (t)	Total Weight (t)
1	**EM Equipment Lock**				
1,1	Lock gates				
1.1.1	Lock head 1			*Total 1.1.1:*	**3.741**
	Lock gates (2)	tons	2	*1.625*	*3.250*
	Fixed ballast for gate stability (2)	tons	0	0	0
	Bulkheads (1)	tons	1	250	250
	Upper support wagon (2)	tons	2	50	100
	Lower support wagon (3)	tons	3	35	105
	Maintenance suport wagons (12)	tons	12	3	36
1.1.2	Lock head 2			*Total 1.1.2:*	**36.707**
	Lock gates (2)	tons	2	*9.325*	*18.650*
	Fixed ballast for gate stability (2)	tons	2	*5.675*	*11.350*
	Bulkheads (1)	tons	1	2.000	2.000
	Upper support wagon (2)	tons	2	0	0
	Lower support wagon (5)	tons	5	900	4.500
	Maintenance suport wagons (46)	tons	46	4,5	207
1,2	Culvert valves and bulkheads			*Total 1.2:*	**766**
1.2.1	Culvert valves (incl. 1 spare)	tons	9	28	248
1.2.2	Culvert bulkheads	tons	8	24	192
1.2.3	Culvert valves slot	tons	8	17	133
1.2.4	Culvert bulkhead slots	tons	16	12	193
1,3	Miscellaneous (culverts)	tons	0	0	0
1,4	Support equipment		1		
1,5	Control system		1		
1,6	Lighting System		1		
1,7	Electrical and Power System		1		
2	**EM Equipment WSB**			*Total 2.:*	**3.007**
2,1	WSB upper valves (incl. 1 spare)	tons	13	40	520
2,2	WSB lower valves (incl. 1 spare)	tons	13	49	631
2,3	WSB bulkheads	tons	4	131	524
2,4	WSB upper valves slots	tons	12		288
2,5	WSB lower valves slots	tons	12		333
2,6	WSB bulkheads slots	tons	24		536
2,7	Miscellaneous	tons	1		175

TASK 4 - CONFIGURATION 2

Table E.28
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Quantities Summary (Lock)

Item	Description	Unit	Combination 1-B	Combination 2-A	Combination 3-B
1	**Excavation**				
1,1	Overburden	m³	1.016.873	1.016.873	1.192.866
1,2	Weathered	m³	254.218	254.218	298.217
1,3	Rock	m³	3.813.274	3.813.274	4.473.249
1,4	Overhaul for spoil (10 km)	m³km	12.624.976	16.226.991	14.687.824
2	**Fill**				
2,1	Backfill	m³	2.212.509	1.336.602	2.337.677
2,2	Gravel layer	m³	1.898	1.898	1.898
2,3	Bank protection WSB	m²	0	0	0
3	**Concrete**				
3,1	RC	m³	1.541.959	1.432.109	2.092.150
3,2	RCC	m³	471.679	1.234.922	614.609
3,3	Concrete slab	m³	5.696	5.696	5.696
3,4	Lean Concrete	m²	87.862	85.092	128.228
3,5	Pavement	m²	71.650	67.150	40.150
3,6	Concrete layer chamber bottom	m³	15.426	14.826	16.627
3,7	Shotcrete (Temporary protection in La Boca)	m²	57.263	57.263	57.263
4	**Reinforcement**				
4,1	Steel reinforcement	tons	115.643	99.531	156.008
5	**Other**				
5,1	Steel corner protection	m	3.402	3.402	5.294
5,2	Rubber joint	m	5.855	5.855	9.719
5,3	Geotextile	m²	0	0	0
5,4	Liner HDPE (WSB)	m²	0	0	0
5,5	Underlaying protective geotextile (WSB)	m²	0	0	0
5,6	Geotextile for drainage (WSB)	m²	0	0	0
5,7	Rails	m	3.882	3.882	3.882
5,8	Rails LSW	m	510	510	510
5,9	Wooden vertical guidances	m	484	484	484
5,10	Steel for support rail and frames	ton	804	804	804
5,11	Vertical element for seals east/recesses	m³	579	579	579
5,12	Vertical element for seals west	m³	664	664	664
5,13	Horizontal elements for seals lock chamber	m³	282	282	282
5,14	Elements for placement habitat	m³	457	457	457

TASK 4 - CONFIGURATION 2

Table E.28
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Quantities Summary (Lock)

Item	Description	Unit	Combination 1-B	Combination 2-A	Combination 3-B
5,15	Horizontal elements for seals gate recesses	m³	88	88	88
5.16.1	Bridge over recesses LHG 1	pcs	2	2	2
5.16.2	Bridge over recesses LHG 2	pcs	2	2	2
5,17	Technical building	m²	3.654	3.654	3.654
6	**Accessories**				
6,1	Bollards 1500kN	pcs	36	36	36
6,2	Fenders	pcs	2	2	2
6,3	Ladders	m	1.800	1.800	1.800
6,4	Mooring bits	pcs	72	72	72

APPENDIX F

SENSIBILITY ANALYSIS
Depth of Lock minus 5'

TASK 4 - CONFIGURATION 2

Table F.1
Conceptual Design
Post-Panamax Lock Structure (Pacific)

TOTAL PROJECT COST

Item	Description	%	Combination 1-B Total USD - 2002	Combination 2-A Total USD - 2002	Combination 3-B Total USD - 2002
	LOCK				
1	**Civil Works**		**468.071.422**	**457.857.676**	**612.960.683**
1,1	Civil works		362.846.063	354.928.431	475.163.320
1,2	Detailed studies and supervision	7%	25.399.224	24.844.990	33.261.432
1,3	Instrumentation	2%	7.256.921	7.098.569	9.503.266
1,4	Grouting and consolidation	3%	10.885.382	10.647.853	14.254.900
1,5	Contingencies	15%	54.426.910	53.239.265	71.274.498
1,6	Administrative costs	2%	7.256.921	7.098.569	9.503.266
2	**Electromechanical equipment**		**305.026.668**	**305.026.668**	**305.026.668**
2,1	Electromechanical equipment		240.690.864	240.690.864	240.690.864
2.1.1	*EM equipment Lock Head 1*		*26.117.963*	*26.117.963*	*26.117.963*
2.1.2	*EM equipment Lock Head 2*		*186.045.401*	*186.045.401*	*186.045.401*
2.1.3	*EM other equipment and system*		*28.527.500*	*28.527.500*	*28.527.500*
2,2	Detailed studies and supervision	7%	16.848.360	16.848.360	16.848.360
2,3	Contingencies		42.673.627	42.673.627	42.673.627
2.3.1	*Lock Head 1*	*10%*	*2.611.796*	*2.611.796*	*2.611.796*
2.3.2	*Lock Head 2*	*20%*	*37.209.080*	*37.209.080*	*37.209.080*
2.3.3	*Other equipment and system*	*10%*	*2.852.750*	*2.852.750*	*2.852.750*
2,4	Administrative costs	2%	4.813.817	4.813.817	4.813.817
	TOTAL LOCK COST		**773.098.090**	**762.884.344**	**917.987.351**
	WSB				
1	**Civil Works**		**87.885.777**	**87.885.777**	**87.885.777**
1,1	Civil works		68.128.509	68.128.509	68.128.509
1,2	Detailed studies and supervision	7%	4.768.996	4.768.996	4.768.996
1,3	Instrumentation	2%	1.362.570	1.362.570	1.362.570
1,4	Grouting and consolidation	3%	2.043.855	2.043.855	2.043.855
1,5	Contingencies	15%	10.219.276	10.219.276	10.219.276
1,6	Administrative costs	2%	1.362.570	1.362.570	1.362.570

TASK 4 - CONFIGURATION 2

Table F.1
Conceptual Design
Post-Panamax Lock Structure (Pacific)

TOTAL PROJECT COST

Item	Description	%	Combination 1-B Total USD - 2002	Combination 2-A Total USD - 2002	Combination 3-B Total USD - 2002
2	**Electromechanical equipment**		**17.888.675**	**17.888.675**	**17.888.675**
2,1	Electromechanical equipment		15.032.500	15.032.500	15.032.500
2,2	Detailed studies and supervision	7%	1.052.275	1.052.275	1.052.275
2,3	Contingencies	10%	1.503.250	1.503.250	1.503.250
2,4	Administrative costs	2%	300.650	300.650	300.650
	TOTAL WSB COST		**105.774.452**	**105.774.452**	**105.774.452**
	Summary				
	Total project cost without WSB		**773.000.000**	**763.000.000**	**918.000.000**
	Total project cost with WSB		**879.000.000**	**869.000.000**	**1.024.000.000**

TASK 4 - CONFIGURATION 2

Table F.2
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total Cost Combination 1-B

Lock without WSB'

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
1	**Excavation**				**34.559.383**		**43.536.605**		**26.439.492**
1,1	Overburden	m³	1.081.946	3,50	3.786.809	4,30	4.652.366	2,70	2.921.253
1,2	Weathered	m³	270.486	4,75	1.284.810	5,90	1.595.870	3,60	973.751
1,3	Rock	m³	4.057.296	6,00	24.343.774	7,50	30.429.718	4,50	18.257.831
1,4	Overhaul of spoil (10 km)	m³km	17.146.630	0,30	5.143.989	0,40	6.858.652	0,25	4.286.658
2	**Fill**				**6.288.719**		**8.381.599**		**4.195.839**
2,1	Backfill	m³	2.091.760	3,00	6.275.279	4,00	8.367.039	2,00	4.183.519
2,2	Gravel layer	m³	2.240	6,00	13.440	6,50	14.560	5,50	12.320
2,3	Bank protection WSB	m²	0	13,00	0	15,65	0	8,60	0
3	**Concrete**				**205.558.291**		**255.985.628**		**155.074.109**
3,1	RC	m³	1.554.718	120,00	186.566.217	150,00	233.207.772	90,00	139.924.663
3,2	RCC	m³	445.590	28,00	12.476.522	33,00	14.704.473	23,00	10.248.572
3,3	Concrete slab	m³	6.720	120,00	806.400	150,00	1.008.000	90,00	604.800
3,4	Lean Concrete	m²	87.862	9,00	790.755	11,00	966.479	6,80	597.460
3,5	Pavement	m²	71.650	24,00	1.719.600	30,00	2.149.500	18,00	1.289.700
3,6	Concrete layer chamber bottom	m³	19.636	90,00	1.767.233	110,00	2.159.952	68,00	1.335.243
3,7	Shotcrete (Temporary protection in La Boca)	m²	57.263	25,00	1.431.563	31,25	1.789.453	18,75	1.073.672
4	**Reinforcement**				**102.030.763**		**116.606.586**		**87.454.939**
4,1	Steel reinforcement	tons	116.607	875,00	102.030.763	1.000,00	116.606.586	750,00	87.454.939

TASK 4 - CONFIGURATION 2

Table F.2
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total Cost Combination 1-B

Lock without WSB'

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
5	**Other**				**12.904.109**		**16.219.619**		**9.588.599**
5,1	Steel corner protection	m	3.402	73,00	248.346	78,00	265.356	68,00	231.336
5,2	Rubber joint	m	5.788	71,00	410.913	112,00	648.200	30,00	173.625
5,3	Geotextile	m²	0	1,80	0	2,25	0	1,50	0
5,4	Liner HDPE (WSB1)	m²	0	13,31	0	16,63	0	10,00	0
5,5	Underlaying protective geotextile (WSB1)	m²	0	1,88	0	2,35	0	1,45	0
5,6	Geotextile for drainage (WSB1)	m²	0	4,71	0	5,90	0	3,55	0
5,7	Rails	m	4.004	280,00	1.121.120	350,00	1.401.400	210,00	840.840
5,8	Rails LSW	m	560	1.000,00	560.000	1.250,00	700.000	750,00	420.000
5,9	Wooden vertical guidances	m	484	400,00	193.600	500,00	242.000	300,00	145.200
5,10	Steel for support rail and frames	ton	870	2.400,00	2.088.000	3.000,00	2.610.000	1.800,00	1.566.000
5,11	Vertical element for seals east/recesses	m³	579	3.050,00	1.765.950	3.812,50	2.207.438	2.287,50	1.324.463
5,12	Vertical element for seals west	m³	664	2.700,00	1.792.800	3.375,00	2.241.000	2.025,00	1.344.600
5,13	Horizontal elements for seals lock chamber	m³	312	2.700,00	842.400	3.375,00	1.053.000	2.025,00	631.800
5,14	Elements for placement habitat	m³	516	275,00	141.900	343,75	177.375	206,25	106.425
5,15	Horizontal elements for seals gate recesses	m³	94	1.520,00	142.880	1.900,00	178.600	1.140,00	107.160
5.16.1	Bridge over recesses LHG 1	pcs	2	500.000,00	1.000.000	625.000,00	1.250.000	375.000,00	750.000
5.16.2	Bridge over recesses LHG 2	pcs	2	750.000,00	1.500.000	937.500,00	1.875.000	562.500,00	1.125.000
5,17	Technical building	m²	3.654	300,00	1.096.200	375,00	1.370.250	225,00	822.150
6	**Accessories**				**1.504.800**		**1.881.000**		**1.128.600**
6,1	Bollards 1500kN	pcs	36	4.900,00	176.400	6.125,00	220.500	3.675,00	132.300
6,2	Fenders	pcs	2	540.000,00	1.080.000	675.000,00	1.350.000	405.000,00	810.000
6,3	Ladders	m	1.800	100,00	180.000	125,00	225.000	75,00	135.000
6,4	Mooring bits	pcs	72	950,00	68.400	1.187,50	85.500	712,50	51.300
	Total Cost				**362.846.063**		**442.611.036**		**283.881.578**

TASK 4 - CONFIGURATION 2

Table F.3
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total Cost Combination 2-A

Lock without WSB'

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
1	**Excavation**				**35.640.799**		**44.978.493**		**27.340.672**
1,1	Overburden	m³	1.081.946	3,50	3.786.809	4,30	4.652.366	2,70	2.921.253
1,2	Weathered	m³	270.486	4,75	1.284.810	5,90	1.595.870	3,60	973.751
1,3	Rock	m³	4.057.296	6,00	24.343.774	7,50	30.429.718	4,50	18.257.831
1,4	Overhaul of spoil (10 km)	m³km	20.751.350	0,30	6.225.405	0,40	8.300.540	0,25	5.187.838
2	**Fill**				**3.753.336**		**5.001.089**		**2.505.584**
2,1	Backfill	m³	1.246.632	3,00	3.739.896	4,00	4.986.529	2,00	2.493.264
2,2	Gravel layer	m³	2.240	6,00	13.440	6,50	14.560	5,50	12.320
2,3	Bank protection WSB	m²	0	13,00	0	15,65	0	8,60	0
3	**Concrete**				**212.623.798**		**263.386.220**		**161.806.286**
3,1	RC	m³	1.452.064	120,00	174.247.677	150,00	217.809.597	90,00	130.685.758
3,2	RCC	m³	1.162.333	28,00	32.545.312	33,00	38.356.975	23,00	26.733.649
3,3	Concrete slab	m³	6.720	120,00	806.400	150,00	1.008.000	90,00	604.800
3,4	Lean Concrete	m²	85.092	9,00	765.825	11,00	936.009	6,80	578.624
3,5	Pavement	m²	67.150	24,00	1.611.600	30,00	2.014.500	18,00	1.208.700
3,6	Concrete layer chamber bottom	m³	19.036	90,00	1.713.233	110,00	2.093.952	68,00	1.294.443
3,7	Shotcrete (Temporary protection in La Boca)	m²	37.350	25,00	933.750	31,25	1.167.188	18,75	700.313
4	**Reinforcement**				**88.501.589**		**101.144.673**		**75.858.505**
4,1	Steel reinforcement	tons	101.145	875,00	88.501.589	1.000,00	101.144.673	750,00	75.858.505

TASK 4 - CONFIGURATION 2

Table F.3
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total Cost Combination 2-A

Lock without WSB'

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
5	**Other**				**12.904.109**		**16.219.619**		**9.588.599**
5,1	Steel corner protection	m	3.402	73,00	248.346	78,00	265.356	68,00	231.336
5,2	Rubber joint	m	5.788	71,00	410.913	112,00	648.200	30,00	173.625
5,3	Geotextile	m²	0	1,80	0	2,25	0	1,50	0
5,4	Liner HDPE (WSB1)	m²	0	13,31	0	16,63	0	10,00	0
5,5	Underlaying protective geotextile (WSB1)	m²	0	1,88	0	2,35	0	1,45	0
5,6	Geotextile for drainage (WSB1)	m²	0	4,71	0	5,90	0	3,55	0
5,7	Rails	m	4.004	280,00	1.121.120	350,00	1.401.400	210,00	840.840
5,8	Rails LSW	m	560	1.000,00	560.000	1.250,00	700.000	750,00	420.000
5,9	Wooden vertical guidances	m	484	400,00	193.600	500,00	242.000	300,00	145.200
5,10	Steel for support rail and frames	ton	870	2.400,00	2.088.000	3.000,00	2.610.000	1.800,00	1.566.000
5,11	Vertical element for seals east/recesses	m³	579	3.050,00	1.765.950	3.812,50	2.207.438	2.287,50	1.324.463
5,12	Vertical element for seals west	m³	664	2.700,00	1.792.800	3.375,00	2.241.000	2.025,00	1.344.600
5,13	Horizontal elements for seals lock chamber	m³	312	2.700,00	842.400	3.375,00	1.053.000	2.025,00	631.800
5,14	Elements for placement habitat	m³	516	275,00	141.900	343,75	177.375	206,25	106.425
5,15	Horizontal elements for seals gate recesses	m³	94	1.520,00	142.880	1.900,00	178.600	1.140,00	107.160
5.16.1	Bridge over recesses LHG 1	pcs	2	500.000,00	1.000.000	625.000,00	1.250.000	375.000,00	750.000
5.16.2	Bridge over recesses LHG 2	pcs	2	750.000,00	1.500.000	937.500,00	1.875.000	562.500,00	1.125.000
5,17	Technical building	m²	3.654	300,00	1.096.200	375,00	1.370.250	225,00	822.150
6	**Accessories**				**1.504.800**		**1.881.000**		**1.128.600**
6,1	Bollards 1500kN	pcs	36	4.900,00	176.400	6.125,00	220.500	3.675,00	132.300
6,2	Fenders	pcs	2	540.000,00	1.080.000	675.000,00	1.350.000	405.000,00	810.000
6,3	Ladders	m	1.800	100,00	180.000	125,00	225.000	75,00	135.000
6,4	Mooring bits	pcs	72	950,00	68.400	1.187,50	85.500	712,50	51.300
	Total Cost				**354.928.431**		**432.611.093**		**278.228.246**

TASK 4 - CONFIGURATION 2

Table F.4
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total Cost Combination 3-B

Lock without WSB'

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
1	**Excavation**				**40.237.209**		**50.680.280**		**30.774.899**
1,1	Overburden	m³	1.263.546	3,50	4.422.409	4,30	5.433.246	2,70	3.411.573
1,2	Weathered	m³	315.886	4,75	1.500.460	5,90	1.863.730	3,60	1.137.191
1,3	Rock	m³	4.738.296	6,00	28.429.774	7,50	35.537.218	4,50	21.322.331
1,4	Overhaul of spoil (10 km)	m³km	19.615.217	0,30	5.884.565	0,40	7.846.087	0,25	4.903.804
2	**Fill**				**6.646.780**		**8.859.013**		**4.434.547**
2,1	Backfill	m³	2.211.113	3,00	6.633.340	4,00	8.844.453	2,00	4.422.227
2,2	Gravel layer	m³	2.240	6,00	13.440	6,50	14.560	5,50	12.320
2,3	Bank protection WSB	m²	0	13,00	0	15,65	0	8,60	0
3	**Concrete**				**275.214.512**		**342.777.338**		**207.584.370**
3,1	RC	m³	2.106.588	120,00	252.790.502	150,00	315.988.128	90,00	189.592.877
3,2	RCC	m³	578.329	28,00	16.193.198	33,00	19.084.841	23,00	13.301.556
3,3	Concrete slab	m³	6.720	120,00	806.400	150,00	1.008.000	90,00	604.800
3,4	Lean Concrete	m²	128.228	9,00	1.154.049	11,00	1.410.505	6,80	871.948
3,5	Pavement	m²	40.150	24,00	963.600	30,00	1.204.500	18,00	722.700
3,6	Concrete layer chamber bottom	m³	20.836	90,00	1.875.200	110,00	2.291.911	68,00	1.416.818
3,7	Shotcrete (Temporary protection in La Boca)	m²	57.263	25,00	1.431.563	31,25	1.789.453	18,75	1.073.672
4	**Reinforcement**				**138.243.450**		**157.992.514**		**118.494.386**
4,1	Steel reinforcement	tons	157.993	875,00	138.243.450	1.000,00	157.992.514	750,00	118.494.386

TASK 4 - CONFIGURATION 2

Table F.4
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total Cost Combination 3-B

Lock without WSB'

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
5	**Other**				**13.316.569**		**16.799.963**		**9.833.175**
5,1	Steel corner protection	m	5.294	73,00	386.462	78,00	412.932	68,00	359.992
5,2	Rubber joint	m	9.652	71,00	685.257	112,00	1.080.968	30,00	289.545
5,3	Geotextile	m²	0	1,80	0	2,25	0	1,50	0
5,4	Liner HDPE (WSB1)	m²	0	13,31	0	16,63	0	10,00	0
5,5	Underlaying protective geotextile (WSB1)	m²	0	1,88	0	2,35	0	1,45	0
5,6	Geotextile for drainage (WSB1)	m²	0	4,71	0	5,90	0	3,55	0
5,7	Rails	m	4.004	280,00	1.121.120	350,00	1.401.400	210,00	840.840
5,8	Rails LSW	m	560	1.000,00	560.000	1.250,00	700.000	750,00	420.000
5,9	Wooden vertical guidances	m	484	400,00	193.600	500,00	242.000	300,00	145.200
5,10	Steel for support rail and frames	ton	870	2.400,00	2.088.000	3.000,00	2.610.000	1.800,00	1.566.000
5,11	Vertical element for seals east/recesses	m³	579	3.050,00	1.765.950	3.812,50	2.207.438	2.287,50	1.324.463
5,12	Vertical element for seals west	m³	664	2.700,00	1.792.800	3.375,00	2.241.000	2.025,00	1.344.600
5,13	Horizontal elements for seals lock chamber	m³	312	2.700,00	842.400	3.375,00	1.053.000	2.025,00	631.800
5,14	Elements for placement habitat	m³	516	275,00	141.900	343,75	177.375	206,25	106.425
5,15	Horizontal elements for seals gate recesses	m³	94	1.520,00	142.880	1.900,00	178.600	1.140,00	107.160
5.16.1	Bridge over recesses LHG 1	pcs	2	500.000,00	1.000.000	625.000,00	1.250.000	375.000,00	750.000
5.16.2	Bridge over recesses LHG 2	pcs	2	750.000,00	1.500.000	937.500,00	1.875.000	562.500,00	1.125.000
5,17	Technical building	m²	3.654	300,00	1.096.200	375,00	1.370.250	225,00	822.150
6	**Accessories**				**1.504.800**		**1.881.000**		**1.128.600**
6,1	Bollards 1500kN	pcs	36	4.900,00	176.400	6.125,00	220.500	3.675,00	132.300
6,2	Fenders	pcs	2	540.000,00	1.080.000	675.000,00	1.350.000	405.000,00	810.000
6,3	Ladders	m	1.800	100,00	180.000	125,00	225.000	75,00	135.000
6,4	Mooring bits	pcs	72	950,00	68.400	1.187,50	85.500	712,50	51.300
	Total Cost				**475.163.320**		**578.990.108**		**372.249.976**

TASK 4 - CONFIGURATION 2

Table F.5
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Total WSB Cost

Item	Description	Unit	Quantity	Selected Unit Price		Upper Unit Price		Lower Unit Price	
				Unit Price	Total USD	Unit Price	Total USD	Unit Price	Total USD
1	Reinforced concrete	m³	237.296	120,00	28.475.544	150,00	35.594.430	90,00	21.356.658
2	Steel reinforcement BE500	tons	18.421	875,00	16.118.410	1.000,00	18.421.040	750,00	13.815.780
3	Roller compact concrete over conduits	m³	85.566	28,00	2.395.848	33,00	2.823.678	23,00	1.968.018
4	Backfill crushed stone over conduits	m³	441.888	3,00	1.325.664	4,00	1.767.552	2,00	883.776
5	Liner HDPE (WSB)	m²	0	13,31	0	16,63	0	10,00	0
6	Underlaying protective geotextile (WSB)	m²	0	1,88	0	2,35	0	1,45	0
7	Geotextile for drainage (WSB)	m²	0	4,71	0	5,90	0	3,55	0
8	Bank protection WSB	m²	0	13,00	0	15,65	0	8,60	0
10	Excavation								0
10,1	Overburden excavation	m³	510.798	3,50	1.787.794	4,30	2.196.432	2,70	1.379.155
10,2	La Boca / weathered rock excavation	m³	127.700	4,75	606.573	5,90	753.427	3,60	459.718
10,3	Rock excavation	m³	1.915.493	6,00	11.492.960	7,50	14.366.199	4,50	8.619.720
11	Backfill WSB 1 to 6	m³	197.556	3,00	592.668	4,00	790.224	2,00	395.112
12	Overhaul for spoil (10 km)	m³km	17.270.830	0,30	5.181.249	0,40	6.908.332	0,25	4.317.708
13	Technical building	m²	506	300,00	151.800	375,00	189.750	225,00	113.850
	Total Cost				68.128.509		83.811.065		53.309.495

TASK 4 - CONFIGURATION 2

Table F.6
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Cost Estimate

CIVIL WORKS SUMMARY

Item	Description	Combination 1-B	Combination 2-A	Combination 3-B
		Total USD - 2002	Total USD - 2002	Total USD - 2002
1	Excavation for lock	34.559.383	35.640.799	40.237.209
2	Entrance walls [1]	51.093.087	43.879.489	105.767.845
3	Lock walls [1]	70.425.570	68.640.120	85.575.455
4	Lock heads [1]	205.263.223	205.263.223	242.078.011
5	Accessories	1.504.800	1.504.800	1.504.800
	LOCK TOTAL COST	**362.846.063**	**354.928.431**	**475.163.320**
6	WSB and conduits (excavation and fill included)	68.128.509	68.128.509	68.128.509

[1] Include cost for backfill crushed stone

TASK 4 - CONFIGURATION 2

Table F.7
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Aggregate Unit Price

Item	Description	Unit	Selected Unit Price USD 2002		
			Maximun	Selected	Minimum
1	**Excavations**				
1,1	Overburden	m³	4,30	3,50	2,70
1,2	Weathered	m³	5,90	4,75	3,60
1,3	Rock	m³	7,50	6,00	4,50
1,4	Overhaul of spoil (10 km)	m³km	0,40	0,30	0,25
2	**Fill**				
2,1	Backfill	m³	4,00	3,00	2,00
2,2	Gravel layer	m³	6,50	6,00	5,50
2,3	Bank protection WSB1	m²	15,65	13,00	8,60
3	**Concrete**				
3,1	RC	m³	150,00	120,00	90,00
3,2	RCC	m³	33,00	28,00	23,00
3,3	Concrete slab	m³	150,00	120,00	90,00
3,4	Lean Concrete	m²	11,00	9,00	6,80
3,5	Pavement	m²	30,00	24,00	18,00
3,6	Concrete layer chamber bottom	m³	110,00	90,00	68,00
3,7	Shotcrete (Temporary protection in La Boca)	m²	31,25	25,00	18,75
4	**Reinforcement**				
4,1	Steel reinforcement	tons	1.000,00	875,00	750,00
5	**Other**				
5,1	Steel corner protection	m	78,00	73,00	68,00
5,2	Rubber joint	m	112,00	71,00	30,00
5,3	Geotextile	m²	2,25	1,80	1,50
5,4	Liner HDPE (WSB1)	m²	16,63	13,31	10,00
5,5	Underlaying protective geotextile (WSB1)	m²	2,35	1,88	1,45
5,6	Geotextile for drainage (WSB1)	m²	5,90	4,71	3,55
5,7	Rails	m	350,00	280,00	210,00
5,8	Rails LSW	m	1.250,00	1.000,00	750,00
5,9	Wooden vertical guides	m	500,00	400,00	300,00
5,10	Steel for support rail and frames	ton	3.000,00	2.400,00	1.800,00
5,11	Vertical element for seals east/recesses	m³	3.812,50	3.050,00	2.287,50
5,12	Vertical element for seals west	m³	3.375,00	2.700,00	2.025,00
5,13	Horizontal elements for seals lock chamber	m³	3.375,00	2.700,00	2.025,00
5,14	Elements for placement habitat	m³	343,75	275,00	206,25

TASK 4 - CONFIGURATION 2

Table F.7
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Aggregate Unit Price

Item	Description	Unit	Selected Unit Price USD 2002		
			Maximun	Selected	Minimum
5,15	Horizontal elements for seals gate recesses	m³	1.900,00	1.520,00	1.140,00
5,16	Bridge over recesses	pcs	625.000	500.000	375.000
5,17	Fixed ballast for gate stability	ton	625,00	500,00	375,00
5,18	Technical building	m²	375,00	300,00	225,00
6	**Accessories**				
6,1	Bollards 1500kN	pcs	6.125,00	4.900,00	3.675,00
6,2	Fenders	pcs	675.000	540.000	405.000
6,3	Ladders	m	125,00	100,00	75,00
6,4	Mooring bits	pcs	1.187,50	950,00	712,50

TASK 4 - CONFIGURATION 2

Table F.8
Cost Estimate
Excavation and Fill

Item	Description	Unit	Unit Price	Combination 1-B		Combination 2-A		Combination 3-B	
				Quantity	Total USD - 2002	Quantity	Total USD - 2002	Quantity	Total USD - 2002
1	**Excavation**								
1,1	Overburden excavation	m³	3,50	1.081.946	3.786.809	1.081.946	3.786.809	1.263.546	4.422.409
1,2	La Boca / weathered rock excavation	m³	4,75	270.486	1.284.810	270.486	1.284.810	315.886	1.500.460
1,3	Rock excavation	m³	6,00	4.057.296	24.343.774	4.057.296	24.343.774	4.738.296	28.429.774
1,4	Overhaul for spoil (10 km) Combination 1-B	m³km	0,30	17.146.630	5.143.989				
1,5	Overhaul for spoil (10 km) Combination 2-A	m³km	0,30			20.751.350	6.225.405		
1,6	Overhaul for spoil (10 km) Combination 3-B	m³km	0,30					19.615.217	5.884.565
2	**Fill**								
2,1	Backfill Combination 1-B	m³	3,00	2.091.760	6.275.279				
2,2	Backfill Combination 2-A	m³	3,00			1.246.632	3.739.896		
2,3	Backfill Combination 3-B	m³	3,00					2.211.113	6.633.340
	Total Cost Combination 1-B				**40.834.662**				
	Total Cost Combination 2-A						**39.380.695**		
	Total Cost Combination 3-B								**46.870.549**

TASK 4 - CONFIGURATION 2

Table F.9

Cost Estimate
Entrance Walls

Option A : RCC + RC

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	Reinforced Concrete	m³	120,00	184.743	22.169.160
2	Steel Reinforcement BE500	tons	875,00	9.237	8.082.506
3	Backfill Crushed Stone	m³	3,00	207.000	621.000
4	Steel Corner Protection	m	73,00	1.350	98.550
5	Rubber Joint	m	71,00	1.778	126.203
6	Lean Concrete	m²	9,00	20.250	182.250
7	RCC	m³	28,00	393.503	11.018.070
8	Pavement	m²	24,00	27.000	648.000
9	Shotcrete (Temporary protection in La Boca)	m²	25,00	37.350	933.750
	Total Cost				**43.879.489**

TASK 4 - CONFIGURATION 2

Table F.10
Cost Estimate
Entrance Walls
Option B : RC

Item	Description	Unit	Unit Price	Combination 1-B		Combination 3-B	
				Quantity	Total USD - 2002	Quantity	Total USD - 2002
1	Reinforced Concrete	m³	120,00	252.788	30.334.500	544.518	65.342.160
2	Steel Reinforcement BE500	tons	875,00	18.959	16.589.180	40.839	35.733.994
3	Backfill Crushed Stone	m³	3,00	560.948	1.682.843	780.957	2.342.871
4	Steel Corner Protection	m	73,00	1.350	98.550	2.700	197.100
5	Rubber Joint	m	71,00	1.778	126.203	3.983	282.758
6	Lean Concrete	m²	9,00	20.250	182.250	48.600	437.400
7	Pavement	m²	24,00	27.000	648.000	0	0
8	Shotcrete (Temporary protection in La Boca)	m²	25,00	57.263	1.431.563	57.263	1.431.563
	Total Cost				**51.093.087**		**105.767.845**

TASK 4 - CONFIGURATION 2

Table F.11.1
Cost Estimate
Lock Walls
Option 1

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	Reinforced Concrete	m³	120,00	352.630	42.315.600
2	Steel Reinforcement BE500	tons	875,00	26.450	23.143.750
3	Backfill Crushed Stone	m³	3,00	623.410	1.870.230
4	RCC	m³	28,00	0	0
5	Concrete Layer Chamber Bottom	m³	90,00	4.960	446.400
6	Steel Corner Protection	m	73,00	600	43.800
7	Rubber joint	m	71,00	1.810	128.510
8	Pavement	m²	24,00	4.500	108.000
9	Lean Concrete	m²	9,00	25.600	230.400
10	Conduit under locks				
10,1	Reinforced Concrete (for all chambers)	m³	120,00	11.524	1.382.880
10,2	Steel Reinforcement BE500	tons	875,00	864	756.000
	Total Cost				**70.425.570**

Table F.11.2
Cost Estimate
Lock Walls
Option 2

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	Reinforced Concrete	m³	120,00	318.020	38.162.400
2	Steel Reinforcement BE500	tons	875,00	20.710	18.121.250
3	Backfill Crushed Stone	m³	3,00	132.230	396.690
4	RCC	m³	28,00	323.240	9.050.720
5	Concrete Layer Chamber Bottom	m³	90,00	4.360	392.400
6	Steel Corner Protection	m	73,00	600	43.800
7	Rubber joint	m	71,00	1.810	128.510
8	Pavement	m²	24,00	0	0
9	Lean Concrete	m²	9,00	22.830	205.470
10	Conduit under locks				
10,1	Reinforced Concrete (for all chambers)	m³	120,00	11.524	1.382.880
10,2	Steel Reinforcement BE500	tons	875,00	864	756.000
	Total Cost				**68.640.120**

TASK 4 - CONFIGURATION 2

Table F.11.3

Cost Estimate
Lock Walls

Option 3

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	Reinforced Concrete	m³	120,00	436.150	52.338.000
2	Steel Reinforcement BE500	tons	875,00	32.710	28.621.250
3	Backfill Crushed Stone	m³	3,00	471.420	1.414.260
4	RCC	m³	28,00	0	0
5	Concrete Layer Chamber Bottom	m³	90,00	6.160	554.400
6	Steel Corner Protection	m	73,00	900	65.700
7	Rubber joint	m	71,00	2.715	192.765
8	Pavement	m²	24,00	0	0
9	Lean Concrete	m²	9,00	27.800	250.200
10	Conduit under locks				
10,1	Reinforced Concrete (for all chambers)	m³	120,00	11.524	1.382.880
10,2	Steel Reinforcement BE500	tons	875,00	864	756.000
	Total Cost				**85.575.455**

TASK 4 - CONFIGURATION 2

Table F.12
Cost Estimate
WSB and Conduits (Civil Works)

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	Reinforced concrete	m³	120,00	237.296	28.475.544
2	Steel reinforcement BE500	tons	875,00	18.421	16.118.410
3	Roller compact concrete over conduits	m³	28,00	85.566	2.395.848
4	Backfill crushed stone over conduits	m³	3,00	441.888	1.325.664
5	Liner HDPE (WSB)	m²	13,31	0	0
6	Underlaying protective geotextile (WSB)	m²	1,88	0	0
7	Geotextile for drainage (WSB)	m²	4,71	0	0
8	Bank protection WSB	m²	13,00	0	0
10	Excavation				
10,1	Overburden excavation	m³	3,50	510.798	1.787.794
10,2	La Boca / weathered rock excavation	m³	4,75	127.700	606.573
10,3	Rock excavation	m³	6,00	1.915.493	11.492.960
11	Backfill WSB 1 to 6	m³km	3,00	197.556	592.668
12	Overhaul for spoil (10 km)	m³km	0,30	17.270.830	5.181.249
13	Technical building	m²	300,00	506	151.800
	Total Cost				**68.128.509**

TASK 4 - CONFIGURATION 2

Table F.13
Cost Estimate
Lock Head Gate

Item	Description	Unit	Unit Price	Combination 1-B / 2-A		Combination 3-B	
				Quantity	Total USD - 2002	Quantity	Total USD - 2002
1	Reinforced Concrete	m³	120,00	678.211	81.385.320	725.038	87.004.604
2	Steel Reinforcement BE500	ton	875,00	50.866	44.507.750	54.378	47.580.643
3	Backfill crushed stone	m³	3,00	804.760	2.414.280	804.760	2.414.280
4	Backfill RCC	m³	28,00	180.126	5.043.528	180.121	5.043.397
5	Concrete layer chamber bottom	m³	90,00	4.296	386.633	4.296	386.600
6	Steel corner protection	m	73,00	968	70.664	968	70.664
7	Rubber joint	m	71,00	692	49.132	692	49.132
8	Lean concrete	m²	9,00	22.380	201.417	22.380	201.417
9	Pavement	m²	24,00	26.230	629.520	26.230	629.520
10	Technical building	m²	300,00	3.654	1.096.200	3.654	1.096.200
	Total Cost				**135.784.445**		**144.476.457**

TASK 4 - CONFIGURATION 2

Table F.14
Cost Estimate
Transition Segment

Item	Description	Unit	Unit Price	Combinations 1-B / 2-A		Combination 3-B	
				Quantity	Total USD - 2002	Quantity	Total USD - 2002
1	Reinforced concrete	m³	120,00	259.566	31.147.917	389.357	46.722.858
2	Steel reinforcement BE500	ton	875,00	19.468	17.034.083	29.202	25.551.563
3	Backfill crushed stone	m³	3,00	102.642	307.926	153.976	461.929
4	Backfil RCC	m³	28,00	265.464	7.432.994	398.207	11.149.801
5	Concrete layer chamber bottom	m³	90,00	10.380	934.200	10.380	934.200
6	Concrete slabs	m³	120,00	6.720	806.400	6.720	806.400
7	Gravel layer	m³	6,00	2.240	13.440	2.240	13.440
8	Steel corner protection	m	73,00	484	35.332	726	52.998
9	Rubber joint	m	71,00	1.508	107.068	2.262	160.602
10	Lean concrete	m²	9,00	19.632	176.688	29.448	265.032
11	Pavement	m²	24,00	13.920	334.080	13.920	334.080
	Total Cost				**58.330.129**		**86.452.904**

TASK 4 - CONFIGURATION 2

Table F.15

Cost Estimate
Lock Head Gate

Equipment (Civil Part)

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	Equipment lock gate (civil part)				3.962.720
1,1	Rails	m	280,00	4.004	1.121.120
1,2	Rails LSW Lock Head 2	m	1.000,00	560	560.000
1,3	Wooden vertical guidances	m	400,00	484	193.600
1,4	Steel for support rails and frames	tons	2.400,00	870	2.088.000
2	Equipment lock head (civil part)				7.185.930
2,1	Vertical elements for seals - east/recesses	m³	3.050,00	579	1.765.950
2,2	Vertical elements for seals - west	m³	2.700,00	664	1.792.800
2,3	Horizontal elements for seals- lock chamber	m³	2.700,00	312	842.400
2,4	Elements for placement habitat	m³	275,00	516	141.900
2,5	Horizontal elements for seals- gate recesses	m³	1.520,00	94	142.880
2,6	Bridges over recesses	pcs			
2.6.1	Bridges over recesses LHG 1	pcs	500.000	2	1.000.000
2.6.2	Bridges over recesses LHG 2	pcs	750.000	2	1.500.000
	Total Cost				**11.148.650**

TASK 4 - CONFIGURATION 2

Table F.16
Cost Estimate
Accessories

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	**Accessories**				
1,1	Bollards 1500kN	pcs	4.900	36	176.400
1,2	Fenders	pcs	540.000	2	1.080.000
1,3	Ladders	m	100	1.800	180.000
1,4	Mooring Bits	pcs	950	72	68.400
	Total Cost				**1.504.800**

TASK 4 - CONFIGURATION 2

Table F.17
Cost Estimate
Electromechanical Equipment

Item	Description	Unit	Unit Price	Quantity	Total USD - 2002
1	**EM Equipment lock**				**240.690.864**
1,1	EM Equipment Lock (gates and bulkheads)	tons		33.268	212.163.364
1.1.1	*EM Equipment Lock Head 1 (gates and bulkheads)*	*tons*	*6.173*	*4.231*	*26.117.963*
1.1.2	*EM Equipment Lock Head 2 (gates and bulkheads)*	*tons*	*6.173*	*29.037*	*179.245.401*
	Fixed ballast for gate stability (2)	*tons*	*500*	*13.600*	*6.800.000*
1,2	EM Equipment Lock (culvert valves and bulkheads)	tons	5.000	766	3.827.500
1,4	Support equipment		14.700.000	1	14.700.000
1,5	Control system		1.700.000	1	1.700.000
1,6	Lighting System		1.200.000	1	1.200.000
1,7	Electrical and Power System		7.100.000	1	7.100.000
2	**EM Equipment WSB (Support and control system**	tons	5.000	3.007	**15.032.500**
	Total Cost				**255.723.364**

Table F.18
Excavation and Fill Quantities

Item	Description	Unit	Combination 1-B		Combination 2-A		Combination 3-B	
			Excavation	Backfill	Excavation	Backfill	Excavation	Backfill
1	Lock from edge east wall Gatun side up to edge east wall Pacific side	m³	*4.919.412*		*4.919.412*		*5.204.412*	
2	Entrance wall Pacific side	m³	*302.628*	311.085	*302.628*	113.715	*645.628*	412.182
3	Entrance wall Gatun side	m³	*187.688*	249.863	*187.688*	93.285	*467.688*	368.775
4	Lock walls [1]	m³		623.410		132.230		471.420
5	Lock head gate [1]	m³		804.760		804.760		804.760
6	Transition segment [1]	m³		102.642		102.642		153.976
7	Overhaul for spoil (10 km) Combination 1-B	m³km	17.146.630					
8	Overhaul for spoil (10 km) Combination 2-A	m³km			20.751.350			
9	Overhaul for spoil (10 km) Combination 3-B	m³km					19.615.217	
	Total Volume Excavation / Backfill	m³	5.409.728	2.091.760	5.409.728	1.246.632	6.317.728	2.211.113

[1] Excavation include in item 1
[2] For WSB`s Excavation and Backfill quantities, see Table F.22

TASK 4 - CONFIGURATION 2

Table F.19
Entrance Walls
Option A : RCC + RC
Quantities Summary

Item	Description	Unit	Combination 2-A	
			Pacific Side	Gatun Side
			Quantity	Quantity
1	Reinforced Concrete	m³	*4.175*	*4.036*
1.1	Footing	m³	1.920	1.920
1,2	Front Wall	m³	1.581	1.442
1,3	Top Structure	m³	765	765
2	Steel Reinforcement BE500	tons	*209*	*202*
3	Backfill Crushed Stone	m³	*5.054*	*4.146*
4	Steel Corner Protection	m	30	30
5	Rubber Joint	m	*41*	*39*
6	Lean Concrete	m²	450	450
7	RCC	m³	*9.261*	*8.228*
8	Pavement	m²	600	600
9	Shotcrete (Temporary protection in La Boca)	m²	1.660	885
	Quantities for one 30 m-segment:			
	Number of segments of 30 m:		22,5	22,5

TASK 4 - CONFIGURATION 2

Table F.20
Entrance Walls
Option B : RC
Quantities Summary

Item	Description	Unit	Combination 1-B		Combination 3-B	
			Pacific Side	Gatun Side	Pacific Side	Gatun Side
			Quantity	Quantity	Quantity	Quantity
1	Reinforced Concrete	m³	*5.747*	*5.488*	*12.390*	*11.811*
1.1	Footing	m³	*1.920*	*1.920*	4.320	4.320
1,2	Front Wall	m³	*1.581*	*1.442*	2.682	2.400
1,3	Top Structure	m³	*1.335*	*1.335*	2.610	2.610
1,4	Buttresses	m³	*1.162*	*1.042*	3.029	2.732
2	Steel Reinforcement BE500	tons	*431*	*412*	*929*	*886*
3	Backfill Crushed Stone	m³	*13.826*	*11.105*	*18.319*	*16.390*
4	Steel Corner Protection	m	30	30	60	60
5	Rubber Joint	m	*41*	*39*	*91*	*87*
6	Lean Concrete	m²	450	450	1.080	1.080
7	Pavement	m²	600	600	0	0
8	Shotcrete (Temporary protection in La Boca)	m²	1.660	885	1.660	885
	Quantities for one 30 m-segment:					
	Number of segments of 30 m:		22,5	22,5	22,5	22,5

TASK 4 - CONFIGURATION 2

Table F.21
Lock Walls
Quantities Summary

Item	Description	Unit	Eastern Lock Wall	Western Lock Wall		
				Combination 1-B	Combination 2-A	Combination 3-B
			Quantity	Quantity	Quantity	Quantity
1	Reinforced Concrete	m³	*19.228*	*16.035*	*12.574*	*24.387*
1.1	Bottom Part with Culvert	m³	2.517	2.517	2.742	5.483
1.2	Toe	m³	6.729	6.729	5.850	6.750
1.3	Front Wall	m³	*3.174*	*2.116*	*2.026*	*4.052*
1.4	Top Structure	m³	1.911	1.575	1.956	4.710
1.5	Counterforts	m³	*4.897*	*3.098*	0	*3.392*
2	Steel Reinforcement BE500	tons	*1.442*	*1.203*	*629*	*1.829*
3	Backfill Crushed Stone	m³	*13.223*	*49.118*	0	*33.919*
4	RCC	m³	0	0	*32.324*	0
5	Concrete Layer Chamber Bottom	m³	248	248	188	368
6	Steel Corner Protection	m	30	30	30	60
7	Rubber joint	m	*91*	*91*	*91*	*181*
8	Pavement	m²	0	450	0	0
9	Lean Concrete	m²	1.280	1.280	1.003	1.500
	Quantities for one 30 m-segment:					
	Number of segments of 30 m:		10	10	10	10

10	Conduits under lock		Lock
10.1	Reinforced Concrete (for all chamber)	m³	11.524
10.2	Steel Reinforcement BE500 (for all chamber)	tons	864

TASK 4 - CONFIGURATION 2

Table F.22
WSB and Conduits (Civil Works)
Quantities Summary

Item	Description	Unit	Quantity
1	Reinforced concrete for valve chambers and valve connection	m³	59.069
2	Steel reinforcement BE500	tons	4.430
3	Reinforced concrete for conduits	m³	*56.528*
4	Steel reinforcement BE500	tons	*4.240*
5	Reinforced concrete for intakes WSB	m³	96.739
6	Steel reinforcement BE500	tons	7.255
7	Roller compacted concrete	m³	85.566
8	Backfill Crushed Stone	m³	*441.888*
9	Reinforced concrete for walls between WSB	m³	24.960
10	Steel reinforcement BE500	tons	2.496
11	Liner HDPE (WSB1)	m²	0
12	Underlaying protective geotextile (WSB1)	m²	0
13	Geotextile for drainage (WSB1)	m²	0
14	Bank protection WSB1	m²	0
15	Excavations		
15,1	WSB 1 to 6	m³	1.906.491
15,2	Extra conduits	m³	647.500
16	Backfill WSB 1 to 6	m³	197.556
17	Overhaul for spoil (10 km)	m³km	17.270.830
18	Technical building	m²	506

Quantities Summary

Item	Description	Unit	Quantity
1	Reinforced concrete	m³	237.296
2	Steel reinforcement BE500	tons	18.421
3	Roller compacted concrete	m³	85.566
4	Backfill Crushed Stone	m³	441.888
5	Liner HDPE (WSB1)	m²	0
6	Underlaying protective geotextile (WSB1)	m²	0
7	Geotextile for drainage (WSB1)	m²	0
8	Bank protection WSB1	m²	0
9	Excavations	m³	2.553.991
10	Backfill WSB 1 to 6	m³	197.556
11	Overhaul for spoil (10 km)	m³km	17.270.830
12	Technical building	m²	506

TASK 4 - CONFIGURATION 2

Table F.23
Lock Head Gate
Quantities Summary

Item	Description	Unit	Combinations 1-B / 2-A	Combination 3-B
			Quantity	Quantity
1	**Lock Head Gate 1**			
1,1	Reinforced Concrete	m³	*183.669*	*197.451*
1,2	Steel Reinforcement BE500	ton	*13.775*	*14.809*
1,3	Backfill crushed stone	m³	*129.614*	*129.614*
1,4	Backfill RCC	m³	*18.897*	*18.897*
1,5	Concrete layer chamber bottom	m³	*1.674*	*1.674*
1,6	Steel corner protection	m	428	428
1,7	Rubber joint	m	324	324
1,8	Lean concrete	m²	8.078	8.078
1,9	Pavement	m²	10.500	10.500
2	**Lock Head Gate 2**			
2,1	Reinforced Concrete	m³	*440.742*	*473.788*
2,2	Steel Reinforcement BE500	ton	*33.056*	*35.534*
2,3	Backfill crushed stone	m³	*440.146*	*440.146*
2,4	Backfill RCC	m³	*161.229*	*161.225*
2,5	Concrete layer chamber bottom	m³	*2.621*	*2.621*
2,6	Steel corner protection	m	540	540
2,7	Rubber joint	m	368	368
2,8	Lean concrete	m²	14.302	14.302
2,9	Pavement	m²	15.730	15.730
3	**Concrete L-shaped walls behind lock heads 1 and 2**			
3,1	Reinforced Concrete	m³	*53.800*	53.800
3,2	Steel Reinforcement BE500	ton	*4.035*	4.035
3,3	Backfill crushed stone	m³	*235.000*	235.000
4	**Operation and maintenance buildings**			
4,1	Technical building	m²	3.654	3.654

TASK 4 - CONFIGURATION 2

Table F.24
Transition Segment
Quantities Summary

Item	Description	Unit	Combinations 1-B / 2-A Quantity	Combination 3-B Quantity
1	**Lock Head Gate 1**			
1,1	Transition segment side Gatún			
1,11	Reinforced concrete	m³	*36.617*	*54.928*
1,12	Steel reinforcement BE500	ton	*2.746*	*4.120*
1,13	Backfill crushed stone	m³	*19.915*	*29.873*
1,14	Backfill RCC	m³	*15.490*	*23.235*
1,15	Concrete slabs	m³	4.284	4.284
1,16	Gravel layer	m³	1.428	1.428
1,17	Steel corner protection	m	112	168
1,18	Rubber joint	m	368	552
1,19	Lean concrete	m²	4.032	6.048
1,20	Pavement	m²	3.360	3.360
1,2	Transition segment side lock chamber			
1,21	Reinforced concrete	m³	*94.270*	*141.410*
1,22	Steel reinforcement BE500	ton	*7.070*	*10.606*
1,23	Backfill crushed stone	m³	*18.501*	*27.751*
1,24	Backfill RCC	m³	*124.359*	*186.545*
1,25	Concrete layer chamber bottom	m³	2.135	2.135
1,26	Steel corner protection	m	150	225
1,27	Rubber joint	m	380	570
1,28	Lean concrete	m²	6.160	9.240
1,29	Pavement	m²	4.200	4.200

TASK 4 - CONFIGURATION 2

Table F.24
Transition Segment
Quantities Summary

Item	Description	Unit	Combinations 1-B / 2-A Quantity	Combination 3-B Quantity
2	**Lock Head Gate 2**			
2,1	Transition segment side Pacific			
2,11	Reinforced concrete	m³	*64.013*	*96.016*
2,12	Steel reinforcement BE500	ton	*4.801*	*7.201*
2,13	Backfill crushed stone	m³	*42.808*	*64.214*
2,14	Backfill RCC	m³	*36.787*	*55.181*
2,15	Concrete slabs	m³	2.436	2.436
2,16	Gravel layer	m³	812	812
2,17	Steel corner protection	m	112	168
2,18	Rubber joint	m	380	570
2,19	Lean concrete	m²	5.040	7.560
2,20	Pavement	m²	3.360	3.360
2,2	Transition segment side lock chamber			
2,21	Reinforced concrete	m³	*64.666*	*97.004*
2,22	Steel reinforcement BE500	ton	*4.850*	*7.275*
2,23	Backfill crushed stone	m³	*21.418*	*32.138*
2,24	Backfill RCC	m³	*88.828*	*133.246*
2,25	Concrete layer chamber bottom	m³	1.525	1.525
2,26	Steel corner protection	m	110	165
2,27	Rubber joint	m	380	570
2,28	Lean concrete	m²	4.400	6.600
2,29	Pavement	m²	3.000	3.000

TASK 4 - CONFIGURATION 2

Table F.25
Lock Head Gate
Quantities Summary
Equipment (Civil Part)

Item	Description	Unit	Quantity
1	**Lock Head Gate 1**		
1,1	Equipment lock gate (civil part)		
1.1.1	Rails USW	m	320
1.1.2	Rails LSW	m	320
1.1.3	Rails MSW	m	340
1.1.4	Rails horizontale guidances in recesses	m	320
1.1.5	Wooden vertical guidance in recesses	m	*136*
1.1.6	Steel for support rails USW	tons	128
1.1.7	Steel for support rails LSW	tons	128
1.1.8	Steel for support rails guidance	tons	48
1.1.9	Maintenance support frames	tons	60
1,2	Equipment lock head (civil part)		
1.2.1	Vertical elements for seals - east/recesses	m^3	*138*
1.2.2	Vertical elements for seals - west	m^3	*181*
1.2.3	Horizontal elements for seals- lock chamber	m^3	247
1.2.4	Elements for placement habitat	m^3	258
1.2.5	Horizontal elements for seals- gate recesses	m^3	44
1.2.6	Bridges over recesses	pcs	2

TASK 4 - CONFIGURATION 2

Table F.25
Lock Head Gate
Quantities Summary
Equipment (Civil Part)

Item	Description	Unit	Quantity
2	**Lock Head Gate 2**		
2,1	Equipment lock gate (civil part)		
2.1.1	Rails USW	m	0
2.1.2	Rails LSW	m	560
2.1.3	Rails MSW	m	2.024
2.1.4	Rails horizontal guides in recesses	m	680
2.1.5	Wooden vertical guidance in recesses	m	*348*
2.1.6	Steel for support rails USW	tons	0
2.1.7	Steel for support rails LSW	tons	336
2.1.8	Steel for support rails guidance	tons	170
2.1.9	Maintenance support frames	tons	0
2,2	Equipment lock head (civil part)		
2.2.1	Vertical elements for seals - east/recesses	m^3	*441*
2.2.2	Vertical elements for seals - west	m^3	*483*
2.2.3	Horizontal elements for seals- lock chamber	m^3	65
2.2.4	Elements for placement habitat	m^3	258
2.2.5	Horizontal elements for seals- gate recesses	m^3	50
2.2.6	Bridges over recesses	pcs	2

TASK 4 - CONFIGURATION 2

Table F.26
ACCESSORIES
Quantities Summary

Item	Description	Unit	Quantity
1	**Accessories**		
1,1	Bollards 1500kN	pcs	36
1,2	Fenders	pcs	2
1,3	Ladders	pcs	36
1,4	Mooring Bits	pcs	72

TASK 4 - CONFIGURATION 2

Table F.27
ELECTROMECHANICAL EQUIPMENT
Quantities Summary

Item	Description	Unit	Quantity (pcs)	Unit Weight (t)	Total Weight (t)
1	**EM Equipment Lock**				
1,1	Lock gates				
1.1.1	Lock head 1			*Total 1.1.1:*	**4.231**
	Lock gates (2)	tons	2	*1.870*	*3.740*
	Fixed ballast for gate stability (2)	tons	0	0	0
	Bulkheads (1)	tons	1	250	250
	Upper support wagon (2)	tons	2	50	100
	Lower support wagon (3)	tons	3	35	105
	Maintenance suport wagons (12)	tons	12	3	36
1.1.2	Lock head 2			*Total 1.1.2:*	**42.637**
	Lock gates (2)	tons	2	*11.165*	*22.330*
	Fixed ballast for gate stability (2)	tons	2	*6.800*	*13.600*
	Bulkheads (1)	tons	1	2.000	2.000
	Upper support wagon (2)	tons	2	0	0
	Lower support wagon (5)	tons	5	900	4.500
	Maintenance suport wagons (46)	tons	46	4,5	207
1,2	Culvert valves and bulkheads			*Total 1.2:*	**766**
1.2.1	Culvert valves (incl. 1 spare)	tons	9	28	248
1.2.2	Culvert bulkheads	tons	8	24	192
1.2.3	Culvert valves slot	tons	8	17	133
1.2.4	Culvert bulkhead slots	tons	16	12	193
1,3	Miscellaneous (culverts)	tons	0	0	0
1,4	Support equipment		1		
1,5	Control system		1		
1,6	Lighting System		1		
1,7	Electrical and Power System		1		
2	**EM Equipment WSB**			*Total 2.:*	**3.007**
2,1	WSB upper valves (incl. 1 spare)	tons	13	40	520
2,2	WSB lower valves (incl. 1 spare)	tons	13	49	631
2,3	WSB bulkheads	tons	4	131	524
2,4	WSB upper valves slots	tons	12		288
2,5	WSB lower valves slots	tons	12		333
2,6	WSB bulkheads slots	tons	24		536
2,7	Miscellaneous	tons	1		175

TASK 4 - CONFIGURATION 2

Table F.28

Conceptual Design

Post-Panamax Lock Structure (Pacific)

Quantities Summary (Lock)

Item	Description	Unit	Combination 1-B	Combination 2-A	Combination 3-B
1	**Excavation**				
1,1	Overburden	m³	1.081.946	1.081.946	1.263.546
1,2	Weathered	m³	270.486	270.486	315.886
1,3	Rock	m³	4.057.296	4.057.296	4.738.296
1,4	Overhaul for spoil (10 km)	m³km	17.146.630	20.751.350	19.615.217
2	**Fill**				
2,1	Backfill	m³	2.091.760	1.246.632	2.211.113
2,2	Gravel layer	m³	2.240	2.240	2.240
2,3	Bank protection WSB	m²	0	0	0
3	**Concrete**				
3,1	RC	m³	1.554.718	1.452.064	2.106.588
3,2	RCC	m³	445.590	1.162.333	578.329
3,3	Concrete slab	m³	6.720	6.720	6.720
3,4	Lean Concrete	m²	87.862	85.092	128.228
3,5	Pavement	m²	71.650	67.150	40.150
3,6	Concrete layer chamber bottom	m³	19.636	19.036	20.836
3,7	Shotcrete (Temporary protection in La Boca)	m²	57.263	37.350	57.263
4	**Reinforcement**				
4,1	Steel reinforcement	tons	116.607	101.145	157.993
5	**Other**				
5,1	Steel corner protection	m	3.402	3.402	5.294
5,2	Rubber joint	m	5.788	5.788	9.652
5,3	Geotextile	m²	0	0	0
5,4	Liner HDPE (WSB)	m²	0	0	0
5,5	Underlaying protective geotextile (WSB)	m²	0	0	0
5,6	Geotextile for drainage (WSB)	m²	0	0	0
5,7	Rails	m	4.004	4.004	4.004
5,8	Rails LSW	m	560	560	560
5,9	Wooden vertical guidances	m	484	484	484
5,10	Steel for support rail and frames	ton	870	870	870
5,11	Vertical element for seals east/recesses	m³	579	579	579
5,12	Vertical element for seals west	m³	664	664	664
5,13	Horizontal elements for seals lock chamber	m³	312	312	312
5,14	Elements for placement habitat	m³	516	516	516

TASK 4 - CONFIGURATION 2

Table F.28
Conceptual Design
Post-Panamax Lock Structure (Pacific)

Quantities Summary (Lock)

Item	Description	Unit	Combination 1-B	Combination 2-A	Combination 3-B
5,15	Horizontal elements for seals gate recesses	m³	94	94	94
5.16.1	Bridge over recesses LHG 1	pcs	2	2	2
5.16.2	Bridge over recesses LHG 2	pcs	2	2	2
5,17	Technical building	m²	3.654	3.654	3.654
6	**Accessories**				
6,1	Bollards 1500kN	pcs	36	36	36
6,2	Fenders	pcs	2	2	2
6,3	Ladders	m	1.800	1.800	1.800
6,4	Mooring bits	pcs	72	72	72