AUTORIDAD DEL CANAL DE PANAMÁ

Conceptual Design of Post Panamax Locks
Single Lift Lock System

Diseño Conceptual de las Esclusas Pospanamax
Sistema de Esclusas de Un Nivel

CONSORCIO POST PANAMAX

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Resumen Ejecutivo

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:

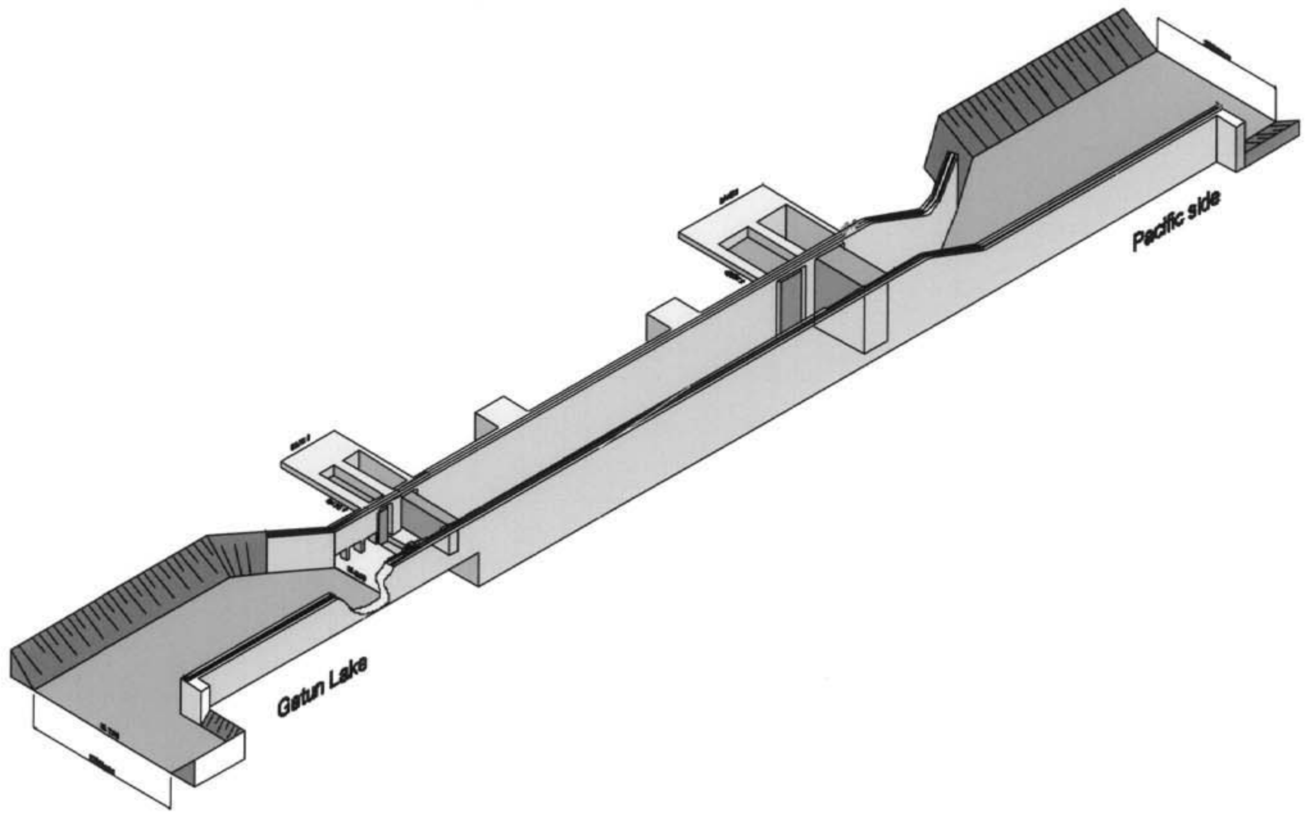
- the vessel positioning system (locomotives or tugboats)
- lower and upper pumping reservoirs and conduits
- road infrastructure outside the lock area
- diversion Rio Cocoli

Task 4 – Conclusions

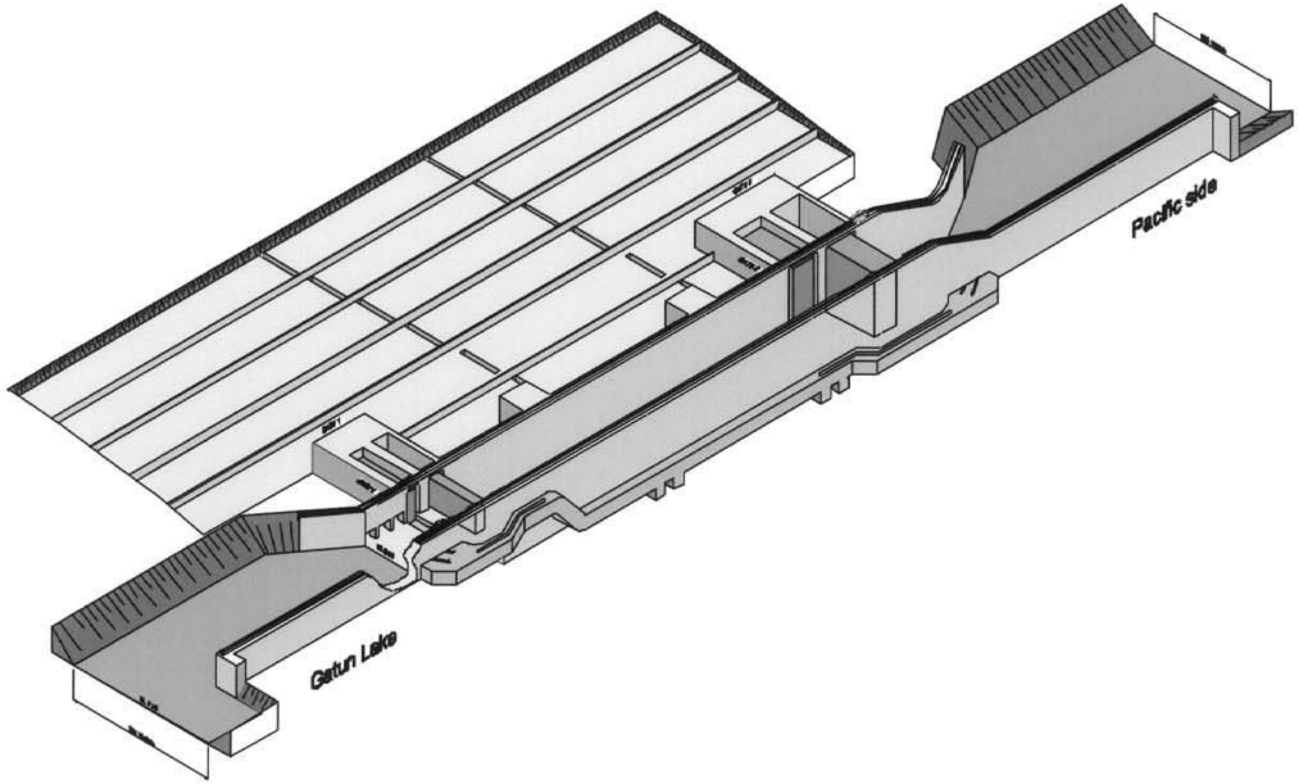
The conceptual design of the single lift lock complex has resulted in the development of a system which meets the requirements of the T.O.R. and the specific design criteria:

- 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;

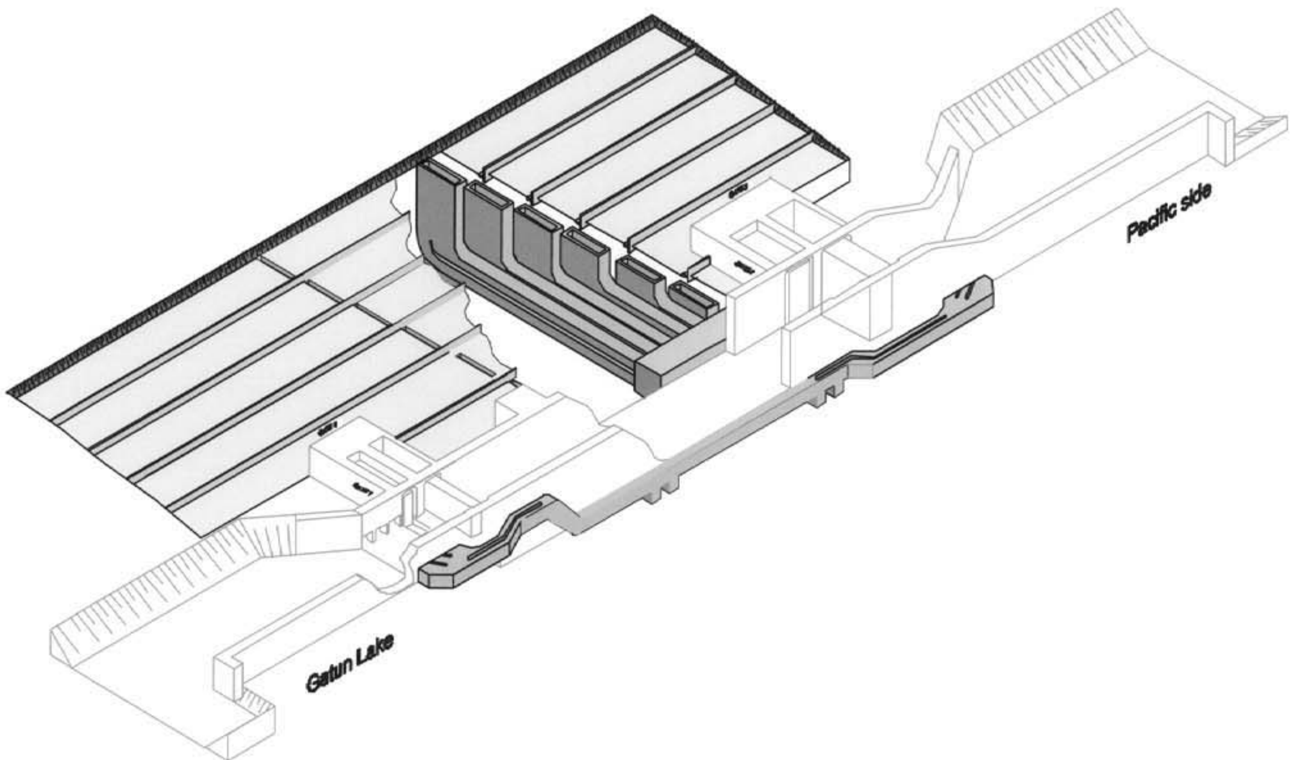
SINGLE LIFT CONFIGURATION



SINGLE LIFT CONFIGURATION



SINGLE LIFT CONFIGURATION



SINGLE LIFT CONFIGURATION