Conceptual Design Study of Locks Water Saving Basins for Proposed Post-Panamax Locks at the Panama Canal

Estudio del Diseño Conceptual de Piletas Laterales para el Ahorro de Agua para las Esclusas Pospanamax Propuestas en el Canal de Panamá

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Resumen Ejecutivo

EXECUTIVE SUMMARY

The Panama Canal Authority (ACP) is conducting a study of the Panama Canal to evaluate the feasibility of constructing facilities and features to augment the Canal's capacity and capability to transit vessels. The proposed locks (~61m x 457m x 18.3m– 200' x 1500' x 60') will be significantly larger than the existing locks (33.5m x 305m x 13m – 110' x 1000' x 43'). Therefore, the new larger locks will dramatically increase the water demands from Gatun Lake. The current lock facilities in addition to the municipal water consumption, hydropower generation, occasional spillage, and evaporation have caused water level changes of up to 2.5 m (9') in Gatun Lake. Therefore, a conceptual study for the design of water saving basin systems for the new locks was warranted to determine the feasibility of various water saving basin system options and the water saving gains which might be realized. The study options for the project were:

- OPTION 1 – Three-lift lock structure – side by side water savings basins to one side of lock – 50% water savings,
- OPTION 2 – Two-lift lock structure – side-by-side water savings basins to one side of lock – 60% water savings,
- OPTION 3 – Three-lift lock structure – side-by-side water savings basins on both sides of lock – 60% water savings, and
- OPTION 4 – Two-lift lock structure – stacked water savings basins on one side of lock – 50% water savings (a side-by-side basin arrangement was also studied).

As part of the study, a comprehensive data collection was completed along with a formulation of detailed design criteria. These criteria and design procedures were applied to determine basin and conduit layouts and associated sizes. These features were then conceptually designed hydraulically, structurally and geotechnically. Detailed breakdowns of opinions of probable costs were also completed.

An in-house spreadsheet model was created to complete the hydraulic analyses. This model was checked against the USACOE's LOCKSIM model and calibrated/verified to the existing locks with satisfactory results. A preliminary design of the lock Filling and Emptying (F/E) culverts was also completed to determine reasonable head loss estimates at the interface of the two systems and more importantly to determine the upper threshold of WSB conduit size (i.e., the WSB conduit should not be larger than the lock F/E culvert).

Hundreds of individual model runs were completed to create parametric curves which provided an opportunity to investigate "what-if" scenarios with a range of culvert sizes and arrangements. These curves were also plotted against the two most important design criteria which were equalization time and instantaneous maximum F/E rate. The explicit criteria for the lock F/E culverts were:

- the instantaneous maximum F/E rate should not exceed 2.28 m/min (7.5 ft/min) (the maximum for the existing locks with two culvert operations), and

- F/E times for a 3-lift system should be 8 – 9 min per lift (based on the existing system) and for a two-lift system, (3 lift x 8 – 9 = 24-27 min total)/2 lift = 12 – 13.5 min/lift. A factor of 3/2 was used to compute the F/E time for a two-lift system, assuming equal total operational times for the three-lift and two-lift systems. This factor was used only as a target in designing the preliminary F/E system.

In applying these criteria, the finalized lock F/E culvert sizes were found to be:

- Options 1 & 3 – Atlantic Side (8.84 m - 29'),
- Options 1 & 3 – Pacific Side (8.53 m - 28'),
- Options 2 & 4 – Atlantic Side (7.92 m - 26'), and
- Options 2 & 4 – Pacific Side (7.62 m - 25').

A comparative study, described in detail on pages 122-124 verified that vertical lift valves should be used for the WSB conduits due to faster equalization times and symmetrical behavior with bi-directional flow. Parametric curves were also created for the design of the water saving basin conduits. The design criteria for the WSB conduits were:

- the WSB conduits should not be larger than the preliminary F/E culvert sizes,
- no conduit solution should exceed an instantaneous maximum F/E rate of 2.28 m/min (7.5 ft/min) for basin to lock operations, and
- no conduit solution should have a single basin operation time of less than 2 minutes (which is the assumed shortest time needed to open and immediately close the valves).

Using these criteria, a myriad of solutions were available so methodologies were formulated to combine the results from the lock F/E culvert and the WSB conduit analyses to compute more meaningful statistics including total operation time, allowable transits/day, etc.

These statistics were submitted to ACP for review. The finalized WSB conduit arrangement and sizes chosen (for square conduits) by ACP were:

- Option 1 – 4 conduits/basin (6.10 m - 20'),
- Option 2 – 4 conduits/basin (7.32 m - 24'),
- Option 3 – 2 conduits/basin (8.53 m - 28'), and
- Option 4 (side-by-side basins) – 4 conduits/basin (6.71 m - 22')

ACP's selection of the number and sizes of conduits for the above options is based upon the desire to obtain a range of price scales for the different options. Therefore, the conduit selections are not necessarily the optimum for each option, but will provide a range of price options from most to least costly.

At this point, work was halted by ACP before the WSB conduit size could be finalized for the stacked basin arrangement for Option 4. The main reason for the work stoppage was that ACP now had new, revised alternative arrangements to be studied. ACP desired that as much of the

remaining fees be applied to the new work order as possible so ACP directed the project team to stop all work on the current contract. The contract amount was reduced in accordance with this directive. A preliminary analysis using the same conduit size as that selected for the side-by-side basins indicated that the performance characteristics of the stacked WSB would be similar. However, these preliminary reviews also indicated that further refinement would be needed to size the conduits for the stacked basin arrangement since the equalization times were approximately 15% longer when compared with the side-by-side basin arrangement.

Based on the finalized conduit sizes selected by ACP, it is expected that the conduits will need to be bifurcated in order to accommodate more manageable, reliable, and likely less costly valves. Therefore, the valve recess to each conduit will house two main control valves and four closure bulkhead recesses (recesses will be located both upstream and downstream of control valves).

Throughout the conceptual design process, it became quickly apparent that two of the most important influences on the size of water saving basins and conduits required was the range of water levels (both lake and ocean) and lockage lengths (426.7 m - 1400', 457.2 m - 1500', and 487.7 m - 1600') for which the systems should be designed. This is especially important on the Pacific Ocean side where the tide range can exceed 7 meters. These variations had significant impacts, especially on the basin wall heights required for the theoretical water savings percentage to be achieved under all conditions. If the results of this study show that ***water saving basin systems*** that would accommodate the full range of water level and lockage length variations are not economically justifiable, the systems could be re-designed under a narrower range of hydrologic (see percent exceedance data in **Appendix C**) and hydraulic conditions (426.7 m - 1400', 457.2 m - 1500', and 487.7 m - 1600' lockage lengths) which may significantly reduce the conduit sizes as well as the basin wall heights.

During the hydraulic design, it was also discovered that the design of a stacked basin arrangement with basins only on one side of the lock is problematic because the range of water levels and lockage lengths necessitate an "overlap" between basins if the theoretical water saving percentage is always to be realized (for a more detailed explanation on "overlap", see pg. 79). Nonetheless, the problem can be overcome by increasing the width of the basins to a value greater than that of the locks ($m > 1.0$). However, this entails additional excavation for the upper locks and higher costs. Therefore, in future studies, a stacked arrangement with basins on both sides of the lock would be a superior configuration based on hydraulic consideration, although it would undoubtedly be more costly. Having basins on both sides of the lock will allow for the basins on one side to be offset from those on the other side (which will better accommodate the necessary "overlap").

The results of the hydraulic analyses are summarized and compared for all options (in both metric and English units) in the following tables.

System Layout and Theoretical Water Savings Percentages for all Options

OPTION	# Lifts	# WSBs per Lift	# Conduits per WSB	Conduit Diameter	Theroretical Water Savings Percentage
Option 1	3	2	4	6.10 m (20')	50%
Option 2	2	3	4	7.32 m (24')	60%
Option 3	3	6 (half size)	2	8.53 m (28')	60%
Option 4	2	2	4	6.71 m (22')	50%

Overall Water Usage and F/E Times per Lockage for Atlantic Side Options

Metric Units

OPTION	Water Intake Height Without Basins (m)			Water Intake Height With Basins (m)			Water Intake Volume With Basins (Avg. Lockage = 61 m x 457 m) ($10\,m^3$)			Average Total F/E Time per Lockage (min)
	min	mean	max	min	mean	max	min	mean	max	
Option 1	7.01	8.49	10.04	3.51	4.24	5.02	97.71	118.27	139.85	31.46
Option 2	10.48	12.73	15.00	4.19	5.10	6.00	116.74	142.06	167.38	26.52
Option 3	7.01	8.49	10.04	2.80	3.40	4.02	78.17	94.65	111.98	36.43
Option 4*	10.48	12.73	15.00	5.24	6.37	7.50	145.97	177.58	209.18	26.35

* side-by-side basins

English Units

OPTION	Water Intake Height Without Basins (ft)			Water Intake Height With Basins (ft)			Water Intake Volume With Basins (Avg. Lockage = 200' x 1500') (million gal)			Average Total F/E Time per Lockage (min)
	min	mean	max	min	mean	max	min	mean	max	
Option 1	23.00	27.85	32.93	11.50	13.92	16.46	25.81	31.24	36.94	31.46
Option 2	34.37	41.78	49.23	13.74	16.72	19.70	30.83	37.52	44.21	26.52
Option 3	23.00	27.85	32.93	9.20	11.14	13.18	20.65	25.00	29.58	36.43
Option 4*	34.37	41.78	49.23	17.18	20.90	24.62	38.55	46.90	55.25	26.35

* side-by-side basins

Overall Water Usage and F/E Times per Lockage for Pacific Side Options

Metric Units

OPTION	Water Intake Height Without Basins (m)			Water Intake Height With Basins (m)			Water Intake Volume With Basins (Avg. Lockage = 61 m x 457 m) ($10\,m^3$)			Average Total F/E Time per Lockage (min)
	min	mean	max	min	mean	max	min	mean	max	
Option 1	6.10	8.46	11.17	3.05	4.23	5.58	84.96	117.93	155.66	34.72
Option 2	9.12	12.70	16.69	3.65	5.08	6.67	101.62	141.55	186.07	27.58
Option 3	6.10	8.46	11.17	2.44	3.38	4.47	67.97	94.31	124.56	37.28
Option 4*	9.12	12.70	16.69	4.56	6.35	8.35	127.11	177.07	232.63	27.55

* side-by-side basins

English Units

OPTION	Water Intake Height Without Basins (ft)			Water Intake Height With Basins (ft)			Water Intake Volume With Basins (Avg. Lockage = 200' x 1500') (million gal)			Average Total F/E Time per Lockage (min)
	min	mean	max	min	mean	max	min	mean	max	
Option 1	20.01	27.77	36.64	10.00	13.92	16.46	22.44	31.15	41.11	34.72
Option 2	29.91	41.67	54.77	11.96	16.72	19.70	26.84	37.39	49.15	27.58
Option 3	20.01	27.77	36.64	8.00	11.14	13.18	17.95	24.91	32.90	37.28
Option 4*	29.91	41.67	54.77	14.96	20.90	24.62	33.57	46.77	61.44	27.55

* side-by-side basins

The opinions of probable costs estimates for three of the four options can be seen in the following tables.

Opinions of Probable Costs (Conceptual Level) for Atlantic Side Options

OPTION	Civil/Structural Construction Costs (U.S. Dollars, in Millions)	Mechanical Item Costs (U.S. Dollars, in Millions)	Electrical Item Costs (U.S. Dollars, in Millions)	**Total Costs (U.S. Dollars, in Millions)**
Option 1	$325	$30.0	$1.6	**$357**
Option 2	$360	$30.0	$1.6	**$392**
Option 3	$418	$23.7	$1.6	**$444**

Opinions of Probable Costs (Conceptual Level) for Pacific Side Options

OPTION	Civil/Structural Construction Costs (U.S. Dollars, in Millions)	Mechanical Item Costs (U.S. Dollars, in Millions)	Electrical Item Costs (U.S. Dollars, in Millions)	**Total Costs (U.S. Dollars, in Millions)**
Option 1	$380	$30.0	$1.6	**$412**
Option 2	$466	$30.0	$1.6	**$498**
Option 3	$547	$23.7	$1.6	**$573**