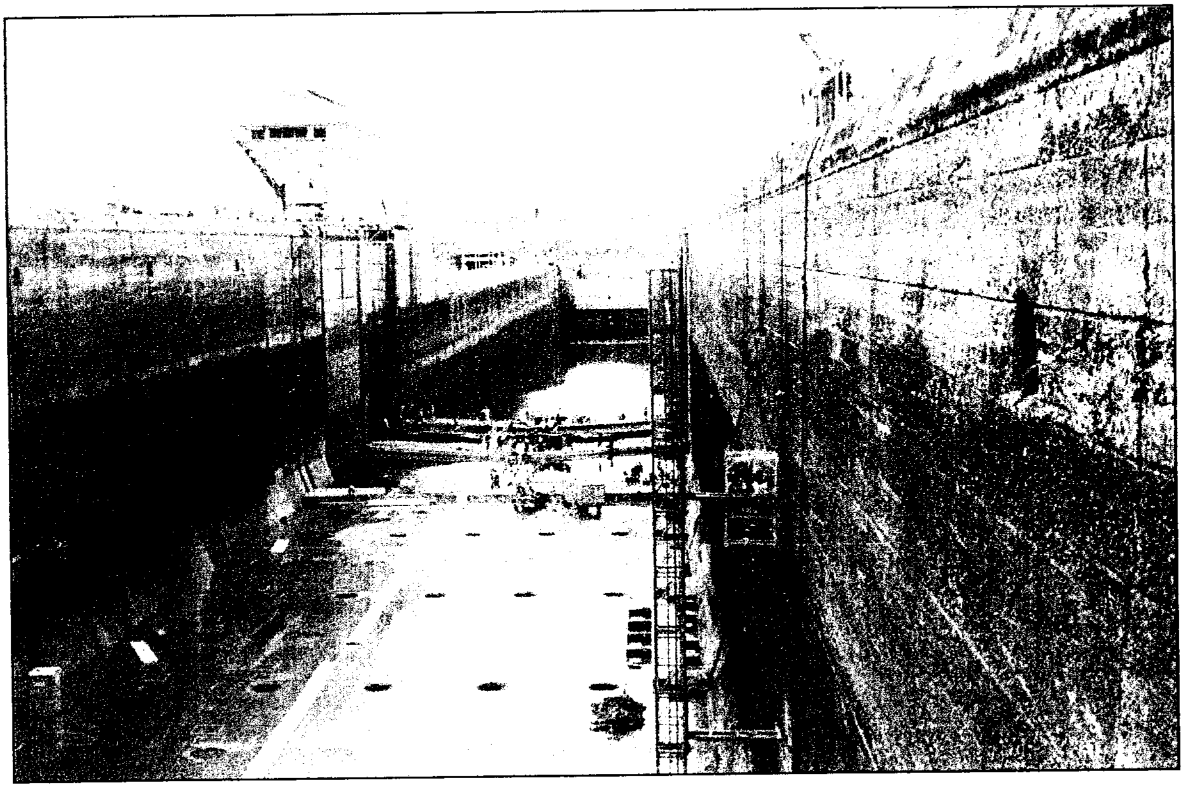
U.S. Army Corps
Of Engineers
Pittsburgh District

PANAMA CANAL
STUDY TO INCREASE DRAFT



FINAL REPORT
11 APRIL 2002

Pending final comments from ACP.

PANAMA CANAL STUDY
TO INCREASE DRAFT

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PANAMA CANAL STUDY
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1. Purpose

The Panama Canal Authority is interested in increasing the allowable draft of vessels through the canal in order to increase canal capacity. At the present time, the maximum draft of 12.04 m (39.5 ft) is limited by the water levels in the lakes and lock chambers and the elevation of the miter gate and caisson sills. The purpose of this study is to evaluate alternative measures that would increase vessel draft beyond the existing 12.04 m (39.5 ft) limitation. The two basic alternatives considered are raising the water levels in Gatun and Miraflores Lakes and lowering critical sill elevations in the locks. Increasing lake levels would necessitate adjustments to the entrance velocity of the lake chambers or to certain features of the locks such as the tops of the miter gates and openings in machinery recesses. These features were evaluated, structural modifications are defined and a maximum practical increase in lake levels is recommended. Likewise, the various gate and caisson sills are evaluated to determine which sills are critical in limiting vessel draft. It was initially established during a site visit to Miraflores Locks on 22 September 1999 that the maximum extent of sill lowering permitted would be that which did not require adjustment of the pintle base. Based on the site inspection in 1999, it was determined that the critical sills could be lowered 305 mm (1 ft). Preliminary designs are prepared to lower the critical sills to the recommended elevations and various methods of demolition and construction are considered. Estimated costs and construction schedules are developed for the various alternatives to enable to ACP to evaluate the economic impacts of performing the work.

2. Methodology

There are two means of increasing the vessel draft – raise Gatun and Miraflores Lakes and lower the sills of the locks. The study focused on identifying the critical structural elements within the locks that placed limits on raising the lakes and lowering the sills. A threshold established at the onset of the study is that no or only minor structural modifications are required of the lock elements for each alternative evaluated. The limit placed on lowering the sills is that modification of the chamber floors and the pintles of the miter gates is not an option. The limit placed on raising the lake elevations is that flooding of machinery recesses and galleries is not permitted.

The identification of the critical sills is based on ACP Dwgs. 6832, 6124-6, 7039, 7041-2, 7045, and 7065-7, the ACP plates entitled "Master Miter Gate and Valve Overhaul Schedule", "Panama Canal Elevations Diagram", and "Under keel Clearance and Over the Sill Clearance for 39.5 Feet Draft Vessels". All of the material was compiled to develop Plate 1 (Appendix 1). Plate 1 served as the basis for identifying the critical sills.

The basis of determining the elevation in which the critical sills may be lowered was a site visit to Miraflores Locks on 22 September 1999 and a review of the aforementioned drawings and ACP Dwgs. 5023, 5025, 5088-223A, 5158, and 5161. The miter gate seals and sills were inspected during the outage (dewatering) of the lock for regularly scheduled maintenance. From visual inspection and measurements, it was determined that the miter gate sills may be lowered by 305 mm (1 ft) without the need to modify the elevations of the pintles and quoin seals. The decision to lower the miter gates sills by only 305 mm (1 ft) minimizes the modifications that need to be made, the level of effort, and the lock outage duration.

The investigation into raising the Gatun and Miraflores Lakes is based on ACP survey data and machinery drawings and the USACE report entitled "Measurement of Pressures Related to Vessel Movement within Miraflores Upper West Lock" dated 30 June 1999. Additional work was also performed to quantify the relationships of entrance velocity, wave action, lake chamber elevation, and vessel draft. This information is used to establish the recommendation in the report for raising lake elevations.

3. Findings

3.1. Raising the Levels of Gatun Lake and Miraflores Lake

There are two critical elevations that would limit the amount that Gatun Lake and Miraflores Lake could be raised in a practical sense, that is, with no or minor structural modification. Those evaluations are (1) the top of the miter gates and (2) the opening on the lock wall to the machinery pits that allows passage of the strut arm. At present, Gatun Lake is held at EL +12.04 m (87.5 ft) when sufficient water is available. Miraflores Lake is held at EL +16.61 m (+54.5 ft). At these levels, waves sometimes top the downstream miter gates as Panamax ships enter the lake chambers from the lakes, likewise the bull gear pit is temporarily flooded. This temporary flooding is only momentary and is generally not a problem as long as the pit drains are functioning properly and it does not flood any part of the tunnel. Bulkheads have been fabricated and are in place to prevent tunnel flooding in critical areas. These bulkheads close the opening from the machinery pit to the tunnel.

Survey data was gathered for the "top of miter gates" for several upper chamber gates at Gatun, Pedro Miguel, and Miraflores Locks. At Gatun Locks the top of the miter gate elevation range from a low of 26.885 m (88.207 ft) for miter gate 21 to a high of 26.930 m (88.352 ft) for miter gate 27. At Pedro Miguel Locks the tops are 26.931 m (88.357 ft) for miter gate 65 and 26.934 m (88.367 ft) for miter gate 64. At Miraflores Locks the tops are 16.752 m (54.959 ft) for miter gate 112 and 16.772 m (55.026 ft) for miter gate 113.

The measurement by the survey party from the top of the miter gate to the bottom of the strut arm is 4½ inches. Using an average miter gate top of 26.911 m (88.291 ft) for Gatun gates, the bottom of the strut arm would be 27.025 m (88.291 ft + 0.375 ft (4½ in) = 88.666 ft). To confirm, refer to Isthmian Canal Commission Dwg. 5056, Section "BB". The center of the 406.4-mm (16-in) diameter strut arm is 0.813 m (2'-8") below top of coping. This would put the bottom of the strut arm at 27.03 m (92 ft – 3.33 ft = 88.67 ft). The situation would be similar at the Pedro Miguel Locks. At Miraflores Locks the coping elevation is 17.89 m (58.7 ft). The bottom of the strut arm would be 16.88 m (58.7 ft – 3.33 ft = 55.37 ft).

Table 1 presents critical elevations for a still water condition at Gatun, Pedro Miguel, and Miraflores Lake Chambers. At Gatun Locks a free board of 0.241 m (0.79 ft) exists at the gate and 0.357 m (1.17 ft) at the strut arm. At Pedro Miguel Locks a free board of 0.263 m (0.862 ft) exists at the gate and 0.357 m (1.17 ft) at the strut arm. At Miraflores Locks a free board of 0.149 m (0.49 ft) exists at the gate and 0.265 m (0.87 ft) at the strut arm. There appears to be an opportunity to hold lake levels slightly higher under still water conditions.

Table 1. - Critical Sill Water Elevations.

Lake Chamber	Top of Gate	Lake Level	Bottom of Strut Arm
Gatun	26.911 m (88.291 ft)	26.67 m (87.5 ft)	27.027 m (88.67 ft)
Pedro Miguel	26.933 m (88.362 ft)	26.67 m (87.5 ft)	27.027 m (88.67 ft)
Miraflores	16.762 m (54.993 ft)	16.61 m (54.5 ft)	16.877 m (55.37 ft)

Upon review of the sill depths, a 14.63 m (48 ft) mean exists at the Gatun Lake Gates in Gatun and Pedro Miguel Locks and 13.01 m (42.7 ft) mean at Miraflores Locks, therefore the greatest benefit would be realized by raising Miraflores Lake. Unfortunately, Miraflores Locks has the least available free board of all the Lake Chambers. Still water conditions present a free board of 0.149 m (0.49 ft) at the miter gates and 0.265 m (0.87 ft) at the strut arm, and these free boards are exceeded momentarily by wave action created by ships entering the locks. This action was studied and documented in a report entitled "Measurement of Pressures Related to Vessel Movement within Miraflores Upper West Lock" dated 30 June 1999. For the purpose of this report, a 76 mm (0.25 ft) raise in pool at Miraflores Lake is proposed and analyzed including wave actions. These effects are analyzed and compared with a baseline condition of 16.61 m (54.5 ft) lake level for Miraflores. A similar situation is presented for Pedro Miguel and Gatun.

As presented in Table 2, the expected surcharge from waves exceeds both critical elevations at all lake chambers. This phenomenon can be confirmed by observation quite frequently during normal lockage operation. Measures have already been implemented to limit flooding of the bull gear pits by partially closing the slots utilizing a flexible material in some locations. Several interesting observations become apparent upon analyzing the Miraflores Lake data. They are: 1) If the lake level is increased by 76 mm (0.25 ft) the surcharge decreases slightly and the maximum elevation increases only slightly. 2) If the lake level is increased by 76 mm (0.25 ft) and the draft is increased to 12.12 m (39.75 ft), the surcharge is about the same and the maximum elevation increases about 76 mm (0.25 ft). 3) If the lake level is increased by 76 mm (0.25 ft), the draft is increased to 12.12 m (39.75 ft), and the ships entrance velocity is decreased slightly, the surcharge is significantly reduced and the maximum elevation is about the same as the baseline elevation. It appears under this scenario that Miraflores Lake could be raised 76 mm (0.25 ft) with almost no effect on the locks if the entrance velocity of a vessel is decreased from 0.69 m/s (2.27 ft/s) to 0.66 m/s (2.15 ft/s). Refer to Figures 17 and 18 in the report referenced in Table 2 for details on surcharges and velocity predictions. A pilot can control the entrance velocity.

The strut arm slots are retrofitted with a flexible material to bulkhead the underside of the strut arm, as noted above. This system functions by minimizing flooding in the bull gear pits. This flooding presents a risk should it convey debris into the pit and clog the drain. This would cause the pit to flood and eventually flood the tunnel. For these reasons it would prove advantageous to further restrict flow into the bull gear pit. The strut arm openings do not have to be made

Table 2. - **Downbound Entering From Lake Maximum Surcharge Wave Estimates - Raise Gatun and Miraflores Lakes 76 mm (0.25 ft).**

Miraflores	**Draft** (m) (ft)	**Pool EL** (m) (ft)	**Aship** (m^2) (ft^2)	**Atotal** (m^2) (ft^2)	**BR' ***	**Vmax *#** (m/s) (ft/s)	**Expected Surcharge** (m) (ft)	**Expected Elevation** (m) (ft)	**Maximum Surcharge** (m) (ft)	**Maximum Elevation** (m) (ft)
Baseline	12.04 39.5	16.61 54.5	385.1 4145	464.8 5003	0.829	0.69 2.27	0.92 3.03	17.54 57.53	1.11 3.63	17.72 58.13
Increase depth	12.04 39.5	16.69 54.75	385.1 4145	467.3 5030	0.824	0.70 2.30	0.90 2.94	17.58 57.69	1.08 3.54	17.77 58.29
Increase depth + draft	12.12 39.75	16.69 54.75	387.5 4171	467.3 5030	0.829	0.69 2.26	0.93 3.04	17.61 57.79	1.11 3.64	17.80 58.39
Increase depth + draft + limit speed	12.12 39.75	16.69 54.75	387.5 4171	467.3 5030	0.829	0.66 2.15	0.84 2.77	17.53 57.52	1.03 3.37	17.71 58.12
Pedro & Gatun										
Baseline	12.04 39.5	26.67 87.5	385.1 4145	536.6 5776	0.718	0.94 3.09	0.52 1.71	27.19 89.21	0.70 2.31	27.37 89.81
Increase depth	12.04 39.5	26.75 87.75	385.1 4145	539.2 5804	0.714	0.95 3.11	0.51 1.68	27.26 89.43	0.69 2.28	27.44 90.03
Increase depth + draft	12.12 39.75	26.75 87.75	387.5 4171	539.2 5804	0.719	0.94 3.08	0.52 1.72	27.27 89.47	0.71 2.32	27.45 90.07
Increase depth + draft + limit speed	12.12 39.75	26.75 87.75	387.5 4171	539.2 5804	0.719	0.85 2.80	0.45 1.47	27.19 89.22	0.63 2.07	27.37 89.82

* Equations from Measurement of Pressures Related to Vessel Movement within Miraflores Upper West Lock, by Raymond A. Povirk and Raymond D. Rush, Pittsburgh District, U.S, Army Corps of Engineers, June 30, 1999

Vmax is the maximum expected velocity for a given modified blockage ratio (BR') based on measurements at Miraflores Upper West Lock

watertight. Smaller and more restricted openings would greatly reduce the entrance of debris and the risk of clogging the bull gear pit drain.

The rising stem valve motors are documented as running overloaded in the "Panama Canal Operations and Maintenance Study, Main Report, June 1996". This overload is likely due to sliding friction when the valve is lifted under head. The report attributes numerous drive-line problems to this overload. This problem is presently being mitigated by the replacement of the motors and drive lines with hydraulic activators, however, this additional load has not been compensated for at the pick-up point on the valve body (H-casting). It must be noted that any increase in pool will increase the head under which these valves are operated resulting in additional overloading of the remaining motors and drive lines that have not been converted to hydraulic activators. It is likely that the increased friction due to the new sliding surfaces of the rising stem valves will increase the total loading and the fatigue loading on the H-castings.

3.2. Lower the Existing Critical Sills and Extend the Bottom of the Affected Miter Gates

3.2.1 Identification of Critical Sills

The primary purpose of lowering the critical miter gate sills is to increase vessel draft beyond the current maximum allowable of 12.04 m (39.5 ft) to permit increased tonnage. Lowering the critical miter gate sills also provides the additional benefits of increasing the capacity of the canal and reducing transit times during periods of low lake levels.

A study was initially conducted to identify the critical sills. The minimum draft for all miter gate, lower guard, caisson, chain fender, and emergency dam sills of Gatun, Pedro Miguel, and Miraflores Locks is presented in Plate 1, Minimum Draft. The minimum drafts are based on the current sill elevations, the lowest lake and chamber pool elevations, and the extreme low water elevations for the Pacific and Atlantic Oceans. The information was compiled from as-built drawings and plates provided by ACP. The tabulation of the minimum drafts provides the means of identifying the eighteen (18) critical sills for modification (Table 3). The current proposal is to lower all sills within a dewatered lock chamber, except for the lower chain fender sills of Pedro Miguel Locks. These sills must be lowered using in-the-wet demolition from a floating plant.

Table 3. - Critical Sills.

Locks	Miter Gate Sills			
	Miter Gate Nos.	Type	Number of Sills	Current Draft
Gatun	13-16	Main	2	12.37 m (40.58 ft)
	17-20	Intermediate	2	12.37 m (40.58 ft)
Pedro Miguel	54-57	Main	2	12.34 m (40.50 ft)
	58-61	Intermediate	2	12.34 m (40.50 ft)
	62-65	Main	2	12.34 m (40.50 ft)
	66-69	Main	2	12.34 m (40.50 ft)
Chain Fender Sills				
Pedro Miguel	Between MG No.s 58-61 & 62-65		2	12.34 m (40.50 ft)
	D/S of MG No.s 70-73		2	12.34 m (40.50 ft)
Emergency Dam Sill				
Miraflores	U/S MG No.s 100-103		2	12.34 m (40.50 ft)

ACP proposed the following sills for consideration in the study. However, the values for the minimum drafts reveal that a majority of the sills proposed are not critical and modification of these sills would not increase the minimum draft for the lock system. As a result, the sills for MG Nos. 37-40 for Gatun Locks and the sills for MG Nos. 50-53, the lower upstream emergency dam, and the lower upstream caisson seat of Pedro Miguel Locks are eliminated from the study.

Table 4. - Initial Sills Proposed by ACP for Study.

Locks	Sill Location	Current Draft
Gatun	MG Nos. 37-40	13.47 m (44.2 ft)
Pedro Miguel	MG Nos. 50-53	13.47 m (44.2 ft)
	MG Nos. 54-69	12.34 m (40.5 ft)
	Lower Upstream Emergency Dam	13.47 m (44.2 ft)
	Lower Upstream Caisson Seat	13.47 m (44.2 ft)

3.2.2 Recommendation for Miter Gate Sill Modification

The recommendation is made to lower the miter gate sills 305 mm (1 ft) in elevation. The basis of this decision is a site visit to Miraflores Locks on 22 September 1999. The miter gate seals and sills were inspected during the outage (dewatering) of the lock for regularly scheduled maintenance. From visual inspection and measurements it was determined that the miter gate sills may be lowered 305 mm (1 ft) without the need to modify the elevations of the pintles and quoin seals. The decision to lower the miter gates sills by only 305 mm (1 ft) minimizes the modifications that need to be made, the level of effort, and the lock outage duration. The modifications proposed are to lower the miter gate sills 305 mm (1 ft) from their present elevations and to extend the bottom of the miter gate leafs 88.9 mm (3-½ in) (Plate 10). These two modifications will increase the draft for the modified sills by 305 mm (1 ft). Relevant miter gate and miter gate sill information is provided in Tables 4 and 5 for the existing condition and proposed future modifications.

3.2.3. Concrete Demolition Methods

Three methods of concrete demolition were investigated for lowering the sills: hydro-demolition, slab/wall saw and percussion hammer, and diamond wire cutting. The list of demolition contractors contacted is provided in Appendix 1.

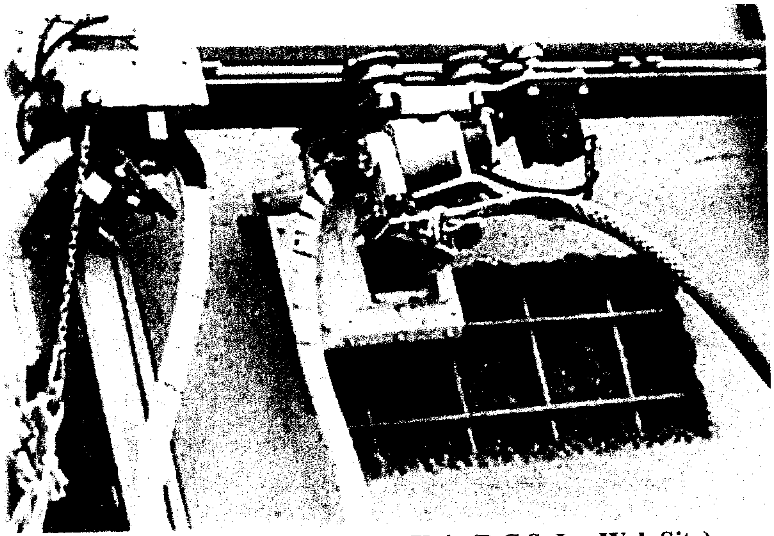

Figure 1. - Robotic Water-Jet Unit (P.C.S. Inc Web Site).

Hydro-demolition typically uses a high-pressure pump and a track mounted water jet to remove concrete to predetermined depths (Fig. 1). Current high-pressure water-jet demolition units operate at pressures up to 276 MPa (40,000 psi) and flow rates up to 208 lpm (55 gpm). Usually the water jet is controlled with robotic technology to control the movement of the water jet. The depth of sound concrete removal is controlled by the travel rate of the water jet, since the water pressure is held constant. While sound concrete may be removed to predetermined depths, the depth of deteriorated concrete cannot be readily controlled. Hydro-demolition may be used to remove concrete from horizontal, vertical and overhead surfaces. The advantages of hydro-demolition are: 1) controlled removal of sound/deteriorated areas of concrete, 2) does not damage or bruise (micro-fractures) concrete, 3) no dust, 4) exposes aggregate and eliminates need to roughen concrete for overlay, and 5) leaves existing reinforcement in place. The term hydro-demolition is slightly misleading for this concrete removal method; a more appropriate term is hydro-rehabilitation, since significant depths of concrete cannot be removed efficiently. The disadvantages of hydro-demolition are 1) limited depths of removal, 2) cost, 3) unpredictable removal depths for unsound concrete, and 4) time required for mass concrete removal. The hydro-demolition contractors that were contacted unanimously agreed that this technology was not appropriate for lowering the miter gate sills.

Slab/wall sawing, augmented by percussion hammers, is used to demolition large sections of horizontal concrete. Slab sawing is used to cut horizontal flat surfaces such as floors, bridge decks, and pavement typically up to 24 in deep. Slab sawing is the most common diamond saw cutting method. The equipment consists of a diamond blade up to a 1.54-m (60-in) diameter that is mounted in a walk behind machine. Wall sawing utilizes a diamond blade on a track-mounted system that can be used for vertical and horizontal cuts. Slab/wall sawing is an efficient means of cutting reinforced concrete and various types of concrete aggregate. The conventional demolition method for removing concrete, following the sawing of concrete into sections, is jack or robotic hammering (Fig. 3). The advantages of robotic-hammer demolition of concrete are efficiency, speed, and control of concrete removal. The disadvantages are 1) excessive dust, 2) noise pollution, 3) micro fracturing and bruising of sound concrete, and 4) unintentional damage to rebar.

Table 5. -Miter Gate and MG Sill Information for Existing Condition.

Lock	Miter Gates			Existing					
	No.	Type	Height (m) (ft)	MG Sill EL (m) (ft)	Chamber Floor EL (m) (ft)	Low Water EL (m) (ft)	MG Seal EL (m) (ft)	Minimum Draft (m) (ft)	MG-Floor Clearance (mm) (in)
Gatun	13-16	Main	23.72 77.83	-4.14 -13.58	-4.75 -15.58	+8.23 +27.0	-4.32 -14.16	12.37 40.58	216 0.71
	17-20	Intermediate	23.72 77.83	-4.14 -13.58	-4.75 -15.58	+8.23 +27.0	-4.32 -14.16	12.37 40.58	216 0.71
Pedro Miguel	54-57	Main	24.08 79.0	+3.96 +13.0	+3.52 +11.0	+16.31 +53.5	+3.79 +12.42	+12.34 +40.5	216 0.71
	58-61	Intermediate	24.08 79.0	+3.96 +13.0	+3.52 +11.0	+16.31 +53.5	+3.79 +12.42	+12.34 +40.5	216 0.71
	62-65	Main	24.08 79.0	+3.96 +13.0	+3.52 +11.0	+16.31 +53.5	+3.79 +12.42	+12.34 +40.5	216 0.71
	66-69	Main	24.08 79.0	+3.96 +13.0	+3.52 +11.0	+16.31 +53.5	+3.79 +12.42	+12.34 +40.5	216 0.71

Table 6. - Miter Gate and MG Sill Information for Future Modifications.

Lock	Miter Gates			Future					
	No.	Type	Height (m) (ft)	MG Sill EL (m) (ft)	Chamber Floor EL (m) (ft)	Low Water EL (m) (ft)	MG Seal EL (m) (ft)	Minimum Draft (m) (ft)	MG-Floor Clearance (mm) (in)
Gatun	13-16	Main	23.72 77.83	-4.14 -13.58	-4.75 -15.58	+8.23 +27.0	-4.32 -14.16	12.67 41.58	128 0.42
	17-20	Intermediate	23.72 77.83	-4.14 -13.58	-4.75 -15.58	+8.23 +27.0	-4.32 -14.16	12.67 41.58	128 0.42
Pedro Miguel	54-57	Main	24.08 79.0	+3.96 +13.0	+3.52 +11.0	+16.31 +53.5	+3.79 +12.42	12.65 41.5	128 0.42
	58-61	Intermediate	24.08 79.0	+3.96 +13.0	+3.52 +11.0	+16.31 +53.5	+3.79 +12.42	12.65 41.5	128 0.42
	62-65	Main	24.08 79.0	+3.96 +13.0	+3.52 +11.0	+16.31 +53.5	+3.79 +12.42	12.65 41.5	128 0.42
	66-69	Main	24.08 79.0	+3.96 +13.0	+3.52 +11.0	+16.31 +53.5	+3.79 +12.42	12.65 41.5	128 0.42

Diamond wire sawing (precision demolition) is a flexible sawing technique that can be used to cut large areas in a confined workspace. Typical applications include difficult cuts in remote, restricted, or hazardous locations, massive bulk removal of concrete, the ability to plunge-cut concrete, and underwater cutting. Very large sections of concrete may be cut with this method. The wire sawing system uses a series of guide pulleys to draw a continuous loop of diamond-studded wire through a cut. A 3-in diameter core hole is drilled at each corner of the section of concrete that is to be removed. The concrete may be plunged-cut or the diamond wire may be threaded through the core holes (provided the back of the concrete section is accessible) and then the concrete sawing may commence from the back to the front of the concrete structure. The diamond-studded wire is pulled as it cuts the concrete. The wire saw leaves a kerf that is approximately 38 mm (1-½ in) in thickness (with respect to the side of the core hole). The advantages of this system are: 1) the ability to remove massive sections of concrete, 2) the ability to work within a restricted space, 3) no damage to adjacent structures and concrete, 4) the concrete surface that remains is smooth and void of micro fractures, and 5) the ability to cut embedded metal and aggregate larger than 24 in. The disadvantages of this system are: 1) cost, 2) the time required to drill 3-in diameter core holes, and 3) the need to handle and demolition very large blocks or slabs of concrete. In many instances, the large slabs of concrete need to be saw cut to facilitate their handling and demolition.

Figure 2. - Slab Saw (Concrete Cutting & Breaking, Inc. Web Site).

3.2.4. Concrete Miter Gate Sill Demolition

The follow options for lowering the miter gate sills are investigated, and preliminary designs and cost estimates are developed for each option:

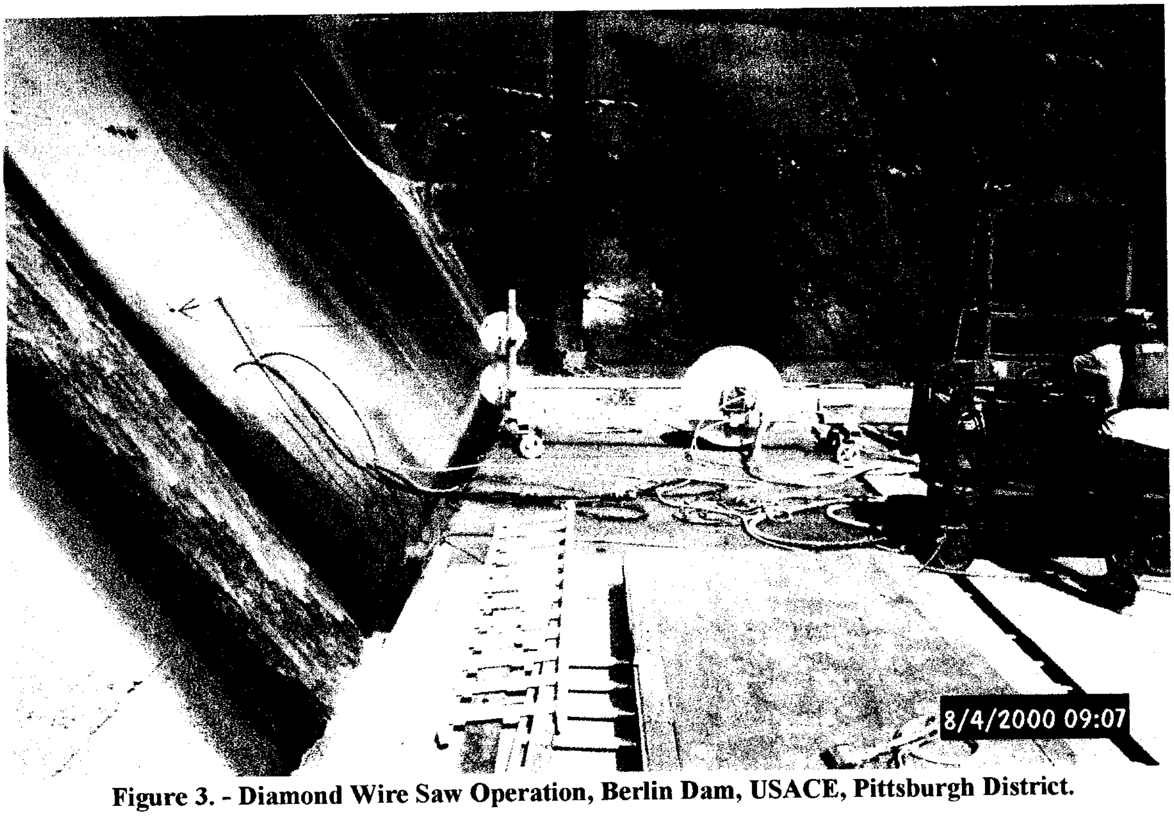

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Figure 3. - Diamond Wire Saw Operation, Berlin Dam, USACE, Pittsburgh District.

1. Lower the existing miter gate sills 610 mm (2 ft) and replace with a 305-mm (1-ft) thick by 1524-mm (5-ft) wide precast panel sill segment.
2. Lower the existing miter gate sills 610 mm (2 ft) and replace with a 305-mm (1-ft) thick by 1524-mm (5-ft) wide CIP panel sill segment.
3. Lower the existing miter gate sills 305 mm (1 ft), cut a 305-mm (1-ft) deep by 356-mm (14-in) wide recess at the upstream side of the sill, install metal embeds, and place concrete.
4. Lower the existing miter gate sills 305 mm (1 ft), cut a 305-mm (1-ft) deep by 610-mm (2-ft) wide recess at the upstream side of the sill, install metal embeds, and place concrete.

In addition, two alternative methods of concrete removal are evaluated for each option in terms of cost – precision demolition (diamond wire saw) and conventional demolition (slab/wall saw and robotic demolition).

The procedure for the lowering a miter gate sill using precision demolition is as follows for options 1-4. The first initial phase is to core drill 76.2-mm (3-in) diameter holes completely through the sill. A 76.2-mm (3-in) diameter, 7.62-m (25-ft) long core drill hole takes approximately 15 to 18 hours to complete and is dependent on the strength of the concrete and the amount of embedded steel encountered. To remove a 305 mm (1-ft) slab from the sill, the centerline of the core hole would be positioned 305 mm (1 ft) below the top of the sill. However, to remove a 610-mm (2-ft) thick slab, the apron of the sill interferes with the proper positioning of the drill centerline. As a result, the bottom of the drill hole will be coincident with the top of the apron. Since a 38-mm (1-½-in) kerf exists with precision demolition, the maximum amount of sill removal with respect to depth is 572 mm (1' 10-½"). A total of five (5) core holes are drilled per sill to partition the slab into four slabs approximately 18.3 m (60 ft) in length. After the completion of two core holes, a diamond-studded wire is threaded through the holes and guide pulleys of the saw. The saw draws the wire through the cut. During the process wire sawing, other crews of the work force will continue to: 1) slab saw (vertically) the wire-saw slabs into smaller sections to facilitate removal, 2) core drill additional holes, and 3) start wire sawing another slab. As a result, potentially three (3) crews/shift will be required to conduct the demolition and concrete placement work for each sill:

1. 2 drilling crews.
2. 2 slab-saw crews.
3. 2 robotic-hammer crews.

The total wire saw and demolition process will take 4 to 5 days/sill, with crews working two (2) 12-hour shifts/day. For option 3 and 4, an additional recess needs to be cut on the upstream side of the miter gate sill. This will be done with slab/wall saws. This effort will take approximately 8 hours to complete. For the conventional demolition, slab saws will be used make vertical cuts (parallel with the longitudinal axis of the lock) into the miter gate sill on approximately 3-m (10-ft) centers. The depth of the passes made with the slab saws range from 76 to 152 mm (3 to 6 in). A 610-mm (2-ft deep), 7.6-m (25-ft) long saw cut takes approximately 2 to 5 hours, depending on the strength of the concrete and the amount and size of the embedded metal. Robotic hammer crews will break out the concrete using multiple passes upon completion of the

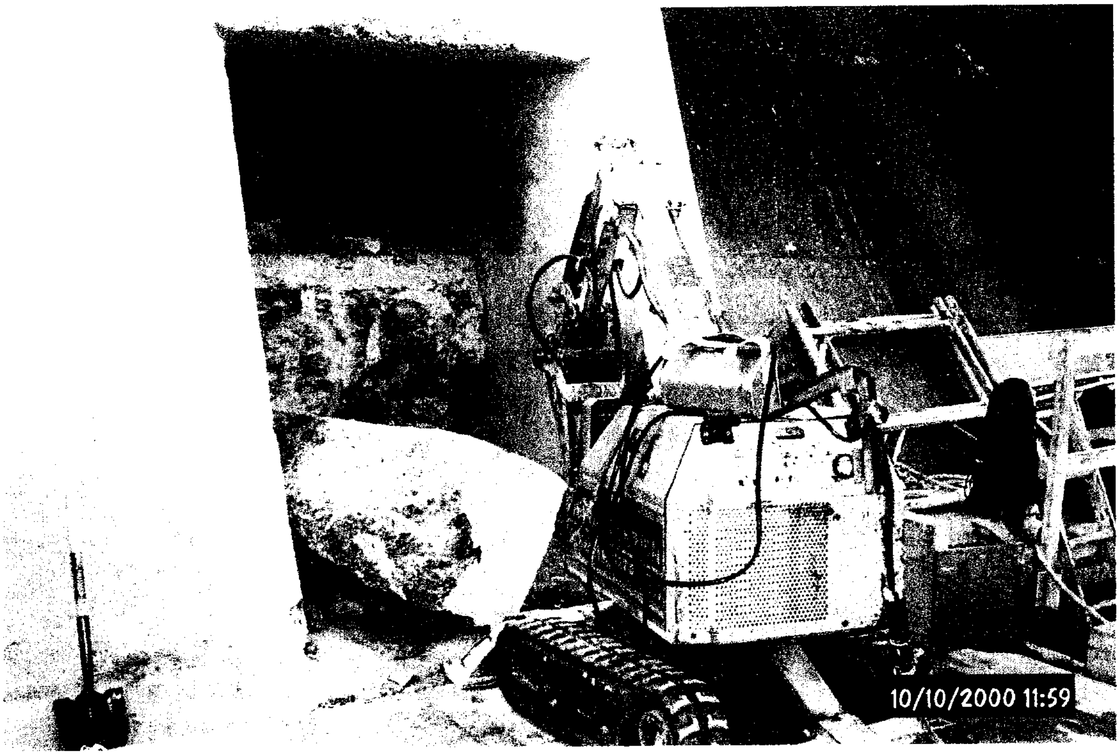

Figure 4. - Robotic Hammer - Berlin Dam, USACE, Pittsburgh District.

vertical saw cuts. The chipped surface will be rough and will need to be milled within an amplitude of roughness equal to 13 mm (½ in). The concrete surface may be sealed with an acrylic, epoxy or polymer coating (methyl methacrylate), but this is not recommended since it will most likely delaminate with time. Approximately seven (7) contractor personnel are required for each 12-hr shift. Two (2) 12-hr shifts will be worked per day. For options 1 and 2, the concrete demolition will take from 3 to 4 days per sill to complete. For options 3 and 4, the concrete demolition will take approximately 3 days per sill to complete.

As a result of the simultaneous work effort of multiple crews and the congestion of equipment, the planning and execution of the demolition work is significant. The demolition work will require a contractor with the experience, personnel, and equipment to conduct the demolition work on two (2) to four (4) sills simultaneously. The estimate of contractor personnel for the precision and conventional demolition methods are for the conduct of the demolition; the estimate does not include the personnel required to water-spray hammers for dust control, pick up the rubble, deal with water/slurry, cut rebar, and remove and dispose all rubble and debris. This work will be subcontracted out to local personnel.

In addition, a tolerance is required for the demolition of the sills in terms of finished elevation after the concrete is removed (precision or conventional methods) and for the conventional method only, when the surface is milled to 7 mm (¼-in) in amplitude. The recommended tolerance is +0 mm to +19 mm (+0 in to + ¾ in). However, in the region of the sill CIP recesses, the tolerance will be +0 mm to + 7 mm (+0 in – ¼ in) since it is desired for the first 0.92 m (3 ft) behind the sealing surface to match to the new sealing surface.

3.2.5 Miter Gate Sill Segment Reconstruction - CIP/Precast Panel Segments

Four (4) options for construction of the concrete sills are developed:

1. Precast Panel Segments:	Plate No. 9
2. CIP Segment:	Plate No. 6
3. CIP Recess, Alternative A:	Plate No. 7
4. CIP Recess, Alternative B:	Plate No. 8

All options require extensive drilling for dowels and/or threadbar for embedded metal, CIP concrete, or precast panel anchorage. The precast panel option is developed to accelerate the construction of the sill segment (Plate 9). The deformed bar will be made in the U.S. and shipped to a precast facility in Panama for fabrication of the panels. The precast panels are provided with combined pick/leveling devices to facilitate handling and leveling. The panels are also provided with ports and vents for grouting and with upstream and downstream compression seals to contain the grout. A grout pressure equal to 69 kPa (10 psi) is recommended. Threadbar anchors are used to hold the panels in place during the grout operation and to resist full hydrostatic uplift pressure for a dewatered condition. The construction sequence is:

1. Place template for anchorage, drill holes, and epoxy grout the threadbars.
2. Place precast panels into position and level.
3. Install the anchor bearing plates and spherical nuts (snug tight).
4. Grout the interface of the existing concrete and precast panel. Start at on end and plug vents/ports with wood dowels when grout daylights.
5. Torque spherical nuts to tighten and grout recesses.
6. The grout mix is design to reach full strength (28 MPa, 4,000 psi) within 24 hours.

For the CIP segment option (Plate 6), the construction requires less time than the precast panel construction and the construction sequence is:

1. Place template for anchorage and dowels, drill holes, and epoxy grout the threadbars.
2. Position and level steel embed (sealing surface).
3. Place reinforcement mats (pre-assembled) and tie to dowels.
4. Place concrete.
5. Concrete mix is designed to reach specified unconfined compressive strength of 28 MPa (4,000 psi) within 24 hours.

For the CIP recesses, Alternatives A and B, the construction sequence is significantly less time consuming than the precast and CIP segment options. The construction sequence is identical to the CIP segment construction sequence.

3.2.6 Preliminary Precast Panel and CIP Panel/Recess Design

The preliminary design of the precast panels, the CIP panels and recesses, the anchorage, and dowels, are based on the following assumptions (Appendix 3):

1. Hydrostatic Pressure: It is assumed that the water level on the upstream side is at the highest lake or chamber pool elevation and on the downstream side the chamber is in the dewatered state.
2. Although the miter gates at Gatun and Pedro Miguel are horizontally framed, it is assumed that the lowest girder transfers all of its loading to the sill segment or recess. The magnitude of the load is equal to the product of the tributary area of the girder (plus the bottom extension) and the upstream hydrostatic pressure.
3. The compression seals for the precast panels and the bond between the CIP panels and recesses are ineffective and full hydrostatic uplift is present.
4. The unconfined compressive strengths assumed are as follows

    - Existing Concrete: 28 MPa (4,000 psi)
    - Precast Concrete: 35 MPa (5,000 psi)
    - CIP Concrete: 28 MPa (4,000 psi)

3.2.7 Concrete Guidance

Concrete guidance is provided for the modification of the lock gate sills at Gatun and Pedro Miguel Locks. The guidance is provided for each sill construction option.

3.2.7.1. Cast-In-Place Option

3.2.7.1.a Construction Scheme: Remove existing concrete for a minimum depth of 2 ft. Replace with 1-foot of new concrete. The lock will be flooded within one or two days after the final concrete placement.

3.2.7.1.b Considerations

1) The main consideration is the accelerated concrete strength required to put the concrete immediately into service. The concrete requirements address this consideration.
2) Joints need to be provided to control shrinkage. The spacing of the joints will be dependent on the dimensions of the placement.
3) The dimensions of the placement will also control the need for a waterstop at the joint between the new and the existing concrete. There should be good consolidation of the new concrete that will minimize leakage at the joint, but some leakage may result from shrinkage. If the full sill is replaced, the need for a waterstop is not necessary. However, the anticipated design is to only replace 1.52 to 3.05 m (5 to 10 ft) of the removed concrete. The final configuration of the sill modification will be evaluated to determine the necessity of a waterstop.
4) A waterstop can be installed in many forms. Additional seepage control can be achieved by providing a key into the existing concrete. This will extend the distance of the seepage path, and therefore would reduce the seepage rate. A conventional waterstop from metal or PVC could be keyed into the existing concrete. Note that this would be more effective than the key alone, but a seepage path may develop where the waterstop is keyed into the existing concrete. A third

type would be a compression seal. This would require that the joint on the outside of the sill be formed with a square groove. A neoprene compression seal could then be installed in the joint. This would also facilitate shrinkage since the concrete will be put in service while the majority of the shrinkage is still occurring, and should also be used at the shrinkage control joints. It appears that compression seals would be the most effective, and most likely would be the least labor-intensive method of minimizing seepage. Note that the installation of a waterstop would increase construction time. Therefore, a waterstop will not be used.

3.2.7.1.c. Concrete Requirements

Compressive Strength:	21 MPa (3,000 psi) in 12 hours, 28 MPa (4,000 psi) in 24 hours, tested in accordance with ASTM C39/C39M.
Water/Cement Ratio:	0.30 to 0.34. The water/cement ratio would be the batch water plus the water portion of the silica fume slurry, divided by the cement plus the silica fume portion of the slurry. Depending on the manufacturer, silica fume slurry is typically about 50% water and 50% silica fume by weight.
Air Content:	Air entrainment is not required, but set the maximum allowable air content at 4% to assure no adverse effect on strength.
Cement Type:	ASTM C150 Type I or II
Cement Content:	Maximum 400 kg/m^3 (675 lb/cy)
Fine Aggregate:	Natural sand in accordance with ASTM C33 for gradation and quality requirements.
Coarse Aggregate:	Crushed stone in accordance with ASTM C33 #57 gradation and Class 1N quality.
Water:	Potable Water
Mineral Admixtures:	Minimum of 10% silica fume by weight of cement, silica fume to be provided in slurry form. Silica fume should comply with the requirements of ASTM C1240.
Chemical Admixtures:	Water Reducer in accordance with ASTM C494/C494M Type A High-Range Water Reducer in accordance with ASTM C494/C494M Type F Accelerator in accordance with ASTM C494/C494M Type C, non-chloride
Placement Temperature:	Concrete Placement Temperature not to exceed 32.2°C (90°F).

3.2.7.2 Precast Option

3.2.7.2.a Construction Scheme: Remove existing sill for a minimum depth of 610 mm (2 ft). Set 229 mm (9-in) thick precast units on top of existing concrete. Level the precast units to the required elevation utilizing the four (4) leveling lugs provided in the precast panels (see Plate 9, Detail 2). The all-thread rod provides the means to raise, lower, or tilt the precast panels to the correct elevation. The gap between the precast units and existing concrete will be approximately 38 to 76 mm (1-½ to 3 in), and will be filled with a cementitious grout. The lock will be flooded within one day after the final grout placement.

3.2.7.2.b Considerations

1) The use of precast units essentially eliminates the concern of shrinkage control required for the cast-in-place option.
2) A method of sealing the gap between the precast units and existing concrete must be provided to contain the grout. The gap under the precast units can be filled under the individual units as they are set, or all units could be set and the grout could be placed over the entire sill at one time.
3) The seal required around the perimeter of the precast unit could be achieved using neoprene compression seals, and would also serve as a seal against leakage at the construction joint. If the sealing surface on the gate side of the sill has to be flush, a temporary bulkhead should be used to contain the grout.
4) As an alternative to the neoprene compression seal, laminated polyethylene sponge could be used around the perimeter of the precast units. A specification sheet is provided as an example of an acceptable product. This type of material would be less sensitive to irregularities in the surface of the existing concrete, and may accommodate the larger joint created by the 76-mm (3-in) gap. The precast unit could be fabricated with a protruding edge to provide key that would recess into the sponge. However, this would not provide as tight a seal as a compression seal, therefore consideration has to be given to the waterstop requirements. For the sealing surface to be flush, this type of seal could only be used on the downstream side and any side seals.
5) The grout will be placed under a 69 kPa (10-psi) pressure to assure complete filling of the gap. The precast units will be anchored to assure that they can resist the grouting pressure.
6) Ports are provided in the precast units to allow the grout to be placed. The ports are placed along two lines 1-foot from the upstream and downstream edges, and spaced no more than 5 feet apart. In addition, vent holes are provided in the four corners of the precast units to assure no air is trapped, if the units are grouted individually. The gap between the units will act as a vent. The sides of the gap between the units will have to be sealed or temporarily bulkheaded. All holes are at least 64-mm (2.5-in) diameter to accommodate the grout line. The grout will be placed in a sequential pattern to allow the grout to flow from one end to the other with the air being driven out as the grout advances.
7) Screw jacks are designed into the precast units to facilitate leveling of the units. A three-point leveling system is preferred but a four-point leveling system will be used.
8) The cementitious grout is prepackaged to provide a more uniform and consistent product. In addition, the grout must provide positive expansion to assure no

shrinkage cracks. A copy of a specification sheet is attached to provide an example of an acceptable product.

3.2.7.2.c. Precast Concrete Requirements

Compressive Strength:	35 MPa (5,000 psi) at 28 days tested in accordance with ASTM C39/C39M. If fabrication of the precast units is not completed more than 28 days prior to placement, the compressive strength should be at least 28 MPa (4,000 psi) at time of placement.
Water/Cement Ratio:	0.40 maximum
Air Content:	Air entrainment is not required, but set the maximum allowable air content at 4% to assure no adverse effect on strength.
Cement Type:	ASTM C150 Type I or II
Cement Content:	Maximum 445 kg/m^3 (750 lb/cy)
Fine Aggregate:	Natural or manufactured sand in accordance with ASTM C33 for gradation and quality requirements.
Coarse Aggregate:	Crushed Stone in accordance with ASTM C33 #57 gradation and Class 1N quality.
Water:	Potable Water
Mineral Admixtures:	Not required
Chemical Admixtures:	Water Reducer in accordance with ASTM C494/C494M Type A High-Range Water Reducer in accordance with ASTM C494/C494M Type F
Placement Temperature:	Concrete Placement Temperature not to exceed 32.2°C (90°F).

3.2.7.2.d. Grout Requirements

Grout Type:	Prepackage, non-shrink grout in accordance with ASTM C1107. The grout must demonstrate positive expansion when tested in accordance with ASTM C109/C109M. The grout must be recommended by the manufacturer for a 3-in thick placement.
Compressive Strength:	28 MPa (4,000 psi) in 24 hours tested in accordance with ASTM C109/C109M
Water Content:	Per manufacturer recommendation. The grout must be sufficiently fluid to flow between the grout ports.
Air Content:	Air entrainment is not required, but set the maximum allowable air content at 4% to assure no adverse effect on strength.
Cement Type:	Per manufacturer mixture design.
Cement Content:	Per manufacturer mixture design.
Fine Aggregate:	Per manufacturer mixture design.

Coarse Aggregate: Not required
Water: Potable Water
Placement Temperature: Maximum temperature per manufacturer recommendation.

3.2.7.3. Replace Sealing Surface Only

3.2.7.3.a. Construction Scheme: Remove existing sill for a minimum depth of 305 mm (1 ft). Remove sealing surface of the sill face to a 356 mm (1'-2") depth and a 305 mm (1 ft) in height. The sealing surface will be replaced with new concrete.

3.2.7.3.b. Considerations

1) This method will significantly reduce costs because the removal and placement of concrete is the minimum required.
2) Joints are provided to control shrinkage. The spacing of the joints is dependent on the dimensions of the placement.
3) Neoprene compression seals may be provided at construction joints to control any leakage created from shrinkage.

3.2.7.3.c. Concrete Requirements

Compressive Strength: 21 MPa (3,000 psi) in 12 hours, 28 MPa (4,000 psi) in 24 hours, tested in accordance with ASTM C39/C39M.
Water/Cement Ratio: 0.30 to 0.34. The water/cement ratio would be the batch water plus the water portion of the silica fume slurry, divided by the cement plus the silica fume portion of the slurry. Depending on the manufacturer, silica fume slurry is typically about 50% water and 50% silica fume by weight.
Air Content: Air entrainment is not required, but set the maximum allowable air content at 4% to assure no adverse effect on strength.
Cement Type: ASTM C150 Type I or II
Cement Content: Maximum 400 kg/m^3 (675 lb/cy)
Fine Aggregate: Natural sand in accordance with ASTM C33 for gradation and quality requirements.
Coarse Aggregate: Crushed Stone in accordance with ASTM C33 #57 gradation and Class 1N quality.
Water: Potable Water
Mineral Admixtures: Minimum of 10% silica fume by weight of cement, silica fume to be provided in slurry form. Silica fume should comply with the requirements of ASTM C1240.
Chemical Admixtures: Water Reducer in accordance with ASTM C494/C494M Type A
High-Range Water Reducer in accordance with ASTM C494/C494M Type F
Accelerator in accordance with ASTM C494/C494M Type C,

non-chloride
Placement Temperature: Concrete Placement Temperature not to exceed 32.2°C (90°F).

3.2.7.3.d Other Considerations

1). ACP is requested to address alkali-aggregate reactions, sulfate reaction, and/or effects of salt water. If any of these is a concern, optional requirements of ASTM C150 and C1240 may need to be invoked, and the cement may need to be restricted to Type II.

2). The use of pozzolans has not been specified due to the early strength requirements, and pozzolans typically do not contribute to early strength gain. There is no other reason to prevent the use of pozzolans, and could be considered at the contractor's request. Fly ash should be in accordance with ASTM C618 Table 1 and Table 3, and ground granulated blast furnace slag should be in accordance with ASTM C989 Table 1 and Table 2. Additional tables may need to be invoked if adverse reaction conditions exist.

3). Potable water is preferred for batching the concrete and grout. If potable water is not available, the water source should be tested in accordance with CRD C400 (USACE Handbook for Concrete and Cement) to determine if deleterious contaminants are present.

4). It appears that ready-mix concrete is available for the proposed work. If access to concrete is a problem, an on-site batch plant will have to be provided or the precast concrete option will have to be considered.

5). It is recommended that ACP provide information on the existing concrete conditions to the bidder/contractor. Given the age of this concrete, and reports of little to no deterioration, the strength of the existing concrete may be substantial. It would not be unexpected to find concrete strengths in excess of 8,000 to 10,000 psi. If this data is not available, the contractor should be required to extract and test core prior to dewatering to verify that their demolition methods are suitable for existing conditions.

6). It is recommended that the method for demolition be left to the contractor. The condition of the final surface should be specified to address the levelness, smoothness, and other tolerances.

3.2.8 Cost Estimate and Comparison

A series of screening level cost estimates is performed for the Concrete Miter Gate Sill Replacement. Several options are evaluated, including a precast segment and three different cast-in-place segments. Each of these options is evaluated using both precision demolition (wire cutting) and conventional demolition (demo hammers). This results in a total of 8 different options that are evaluated.

The screening level cost estimates are developed using historic/standard unit prices adjusted for work in Panama, contractor quotes, and development of detailed labor and equipment cost. Appropriate contingencies are added to each individual item to account for any uncertainties unforeseen at this time. For the purpose of these estimates, it is assumed that the contractor will be from Panama and will provide the equipment, labor and materials (except concrete). These estimates are also based on a maximum chamber shutdown of 10 days. This results in the assumption that construction will proceed 24-hours per day. All of the estimates allow 2 days for dewatering the chamber and 1 day for cleanup and to refill the chamber. It is assumed that 4 dewaterings will be necessary (one for each chamber). The cost of pumping out the chambers is included in the estimate, however, the cost of removing/resetting the gates and placing/removing bulkheads if required are not included.

Joe Ellsworth (Cost Engineer, USACE Mobile District) was contacted in order to get some background on construction costs and practices within Panama. He has previously performed estimates for construction in Panama and other Central American countries. He provided information on material availability as well as production rates and costs for local work crews.

Two separate concrete demolition contractors were contacted and furnished budgetary quotes for the concrete demolition involved with the miter sills. They are Bluegrass Concrete Cutting Inc, and Cutting Edge Services. Bluegrass quoted on the cost of precision demolition while Cutting Edge Services quoted the conventional demolition. These quotes are used as references in preparing the unit costs, as well as unit costs provided by ACP for the concrete demolition items. Also included in the cost estimate for precision demolition is that ACP owns wire cutting units.

The resulting screening level cost estimates are presented in the attached pages. Upon viewing these costs, it can be seen that the conventional concrete demolition is more cost effective than the precision method. It can also be seen that the precast concrete option doesn't prove to be more cost effective than the cast-in-place concrete options. The option that ranks as the most cost effective and requires the shortest time is to remove a 305-mm (1-ft) layer of concrete with conventional methods and then to remove and replace an additional 610-mm (2-ft) wide by 305-mm (1-ft) deep area across the sealing edge of the sill. The only concerns with this option are that any uncertainties involved with the concrete demolition could have a more negative effect (time and cost wise) on the conventional demolition method than on the precision method. Also although the cast-in-place concrete appears more cost effective, it could possibly lead to a longer duration and higher cost if difficulties arise on site.

3.2.9 Maximum Surcharge Wave Estimates for Effects of Lowering Critical MG Sills

Still water conditions at Miraflores Lake Chamber present a free board of 150 mm (0.49 ft) at the miter gates and 265 mm (0.87 ft) at the strut arm, and these free boards are exceeded momentarily by wave action created by ships entering the locks. This action was studied and documented in a report entitled "Measurement of Pressures Related to Vessel Movement within Miraflores Upper West Lock" dated June 30, 1999. For the purpose of this report, a 76 mm (0.25 ft) raise in pool at Miraflores Lake is proposed and analyzed including wave actions. These effects are analyzed and compared with a baseline condition of 16.61 m (54.5 ft) lake level for Miraflores. A similar situation is presented for Pedro Miguel and Gatun.

As presented in Table 7, the expected surcharge from waves exceeds both critical elevations at all lake chambers. This phenomenon can be confirmed by observation quite frequently during normal lockage operation. Measures have already been implemented to limit flooding of the bull gear pits by partially closing the slots utilizing a flexible material in some locations.

3.2.10 Recommendations for Demolition of Sill

Based on the preliminary time and cost estimates for demolition and construction for precision and conventional demolition and the four (4) construction options, the following recommendations are made for the miter gate sill modification:

1. Lower the elevation of the miter gate sills by 305 mm (1 ft) using the conventional method of demolition.
2. Cut a recess in the upstream side of the miter gate sills, 356 mm (1'-2") wide by 305 mm (1-ft) deep.
3. Use the metal embed of CIP Alternative A.

3.2.11 Modification to Miter Gates

3.2.11.1 Preliminary Design

The preliminary design that was originally submitted to ACP for review is modified. Modifications are required since insufficient clearance was provided between the bottom of the miter gates and the chamber floor and to minimize the additional loading on the lowest

Table 7. - Downbound Entering From Lake Maximum Surcharge Wave Estimates: Lower Sill 305 mm (1.0 ft).

Miraflores	Draft (m) (ft)	Pool El. (m) (ft)	Aship (m^2) (ft^2)	Atotal (m^2) (ft^2)	BR' *	Vmax *# (m/s) (ft/s)	Expected Surcharge (m) (ft)	Expected Elevation (m) (ft)	Maximum Surcharge (m) (ft)	Maximum Elevation (m) (ft)
Baseline	12.04 39.5	16.61 54.5	385.1 4145	464.8 5003	0.829	0.69 2.27	0.92 3.03	17.54 57.53	1.11 3.63	17.72 58.13
Lower sill	12.04 39.5	16.61 54.5	385.1 4145	475.0 5113	0.811	0.73 2.40	0.82 2.70	17.43 57.20	1.01 3.30	17.62 57.80
Lower sill + increase draft	12.34 40.5	16.61 54.5	394.8 4250	475.0 5113	0.831	0.69 2.25	0.94 3.08	17.55 57.58	1.12 3.68	17.73 58.18
Lower sill + increase draft + limit speed	12.34 40.5	16.61 54.5	394.8 4250	475.0 5113	0.831	0.68 2.22	0.92 3.01	17.52 57.51	1.10 3.61	17.71 58.11
Pedro & Gatun										
Baseline	12.04 39.5	26.67 87.5	385.1 4145	536.6 5776	0.718	0.94 3.09	0.52 1.71	27.19 89.21	0.70 2.31	27.37 89.81
Lower sill	12.04 39.5	26.67 87.5	385.1 4145	546.8 5886	0.704	0.97 3.19	0.49 1.62	27.16 89.12	0.68 2.22	27.35 89.72
Lower sill + increase draft	12.34 40.5	26.67 87.5	394.8 4250	546.8 5886	0.722	0.93 3.06	0.53 1.74	27.20 89.24	0.71 2.34	27.38 89.84
Lower sill + increase draft + limit speed	12.34 40.5	26.67 87.5	394.8 4250	546.8 5886	0.722	0.92 3.03	0.52 1.71	27.19 89.21	0.70 2.31	27.37 89.81

* Equations from Measurement of Pressures Related to Vessel Movement within Miraflores Upper West Lock, by Raymond A. Povirk and Raymond D. Rush, Pittsburgh District, U.S, Army Corps of Engineers, June 30, 1999
# Vmax is the maximum expected velocity for a given modified blockage ratio (BR') based on measurements at Miraflores Upper West Lock

horizontal girder. The final preliminary design is presented in Plate 10. The use of the Buckhorn No. 2990 seal permits the position of the seal to be raised with respect to the girder centerline. The bottom of the gate was only extended 89 mm (3-½ in). Taking into account the hydrostatic pressure on both sides of the bottom miter gate extension (Detail 1), the additional loading on the girder is minor, in terms of increase in hydrostatic loading. In addition, the stiffener height is shortened and a flange plate was added to stiffen the assembly. In addition, the quoin seals and the pintles do not have to be modified.

3.2.11.2 Cost Estimate

A screening level cost estimate was performed for the Miter Gate Bottom Extension. The estimate was developed using both historic and standard unit prices adjusted to account for freight to Panama as well as working in Panama. The estimate includes all necessary materials, labor, equipment, and markups to add the bottom extension onto the gate leafs. It does not include any cost for removing/resetting the gate leafs.

For the purpose of the estimate it was assumed that all materials (including fabrication) would come from local fabricators, contractors, or the ACP. It was also assumed that the gate leafs would be available to work on without any additional handling or transportation required by the contractor. A contingency was added to each individual item to account for any uncertainties encountered by the contractor and unforeseen at this time. The screening level estimate for this work is $80,000 per set of leafs. There are 12 sets total, therefore the over all estimate is for $960,000.

3.3 Lower Chain Fender and Emergency Sills

Two (2) chain fender sills of Pedro Miguel Locks and one (1) emergency dam sill of Miraflores Locks need to be lowered to permit an increase in vessel draft (Plate No. 1 and Table 3). The chain fender sill situated between miter gate No.s 58-61 and 62-65 of Pedro Miguel Locks and the emergency dam sill of Miraflores Locks will be lowered within the dewatered chambers. The downstream chain fender sill of Pedro Miguel Locks (Miraflores Lake side) needs to be lowered utilizing in-the-wet demolition from a floating plant.

Within the dewatered chambers, the chain fender sill and the emergency dam sill are recommended to be lowered 305 mm (1 ft) and 0.53 m (1.75 ft), respectively. Based on the cost estimates developed for the concrete demolition (hydro-demolition, slab/wall saw and percussion hammer, and diamond wire cutting) for the miter gate sills, conventional demolition is also recommended for these two (2) sills. Appendix 5 provides the cost estimates for their demolition.

The downstream chain fender sill of Pedro Miguel Locks must be lowered utilizing in-the-wet demolition. Three options of in-the-wet concrete demolition were investigated: 1) drill the sill with an array of core holes and remove the concrete using a non-explosive demolition agent (Bristar, Demolition Technologies Inc.), 2) remove the concrete by means of slab sawing and percussion hammer (hydraulic excavator as the carrier, Fig. 5), and 3) remove concrete using a rotary rock-cutting head (hydraulic excavator as the carrier). A non-explosive demolition agent may be used for underwater applications but the agent is effective when the core holes are longer than approximately 2 m (6-7 ft). For shorter length holes, clean breaks would not occur between adjacent core holes due to the lack of expansive pressure developed by the chemical reaction. As a result, this concept was eliminated from further study. The mechanical methods of concrete demolition are the two viable options. The demolition of the concrete using a rotary rock cutter mounted to a hydraulic excavator provides certain advantages over underwater slab sawing and pneumatic hammering. The advantages of the rotary rock cutter demolition in comparison to percussion demolition are: 1) more control in profiling the concrete, 2) the size of the cuttings are more uniform, 3) the finished concrete surface is more uniform, 4) significantly less damage to the concrete (over break), and 4) the rotary rock cutters are robust and durable. The recommendation is made to remove the concrete utilizing a rotary rock cutter. In terms of concrete removal, it is proposed to utilize the hydraulic excavator with a bucket to remove a majority of the concrete material and to remove the fine concrete material with an airlift. Divers should be used to inspect the chamber and entrance bottom for concrete cuttings. There is a concern for propeller damage for deep-draft vessels. Appendix 5 provides the cost estimate for demolition, concrete removal, and diver inspection for lowering the chain fender sill using in-the-wet demolition.

3.4 Lower Critical Sills and Raising Gatun and Miraflores Lakes

Still water conditions at Miraflores Lake Chamber present a free board of 150 mm (0.49 ft) at the miter gates and 265 mm (0.87 ft) at the strut arm, and these free boards are exceeded momentarily by wave action created by ships entering the locks. This action was studied and documented in a report entitled "Measurement of Pressures Related to Vessel Movement within

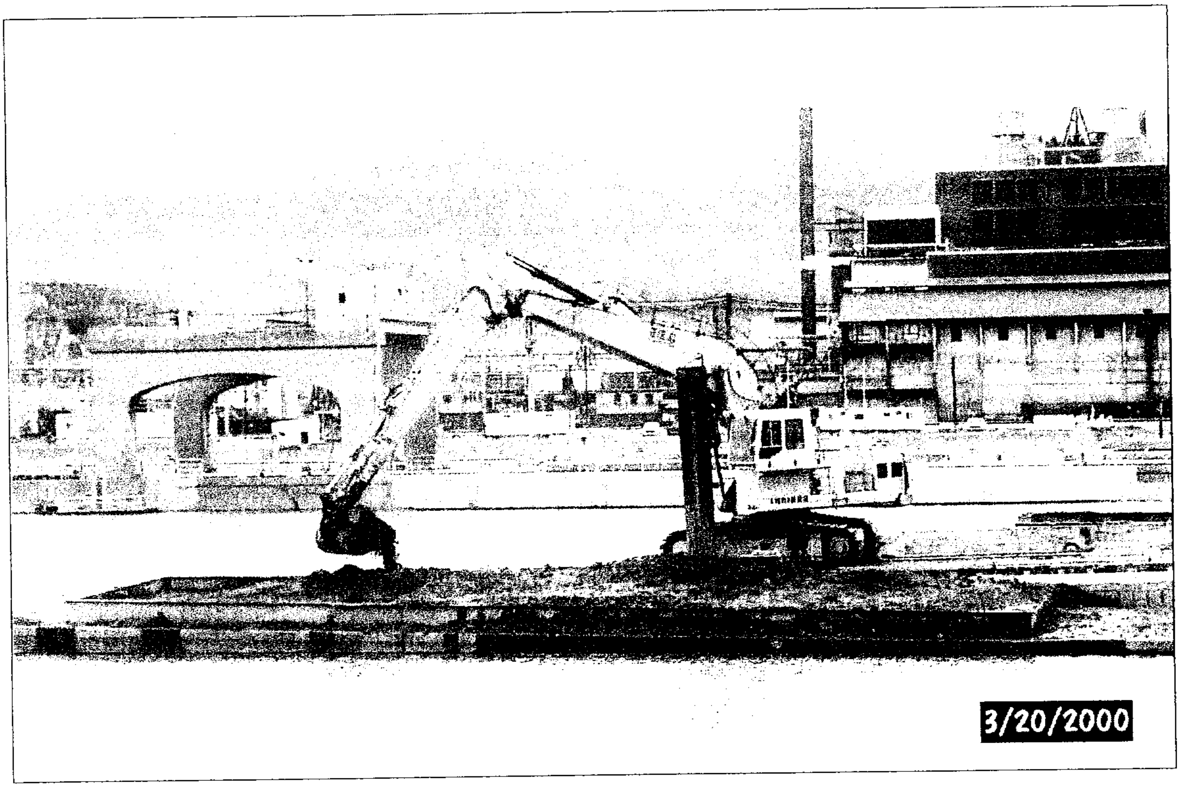
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Figure 5. - Hydraulic Excavator (USCAE, Braddock Dam, Monogahela River).

Miraflores Upper West Lock" dated 30 June 1999. For the purpose of this report, a 76 mm (0.25 ft) raise in pool at Miraflores Lake is proposed and analyzed including wave actions. These effects are analyzed and compared with a baseline condition of 16.61 m (54.5 ft) lake level for Miraflores. A similar situation is presented for Pedro Miguel and Gatun.

As presented in Table 8, the expected surcharge from waves exceeds both critical elevations at all lake chambers. This phenomenon can be confirmed by observation quite frequently during normal lockage operation. Measures have already been implemented to limit flooding of the bull gear pits by partially closing the slots utilizing a flexible material in some locations.

Table 8. - Downbound Entering From Lake Maximum Surcharge Wave Estimates - Raise Gatun and Miraflores Lakes 76 mm (0.25 ft) and Lower Critical Sills 305 mm (1 ft).

Miraflores	Draft (m) (ft)	Pool El. (m) (ft)	Aship (m^2) (ft^2)	Atotal (m^2) (ft^2)	BR' *	Vmax *# (m/s) (ft/s)	Expected Surcharge (m) (ft)	Expected Elevation (m) (ft)	Maximum Surcharge (m) (ft)	Maximum Elevation (m) (ft)
Baseline	12.04 39.5	16.61 54.5	385.1 4145	464.8 5003	0.829	0.69 2.27	0.92 3.03	17.54 57.53	1.11 3.63	17.72 58.13
Raise lake + Lower sill	12.04 39.5	16.69 54.75	385.1 4145	477.5 5140	0.806	0.74 2.43	0.80 2.63	17.49 57.38	0.98 3.23	17.67 57.98
Raise lake + Lower sill + increase draft	12.42 40.75	16.69 54.75	397.3 4276	477.5 5140	0.832	0.68 2.24	0.94 3.10	17.63 57.85	1.13 3.70	17.82 58.45
Raise lake + Lower sill + increase draft + limit speed	12.42 40.75	16.69 54.75	397.3 4276	477.5 5140	0.832	0.64 2.11	0.84 2.77	17.53 57.52	1.03 3.37	17.71 58.12
Pedro & Gatun										
Baseline	12.04 39.5	26.67 87.5	385.1 4145	536.6 5776	0.718	0.94 3.09	0.52 1.71	27.19 89.21	0.70 2.31	27.37 89.81
Raise lake + Lower sill	12.04 39.5	26.75 87.75	385.1 4145	549.4 5914	0.701	0.98 3.21	0.49 1.60	27.23 89.35	0.67 2.20	27.42 89.95
Raise lake + Lower sill + increase draft	12.42 40.75	26.75 87.75	397.3 4276	549.4 5914	0.723	0.93 3.05	0.53 1.75	27.28 89.50	0.72 2.35	27.46 90.10
Raise lake + Lower sill + increase draft + limit speed	12.42 40.75	26.75 87.75	397.3 4276	549.4 5914	0.723	0.83 2.73	0.45 1.46	27.19 89.21	0.63 2.06	27.37 89.81

* Equations from Measurement of Pressures Related to Vessel Movement within Miraflores Upper West Lock, by Raymond A. Povirk and Raymond D. Rush, Pittsburgh District, U.S, Army Corps of Engineers, June 30, 1999
\# Vmax is the maximum expected velocity for a given modified blockage ratio (BR') based on measurements at Miraflores Upper West Lock

4. Recommendations

Based on the results of this study, the following recommendations are made:

- Raise Miraflores Lake by 76 mm (0.25 ft) to EL +16.69 m (+54.75) from EL +16.61 m (+54.5 ft).
- Raise Gatun Lake by 76 mm (0.25 ft) to EL +26.75 m (+87.75 ft) from EL +26.67 m (+87.5 ft).
- Lower the elevation of the Sills for Miter Gates Nos. 13-20 for Gatun Locks and for Miter Gates Nos.54-69 for Pedro Miguel Locks by 305 mm (1 ft).

- Modify the bottom of the miter gates of the critical sills - Miter Gates Nos. 13-20 for Gatun Locks and for Miter Gates Nos.54-69 for Pedro Miguel Locks.
- Lower the chain fenders sills of Pedro Miguel by 305 mm.
- Lower the emergency dam sill of Miraflores Locks by 530 mm.
- Decrease the entrance velocity of the ships by 0.05 m/s (0.16 ft/s) for the lake chambers of Miraflores Locks to 0.64 m/s (2.11 ft/s) from 0.69 m/s (2.27 ft/s) [Table 8].
- Decrease the entrance velocity of the ships by 0.11 m/s (0.36 ft/s) for the lake chambers of Gatun and Pedro Miguel Locks to 0.83 m/s (2.73 ft/s) from 0.94 m/s (3.09 ft/sec) [Table 8].

5. Conclusions

Based on the cost estimates for modifying the critical miter gate sills and gates, and the results of the wave surcharge evaluation for raised lake levels, we recommend: 1) raising both Gatun and Miraflores Lakes by 76 mm (0.25 ft), 2) lowering all critical sills by 305 mm (1 ft) with the exception of the emergency dam sill of Miraflores Locks, it should be lowered 530 mm (1.75 ft) to place it at the same elevation as the upper lake sills, and 3) reducing the entrance velocity of vessel to mitigate wave surcharge. These modifications will result in an increase in draft of 381 mm (1.25 ft), from 12.04 m (39.5 ft) to 12.42 m (40.75 ft). Raising the lake levels and lowering the critical sills will result in an increase in draft of 3.2 pct. Determination of the benefits and disbenefits that would result from the increase in allowable draft is outside the scope of this study. The US Army Corps of Engineers recommends that the PCA: 1) assess the impact of raising Miraflores and Gatun Lakes on the dams, shoreline structures, and other structures, 2) investigate the operational feasibility of raising and maintaining the recommended lake levels, and 3) estimate those benefits and using the costs herein to determine the economic feasibility of further developing these concepts into plans and specifications.

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Panama Canal

Study and Preliminary Design to Raise Miter Gate Heights and Lower Miter Gate Sills To Increase Allowable Vessel Draft

Richard A. Allwes, USACE-CELRP-ED-DS
21 November 2001

A. The Scope of Work is to consider the following four (4) alternatives to increase draft:

1. Increase Height of Gatun Lake Miter Gates:
    - a. Gatun Locks: raise MGs Nos. 21-40
    - b. Pedro Miguel Locks: raise MGs Nos. 50-69

2. Increase Height of Miraflores Lake Miter Gates:
    - a. Miraflores Locks: raise MGs Nos. 100-119

3. Lower Gatun Lake Miter Gate Sills:
    - a. Gatun Locks: lower MG Sills Nos. 37-40
    - b. Pedro Miguel Locks: lower MG Sills Nos. 50-53
      lower upstream emergency dam sill
      lower upstream caisson seat sill

4. Lower Critical Miter Gate Sills:
    - a. Pedro Miguel Locks: lower MG Sills Nos. 54-69

B. USACE Current Progress and Request for Clarification:

1. The present plan proposed by the Pittsburgh District is to raise the heights of Gatun Lake and Miraflores Lake by a height of 3 in and not to increase any of the heights of the miter gates in the three (3) locks as proposed in Items 1 and 2 (a. and b. in the Scope of Work). In order to raise the lake elevations by 3 in and not increase the heights of the miter gates, the entrance velocity of the vessels will have to be decreased to prevent overtopping of the miter gates. The reduced vessel velocity study is completed. Boots are required for the direct-connect cylinders to prevent floating lake debris and water from entering the machinery recess areas. In addition, bulkheads are required for the machinery access areas to protect the galleries from flooding.

2. ACP is requested to review the attached Pittsburgh District's Minimum Draft Drawing for concurrence. It was compiled from as-built drawings and plates

provided by ACP. The Minimum Draft Drawing serves as the basis for modifying miter gates sills and seals. The following discrepancy is noted for the record.

a. The upstream emergency dam sill of Miraflores Locks was removed according to Isthmian Canal Commission Dwg 7065 M-28 (revised 2-5-68) and provides a sill elevation EL +11.3. The Panama Canal Elevations Diagram Plate (NIVELES.DGN) provides a sill elevation EL +13.0 for the upstream emergency dam. ACP is requested to verify that the emergency sill elevation is EL +11.3.

3. ACP proposed miter gate sills to be lowered for all three (3) locks. However, a review of the Pittsburgh District's Minimum Draft Drawing reveals that a majority of the proposed sills do not need to be lowered, specifically:

Gatun Locks:	MG Sills Nos. 37-40
Pedro Miguel Locks:	MG Sills Nos. 50-53 Upstream emergency dam sill Upstream caisson seat sill

A review of the Minimum Draft Drawing reveals that drafts above the sills are equal to or greater that 42.2 ft.

4. The miter gate sills planned to be lowered by the Pittsburgh District are MG Sills Nos. 54-69 of Pedro Miguel Locks. The current draft at minimum Gatun Lake Elevation (L.W. EL +81.5) is 40.5 ft. The sills will be lowered 1.0 ft. Accordingly, the miter gate seals of MGs Nos. 54-69 of Pedro Miguel Locks will be extended 1.0 ft.

5. The MG Sills Nos. 13-20 of Gatun Locks should be lowered 1.0 ft since they restrict draft to 40.58 ft at the lowest chamber pool (EL +27.0). ACP is requested to provide concurrence to lower these MG sills 1.0 ft and extend the MG seals 1.0 ft.

6. The current proposal is to remove approximately 2.0 ft of each sill and then raise a nominal portion of the sills 1.0 ft. Two methods of concrete removal are being investigated – hydroblasting and diamond wire concrete cutting.

7. Three MG sill preliminary designs (steel frame, precast panel, and cast-in-place) are being investigated and the preliminary designs will be evaluated in terms of cost and construction time.

8. A mix design is being investigated to achieve a design strength of 4,000 psi within 8 hours to minimize construction time. The time to demobilize and flood the chambers may be incorporated into the cure time of 8 hours to reduce total chamber outage time.

9. Since the miter gates are horizontally framed, the sill extensions will be designed to resist the maximum hydrostatic pressure corresponding to maximum lake or chamber pool elevation.