PANAMA CANAL CONCEPT DESIGN

Atlantic Locks Structure
Third Lane Lock
Final Report

Prepared for

Canal Capacity Projects Office

By

US Army Corps
of Engineers

Volume 2 –Appendices D through J

23 July 2003

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Third Lane Lock
Appendix D
Alignment Optimization Report

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ACP	Autoridad Del Canal De Panama (Panama Canal Authority)
COE	Corps of Engineers
DTM	Digital Terrain Model
IPC	Canal Capacity Projects Office
PLD	Precise Level Datum

Existing Locks at Gatun

Figure D-1 Gatun Locks Looking South

Atlantic entrance at bottom of photo. Gatun Lake at top (South) of photo. Proposed alignment for Third Lane construction will be positioned to the left (east) of the existing locks.

1. INTRODUCTION

1.1. Purpose

The purpose of this Alignment Optimization Report is to make an alignment recommendation for the Double-Lift Lock for the Third Lane construction at Gatun. This report presents a refinement of the Draft Report dated June 14, 2002 that was submitted to the Autoridad Del Canal De Panama (ACP) for review. The optimization study was based on the Harza Report alternatives, available geotechnical data, surveying and mapping data, topographic data, and input from the ACP and all Production, Independent Technical Review (ITR), and Oversight Committee Teams.

1.2. General Information

Based on previous studies, the Canal Capacity Projects Office (IPC) concluded that the next evaluation should consider alignments that would use the Gatun Lake at the current level (El 25.9 m PLD). Future lock alignment would be in the vicinity of the existing facilities in order to make use of the rest of the canal without long bypass channels.

1.3. Scope of Study

The scope of the alignment optimization study was to determine the optimum lock location with respect to location of the water saving basins, costs, operating conditions including navigational safety, expansion to a Fourth Lane and efficiency of construction. The report defines the lateral space requirements and location of the lock structure and associated facilities. The study determines the optimum lock structure location considering the rock foundation conditions, minimizing excavation requirements for the entrance channels, minimizing costs associated with temporary construction features, consideration of ship entry and exit considering navigation and site conditions, and allowing construction without interference with existing operations.

The study started with an analysis of Alignment A-1 from the Harza study with adjustments to minimize excavation, utilize local disposal in the vicinity of the lock sites only, and provide better navigation lines. The quantity and cost estimates as presented in the HARZA Alignment Report were also analyzed and refined.

Harza Alignment A-1 positions the proposed Third Lane through the 1939 Excavation and is shown on Harza Exhibit 6. The majority of the excavation for alignment A-1 was performed during the World War II era; hence, this proposed Baseline alignment would likely require significantly less excavation and relocation requirements than would be the case for Alignment A-2, or Alignment A-2' that is recommended in this report. Alignment A-1 is also aligned such that the Gatun Lake approach is further to the east of the Gatun Locks than the Atlantic entrance approach.

Harza Alignment A-2 positions the proposed Third Lane immediately adjacent, and to the east of the existing Gatun locks. Alignment A-2 is shown on Harza Exhibit 7. The alignment recommended by this report is designated Alignment A-2'.

1.4. Gatun Site Photos, Existing Lock, Buildings, Roadways

Figure D-1-1 Standing Along North Shoreline, Looking South Toward The Gatun Locks. Proposed 9.75 Degree Alignment Shown

Figure D-1-2 Standing Along North Shoreline, Looking North Toward The Atlantic Approach. Proposed Third Lane Centerline Depicted

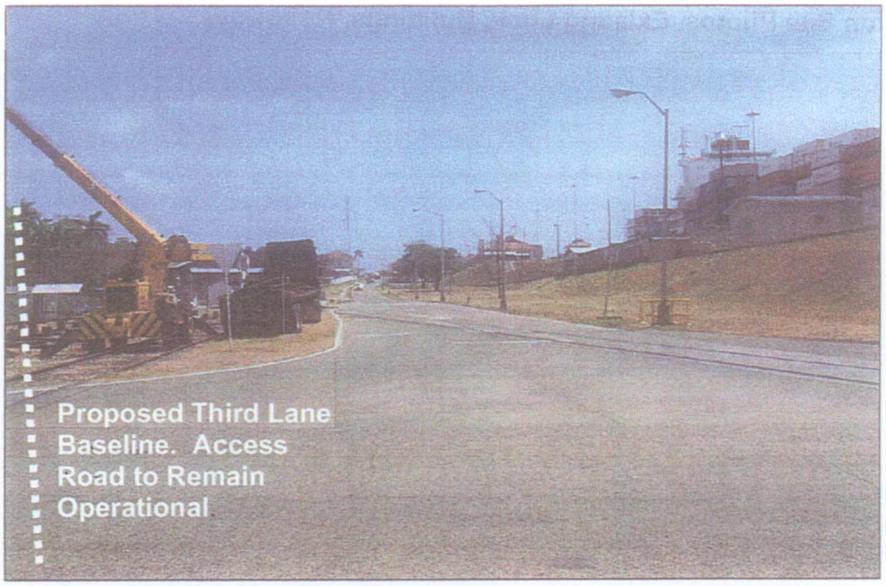

Figure D-1-3 Access Road Adjacent To The Gatun East Wall

Access to the existing locks and around the perimeter of the Water Storage Basins will be maintained via this access road. Horizontal clearance along this North end will be tight once the Water Storage Basins have been constructed.

Figure D-1-4 Southern End Of Access Road, Which Extends Along Gatun East Wall

Maintenance facility shown to the left. This facility to remain operational during and following Third Lane construction.

Figure D-1-5 Access Road Entering Lower (North) End Of Gatun Locks

Access to the existing Gatun locks will be maintained during Third Lane construction along the site's northeast shore.

Figure D-1-6 Buildings Along Esplanade

Buildings along esplanade to remain (foreground) and buildings along access road (rear) will require removal/relocation prior to Third Lane construction. Proposed alignment centerline shown.

Figure D-1-7 Access Road Adjacent To Gatun East Wall, At The North (Lower) End Of Locks

Access road to remain during and following Third Lane construction. Roadway provides Gatun lock access and will provide access to the Water Storage Basins and the west wall.

Figure D-1-8 View Of Esplanade, Looking Northeast From Middle Wall Operations Building

Figure D-1-9 Real Estate North of the Esplanade

The Proposed Third Lane Alignment (9.75 Degrees) Would Cut Thru This Parcel.

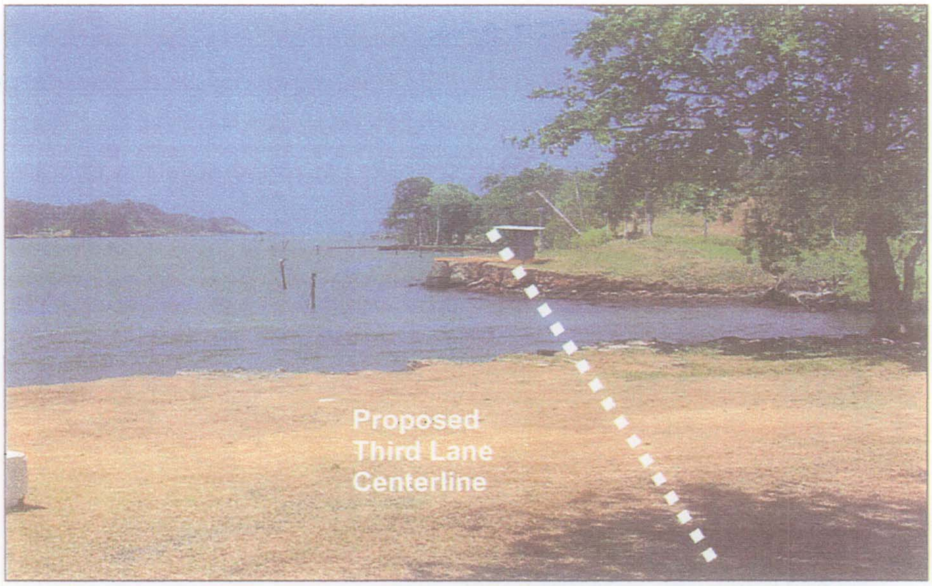

Figure D-1-10 The Atlantic Entrance, North of the Esplanade

The Proposed Third Lane Alignment Centerline (9.75 Degrees) Would Cut Thru This Parcel.

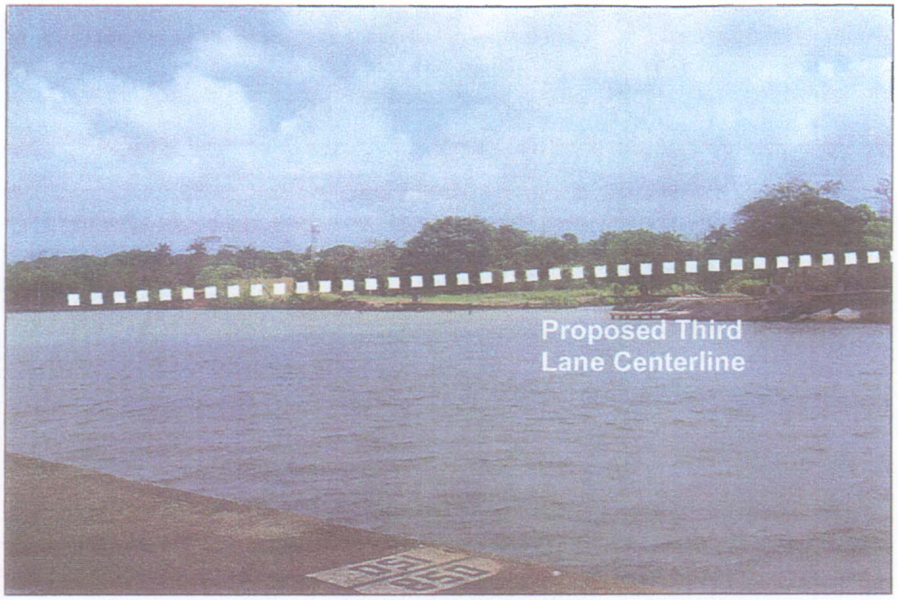

Figure D-1-11 Standing on North (Atlantic Entrance) End of the Gatun Middle Wall

Looking NE 9.75-Degree Alignment Will Cut Thru This Area.

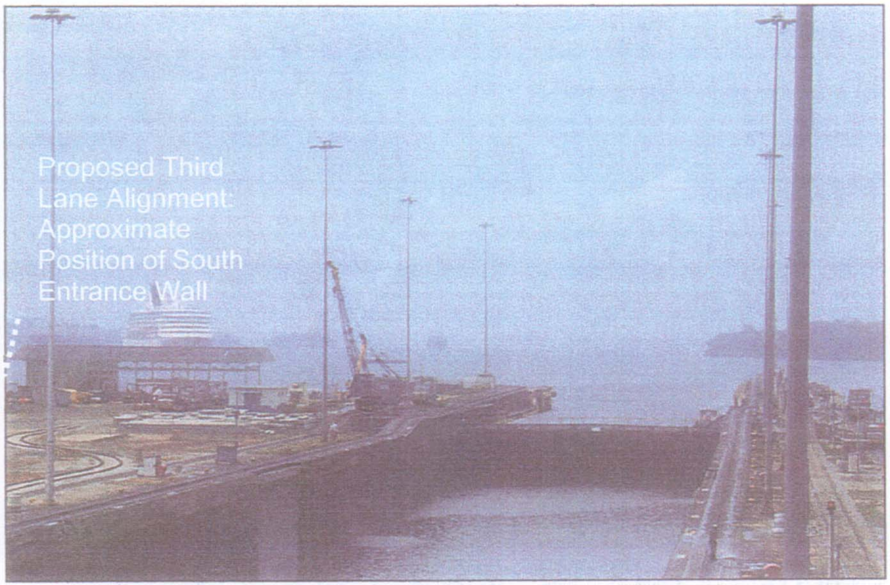

Figure D-1-12 Standing On The Gatun Middle Wall Operations Building, Looking South toward Gatun Lake

Note the ships anchored, awaiting locking priority. Cruise ship would be positioned to enter South Approach to Third Lane Locks.

Figure D-1-13 North End of the Gatun Middle wall, looking North 7 Degrees East, (7 Degrees azimuth) toward the Atlantic Entrance

Figure D-1-14 North End of the Gatun East Wall and Esplanade

Visitors observation building (stairway) shown on the right Construction of Third Lane will not affect buildings along the Gatun esplanade. Lock operations will be maintained during Third Lane construction.

2. REVIEW OF EXISTING INFORMATION

2.1. Harza Report and Files

Harza Engineering Company, Inc. in association with TAMS Consultants, Inc. was retained in October 1999 by the PCC under Contract No. CC-5-536, Work Order No. 1, to evaluate alignment alternatives for the proposed new Panama Canal lock channels. Twenty-four alignment alternatives were evaluated, eight of which were at the Atlantic side of the Canal. The objective of this study was to evaluate all possible reasonable alignment alternatives and through an evaluation process, against set criteria, provide a recommendation for the two most favorable alignments at both sides of the Canal. Computation of excavation quantities was made which included excavation requirements for the lock structure. Design of the lock structure was not included in the work, but a lock footprint was developed for the computations. These alignments would be used in continuing studies that would include design of the locks.

The Harza report, dated August 2000, recommended two lock channel alignments for both the Atlantic and Pacific Entrances. The ACP actively participated in each phase of the study, including costs for excavations from recent contract work and development of the evaluation criteria. The recommended alignments were the highest ranked, based on economics (excavation costs), navigational safety and lockage requirements, navigational channel characteristics and operational characteristics. These Third Lane alignments were planned assuming one-way traffic approach channels. The assumption was made that approach widening could be implemented at a future date, as traffic demand reached and exceeded capacity to allow two-way traffic. Furthermore, these two recommended alignments would be planned and positioned such that Fourth Lane expansion could be constructed. Alignments A1 and A2 were carried forward and ultimately ranked the two top Atlantic entrance alignments, because they also combined good operational qualities and ease of construction. The proposed Third Lane, and eventually Fourth Lane, would both be constructed with Post-Panamax dimensions. Vessel dimensions for design are 350 m in length, 46 m in beam and 14 m in draft. Accordingly, each new lock chamber will measure 381 m long, 49 m wide and 17 m deep, measured over the sills. New entrance walls would be 450 m long and approximately 18 m wide on both the upstream and downstream sides. That length (in the Harza Report) is 120% of the chamber length. These relative lengths are consistent with the existing entrance walls that are 365 m long, or 120% the length of the existing Gatun chambers. Transition walls would be placed at the outside approach to each lock complex, and were 100 m long, tapering out at a 1:4 ratio. The alignment excavation would assume an initial width of four times the design vessel beam, or 184 m with future expansion to six times the design vessel beam, or 276 m. Harza made the assumption that the Third Lane and Fourth Lane lock complexes are completely separate structures, divided by 30 m. It could be possible to construct the east Third Lane wall such that it could be integrated as the west wall of a Fourth Lane later. However, the dimensions of the Fourth Lane had not been established, thus a shared middle wall between the Third and Fourth Lanes has not been considered at this stage of study progress.

Overall rankings for the Atlantic entrance (Harza Report, Section 5.0 "Conclusions", page 20) lists eight alternatives, three of which warrant further evaluation. Two of these were positioned on the east side of Gatun locks. Alignment A-1 is positioned along the 1939 excavation and Alignment A-2 is positioned to the east, parallel and immediately adjacent to the Gatun east wall.

The A-1 alignment is excluded from this study. Alignment A-1 positions the Third Lane within this previously excavated area, and is in excess of 1000 m away from the Gatun locks centerline. Alignment A-1 separates the existing and proposed shipping lanes and clearly is a superior choice in terms of navigational safety. Being the furthest east, A-1 totally avoids any disruption of Gatun lock operations during all phases of construction; but being separated by that distance would require new ancillary facilities and equipment. A-2 takes advantage of positioning the Third Lane immediately adjacent to the existing locks and reduces the need for duplicate facilities; however, A-2 interferes with canal operations during construction (Harza Report, Section 6.3.1, page 25).

Refer to Section 3.3 and 3.4 of this Report for a discussion of the baseline Alignments modeled, and Section 4 for accompanying rock and overburden excavation volumes for the recommended alignment. The positioning of the lock chambers along the alignments throughout this Report, is such that the first or Northern-most set of gates is set within the land mass (Station 12+300 or greater), except for Run No. 5 (Plan E), which positioned the Northern-most set of gates at Station 12+020. Lock positioning was considered in which the chambers were positioned further to the North however, ship entry and exiting geometric requirements, along with the need for a significant cofferdam system during construction, eliminated these from further consideration. Cofferdam construction along the Limon Bay Entrance would infringe on the existing channel width, and pose a navigational restriction with vessels entering Gatun Locks during construction. The Harza excavation volumes for the A-2 Alignment cut are different (higher) than those modeled in this Report, due largely to the template cut width. Refer to the Harza Report, Part 3 "Exhibits", Exhibit No. 24 "Evaluation of Lock Channel Alignments, Optimization, Post-Panamax Lock Complex, Plan View and Section A-A". The proposed Third Lane is cut 49.0 m wide, measured inside to inside of lock walls. The lock walls shown are 18.0 m in width, measured at the base of the cut. Refer also to Harza report, Section 6.1, Preliminary Lock Layouts, Criteria No. 7, page 21: *"The alignment excavation will assume an initial width of four times the design vessel beam (184 m) with future expansion to six times the design vessel beam (276 m).* For this study, alignment excavation is based on a single-lane design, at a width of 61 m, face to face of lock walls. This width variation accounts for volume differences, as do other factors such as baseline alignment orientation (alignment A-2 vs. the 9.75 degree baseline or other orientations), lock wall footing width and depth of rock.

2.2. Topographic Mapping

All mapping refers to the UTM zone 17 NAD 27 Clarke 1866 projection/grid system. One-meter contours were produced from controlled aerial photography.

3. EVALUATION OF THIRD LANE LOCK CHANNEL ALIGNMENTS

3.1. Introduction

The Harza work was used as an informational tool in advancing the Concept Design work for the proposed Third Lane. Excavation volumes for the Harza work are reported in "Part 3, Final Evaluation" under Table 11, page 44 of the Harza Report, and represent Post-Panamax channel quantity takeoffs. Figure 1, page 45 of the Harza Report, provides a graphical illustration of the different excavation quantities required for construction of various approach channel widths for the new alignments. Harza reports that for the Atlantic Entrance, there is little difference between the two alignments for a 138 m or 184 m Post-Panamax channel. However, Harza Alignment A-1 (thru the 1939 excavation) requires significantly greater excavation for a 276 m channel width (two-way traffic case).

For the A-2 alignment, Harza calculated that the rock excavation would require 3 800 000 m^3 of wet excavation and 2 100 000 m^3 of dry excavation. Overburden excavation required 1 800 000 m^3 of wet excavation and 2 400 000 m^3 of dry excavation. The total excavation for the A-2 alignment was 10 100 000 m^3. Similarly, for the A-1 alignment, Harza calculated that the rock excavation would require 900 000 m^3 of wet excavation and 4 800 000 $m^3$of dry excavation. Overburden excavation required 1 200 000 m^3 of wet excavation and 2 700 000 m^3 of dry excavation. The total excavation for the A-1 alignment was 9 600 000 m^3.

Harza's Alignment A-2, located immediately to the east and parallel to the Gatun locks, was Harza's recommended alternative for this design, and serves as the "beginning point" for optimization. Given the growing volume of traffic and delay times as vessels await lock entry priorities, maintaining Gatun lock operations during construction, in conjunction with navigational safety are key factors driving alignment optimization.

Alignment A-2 takes advantage of positioning the Third Lane immediately adjacent to the existing locks and reduces the need for duplicate maintenance facilities. The skewing of the alignment for this new study and addition of water saving basins pushes the locks far enough east of the Gatun Locks entrance channels to provide a separation for safety of the transiting ships.

Harza's Alignment A-2 considered Water Storage Basins (WSB's), but did not model the basins as a part of the template cuts. The Harza Report recognized a disadvantage of positioning Alignment A-2 immediately adjacent to the existing locks. WSB geometry would necessitate making cut lines tie in to existing ground, along the Gatun Lock side of the basins. These cut lines would disrupt traffic flow along the Gatun access road, hence causing a logistical impediment to lock operations. Furthermore, basin construction would likely require overburden cut lines to extend well beyond the limits of the basin perimeters, extending perhaps to the Gatun east wall. This phase of construction would further disrupt Gatun Locks operations and perhaps require some type of anchoring or other means be accomplished to stabilize the east wall. Hence, construction of the WSB's is a crucial element in lock alignment optimization since geometric and excavation requirements must be considered.

Geotechnical conditions are an important concern for optimization. Atlantic muck is prevalent along the eastern edge of the Atlantic entrance. Material properties of the muck (refer to Appendix C) necessitate an extremely flat cut slope of 8:1. Positioning of the basins along the west side of the Third Lane (between the Third Lane and the existing Gatun locks) allows for future Fourth Lane construction immediately to the east of the Third Lane, utilizing the eastern Third Lane lock walls as a common middle wall for Fourth Lane construction. No esplanade area was anticipated along the east wall to house control or maintenance buildings. Access to the top of the east wall will be provided in the vicinity of the South miter gates, since the rock line is approximately at the top of lock wall elevation. A paved parking area will be provided, which can easily be removed for Fourth Lane construction.

Positioning of the water saving basins between the existing and Third Lane locks, however, presents some challenges. Water saving basin geometric requirements demand considerable horizontal distance for basin construction and establishing cut/fill requirements to tie-in to existing ground. Basin requirements play a significant role in Third Lane alignment optimization. The Gatun east wall must remain stable throughout construction to allow the existing two lanes to remain operational. Hence, sufficient horizontal clearance would be maintained to avoid disrupting east wall stability and to allow sufficient space for maintaining the access road that serves the existing lock. Following Third Lane construction, it will service both the First and Second Lanes (existing locks) as well as the Third Lane locks, along the western lock wall side. Access will be vital to gain entry to the water saving basins perimeter as well as proposed buildings along the west wall.

A specific Point of Intersection, PI, with coordinates N 1,027,955.80 and E 618,673.74 is defined on the Atlantic entrance, along a projection of the Gatun Middle wall centerline. This PI point lies just South of the 1939 excavation entrance -. Navigation Chart No. S-6118-77, Sheet 2 defines the Atlantic Entrance as extending from Buoy No 2 to Buoy No. 16. This distance is 3.3 nautical miles with the entrance width at 198.2 m. Buoy No. 16 marks the limit of the east prism line of the navigation channel. The PI is located at the Canal center, and is used as a "turning point". The Atlantic Approach, from Limon Bay, lies along an azimuth of 180 degrees, 4 minutes, 23.5728 seconds. Gatun Locks lies along an azimuth of 187 degrees, 38 minutes, 10.5758 seconds. Hence, a clockwise navigational turn of slightly over 7 degrees is required for ships to align with the Gatun lock chambers. This PI (turning point) was used as a "Point of Beginning" to create the proposed Third Lane alignment. Stationing is defined along the Third Lane baseline, beginning at the PI. The PI was defined to be Station 10+000 with stationing increasing upstream, toward Gatun Lake. Using 10+000 allows future modeling efforts to project backwards (toward the ocean) 10,000 m into the Atlantic entrance for dredging (wet) excavation runs, performing detailed site modeling of the disposal area along the east shoreline, future widening of the Atlantic entrance, etc.)

The initial modeling, as presented in the Interim Alignment Optimization Report (June 2002) recommended construction of the Third Lane along the 9-degree baseline. Various factors developed after Interim Report submission drove a refinement in the corridor location, such that the alignment recommended for construction of the Third Lane is along the 9.75-degree baseline.

Several factors contributed to shifting the baseline alignment from 9 degrees to 9.75 degrees. Entrance wall geometry (navigation safety) and cofferdam layout requirements were major factors. Water Storage Basin (WSB) construction was another significant factor. The rock strata rises in elevation as stationing increases toward the South (hillside, i.e. higher rockline). Seismic concerns (lock wall design) drove the need to eliminate any soil layer, beneath the WSB's. The upper WSB's (Gatun Lake side) were founded on rock; however, the lower (Atlantic side) WSB's were partially cut into rock and partially founded on overburden (need to support with piles driven to rock). Shifting the basins into rock (to the east: from 9 to 9.75 degrees, and to the South, 350 m toward Gatun Lake) improved the lock wall design (seismic requirements) and improved available clearance between the basins and the existing east wall and access road. This shift avoided the need to excavate adjacent to the existing Gatun east wall. Any unloading of this east wall could introduce east wall stability problems, thereby negating benefits of such alignment. Alignment A-2' (A-2 prime) was optimized/developed, which takes advantage of utilizing the PI (along the Gatun Middle wall) as the point about which an angular rotation is turned to create a new baseline (9.75-degree baseline). This alignment accrued several benefits

a. Gatun locks could safely remain fully operational for all phases of construction

b. Proposed Fourth Lane expansion could take advantage of a common middle wall design by positioning the basins along the west Third Lane lock wall

c. Alignment rotation counter-clockwise from the existing locks improves ship entry/exit by reducing the turn angle, and

d. Alignment A-2' positions the Third Lane corridor primarily within the Gatun land mass cut such that cofferdam cells needed for the entrance wall construction would be eliminated.

This report includes the InRoads-generated horizontal and vertical alignment and cross-sections for the 9.75-degree Alignment. Horizontal alignments may involve tangent or curved sections. For navigation traffic, curvature in the alignment is undesirable. However, ships must be able to traverse both the existing Gatun locks as well as utilize the proposed Third Lane. The alignment of the existing Gatun Middle wall is positioned along an azimuth of approximately 187 degrees. The Atlantic entrance shipping lanes are aligned along due North and South. Southbound traffic entering the North approach to Gatun Locks would be traveling along an azimuth of 180 degrees. Entry into Gatun Locks from the Atlantic approach requires traffic to make a westward turn for lock entry. The amount of westward turn is approximately 7 degrees (187 – 180 degrees). Using the PI as the point about which to turn a counterclockwise angle for the proposed Third Lane baseline is helpful in that the 7 degree westward turn is diminished. Defining the Third Lane alignment along the 9-degree baseline would eliminate any westward turn, and provide essentially straight-line entry into the new lock. degrees are measured from due South (187 degrees – 9 degrees = 178 degrees).

The Gatun site terrain was modeled using InRoads software, a state-of-the art, commercially-available, MicroStation-based, civil engineering software package (SelectCAD V8.2). InRoads is designed for civil/site development applications, although it has many other capabilities. Modeling runs produce excavation volume reports, given input parameters. The ACP furnished a digital terrain model (DTM) of the existing Gatun site topography, extending from the Atlantic approach to Gatun Lake, from the existing locks eastward across the 1939 excavated areas and up the hillside to Gatun. This DTM established the three-dimensional (3-D) topography surface of the Gatun site, and was imported into InRoads. Core boring logs were also provided by the ACP, from which coordinates and elevations of the rock layer were taken to create a digital rock profile (rock DTM). The rock DTM established the 3-D "top of rock" surface along the Gatun site, and was also imported as an ASCII file into InRoads. This top of rock surface is the surface below which rock removal techniques would be required for excavation. Once these 3-D surfaces were imported (defined), the modeling process began. Site modeling was an iterative process to establish horizontal and vertical alignments along the site topography, trying to establish a "best fit" between the rock line and the proposed Third Lane construction. The InRoads software stored both DTM's and used them for all corridor modeling runs. Horizontal alignments, vertical profiles and templates were defined and identified for each modeling run. Templates for each change in cross-section were defined. As the lock wall design advanced, establishing footing widths and thicknesses for differing monolith loadings (gate monoliths, valve monoliths, typical interior monoliths, entrance walls, etc), additional templates were defined to capture geometric changes in excavation limits (widths and elevations). Once the alignments and numerous templates were defined, the software "pushed" each successive template along the profile, from the beginning to ending station of each geometrically defined template, along the alignment. Pushing the template from point of beginning to end, along the defined vertical alignment (profile) constitutes a modeling run for that defined corridor. For each corridor-modeling run, the software generated plan views, profiles and cross-sections for the defined range of stations, at the defined interval (100 m). Reports were created depicting excavation and embankment volumes, by station, distinguishing between material layers of rock and overburden.

Corridor modeling was not complete until the lock footprint was positioned along the alignment such that the "best fit" position of the lock had been determined. Modeling site topography for optimization requires engineering judgment in conjunction with trial-and-error processing, in order to weigh all variables that contribute to the decision. Excavation requirements for the rock and overburden cuts contribute significantly to the economics of making the Third Lane cut. However, excavation volumes are only one facet of this equation. Site conditions, type of material, size and locations of the water saving basins and filling and emptying culverts, gate type, lock wall type and dimensions, position of competent rock integrated with the lock wall foundation loading and design, and overburden variations, as well as other factors, play an equally important role in the decision-making process for screening out alternatives and arriving at the most prudent and desired alternative. Close coordination with the ACP has been an integral part of the optimization process, as project development advances. Once the software "pushed" the templates (models) along the terrain, excavation volumes for both rock and overburden were generated. Excavation quantity accuracy is limited only by the accuracy of the input data. One-meter topography was used to create the existing ground DTM. Rock location was defined by the subsurface core borings taken, both the World War II era along the 1939 cut, and more recent data, adjacent to the existing locks.

3.2. Preparation of 3-D Digital Terrain Models and Alignment Modeling

An electronic copy of the Gatun Digital Terrain Model (DTM) (1-m accuracy) was uploaded onto the Corps of Engineers FTP site. Due to the size of this file, it was edited include only pertinent areas and make the file more manageable. The DTM was imported into InRoads SelectCAD V8.2, and used for all subsequent modeling runs.

A second DTM was created from geotechnical boring log information, provided by the ACP, to establish the "top of rock DTM", which is a surface below which rock removal techniques would be required. This DTM was used in all modeling runs. Excavation quantities below this rock line are considered "rock excavation", whereas quantities above this line are considered "overburden excavation".

Two sets of boring data (1939 data developed during the World War II era for the 1939 excavation and the 2001 data, drilled along an axis closer to the existing locks) were used to develop the top of rock DTM. The top-of-sound-rock elevations indicated on the boring logs were entered into the 'Surfer' contouring and surface-mapping program to develop the rock surface. This program analyzed the input data, in this case, about 50 rock elevation points, and produced a grid of interpolated points across the study area. The program then produced a grid of about 3,000 points that was exported into InRoads.

All modeling runs were made, creating vertical profiles of the cuts, along the horizontal alignment. All horizontal alignment orientations (X degree baseline) were based on angles turned in a counterclockwise rotation, from the 187 degree Azimuth, on which the Gatun Locks Middle wall is located. The Atlantic entrance shipping lanes are aligned along a North/South (O degrees or 180 degrees) azimuth, depending on traffic direction. The Atlantic entrance extends due South from the Ocean into Limon Bay. Southbound traffic entering the North approach to Gatun locks would be traveling along an azimuth of 180 degrees. Entry into Gatun locks from the Atlantic approach requires traffic to make a westward turn for lock entry. The amount of westward turn is approximately 7 degrees (187 – 180 degrees). Using the PI as the point about which to turn a counterclockwise angle for the proposed Third Lane baseline is helpful in that the 7 degree westward turn is diminished. Defining the Third Lane alignment along the 9 degree baseline would eliminate any westward turn, but create a smaller, eastward turn of approximately 2 degrees, measured from due South (187 degrees – 9 degrees = 178 degrees). This baseline would reduce the required traffic turn (from 7 degrees westward to 2 degrees eastward), and hence facilitate traffic movements to and from the locks. This is more advantageous for the larger Post-Panamax vessels.

The 9.75-degree angle was chosen, as a practical position along the topography for the Third Lane cut, based on the preliminary alignment proposal, A-2, by Harza, as well as the iterative screening process, investigating alignment alternatives. The "Post-Panamax Locks Elevations Diagram" was used to determine the elevations of the navigational channel cuts from the Atlantic side to the Gatun Lake side, progressing through the proposed Third Lane lock configurations. This elevation diagram was refined as concept level design work progressed.

The Third Lane modeling template uses a 100 m wide cut, which consists of a lock chamber of 60.96 m and gravity lock wall footings, which, according to preliminary design estimates, add approximately 39 m (total footing width of 22.86 m minus the toe width of 3.81 m, for each lock wall footing). The gravity walls were sized based on loading conditions, including seismic.

Several modeling runs are defined in the Draft Alignment Report as 1C, 1D, 2, 2A, 3, 3A, 4, 5 and 6. Runs No. 1A and 1B were the initial runs made, but eliminated from further consideration. Both Runs 1A and 1B positioned the lock structure North of the existing Gatun Locks, in the approach area (Sta. 11+040 and 11+300). Constructing the lock in this position along the 9-degree alignment would require a long cofferdam, which would be costly and infringe on the navigation approach area for the existing locks.

All modeling runs begin on the Atlantic approach and move toward Gatun Lake. A vertical profile was created for the Double-Lift lock, along the entire reach of the Third Lane cut. This vertical profile defines the series of steps needed to construct the locks and approaches. The profile establishes the bottom of excavation line, from the Atlantic entrance thru the locks and out to the South Approach (Gatun Lake).

3.2.1. The InRoads Model for the Double-Lift Lock Configuration Is Defined as Follows:

a North (Atlantic) Approach: The entrance elevation cut is defined at –19.57 m, which extends to sill of the first (Northern-most) miter gate. An exception to this cut line occurs between Stations 11+355.75 and 11+500, over which the entrance cut will make a series of steps in order to ride along the top of rock line to accommodate the entrance wall footing. Cuts in side slopes will be made at 6V:1H in rock upward to a height of 19 m. A bench is cut in at the 19 m point (4.5 m). The side slope continues upward along the same 6V:1H slope for an additional 16.5 m (total height at this point: 35.5 m). At the 35.5 m point, a second bench will be cut in (3.5 m). If the side slope cut needs additional rock removal, the cut will be made at a 1V:1H side slope until the cut reaches the top of rock. Overburden cuts for the North Approach side slopes will be made at 1V:8H. This flat cut will continue until tie-in has been made with existing ground.

b. Double-Lift Lock: The double lift lock structure is positioned along the alignment corridor such that the Northern-most miter gate pintle is aligned at Station 12+150. The cut line for the lower (Atlantic side) chamber is at elevation –24.78. A similar cut line for the upper (Lake side) chamber is elevation –12.13. Vertical offsets (steps) exist depending on lock wall loading and design. Footing elevation offsets are modeled for the cut. Refer to the lock wall elevation views for footing arrangement and elevations. Side slopes in rock will be made at 10V:1H up to a height of 16 m. A bench will be cut in at the 16 m point (3 m). The cut slope will then continue upward on a 6V:1H slope until reaching the top of rock. Cut slopes in overburden will be made at 1V:4H along the lock chamber area.

c. South (Gatun Lake) Approach: The entrance elevation cut is defined at +5.03 m, which extends to sill of the Southern-most miter gate. Cuts in side slopes will be made at 6V:1H in rock upward to a height of 19 m. A bench is cut in at the 19 m point (4.5 m). The side slope continues upward along the same 6V:1H slope for an additional 16.5 m (total height at this point: 35.5 m). At the 35.5 m point, a second bench will be cut in (3.5 m). If the side slope cut needs additional rock removal, the cut will be made at a 1V:1H side slope until the cut reaches the top of rock. Overburden cuts for the South Approach side slopes will be made at 1V:6H. This cut will continue until tie-in has been made with existing ground. The shipping channel width thru Gatun Lake maintains a width of 4B (4 beam widths or 4(60.96 m) or 243.84 m. 2.5 B, measured from the face of the wall is provided along the South Approach. (Note: This channel width requirement was coordinated with the ACP staff, during the week of January 20, 2003.)

3.3. Geotechnical Data

Refer to the Appendix C, Geotechnical Investigations, Analyses and Designs, for soil (overburden) and rock data. This data was crucial to establishment of modeling templates for cuts thru the rock and overburden strata, both along the approaches and thru the double-lift lock reach.

4. EXCAVATION QUANTITIES -

Table D-4-1 Double-Lift Lock, 9.75-Degree Baseline With Northern-Most Miter Gate Pintle At Station 12+150

Excavation Area Along 9.75 Degree Baseline: North Miter Gate Pintle @ Sta 12+150	Rock Excavation (m^3)	Overburden Excavation (m^3)	Total Excavation (m^3)
North (Atlantic) Approach	941 246	2 365 416	3 306 662
Double-Lift Lock	3 509 445	2 516 346	6 025 791
South (Gatun) Approach	1 056 691	1 943 384	3 000 075
Total Excavation: Third Lane	5 507 382	6 825 146	12 332 528
Total Excavation: Third Lane, rounded	5 500 000	6 800 000	12 300 000

Table D-4-2 Double-Lift Lock, 9.75 Degree Baseline, Northern-Most Miter Gate Pintle at Station 12+500

(Lock footprint shift of 350 m, toward Gatun Lake).

Excavation Area Along 9.75 Degree Baseline: North Miter Gate Pintle @ Sta 12+500 (350 M shift in lock footprint)	Rock Excavation (m^3)	Overburden Excavation (m^3)	Total Excavation (m^3)
North (Atlantic) Approach	1 315 343	2 053 210	3 368 553
Double-Lift Lock	4 669 478	2 592 304	7 261 782
South (Gatun) Approach	415 024	674 894	1 089 918
Total Excavation: Third Lane	6 399 845	5 320 408	11 720 253
Total Excavation: Third Lane, rounded	6 400 000	5 320 000	11 720 000

Table D-4-3 Water Saving Basins

WSB Identification	Rock Excavation (m^3)	Overburden Excavation (m^3)	Total Excavation (m^3)
WSB's 1A and 1B: Serving Upper (Gatun Lake) Lock	866 832	926 541	1 793 373
WSB's 2A and 2B: Serving Lower (Atlantic Approach) Lock	182 115	324 402	506 517
Total Excavation, WSB's	1 048 947	1 250 943	2 299 890
Total Excavation, WSB's rounded	1 050 000	1 250 000	2 300 000

Table D-4-4 Double-Lift Lock, 9.75 Degree Baseline, Northern-Most Miter Gate Pintle at Station 12+500 with Water Saving Basins

Excavation Area: Identification	Rock Excavation (m^3)	Overburden Excavation (m^3)	Total Excavation (m^3)
Total Excavation: Locks and Approaches	6 399 845	5 320 408	11 720 253
Total Excavation, WSB's	1 048 947	1 250 943	2 299 890
Total Excavation, Locks, Approaches, WSB's	7 448 792	6 571 351	14 020 143
Total Excavation, Locks, Approaches, WSB's, rounded	7 450 000	6 570 000	14 020 000

5. DOUBLE-LIFT LOCK CONCLUSION

The Atlantic side locks alignment has been optimized as required in the Scope of Work. The A-2 alignment as defined in the Harza Alignment Report was used as the starting point for further development of the optimized alignment. The Harza alignment was located adjacent to and parallel to the east wall of the existing Gatun Locks but did not afford sufficient room to comfortably include water saving basins and minimize excavation costs. It also did not provide good transitions with the existing navigation channels.

Alignment A-2 as modified under these studies (A-2 Prime) is the recommended alignment considering all of the evaluation criteria. The A-2 alignment was modified by incorporating water saving basins to the west of the locks and making a 9.75 degree counter-clockwise angular rotation of the southern end of the alignment to the east. This minimized excavation in the approach channel to the north while providing better sailing lines with the existing navigation channels. A number of angular rotations were studied which led to a preliminary conclusion of using a 9 degree rotation from the existing Gatun Locks and eventually a 9.75 degree rotation proved to be the best fit. The location was optimized with respect to the location of the water saving basins, total costs, excavation costs, features layout, operating conditions including navigational safety, efficiency of construction and expansion to a fourth lane. Local disposal in the vicinity of the locks was assumed.

Lateral space requirements were critical for inclusion of the water saving basins without interfering with existing locks operations. The lock structure was located longitudinally to fit the rock stratigraphy and minimize entrance channel requirements. Essentially all of the structures are founded on rock and the need for special or extra construction features and techniques is virtually eliminated. The 9.75 degree alignment centerline provides a virtually straight-run entry from the Atlantic Ocean through the locks and into the Gatun Lake navigation channel. At the southern entrance, there is only a slight requirement for deviation from the navigation entrance channel in Gatun Lake and avoids any sharp or right-angled turns for these much larger Post-Panamax vessels are avoided. It actually provides a better entrance/exit condition into the locks from the navigation channel to the east of Isla Guarapo than that existing for Gatun Locks. It was considered critical to avoid turns for these large Post-Panamax vessels. The siting of the alignment also provides sufficient separation of from the entrances into Gatun Locks to maximize vessel navigational safety and avoid interferences of ship management.

The 9.75 degree angled alignment is rotated counter-clockwise from the point-of-intersection (PI) along the Gatun Middle wall axis (187 degree, 38 minutes azimuth) of the existing locks extending north along the approach channel to the turn near Buoy No. 16. This is the recommended axis to fully satisfy all criteria and provide maximum navigational safety. It is a nearly straight run line (2 degrees 11 minutes of angular rotation) of the navigation approach channel from the North, Atlantic entrance.

6. RELOCATIONS

6.1. Buildings:

To facilitate construction of the Third Lane (Double-Lift Lock), Entrance Walls and Water Saving Basins, the area east of the Gatun Locks, along the 9.75 degree baseline, must be free of obstructions. This area will require building removal, followed by clearing and grubbing, prior to commencement of excavation activities. The areas cleared would also accommodate space for the Contractor's work areas.

A number of buildings occupy the parcels of land adjacent to the access roadways that traverse the Gatun site as shown on the Relocations (Buildings and Roadways) Drawing. Buildings requiring removal/relocation are shaded whereas buildings not affected by construction activities remain clear/unshaded. The ACP provided an AutoCADD (Dwg) file of the buildings. This file was converted to MicroStation (Dgn), and superimposed over the site, as a Reference File. A number of buildings fall within the proposed construction zone. Buildings have been categorized as those falling within the Lock Area, Entrance Wall Areas, WSB area and additional areas not within the excavation limits, but needed for positioning of batch plants, construction field offices, parking areas, and temporary roadways for off-road construction equipment.

The following Tables summarize the buildings (by numeric descriptions), which must be removed/relocated prior to start of construction. If not relocated in advance of construction, the assumption is made in the Cost Estimate that these buildings would require demolition (removed by clearing contract):

Table D-6-1 Buildings Located Within The Double-Lift Lock Area (Main Excavation Template)

Building Series	Building Identification Numbers	Number for Removal
00's	None	0
100's	146,147,148,150,151,153,155,156 ,157,159,161	11
200's	201, 202, 203, 210	4
300's	329, 353, 355, 373	4
Misc.	THA1081, THA-4A7, X-2	3
Total:		22

Table D-6-2 Buildings Located Within The Atlantic Entrance Wall Area

Building Series	Building Identification Numbers	Number for Removal
00's	None	0
100's	None	0
200's	None	0
300's	327, 378, 390	3
Misc.	None	0
Total:		3

Table D-6-3 Buildings Located Within The Gatun Lake Entrance Wall Area

Building Series	Building Identification Numbers	Number for Removal
00's	None	0
100's	None	0
200's	None	0
300's	None	0
Misc.	None	0
Total:		0

Table D-6-4 Buildings Located Within The WSB's Area, Lower (Atlantic Side) WSB Area

Building Series	Building Identification Numbers	Number for Removal
00's	29, 29A, 32, 33, 34, 35, 40, 40A, 40G,	9
100's	139	1
200's	None	0
300's	315-X, 317, 344-X	3
Misc.	THA445, THA4X1	2
Total:		15

Table D-6-5 Buildings Located Within The WSB's Area, Upper (Lake Gatun Side) WSB Area

Building Series	Building Identification Numbers	Number for Removal
00's	None	0
100's	100, 102-X, 103, 104, 105, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 119, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 134, 135, 136, 137, 138, 140, 141, 143, 144, 145, 173-X	40
200's	None	0
300's	None	0
Misc.	THA4A-A	1
Total:		41

Table D-6-6 Buildings Outside The Main Excavation Template, But Located Within The Area Needed For Batch Plants And Aggregate Piles

Building Series	Building Identification Numbers	Number for Removal
00's	None	0
100's	161-X, 191, 193, 194, 195, 196	6
200's	204, 206, 207, 208, 209, 213, 215, 217, 219, 219-A	10
300's	None	0
Misc.	THA1181, THA11D1, THA11Z1, UX-3	4
Total:		20

Table D-6-7 Buildings Adjacent To The Gatun Lock Access Road

(Area needed to facilitate movement of construction vehicles and installation of WSB's and WSB access roadways)

Building Series	Building Identification Numbers	Number for Removal
00's	25, 27, 30, 31, 42, 42X, 49	7
100's	None	0
200's	None	0
300's	None	0
Misc.	None	0
Total:		7

Table D-6-8 Buildings Adjacent To Gatun Warf Area Which Requires Removal To Accommodate Construction Of Permanent Dike (Vehicular Access To West Wall)

Building Series	Building Identification Numbers	Number for Removal
00's	10,13,14,17	4
100's	None	0
200's	None	0
300's	None	0
Misc.	G8-13, THA1Y1, THA1A2	3
Total:		7

Table D-6-9 Buildings Adjacent To Roadway, Located Due East Of The Atlantic-Side Miter Gate Monoliths (Area Needed For Construction Office Trailers)

Building Series	Building Identification Numbers	Number for Removal
00's	None	0
100's	None	0
200's	None	0
300's	382, 383, 385	3
Misc.	None	0
Total:		3

Table D-6-10 Building Summary

The following buildings (identified above with a specific building number) fall within the general construction zone for the proposed Third Lane baseline Alignment (9.75 degree baseline) and hence, require removal/relocation.

Buildings Located Within The Following Areas Requires Removal to Accommodate Construction of Third Lane Locks and WSB's	Number of Buildings To be Removed
Double-Lift Lock Chamber Area	22
Atlantic Entrance Wall Area	3
Gatun Lake Entrance Wall Area	0
WSB Area: Lower (Atlantic side)	15
WSB Area: Upper (Gatun Lake side)	41
Batch Plant, Construction Zone: East of East Wall	20
Access Roadway Area: Adjacent to Gatun East Wall	7
Gatun Warf Area	7
Gatun Access Roadway Area: Buildings East of Lower Gates	3
Total Buildings:	118

6.2. Roadways

Numerous existing roadways occupy the Gatun site, east of the existing Gatun locks. Refer to the Relocations (Buildings and Roadways) Drawing for an indication of affected roadways. Roadways requiring removal/relocation have been shaded. The access roadway serving the Gatun locks has been left undisturbed. The existing locks must remain operational during all phases of construction. Hence, access to the existing locks must remain open and operational. The roadway providing access to the town of Gatun is partially affected by the Third Lane excavation. Note the excavation limits on Drawings Nos. ACP-R-3/3 through 3/5. All roadways falling within these excavation limits must be removed prior to excavation and relocated, if needed. The Gatun access roadway falls partially within these limits, along the Northern edge of the site, and hence will be located to provide uninterrupted access to town.

6.3. Utilities

All utilities servicing the existing Gatun locks would be relocated both temporary (during construction) and permanent if falling within the construction zone for the Third Lane. An Adobe Acrobat (Pdf) file of the site utilities was provided by the ACP. This file contained electric lines (shown in blue), water lines (shown in green) and telephone lines (shown in red) extending on the east side of the Gatun locks. Some of these utilities have lines which fall within the excavation limits, and would require removal (temporary service hook ups) prior to initiating the Third Lane contract. Gatun Locks will remain operational during all construction activities, hence, utility service must continue uninterrupted.

7. SITE DEVELOPMENT

Refer to Drawings Nos. ACP-R-3/1 for the General Site Map and ACP-R-3/2 through 3/5 for Detailed Site Plans of the Third Lane construction site. Data provided on the Site Map include existing and proposed lock data, alignment orientation data, as well as general site orientation information (coordinated grid system). Detailed Site Plans break up the proposed construction site into segments, at a much larger scale, for emphasis on Double-Lift Lock construction details. Excavation requirements, lock footprint perimeters and orientation, WSB locations and layout, access road removals and relocations, overburden cut slopes and other pertinent site development information is shown. All drawings reflect Third Lane construction along the 9.75-degree baseline corridor (the recommended Plan for the Double-Lift Lock).

PANAMA CANAL CONCEPT DESIGN

Atlantic Locks Structure

Third Lane Lock

Appendix E

Hydraulic Analyses and Designs

Prepared for

Canal Capacity Projects Office

By

US Army Corps
of Engineers®

Final Report

23 July 2003

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1. REFERENCES

A list of technical references is provided in Section 2.1 of Appendix A.

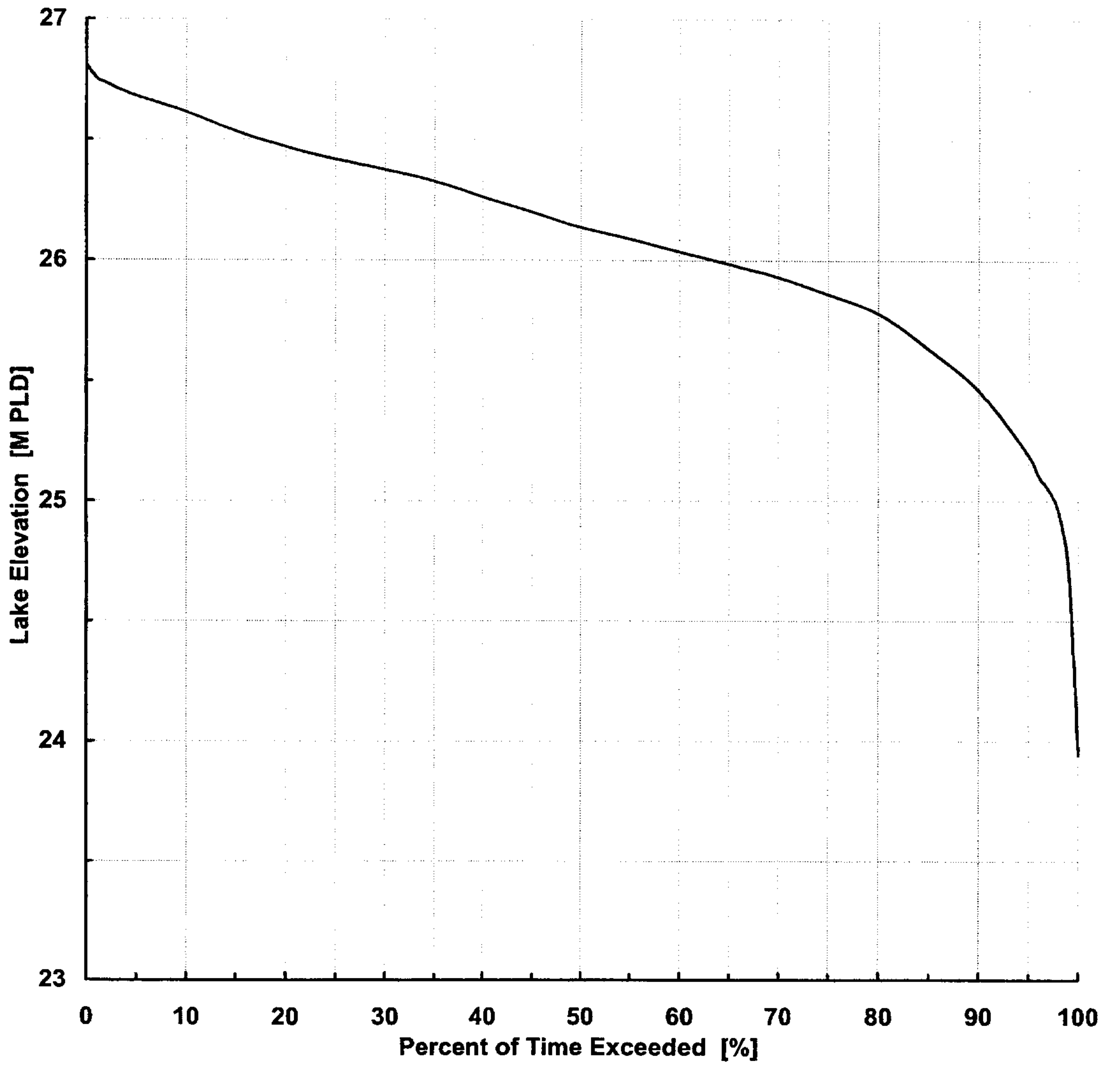
2. STAGE DURATION DATA

Moffatt and Nichol Engineers developed stage duration relations from data provided by the ACP for their conceptual design study of the water saving basins. These relations were adopted for use in this study.

2.1. Gatun Lake

The Gatun Lake relation was based on 35 years of measured data from 1966 through 2000. The data ranged from a high of 26.814 m PLD to a low of 23.942 m PLD. A summary of the data is presented in Figure E-2-1.

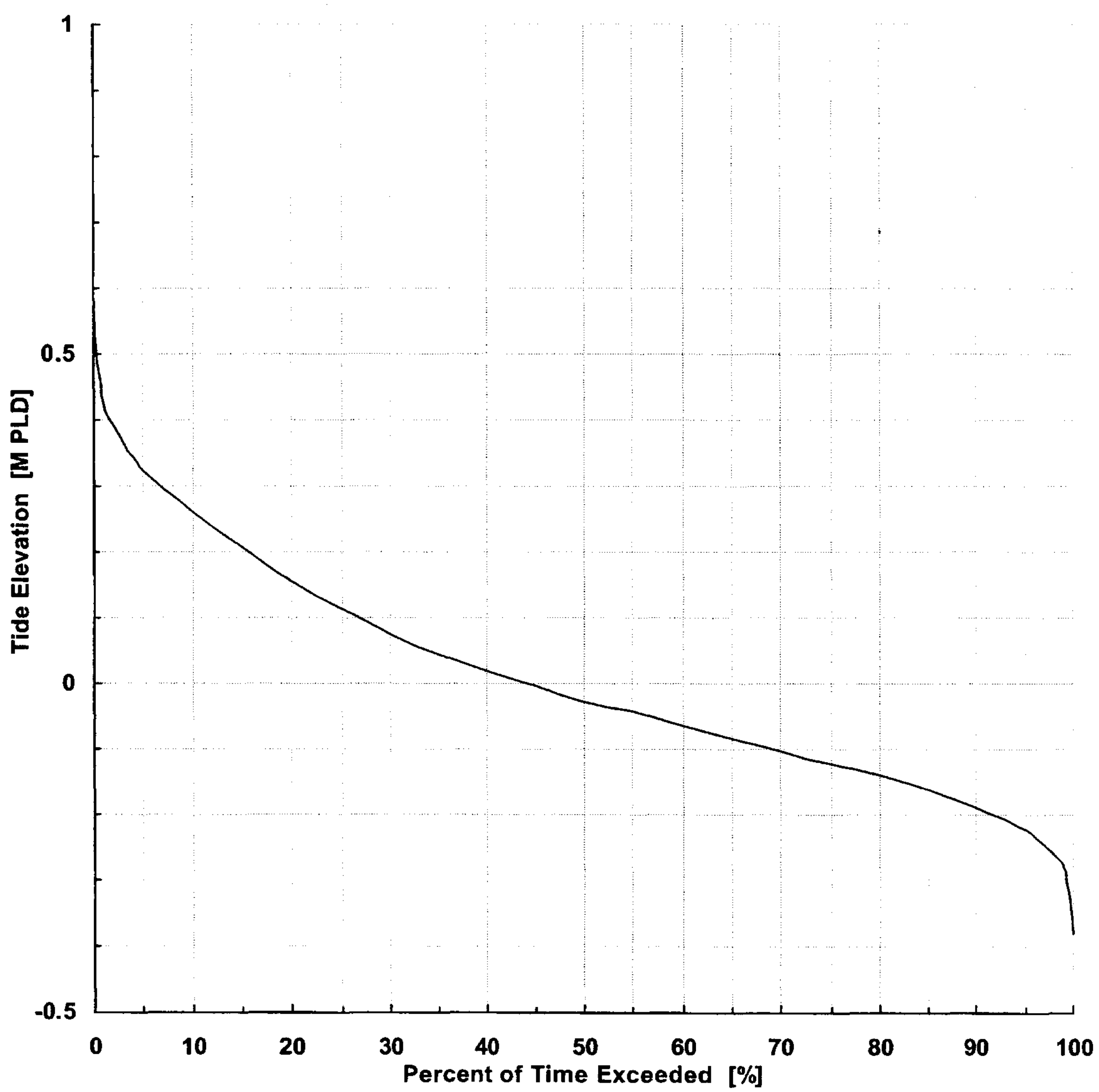
Figure E-2-1 Stage Duration for Gatun Lake



2.2. Atlantic Ocean

The Atlantic Ocean stage duration relationship included analysis of 10 years of measured data from 1989 through 1998 at the Coco Solo Gage. Predicted data was also developed for the 1978 tidal epoch (1960-1978) at the Cristobal Gage. The final stage-duration relationship developed and recommended by Moffatt and Nichol used the predicted tides with adjustments to account for observed extremes. The data ranged from a high of 0.564 m PLD to a low of –0.381 m PLD. A summary of the data is presented in Figure E-2-2.

Figure E-2-2 Stage Duration for Atlantic Ocean



2.3. Lock Equalization

A duration curve for equalization between the upper and lower lock was derived from the duration data for Gatun Lake and the Atlantic Ocean. The duration data was grouped into intervals with a representative value assigned to each interval. A probability was then assigned to each interval based on the duration range for that interval. The sum of probabilities for all intervals must equal one to satisfy the total probability theorem. The representative values and probabilities were then combined to estimate the equalization elevation and associated probability of occurrence. The combined equalization elevation is the average of the Gatun Lake and Atlantic Ocean elevations. The combined probability is the product of the Gatun Lake and Atlantic Ocean probabilities. Again, the sum for all of the combined probabilities in the matrix must equal one to satisfy the total probability theorem. A sample computation matrix for the intervals shown in Figures E-2-3 and E-2-4 is presented in Table E-2-1. The final duration curve is then derived by selecting a series of equalization elevations from the values computed in the matrix. For a particular equalization elevation, the percent exceedence is then computed as the sum of the probabilities for all equalization elevations in the matrix that are greater than the value. A sample percent exceedence table using the four sample intervals is presented in Table E-2-2. The duration curve is then plotted from this percent exceedence data. A plot of the final estimated duration curve is presented in Figure E-2-5.

Table E-2-1 Computation Matrix for Equalization Duration

		Representative Gatun Lake Elevations and Probabilities			
		26.588	**26.109**	**25.634**	**25.167**
		0.25	**0.55**	**0.10**	**0.10**
Representative Atlantic Ocean Elevations and Probabilities	**0.274**	13.431	13.192	12.954	12.721
	0.20	*0.05*	*0.11*	*0.02*	*0.02*
	0.094	13.341	13.102	12.864	12.631
	0.15	*0.04*	*0.08*	*0.02*	*0.02*
	-0.073	13.258	13.018	12.781	12.547
	0.55	*0.14*	*0.30*	*0.06*	*0.06*
	-0.229	13.180	12.940	12.703	12.469
	0.10	*0.03*	*0.06*	*0.01*	*0.01*

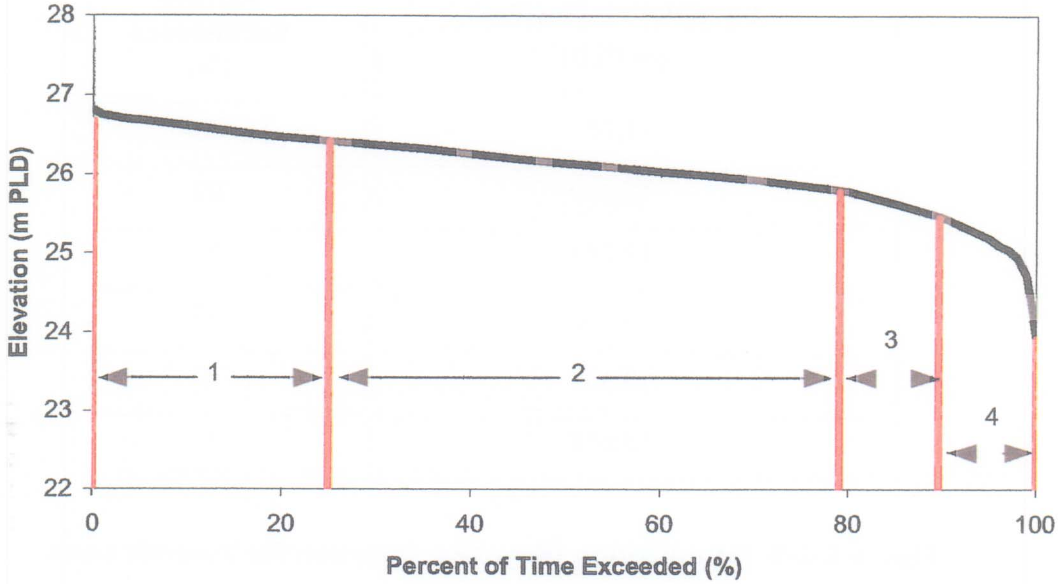


Figure E-2-4 Sample Intervals for Atlantic Ocean

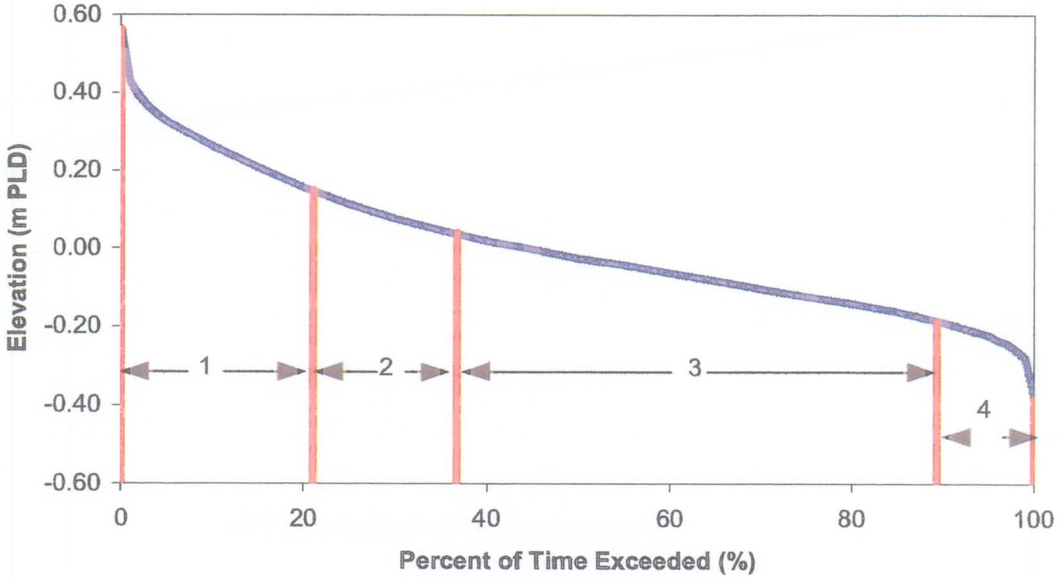
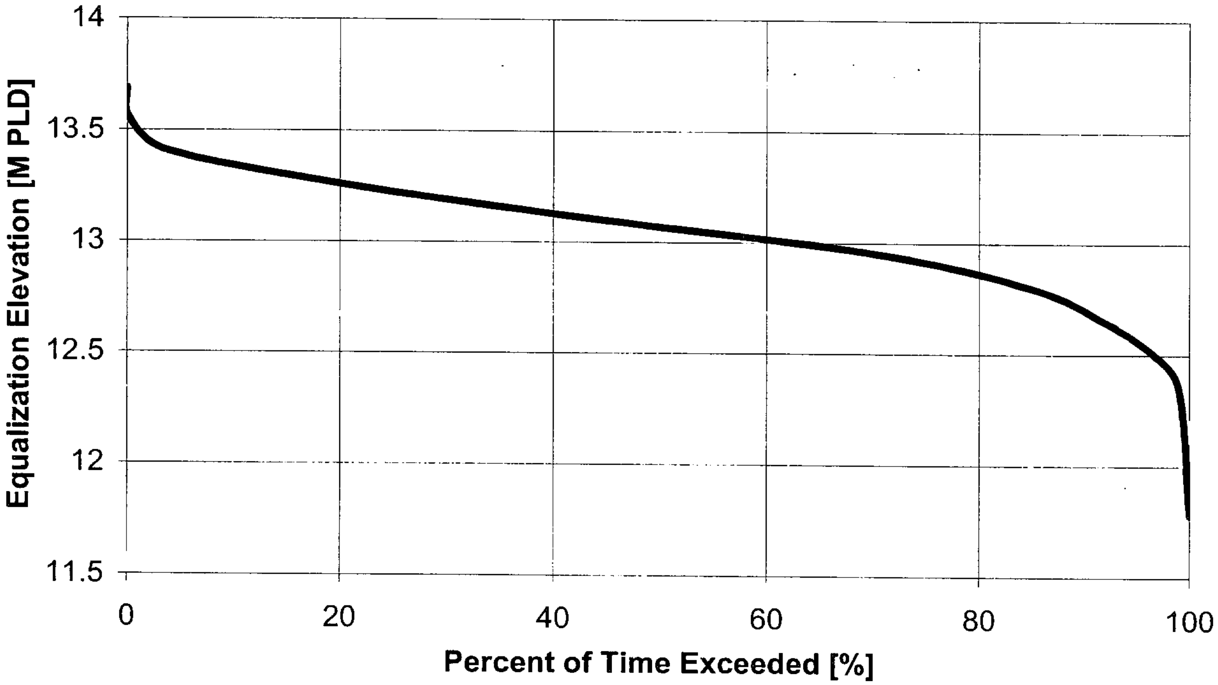


Table E-2-2 Percent Exceedence for Equalization Duration

Equalization Elevation (m PLD)	Percent Exceedence (%)
11.781	100
12.469	99
12.781	91
13.102	45
13.431	5
13.689	0

Figure E-2-5 Equalization Elevation Duration for Two-lift Lock



3. LOCK PROFILE

3.1. Operating Water Surface Elevations

In accordance with the terms of reference, the locks will be designed to operate between Gatun Lake levels of 26.670 and 23.927 m PLD and Atlantic Ocean levels of 0.564 and –0.381 m PLD. Although the historical extremes for Gatun Lake are slightly different, the elevation range specified in the terms of reference was used for design. Based on the design operating ranges, the locks would equalize between 13.619 and 11.775 m PLD.

3.2. Sill Elevations

The lock sill elevations were selected based on low lake and ocean levels and the required minimum clearance over the sills. This reduces the need for make up water (that volume of water taken from the lake into the upper lock to ensure sufficient clearance over the sills) during critical low water periods when the locks will equalize at a low level. It should minimize the risk of draft restrictions during critical low water periods by ensuring that there will be sufficient clearance over the sills.

The lake level used was 23.927 m PLD and the ocean was -0.381 m PLD with the two locks equalizing at 11.775 m PLD. The required minimum sill clearance is 18.288 m. The sill at the entrance to the upper lock chamber would be set at 5.639 m PLD, the sill between the locks would be set at –6.517 m PLD, and the sill at the exit to the ocean would be set at –18.669 m PLD.

3.3. Hydraulic Freeboard Requirements

3.3.1. Existing Gatun Locks

The existing Gatun Locks were built with 2.134 m (upper and middle locks) to 1.554 m (lower lock) of freeboard above the maximum operating elevations; this was later reduced to 1.372 m, 1.615 m and 1.311 m (upper to lower lock) when the Gatun Lake level was raised 0.762 m from 25.908 to 26.670 m PLD.

3.3.2. Other Existing Large Locks

The Eisenhower Locks on the Saint Lawrence Seaway operate with a range of freeboard from 1.5 - 4 m due to the variation of Lake Saint Lawrence; the Snell Locks operate with a lesser range of freeboard of 1.54 - 1.69 m due to the controlled elevations in the Wiley-Dondero Ship Canal. No pilot visibility or operational concerns were reported at either lock. The Eisenhower Lock maintenance staff reported that the chamber pool variability sometimes affects access.

The Soo Locks operate with a range of freeboard from 1.036 - 2.225 m due to the variation of Lake Superior. No pilot visibility or operational concerns were reported.

The Dutch Berendrecht Lock handles post-Panamax ships. It operates with a freeboard of 3 m at mean high tide, at the extreme high tide there will be somewhat less freeboard.

3.3.3. Ship Induced Surcharges

Surcharges resulting from vessel movements into the locks were estimated to assure sufficient lock wall freeboard is available. Basic equations were taken from "Measurement of Pressures Related to Vessel Movement within Miraflores Upper West Lock" (USACE, 1999). The equations were converted to metric units and adjusted to provide conservative estimates for the larger locks of the proposed third lane. Although the maximum surcharges would occur with the lowest water surface levels, the surcharges were computed for the maximum water surface elevations, to arrive at the overall maximum surcharge elevations.

The important factors determining surcharge are ship speed and modified blockage ratio, BR', which is the ratio of cross-sectional area of the ship to total area, and accounts for flow through culverts in addition to flow around the ship. It is difficult to estimate vessel speeds for the proposed locks, but to be conservative, the speeds computed with the Miraflores equations were adjusted by a factor of 1.5 because the proposed locks will be roughly 50% longer than the existing locks. Cross sectional dimensions of the design ship were assumed to be a beam of 54.864 m and a draft of 15.240 m. Culvert area was assumed to be 48 m^2 based upon estimates for the interlaced bottom lateral system presented in Section 12.1.1 of Appendix E. Assuming two culverts, the total culvert area would be 96 m^2. The area of the lock is computed as the width times the depth over the sill.

The upper lock surcharge computation is based on the Miraflores southbound entering condition from Miraflores Lake. The maximum ship speed for the upper lock is computed with equation E-3-1:

$$V_{SHIP,MAX}(m/s) = 1.5\left(2.560 - 2.256\,BR'\right) \tag{E-3-1}$$

In the equation for maximum surcharge, shown as equation E-3-2 below, the constant has been adjusted by a factor of 1.5 because of the proposed larger lock:

$$SURCHARGE(m) = 1.5\left(0.098 + 0.183\right) + 0.007\left(\frac{V_{SHIP,MAX}}{0.3048\left(\frac{1}{BR'} - 1\right)}\right)^2 \tag{E-3-2}$$

The lower lock surcharge is based on the northbound entering condition into Miraflores upper west lock because no measurements were made in the lower lock. Surcharges should be similar for the two conditions. The maximum ship speed for the lower lock is computed with equation E-3-3.

$$V_{SHIP,MAX}(m/s) = 1.5\left(1.829 - 1.326\,BR'\right) \tag{E-3-3}$$

The maximum surcharge for the lower lock is computed with equation E-3-4. An adjustment of 1.5 was applied to the constant to account for the larger design ship.

$$SURCHARGE(m) = 1.5(0.091) + 0.005\left(\frac{V_{SHIP,MAX}}{0.3048\left(\frac{1}{BR'} - 1\right)}\right)^2 \tag{E-3-4}$$

Results are summarized in Table E-3-1.

Table E-3-1 Predicted Ship Induced Surcharges

Alternative	Upper Lock	Lower Lock
Max static water surface [m PLD]	26.670	13.620
Sill Elevation [m PLD]	5.640	-6.510
Depth over sill [m]	21.030	20.130
Width of lock [m]	60.960	60.960
Area of lock + culverts [m^2]	1,377	1,323
BR'	0.607	0.632
Maximum ship speed [m/s]	1.786	1.486
Maximum surcharge [m]	0.995	0.487
Max surcharge water surface [m PLD]	27.665	14.107

3.3.4. Overtravel

Deceleration of the flow during the later stages of an equalization operation results in an inertial head that increases the total head producing flow in the system. This inertial head component results in overtravel of the water surface in the lock chamber beyond the target equalization level. Sufficient freeboard is required on the lock walls to accommodate increases in water surface elevations due to overtravel, which are higher than the design target water surface. Preliminary estimates for the third lane locks indicate that surcharges due to filling would be approximately 0.3 m.

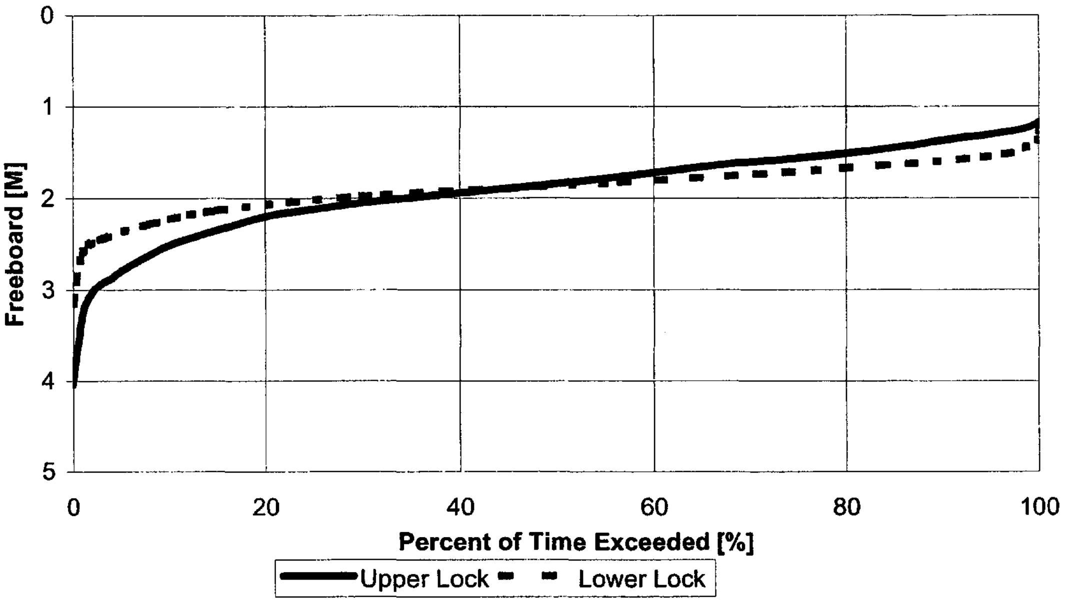
3.3.5. Recommended Hydraulic Freeboard

The recommended amount of freeboard is 1.311 m. This is the minimum amount of freeboard that the Panama Canal Authority currently finds acceptable; it is also in line with the other large locks. This freeboard should be applied above the maximum operating elevation to always provide at least 1.311 m of freeboard. This 1.311 m of freeboard will be used to set the minimum top of wall and gate elevations for hydraulic design considerations. Additional freeboard may be required for structural and mechanical reasons.

3.4. Variable Freeboard

Applying the minimum freeboard above the maximum design operating elevation ensures that there will always be 1.311 m or more of freeboard on the lock walls and gates. The amount of freeboard at each lock would vary with the stage durations as presented in Figure E-3-1.

Figure E-3-1 Freeboard Duration



3.5. Recommended Lock Profile

The lock wall elevations were selected based on high lake and ocean levels and the resultant equalizing elevations in the locks. This would eliminate the need to spill water (that volume of water spilled from the locks to prevent flooding over the walls) during high water periods when the locks would equalize at a high level.

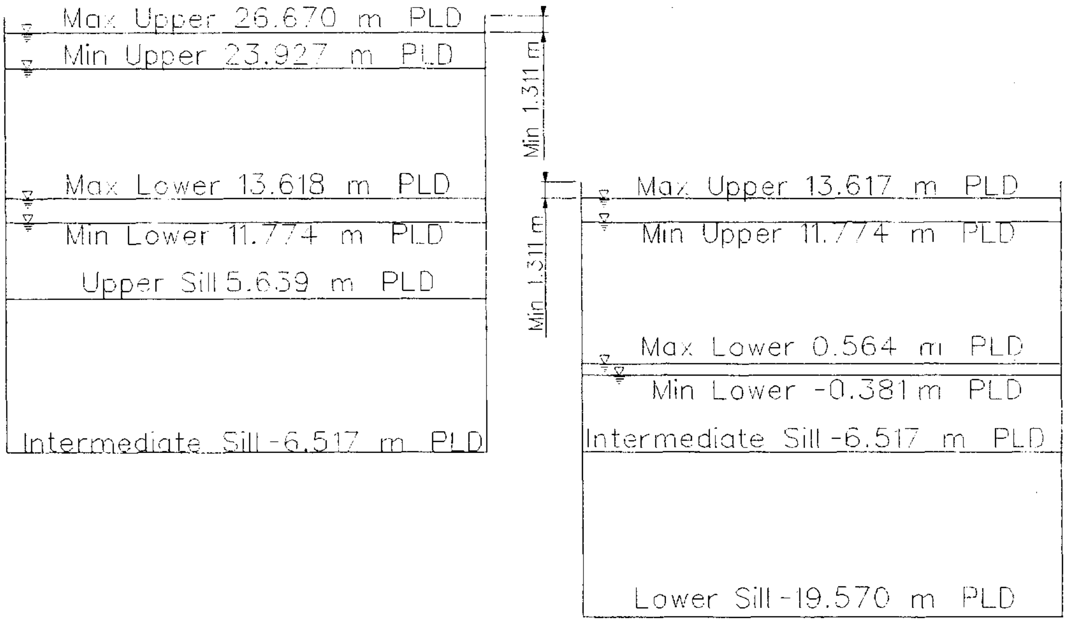
The lake level used was 26.670 m PLD and the ocean level was 0.564 m PLD. The 1.311 m of freeboard will be used to set the minimum top of wall and gate elevations for hydraulic design concerns. This freeboard should be applied above the maximum operating elevation to always provide 1.311 m or more of freeboard. A summary of resulting design elevations is presented in Table E-3-2. A schematic of the lock profile is presented in Figure E-3-2.

A duration analysis, which considered the entire range of possible lake and ocean elevation combinations, was conducted to determine the average amount of water required for a single downbound lockage without water saving basins. The average amount of water required per lockage expressed as a water column was computed as 13.041 m. The total volume of water required can be computed by multiplying the water column by the surface area of the lock.

Table E-3-2 Recommended Lock Profile

Upper lock	Minimum top of wall [m PLD]	27.981		
	Freeboard [m]	1.311	→	4.054
	Maximum upper pool elevation [m PLD]	26.670	Minimum upper pool elevation [m PLD]	23.927
	Sill [m PLD]	-6.517		
Lower lock	Minimum top of wall [m PLD]	14.929		
	Freeboard [m]	1.311	→	3.155
	Maximum upper pool elevation [m PLD]	13.618	Minimum upper pool elevation [m PLD]	11.774
	Sill [m PLD]	-18.669 (used –19.570 for common gate height)		

Figure E-3-2 Lock Profile Without Water Saving Basins



4. USEABLE LOCK LENGTH

The useable lock length at the upstream end of the chamber is limited by the location of the gate sill. At the downstream end, the swing of the miter gate controls useable length with the approximate limit near the edge of the gate recess.

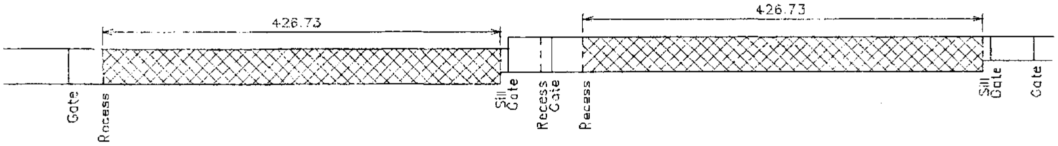
Redundant safety protection against loss of pool due to a gate impact generally consists of providing a minimum of two barriers in front of a moving ship. This requirement is less critical at the downstream end of the lower lock because the chamber is designed to accommodate ocean water levels while the upstream gates can be closed to prevent loss of pool. Redundant protection at the downstream end of a lock consists of double sets of miter gates in front of a downbound ship. For upbound ships, redundancy is provided by double sets of miter gates and the gate sill at the upstream end of each lock.

Original design configurations presented to ACP in October 2002 provided a 426.720 m useable lock length with redundancy for all situations except a downbound ship at the downstream end of the lower lock. This arrangement is presented as configuration A in Figure E-4-1.

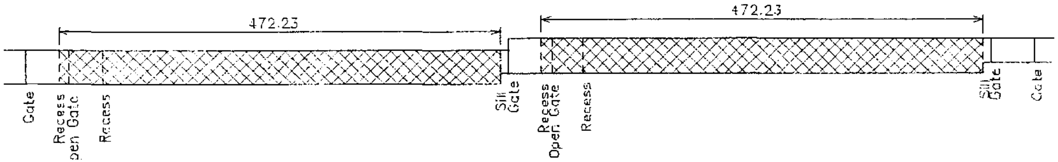
A second configuration was developed to provide a 426.720 m useable lock length with redundancy for all situations. Additional capacity is available for 472.230 m of useable lock length with redundancy for upbound ships. Redundancy in the downbound direction is not provided for the 472.230 m length. This arrangement is presented as configuration B in Figure E-4-1. The designs presented in this report are based upon configuration B.

A third alternative is presented as configuration C in Figure E-4-1. A maximum useable lock length of 457.210 m with redundancy would be provided by this configuration for all situations except at the downstream end of the lower lock for a downbound ship. The overall length of the locks is not changed from configuration B. Instead, the upper sill of the upper lock is lowered at the inner gate to provide the additional length with redundancy for a downbound ship. This configuration requires an increase in height for these inner miter gates and reconsideration of filling capacity requirements between gates. Upbound ships would have redundancy at a useable lock length of 472.230 m. Redundancy is not provided for downbound ships at the 472.230 m length.

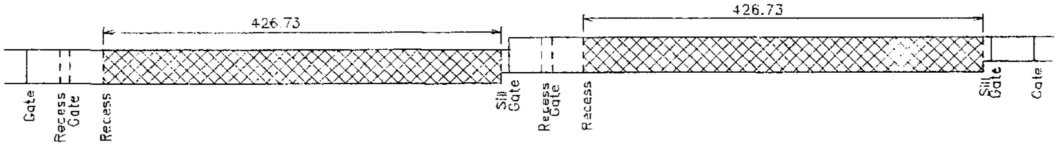
Figure E-4-1 Useable Lock Lengths With Redundancy



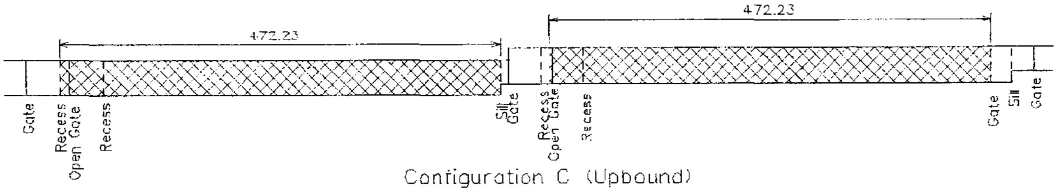
Configuration A



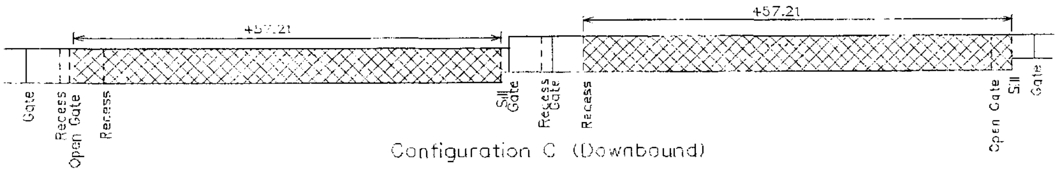
Configuration B (Upbound)



Configuration B (Downbound)



Configuration C (Upbound)



Configuration C (Downbound)

5. WATER SAVING BASINS

The volume of water used during a lockage can be reduced with a system of water saving basins. The basins provide a means for recovery, temporary storage, and reuse of water during operation of the locks. When a lock is emptied, a portion of the water is transferred to the water saving basins. The water can then be stored in the basin until it is ready to be reused during the next lock filling operation. The net effect is a reduction in the amount of source water required during each lockage.

5.1. Theoretical Water Savings

The Permanent International Association of Navigation Conferences (PIANC, 1986) provides water saving basin design parameters and their effect on water savings. Primary factors that determine the potential for water saving include the number of basins (n), the basin to lock surface area ratio (m), and the residual filling depth (e) of the basin. The terms of reference specify two basins per lock (n=2) and a target water savings percentage of 50%. Design values for m and e will be recommended based on analyses presented in this report.

5.1.1. Governing Equations

5.1.1.1. Water Savings

For a given lockage lift (H), the theoretical water savings (E) can be computed using equation E-5-1.

$$E = \frac{n \cdot m \cdot (H - 2e)}{H[(1 + m(1 + n)]} \qquad \text{(E-5-1)}$$

As specified in the terms of reference, analyses will be limited to a configuration of two basins per lock (n=2). For the design lift of a double-lift configuration, the influence of the basin to lock surface area ratio (m) and basin residual (e) on theoretical water savings is presented in Figure E-5-1.

5.1.1.2. Basin Elevations

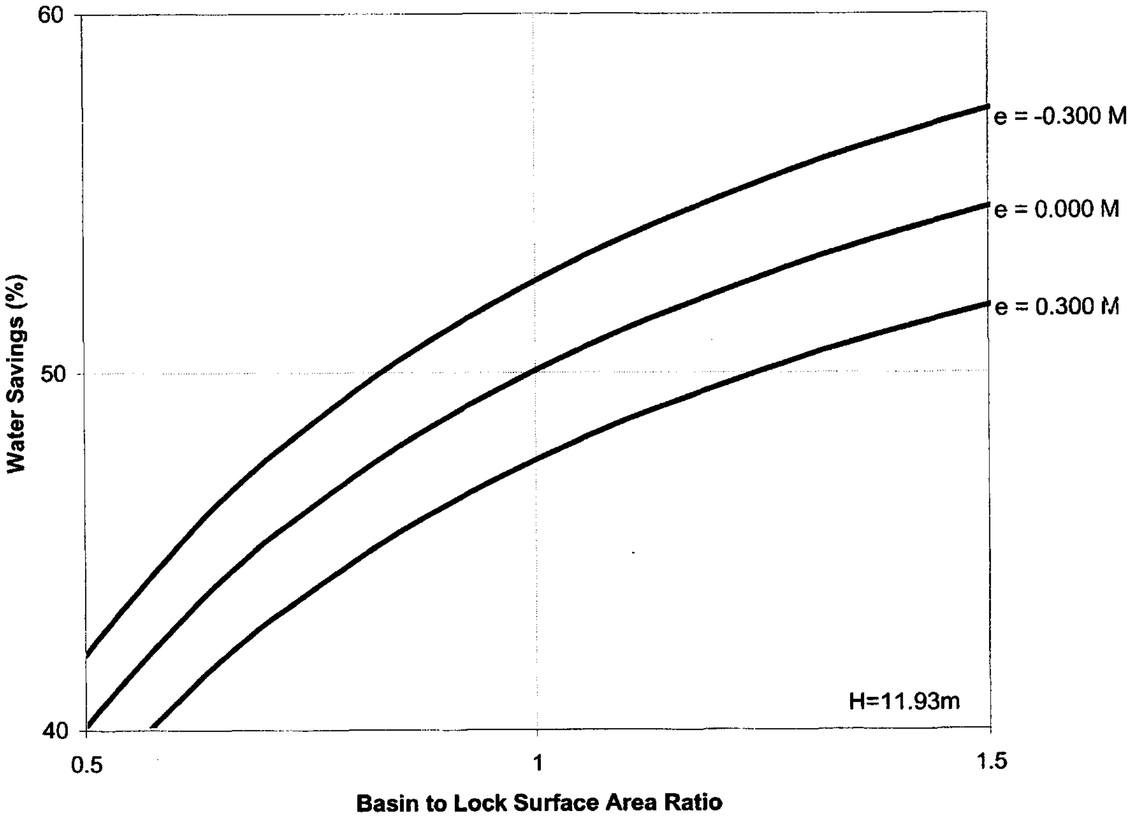
The theoretical floor elevation and operating water surface elevation for a given water saving basin can be computed using equations E-5-2 and E-5-3. In the equation, EQ_l is the lower pool equalization elevation of the lock.

$$Floor_i = EQ_l + i\,m\,\frac{(H - 2e)}{1 + m(1 + n)} + e \qquad for\ i = 1 \ldots n \qquad \text{(E-5-2)}$$

$$Water\ Surface_i = EQ_l + (i\,m + 1)\frac{(H - 2e)}{1 + m(1 + n)} + e \qquad for\ i = 1 \ldots n \qquad \text{(E-5-3)}$$

As specified in the terms of reference, analyses will be limited to a configuration of two basins per lock (n=2).

Figure E-5-1 Theoretical Water Saving for Two Basins



5.1.2. Recommended Design Parameters

Recommended design parameters for the water saving basins are a basin to lock surface area ratio of one (m=1) and a basin residual of zero (e=0). These parameters provide a design that achieves the target water savings of 50%. Analyses presented in Section 11.8 of Appendix E indicate negligible reductions in equalization time when applying a relatively small basin residual (e=0.300 m) with a corresponding increase in basin area ratio (m=1.23).

5.1.2.1. Basin Residual

The concept of a basin residual can be approached from two different perspectives. Guidelines presented by PIANC recommend a relatively small basin residual to save time during equalization. It is suggested that time savings can be achieved by reducing the period of inefficient transfer of water that occurs near the end of each basin operation when there is a small head differential between the lock and basin. The net effect would be to shorten the equalization time at the expense of water savings.

The opposite approach to basin design would be to allow for a small negative basin residual during basin operations. Because the residual is relatively small, the overtravel that normally occurs with lock and basin operations could be used to capture additional water in the basins. The net effect of this approach is to increase the equalization time while increasing water savings. In either case, the influence of basin residual on equalization time and water savings is relatively small. For concept level design, a zero residual is recommended for design of the basins. The system will be designed with the flexibility to operate with a basin residual as needed. During periods of adequate water supply, a positive basin residual could be used to reduce equalization times. A negative basin residual could be put into effect during critical low water periods to maximize water savings.

LOCKSIM results presented in Section 11.8 of Appendix E suggest that a time variation of approximately 30 seconds can be realized for a basin residual of 0.300 m or -0.300 m. However, the savings appears to occur because of a reduction in the volume of water being transferred and not an improvement in the efficiency of water transfer as suggested by PIANC. A possible explanation is that the inefficient transfer at low heads that might be expected with a falling head type situation does not occur in lock operations due to the inertial head that develops as the flow decelerates. More detailed studies would be required to verify these effects.

5.1.2.2. Lock to Basin Surface Area Ratio

Increases in water savings can be realized for values of m greater than one, but the benefits are relatively small and inefficient considering the additional space requirements for each basin. For example, increasing the surface area of each basin by 50% results in a net increase in water savings of less than 5% at the average lift. A more efficient increase in water savings would be achieved by adding a third basin. Since basin to lock area ratios greater than one provide an inefficient approach to saving water, a ratio of one (m=1) is recommended for the concept design.

LOCKSIM results presented in Section 11.8 of Appendix E indicate a negligible time savings for an area ratio of 1.23 and a corresponding basin residual of 0.300 m. Again, this suggests that the inefficient water transfer at low heads suggested by PIANC might not occur in lock operations due to the inertial head that develops as the flow decelerates. More detailed studies are required to verify these effects.

5.1.3. Effect of Variable Lift

Theoretical estimates of water saving percentage computed with equation E-5-1 assume an idealized condition for a specific lift. For the third lane locks, the varying levels of Gatun Lake and the Atlantic Ocean result in a range of possible lifts. The analysis of water savings is complicated somewhat by this condition. Because the floor and operating water surface elevations of a basin are influenced by the lift, there will be a range of possible floor and operating surfaces from which to select a design. Maximum water saving will be achieved by selecting the minimum floor elevation and maximum operating water surface. The minimum floor elevation is computed from the combination of the minimum Gatun Lake elevation and minimum Atlantic Ocean elevation. The maximum operating water surface is computed from the maximum combination of Gatun Lake and Atlantic Ocean elevations. This design approach can result in relatively high and costly water saving basin walls that will overlap with adjacent basins. Cost savings could be realized by increasing the floor elevation and/or decreasing the operating water surface of the basins. The tradeoff is a reduction in water saving capacity. Selection of design floor and operating water surface elevations requires a comparison of water savings versus cost. Details of this comparison are presented in Section 5.2 of Appendix E.

5.1.4. Numerical Model

Analysis of the various design parameters for the basins under a variable lift condition cannot be readily accomplished using equations E-5-1, E-5-2 and E-5-3. In general, the lift becomes a function of basin parameters due to changes in the equalization levels while the basin parameters are a function of the lift. A solution requires an iterative process that is best accomplished using a numerical model. The spreadsheet previously developed by Moffatt and Nichol Engineers was adopted for the present study. The spreadsheet was modified to permit analysis with or without water saving basins. Additional enhancements include the ability to configure the locks and basins independently, evaluate a variable equalization target elevation, and check computed equalization levels against minimum sill clearances. The spreadsheet was verified by comparison with the theoretical water saving basin equations and results obtained using LOCKSIM.

5.2. Screening Analysis of Water Saving Basin Floor Alternatives

The range of possible water saving basin floor elevations was determined the same way that the operating elevations for the locks were selected. A duration analysis, which considered the entire range of possible lake and ocean elevation combinations, was conducted to determine the range of possible floor elevations and average water requirements.

This duration analysis showed that there was a narrow range of possible water saving basin floor elevations with resulting narrow ranges of water saving percentages and amount of water taken from the lake. Relatively low and high floor elevations were selected for consideration, as shown in Table E-5-1. The costs are for comparison purposes only as items common to both alternatives (valves, conduits, etc) are not included; they do not represent the total cost of the water saving basins.

Table E-5-1 Water Saving Basin Floor Alternatives

		Low Floor	High Floor
Average Water Savings [%]		50.00	47.78
Minimum Water Savings at Extreme Low Water* [%]		45.81	39.67
Average Water Column Required Per Lockage**[m]		6.520	6.767
Floor Elevation [m PLD]	Basin 1A	18.818	20.010
	Basin 1B	15.646	16.722
	Basin 2A	6.120	6.852
	Basin 2B	2.947	3.563
Incremental Cost (Screening Level) [$ Millions]		$2.89	$0

*Gatun Lake at 23.927 m PLD and Atlantic Ocean at –0.381 m PLD

**Total volume is water column times surface area of lock

These two alternatives cover the lake and tide configurations that result in the most and the least efficient overall combinations. The ranges of average water savings (50 – 47.8%) and water taken from the lake (6.520 – 6.767 m) are not great. At extreme low water, the differences become more significant with water savings of 45.81% and 39.67%. The alternatives represent differences in basin floor elevations of 1.191 m (Basin 1A), 1.076 m (Basin 1B), 0.732 m (Basin 2A) and 0.616 m (Basin 2B).

A selection based on maximizing the water saving percentage or minimizing the amount of water taken from the lake would favor the low floor alternative. A selection based on minimizing the initial cost of construction would favor the highest floor alternative.

5.3. Recommended Water Saving Basin Floor Elevations

The low floor elevation alternative is recommended for the concept design for the following reasons: 1) Provides average water savings of 50%, 2) Provides reasonable water savings of 45.81% at extreme low water, and 3) Incremental cost is relatively small. The lake level used to configure the basin floor elevations would be 25.168 m PLD and the ocean level would be –0.229 m PLD.

5.4. Operating Water Surface Elevations

Selecting the floor elevations of the water saving basins allowed the equalization elevations of the basins and locks to be determined. The range of possible basin equalization elevations was determined the same way that the operating elevations for the locks were evaluated. Results from the duration analysis that were used to select the basin floor elevation were used to determine the range of possible basin equalization elevations.

The water saving basins would operate between Gatun Lake levels of 26.670 and 23.927 m PLD and Atlantic Ocean levels of 0.564 and –0.381 m PLD. The locks would equalize between 13.618 and 12.099 m PLD. The water saving basins would equalize at the elevations shown in Figure E-5-2.

5.5. Hydraulic Freeboard Requirements

One meter of freeboard is recommended as appropriate for the water saving basins. This freeboard would be applied above the maximum operating elevations so that there would always be 1 m or more of freeboard in the basins. This freeboard would be used to set the minimum top of basin wall elevations for hydraulic design concerns.

5.6. Recommended Water Saving Basin Profile

The water saving basin wall elevations were selected based on maximum lake and ocean levels and the resultant equalizing elevations in the basins. The minimum freeboard will be used to set the minimum top of wall and gate elevations for hydraulic design concerns. This freeboard would be applied above the maximum operating elevation so that there will always be at least the minimum amount of freeboard. This eliminates the need to spill water (that volume of water spilled from the locks to prevent flooding over the walls) during high water periods when the locks and basins will equalize at a high level. The lake level used was 26.670 m PLD and the ocean level was 0.564 m PLD. The recommended water saving basin floor elevations were selected based on relatively low lake and ocean levels. This will ensure that the basins will save water during times when it is most needed and water availability is low. The lake level used was 25.168 m PLD and the ocean level was –0.229 m PLD. A summary of design elevations is presented in Table E-5-2. A schematic of the water saving basin profile is provided in Figure E-5-3.

Figure E-5-2 Equalization Elevation Durations for Water Saving Basins and Locks

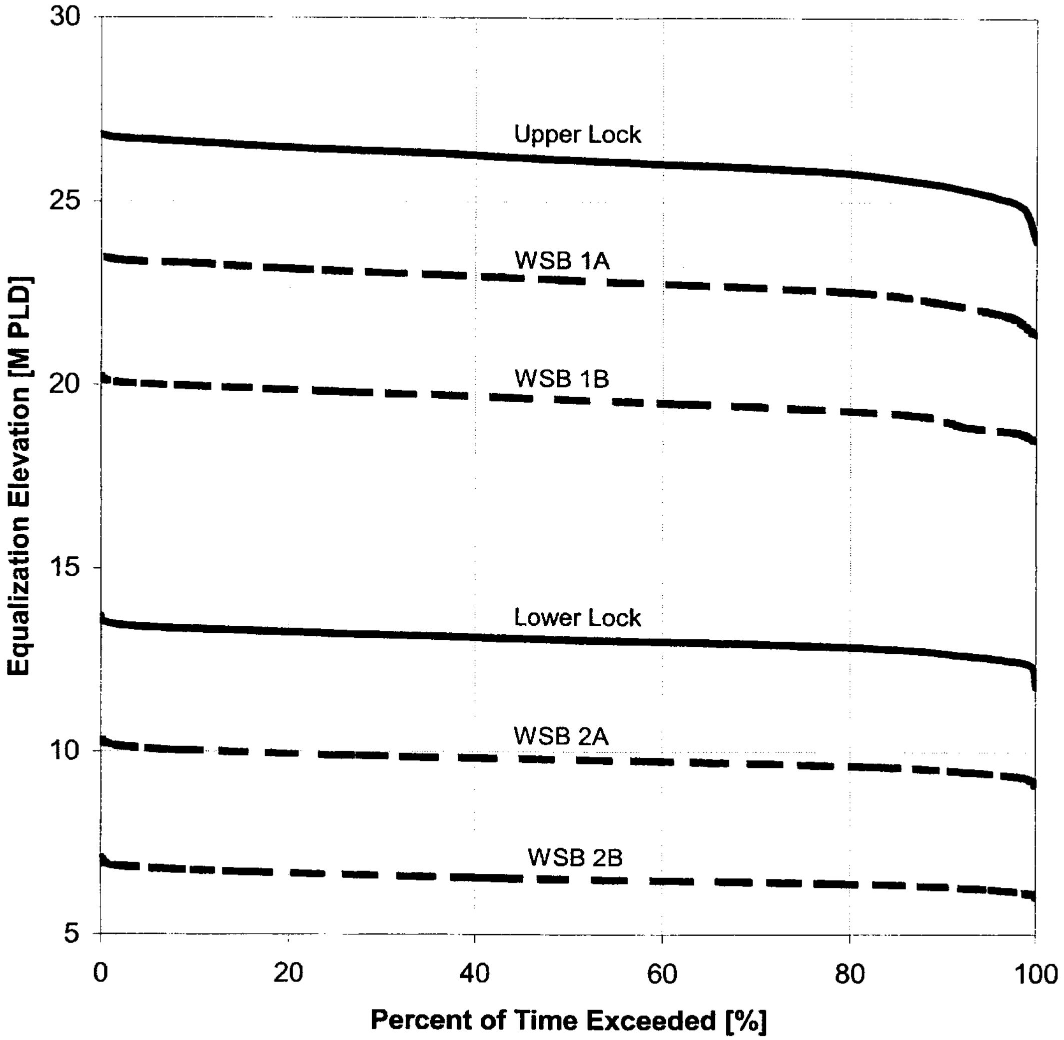


Table E-5-2 Recommended Basin Configuration

Basin 1A	Top of Wall [m PLD]	24.407
	Freeboard [m]	1
	Maximum Water Surface [m PLD]	23.407
	Floor Elevation [m PLD]	18.819
Basin 1B	Top of Wall [m PLD]	21.144
	Freeboard [m]	1
	Maximum Water Surface [m PLD]	20.144
	Floor Elevation [m PLD]	15.646
Basin 2A	Top of Wall [m PLD]	11.354
	Freeboard [m]	1
	Maximum Water Surface [m PLD]	10.354
	Floor Elevation [m PLD]	6.120
Basin 2B	Top of Wall [m PLD]	8.090
	Freeboard [m]	1
	Maximum Water Surface [m PLD]	7.090
	Floor Elevation [m PLD]	2.947

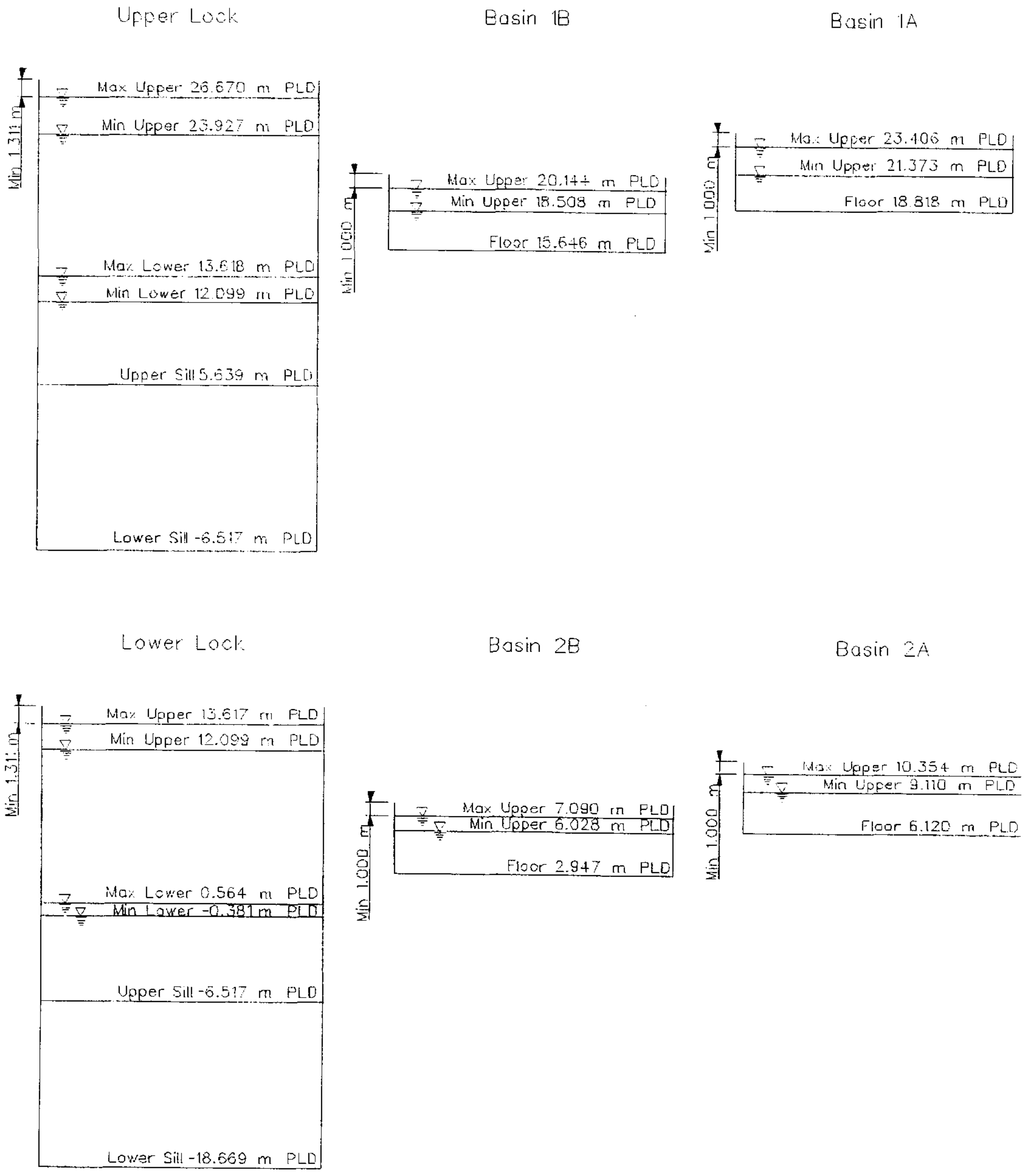
5.7. Water Consumption

The ACP typically fills Gatun Lake to the maximum operating elevation of 26.670 m PLD for 2-3 months of the year and anticipates a much more aggressive operational plan in the future. Review of the duration analysis shows that the representative elevation used for the high lake alternative (26.588 m PLD) is only 0.082 m below this elevation. The representative elevation used for the low lake alternative (25.168 m PLD) is approximately the same as the minimum normal operating elevation of 25.146 m PLD. Discounting the extremes on the duration curve for the highest lake and ocean levels had no impact on the water consumption analysis of the water saving basins because the maximum operating water surface in the basins was determined from the maximum lake and ocean levels. Discounting the extremes on the duration curve for the lowest lake and ocean levels had a negligible effect on the average water consumption computations. The difference in computed average water savings would be less than 0.5%. During an extreme low water condition, the difference in water savings between the recommended low floor alternative and the minimum floor would be approximately 4% (46% vs. 50%) for a 2-lift configuration.

The difference in floor elevations would be between 0.274 m (lower lock, lower basin) and 0.975 m (upper lock, upper basin).

The average amount of water required for a single downbound lockage with the recommended low floor configuration of water saving basins would be a 6.520 m water column. The total volume of water required can be computed by multiplying the water column by the surface area of the lock. This represents a 50% average savings of water compared to operations without water saving basins.

Figure E-5-3 Lock Profile Schematic With Water Saving Basins



6. DESIGN SHIPS

An important consideration in the design of the third lane is the type and size of the ships expected to utilize the locks. The two design ship types specified by ACP are the bulk carrier and container ship. Ships of the bulk carrier variety are typically designed to carry dry cargo (e.g. coal, iron ore, grain). Ships designed for liquid cargo (e.g. crude oil) are usually referred to as tankers, but they can be grouped with bulk carriers for purposes of selecting the design ship. Container ships are designed to carry cargo in standard carrying boxes. A standard measure of the cargo capacity for this type of ship is a container that is twenty feet long by 8.5 feet square. The unit of measure for this container is the twenty-foot equivalent unit (TEU).

The deadweight of a ship is typically defined as the carrying capacity of the ship. The capacity includes cargo, supplies, fuel, crew, etc. The displacement of a ship is defined as the total weight of a fully laden ship. The block coefficient of a ship is the ratio of the ship's underwater volume to the volume of a rectangular prism with dimensions approximately equal to the length, beam, and draft of the ship.

6.1. Panamax

The limiting dimensions in the existing locks for a Panamax vessel are a length of 294.1 m, a beam of 32.3 m, and a draft of 12.0 m. Panamax container vessels push the limits of all three dimensions and can have a cargo capacity of approximately 4,500 TEU. The deadweight for this type of vessel is approximately 44 000 t with a displacement of approximately 74 000 t. Typical bulk carriers of the Panamax variety can have a length of 225 m, a beam of 32.3 m, and a maximum draft of 12.0 m. The deadweight for this type of vessel is 59 000 t with a displacement of approximately 74 000 t.

6.2. Post-Panamax

6.2.1. Existing

Post-Panamax container vessels with a cargo capacity of 6600 TEU exist today with a length of 347.0 m, a beam of 42.8 m, and a draft of 14.5 m. The deadweight for this type of vessel is approximately 84 000 t with a displacement of 140 000 t. Large bulk carriers can have a length of 343.0 m, a beam of 63.0 m, and a draft of 23.0 m. This vessel would have a deadweight of approximately 365 000 t and a displacement of 422 000 t. The largest vessel in the world is currently an ultra large crude carrier with a length of 458.5 m, a beam of 68.9 m, and a draft of 24.6 m. The vessel has a deadweight of approximately 565 000 t and a displacement of 661 000 t.

6.2.2. Projected

The largest container vessel under consideration today is the "Malacca Max" with a capacity of 18 000 TEU. The vessel is projected to have a length of 400 m, a beam of 60 m, and a draft of 21 m. A vessel of this size would have a deadweight of approximately 197 000 t and a displacement of 328 000 t. The design would be in accordance with the limitations of the Malacca Straight and would permit only one route from Europe to the Far East via the Suez Canal with calls in Rotterdam and Singapore. Current trends in Post-Panamax container vessels seem to be leading towards a projection of 10 000-12 500 TEU capacity vessels being built within 10 years. These vessels would have a length of 350-400 m, a beam of 50-54 m, and a draft of 14-15 m. The largest of these vessels would have a deadweight of approximately 126 000 t with a displacement of 211 000 t. Definitive future trends in the size of bulk carriers could not be determined. The "Capesize" bulk carrier loaded to a draft of 15.2 m is consistent with the bulk carrier deadweight specified by the terms of reference. The ship would have a length of 290.0 m, a beam of 45.0 m, and an allowable draft of 15.2 m. It should be noted that this bulk carrier could be undersized based upon the size of other existing bulk carrier ships.

6.3. Design Ships

The terms of reference specify a container ship with a deadweight of 120 000 t and a bulk carrier ship with a deadweight of 110 000 – 140 000 t. The projected 12 000 TEU container ship and the "Capesize" bulk carrier both have deadweights within the specified range. Table E-6-1 presents a summary of the design ships to be used in the concept level design. Future studies should include a more detailed evaluation of trends in container and bulk carrier shipping. Refinements to the design ship sizes should be made based upon the findings of these additional studies.

Table E-6-1 Design Ships

Vessel Type	Length [m]	Beam [m]	Draft [m]	Block Coefficient	Deadweight [t]	Displacement [t]
Container	385.7	54.9	15.2	0.65	125 000	209 000
Bulk Carrier	290.0	45.0	15.2	0.85	135 000	169 000

7. LOCKSIM NUMERICAL MODEL

The LOCKSIM numerical model was developed at the Tennessee Valley Authority's (TVA) Engineering Laboratory. The current version of the program has the capability to perform a one-dimensional transient analysis of lock filling and emptying systems. The origin of the model is a computer code developed in the 1980s for analysis of water hammer in closed conduits. The first application of the program on a navigation lock was a 1989 investigation of transient conditions at TVA's Wheeler Main Lock. In the early 1990s, features were added to allow modeling of closed conduits and open channel components in a single network. This modification provided a means for estimating water surface slopes and associated hawser forces during lock equalization. The U.S. Army Corps of Engineers has been successfully using the model for lock analysis and design since approximately 1992.

As a design tool for lock filling and emptying systems, LOCKSIM can provide information on many of the key hydraulic design parameters. Some parameters, however, still require a physical hydraulic model of the filling and emptying system. A summary of the capabilities of both LOCKSIM and physical hydraulic models in terms of filling and emptying system design is provided in Table E-7-1.

The LOCKSIM model was used as the primary tool for analysis of design of the filling and emptying systems presented in this report. LOCKSIM is an appropriate model for screening analysis and preliminary design of lock filling and emptying systems. For final design, a physical hydraulic model is recommended.

Table E-7-1 Hydraulic Parameters for Lock Filling and Emptying Systems

Hydraulic Design Parameters	LOCKSIM	Physical Hydraulic Model
Lock Chamber		
Equalization Time	X	X
Surface Turbulence		X
Longitudinal Hawser Force	X	X
Transverse Hawser Force		X
Effects of ship in chamber		X
Culvert		
Pressure	X	X
Discharge	X	X
Air Pocket		X
Valves		
Cavitation Potential	X	X
Design Load		X
Air Vent Capacity	X	
Operating Schedule	X	X
Vibration Potential		X
Approaches		
Near Velocity	X	X
Far Current	X	
Vortex Formation		X
Hawser Force	X	X
Wave Height	X	X

8. HAWSER FORCES

Shear, drag, and hydrostatic forces all contribute to the hydrodynamic loads on a moored ship. During lock equalization, the hydrostatic component produces the greatest force as a result of water surface oscillations that occur within the lock chamber. These forces are commonly referred to as hawser forces. Longitudinal hawsers are produced primarily by water surface differentials between the bow and stern of a ship. Transverse hawser forces develop due to water surface differentials between the port and starboard sides of a ship and impingement or drag of submerged jets from the filling system.

8.1. Longitudinal Hawser Forces

The hydrostatic forces (F), which produce longitudinal hawsers, can be estimated as the product of the ship's displacement (D) and the longitudinal slope (S) of the water surface as shown by equation E-8-1.

$$F = D \cdot S \qquad \text{(E-8-1)}$$

Since the estimated hawser force is directly proportional to the water surface slope, evaluations of lock performance can be conducted based on a water surface slope criteria. This approach facilitates the proportioning of existing system forces for the larger design ships expected to transit the third lane locks. The maximum allowable longitudinal hawser force can be expressed as a fraction of a ship's displacement. This fraction is equivalent to an allowable water surface slope.

8.1.1. Existing Miraflores Locks

Data obtained in 1999 for the Miraflores Upper West Lock was analyzed for end-to-end slopes during filling operations. Of 21 measurements, the maximum measured slope was 1.25/1000 for a bulk carrier with a 9.91 m draft, 225 m length, a 32.3 m beam, and a 0.74 blockage factor. The blockage factor is defined as the ratio of the maximum cross sectional area of a ship to the total cross sectional area of the lock. The estimated displacement is 59,000 t with a driving hawser of 68 t. Actual stresses in the locomotive cables may be different from the computed hawser.

A LOCKSIM model of the Miraflores West Locks was prepared to develop an understanding of the present filling and emptying system, determine loss coefficients and assess water surface slopes. The model was calibrated to data extracted from the 1999 study. To assure the most accurate representation of the system, the west wall culvert was calibrated separately using filling and emptying data in which the center wall culvert was not utilized. Filling curves and plots of end to end slope comparing LOCKSIM predictions with the prototype data are shown in the Figures E-8-1 and E-8-2. Good agreement was obtained for the filling curve shown, as well as all other computed filling and emptying curves used in the calibration. This implies the system components are properly represented. Although LOCKSIM was able to reproduce the general oscillating slope pattern, it underpredicted the magnitude. This is most likely due to the blocking effect of the ship, which cannot be accounted for in the present published version of LOCKSIM. Additionally, there is interaction with the oscillation set up by ship movements prior to filling.

Although no prototype data is available, higher slopes would occur in the Lower West Lock due to the higher head. LOCKSIM predicts a maximum of 0.9/1000 for the high lake level of

16.76 m PLD in conjunction with the extreme (rare) low tide of –3.44 m. A more common and representative low tide of –1.52 m produces a slope of 0.7/1000.

8.1.2. Ship Effects

The Miraflores data suggests that the presence of a ship in the chamber with a high blockage factor causes the actual longitudinal slope to be about twice as high as LOCKSIM predicts for an unoccupied chamber. Empirical evidence from physical model tests conducted by the Corps Engineer Research and Development Center tends to confirm this supposition, as does a beta version of LOCKSIM that accounts for the ship effects. The LOCKSIM predicted slope in the unoccupied third lane locks should not be higher than the maximum value computed for Miraflores (0.7/1000). Since ship blockage factors will be lower with the new locks, limiting the LOCKSIM predicted slope to the maximum value associated with the existing locks should ensure that conditions will be no more severe, on a scaled-up basis, in the third lane locks. However, other criteria should also be considered, if more restrictive.

The prior oscillations set up by the ship moving into position and stopping are very evident in the Miraflores data. The waves generated by the filling system are superimposed on these pre-oscillations and they may tend to amplify or cancel each other, depending on valve timing. The oscillations induced by ship movements cannot be avoided but instrumentation could be included to monitor them. Delaying the initial valve opening by up to one-half minute would cause the waves to be out of phase and prevent longitudinal slopes from being amplified.

8.1.3. Corps of Engineers Criteria

The maximum allowable hawser force during lock equalizations is 4.5 t for a barge tow moored in the chamber. Larger maximum hawser forces are permitted for ships with limits of 9.1 t for ships up to a displacement of approximately 45 000 t. A higher limit of 22.7 t is permitted for ships up to a displacement of approximately 154 000 t.

8.1.4. International Criteria

The Permanent International Association of Navigation Conferences (PIANC, 1986) completed a survey of hawser criteria for the United States and Europe. In France and Germany, hawser forces are generally limited to 1.67/1000 of a vessel's displacement. The Netherlands and Belgium permit a maximum fraction of 1/1000. In addition, the Netherlands limit hawser forces to less than approximately 10 t for barge tows. Shallow draft barge tows are limited to 5 t in the United States and Austria. A force of 10 t is permitted in the United States for ships transiting the Saint Lawrence Seaway.

8.1.5. Recommended Allowable Longitudinal Hawser Forces

The recommended maximum allowable water surface slope for concept design of the third lane locks is 0.5/1000 for an unoccupied chamber as predicted by LOCKSIM, which should equate to about 1/1000 when a ship with a high blockage factor is in the chamber. This is less than the maximum water surface slope computed for Miraflores. In addition, the proposed allowable slope is consistent with the fractions prescribed by France, Germany and the Netherlands. Since the projected Post-Panamax ships are significantly larger than those transiting locks today, future studies should include physical hydraulic models of the lock filling and emptying system to obtain more accurate estimates of the expected hawser forces for design of ship positioning systems and other related appurtenant facilities.

8.2. Transverse Hawser Forces

The forces associated with transverse hawsers cannot be estimated from a one-dimensional numerical model such as LOCKSIM. Limited prototype data on transverse water surface slopes is available for the existing Miraflores Locks. The data is not useful for design of the third lane because the data cannot be accurately extrapolated. To address the potential for transverse hawsers, design of the third lane will be based upon designs of similar systems that have been evaluated with a physical hydraulic model and shown to have acceptable transverse hawsers. Future design studies should include a physical hydraulic model testing program to measure and evaluate transverse hawser forces.

Figure E-8-1 Equalization for Miraflores Upper West Lock

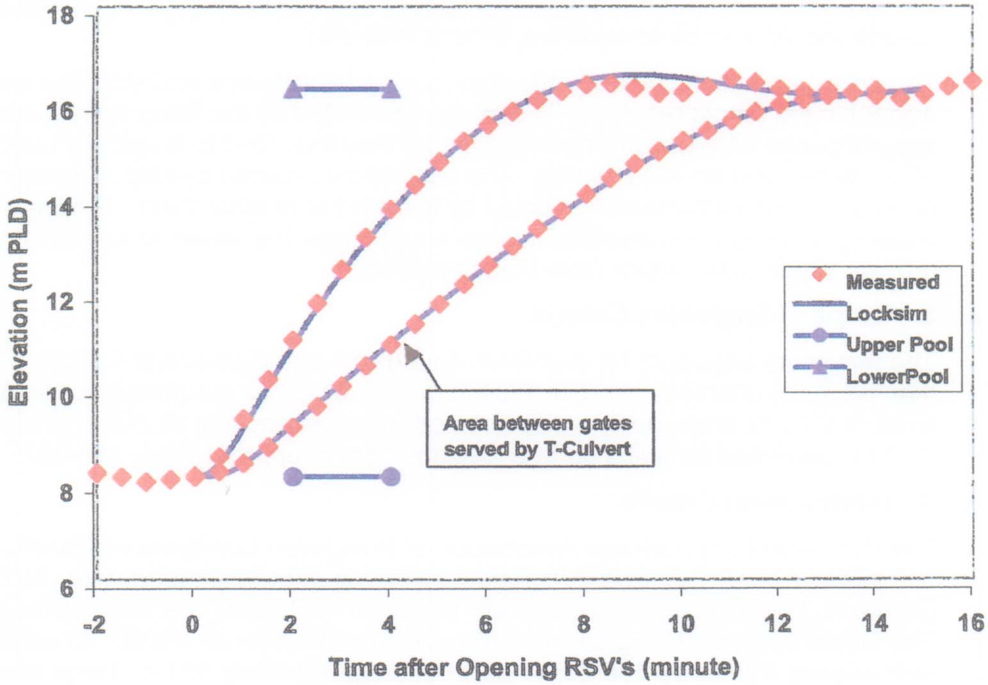
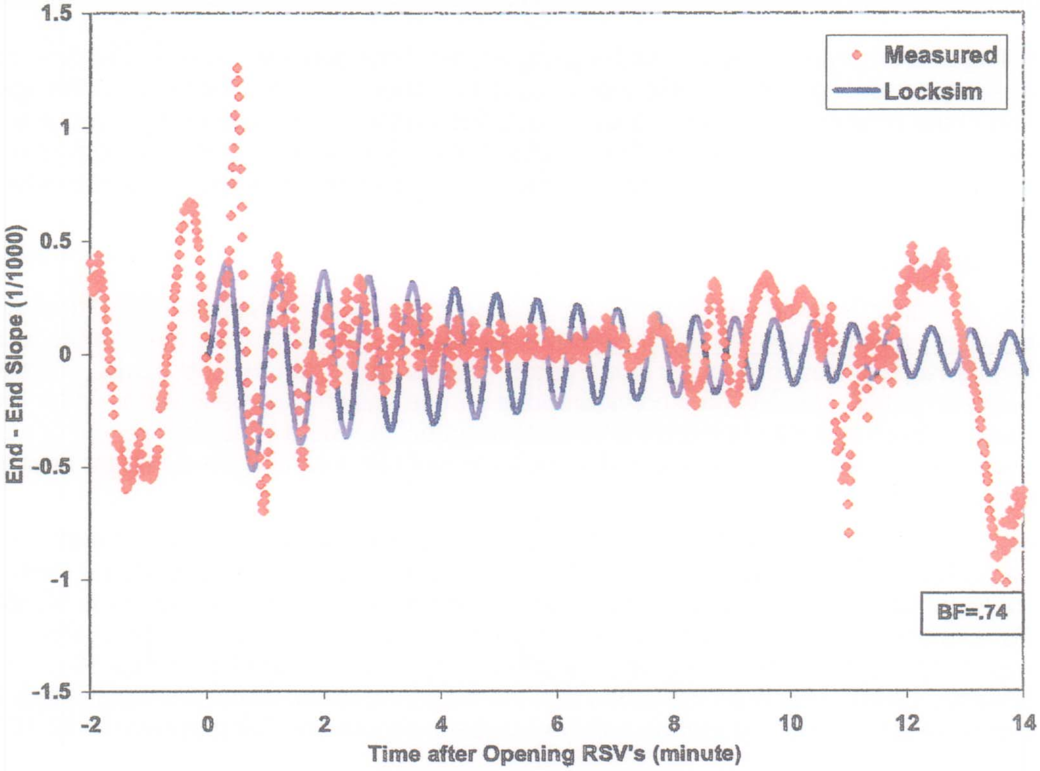


Figure E-8-2 End-End Slope for Miraflores Upper West Lock



9. OVERVIEW OF LOCK FILLING AND EMPTYING SYSTEMS

Filling and emptying systems can be grouped into three general classes. The first class is designated as end filling. In this type of system, water enters the lock only at the upstream end of the chamber. The second class includes systems that use longitudinal culverts in the lock walls or along the chamber floor to distribute flow more evenly into the lock chamber. The third class is a hybrid that incorporates elements of both the end filling and culvert systems.

9.1. End-Filling

The end-filling system design generally passes water into the lock chamber either through, between, under, or around the lock gates. Options for passing water through the lock gates include slide or butterfly valves in the gates. Sector gates can be designed to pass water between gates. Various gate configurations can be designed to pass water under the lock gates. These include submergible vertical lift gates, submergible tainter gates, or rising sector gates. Loop culverts located in the gate monoliths can be used to pass flow around the lock gates.

According to Corps guidance, end-filling systems can be designed to perform efficiently and safely for lifts that are less than 3 m. For lifts greater than 3 m, these systems cannot safely meet performance requirements for equalization time as specified in the terms of reference. For example, locks on the Albert Canal in Belgium using an end-filling type system have a reported filling time of 14 minutes for a 200 m long by 24 m wide lock with a 10 m lift (PIANC, 1986). This is an indication that the third lane locks, which are significantly larger and have a higher lift, cannot be safely equalized with an end-filling system in 12-15 minutes.

9.2. Side Port

The side port system consists of a culvert in each of the lock walls. Water enters the culvert through an upstream intake and exits through a downstream outlet manifold. Ports in the lock walls connect the culverts directly to the lock chamber. Valves in the culverts located upstream and downstream of the ports control flow. General design parameters include a total port area approximately equal to the culvert area, a staggered port arrangement to dissipate turbulence, and a submergence equal to one-half the port spacing.

The side port filling and emptying system is a proven design generally recommended by the Corps for lifts less than 9 m, however, designs for lifts in the 12 m range are feasible. Of the more than 350 locks in 10 countries documented by PIANC (1986), nearly 100 utilize a side port system. Of the more than 70 locks in 8 countries with a lift greater than 12 m, 11 utilize a side port system. At 19.2 m, the Cordell Hull Lock and Dam on the Cumberland River is one of only two side port systems documented as having a lift greater than 15 m.

Concerns with this type of system, particularly for large locks and relatively high lifts, include the surge buildup that typically occurs in the upstream portion of the chamber due to the sequential increase in flow through the ports from upstream to downstream. This surge can produce unacceptable water surface slopes in the lock chamber. In addition, variations in geometric or operational symmetry can result in dangerous transverse water surface slopes. Jets from the relatively large individual ports may not dissipate completely, causing turbulence at the surface that may endanger smaller vessels. During certain maintenance conditions the lock cannot be safely equalized in a reasonable time.

9.2.1. Multiport

The Tennessee Valley Authority (TVA) has developed multiport systems as a variation of the conventional side port system. The primary difference is a decrease in size and increase in number of ports for the multiport system. Studies by the Corps of Engineers indicate no significant advantage in cost or performance compared to a conventional side port system.

9.3. In-chamber Longitudinal Culvert

The In-chamber Longitudinal Culvert System (ILCS) consists of through the sill intake and outlet manifolds, operating valves in the sills, longitudinal culverts along the lock floor, and ports located on the sidewall or top of the longitudinal culverts. General design parameters include two longitudinal culverts centered at the transverse quarter points of the lock. Each culvert should have two groupings of ports in a staggered arrangement centered at the longitudinal third points of the lock. Port area should be approximately equal to the culvert area. The design can be modified if required to incorporate intakes, outlets, and valves in the lock walls.

The ILCS is a proven design generally recommended for lifts less than 12 m. Acceptable performance can be achieved for relatively low to medium lift locks. The summary of locks presented by PIANC (1986) does not clearly identify locks with an ILCS. The Davis and Sabin locks on the St Mary's River were constructed in the early 1900s with this type of system. Some examples of more recent projects utilizing the ILCS include: 1) McAlpine Locks and Dam on the Ohio River (under construction), 2) Marmet Locks and Dam on the Kanawha River (under construction), 3) Charleroi Locks and Dam (final design), and 4) Soo Lock on the St. Mary's River (preliminary design).

The system provides improved flow distribution into the lock chamber as compared to the side port system. The potential for upstream water surface surges still exists. Port deflectors can be added to the upstream group of ports to reduce the impact of these surges. Moderate increases in equalization time would be expected under certain maintenance conditions

9.4. Bottom Lateral

The bottom lateral type system has culverts in the lock walls with an upstream intake and downstream outlet manifold. Instead of connecting directly to the lock chamber, the culverts connect to transverse laterals that extend across the lock chamber. Ports are distributed along the lateral to minimize transverse water surface slopes. These laterals discharge into the lock through ports located either in the sidewall or top of each lateral. The total lateral and port area usually exceeds the culvert area with the actual ratios that have been used varying considerably. Valves located upstream and downstream of the laterals control flow.

The bottom lateral system is a proven design that would be similar to the existing locks. Many bottom lateral systems have a lift of 15 m or less, but lifts up to 30 m are feasible. Of the more than 40 locks in 6 countries with a lift greater than 15 m, 8 utilize a bottom lateral system (PIANC, 1986). Four of these locks, located on the Snake and Columbia Rivers, have a lift in the range of 30 m.

Bottom lateral systems provide better distribution of flow across the chamber during equalization compared with the side port and ILCS systems. As a result, satisfactory performance can be achieved for higher lifts. Surges in the upstream portion of the lock chamber can still be a concern with this type of system.

9.4.1. Interlaced Lateral

With an interlaced lateral system, the laterals within the lock chamber are connected to the culverts in an alternating pattern. A lateral from one lock culvert is followed downstream by a lateral from the other lock culvert. This alternating pattern continues along the length of the lock chamber. The system performs well under both normal and maintenance conditions. The interlaced arrangement significantly reduces water surface slopes associated with unsynchronized valve operations and maintenance conditions.

9.4.2. Split Lateral

Instead of an alternating arrangement, the laterals of a split lateral system are divided into two groups. One group, located in the upstream portion of the lock chamber, is connected to one of the lock culverts. The other group, located in the downstream portion of the lock chamber, is connected to the other lock culvert. The split lateral arrangement has been shown to produce a good flow distribution for relatively high lifts. The split grouping of the laterals reduces the upstream surges and resulting water surface slopes that can occur with other designs. A disadvantage of the system is the need for synchronized valve operations. Unsafe longitudinal water surface slopes can occur if the valve timing is not properly synchronized and maintained. Significant increases in equalization times would be required to operate safely under certain maintenance conditions.

9.5. Bottom Longitudinal

The bottom longitudinal system has culverts in the lock walls with an upstream intake and downstream outlet manifold. Connection to the lock chamber occurs near the midpoint of the lock where the culvert turns into a cross culvert. Longitudinal culverts then extend both upstream and downstream from the cross culvert. The longitudinal culverts are arranged in four branches to form an "H" pattern in the floor of the lock chamber. Flow enters the lock through ports located along the longitudinal culverts, with total port area approximately equal to culvert area.

The bottom longitudinal system is a proven design suitable for high lift locks. Of the 10 locks in 2 countries with a lift greater than 25 m, 5 utilize a dynamically balanced system similar to the bottom longitudinal system (PIANC, 1986). All of the locks with lifts greater than 25 m that have been built since 1970 utilize a dynamically balanced system. The Carrapatelo Lock in Portugal tops the list with a lift of 35 m.

Good performance can be achieved with this system for high lift locks. Compared to other systems, the bottom longitudinal system provides the best combination of rapid equalization times and safe operations. Upstream surges do not present a concern since flow in the longitudinal culverts proceeds both upstream and downstream from the cross culvert. The system performs well under both normal and maintenance conditions. A disadvantage of the system is the additional cost that can be attributed to deeper excavation requirements near the center of the lock.

9.6. Water Saving Basin Considerations

Of the systems presented, the end-filling type system is the only one that is incompatible with water saving basins. To achieve safe equalizations within specified time targets, a supplemental culvert system would be required to distribute flow from the basins into the lock chamber.

The water saving basins would be compatible with all of the culvert based systems. Connections between the water saving basins and lock would consist of several conduits with valves designed for two-way flow control. With basins on both sides of the lock, conduits would connect directly to the adjacent lock culvert. Crossover conduits would be required if the basins are located on one side of the lock, and would not balance flow between the culverts as well as a system with basins on both sides.

The head differential driving filling and emptying when using the water saving basins is one-half of that which exists without basins. Since discharge is proportional to the square root of the head, the discharge will be lower, and filling or emptying times increased significantly assuming other factors are the same. The additional valve movements associated with controlling flow from the basins increases the percentage of the time when the valves are not fully open, which also reduces average discharge and increases filling and emptying times. To help compensate for these factors, while attempting to provide filling and emptying times with the basins operating that are close to those achievable without the basins, the controlling flow area should be greater when using the basins. The controlling flow area can generally be considered to be the minimum flow area encountered along the filling or emptying route. In this regard, filling and emptying systems that allow a greater flow area for the distribution system between the main culvert control valves have an advantage over systems that require area ratios close to 1.0. This is because the water saving basin connections can by-pass the culvert valves and transfer controlling flow area to another component with a larger area. Systems with an area ratio close to 1.0 may require the culvert area downstream of the valves to be increased. If increasing the culvert area is not compatible with the system, an auxiliary distribution system within the chamber for some of the water saving basin connections may need to be considered. Therefore, any system with other good characteristics and which can also accommodate an increased culvert area or auxiliary distribution system is also worthy of consideration.

10. SCREENING ANALYSIS OF LOCK FILLING AND EMPTYING SYSTEMS

10.1. End-Filling

Without water saving basins, the maximum head differential for lock to lock equalization (27 m) greatly exceeds the maximum design lift recommended by Corps guidance (3 m). With water saving basins, the maximum initial head differential is reduced to 6.8 m, which still exceeds accepted limits. This type of system is not recommended for further study because the design lift is significantly greater than the recommended maximum. The system would not be able to safely meet equalization time criteria for a double-lift configuration of the third lane.

10.2. Side Port

10.2.1. Design Considerations

Without water saving basins, the maximum head differential for lock to lock equalization (27 m) exceeds the maximum design lift recommended by Corps guidance (9 m). Assuming equalizations with water saving basins represent the primary mode of operation, the maximum initial lift is reduced to 6.8 m, which is within acceptable limits. The maximum head differential for lock to lock operations would be reduced to 13.5 m, which is closer to the feasible range (12 m). The additional submergence that exists because the lock is already half filled would reduce the concern associated with lock to lock operations. Some of the reservations with using side port systems for higher lifts stem from concerns over the effect of turbulence on tied-together barge trains and smaller vessels. These concerns may be less relevant if the traffic consists only of very large ships. An additional concern is the potential for unsafe hawser forces that might occur due to a lack of synchronization or malfunction of the valves. Operating without water saving basins where the maximum head is experienced is considered an unusual condition. Even under this scenario, the equalization time target of 12-15 minutes could probably be safely met for large ships. Significant increases in equalization time would be required under certain maintenance conditions. Generally, the increases would be due to both a reduction in flow capacity and poor hydraulic performance resulting from a loss of symmetry.

Hydraulic performance would be acceptable under normal operating conditions in the range of the recommended lift. Safe and efficient equalizations would be achieved, but hawser forces would be somewhat higher than the other systems under consideration. Surface turbulence during equalizations would also be more significant with this system. The side port system would require a lower lock floor to provide additional submergence and minimize the effects of turbulence. The system would provide acceptable performance with or without use of water saving basins, but would require longer valve times for operations without water saving basins due to the higher head. With water saving basins on one side of the lock, there are some concerns regarding distribution of flow from the basins to each lock culvert. It is likely that a reasonably balanced distribution could be achieved through physical modeling.

10.2.2. Preliminary Design

Designs for this system are primarily based upon guidance contained in EM 1110-2-1604, Hydraulic Design of Navigation Locks. Additional design information was obtained from model tests completed in 1961 for the side port systems of the Snell and

Eisenhower ship locks. An upstream intake and downstream outlet manifold would connect to 8 m wide by 7 m high culverts located in each lock wall. Ports would be located along the bottom of the culverts. The ports would form a vertical shaft before turning 90 degrees to connect directly with the lock chamber. The ports would enter the chamber near the midpoint of the submergence zone beneath the design ship, similar to the Snell and Eisenhower configurations. This port design allows the culvert to be raised, which should facilitate a more narrow wall base and reduce the volume of concrete. Another advantage created by the longer port length would be a reduction in the downstream component of flow exiting the port. Each culvert would have 26 ports for a total of 52 ports per lock. Ports from one culvert would be staggered with respect to ports from the other culvert to reduce and dissipate turbulence. The ports would extend along 85% of the chamber length, which is somewhat more than the 50%-60% referenced in the Corps guidance. The additional coverage is required to meet equalization time criteria while maintaining the recommended port size and spacing. The ports would have an area of 2.85 m^2 each and would be spaced at 16 m on center. Two laterals, one from each culvert, would be used to serve the areas between miter gates. Each lateral would have an area of 8 m^2. Ports would be distributed along the lateral with a total port area of 7.0 m^2 per lateral. A submergence equal to one-half the port spacing (8 m) would be provided beneath the design ship in accordance with Corps design guidance. The submergence would be less than the Snell and Eisenhower ship locks provide on a scaled up basis (11-14 m); however, it should be sufficient for dissipation of turbulence because of the reduced effective lift and a lower discharge per unit volume under the design ship. Redundant valves in parallel would be provided by bifurcating the lock culvert into two 4 m wide by 7 m high valves.

There would be four conduits connecting each water saving basin to its corresponding lock chamber. Each conduit would be 6 m wide by 7 m high with a valve of the same dimensions. Two conduits from each basin would connect to the lock culvert on the basin side of the lock. The other two conduits would pass under the lock chamber through a crossover conduit and connect to the lock culvert opposite the basins. An alternate design would have water saving basins on both sides of the lock. Flow distribution from the basins to the lock would be improved and the crossover conduits could be eliminated.

The port to culvert area ratio (1.32) is higher than that typically recommended for a side port system. However, operating without water saving basins will be an unusual occurrence. Since the primary operating mode is with water saving basins, design emphasis was instead placed on the port to conduit area ratio. Note that the water saving basin operations occur first, and, at the start of a filling operation, the submergence beneath a ship would be a minimum. The adopted port to conduit ratio (0.88) should produce port control and good distribution for this critical part of the filling operation.

Plates E-1and E-2 show plan and profile of the upper and lower lock, respectively, for the side port filling and emptying system layout with water saving basins on one side. Cross sections are shown on Plate E-3. Refer to Plates E-4 to E-6 for the configuration with water saving basins on both sides.

10.2.3. Analysis

The system would be able to safely meet target equalization and water surface slope criteria for the revised operating assumptions. Of the alternatives under consideration, the side port system would have the highest hawser forces and more turbulence during equalizations. Overall, the system would provide acceptable hydraulic performance under normal conditions. Poor performance under certain maintenance conditions would result in longer equalization times.

A summary of preliminary equalization times and estimated water surface slopes is presented in Table E-10-1. The maximum slopes with water saving basins barely meet the 0.5/1000 criterion; however, they have been conservatively calculated. To determine the maximum slopes, valve openings were delayed by a fraction of a minute such that the new waves they generate would be in phase with those already set up by the previous valve operation. This caused the waves to be amplified instead of cancelled. The tabulated equalization times reflect the minimum times achieved by opening the next valves immediately upon closure of the previous ones. The tabulated equalization times without water savings basin should be considered optimistic and may need to be increased to produce conditions in the chamber that would be acceptable for all vessels using the locks.

Table E-10-1 Side Port System - Equalization Times and End-End Slopes

Equalization	Without WSBs		With WSBs			
			WSBs on One Side		WSBs on Both Sides	
	Time (min)	End-End Slope (1/1000)	Time (min)	End-End Slope (1/1000)	Time (min)	End-End Slope (1/1000)
Lake Gatun to Upper Lock	12.7	0.36	15.3	0.51	15.4	0.53
Upper Lock to Lower Lock	10.3	0.27	13.8	0.41	13.7	0.46
Lower Lock to Atlantic Ocean	12.2	0.22	15.1	0.34	15.2	0.33

10.2.4. Summary

A side port system would be acceptable for the double-lift configuration of the third lane if water saving basins would be used most of the time. Significant increases in equalization time can be expected under certain maintenance conditions. The standard submergence (8 m) equal to one-half the port spacing between the bottom of the design ship and chamber floor appears to be just adequate. The actual requirement could be slightly more or less than 8 m but can only be determined by physical modeling.

10.3. Multi Port

The multi port system is a variation of the side port design. Generally speaking, the number of ports is increased while the size of each port is decreased. Since there is no clear advantage in performance or cost compared to a side port system, the multi port type of system will not be evaluated in detail.

10.4. In Chamber Longitudinal Culvert (ILCS)

10.4.1. Design Considerations

Without water saving basins, the maximum head differential for lock to lock equalization (27 m) exceeds the maximum design lift suggested by Corps research (12 m). Assuming equalizations with water saving basins represent the primary mode of operation, the maximum initial lift is reduced to 6.8 m, which is within acceptable limits. The maximum head differential for lock to lock operations would be reduced to 13.5 m, which is closer to the suggested range. The additional submergence that exists because the lock is already half filled would reduce the concern associated with the head differential for lock to lock operations. Although operations without water saving basins would be considered unusual, the target of 12-15 minutes for safe equalizations could probably be met with the higher head. Moderate increases in equalization times would be required under certain maintenance conditions. Generally, the increases would be due to both a reduction in flow capacity and slightly degraded hydraulic performance resulting from a loss of symmetry.

Performance would by hydraulically acceptable under normal operating conditions in the range of the suggested lift. Safe and efficient equalizations would be achieved, but hawser forces would be somewhat higher than the bottom lateral and bottom longitudinal type systems. Hawser forces would be slightly lower than the sideport system. The system would not perform well under certain maintenance conditions and would require increases in equalization time for safe operation. Water saving basins on both sides of the lock is hydraulically preferable because the symmetry would balance the flow between culverts; however, there is nothing to preclude the basins from being on one side.

10.4.2. Preliminary Design

Designs for this system are primarily based upon research conducted by the Coastal and Hydraulics Laboratory of the Corps Engineer Research and Development Center. Additional data was gathered from previous hydraulic model studies. An upstream intake and downstream outlet manifold would connect to 8 m wide by 7 m high culverts. Within the lock chamber the culverts run longitudinally along the lock floor. At the intake, outlet, and valves, the lock culverts turn into the lock walls in a wrap-around arrangement. The elevation of the top of the culverts would be set equal to the sill elevation to provide the required clearance. The lock floor adjacent to the culverts would be slightly lower to allow sufficient space for the ports. The centerline of the longitudinal culverts would be located at the transverse quarter points of the chamber. Ports would be located on both sides of the longitudinal culverts just below the culvert roof. Two groupings of ports would be centered at the longitudinal one-third points of the chamber. Each culvert would have 32 pairs of ports spaced in a staggered arrangement at 5.5 m on center for a total of 128 ports per lock. Each port has an area of 1.20 m^2. The distance between the upstream and downstream most port is approximately 50% of the pintle to pintle distance in accordance with research findings. Additional features related to the ports would include a culvert roof overhang to redirect the jet and a wall baffle to diffuse the jet. Two laterals, one from each culvert, would be used to serve the areas between miter gates. Each lateral has an area of 8 m^2. Ports are distributed along the lateral with a total port area of 7.0 m^2 per lateral. Redundant valves in parallel would be provided by bifurcation of the lock culvert into two 4 m wide by 7 m high valves.

Each water saving basin would have two 6 m wide by 7 m high conduits connecting to the adjacent lock culvert. In the initial screening study, water saving basins were located on both sides of the lock. The conduits would tee into the side of the culvert just upstream and downstream of the ports. Conduit valves would be low, i.e., at the level of the culverts. In the configuration with water saving basins on only one side, the conduits and valves would be at a higher level. Companion conduits from the two basins would combine, then dive below the culvert. The combined conduits would tee into to the culvert bottoms between the ports.

The port to culvert area ratio (1.50) for the design is high by the usual standards because emphasis was placed on the port to conduit ratio instead. The port to conduit ratio (1.00) is kept low to provide better distribution of flow among the ports when the water saving basins are operating.

Plates E-7and E-8 show plan and profile of the upper and lower lock, respectively, for the ILCS filling and emptying system layout with water saving basins on one side. Cross sections are shown on Plate E-9. Refer to Plates E-10 to E-12 for the configuration with water saving basins on both sides.

10.4.3. Analysis

The system would be able to safely meet target equalization and water surface slope criteria for the revised operating assumptions. Hydraulic performance is expected to be slightly better than a side port system. Hawser forces are expected to be slightly higher than the interlaced bottom lateral and bottom longitudinal systems. The tabulated slopes just meet the 0.5/1000 criterion and, for operations with water saving basins, represent maximums with delayed valve openings. Overall, the system would provide acceptable hydraulic performance with or without use of water saving basins under normal conditions. Performance under maintenance conditions would be better than a side port system but not as good as a bottom lateral or bottom longitudinal system. A summary of preliminary equalization times and estimated water surface slopes is presented in Table E-10-2. The tabulated times without water saving basins may be optimistic.

Table E-10-2 ILCS System - Equalization Times and End-End Slopes

Equalization	Without WSBs		With WSBs			
			WSBs on One Side		WSBs on Both Sides	
	Time (min)	End-End Slope (1/1000)	Time (min)	End-End Slope (1/1000)	Time (min)	End-End Slope (1/1000)
Lake Gatun to Upper Lock	11.5	0.32	14.5	0.52	13.8	0.47
Upper Lock to Lower Lock	9.1	0.25	13.7	0.50	13.1	0.28
Lower Lock to Atlantic Ocean	11.8	0.21	15.3	0.32	14.6	0.34

10.4.4. Summary

An ILCS system would be acceptable for the double-lift configuration of the third lane if water saving basins would be used most of the time. Increases in equalization time would be expected under certain maintenance conditions.

10.5. Interlaced Bottom Lateral

Without water saving basins, the maximum head differential for lock to lock equalization (27 m) exceeds the typical design lift for this type of system but is within the feasible range. For equalizations with water saving basins, the maximum initial lift is reduced to 6.8 m, which is well below acceptable limits. The maximum head differential for lock to lock operations would be reduced to 13.5 m, which is within acceptable limits. Equalizations with or without use of water saving basins would be safely achieved within the 12-15 minute time criteria. Moderate increases in equalization times would be expected under certain maintenance conditions. Generally, the increases would be due to a reduction in flow capacity. Degradation of hydraulic performance due to a loss of symmetry would be minimal. The interlaced lateral arrangement would improve performance under maintenance conditions compared to the split lateral arrangement.

Performance would by hydraulically acceptable under all normal operating conditions. Safe and efficient equalizations would be achieved, but hawser forces would be higher than the bottom longitudinal system. Hawser forces would be lower than the side port and ILCS type systems. The system would perform well under most maintenance conditions and would require only moderate increases in equalization time for safe operation. The system would provide acceptable performance with or without use of water saving basins. Water saving basins could be located either to one side or both sides of the lock. The screening analysis assumed water saving basins on one side.

10.5.1. Preliminary Design

Designs for the interlaced bottom lateral system were primarily based upon the existing locks and the third lane lock model tests completed in 1942. An upstream intake and downstream outlet manifold would connect to 6 m wide by 8 m high culverts located in each lock wall. Within the lock chamber the culverts would connect to transverse lateral culverts that extend across the lock chamber. There would be twelve laterals per culvert arranged in an alternating pattern for a total of twenty-four per lock. Two laterals, one from each culvert, would be used to serve the areas between miter gates. Each lateral has an area of 8 m^2. Ports would be distributed along the lateral to minimize transverse water surface differentials. The total port area would be 8.16 m^2 per lateral. Valves located upstream and downstream of the laterals would control flow. The valves would be 6 m wide by 8 m high. However, it is feasible to bifurcate the valves to 4 m by 6 m to reduce the size of each valve, which would reduce power and mechanical requirements. Bifurcating would have little effect on performance and would require a slightly wider valve monolith.

There would be four conduits connecting each water saving basin to its corresponding lock chamber. Each conduit would be 6 m wide by 8 m high with a valve of the same dimensions. Two conduits from each basin would connect to the lock culvert on the basin side of the lock. The other two conduits would pass under the lock chamber through a crossover conduit and connect to the lock culvert opposite the basins.

The lateral to culvert area ratio (2.0) for the design is higher than the existing system (1.8) but should be acceptable. The total port to culvert area ratio of (2.04) is less than the existing system and within acceptable limits. The port to conduit ratio of 1.0 would provide efficient operation with use of the water saving basins.

Plates E-13 and E-14 show plan and profile of the upper and lower lock, respectively, for the interlaced bottom lateral filling and emptying system layout with water saving basins on one side. Cross sections are shown on Plate E-15.

10.5.2. Analysis

The system would be able to safely meet target equalization and water surface slope criteria with or without use of the water saving basins. Hydraulic performance is expected to be better than the side port or ILCS systems. Hawser forces are expected to be slightly higher than the bottom longitudinal system. Overall, the system would provide good hydraulic performance with or without use of water saving basins under normal and maintenance conditions. A summary of preliminary equalization times and estimated water surface slopes is presented in Table E-10-3.

Table E-10-3 Interlaced Bottom Lateral System – Equalization Times and End-End Slopes

Equalization	Without WSBs		With WSBs on One Side	
	Time (min)	End-End Slope (1/1000)	Time (min)	End-End Slope (1/1000)
Lake Gatun to Upper Lock	12.6	0.35	14.9	0.42
Upper Lock to Lower Lock	10.8	0.25	13.8	0.32
Lower Lock to Atlantic Ocean	12.9	0.20	15.5	0.36

10.5.3. Summary

The interlaced bottom lateral system would be acceptable for the double-lift configuration of the third lane. Performance would be good under both normal and maintenance conditions.

10.6. Split Bottom Lateral

The split lateral system is a variation of the interlaced bottom lateral system. The laterals in a split lateral system are divided into two groups. The first group would be located in the upstream portion of the lock and connect to one of the lock culverts. The other group would be located in the downstream portion of the lock and connect to the other lock culvert. There are no significant differences in cost between the two types of lateral systems. Performance under normal operating conditions is slightly better with the split arrangement; however, performance under maintenance conditions is significantly improved with an interlaced arrangement. Because the cost would be similar and the maintenance performance is poor compared to an interlaced lateral system, the split lateral system will not be evaluated in detail.

10.7. Bottom Longitudinal

Without water saving basins, the maximum head differential for lock to lock equalization (27 m) is within acceptable limits for this type of system. For equalizations with water saving basins, the maximum initial lift is reduced to 6.8 m, which is well below acceptable limits. The maximum head differential for lock to lock operations would be reduced to 13.5 m, which is well below acceptable limits. Equalizations with or without use of water saving basins would be safely achieved within the 12-15 minute time criteria. Moderate increases in equalization times would be expected under certain maintenance conditions. The increases would be due solely to a reduction in flow capacity. Maintenance conditions generally have no impact on hydraulic performance of this system.

Performance would by very good hydraulically under all operating conditions. Safe and efficient equalizations would be achieved and hawser forces would be lower than the other systems. The system would perform well under maintenance conditions. The system would provide very good performance with or without use of water saving basins. Water saving basins could be located either to one side or both sides of the lock, although the screening analysis assumed basins to one side.

10.7.1. Preliminary Design

Designs for the bottom longitudinal system were primarily based upon designs for the Bonneville Lock, documented in WES TR HL-96-13 (1996). An upstream intake and downstream outlet manifold would connect to 7 m wide by 8 m high culverts located in each lock wall. Near the midpoint of the chamber, the lock culverts are split vertically and horizontally before transitioning into four longitudinal floor culverts. Each floor culvert is 8 m wide by 4 m high. The four floor culverts would be arranged in a single-H pattern along the lock chamber floor. Fourteen ports would be distributed along each side of each floor culvert. The ports would be 0.65 m wide by 1.75 m high for a total port area of 31.85 m^2 per floor culvert. Two laterals, one from each culvert, would be used to serve the areas between miter gates. Each lateral has an area of 8 m^2. Ports would be distributed along the lateral to minimize transverse water surface differentials. The total port area would be 8.16 m^2 per lateral. Valves located at the upstream and downstream ends of the lock wall culverts would control flow. However, it is feasible to bifurcate the valves to 4 m by 7 m to reduce the size of each valve, which would reduce power and mechanical requirements. Bifurcating would have little effect on performance and would require a slightly wider valve monolith.

There would be four conduits connecting each water saving basin to its corresponding lock chamber. Each conduit would be 7 m wide by 8 m high with a valve of the same dimensions. Two conduits from each basin would connect to the lock culvert on the basin side of the lock. The other two conduits would pass under the lock chamber through a crossover conduit and connect to the lock culvert opposite the basins.

The total port to culvert area ratio for the floor culverts (1.0) is within acceptable limits. The ratio of port to culvert area for the lateral (1.02) is also within acceptable limits.

Plates E-16 and E-17 show plan and profile of the upper and lower lock, respectively, for the bottom longitudinal filling and emptying system layout with water saving basins on one side. Cross sections are shown on Plate E-18.

10.7.2. Analysis

The bottom longitudinal system would be able to safely meet target equalization and water surface slope criteria with or without use of the water saving basins. Hydraulic performance is expected to be the best of the systems considered. Hawser forces would be lower than the other systems. Overall, the system would provide good hydraulic performance with or without use of water saving basins under normal and maintenance conditions. A summary of preliminary equalization times and estimated water surface slopes is presented in Table E-10-4. The slopes would be lower if the inner downstream miter gates were closed during the equalization.

Table E-10-4 Bottom Longitudinal System – Equalization Times and End-End Slopes

Equalization	Without WSBs		With WSBs on One Side	
	Time (min)	End-End Slope (1/1000)	Time (min)	End-End Slope (1/1000)
Lake Gatun to Upper Lock	11.9	0.04	13.8	0.25
Upper Lock to Lower Lock	12.4	0.06	13.8	0.23
Lower Lock to Atlantic Ocean	10.8	0.08	15.6	0.17

10.7.3. Summary

The bottom longitudinal system would provide superior performance for the double-lift configuration of the third lane under both normal and maintenance conditions. This alternative should be given consideration even though the initial cost may be higher than other systems.

10.8. Selected Filling and Emptying Systems

With respect to overall hydraulic performance, the bottom longitudinal and interlaced bottom lateral systems with water saving basins on both sides of the lock would be the best alternatives for the double-lift configuration of the third lane locks. Both systems are proven designs that would perform well for the entire range of possible lifts and operating conditions. These two systems would perform well with or without use of the water saving basins under both normal and maintenance conditions. Both systems would be compatible with basins on one side of the lock without a significant impact on hydraulic performance

Based on an evaluation of the overall project, ACP selected the ILCS and interlaced bottom lateral systems with water saving basins on one side of the lock for more detailed development in the concept design. The ILCS would provide good performance for normal operations with water saving basins. Acceptable performance would be achieved for operations without water saving basins or under certain maintenance conditions; however, hydraulic performance could be degraded due to the higher head or loss of symmetry associated with these operations. The interlaced bottom lateral system would perform well with or without use of the water saving basins under both normal and maintenance conditions. Both systems are compatible with water saving basins located on one side of the lock. In consideration of operational advantages, the selected plans would have basins on one side of the lock.

11. FILLING AND EMPTYING SYSTEM DESIGN PARAMETERS

Unless otherwise noted, the interlaced bottom lateral design presented in Section 10.5 was used to evaluate design parameters common to both of the selected filling and emptying systems. In general, these parameters would not be significantly affected by differences between the systems.

11.1. Valve Time

Several factors influence the operation of the valves during lock equalizations. Relatively rapid valve operations can reduce equalization times, but can increase maximum hawser forces beyond acceptable limits. Mechanical equipment requirements also influence the recommended valve times.

11.1.1. Hydraulic Considerations

Various valve times were evaluated using LOCKSIM for equalization at the average lift without water saving basins. Performance of the filling and emptying system was measured in terms of equalization time and maximum water surface slope. A summary of the results is presented in Figures E-11-1 and E-11-2.

For equalizations with water saving basins, a minimum practical valve time of one minute was assumed for the water saving basin valves. The assumed operating time for the lock valves was generally reduced by 50% to compensate for the reduced initial head and additional valve operations that occurs with use of the water saving basins. In some cases the reduction could be less than 50% if required to maintain maximum water surface slopes below 0.5/1000.

11.1.2. Mechanical and Electrical Considerations

In some cases, mechanical and electrical constraints limit the practical speed at which large valves may be lifted. Consideration was given to these constraints in selection of the valve times. The mechanical and electrical evaluation was done for 6 m by 8 m valves, which would be the largest valve size being considered for either of the selected systems.

11.1.3. Recommended Valve Times

The recommended valve times for concept design of the double-lift configuration are presented in Table E-11-2. The limiting times are based on equalization times, water surface slopes, and electrical and mechanical constraints. Slopes resulting from these times generally meet the 0.5/1000 criteria. Unless otherwise noted, further analysis and design for the selected filling and emptying systems assumed the proposed valve schedule.

Figure E-11-1 Effect of Valve Time on Equalization Time

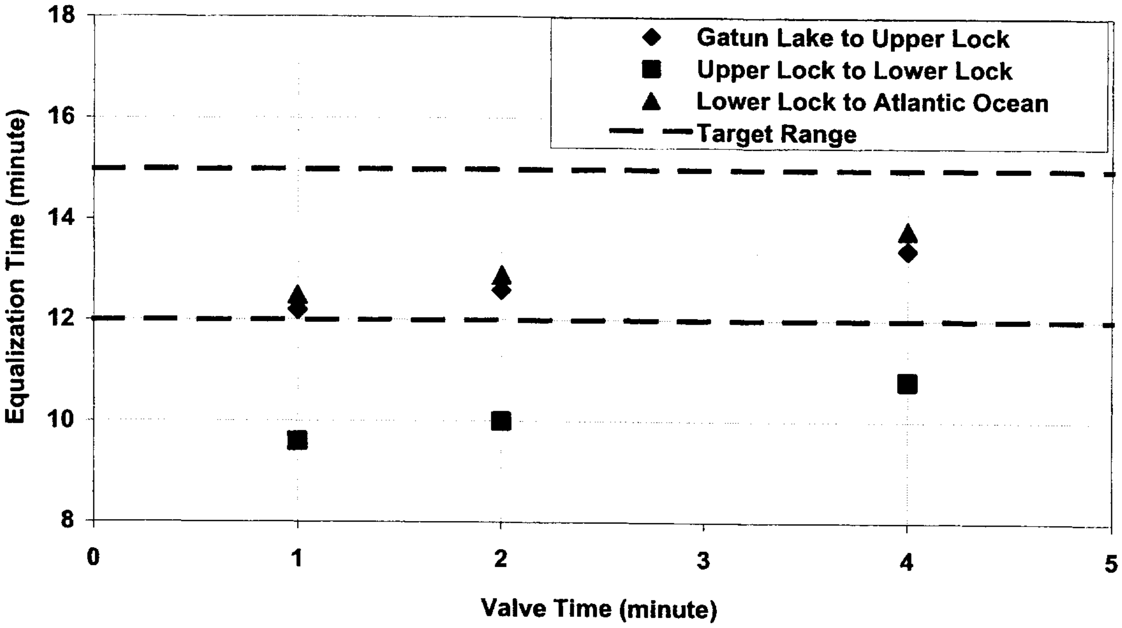


Figure E-11-2 Effect of Valve Time on End to End Slope

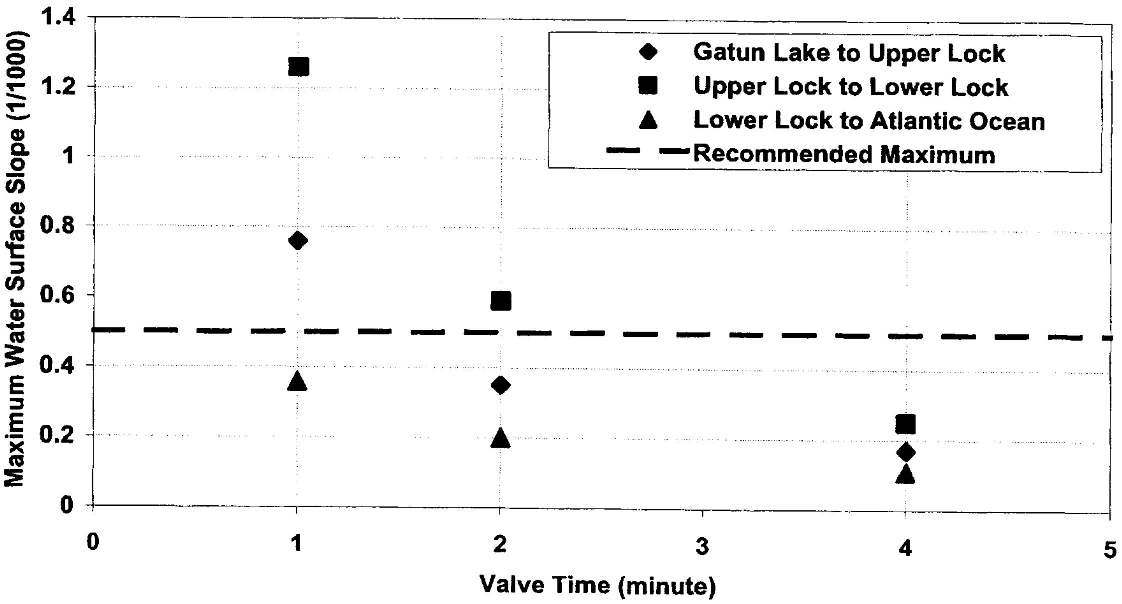


Table E-11-2 Recommended Valve Times

Valve Location	Operating Time [Minutes]	
	Without WSBs	With WSBs
Upper Lock Fill Valves	2	1
Valves Between Locks	4	2
Lower Lock Empty Valves	2	1
Water Saving Basin Valves	N/A	1

11.2. Valve Overlap

For operations with water saving basins, screening analyses have assumed a sequential series of valve openings. A more detailed analysis of the valve operations revealed potential time saving that could be achieved by overlapping the valve sequence. During initiation of a valve opening, time would be required to develop flow in the culverts. Time saving could be realized without adverse impact to performance by overlapping valve operations during development of this initial surge. LOCKSIM results indicate that the lock culvert valves can be overlapped with the water saving basin conduit valves by approximately ½ minute. A negligible amount of overlap could be achieved between water saving basin operations because the conduits would be relatively close to each other. An overlapping valve opening sequence is recommended for implementation as needed to reduce equalization times. The overlapping valve sequence would require precise operating equipment and controls to achieve maximum benefits.

11.3. Valve Loads

The hydrostatic head experienced by the lock culvert valves would be equal to the maximum lift for each lock. This would be the maximum head differential experienced by the valves under normal conditions. The direction of the load would be in the downstream direction.

The maximum hydrostatic head experienced by the water saving basin valves would vary between 50% and 75% of the maximum difference between upper and lower pool in each lock. A value of 75% is recommended to provide a consistent basis for design of the water saving basin valves.

Rapid closure of a valve during an equalization operation would produce a head differential that is greater than the hydrostatic head. The potential need for an emergency valve closure during the early stages of an equalization should be considered in the design of the valves. The LOCKSIM numerical model was used to perform an analysis of this operating scenario. The analyses consisted of opening the valves according to the valve schedule presented in Table E-11-2. Upon reaching a 25% opening, the valve was rapidly closed at a rate equivalent to a one-minute valve operation. Similar model runs were performed for valve openings of 50% and 75%. Maximum hydrodynamic head differentials across the valve were then recorded and compared to the maximum hydrostatic head. The ratio of hydrodynamic to hydrostatic head varied between 1.1 and 1.5 for the conditions modeled. A design ratio of 1.5 is recommended for design of the valves for a double-lift configuration with the interlaced bottom lateral system. The recommended ratio is consistent with Corps guidance (EM 1110-2-1610, 1975). For the lock culvert valves, this ratio would be applied to the maximum lift for each lock. For the water saving basin valves, this ratio would be applied to one-half of the maximum lift since this is the head experienced by these valves at the start of their operation.

A summary of recommended maximum design loads for the valves is presented in Table E-11-3.

Table E-11-3 Design Head Differentials Across Valves

Valve Location	Maximum Head Differentials Normal Operating Conditions [m]	
	Hydrodynamic	Hydrostatic
Upper lock fill valves	20.288	13.525
Valves between locks	40.576	27.051
Lower lock empty valves	20.288	13.525
Water saving basin valves	10.144	10.144

11.4. Lock Gate Head Differentials

During lock equalizations, head differentials produce loading conditions on various components within the system. An important consideration in the design is the head differential that could occur across the lock gates. These head differentials produce reverse loading conditions that should be considered in the design and performance of the gates.

11.4.1. Overtravel

The inertial head component of the flow that exists during the later stages of an equalization causes the water surface to overtravel beyond the target equalization level. Significant overtravel can occur if the gates are not opened immediately upon reaching equalization. This overtravel could produce a reverse load on the lock gates that should be considered in the design. LOCKSIM analyses indicated a typical overtravel of approximately 0.3-0.4 m. The maximum reverse head produced by this overtravel varied between 0.3 and 0.7 m. The larger reverse head would occur because equalization from the upper to lower lock produces an overtravel in each lock resulting in a reverse head that would be approximately double the overtravel.

11.4.2. Between Gates

As specified in the terms of reference, all hydraulic design and analysis assumed a nominal lock chamber length of 457.200 m. This assumption implies that both lock gates between Lake Gatun and the upper lock would remain closed during equalizations. Between the upper and lower locks, the upper gate would remain open during equalizations while the lower gate of this pair would be closed. A similar configuration would occur between the lower lock and the Atlantic Ocean with the upper gate open and the lower gate closed.

Under certain operating conditions, it is reasonable to consider that both gates between locks and both gates between the lower lock and Atlantic Ocean might be closed during an equalization. For this condition, the area between gates would equalize at a different rate because it would be separated from the lock chamber. The resulting head differentials could produce a reverse load on the lock gates. LOCKSIM analyses of this condition indicated a range of reverse heads between approximately 0.3 and 0.7 m.

11.5. Cavitation Index

The cavitation index (K_i) as defined by equation 11-2 was evaluated for various equalization operations. In the equation, P is the pressure head at the vena contracta, P_a is the atmospheric pressure, P_v is the vapor pressure of water, and V_v is the velocity at the vena contracta.

$$K_i = \frac{P + P_a - P_v}{\frac{V_v^2}{2g}} \qquad (11\text{-}2)$$

A value of K_i greater than 0.61 is generally considered to be acceptable. Cursory checks performed for each filling and emptying system show values of the cavitation index greater than 0.61.

11.6. Salinity

The potential effect of salinity on performance of the filling and emptying system was investigated. Physical properties for water ranging between fresh and salt water were input into the LOCKSIM model. The results indicated no significant difference between salt and fresh water. The analyses presented in this report adopted the default values within LOCKSIM for the properties of water. The default values closely approximate a fresh water condition.

11.7. Number of WSB Conduits

Screening level analyses were performed using LOCKSIM to evaluate the number of conduits connecting each water saving basin to its respective lock. The analyses assumed basins on one side of the lock. Results of the analyses are presented in Table E-11-4. To meet target equalization times, four conduits are recommended for each water saving basin with two crossover conduits per lock. Further analysis and design of the selected systems will be based upon a four conduit per basin design. Two conduits would connect to one of the lock culverts with the other two conduits connecting to the other lock culvert.

Similar results would be obtained with basins located on both sides of the lock. Under this arrangement, each side of the lock would have two basins with an area equal to one-half of the lock chamber. There would be two conduits connecting each of these basins to the lock culvert on the basin side of the lock.

Table E-11-4 Equalization Time vs. Number of Conduits Per Water Saving Basin

Equalization (Operation With WSBs)	Equalization Time [Minutes]			
	Without Crossover Conduits		With Crossover Conduit(s)	
	One Conduit	Two Conduits	Three Conduits	Four Conduits
Lake Gatun to Upper Lock	25.4	20.1	16.0	14.9
Upper Lock to Lower Lock	27.2	19.4	15.2	13.8
Lower Lock to Atlantic Ocean	28.8	21.0	16.8	15.5

11.8. Basin Residual and Area Ratio

The filling and emptying systems would have the flexibility to operate with or without a residual in the water saving basins. Operation with a positive residual would reduce equalization times at the expense of water savings. A negative residual would achieve a small increase in water savings. A summary of the effect of basin residual on equalization times and water savings for the average lift is presented in Table E-11-5. The first three columns of data demonstrate the effect of basin residual with a basin area ratio of 1.0. The last column of data demonstrates the impact of increasing the basin area ratio to offset the reduction in water savings resulting from the basin residual.

A basin residual of 0.0 and a basin to lock area ratio of 1.0 are recommended for the concept design. The time reduction due to a basin residual with an equivalent adjustment to the area ratio would be negligible. Equalization time variations of approximately 30 seconds could be realized with a basin residual only. To take advantage of this effect, a flexible lock operation plan could be formulated to operate with a basin residual to reduce equalization times during periods of adequate water supply. During critical low water periods, the system could be operated with a zero or negative residual to maximize the amount of water saved. A basin to lock area ratio greater than 1.0 is not recommended because it is an inefficient means of saving water and does not have a benefit in terms of equalization time. The area of the basins would have to be increased by 23% to achieve a 2.3% increase in water savings.

Table E-11-5 Effect of Basin Residual on Equalization Time and Water Savings

Equalization (Operation With WSBs)	Equalization Time [Minutes]			
	M = 1.0			M = 1.23
	e = -30 CM 52.3% Water Saving	e = 0 CM 50.0% Water Saving	e = 30 CM 47.7% Water Saving	e = 30 CM 50.0% Water Saving
Lake Gatun to Upper Lock	15.4	14.9	14.6	14.8
Upper Lock to Lower Lock	14.4	13.8	13.5	13.7
Lower Lock to Atlantic Ocean	16.0	15.5	15.2	15.4

12. INTERLACED BOTTOM LATERAL FILLING AND EMPTYING SYSTEM

Plate E-13 shows a plan and profile of the interlaced bottom lateral filling and emptying system for the upper lock. The lower lock layout is presented in Plate E-14. Typical sections are shown on Plate E-15.

12.1. Lock Components

12.1.1. Culverts

A preliminary culvert size was determined using equation E-12-1 (Davis, 1989). Parameters related to the lock size and lift were based upon preliminary estimates for the third lane. Parameters related to the filling and emptying system characteristics were estimated based upon data in published reports (Davis, 1989).

$$A_c = \frac{A_s\left(\sqrt{H+d}-\sqrt{d}\right)}{C_L\sqrt{2g}\left(T-U\,t_v\right)} \qquad \text{(E-12-1)}$$

The culvert was sized for equalization without water saving basins between Gatun Lake and the upper lock at the average lift. Parameters used in equation E-12-1 are summarized in Table E-12-1. The estimated culvert size required for an equalization time of 13.5 minutes is 43 m^2. The culvert size selected for design is 6 m wide and 8 m high with an area of 48 m^2. The additional culvert area would allow target equalization times to be met when using the water saving basins.

Table E-12-1 Parameters to Estimate Culvert Size (Interlaced Bottom Lateral)

Parameter	Description	Estimated Value
A_s	Surface area of lock [m^2]	32,140
H	Lift height [m]	12.92
d	Overtravel [m]	0.3
C_L	Lock coefficient	0.70
g	Gravity [m/s^2]	9.81
T	Target equalization time [s]	810
U	Valve coefficient	0.50
t_v	Valve time [s]	120

The culverts would be located in the lock walls and would be generally straight except at the miter gates where they bend horizontally around the gate recesses. The culverts would be level throughout most of their length with transition slopes just below the intake and between the locks. In order to provide reasonable submergence and transition distance for the water saving basin conduit connections, the culvert roofs would need to be at least about 4m below minimum lower pool. EM 1111-2-1610 states that all elements of the filling system between the valves should be a minimum of 1.524 m below lower pool. This is to prevent the admission of air into the culvert system and to avoid cavitation potential at the valves. For the screening level design, the culvert roof was generally located at 5 m below minimum lower pool to meet submergence requirements and provide convenient access to valves. However, more detailed structural analyses revealed a cost advantage in lowering the culverts to maximize the use of RCC. As a result of this finding, the screening level design was modified to lower the culvert an additional 5.9 m with the invert now at the same elevation as the lock chamber floor.

12.1.2. Intakes

Typical manifolds in the wall faces are proposed. The concept manifold shows eight ports with the same height and invert as the culvert. Total intake port area-to-culvert area ratios are typically in the range of 2.5-4.0. A value of 4.0 was adopted for the concept design. All ports have the same width at the wall face; however, a variable throat width helps equalize flow among the ports. The invert elevation, 7.930 m PLD, provides 8 m or one culvert height of submergence at the roof to minimize the potential for unacceptable vortices. Removable screens would be provided on the intakes to prevent debris from entering the culverts.

12.1.3. Valves

Vertical lift valves to fit the 6 m by 8 m culverts and conduits are proposed. The valves would move with low frictional resistance on rollers in slots in the culvert side walls. This type of valve was selected because of its compactness and the ability to place two valves close together in series and close to adjacent bulkhead slots. This compactness has significant advantages because the horizontal and vertical bends, lateral connections and miter gate anchorages in the vicinity of the valves limit the length of straight level culvert available for tandem valves. In order to save initial cost, redundant valves in series are not proposed. If desired, a slot could be provided in the culvert wall to accommodate the possible future installation of a backup valve. The reduced emphasis on maintenance conditions specified by ACP helped to facilitate this change. During maintenance conditions where a culvert valve is taken out of service, the locks could still be safely operated with the other lock culvert. Equalization times under this condition would be approximately doubled due to the reduced flow capacity.

Reverse tainter valves were considered but not recommended due to the relatively large recess required for this type of valve. There would also be concerns with the placement of two reverse tainter valves in series within close proximity. Operating the upstream valve at partial openings would cause turbulence and possibly higher head losses as the jet expands into the large well above the downstream valve. Reverse tainter valves could still be considered during final design if it is decided that backup valves would not be required.

12.1.4. Laterals

Twelve laterals per culvert were selected based on similarity to the present system and 1942 model tests. An additional factor was the desirability of having an even multiple of four to provide symmetry with the two connections to each water saving basin. The total lateral to culvert area of 2.0 exceeds the present system (1.8) and most other bottom lateral systems to provide faster equalizations when using the water saving basins. The total port to culvert area (2.04) is within the normal range and less than the existing system (2.6).

The lateral design was based on Design 2 of the 1942 model study. This design was selected because its ratio of diameter to chamber width (0.050) is closest to the proposed third lane design (0.045). The aspect ratios, 0.65 (Design 2), and 0.69 (proposed), are also reasonably close. Design 2 from the 1942 model study was found to provide very good distribution of flow across the chamber, which should keep transverse slopes and hawsers low when operating from one side during maintenance conditions. The lateral invert is 5 m below the chamber floor in accordance with the scaled-up geometry of 1942 Design 2.

Two laterals would feed the area between the lower miter gates in each lock. This area would be slightly underserved proportionally so that the water level in this region would lag behind the main chamber during filling. Bulkheads would be provided in these laterals to close off the flow between the upper and lower chambers when the downstream miter gate would be taken out of service. Future studies should consider potential advantages of equipping these laterals with valves for better control.

12.1.5. Ports

Design 2 from the 1942 model study proposed eight unevenly spaced vertical ports between the roof of the lateral and floor of the chamber. Scaled dimensions for the third lane would be 1.4 m by 0.73 m. Corners would be rounded for hydraulic efficiency.

12.1.6. Outlet

To minimize turbulence in the immediate lower lock approach, a diffusion chamber similar to the existing locks is proposed inside each wall. The configuration shows the culvert splitting into three forks to divide the jet just upstream of the chamber. Expansion of the jets when they reach the chamber would dissipate much of the energy before the water exits from under the wall. The arrangement is only a concept and will require more study to refine the geometry and physical modeling to check performance.

The diffusion chamber would not affect the amount of flow heading toward the ocean during emptying, and thus would not reduce the surge experienced by ships in the approach channel. This surge would only be avoided if the discharge were routed to another location. The proposed piping shows branches from the culverts of the lower lock on the east side leading to a discharge channel and/or lower recycling basin. The connection to the west culvert would make double use of the downstream crossover, which is needed for efficient use of the water saving basins. This alternate discharge feature has not been designed beyond the control valves. If adopted, the configuration could increase empty time of the lower lock.

12.2. Water Saving Basin Components

12.2.1. Conduits and Crossovers

To provide sufficient flow area to meet equalization time criteria, the conduits would be the same size as the culverts, 6 m wide by 8 m high. To connect to the lowered lock culverts, the near (lower basin) conduits would be lowered from what was proposed previously in the screening study. The far (upper basin) conduit invert near the basin intake would be approximately 17 m below the basin floor to meet the submergence requirements discussed in Section 12.2.2. From the intake the conduit slopes mildly downward. At a point opposite the lower basin intake, it would reach the level of the culverts and lower basin conduits. Conduits serving the lower and upper basins and their control valves would run in side-by-side pairs. Two pairs of conduits would tie directly into the west culvert in T-junctions. For symmetry, the tie-ins would occur between the third and fourth laterals and between the ninth and tenth laterals.

Conduits feeding the east culvert would merge on the lock side of the valves before diving under the chamber. A vertical shaft would intersect the floor of the east culvert between the ninth and tenth laterals (upper lock) and third and fourth laterals (lower lock). On the west side, another vertical shaft would intersect the floor of the recycle culvert. The recycle culvert would have control valves in two directions. One direction leads to the recycle pond, the other to the east culvert between the third and fourth laterals (upper lock) and ninth and tenth laterals (lower lock). This arrangement would enable the crossover to be used with either the water saving basins or recycling ponds.

12.2.2. Intakes

Intakes would be flared in a vertical shaft to 4 times the conduit area, rounded, and lowered 2 m below the official basin floor elevation to improve efficiency and avoid weir flow at the intake. For the upper basins, conduit roofs at the bottom of the shaft would be set about 9 m below the basin floor to avoid strong vortices at the intakes. Intake roofs for the lower basins would be more than 5 m deeper.

12.2.3. Valves

The valves would be the same size and type as the culvert valves. However, to permit reverse flow and heads, the shape and seals would vary. Access would be from platforms adjacent to and at the same level as the lock walls, which project into the basins. Back-up valves or slots would not be provided because more than one valve/conduit would serve each basin.

12.3. Recycling

Culvert connections for possible recycling ponds were included on the east side near the upstream end of the upper lock and downstream end of the lower lock. The lower pond would capture discharge normally released to the ocean when using the water saving basins. It has been assumed that the lower recycling pond would have a storage capacity approximately equal to one-half of one lift located entirely below ocean level for gravity operation. The captured water would be pumped to the upper recycling pond, which would have an equivalent volume located entirely above the level of Gatun Lake.

The crossover conduits necessary to connect the water saving basins to the east culvert would also be used to convey flow between the recycling ponds and west culvert. No computations were made of fill and empty times because the locations and elevation-storage relationships of the ponds are not known. Head losses in the crossover and friction in long connecting culverts would tend to increase the times. However, the increased head would tend to shorten the times. The net effect of these two factors is unknown.

12.4. LOCKSIM Model

The LOCKSIM model represents the entire system including both locks and all water saving basins. The valve operations and starting water surface elevations determine the mode of operation.

The head losses in the closed conduit were comprised of intake loss, friction, valve loss, losses at bends, junctions, and outlet. An intake loss of 0.2 was used, which should be conservative based on information in EM 1111-2-1604. Frictional head losses were computed using an absolute roughness of 0.9 mm for rectangular concrete conduits in accordance with the USACE Hydraulic Design Criteria 224-1. Losses at the vertical lift valves for partial and full openings are from Figure 14.22 of Millers' *Internal Flow Systems*. T-junction losses were taken from Figures 13.16 and 13.27 of the same reference. Figure 43 of the 1942 model report was used to account for flow entering laterals from the culvert. For lock emptying, a port intake loss of 0.1 was used, per Figure 14.11 of Miller. Bend loss coefficients were also chosen based on information in the Miller publication and ranged from 0.05 to 0.20 depending on the angle and degree of curvature. Minor bends were neglected. The loss at the outlets is 1.0.

The lock chambers were represented by open channel components. Connections between the open channel and closed conduit occur at each lateral.

The water saving basins were divided into two half-basin segments, each represented by a storage component. The component had a constant surface area of approximately one-half the lock area based on a nominal 457.200 m by 60.960 m nominal lock. Open channel connections between the two segments facilitated transfer of water. It is recommended that these connections between basin segments be designed with a stoplog or similar closure for maintenance purposes. Details of the opening size and closure requirements were not determined for the concept level.

12.5. LOCKSIM Analysis

Lock water surface elevations at the upper sill, middle of chamber, and lower sill were computed to evaluate slopes and equalization times. Basin water surfaces were also monitored in trial and error model runs to arrive at the correct valve timing for water saving basin operations. Computations were performed at the average lift. Cursory checks were performed for the maximum and minimum lifts. Equalization times would decrease approximately 0.5 minutes at the minimum lift and would increase approximately 0.5 minutes at the maximum lift. Unless otherwise noted, the downstream inner gates were assumed to be open to provide the specified nominal lock length of 457.200 m. Cursory checks were made with the downstream inner gates closed.

12.6. Baseline Equalizations

Baseline equalizations were performed for operations with and without water saving basins. Results are summarized in Table E-12-2. The valve times presented in Table E-11-2 were used with the inner gates opened. Equalization times generally satisfy the 12-15 minute criteria with the exception of emptying the lower lock with water saving basins, which is slightly over 15 minutes.

Table E-12-2 Baseline Equalizations (Interlaced Bottom Lateral)

Equalization	Time [Minutes]	
	With WSBs	Without WSBs
Lake Gatun to Upper Lock	14.9	12.7
Upper Lock to Lower Lock	13.8	10.8
Lower Lock to Atlantic Ocean	15.5	12.8

12.7. Valve Overlap

Baseline operating procedures assumed successive valve operations without any overlap. By using the overlapping valve sequence described in Section 11.2, time savings can be realized for operations with water saving basins. Equalization times with valve overlap are presented in Table E-12-3. An overlapping valve sequence is recommended for the interlaced bottom lateral system.

Table E-12-3 Equalization Times with WSBs and Valve Overlap (Interlaced Bottom Lateral)

Equalization	Time [Minutes]
Lake Gatun to Upper Lock	14.6
Upper Lock to Lower Lock	13.4
Lower Lock to Atlantic Ocean	15.1

12.8. Valve Loads

The valve loads presented in Table E-11-3 were used for the interlaced bottom lateral system.

12.9. Lock Gate Head Differentials

12.9.1. Overtravel

LOCKSIM analyses indicated a maximum reverse head of 0.67 m for a double-lift configuration with the interlaced bottom lateral system. Recommended maximum reverse head differentials due to overtravel for use in concept design of the double-lift configuration with the interlaced bottom lateral system are presented in Table E-12-4.

Table E-12-4 Maximum Reverse Head Differential Due to Overtravel (Interlaced Bottom Lateral)

Lock Gate Location	Maximum Reverse Head Differential [m]	
	w/o WSBs	w/ WSBs
Between Lake Gatun and Upper Lock	0.38	0.39
Between Upper Lock and Lower Lock	0.64	0.67
Between Lower Lock and Atlantic Ocean	0.27	0.26

12.9.2. Between Gates

LOCKSIM analyses indicated a maximum reverse head differential of 0.67 m for a double-lift configuration with the interlaced bottom lateral system. Recommended maximum reverse head differentials due to operating with the inner gates closed for use in concept design of the double-lift configuration with the interlaced bottom lateral system are presented in Table E-12-5.

Table E-12-5 Maximum Reverse Head Differential Due to Closed Inner Gates (Interlaced Bottom Lateral)

Lock Gate Location	Maximum Reverse Head Differential [m]	
	w/o WSBs	w/ WSBs
Between Upper Lock and Lower Lock	0.44	0.67
Between Lower Lock and Atlantic Ocean	0.32	0.42

12.10. Cavitation Index

A value of K_i greater than 0.61 is generally considered to be acceptable. For the interlaced bottom lateral system, a minimum value of approximately 1.06 was computed for a normal operation at the average lift.

12.11. Culvert Velocity

Culvert velocities were computed using Locksim. Maximum culvert velocities were estimated between 8.0 m/s for equalization with water saving basins and 10.8 m/s for operation without water saving basins. Maximum water saving basin conduit velocities were estimated to be 4.8 m/s.

12.12. Water Saving Basin Intakes

Cursory checks were made concerning the potential for serious vortices forming at the water saving basin intakes. Air entraining vortices could degrade the efficiency of the intake and cause problems in the chamber when the air is expelled. According to Knauss' *Swirling Flow Problems at Intakes*, the potential for air entraining vortices is related to the submergence depth of the conduit roof at the intake (S), conduit diameter (D) and Froude Number. if the value of S/D exceeds 2.3 times the Froude Number, air entraining vortices would not be expected. The minimum value calculated for draining the upper basin of the upper lock is 2.9. This suggests vortices should not be a problem. However, this is an item that should be verified with a physical model.

12.13. Maintenance Conditions

Several maintenance conditions were evaluated to determine the potential impact of maintenance on system performance. The first maintenance condition assumes equalizations without use of the water saving basins while one lock culvert is out of service. Two additional maintenance conditions were evaluated for equalizations with use of the water saving basins. One of these conditions assumes that both lock culverts are in service and one conduit per basin is out of service. The other condition assumes that one lock culvert is out of service and all basin conduits are in service. Results of these analyses are presented in Table E-12-6.

It is possible that the valves may need to be slowed down to prevent high transverse hawsers due to unbalanced flows under some of the maintenance conditions. This would increase the equalization times further. These effects cannot be evaluated using LOCKSIM and will require physical modeling.

Table E-12-6 Effect of Maintenance Conditions on Equalization Time (Interlaced Bottom Lateral)

Equalization	Equalization Time [Minutes]				
	Operation Without WSBs		Operation With WSBs		
	Normal Operation	One Lock Culvert Out of Service	Normal Operation	One Lock Culvert Out of Service	One Conduit Per WSB Out of Service
Lake Gatun to Upper Lock	12.6	25.5	14.9	23.0	15.9
Upper Lock to Lower Lock	10.8	20.9	13.8	20.4	15.0
Lower Lock to Atlantic Ocean	12.9	26.1	15.5	24.3	16.9

12.14. Hawser Forces

12.14.1. Longitudinal Hawsers

In general, computed end-to-end water surface slopes for an unoccupied chamber were significantly less than the recommended design criteria of 0.5/1000. The filling and emptying system provided satisfactory performance under both normal and maintenance conditions. The estimated slopes and hawsers presented in the following paragraphs are a relative indicator of lock performance and not necessarily a prediction of actual forces. Future studies should include a physical hydraulic model that would include measurement of longitudinal hawser forces.

12.14.1.1. Downstream Inner Gates Open

A summary of longitudinal water surface slopes for equalizations with the downstream inner gates open is presented in Table E-12-7.

Table E-12-7 Estimated Typical Longitudinal Water Surface Slopes (Interlaced Bottom Lateral with Downstream Inner Gates Open)

Equalization	Operation Without WSBs	Operation With WSBs
	Maximum Slope (1/1000)	Maximum Slope (1/1000)
Lake Gatun to Upper Lock	0.35	0.40
Upper Lock to Lower Lock	0.25	0.28
Lower Lock to Atlantic Ocean	0.20	0.27

12.14.1.2. Downstream Inner Gates Closed

A summary of longitudinal water surface slopes for equalizations with the downstream inner gates closed is presented in Table E-12-8. Overall, the values are slightly lower than Table E-12-7.

Table E-12-8 Estimated Typical Longitudinal Water Surface Slopes (Interlaced Bottom Lateral with Downstream Inner Gates Closed)

Equalization	Operation Without WSBs	Operation With WSBs
	Maximum Slope (1/1000)	Maximum Slope (1/1000)
Lake Gatun to Upper Lock	0.29	0.27
Upper Lock to Lower Lock	0.22	0.21
Lower Lock to Atlantic Ocean	0.14	0.21

12.14.1.3. Maximized Slopes

Maximum slopes for superimposed oscillations resulting from successive valve operations were computed assuming downstream inner gates open. A summary of maximum longitudinal water surface slopes is presented in Table E-12-9. Note that this phenomenon does not affect operations without water saving basins so the values of Table E-12-7 are repeated. The values with water saving basins are only slightly higher than Table E-12-7.

Table E-12-9 Estimated Maximum Longitudinal Water Surface Slopes (Interlaced Bottom Lateral with Downstream Inner Gates Open)

Equalization	Operation Without WSBs	Operation With WSBs
	Maximum Slope (1/1000)	Maximum Slope (1/1000)
Lake Gatun to Upper Lock	0.35	0.42
Upper Lock to Lower Lock	0.25	0.32
Lower Lock to Atlantic Ocean	0.20	0.36

12.14.1.4. Ship Effects

The current published version of LOCKSIM cannot account for the effect of a ship in the lock. Although the design ship will block more than half the flow conveyance area, there would be virtually no effect on equalization times. However, increased longitudinal slopes would be expected. A beta version of LOCKSIM capable of representing the ship has recently become available. The beta version is based on theory and has not yet been verified, although it produced reasonable results when applied to the Miraflores data. Cursory computations were done with the design container ship represented and downstream inner gates open. Refer to Table E-12-10. The predicted slopes (maximized for operations without water saving basins) are approximately twice as high as those shown in Table E-12-9. However, they remain below 1/1000. The estimated forces are less than the recommended maximum of 209 t.

Table E-12-10 Estimated Maximum Longitudinal Hawsers for Design Container Ship (Interlaced Bottom Lateral with Downstream Inner Gates Open using LOCKSIM Beta Version - Ship Effect Included)

Equalization	Operation Without WSBs		Operation With WSBs	
	Maximum Slope (1/1000)	Estimated Hawser [t]	Maximum Slope (1/1000)	Estimated Hawser [t]
Lake Gatun to Upper Lock	0.75	157	0.77	161
Upper Lock to Lower Lock	0.59	123	0.74	155
Lower Lock to Atlantic Ocean	0.21	44	0.57	119

12.14.2. Transverse Hawsers

The one-dimensional LOCKSIM model does not have the capability to estimate transverse hawsers. Designs have been developed based upon the 1940 design and other similar designs to minimize the potential for adverse transverse hawsers. Future studies should include a physical hydraulic model testing program which includes the measurement of transverse hawsers.

12.15. Recommended Operation Plan

12.15.1. Without Water Saving Basins

Filling and emptying curves and end to end water surface slopes for equalizations without water saving basins using the recommended operating plan are shown in Figures E-12-1 and E-12-2. The recommended operating plan incorporates the valve schedule presented in Table E-11-2. The downstream inner gates are assumed to be in a closed position.

Figure E-12-1 Equalization Without Water Saving Basins (Interlaced Bottom Lateral)

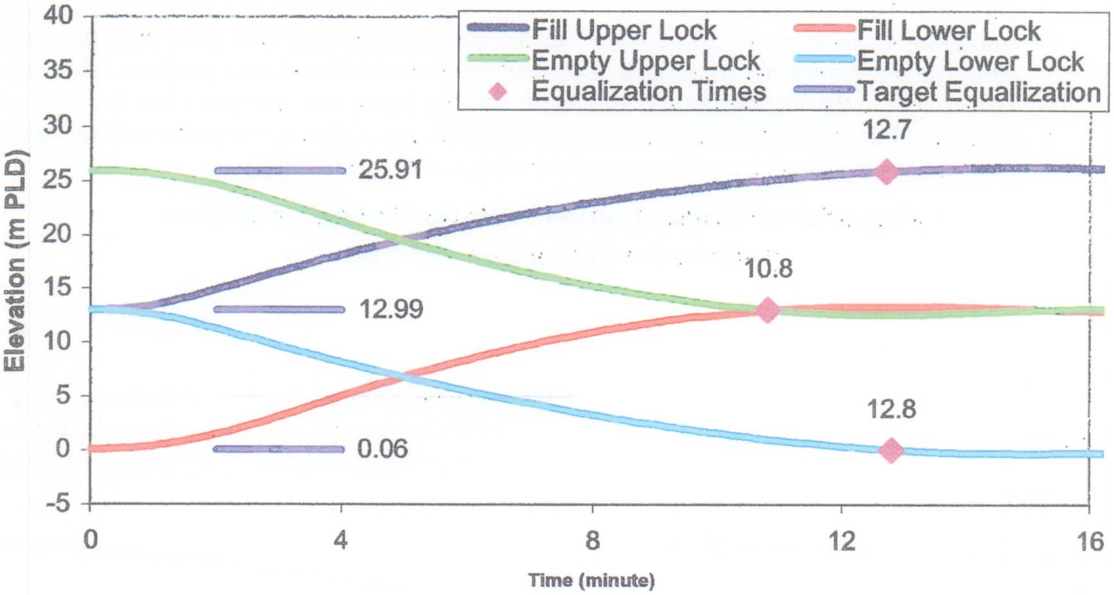
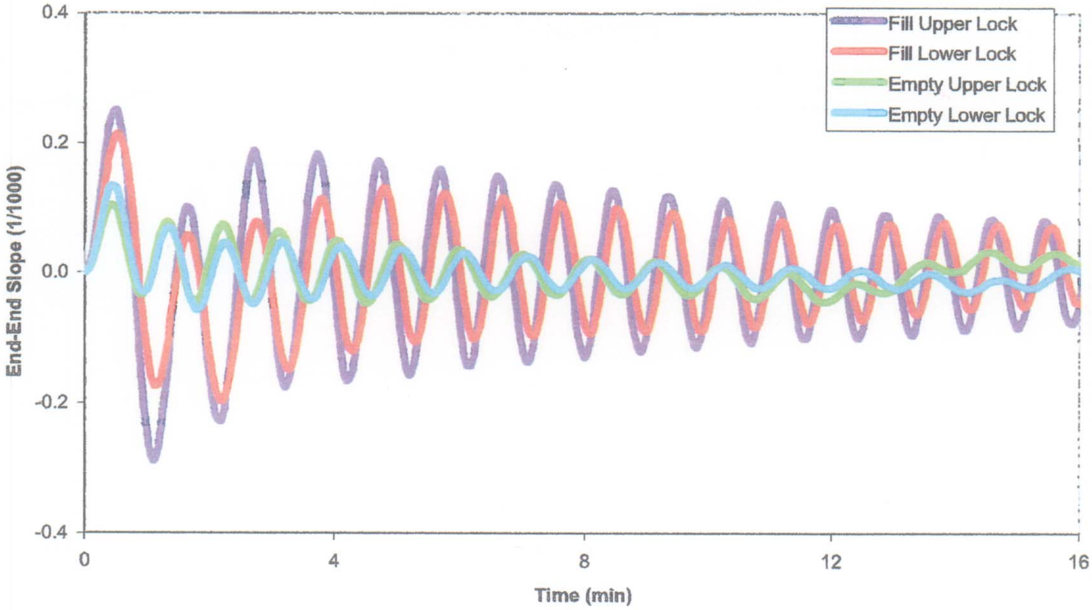


Figure E-12-2 End to End Water Surface Slopes Without Water Saving Basins (Interlaced Bottom Lateral)



12.15.2. With Water Saving Basins

Filling and emptying curves and typical end-to-end water surface slopes for equalization with water saving basins using the recommended operating plan are shown in Figures E-12-3 and E-12-4. The recommended operating plan incorporates the valve times presented in Table E-11-2 with a 0.4 minute overlap between the water saving basin valves and the lock culvert valves. The basins are operated with zero residual depth and the downstream inner gates are assumed to be in the closed position. Equalization times tend to be slightly longer with water saving basin use compared to the without water saving basin operations because of a 50% reduction in the initial driving head and the additional valve operations required with use of the basins.

Figure E-12-3 Equalization With Water Saving Basins (Interlaced Bottom Lateral)

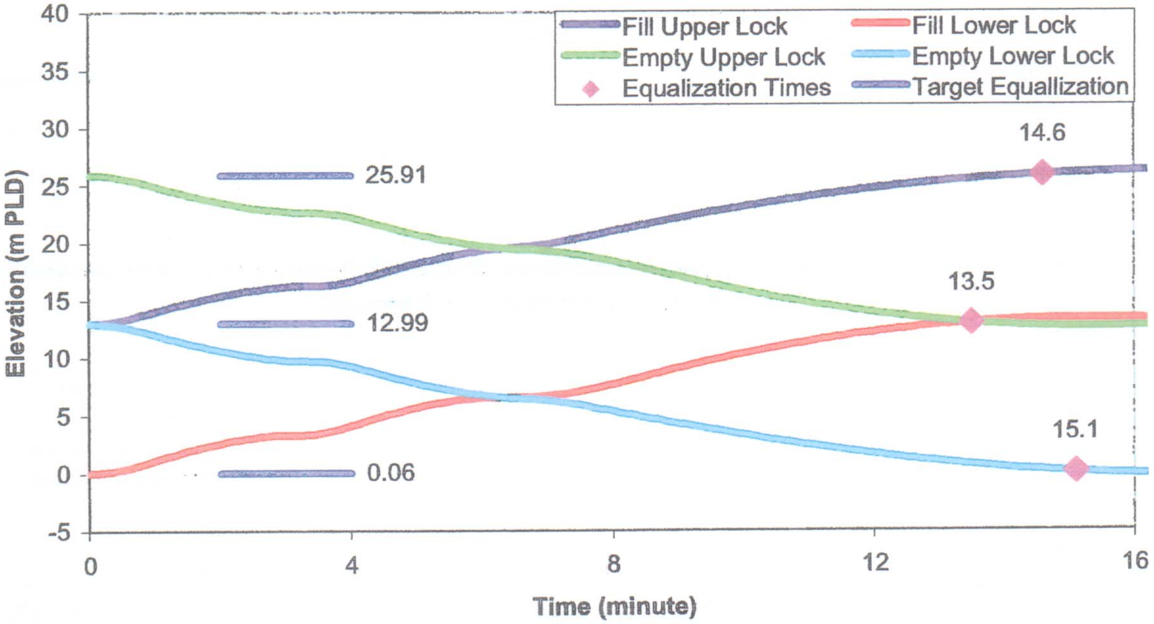
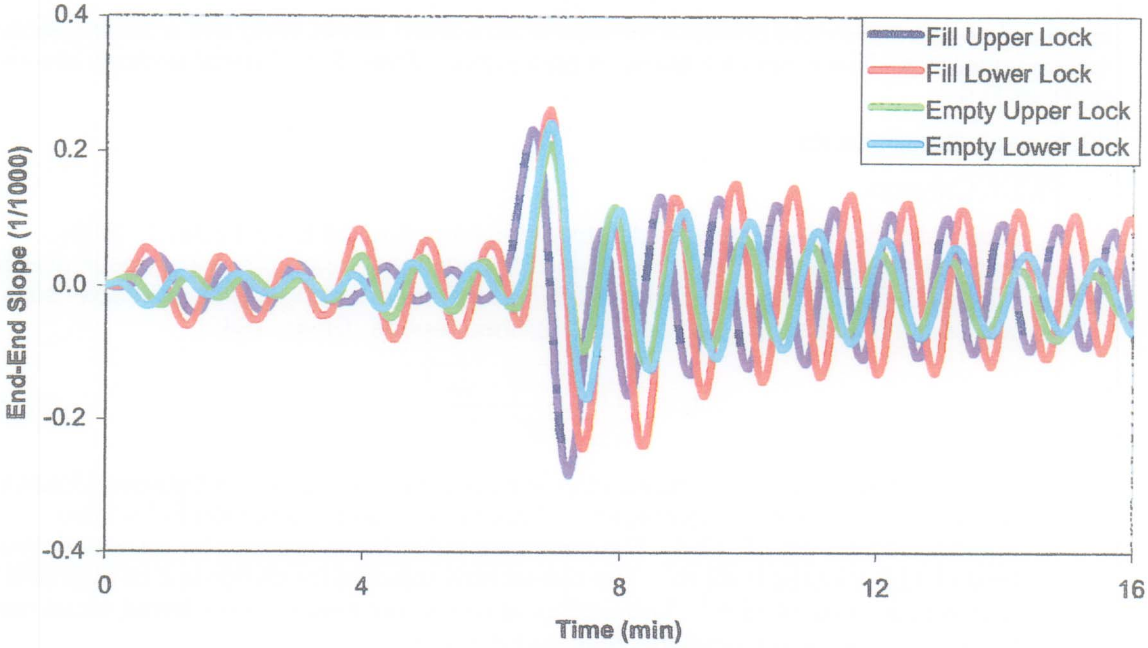


Figure E-12-4 End to End Water Surface Slopes With Water Saving Basins (Interlaced Bottom Lateral)



13. IN CHAMBER LONGITUDINAL CULVERT SYSTEM (ILCS)

Plate E-7 shows a plan and profile of the interlaced bottom lateral filling and emptying system for the upper lock. The lower lock layout is presented in Plate E-8. Typical sections are shown on Plate E-9.

13.1. Lock Components

13.1.1. Culverts

A preliminary culvert size was determined using equation E-13-1 (Davis, 1989). Parameters related to the lock size and lift were based upon preliminary estimates for the third lane. Parameters related to the filling and emptying system characteristics were estimated based upon data in published reports (Davis, 1989).

$$A_c = \frac{A_s\left(\sqrt{H+d}-\sqrt{d}\right)}{C_L\sqrt{2g}\left(T-U\,t_v\right)} \qquad \text{(E-13-1)}$$

The culvert was sized for equalization without water saving basins between Gatun Lake and the upper lock at the average lift. Parameters used in equation E-13-1 are summarized in Table E-13-1. The estimated culvert size required for an equalization time of 13.5 minutes is 49 m^2. The culvert size selected for design is 8 m wide and 7 m high with an area of 56 m^2. The additional culvert area would allow target equalization times to be met when using the water saving basins.

Table E-13-1 Parameters to Estimate Culvert Size (Interlaced Bottom Lateral)

Parameter	Description	Estimated Value
A_s	Surface area of lock [m^2]	32,140
H	Lift height [m]	12.92
d	Overtravel [m]	0.3
C_L	Lock coefficient	0.62
g	Gravity [m/s^2]	9.81
T	Target equalization time [s]	810
U	Valve coefficient	0.50
t_v	Valve time [s]	120

The culverts are located outside the lock chamber in the vicinity of the miter gate recesses. The straight sections of the culverts begin 122.21 m downstream from the pintle of the closest upper miter gate after a vertical transition and 2 horizontal bends. The straight section is 313.5 m long and then the culverts begin the transition back outside the chamber to pass around the lower miter recesses. The culvert ports are located in the straight section inside the chamber. This lower transition begins 122.21 m upstream from the pintle of the lower miter gate. The top of the culverts inside the chamber were set at the lower sill elevations (-6.52 for the upper lock and –18.67 for the lower lock). The assumed culvert thickness is 0.914 m resulting in a culvert soffit elevation of –7.43 in the upper lock and –19.55 in the lower lock.

13.1.2. Intakes

A conventional manifold type intake is proposed for the upper lock. The total intake port area (at the face) ratio to the culvert area is 3.5 which is in the range of typical area ratios (2.5 to 4.0). The intake invert el was set at 4.43 to reduce vertical transitioning required between the intake and culvert section through the upper valves. A lower intake will help minimize vortex formation at the intakes. Removable screens will be needed on the intakes to prevent debris from entering the culverts.

13.1.3. Valves

Vertical lift valves are again proposed. If desired, a slot could be provided in the lock wall to accommodate the possible future installation of a backup valve. The reduced emphasis on maintenance conditions specified by ACP helped to facilitate this change. The culvert would bifurcate to accommodate side-by-side valves, each 4 m wide by 7 m high. During maintenance conditions where a culvert valve is taken out of service, the locks could still be safely operated by not operating the corresponding valve in the opposite culvert. Equalization times under this condition would be approximately doubled due to the reduced flow capacity.

Reverse tainter valves were considered but not recommended due to the relatively large recess required for this type of valve. There would also be concerns with the placement of two reverse tainter valves in series within close proximity. Operating the upstream valve at partial openings would cause turbulence and possibly higher head losses as the jet expands into the large well above the downstream valve. Reverse tainter valves could still be considered during final design if it is decided that backup valves would not be required.

13.1.4. Ports and Port Extensions

The ports are arranged along the length of each culvert in two sets of 16 pairs of ports centered roughly at the one-third points of the lock totaling 32 pairs of ports centered 5.5 m apart. Initially each port is 1.85 m tall by 0.65 m wide. This port area provides a culvert port to water saving basin conduit ratio of 1.0.

The typical ILCS design recommends port extensions on the ports in the upper half of the lock to help evenly distribute the flow in the chamber during normal filling. This conceptual design proposes the use of water saving basins that will connect to the lock chamber culverts near the center of the lock. Since the flow from the water saving basins that discharges from the upper ports is approaching the ports from a downstream direction, an enclosed port extension is recommended. The details of these enclosed port extensions will need to be determined in the final design process. An estimate of the port extension length would be 3 m. Also, since the water saving basin culverts connection in the lower half of the lock are located near the downstream ports, port extensions are recommended for the lower ports. .

13.1.5. Wall Baffles

Wall baffles typical of the ILCS design are proposed as shown in Plate 9. These baffles prevent the jet flow from the outer ports from running up the lock walls and bulking the lock water-surface at the walls. The baffles help maintain a smoother water-surface in the chamber during filling operations. .

13.1.6. Laterals

The area between downstream gates is served by two late[illegible] each of which is fed by one of the main culverts. Each lateral is proposed to be 3.[illegible] wide by 2.29 m high with eight ports in the ceiling. Each port has an area of 0.875 m[illegible] for a total of 7 m^2. The laterals would be able to be bulkheaded to close off a direct connection between the upper and lower levels in the event the lower gates of the upper lock are used to retain the upper pool. Future studies should consider the need for equipping the laterals with valves.

13.1.7. Outlet

To minimize turbulence in the immediate lower lock approach, a diffusion chamber similar to that proposed for the bottom lateral system would also be appropriate for the ILCS system outlet. The diffusion chamber would dissipate much of the energy before the water exits from under the wall. It is more fully described in Section 11.6.1. The arrangement is only a concept and will require more study to refine the geometry and physical modeling to check performance.

The diffusion chamber would not affect the amount of flow heading toward the ocean during emptying, and thus would not reduce the surge experienced by ships in the approach channel. This surge would only be avoided if the discharge were routed to another location. The proposed layout shows extensions of the in-chamber culverts of the lower lock running into the lower miter sill and turning east side leading to a set of valves. The valves lead to a discharge channel and/or lower recycling basin. This alternate discharge feature has not been designed beyond the control valves. If adopted, the configuration could increase empty time of the lower lock.

13.2. Water Saving Basin Components

13.2.1. Conduits and Crossovers

Conduits serving the lower and upper basins and their control valves would run in side-by-side pairs. The conduits from the basin intakes through the valves will be 7 m high by 6 m wide. Just downstream of the valves the pairs of conduits combine, turn downward, then run horizontally to connect to the lock culverts near the middle of the chamber and from underneath the lock. This should help distribute the flow more evenly in the lock culverts during filling. The conduit size will change from 7 m high by 6 m wide to 6 m high by 7 m wide during the vertical transition.

13.2.2. Intakes

Intakes would be flared in a vertical shaft to 4 times the conduit area, rounded, and lowered 2 m below the official basin floor elevation to improve efficiency and avoid weir flow at the intake. For the upper basins, conduit roofs at the bottom of the shaft would be set 9 m below the basin floor to avoid strong vortices at the intakes.

13.2.3. Valves

The valves for the water saving basins are 7 m high by 6 m wide. Since the valves will experience reverse flow and heads, the shape and seals will vary from the lock culvert valves. Access would be from one central platform for each lock that would be adjacent to and at the same level as the lock wall. The valve platforms project into the rectangular basins. Back-up valves or slots would not be provided because more than one valve/conduit would serve each basin.

13.3. Recycling

Culvert connections for possible recycling ponds were included on the east side near the upstream end of the upper lock and downstream end of the lower lock. The lower pond would capture discharge normally released to the ocean when using the water saving basins. It has been assumed that the lower recycling pond would have a storage capacity approximately equal to one-half of one lift located entirely below ocean level for gravity operation. The captured water would be pumped to the upper recycling pond, which would have an equivalent volume located entirely above the level of Gatun Lake.

The recycling connections would be through the upper miter sill of the upper lock and lower miter sill of the lower lock. In plan view, they appear as extensions to the in-chamber culverts where the culverts turn into the lock walls. No computations were made of fill and empty times because the locations and elevation-storage relationships of the ponds are not known. Head losses in the crossover and friction in long connecting culverts would tend to increase the times. However, the increased head would tend to shorten the times. The net effect of these two factors is unknown.

13.4. LOCKSIM Model

The LOCKSIM model represents the entire system including both locks and all water saving basins. The valve operations and starting water surface elevations determine the mode of operation.

The head losses in the closed conduit were comprised of intake loss, friction, valve loss, losses at bends, junctions, and outlet. An intake loss of 0.2 was used, which should be conservative based on information in EM 1111-2-1604. Frictional head losses were computed using an absolute roughness of 0.9 mm for rectangular concrete conduits in accordance with the USACE Hydraulic Design Criteria 224-1. Losses at the vertical lift valves for partial and full openings are from Figure 14.22 of Millers' *Internal Flow Systems.* T-junction losses were taken from Figures 13.16 and 13.27 of the same reference. Port manifold losses for filling operations were based on laboratory data. For lock emptying, a port intake loss of 0.15 was used. Bend loss coefficients were also chosen based on information in the Miller publication and ranged from 0.05 to 0.20 depending on the angle and degree of curvature. Minor bends were neglected. The loss at the outlets is 1.0.

The lock chambers were represented by open channel components. Connections between the open channel and closed conduit occur at each lateral.

The water saving basins were divided into two half-basin segments, each represented by a storage component. The component had a constant surface area of approximately one-half the lock area based on a nominal 457.200 m by 60.960 m lock. Open channel connections between the two segments facilitated transfer of water. It is recommended that these connections between basin segments be designed with a stoplog or similar closure for maintenance purpc s. Details of the opening size and closure requirements were not determined for the cept level.

13.5. LOCKSIM Analysis

Lock water surface elevations at the upper sill, middle of chamber, and lower sill were computed to evaluate slopes and equalization times. Basin water surfaces were also monitored in trial and error model runs to arrive at the correct valve timing for water saving basin operations. Computations were performed at the average lift. Cursory checks were performed for the maximum and minimum lifts. Equalization times would decrease approximately 0.5 minutes at the minimum lift and would increase approximately 0.5 minutes at the maximum lift. Unless otherwise noted, the downstream inner gates were assumed to be open to provide the specified nominal lock length of 457.200 m. Cursory checks were made with the downstream inner gates closed.

13.6. Baseline Equalizations

Baseline equalizations were performed for operations with and without water saving basins. Results are summarized in Table E-13-2. The valve times presented in Table E-11-2 were used with the inner gates opened with one modification. For lock to lock equalizations with water saving basins, a valve time of 3 minutes was used to maintain maximum water surface slopes below 0.5/1000. Equalization times generally satisfy the 12-15 minute criteria with the exception of emptying the lower lock with water saving basins, which is slightly over 15 minutes.

Table E-13-2 Baseline Equalizations (ILCS)

Equalization	Time [Minutes]	
	With WSBs	Without WSBs
Lake Gatun to Upper Lock	14.6	11.6
Upper Lock to Lower Lock	13.7	9.2
Lower Lock to Atlantic Ocean	15.3	11.7

13.7. Valve Overlap

Baseline operating procedures assumed successive valve operations without any overlap. By using the overlapping valve sequence described in Section 10.2, time savings can be realized for operations with water saving basins. Equalization times with valve overlap are presented in Table E-13-3. An overlapping valve sequence is recommended for the interlaced bottom lateral system.

Table E-13-3 Equalization Times with WSBs and Valve Overlap (ILCS)

Equalization	Time [Minutes]
Lake Gatun to Upper Lock	14.1
Upper Lock to Lower Lock	13.3
Lower Lock to Atlantic Ocean	14.9

13.8. Valve Loads

The valve loads presented in Table E-11-3 were used for the ILCS design.

13.9. Lock Gate Head Differentials

13.9.1. Overtravel

LOCKSIM analyses indicated a maximum reverse head of 0.89 m for a double-lift configuration with the ILCS. Recommended maximum reverse head differentials due to overtravel for use in concept design of the double-lift configuration with the ILCS are presented in Table E-13-4.

Table E-13-4 Maximum Reverse Head Differential Due to Overtravel (ILCS)

Lock Gate Location	Maximum Reverse Head Differential [m]	
	w/o WSBs	w/ WSBs
Between Lake Gatun and Upper Lock	0.39	0.43
Between Upper Lock and Lower Lock	0.87	0.89
Between Lower Lock and Atlantic Ocean	0.32	0.34

13.9.2. Between Gates

LOCKSIM analyses indicated a maximum reverse head differential of 0.99 m for a double-lift configuration with the interlaced bottom lateral system. Recommended maximum reverse head differentials due to operating with the inner gates closed for use in concept design of the double-lift configuration with the interlaced bottom lateral system are presented in Table E-13-5.

Table E-13-5 Maximum Reverse Head Differential Due to Closed Inner Gates (ILCS)

Lock Gate Location	Maximum Reverse Head Differential [m]	
	w/o WSBs	w/ WSBs
Between Upper Lock and Lower Lock	0.57	0.99
Between Lower Lock and Atlantic Ocean	0.31	0.80

13.10. Cavitation Index

A value of K_i greater than 0.61 is generally considered to be acceptable. For the interlaced bottom lateral system, a minimum value of approximately 0.99 was computed for a normal operation at the average lift.

13.11. Culvert Velocity

Culvert velocities were computed using Locksim. Maximum culvert velocities were estimated between 7.5 m/s for equalization with water saving basins and 10.7 m/s for operation without water saving basins. Maximum water saving basin conduit velocities were estimated to be 4.9 m/s.

13.12. Water Saving Basin Intakes

Cursory checks were made concerning the potential for serious vortices forming at the water saving basin intakes with the ILCS system. The minimum value of S/D calculated for draining the upper basin of the upper lock equals 2.9 times the Froude Number. The minimum desirable value is 2.3, suggesting vortices should not be a problem.

The plan shows both intakes for the lower basin located in a narrow corner opposite the valve platform. The maximum velocity within the basin at the edge of the platform was calculated as 1.34 m/s. Based on this velocity, water surface drawdown is estimated at 0.09 m, which should not have a significant effect on intake efficiency. Although the basin velocity does not seem excessive, contraction at the valve platform corner could contribute to a vortex. This should be checked with the physical model. If necessary, one or both intakes could move to another location within the basin.

13.13. Maintenance Conditions

Several maintenance conditions were evaluated to determine the potential impact of maintenance on system performance. The first maintenance condition assumes equalizations without use of the water saving basins while one valve in each lock culvert is out of service. Even if only one of the valves requires maintenance, one from each culvert should be taken out of service to maintain symmetry of the system. Two additional maintenance conditions were evaluated for equalizations with use of the water saving basins. One of these conditions assumes that all lock culvert valves are in service and one conduit per basin is out of service. The other condition assumes that one valve in each lock culvert is out of service and all basin conduits are in service. Results of these analyses are presented in Table E-13-6.

It is possible that the valves may need to be slowed down to prevent high transverse hawsers due to unbalanced flows under some of the maintenance conditions. This would increase the equalization times further. These effects cannot be evaluated using LOCKSIM and will require physical modeling.

Table E-13-6 Effect of Maintenance Conditions on Equalization Time (ILCS)

Equalization	Equalization Time [Minutes]				
	Operation Without WSBs		Operation With WSBs		
	Normal Operation	One Valve Per Culvert Out of Service	Normal Operation	One Valve Per Culvert Out of Service	One Conduit Per WSB Out of Service
Lake Gatun to Upper Lock	11.7	19.8	14.5	20.3	16.2
Upper Lock to Lower Lock	9.2	15.1	13.7	17.8	15.7
Lower Lock to Atlantic Ocean	11.8	20.0	15.3	21.0	17.3

13.14. Hawser Forces

13.14.1. Longitudinal Hawsers

In general, computed end-to-end water surface slopes for an unoccupied chamber were less than the recommended design criteria of 0.5/1000. The filling and emptying system provided satisfactory performance under both normal and maintenance conditions. The estimated slopes and hawsers presented in the following paragraphs are a relative indicator of lock performance and not necessarily a prediction of actual forces. Future studies should include a physical hydraulic model that would include measurement of longitudinal hawser forces.

13.14.1.1. Downstream Inner Gates Open

A summary of longitudinal water surface slopes for equalizations with the downstream inner gates open is presented in Table E-13-7.

Table E-13-7 Estimated Typical Longitudinal Water Surface Slopes (ILCS with Downstream Inner Gates Open)

Equalization	Operation Without WSBs	Operation With WSBs
	Maximum Slope (1/1000)	Maximum Slope (1/1000)
Lake Gatun to Upper Lock	0.31	0.52
Upper Lock to Lower Lock	0.25	0.35
Lower Lock to Atlantic Ocean	0.21	0.31

13.14.1.2. Downstream Inner Gates Closed

A summary of longitudinal water surface slopes for equalizations with the downstream inner gates closed is presented in Table E-13-8. Overall, the values are lower than Table E-13-7.

Table E-13-8 Estimated Typical Water Surface Slopes (ILCS with Downstream Inner Gates Closed)

Equalization	Operation Without WSBs	Operation With WSBs
	Maximum Slope (1/1000)	Maximum Slope (1/1000)
Lake Gatun to Upper Lock	0.30	0.23
Upper Lock to Lower Lock	0.22	0.13
Lower Lock to Atlantic Ocean	0.13	0.22

13.14.1.3. Maximized Slopes

Maximum slopes for superimposed oscillations resulting from successive valve operations were computed assuming downstream inner gates open. A summary of maximum longitudinal water surface slopes is presented in Table E-13-9. Note that this phenomenon does not affect operations without water saving basins so the values of Table E-13-7 are repeated. The values with water saving basins are only slightly higher than Table E-13-7.

Table E-13-9 Estimated Maximum Longitudinal Water Surface Slopes (ILCS with Downstream Inner Gates Open)

Equalization	Operation Without WSBs	Operation With WSBs
	Maximum Slope (1/1000)	Maximum Slope (1/1000)
Lake Gatun to Upper Lock	0.31	0.52
Upper Lock to Lower Lock	0.25	0.50
Lower Lock to Atlantic Ocean	0.21	0.32

13.14.1.4. Ship Effects

Cursory computations were performed with the beta version of LOCKSIM, which accounts for the presence of a ship in the lock chamber. The design container ship was represented with downstream inner gates open. Results are presented in Table E-13-10. The predicted slopes (maximized for operations without water saving basins) are approximately twice as high as those shown in Table E-13-9. However, they remain below 1/1000. The estimated forces are less than the recommended maximum of 209 t.

Table E-13-10 Estimated Maximum Longitudinal Hawsers for Design Container Ship (ILCS with Downstream Inner Gates Open using LOCKSIM Beta Version - Ship Effect Included)

Equalization	Operation Without WSBs		Operation With WSBs	
	Maximum Slope (1/1000)	Estimated Hawser [t]	Maximum Slope (1/1000)	Estimated Hawser [t]
Lake Gatun to Upper Lock	0.67	140	0.82	171
Upper Lock to Lower Lock	0.59	123	0.70	146
Lower Lock to Atlantic Ocean	0.30	63	0.73	153

13.14.2. Transverse Hawsers

The one-dimensional LOCKSIM model does not have the capability to estimate transverse hawsers. Designs have been developed based upon research findings and other similar designs to minimize the potential for adverse transverse hawsers. Future studies should include a physical hydraulic model testing program which includes the measurement of transverse hawsers.

13.15. Recommended Operation Plan

13.15.1. Without Water Saving Basins

Filling and emptying curves and end to end water surface slopes for equalizations without water saving basins using the recommended operating plan are shown in Figures E-13-1 and E-13-2. The recommended operating plan incorporates the valve schedule presented in Table E-11-2. The downstream inner gates are assumed to be in a closed position.

Figure E-13-1 Equalization Without Water Saving Basins (ILCS)

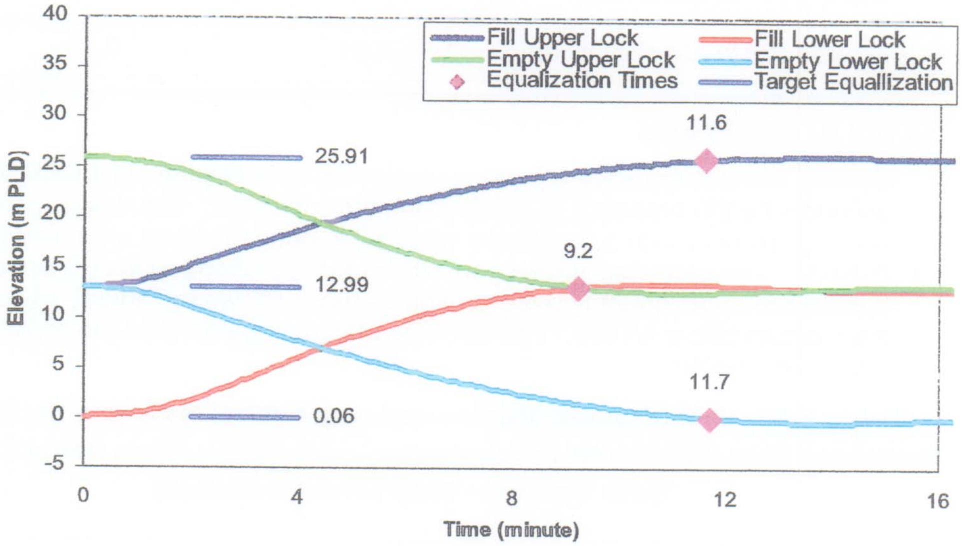
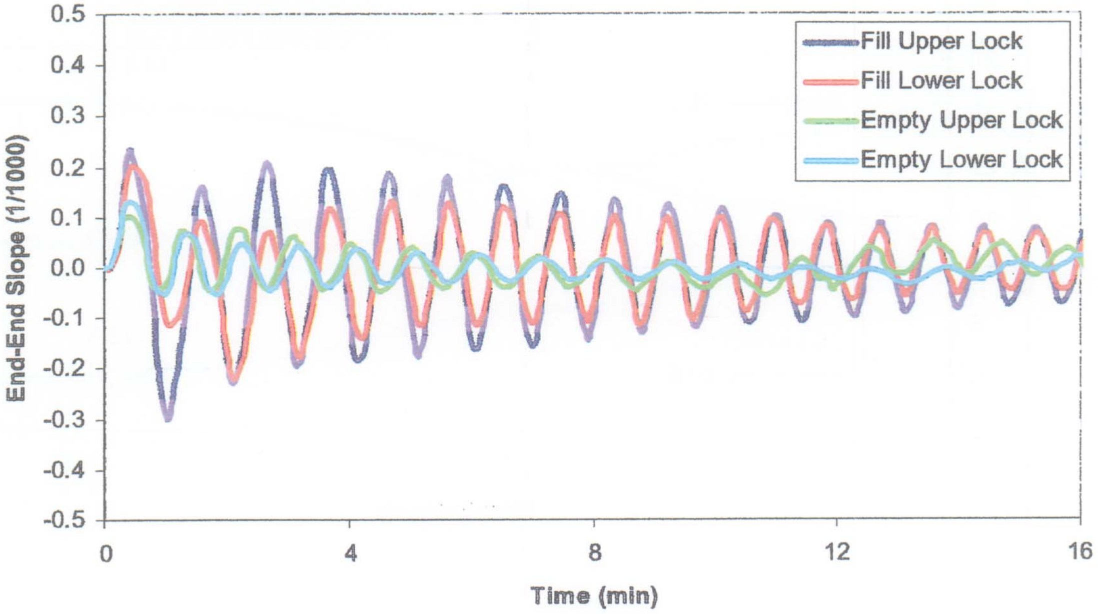


Figure E-13-2 End to End Water Surface Slopes Without Water Saving Basins (ILCS)



13.15.2. With Water Saving Basins

Filling and emptying curves and typical end-to-end water surface slopes for equalization with water saving basins using the recommended operating plan are shown in Figures E-13-3 and E-13-4. The recommended operating plan incorporates the valve times presented in Table E-11-2 with a 0.4 minute overlap between the water saving basin valves and the lock culvert valves. In addition, the valve time for lock to lock operations was assumed to be three minutes to maintain maximized slopes less than 0.5/1000. The basins are operated with zero residual depth and the downstream inner gates are assumed to be in the closed position. Equalization times tend to be slightly longer with water saving basin use compared to the without water saving basin operations because of a 50% reduction in the initial driving head and the additional valve operations required with use of the basins.

Figure E-13-3 Equalization With Water Saving Basins (ILCS)

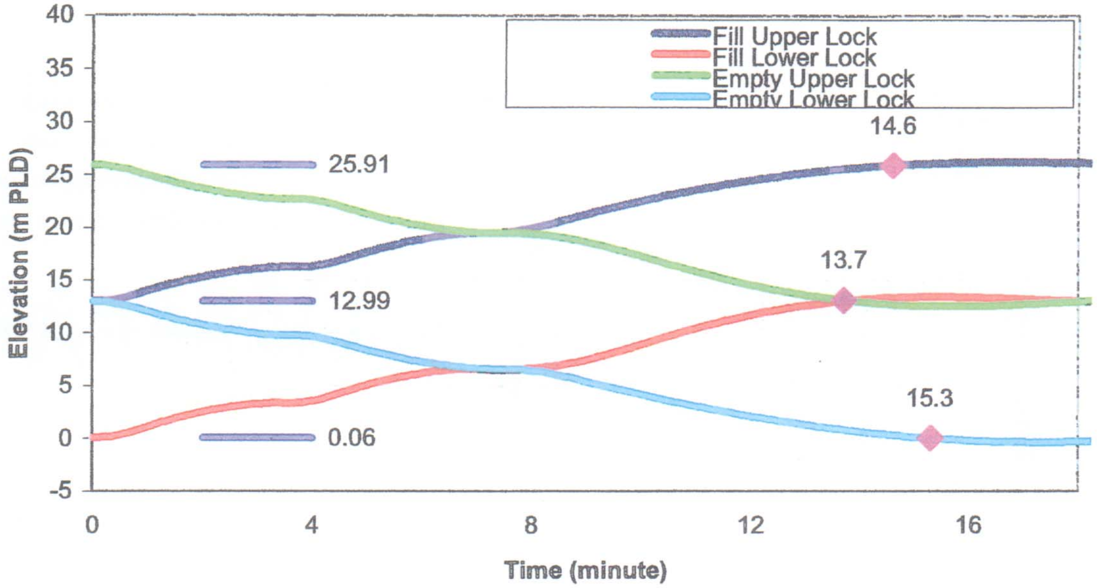
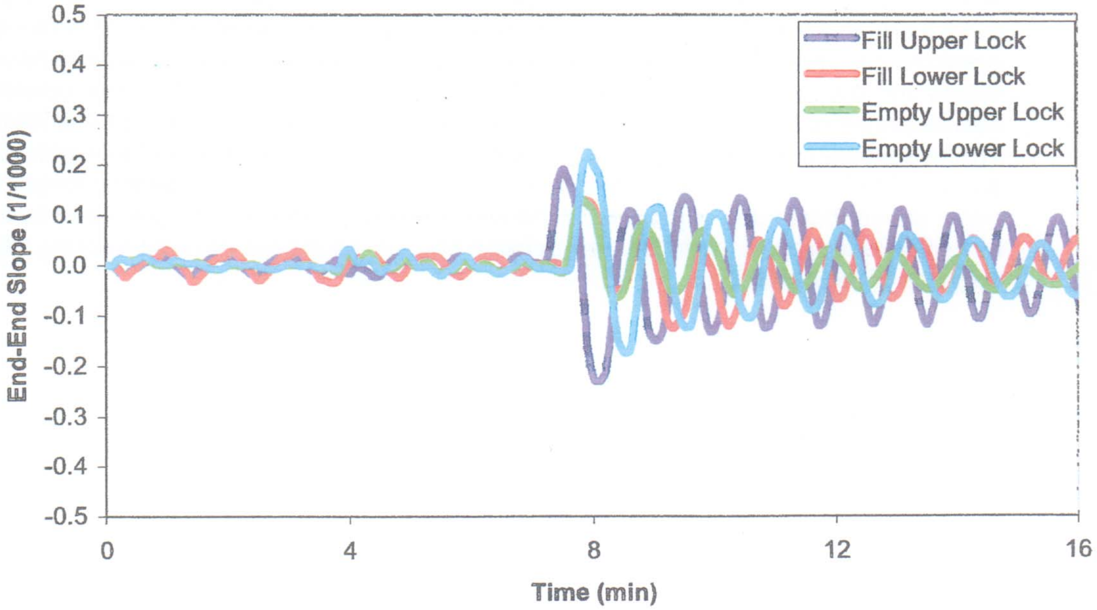
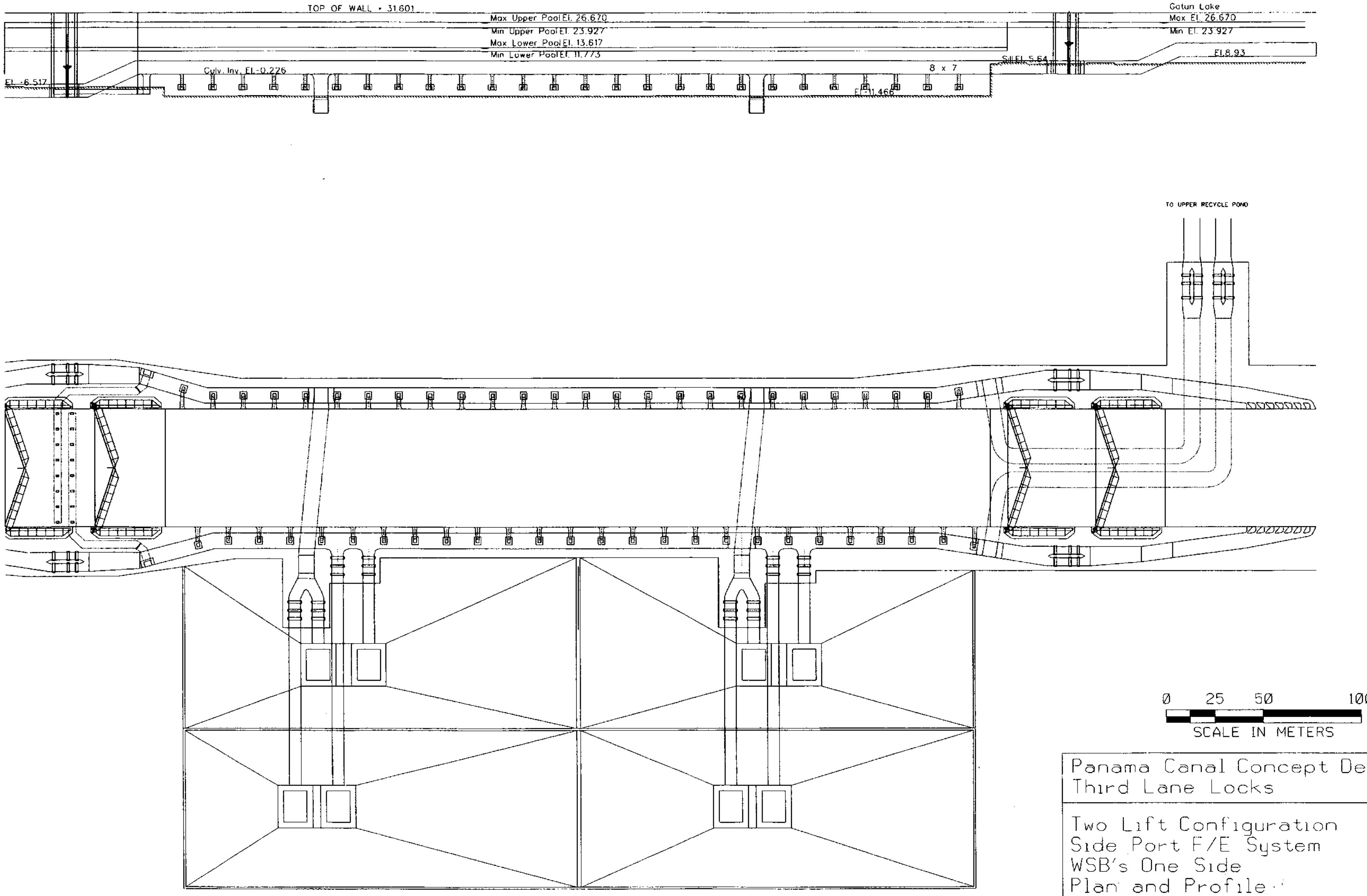


Figure E-13-4 End to End Water Surface Slopes With Water Saving Basins (ILCS)



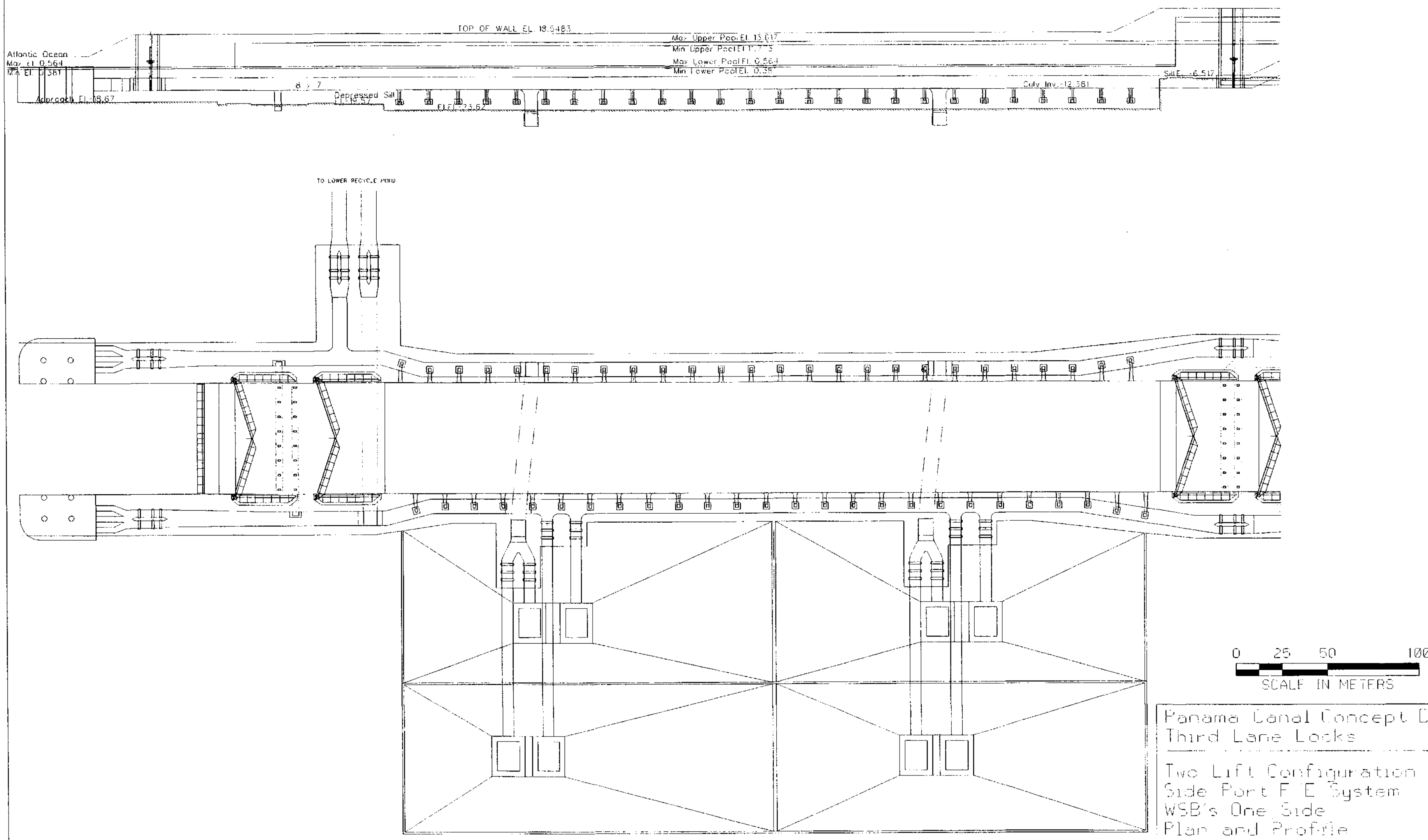
PLATES



Panama Canal Concept Design
Third Lane Locks

Two Lift Configuration
Side Port F/E System
WSB's One Side
Plan and Profile
Upper Lock

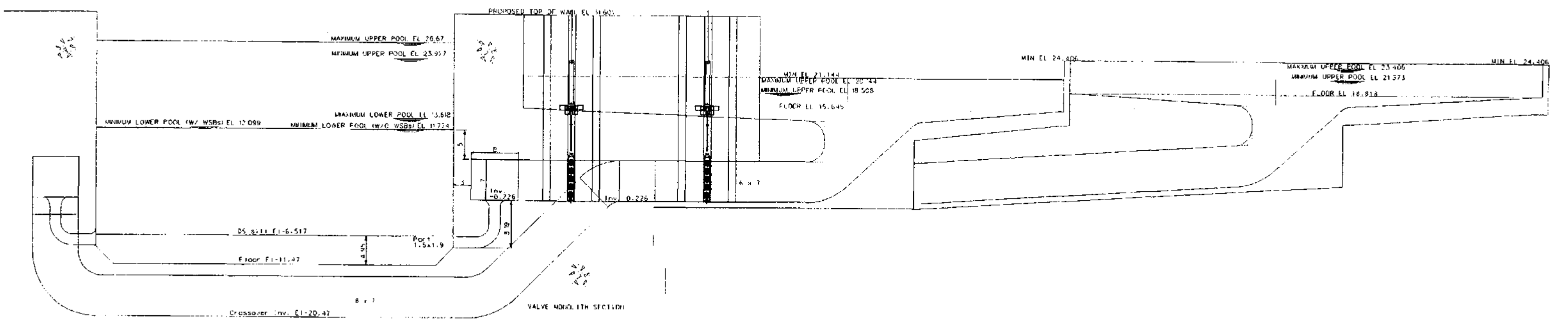
Plate E-1



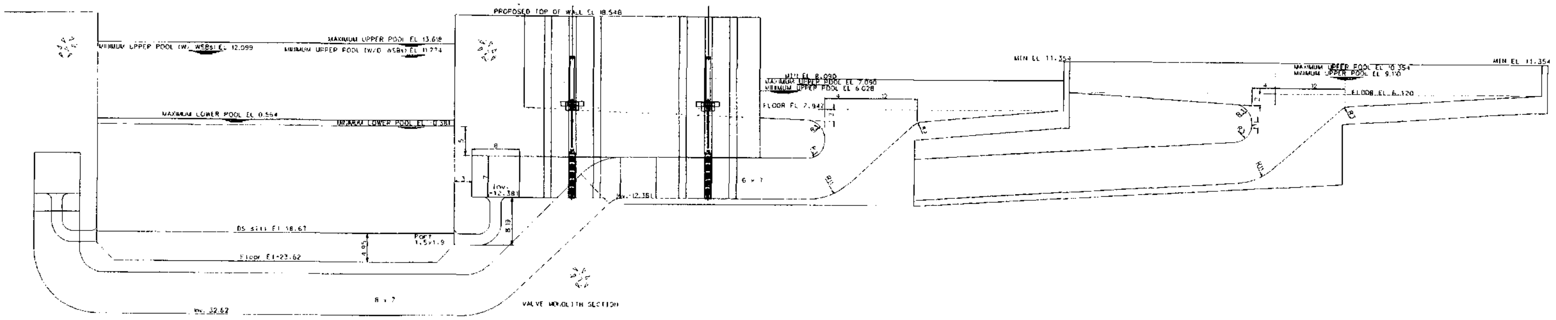
Panama Canal Concept Design
Third Lane Locks

Two Lift Configuration
Side Port F E System
WSB's One Side
Plan and Profile
Lower Lock

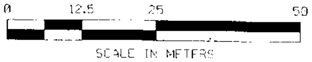
Plate E-2



Upper Lock



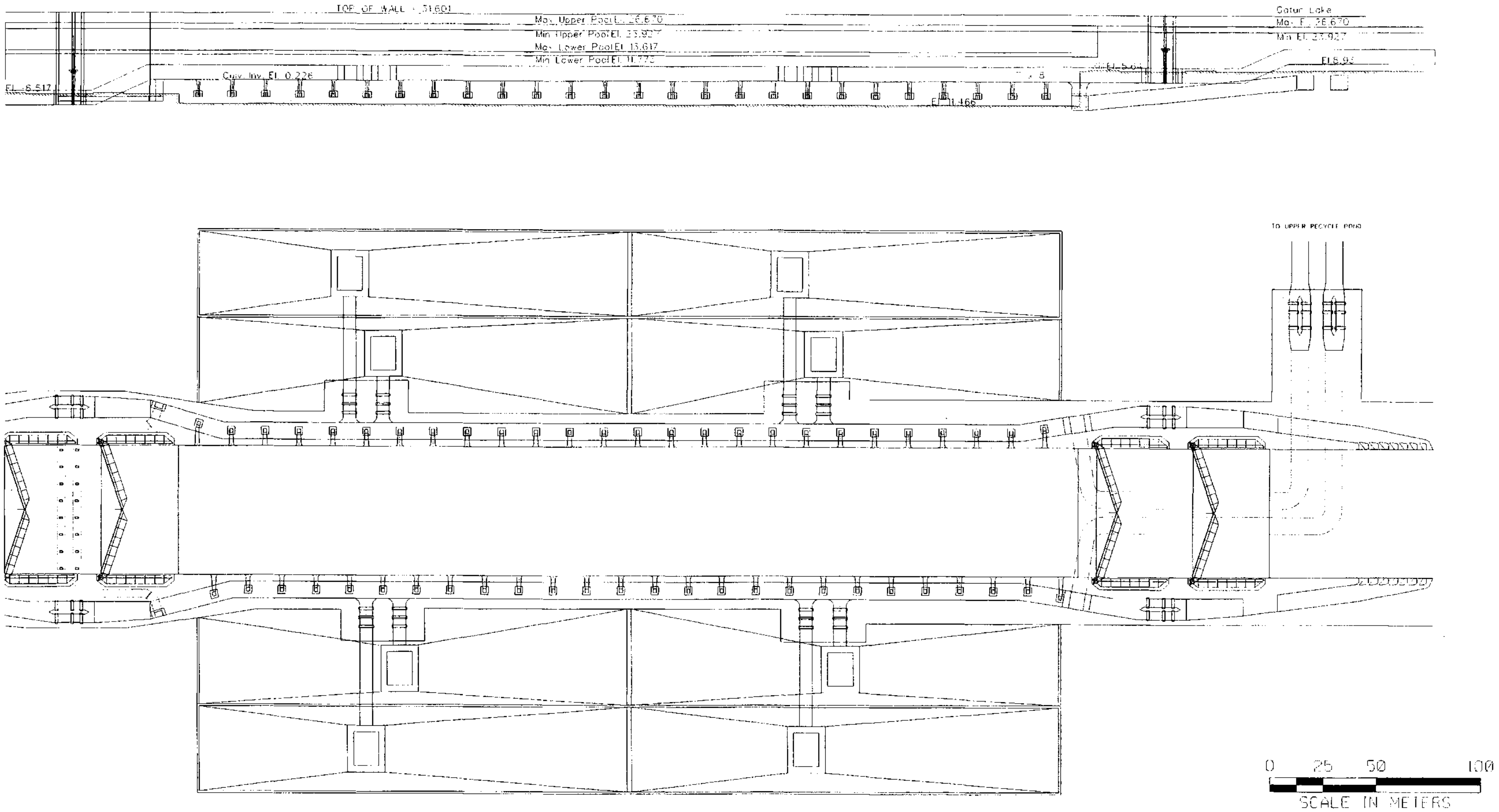
Lower Lock



Panama Canal Concept Design
Third Lane Locks

Two Lift Configuration
Side Port F/E System
WSB's One Side
Cross Sections
Upper and Lower Lock

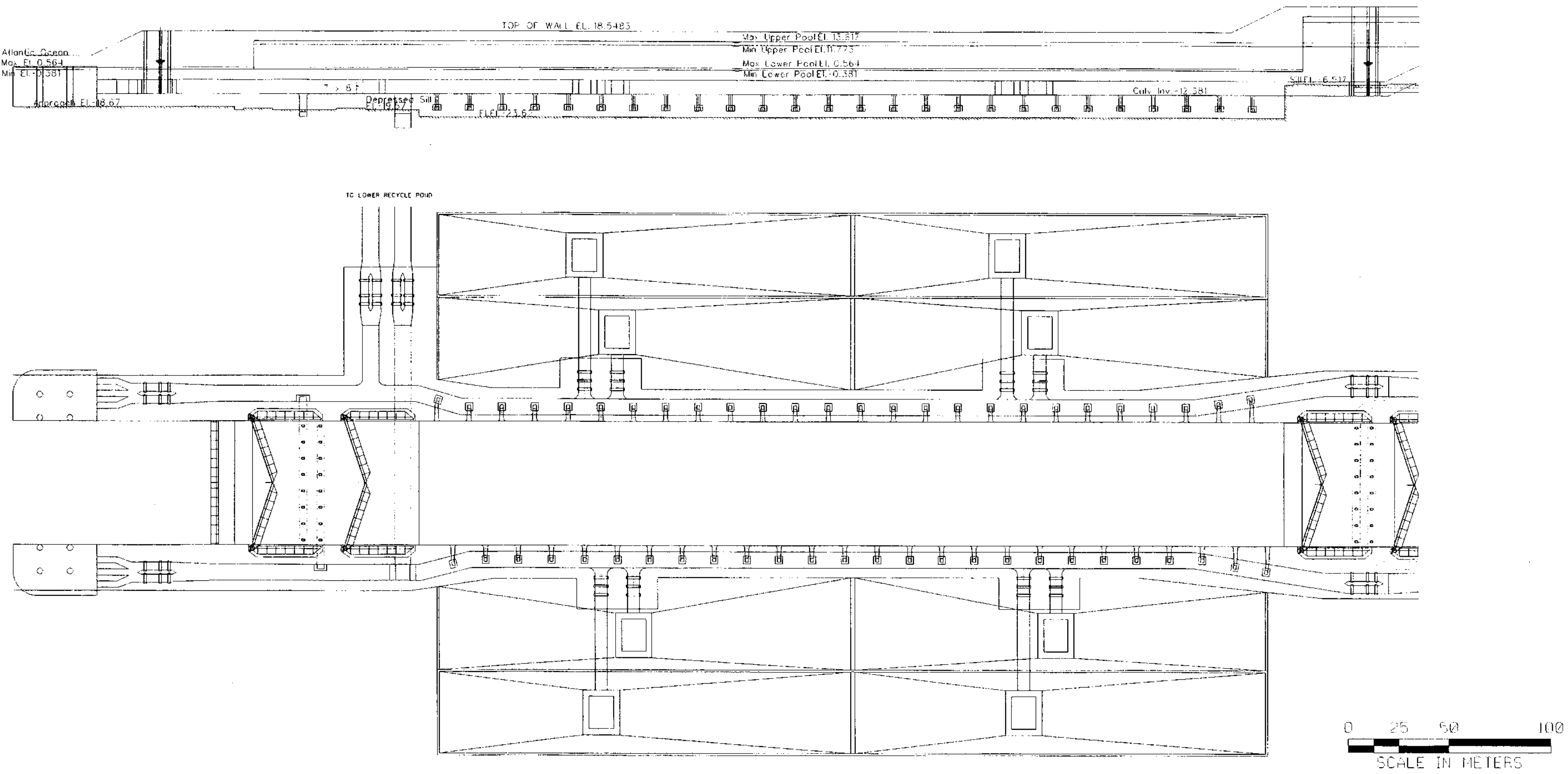
Plate E-3



Panama Canal Concept Design
Third Lane Locks

Two Lift Configuration
Side Port F/E System
WSB's Both Sides
Plan and Profile
Upper Lock

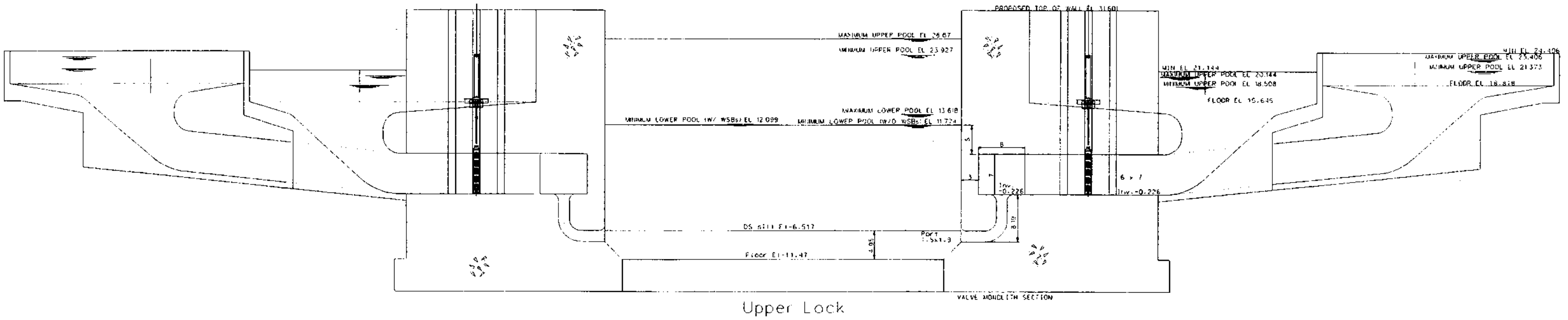
Plate E-4



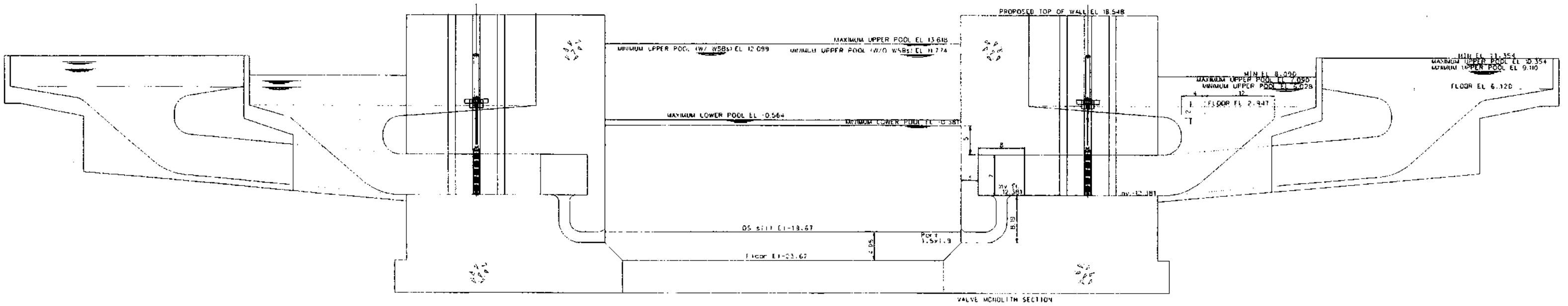
Panama Canal Concept Design
Third Lane Locks

Two Lift Configuration
Side Port F/E System
WSB's Both Sides
Plan and Profile
Lower Lock

Plate E-5



Upper Lock



Lower Lock

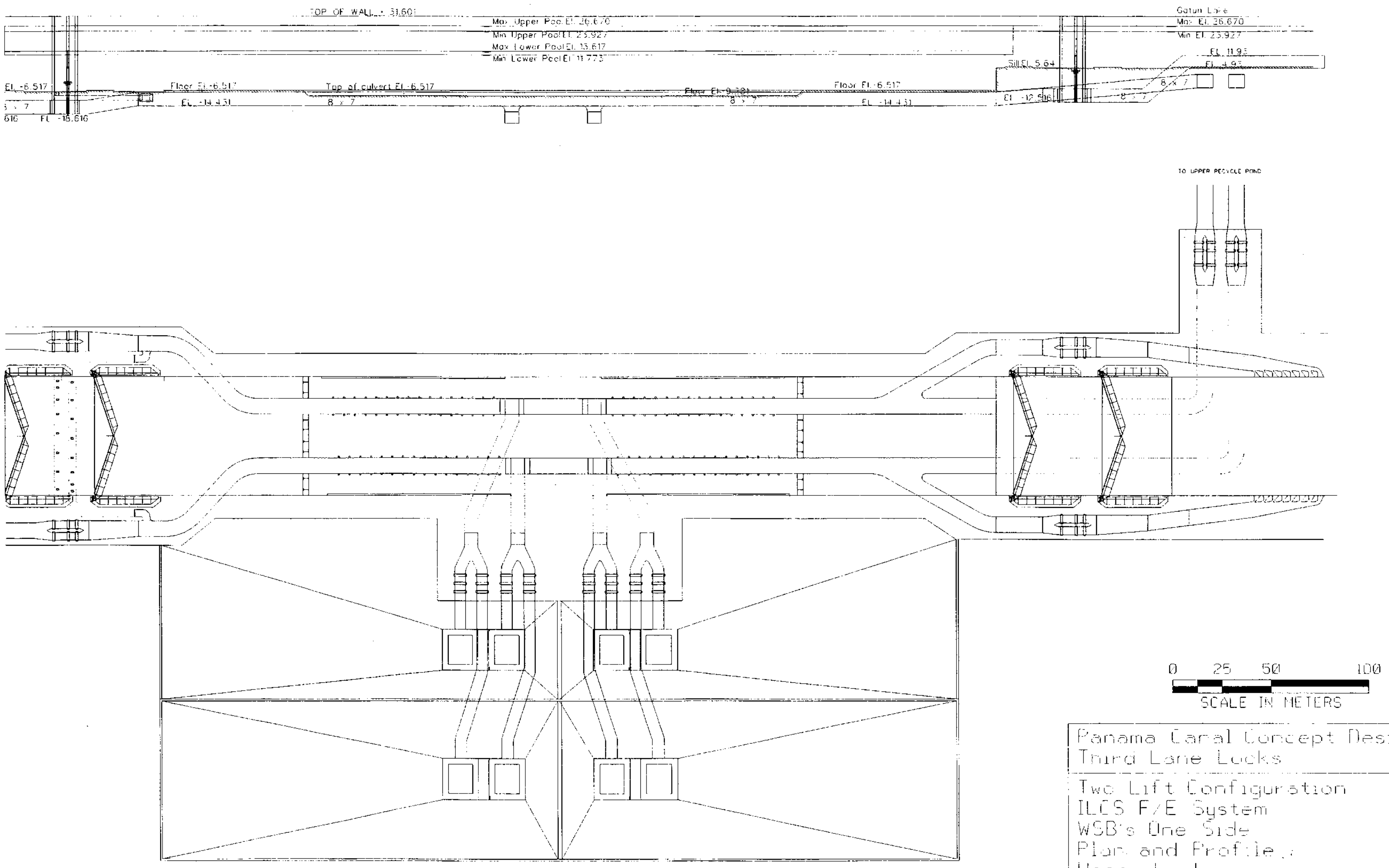
0 12.5 25 50

SCALE IN METERS

Panama Canal Concept Design
Third Lane Locks

Two Lift Configuration
Side Port F/E System
WSB's Both Sides
Cross Sections of
Upper and Lower Lock

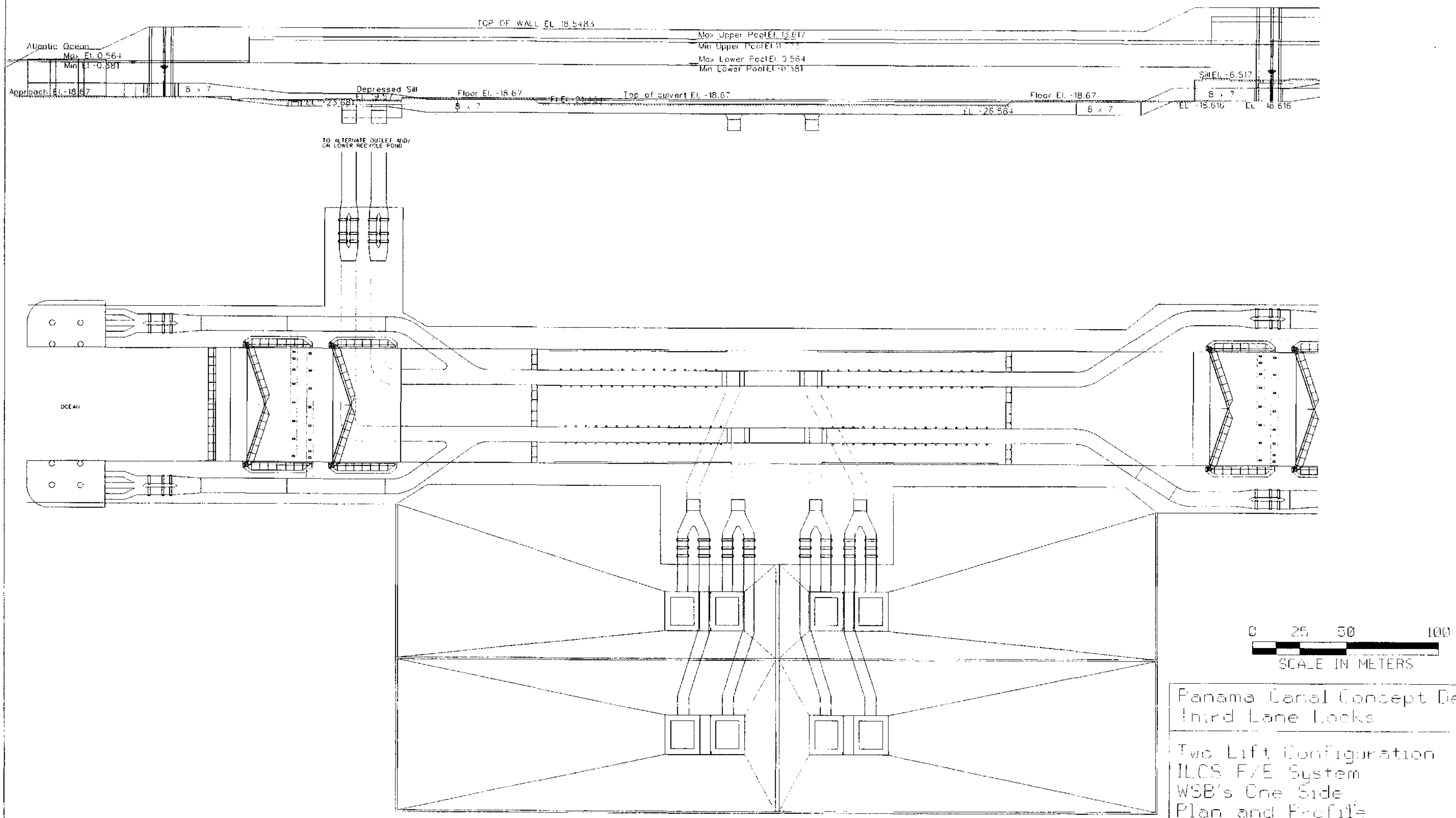
Plate F-6



Panama Canal Concept Design
Third Lane Locks

Two Lift Configuration
ILCS F/E System
WSB's One Side
Plan and Profile,
Upper Lock

Plate E 7

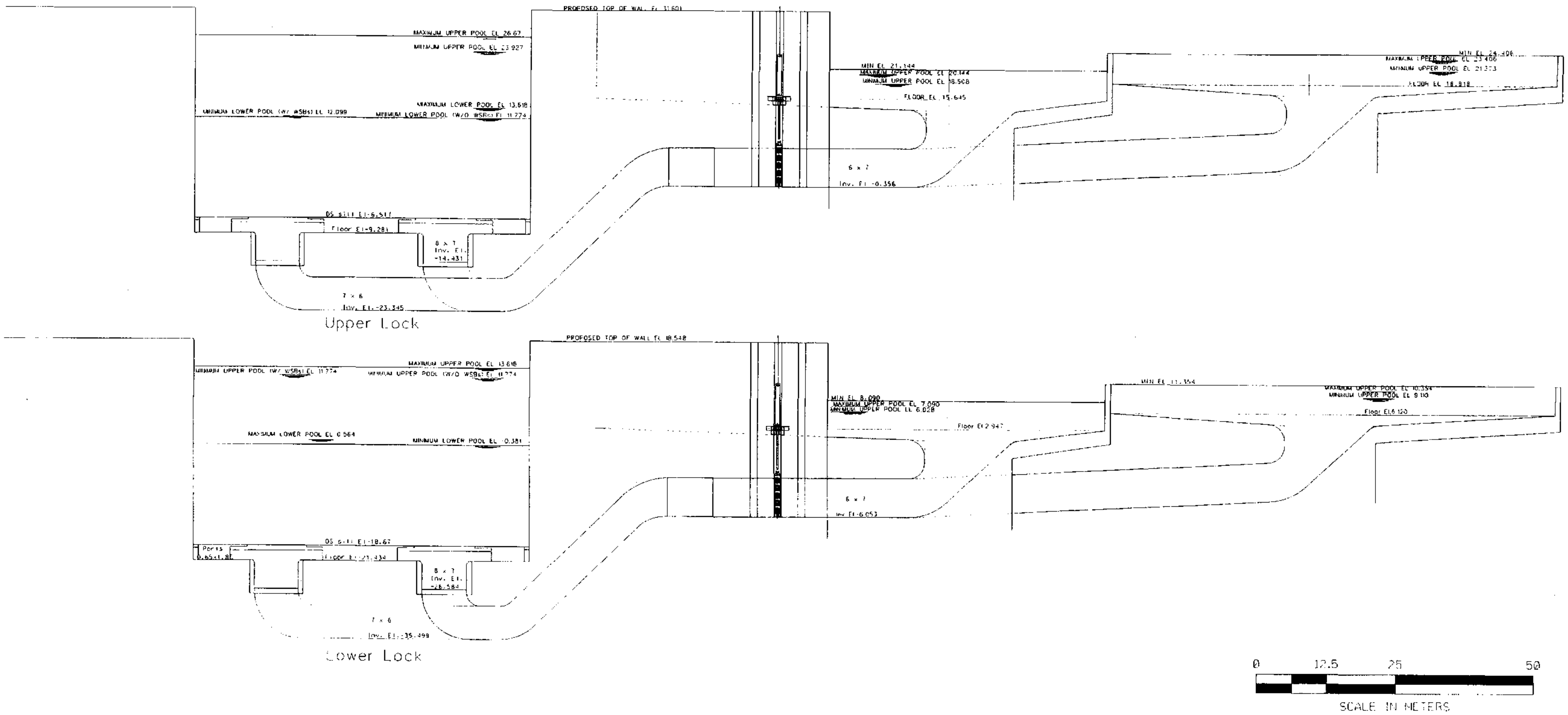


Panama Canal Concept Design
Third Lane Locks

Two Lift Configuration
ILCS F/E System
WSB's One Side
Plan and Profile
Lower Lock

Plate E-8

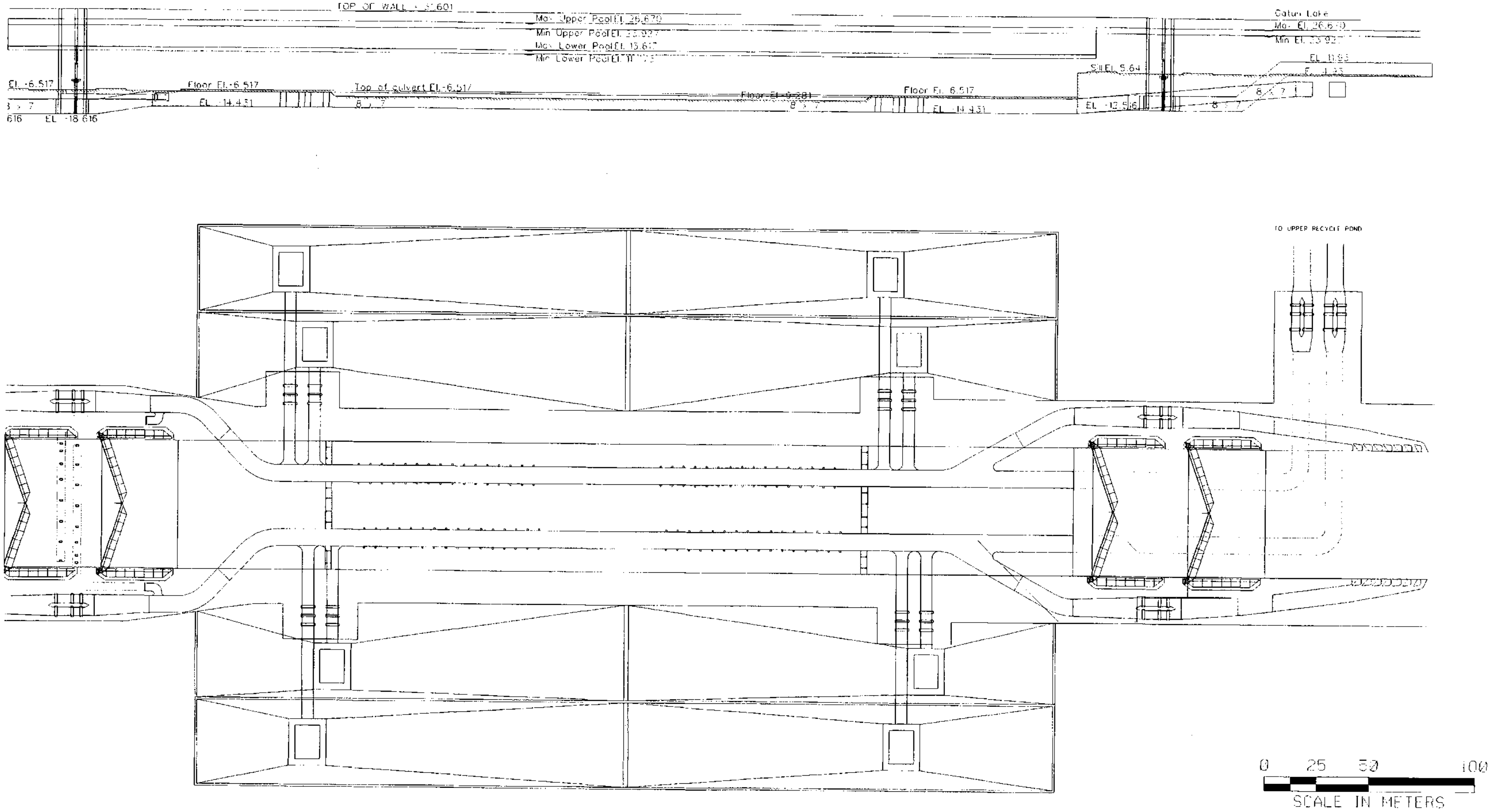
MEAN POOLS ELEV'S:
Lake: 25.91
Middle: 12.99
Ocean: 0.06



Panama Canal Concept Design
Third Lane Locks

Two Lift Configuration
ILCS F/E System
WSB's One Side
Cross Sections
Upper and Lower Lock

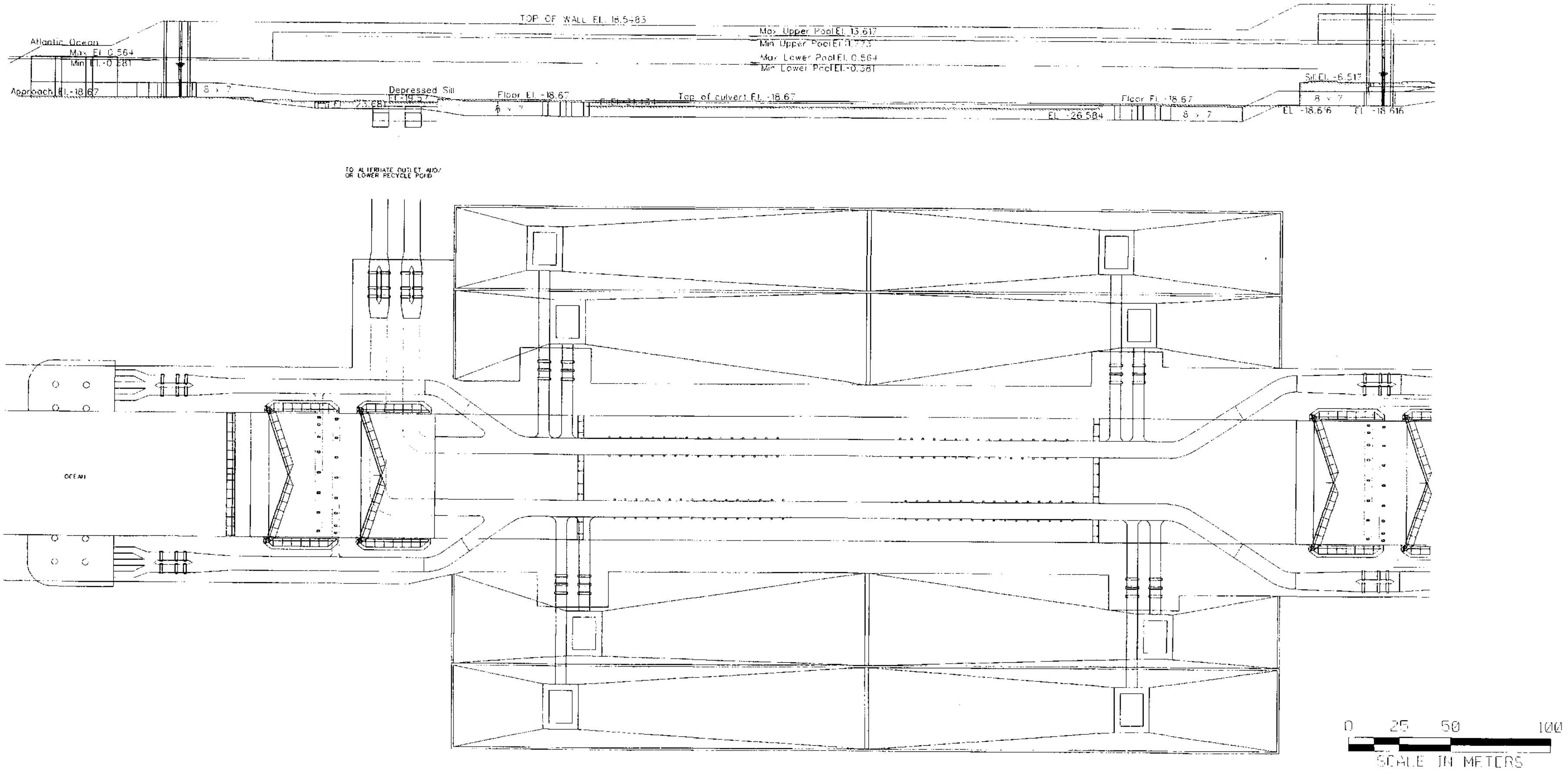
Plate E-9



Panama Canal Concept Design
Third Lane Locks

Two Lift Configuration
ILCS F/E System
WSB's Both Sides
Plan and Profile
Upper Lock

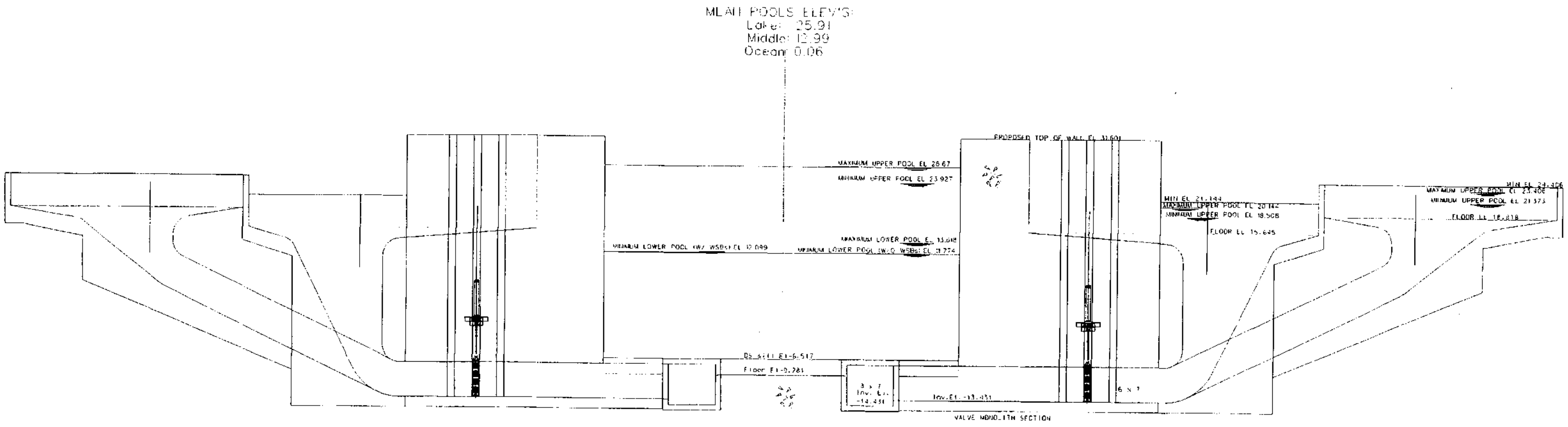
Plate E-10



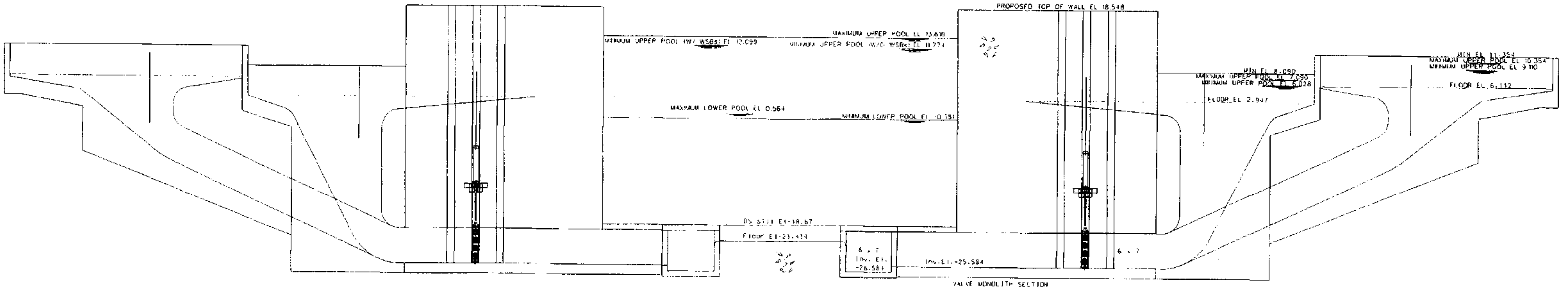
Panama Canal Concept Design
Third Lane Locks

Two Lift Configuration
ILCS F/E System
WSB's Both Sides
Plan and Profile
Lower Lock

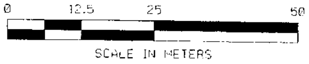
Plate E-11



Upper Lock



Lower Lock

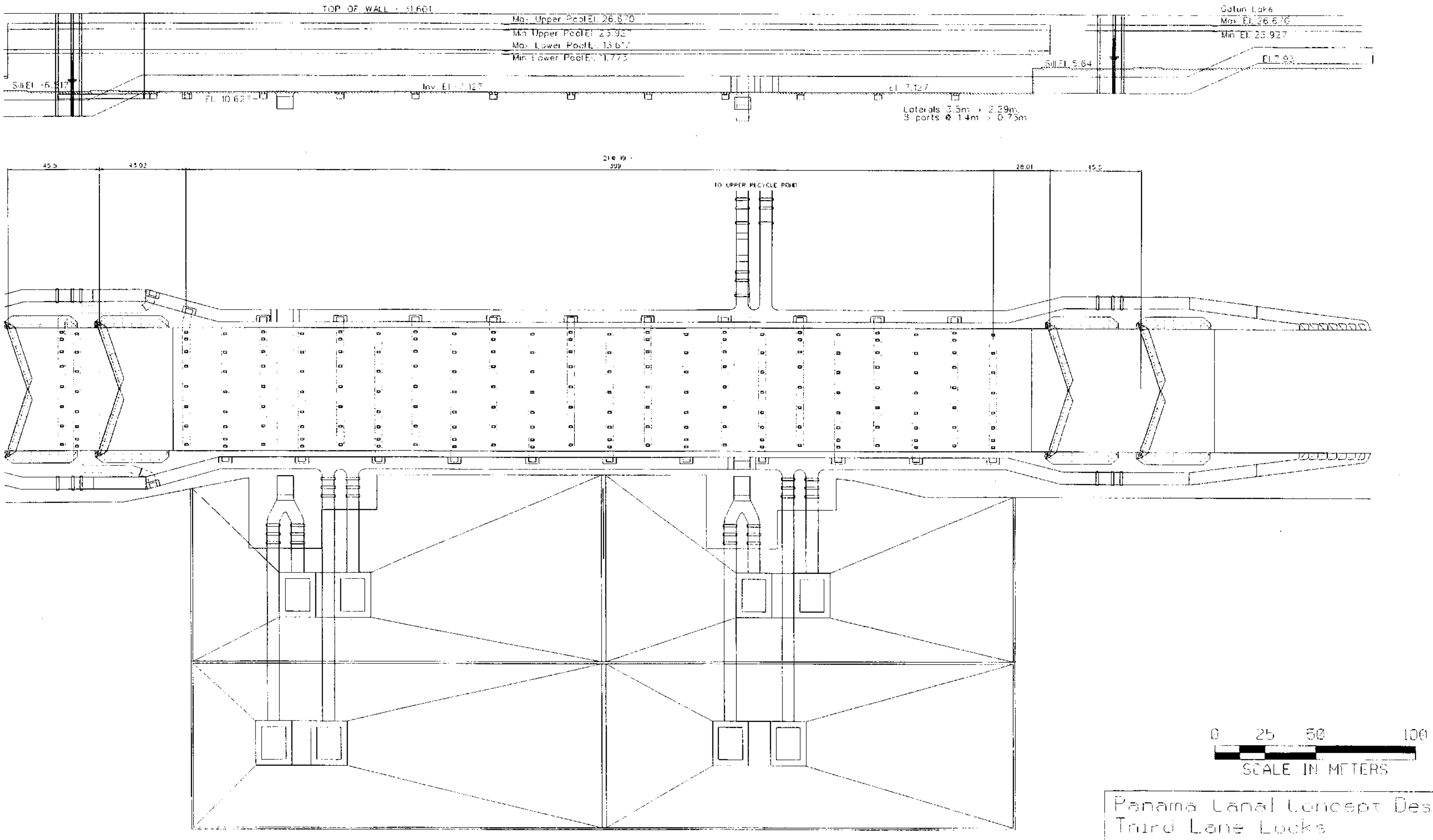


SCALE IN METERS

Panama Canal Concept Design
Third Lane Locks

Two Lift Configuration
ILCS F/E System
WSB's Both Sides
Cross Sections
Upper and Lower Lock

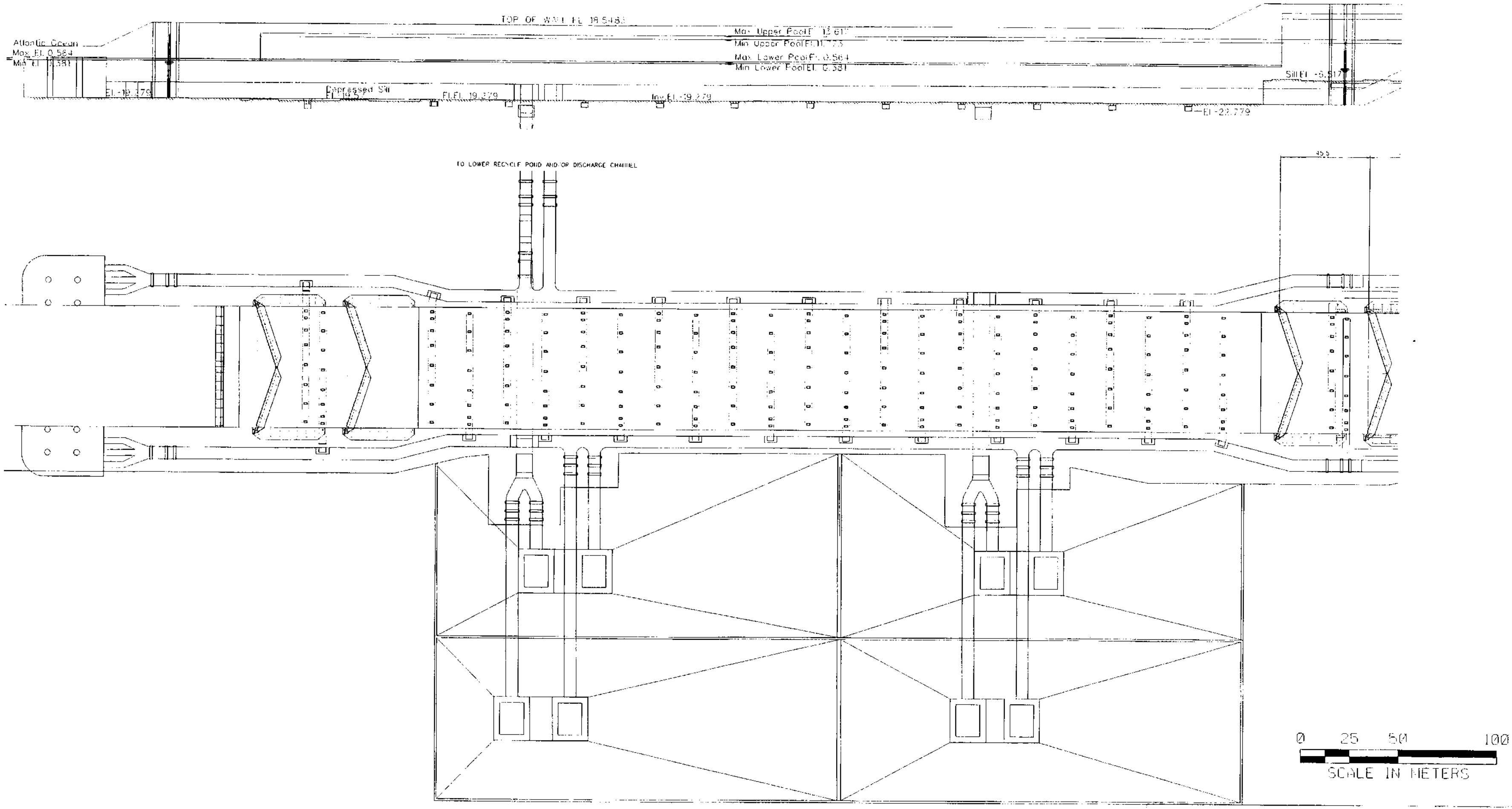
Plate E-12



Panama Canal Concept Design
Third Lane Locks

Two Lift Configuration
Bottom Lateral F. E. System
WSB's One Side
Plan and Profile
Upper Lock

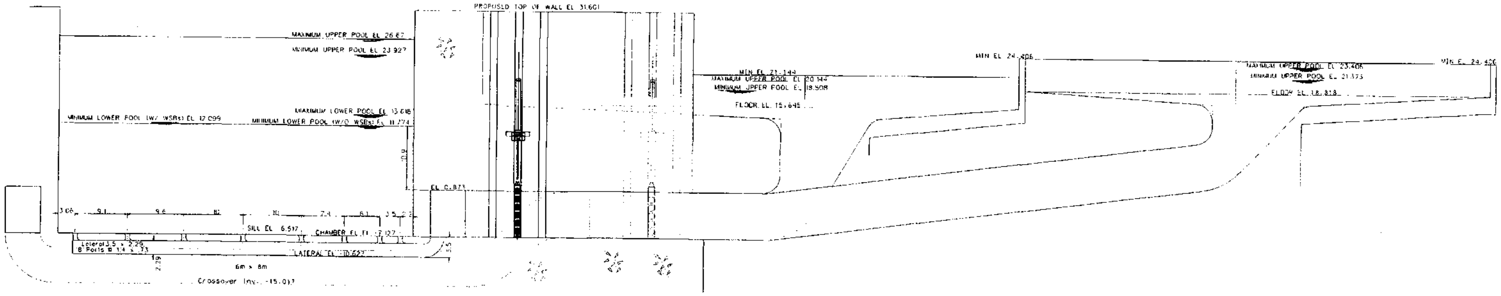
Plate E-13



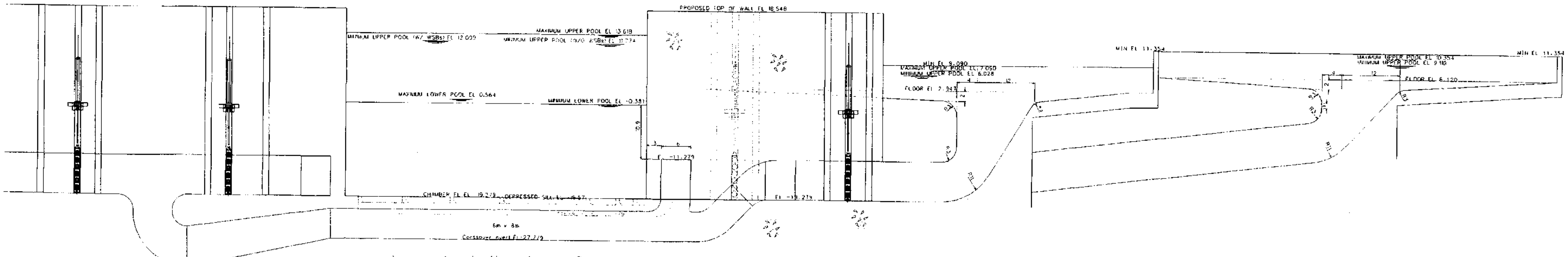
Panama Canal Concept Design
Third Lane Locks

Two Lift Configuration
Bottom Lateral F E System
WSB's One Side
Plan and Profile
Lower Lock

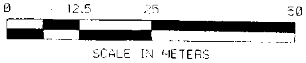
Plate E-14



Upper Lock thru Lateral



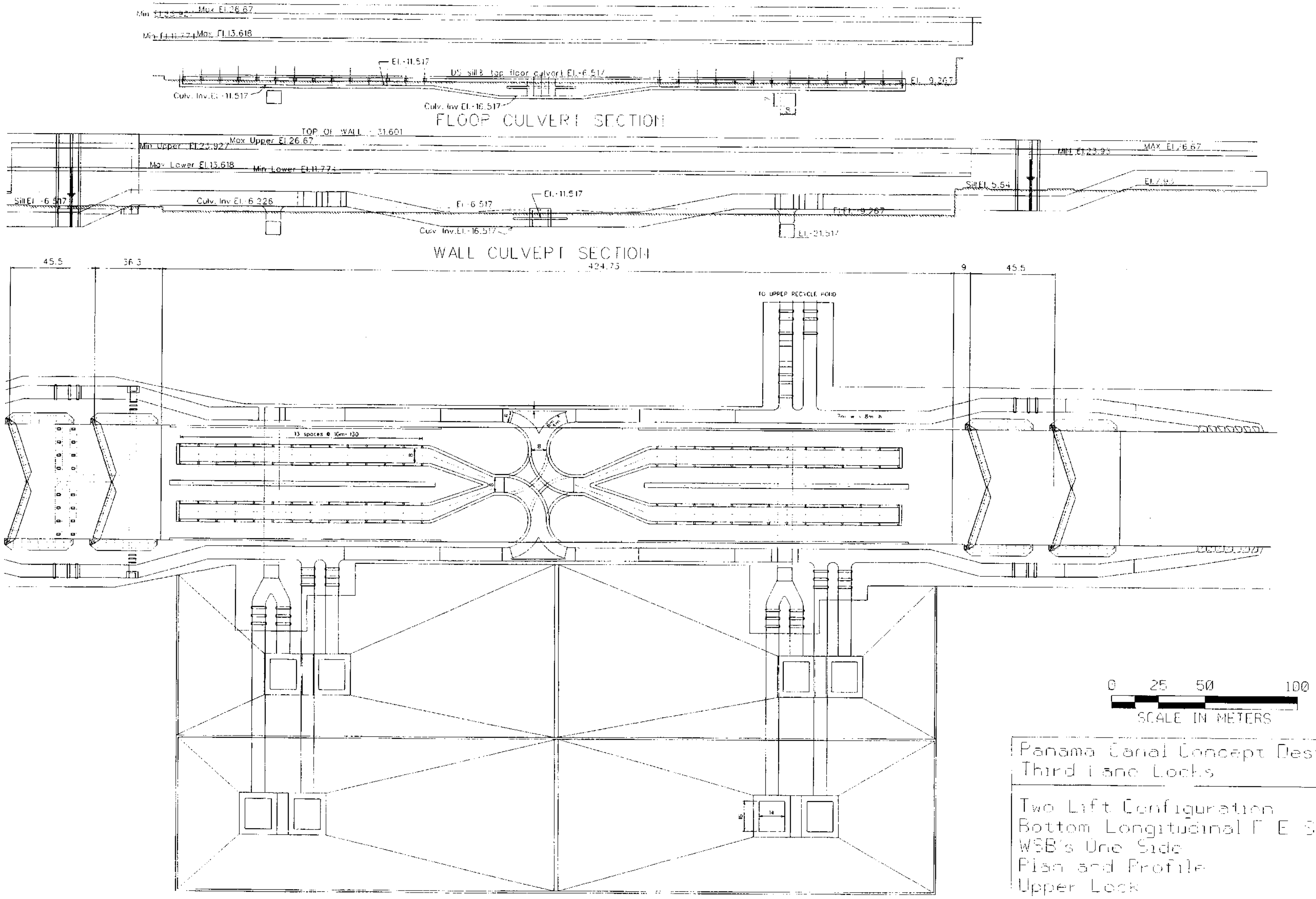
Lower Lock thru lower Crossover



Panama Canal Concept Design
Third Lane Locks

Two Lift Configuration
Bottom Lateral F E System
WSB's One Side
Cross Sections
Upper and Lower Lock

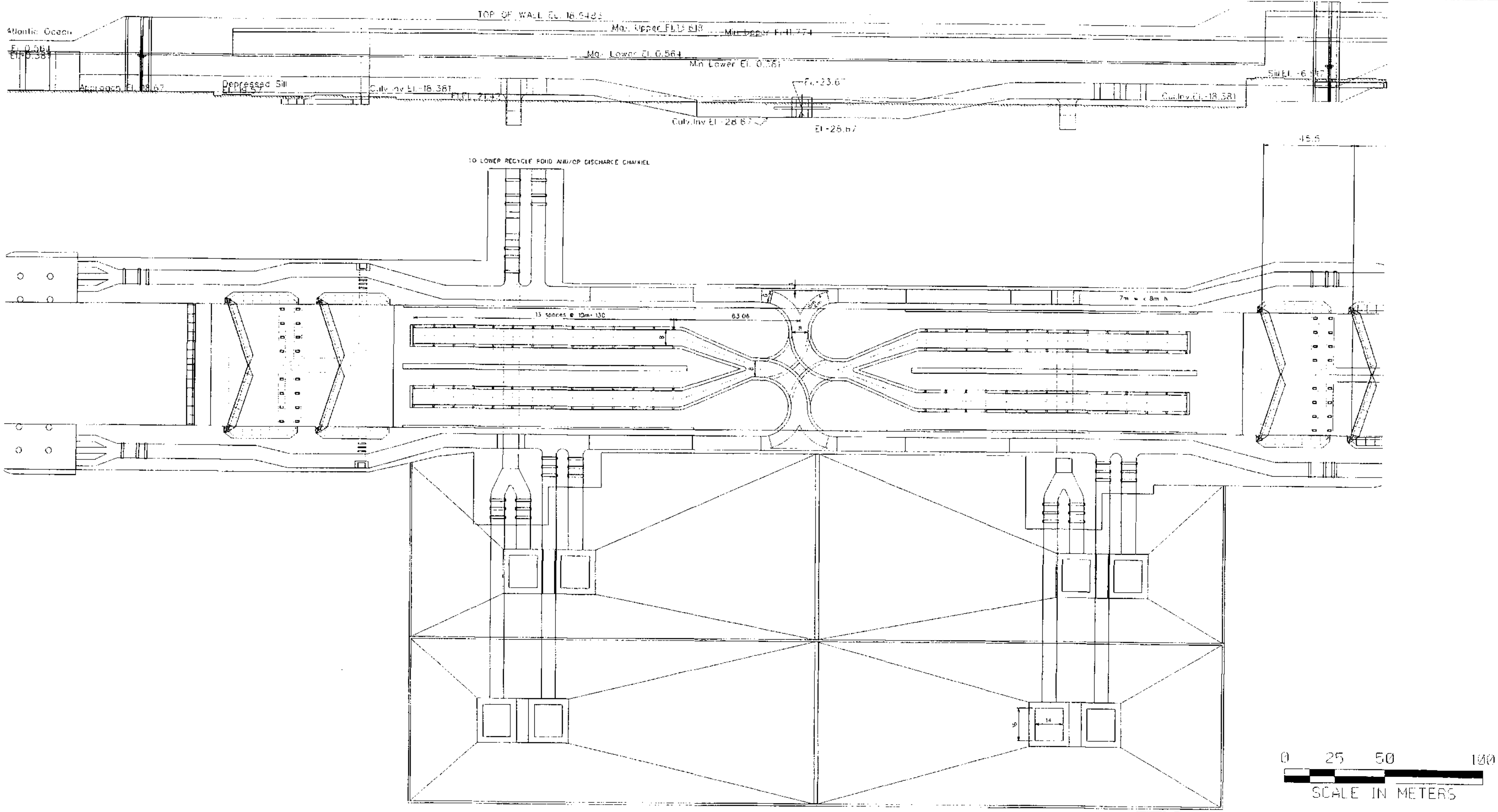
Plate E-15



Panama Canal Concept Design
Third Lane Locks

Two Lift Configuration
Bottom Longitudinal F E System
WSB's One Side
Plan and Profile
Upper Lock

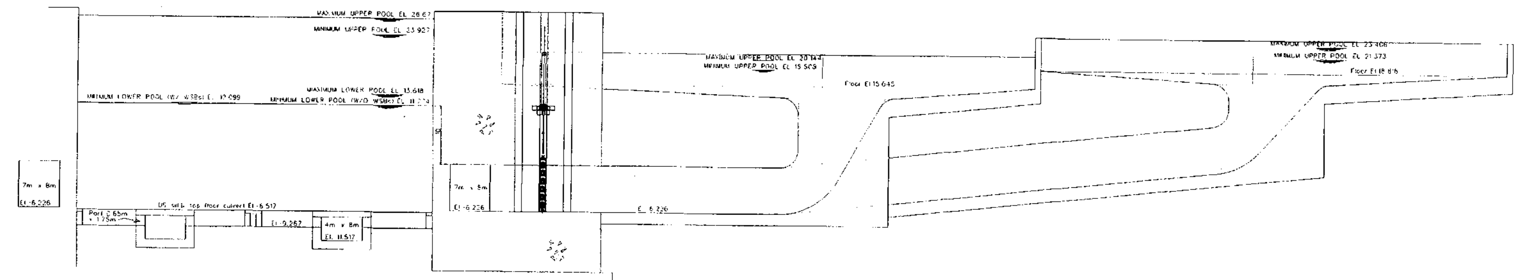
Plate E-16



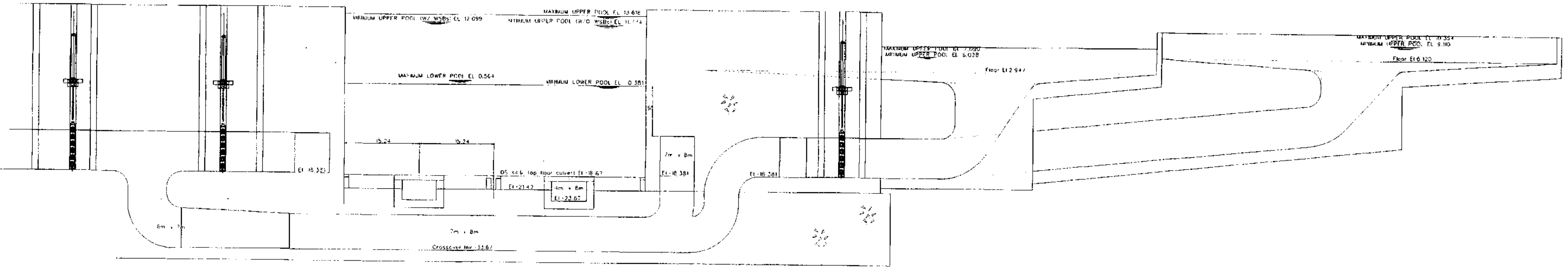
Panama Canal Concept Design
Third Lane Locks

Two Lift Configuration
Bottom Longitudinal F E System
WSB's One Side
Plan and Profile
Lower Lock

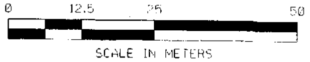
Plate E-17



UPPEP LOCK SECTION THRU DIPFCT COIINECT CONDUIT



LOWER LOCK SECTION THRU CROSSOVER & RECYCLE CULVERT



Panama Canal Concept Design
Third Lane Locks

Two Lift Configuration
Bottom Longitudinal F E System
WSB's One Side
Cross Sections
Upper and Lower Lock

Plate E-18

PANAMA CANAL CONCEPT DESIGN

Atlantic Locks Structure

Third Lane Lock

Appendix F

Lock Masonry Analyses and Designs

Prepared for

Canal Capacity Projects Office

By

US Army Corps
of Engineers®

Final Report
23 July 2003

Table of Contents

Table of Contents

List of Figures

List of Tables

1. PRELIMINARY/CONCEPT ANALYSIS AND DESIGN OF THE MITER GATE MONOLITHS

1.1. Background

This section discusses the design for gravity Lock Monoliths to be used as miter gate monoliths. This design will provide support for overall design conceptualization and preliminary cost estimates. Three (3) gravity lock monolith designs are provided – the north (Atlantic), center and south (Gatun Lake) miter gate monoliths.

1.2. Scope

This work includes the preliminary assessment of loads and combinations, structural analyses and concrete reinforcement design for three new gravity miter-gate monoliths. The work has been accomplished using the worst-case design cross-sections and loads (seismic) for the miter gate monoliths.

1.3. Description.

The miter gate monoliths are designed as concrete gravity structures (Figure F-1-1 and report drawings ACP-R-20/10 and 20/11). There are three gate bays in the proposed double-lift lock arrangement. Each gate bay has two sets of lock gates and requires 4 miter gate monoliths (report drawings ACP-R-20/2 and 20/3). The lock will have twelve (12) miter gate monoliths, four (4) in each of the three gate bays. These monoliths house the gate operating machinery and the gate anchorages (the pintle and the top anchorage) and contain the Operating, Electrical and Valve HPU (Hydraulic Power Unit) Galleries, Valve HPU and Transformer Rooms, Valve Chambers and Culverts. The monoliths will have 5-m recesses under a cantilevered top concrete section that allows the gates to be recessed flush with the faces of the walls. A removable bridge is provided over the gate anchorage to support a locomotive type ship positioning system (report drawing ACP-R-20/19). The removable bridge provides access to the miter gate anchorage and permits the removal and replacement of a gate leaf. A culvert for the filling and emptying system passes through each gate monolith and galleries are provided to access operating equipment.

The tops of the south (Gatun Lake) and the center gate bay monoliths are at elevation EL +31.60. The top elevation of the north gate bay is EL +18.55. The overall length of each gate bay is 91 m with a spacing between pintles of 45.46 m. The base width varies from 23.3 m to 29.5 m, and the top width varies from 22.5 m to 25.5 m. The miter gate monoliths are all founded on the tuffaceous sandstone unit. For details of the miter gate monoliths, see report drawings ACP-R-20/2, 20/3,

1.4. Design Criteria and Assumptions

The miter gate monoliths are proportioned to satisfy the design criteria listed in Appendix A, Section 5.24. Each monolith is assumed to act independently of the adjacent monoliths.

1.4.1. References

1. ER 1110-2-1150 Engineering and Design for Civil Works Projects, 31 Aug. 1999.

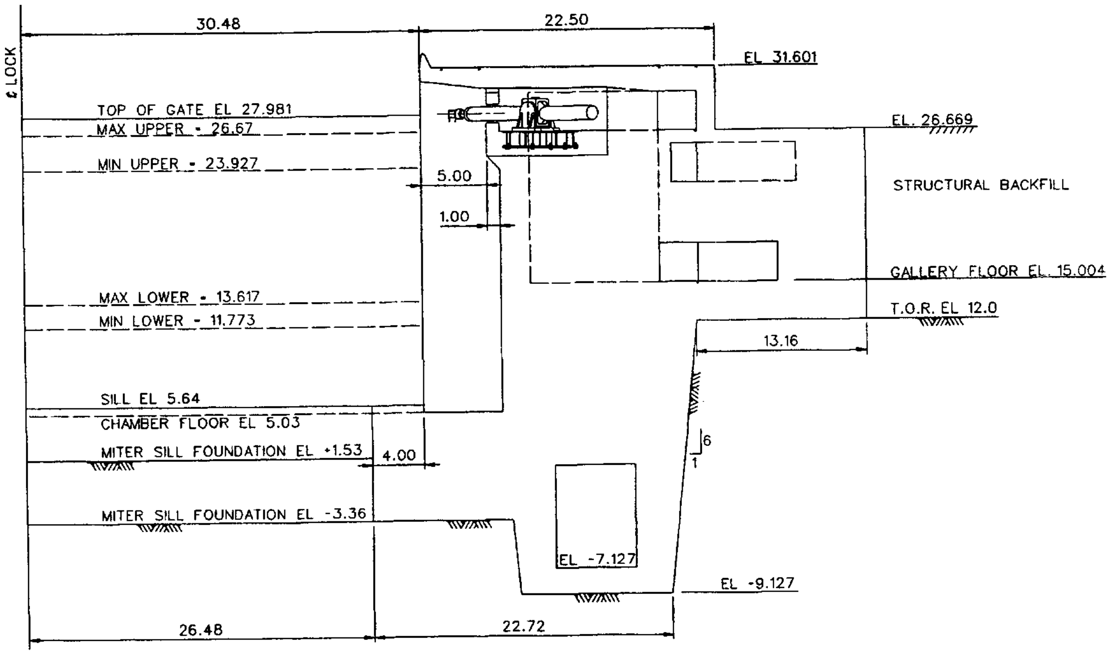


Figure F-1-1 Gatun Miter Gate Monolith

2. EM 1110-2-2100 (DRAFT) Stability Analysis of Concrete Structures, 20 May 2001.
3. EM 1110-2-2104 Strength Design for Reinforced Concrete Hydraulic Structures, 30 June, 1992.
4. EM 1110-2-2200 Gravity Dam Design, 30 June, 1995.
5. EM 1110-2-2502 Retaining and Flood Walls, 29 Sept. 1989.
6. EM 1110-2-2602 Planning and Design of Navigation Locks, 30 Sept. 1995.
7. ACI 318M-99 Building Code Requirements for Structural Concrete, 1999.

1.4.2. Allowable Stresses

1. Concrete – $F'_c = 21$ MPa - Concrete stresses are evaluated based on interaction diagrams.
2. Reinforcement – $F_y = 420$ Mpa

1.4.3. Load Factors used for design:

1. Normal and Unusual Operations: $U = H_f \times 1.7 \times (D+L)$; where $H_f = 1.3$
2. Earthquake Condition:
   a. Static Effects:

      $U = 1.7\ H_f\,(D+L)$

   b. Earthquake Effects:

1. Unusual: Site specific ground motion for design earthquake with time-history and response spectrum analysis (OBE)

   $U_h = 1.4\ (D+L) + 1.5\ E$

2. Extreme: Site specific ground motion (MCE)

   $U_h = 1.0\ (D+L+E)$

1.5. Loads / Combinations

Dead loads, hydrostatic loads, lateral earth and water pressures, uplift, seismic loads, miter gate reactions and operational loads are included in the various structural analyses performed. Passive resistance of the rock was applied when appropriate. These loads are combined to yield the most severe conditions. These loading conditions are listed Appendix A – Table A-5-3 Load Combinations for Lock and entrance walls.

1.5.1. Data/Assumptions Used:

1. Concrete Density. = 2402.8 kg/m^3
2. Water Density = 1001.2 kg/m^3
3. Lateral Earth Pressure Coefficient (at rest) = 0.441
4. Earthquake Loads:
   a. MDE Pseudo-static EQ Coefficient = 0.313
   b. Hydro-dynamic effects using Westergard Formulations
   c. "Dynamic" earth pressures calculated using Wood's simplified formulas.
   d. Miter Gate Reactions values used in the design of the miter gate monoliths are obtained from Appendix B, Gate Selection Study.
   e. Weight of the Ship Positioning System equals 1.53 MN, applied as a distributed line load equal to 0.102 MN/m along the monolith at line of the chamber side rails.
   f. Lateral Line Pull from the Shop Positioning System equals 0.36 MN, applied as a distributed load of 0.024 MN/m at elevation 1 m above the top of the monolith.
   g. The extreme earthquake loading (Load Case 2G [MCE]) was used to size the north, center and south miter gate monoliths since this is the most extreme load case and controls the design of the monoliths.

1.6. Cross Sections and Configurations.

The MS Excel stability spreadsheet used to design the "typical" gravity monoliths was also modified and used to design the miter gate monoliths (provided in Calculations CD, pdf format). Modifications to the monolith stability spreadsheet are required for the center and south miter gate monoliths to account for: 1) the difference in elevation between the toe and heel of monolith bases of the, 2) the resultant differential uplift pressures, and elevated 3) the elevated point of overturning for the miter gate monoliths. The lock walls are designed considering the related features, with space provided for locomotives as the ship-positioning system, and provide the most economical solution for the integration of the project features. The lock walls include the lock filling/emptying culverts and are gravity monoliths founded on a rock foundation. Specifically, the miter gate monoliths utilize a stub toe at the base to increase stability, to reduce bearing pressures and to eliminate the need for a concrete bearing base slab. The length of the toe stub was limited to less than 6 m since the steel reinforcement due to flexure became excessive for greater lengths. The multilevel base is used to reduce bearing pressures, reduce uplift pressures, and increase stability by accounting for the passive resistance of the rock and elevated point of overturning for the monoliths. Roller compacted concrete is used extensively for economy of construction of the lock walls; conventional concrete is used in the areas of culverts, galleries, rooms and the lock chamber face and recesses. Space is provided at the top of walls to include a ship positioning system similar to the existing locks. The lock gate monoliths are to be constructed as conventional gravity structures founded on a rock foundation.

1.6.1. Geometric Considerations

When considering all aspects of the functional requirements of the miter gate monoliths, there are many dimensional provisions required regardless of analyses optimization. With a 5 m recess to accommodate the miter gates, the tracks and clearance requirements for the locomotives of the ship positioning system, direct connected cylinder arrangement at the top of the wall, valve recess opening and the 6 m wide culverts wrapping around the gate recesses, it was determined that a monolith wall width of 19.5 m would be a minimum.

1.6.2. Analysis & Design.

The design of the miter gate monoliths proceeded using the Excel stability spreadsheet that was used to design the “typical” lock monoliths. The base of the structures are sized to minimize rock excavation, to minimize concrete, to reduce bearing pressures at the concrete-rock interface and to meet stability requirements in terms of overturning, bearing and sliding. A stub toe is used to provide stability and to reduce the bearing pressures on the tuffaceous sandstone unit. Bearing, due to high overturning moments during a seismic event, predominantly controlled the design of the miter gate monoliths. Sliding stability is achieved by accounting for the passive resistance of the rock wedge for the center and south miter gate monoliths and the passive resistance provided by the miter gate sills, that will act as a compression strut. Therefore, the shape of each monolith was adjusted until the location of the base pressure resultant was near to its allowed bound in the controlling load case. For sliding stability, the compressive force required to be mobilized by the miter gate sills was calculated to.

The internal stability of the monoliths was also checked at a cross section cut through the monoliths at the chamber floor elevation or through a culvert section. In all instances, concrete reinforcement is required to stabilize the monoliths for overturning in the region of the culvert area.

In general, the concrete reinforcing for the culvert faces, galleries and rooms require #29 @ 300 mm. The concrete reinforcing for the toe stubs required bundled (2) #57 @ 300 mm (south and center miter gate monoliths) and bundled (2) #43 @ 300 mm (north miter gate monoliths), and depended on the length of the toe projection provided. The shorter toe stub of the north miter gate monoliths has a single layer of #43 @ 300 mm. For the internal stability of the Atlantic miter gate monoliths at a cross section cut at the chamber floor elevation, the vertical concrete reinforcement required is #57 @ 425 mm. For the internal stability of the center and south miter gate monoliths at a cross section cut at the toe stub foundation-rock interface elevation, the vertical concrete reinforcement required is #43 @ 350 mm and #43 @ 400 mm, respectively. The steel requirements in this area will be refined in the plans and specifications stage of the development as described above in paragraph 2.g (5) (d) for the typical chamber monoliths.

2. ENTRANCE WALLS

2.1. General Description of Project Features

2.1.1. Introduction

The Atlantic Locks Third Lane Project is designed to permit transit of vessels significantly larger than those vessels utilizing the Panama Canal at this time. The entrance walls are the locations where the vessels first encounter the new Locks, either by connecting with the Ship Positioning System, or by physically impacting or rubbing against the walls. The geometry, displacement and handling characteristics of these Post-Panamax ships will be the primary considerations for the design of the entrance walls. At this Concept design level, four entrance walls are planned. Wall lengths were optimized by the Corps Design Team after consultation with ACP. The lengths of the walls listed below include the end piers.

- Gatun Lake Approach, Right Descending Wall (East Wall): 670 m.
- Gatun Lake Approach, Left Descending Wall (West Wall): 59.9 m.
- Atlantic Approach, Right Descending Wall (East Wall): 670 m.
- Atlantic Approach, Left Descending Wall (West Wall): 57.3 m.

The two east entrance walls are oriented parallel to the lock chamber walls. The Gatun Lake east wall alignment is set back approximately 1.825 m from the line extending from the chamber wall faces, to permit space for installation of the selected fender system. The Atlantic Ocean east wall alignment has no setback from the chamber wall faces, as no fender system has been incorporated into this wall.

The ends of each wall most remote from the Locks have an orientation with an angle of approximately 15 degrees to permit a transition to the approaches. The "knuckle" at the exposed corner where the straight and angled walls meet is protected with wheeled roller fenders.

The top-of-wall elevation for the Gatun Lake walls was checked to permit installation of high capacity fenders such that maintenance and access to anchor bolts can be accomplished entirely above the water line. The fender system selected measures approximately 3.186 m from the lowest anchor bolt to the top of wall. The minimum top of wall heights established in Appendix A, Project Design Criteria were only 3.31 m above Gatun Lake's maximum elevation and the Atlantic Ocean high tide level (plus wave run-up). Thus the selected top-of-wall elevations equal the minimum heights previously established.

It is proposed that the Gatun Lake entrance walls be supported by two parallel rows of 2.44 m diameter drilled shafts, spaced at 30 m center-to-center, each having permanent steel casings. The installation of these foundation elements can be accomplished "in the wet" out in Gatun Lake, utilizing barge-mounted equipment, and on dry land using land-based equipment inshore of Gatun Lake. The foundation elements would support conventional or precast concrete cap beams that would span between the shafts. These rectangular cross-section beams would support the Ship Positioning Locomotives, and would accept and distribute the vessel impact reaction loads that are transmitted from the continuous fender system. A continuous fender system would be mounted on the face of all of the entrance walls to absorb impact energy. The fenders have been designed to absorb nearly all of the impact energy from collisions that can be expected to occur within the lifetime of the structures.

The Atlantic Ocean entrance walls will be constructed with Roller Compacted Concrete monoliths. This type of wall is discussed in detail in other sections of this Report. No fender system has been incorporated into these walls.

2.1.2. Topography of Alignment

2.1.2.1. Gatun Lake Entrance

The main Gatun Lake entrance wall runs between approximate stations 14+451 and 13+781. For the purposes of discussion, the entrance wall beginning station has been designated to be at the knuckle just upstream of the Gatun Lake Intake Port monolith. The channel bottom elevation would be no higher than +5.63 m. The top of wall would be at elevation +31.60 m. Approximately 400 m of the main wall would be located in areas that have top of ground elevations higher than the existing Gatun Lake mean elevation. Approximately 233 m of the wall would be located in the existing Lake. The part of the wall that is located within the “footprint” of the Lake can be constructed within a cofferdam, entirely in the dry, or could be constructed entirely in the wet. The deepest Gatun Lake bottom elevation is estimated at approximately +3 m at Station 14+423; this results in a maximum wall height of approximately 29.3 m at the upstream terminus. The entrance channel would be excavated to a depth of no less than 18.3 m below minimum Gatun Lake elevation of 23.93 m, or +5.63 m.

At this time, the depth to rock along the wall alignment is not known between approximate wall stations 14+150 and 14+423 and will need to be verified by the ACP Design Team in the near future. In this portion of the wall alignment, the design assumption has been made that the top of rock elevation is within 5 m of the excavation depth. The rock is overlain by Atlantic Muck, a material with relatively low strength. Under this assumption, the wall would be as high as 34 m above sound rock. If this assumption is not correct, and the depth to rock is significantly greater than the assumed 5 m below the mud line, the conceptual wall design for the upstream 273 m of the Gatun Lake entrance wall will have to be revised accordingly.

2.1.2.2. Atlantic Entrance

The main Atlantic entrance wall runs between approximate stations 11+611 and 12+281. For the purposes of discussion, the entrance wall ending station has been designated to be at the knuckle of the west wall. The top of wall would be at elevation +3.54 m. The top of wall elevation was determined by an evaluation of wave heights in conjunction with maximum tidal elevation. All of this long wall would be located in cut, and at no point is the existing top of ground surface below +2 m. It is anticipated that the wall would be constructed prior to channel excavation. Therefore it is reasonable to assume that the construction of this wall can be performed in the dry. The rock elevation along the wall alignment varies from -11 m at wall station 12+150 to –4 m at Station 11+800. The average top of rock elevation is approximately -8.6 m. The channel bottom elevation would be no higher than -18.65 m; thus the wall height would be uniform, approximately 22.19 m. At all locations along the alignment, the bottom of the channel excavation would be in sound rock.

2.2. Load Cases

The load cases established for the design of the entrance walls are shown in the following table:

Table F-2-1 Entrance Wall Load Cases

Case Name	Description	Case	Details
Case 1UP	Normal Operating Condition, Gatun Lake Wall	Usual	(1) Minimum Pool of Gatun Lake on face of wall. (2) Saturated fill. (3) Locomotive load on top of wall. (4) Ship-positioning pull force away from face of wall.
Case 1UPV	Normal Operating Condition Gatun Lake Wall	Usual	(1) Normal Pool of Gatun Lake on face of wall. (2) Saturated fill. (3) Maximum of the Usual Vessel Impact Forces, developed from Table F-2-4. (4) Locomotive load on top of wall.
Case 1LP	Normal Operating Condition, Atlantic Wall	Usual	(1) Minimum Atlantic Ocean tidal level on face of wall. (2) Saturated fill. (3) Locomotive load on top of wall. (4) Ship-positioning pull force away from face of wall.
Case 1LPV	Normal Operating Condition, Atlantic Wall	Usual	(1) Mean Atlantic Ocean Sea Level on face of wall. (2) Saturated fill. (3) Maximum of the Usual Vessel Impact Forces, developed from Table F-2-4. (4) Locomotive load on top of wall.

Case Name	Description	Case	Details
Case 2DUP	Normal Operating Condition, Gatun Lake Wall with Unusual Vessel Impact	Unusual	(1) Normal Pool of Gatun Lake on face of wall. (2) Saturated fill. (3) Maximum of the Unusual Vessel Impact Forces, developed from Table F-2-4. (4) Locomotive load on top of wall.
Case 2DLP	Normal Operating Condition, Atlantic Wall with Unusual Vessel Impact	Unusual	(1) Mean Atlantic Ocean Sea Level on face of wall. (2). Maximum of the Unusual Vessel Impact Forces, developed from Table F-2-4. (3) Saturated fill. (4) Locomotive load on top of wall.
Case 2GUP	Normal Operating Condition, Gatun Lake wall, with MDE	Extreme	(1) Maximum Design Earthquake in transverse direction toward Canal. (2) Normal Pool of Gatun Lake on face of wall. (3) Saturated fill. (4) Locomotive load on top of wall.
Case 2GLP	Normal Operating Condition, Atlantic wall, with MDE	Extreme	(1) Maximum Design Earthquake in transverse direction toward Canal. (2) Mean Atlantic Ocean Sea Level on face of wall. (3) Saturated fill. (4) Locomotive load on top of wall.
Case 2XUP	Normal Operating Condition, Gatun Lake Wall with Extreme Vessel Impact	Extreme	(1) Normal Pool of Gatun Lake on face of wall. (2) Saturated fill. (3) Maximum of the Extreme Vessel Impact Forces, developed from Table F-2-4. (4) Locomotive load on top of wall.
Case 2XLP	Normal Operating Condition, Atlantic Wall with Extreme Vessel Impact	Extreme	(1) Mean Atlantic Ocean Sea Level on face of wall. (2). Maximum of the Extreme Vessel Impact Forces, developed from attached Table F-2-4. (3) Saturated fill. (4) Locomotive load on top of wall.

Case Name	Description	Case	Details
Case 3	Construction Condition	Unusual	(1) Saturated backfill due to heavy rain. (2) Permanent or construction surcharge. (3) Wind as applicable. (4) Uplift.

2.2.1. Cross-Sections Analyzed

For the Concept Design, representative cross-sections were analyzed to establish best and worst case design load conditions. For example, all load cases outlined above for the Gatun Lake entrance wall were applied to the representative Gatun Lake cross sections.

2.2.1.1. Gatun Lake Entrance Wall

The cross section with the greatest depth to "sound" rock is assumed to be at the south termination of the Gatun Lake Approach, at Station 14+423. With a height from top of wall to sound rock of approximately 33 m, the wall at this station is anticipated to have the greatest seismic driving force, and the lowest passive resistance to vessel impact. Therefore, it will be the critical section for all load cases.

The average height from top of wall to sound rock will be established by the bottom of the channel excavation for most of the Gatun Lake entrance wall alignment. The average height from top of wall to sound rock is therefore approximately 25 m. Therefore the most representative cross-section is at Station 13+800. Analysis of this section will provide a design that will be applicable to much of the wall length.

2.3. Analyses Methodology

2.3.1. Vessel Impact Zone and Fender Concepts

Because of the great size of the vessels that are to utilize the new Locks, the potential exists for very significant impacts to the entrance walls. The use of fenders to reduce the impact forces imparted to structures, be they quays, docks or lock walls, is standard practice in the world of ocean-going vessels in ports and harbors. In port facilities, large capacity fenders are installed at discrete locations, because the vessels generally approach laterally to the dock or quay. For the Panama Canal, vessels will always be moving forward into or out of the lock chambers to permit maximum usage and capacity of the facility. The location of the vessel's arrival, or initial contact with the entrance walls, is thus randomly distributed. Therefore continuous horizontal fenders are recommended along the entire lengths of all of the entrance walls.

The impact zone of the entrance walls will be based on a combination of the recommended fender system in conjunction with the Design Vessel geometry. The top elevation of the walls will be 4.2 m above the mean water level at the Gatun Lake approach. The sidewalls on the vessels proposed to use the new canal vary from vertical to round with large radii. Vessels will have a maximum draft of about 15.2 m.

PIANC Design criteria (Reference #3, Chapter 7) recommend that the fender impact surface be designed such that a maximum hull pressure in t/m^2 be approximately equal to the vessel draft in meters. However, most fender manufacturers recommend that for bulk and container vessels, a maximum hull pressure of approximately 25 t/m^2 be not exceeded. For this design, this criterion will be applied to both the "Usual" and "Unusual" design loading.

The size and elevation of the fenders will be established to permit maintenance and replacement with all connections above the mean water surface.

2.3.2. Hydrodynamic Added Mass

At the Gatun Lake approach, the low water elevation is 23.93 m (PLD) (see Appendix A, Project Design Criteria, Table A-2-2 "Pool Operating Range"); and the bottom of canal cut is projected to be 5.63 m (PLD) (see drawing entitled, "Task 3, Optimization of Alignment, Plan A, 9 degree Baseline, 2 Lifts, Run No. 1D, PROFILE" dated 1 June 2002). Therefore the depth of the approach channel may be as low as about 18.4 m, compared to the vessels' drafts of up to 15.2 m. Under keel clearance will therefore be about 0.21 x draught.

PIANC ("Report of the International Commission for Improving the Design of Fendering Systems" Supplement to Bulletin No. 45 (1984) recommends that the "Effective Mass", Cm, range between 1.5 for very large under keel clearances to 1.8 for under keel clearances approaching 0.1x draught. Therefore, it is recommended that Cm be set equal to 1.7 for this project.

2.3.2.1. Eccentricity Factor

PIANC states that "Ce" is based on "k" and "a". "k" is based on blockage coefficient "Cb" and the vessel length. Blockage coefficients and Design Vessel lengths were based on the Memorandum: *"Panama Canal Concept Design of Lock Structures – Design Vessel Size"*, 18 June 2002, prepared by Mr. David Margo, Pittsburgh District, U. S. Army Corps of Engineers.

2.4. Vessel Impact Energy – Summary

Generally, the design for vessel impact follows methodology outlined in the PIANC "Guidelines for the Design of Fenders Systems: 2002".

2.4.1. Energy Modeling for the Impact Loads for Entrance Walls

2.4.1.1.1. Introduction

Simple energy concepts can be utilized for modeling the impact loads on the entrance walls for the concept design. The entrance wall system is comprised of drilled shafts supporting a cap beam with a state-of-the-art fender system. Using energy concepts permits the design of the entrance wall to incorporate both the energy absorbed by the fenders, the energy absorbed by the deflection of wall, and if needed, the energy absorbed in the crushing of the ship hull.

2.4.1.1.2. Energy formulation

The energies of this entrance wall system can be related to both potential and kinetic energies that exist within all the components. The total energies must be balanced to obtain equilibrium of the entire system during an impact. This equilibrium is t[illegible]to account throughout the system using the capacities of the fen[illegible]wall, and hull to absorb and transmit energies. While energy systems generally consider elastic states, the model developed for this concept design does account for some non-linear behavior of the materials that are reflected in the energies for the fenders and ship hull.

The general equation used to represent the vessel impacting the entrance wall is defined as:

$$KE_{ship} = PE_{fenders} + PE_{wall} + PE_{hull}$$

The system components are very interdependent upon the loads and the rate of loading. Each component reacts at different levels so the rate of loading for this model is assumed to be over constant time duration.

2.4.1.1.3. Fender/Wall Energies

The energy equation for the fender system and wall is based on the stiffness, k, and deflection, d, for each component. The fender and wall system are interrelated in that the fenders upon impact produce a reaction force into the wall causing deflections. These systems are tied together in the current model. Their capacity can be shown through the following energy equation as:

$$PE = \frac{1}{2} kd^2$$

2.4.1.1.4. Hull Energy

The energy absorbed by the vessel's hull can be represented using an energy relationship defined by Minorsky. Minorsky examined the energy and collision damage (i.e., deformations) from accident records. From this Minorsky developed an interaction coefficient based on the effective thickness of steel in the impact zone. The equation Minorsky developed to represent the stiffness from these energy relationships is shown as follows:

$$k_{hull} = P_m * 12 * t_{eff} ((1 + \tan^2\phi) / \tan \phi))$$

where P_m = Minorsky Interaction coefficient

t_{eff} = Effective thickness of hull steel

ϕ = angle of impact

This stiffness is then included into the model using the stiffness relationships for the wall/fenders discussed above. This deformation for a ship hull only occurs in the most extreme impact cases. The current model and shaft design tries to minimize the effects on the pressure (usual less than 34.5 kPa) and deformations on the ship's hull while trying to maximize the energy potential of the fender/wall system.

2.4.1.1.5. Ship Energy

The kinetic energy of a vessel is determined by the mass and velocity of the vessel as it nears the entrance wall. This equation is valid since a ship is considered a rigid body at impact. The generic equation to represent the energy for the vessel is shown as follows:

$$KE = \frac{1}{2} mv^2$$

However, this equation does not fully reflect the full dissipation of energy during impact since a vessel does not move in pure translation. PIANC recommends that the kinetic energy be factored for eccentricity, added mass, softness factor, and berthing configuration to reflect this fact. The current model developed for the Panama Third Lane Atlantic entrance walls accounts for both the softness factor and the berthing configuration within the fender/wall energies. The equation used in this analysis for the kinetic energy is modified as follows:

$$K = (\frac{1}{2} (W_d + W_{am}/g)^* v_n^2)^* C_e$$

where W_d = the displaced weight of the vessel

W_{am} = added mass of the vessel

G = gravitational constant

V_n = velocity normal to fender/wall system

C_e = eccentricity factor

The added mass, W_{am}, for the vessel is based on guidelines and equations given in PIANC and Tsinker. The added mass coefficient used for the vessel impact analysis is 0.7. The eccentricity factor, C_e, is a function of the radius of longitudinal gyration and distance to the ship's center of gravity. This value depends upon the length and block coefficient of the vessel. This value is calculated directly in the analysis and typically ranged around 0.3.

2.5. Design Vessel

Design Vessel sizes were based on the contents of the Project Design Criteria Report, dated 12 April 2002. This document provided general vessel information for two different Design Vessels: a Bulk Carrier and a Container Ship. The selected vessel size is within the range of ship sizes listed in the Scope of Work. Additional investigation should be performed as more detailed design is performed is following studies. Impact energies were computed for each of the possible Design Vessels. Details of the two design vessels are presented below.

Table F-2-2 Design Vessel

	Bulk Carrier	Container Ship
LOA	385.7 m	385.7 m
Beam	54.9 m	54.9 m
Draft, tropical fresh water	15.2m	15.2m
Block Coefficient. Cb	0.825	0.825
DWT	130,000 t	110,000 t

2.6. Design Velocity and Angle of Impact

For obtaining design velocity and angle of impact, the Corps of Engineers has developed a standard methodology on inland navigation projects. The actual approach velocities and angles of approach are recorded for many arrivals over a long period of time at an existing project with similar geometric characteristics. For the Third Lane Atlantic Locks project, the obvious choice would be to record arrivals at Gatun Locks. Since this information will not be available for this Concept Design, the design team relied upon information supplied by the ACP.

The Corps recommends that the following Vessel Approach Design Criteria to be utilized for entrance wall design:

Table F-2-3 ACP Vessel Impact Velocity and Angle

	Container Vessel			Bulk Vessel		
Load Case	Longitudinal Velocity (knots)	Longitudinal Velocity (m/s)	Angle of Approach (degrees)	Longitudinal Velocity (knots)	Longitudinal Velocity (m/s)	Angle of Approach (degrees)
Usual	1	0.514	7	1	0.514	7
Unusual	2	1.029	10	2	1.029	10
Extreme	3	1.543	15	3	1.543	15

For the vessels under consideration, the above velocities and angles will impose high impact energies on the entrance walls. PIANC (Ref. #4, Chapter 4, paragraph 4.2.3) advises that for vessels of the size of the Panama Third Lane Design Vessels, in exposed and difficult navigation conditions, berthing velocities can be expected to be on the order of 8-20 cm/sec, with the higher value being that observed in "unfavorable conditions". However berthing in a port is very different from landing on an entrance wall at Panama. Although assisted by tugs, the Design Vessels at

Panama are primarily propelled by their own power. Thus sufficient forward velocity must be applied in order to maintain steerage. One knot is approximately 51 cm/s. Thus, the "Usual" impact will be based on a longitudinal velocity of 1knot, and the "Unusual" was based on 2 knots.

Approach angle is generally less than 5 degrees with occasional impacts up to 6 degrees maximum, according to PIANC (Ref. #4, Chapter 4, paragraph 4.2.4). At a forward speed of one knot coming at an angle of 7 degrees to the wall, the normal velocity is about 6.27 cm/s. At a forward speed of two knots coming at an angle of 10 degrees to the wall, the normal velocity is about 18 cm/s. Thus the recommended Usual and Unusual velocities and angles of approach for the Bulk Vessel and the Container Vessel are bracketed well within PIANC's berthing guidelines of 8 to 20 cm/sec. At a forward speed of three knots coming at an angle of 15 degrees to the wall, the normal velocity is about 40 cm/s. Thus the recommended Extreme velocity and angle of approach for the ACP Panamax "Plus" Container ship result in approximately twice PIANC's berthing guidelines of 10 to 20 cm/s. This combination of speed and angle result in design demands beyond the realm of any previously designed entrance walls. The Corps feels that this is appropriate for an extreme case, which is intended to represent the case where there is a problem with the assistance of tugs.

There is a patented commercial fendering system with the capability to survive the "Extreme" vessel impact load cases developed. The design approach recommended by the Corps for these extreme impacts is to allow damage to the structure; however the damage should be repairable above the waterline. Such repairs would not be anticipated to cause prolonged closure of the Locks.

2.7. Energy Model Results

The three load cases considered in this analysis are usual, unusual, and extreme events. The usual load case is to be expected to occur on an annual basis (i.e., return period of 1 year). The fenders during this event are expected to handle the entire vessel loads and no damage would occur to either the entrance wall or vessel. The unusual load case is expected to have a return period of 5 years. The fendering system is expected to absorb most of the energy (see discussion of fender system in paragraph below). Minimal damage may occur to the wall from deflections but no damage occurs in the vessel. The extreme load case is expected to have a return period of 100 years. During this event the fenders would compress beyond the elastic range and damage to both the wall and vessel are expected. The total collapse of the wall or sinking of the vessel is not expected to occur during this event and any damages to either the wall or vessel are expected to be repairable.

The following table shows the result for the six load cases for the Post-Panamax vessels selected for the analysis. The impact forces for the entrance wall design and the deflections for the each component are reflected in the table below.

Table F-2-4 Selected Load Cases for Post-Panamax Vessels

Panama Canal Third Lane Impact Forces
(revised March 2003)

Vessel Type (displacement)	Load Case	Velocity (normal) (m/sec)	Impact Angle (deg)	Deflection of Fenders (m)	Deflection of Wall (m)	Deformation of Hull (m)	Force (normal to wall) (kN)
METSO MV1400x1000 Fenders on Two 8-ft Drilled Shafts							
ACP Container (Deadweight 110,000 metric tons)							
	Usual	0.064	7	0.11	0.11	0	1079.7
	Unusual	0.18	10	0.9	0.22	0	5050.73
	Extreme	0.4	15	0.9	1.54	0.04	18078.08
ACP Bulker (Deadweight 130,000 metric tons)							
	Usual	0.064	7	0.07	0.07	0	719.8
	Unusual	0.18	10	0.83	0.29	0	2879.32
	Extreme	0.4	15	0.9	1.43	0.04	17041.8

2.8. Bulbous Bows

Many of the modern vessels transiting the Panama Canal Third Lane may have bulbous bows. When a fully laden ship impacts a port facility or entrance wall at an angle exceeding some critical angle, the bulb may impact foundation elements below the waterline. A 1990 PIANC Report entitled “The Damage Inflicted By Ships With Bulbous Bows On Underwater Structures” was evaluated by the Corps with respect to the Third Lane entrance walls. A rigorous study of the hull and bow geometry of all vessels that will transit the locks is required to evaluate the setback required for foundation elements. The Corps did evaluate the geometry of several bulbous bows using available literature. The results of this limited study are reflected in the Corps recommendation to include a 3.0 m setback beyond the depth of the fenders. Including the recommended 1.825 m deep fender system, the total setback would be 4.825 m between the initial impact surface and the closest foundation element.

2.9. References:

1. AASHTO Manual: “Guide Specification and Commentary for Vessel Collision Design of Highway Bridges, Volume 1: Final Report”, dated February 1991.
2. “Guidelines for the Design of Fenders Systems: 2002”. Permanent International Association of Navigational Congresses (PIANC), (2002).
3. International Association for Bridge and Structural Engineering - "Ship Collisions With Bridges: The Interaction between Vessel Traffic and Bridge Structures" by Ole Damgaard Larsen (1993).

4. "Handbook of Port and Harbor Engineering – Geotechnical and Structural Aspects" by Gregory P. Tsinker, published by Chapman and Hall, International Thompson Publishing (1997).
5. "The Damage Inflicted By Ships With Bulbous Bows On Underwater Structures", Report of Working Group 8 of the Permanent Technical Committee II, Supplement to Bulletin No. 70, Permanent International Association of Navigational Congresses (PIANC), (1990).
6. E-mail dated 23 May 2002 from John Gribar to Frank Zovack on the subject of approach velocity

2.10. Fender system

2.10.1. Available Fender Systems

The Corps Design Team researched the fender systems available in the commercial market today. Contact was made with representatives from Metso-Trellex; Fentek Marine System GmbH; and Bridgestone Corporation. The goal of the research was to identify the fender type and particular system with the largest energy absorption capacity.

The highest capacity fender system identified is the Bridgestone C3000H Super Cell Fender. Each fender has the rated capacity, as rated by the manufacturer, to absorb up to 720.0 t-m of energy. These fenders are 3.00 m in depth, measured between the outsides of flanges, and weigh 18,500 kg. These fenders have a cylindrical shape and have steel mounting plates permanently bonded to the main rubber column during the vulcanization process. The fenders absorb energy by buckling; the effect is that the total fender bulges as it collapses. They are ideally suited for berthing applications and frontal frames are generally attached to increase the contact area on the vessel hull.

The highest capacity linear fender found in the research is the MI2000 fender element, manufactured by Metso-Trellex. Two individual MI2000 elements paired together have the rated capacity, as rated by the manufacturer, to absorb 281 t-m of energy. The MI2000 fender is 2.00 m in depth. These fender elements have steel mounting plates permanently bonded to the rubber during the vulcanization process. The steel is fully encapsulated to minimize corrosion. Multiple configurations can be utilized for combining these fender elements to absorb energy and reduce hull pressure. Frontal frames are generally attached to increase the contact area on the vessel hull, and low friction Ultra-High Molecular Weight Polyethylene (UHMW-PE) pads are generally attached as a facing.

A linear fender with a lower capacity and lower cost is the MV1450 element, also manufactured by Metso-Trellex. Two individual MV1450 elements paired together have the rated capacity, as rated by the manufacturer, to absorb 106.7 t-m of energy. The MV1450 fender is 1.45 m in depth. These fender elements have steel mounting plates permanently bonded to the rubber during the vulcanization process. The steel is fully encapsulated to minimize corrosion. Frontal frames are attached to the fender elements to increase the contact area on the vessel hull, and low friction Ultra-High Molecular Weight Polyethylene (UHMW-PE) pads are attached as a facing.

For comparison, Bridgestone's largest "Hyper Cell" fender, model HC1150H, has a rated capacity, as rated by the manufacturer, to absorb 100.9 t-m of energy.

2.10.2. Recommended Fender System

Because the ACP has expressed a desire for continuous fenders along the entrance walls, the Corps Design Team focused on a linear type fender element for the design. A patented directional fender system utilizing MV1450 rubber elements has been developed jointly by the Corps of Engineers and Metso-Trellex, and has been tested in full-scale testing in the U.S.A. by the Corps. This system is recommended for the Gatun Lake entrance wall. Adjacent frontal frames and mounted UHMW facings are lapped so that a moving vessel will be provided with continuous energy absorption as it proceeds down along the face of the wall. An analysis performed for energy absorption along the walls has been completed by the Corps assuming this system will be utilized.

The design concept for the fendering system was developed around similar concepts used for the design of fendering system for docks and ferry facilities. However, the difference with the navigation fenders is that they need to permit a vessel to land at higher speeds and angles than traditional harbor fender designs. In addition, the design had to consider the ability of a vessel to rub continuously along the surface, change the direction of the energy from the vessel, and react to a motion unfamiliar to dock fendering systems.

The fenders use traditional fender elements design by Metso-Trellex in conjunction with a steel impact box faced with Ultra-High Molecular Weight (UHMW) plastic. This UHMW product can be considered frictionless and is so dense that it is nearly incompressible. This UHMW surface permits the vessel to slide along the wall without having to slow down or hang up on the wall. Figure F-2-1 shows the as built design for the prototype fendering segments, and Figure F-2-2 shows how the fender system permits a moving vessel to continuously transfer load to the fenders.

Figure F-2-1 Prototype Fenders (Top View)

Figure F-2-2 Typical deflections of fender system during impact (top view)

2.10.3. References

Full-Scale Barge Impact Experiments Robert C. Byrd Lock and Dam, Gallipolis Ferry, West Virginia, US Army Corps off Engineers, ERDC/ITL TR-02-XX, 30 April 2002.

2.11. Drilled Shaft Construction

2.11.1. Casing Size

The high magnitude of the bending moments resulting from the Unusual and Extreme Load cases has lead to the selection of two 2.44 m diameter drilled shafts with permanent 25 mm thick steel casings. The table below presents several scenarios for the proposed casings:

Table F-2-5 50.8 mm CASING SCENARIOS

50.8 mm CASING WALL THICKNESS				
Caisson Length, l =	35	40	45	m
Outside diameter of Caisson, d_o =	2.438	2.438	2.438	m
Inside diameter of Caisson, d_i =	2.337	2.337	2.337	m
Diameter of #57 reinforcing bar, db=	57.3	57.3	57.3	mm
Number reinforcing bars, n_b= (based on 9 bundles of four, and eleven individual bars)	47	47	47	
Caisson Wall Thickness, t=	50.8	50.8	50.8	*mm*

50.8 mm CASING WALL THICKNESS				
Caisson Length, l =	35	40	45	m
Volume of Steel in Caisson Wall, $v_s = \{[p(d_o^2 - d_i^2)]/4\}\, l =$	13.34	15.24	17.15	m^3
Weight of Steel in Caisson Wall, $w_s = v_s * 7.8483$ tonnes/m^3 =	104.67	119.62	134.57	t
Volume of Reinforcing in Caisson, $v_r = [(p(d_b)^2)/4]\, l\, n_b =$	4.24	4.85	5.45	m^3
Weight of Reinforcing Steel in Caisson Wall, $w_r = v_r * 7.8483$ tonnes/m^3 =	33.29	38.05	42.80	t
Volume of Concrete in Caisson, $v_c = [(p d_i^2)/4] l - v_r =$	145.87	166.70	187.54	m^3

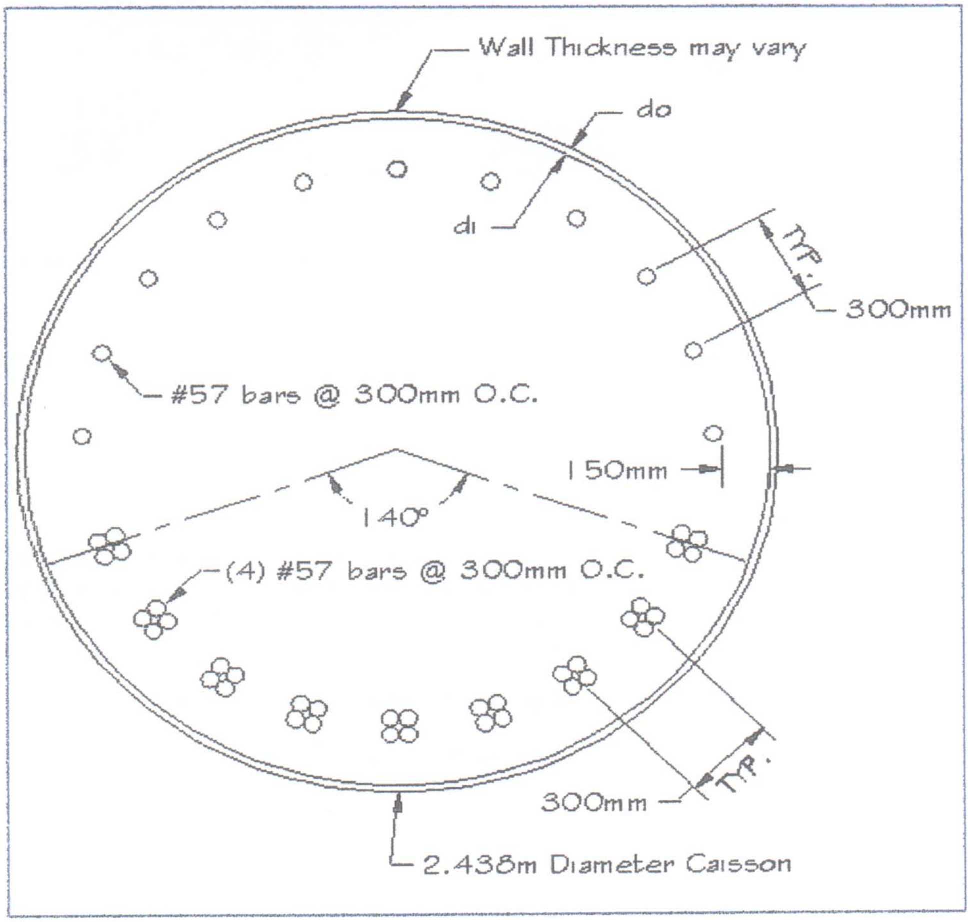


Figure F-2-3 Drilled Caisson

2.11.2. Casings: Fabrication Considerations

The fabrication of 2.44 m diameter, 50 mm thick steel casings is well within the capabilities of all major steel fabricators contacted by the Corps of Engineers. Mr. Jim Travis with Eaton Metal Products of Denver, Colorado, and Boise, Idaho, U.S.A. was contacted on 24 March 2003 in reference to the fabrication of the proposed drilled shaft casings for the Panama entrance walls. Eaton fabricated 3.05 m diameter casings for the Corps' Olmsted Approach Walls project in 2000 and 2001. Eaton told the Corps that they have the facility and capabilities to fabricate the 2.44 m diameter casings with a 25 mm wall thickness. Mr. Travis felt that delivery of the casings could be expected to begin approximately 16 to 20 weeks after receiving a notice to proceed, depending upon availability of steel plate. Transportation of the approximately 40 m long caissons would likely not be practical from their land-locked location. However, transportation could be accomplished using both the rail system and the U.S. inland waterway system utilizing barges on the Columbia River.

The Corps also contacted Mr. Bill Osburg, General Manager of Engineering of J. Ray McDermott Inc. on 24 March 2003. McDermott has extensive experience in fabrication and construction of enormous offshore oil platforms that incorporate large diameter steel casings. Mr. Osburg stated that McDermott had the capability and manpower to fabricate the proposed 2.44 m diameter casings. Their plant is located in Morgan City, Louisiana, on a tributary to the Mississippi River. McDermott has the capability to directly load the casings onto a barge and ship them directly to Panama. Mr. Osburg said their company could easily supply all of the project's casings given a lead time of six to nine months, based on the assumption of 40-50 m long casings spaced at 30 m over a total project wall length of 733 m.

Irby Steel of Gulfport, Mississippi, U.S.A. is a large steel fabricator specializing in the fabrication of bridge caissons, heavy offshore pipes and other associated fabrications. They have the capacity to produce the entrance wall shaft casings with ease. They have fabricated steel casings up to 7.6 m in diameter for offshore applications. Their plant is directly on the Gulf of Mexico with relatively easy access to Panama. Mr. Tom Marbry, Director of Sales for Irby Steel was contacted on 26 March 2003.

He stated that casings of this size and wall thickness could definitely be completed in their Gulfport, Mississippi facility, and could shipped by barge (but not their own barge) directly from there to Panama. Mr. Marbry thought the last casings could be loaded onto the barges in a 16- to 20-week time frame after receiving the order. Costs would be based on $1.15/kilogram fabricated cost. He estimated the cost would be about $3,500,000 for the 25 mm casings. Cost for the 50-mm casings would be approximately double that amount. Delivery would be in addition to that amount.

Two of the world's largest producers of steel plate are located in Brazil - Acominas and Companhia Siderúrgica de Tubarão. Each company has the capability to easily produce the steel plate required for fabrication of the casings. There are numerous fabricators in Brazil, Argentina and Mexico capable of delivering the steel casings to the Panama site within four months of receiving the order.

2.11.3. Casings: Handling Considerations

Given the maximum estimated casing weight of approximately 68 to 70 t, there are many standard truck- or track-mounted cranes available with the capacity to lift the proposed casings in a single piece. Examples are the Manitowoc (U.S.A.)

Model 777 crawler-mounted and 777T truck-mounted cranes; each crane has the capacity to lift up to 180 t. These cranes can work off of barges. This manufacturer also makes several other cranes with much greater capacities, with boom lengths greater than 100 m. Ringer-mounted cranes can be installed on work barges to greatly extend both the working radius and the lift capacity.

Specialty lifting and rigging contractors do not consider the lifts required for the proposed 2.44 m casings to present a difficult challenge. Shaughnessy & Co. (U.S.A.) of Auburn, Washington, U.S.A. has cranes with capacities up to 600 t. The Corps also spoke with Mr. Pete Ashton of Bigge Crane and Rigging Co., San Leandro, CA (U.S.A.). They have several cranes that can handle 453 t or more.

In conclusion, the project demands regarding boom height, working radius and lifting capability for handling and installation of the drilled shaft casings should not present a difficult or unusual challenge for contractors.

2.11.4. Casings: Driving Considerations

Casings of the proposed diameter, wall thickness and weight are routinely driven with vibratory hammers of normal capacity on both offshore and inland projects. Driving of large diameter casings as proposed for the Panama Third Lane Atlantic Locks project is therefore not considered to be a problem. The Model 400B "King Kong" vibratory hammer developed by American Piledriving Equipment (APE) of Kent, Washington, U.S.A. is one hammer that can easily advance the proposed casings to final grade. This machine has an eccentric moment of 30 000 kg-cm and produces maximum amplitude at the tip of the casing of approximately 30 mm. Another hammer of similar size and capacity is the model 1600 manufactured by HPSI of Kansas City, Missouri, U.S.A. This machine has an eccentric moment of 18 400 kg-cm and produces maximum amplitude of approximately 25 mm.

These hammers are so large that they present a lifting challenge in themselves. The two specialty vibratory hammers mentioned above weigh approximately 47 t and 21 t, respectively.

The analyses presented in the next section of this report shows that the proposed casings would have to be socketed approximately 10-15 m into the Gatun Sandstone formation. The use of vibratory equipment alone would therefore not likely be sufficient to get these casings to their required founding elevation. Specialized cutting tools would have to be developed for the project by a specialty contractor. It is the Corps' experience that for shafts of about 2 m or greater diameter, specialty contractors usually have custom drilling tools fabricated specifically for the project requirements. For example, the drilling rig may require a Kelly bar that is 300 mm across, which is the size found on the largest commercially available rigs in North America today.

Malcolm Drilling of Hayward, California, U.S.A. is currently installing 4.88 m diameter drilled shafts at the Benicia Bridge Project in Concord/Vallejo, California. Mr. Lee David of Malcolm stated that the turning of the drilling tools for 2.44 m casings at Panama could definitely be accomplished. The casings could be advanced and the hole cleaned out by utilizing either normal-sized hollow Kelly bars to transmit the torque to the drilling tools. The Kelly bar would be the conduit for a reverse circulation system to remove the drill cuttings.

2.11.5. Design of Drilled Shaft Foundations

2.11.5.1.Overall Approach

There is a high degree of variability for the depth to sound rock along the alignment of the Gatun Lake entrance wall, and there is absolutely no information available regarding the depth or quality of rock upstream of about Station 14+150. The limited scope of the Concept Design therefore required that critical load cases be evaluated in order to develop a typical drilled shaft section and embedment depth. As the design progresses to higher levels of completion, analyses will have to be completed for any cross-section with deeper or less competent rock, and to verify that this design does not result in an overly conservative and expensive wall section.

The channel excavation will define the depth to sound rock in the majority of locations. Therefore, the analyses described below are based on an average height from top of wall to sound rock of approximately 25 m. The height from the vessel's impact point against the wall fender system to sound rock is approximately 22.8 m.

2.11.5.2.L-Pile Analysis of Shaft Capacity

An analysis was conducted using the computer program *LPILE Plus 3.0* to determine the ultimate bending resistance and flexural rigidity for a 2.44 m drilled shaft with permanent steel casing and steel reinforcement. The input parameters used for the drilled shaft are as follows:

Diameter	2.44 m
Steel shell thickness	0.0508m
Concrete compressive strength	27579.03 kN/m^2
Rebar yield strength	413685.52 kN/m^2
Steel shell or core yield strength	413685.52 kN/m^2
Modulus of Elasticity	2E+08 kN/m^2
Cover thickness	0.152 m
Number of reinforcing bars	25 bundles (every 0.3048m around shaft)
Area of bars	Bundles of 4- #57 bars (0.0103m^2)

The ultimate capacity of the shaft section is determined at a 0.003 strain level for the concrete. This produces an ultimate moment capacity for the shaft at 184 592 kN-m. Also, based on the stress-strain model utilized in LPILE, the yield capacity of the pile can be determined to be 166 800 kN-m.

2.11.5.3. Moment and Shear Demand Analysis of the Shaft

A 2.44 m diameter drilled shaft with a 50.8 mm casing was modeled using the Corps of Engineers CASE Program, X0050, *CBEAMC* (Analysis of Beam-Columns with Non-linear Supports). CBEAMC uses a 2-D finite element formulation, which includes axial effects to determine the moments, shears, and points of inflection down the shaft length. The drilled shaft was modeled using the moment of inertia and areas at nodes spaced at approximately 300 mm along the shaft. The rock was modeled using the distributed linear spring formulation. The input properties for a 2.44 m drilled shaft and the rock in the CBEAMC model are shown below.

2.44 m <u>Drilled Shaft</u> (not scaled to per unit width)	
Modulus of Elasticity	4.62E+08 kN/m^2
Moment of Inertia	3.75 m^4
Area	7.29 m^4
Length (above mudline)	30.48 m
(below mudline)	10.67 m
Rock	
Distributed Linear Springs	
A Coefficient	0
B Coefficient	47 kN/m^2
C Coefficient	1

The lateral load was divided and applied at distances of 1.524m and at 3.048 m from the top of the shaft. A lateral load of 4519.57 kN was applied at two locations on the shaft. An axial load of 18 683.27 kN is applied to the top of the shaft as shown in the figure below. The limit of shaft embedment into the rock was based on reaching two points of zero inflection. A diagram of the CBEAMC model and how the loads were applied is shown below.

The output results from CBEAMC analysis will be presented only for the extreme load case for the ACP Container. The results are summarized in the table below. This load case is used in the design since it has the controlling lateral load.

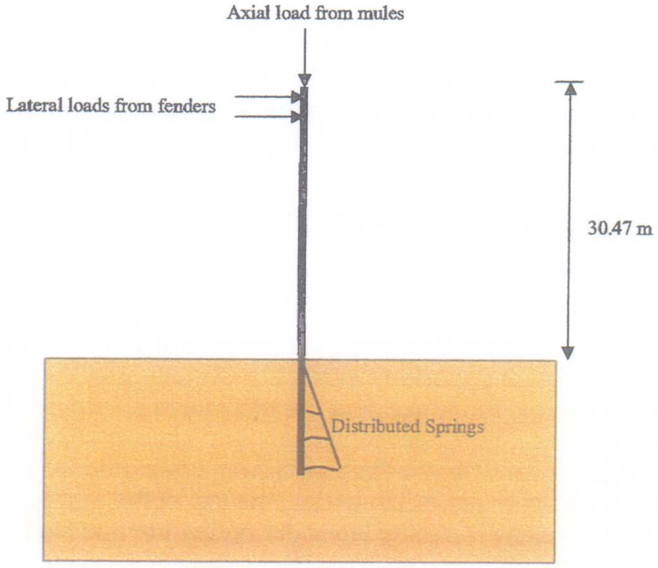


Figure F-2-4 CBEAMC Model for 2.44 m Shafts

Results for Extreme Load Case – ACP Container		
	Distance from top of shaft	Results
Maximum Shear	30.47 m	22034.45 kN
Maximum Moment	25.29m	182368 kN-m
Maximum Axial Load	2.133m	18790 kN

2.11.6. Conclusions – Drilled Shafts

The 2.44 m diameter drilled shafts have been assumed to have tip elevations approximately 11 m below the top of sound rock. This is based on the curve of shaft deflection passing through the point of zero deflection twice, and this is based on the deepest rock known at this time. It should be noted that the shafts along most of the Gatun Lake wall alignment would be considerably shorter than the shaft analyzed. The bending moments imposed by all impact load cases would not exceed either the yield or ultimate moment capacity of the drilled shaft systems.

The maximum deflection of the Gatun Lake entrance wall is limited to under 11 cm for the usual impact; to under 29 cm for unusual impact; and to approximately 1.5 m for the extreme loads considered. These deflections are based on an assumed shaft length of 25 m from sound rock to the top of wall.

It is recommended that a more detailed finite element analysis of the shaft-fender system be performed during final design phase. This analysis would better define the maximum stresses in the shaft and reflect the true stiffness of the wall system to include the effects of the cap beams, and contributions from adjacent shafts.

2.12. Seismic Design of Entrance Walls

2.12.1. Introduction

The entrance wall seismic design was accomplished in accordance with the Corps of Engineers Engineering Manual EM 1110-2-2502, Engineering and Design of Retaining and Flood Walls. In Chapter 3 of this manual a rational method is provided for computing the seismic loads on a retaining wall. Along the entirety of the Atlantic entrance wall and along a significant percentage of the Gatun entrance wall, the finished backfill grade would be at an elevation approximately equal to, or just below, the top of the cap beam. Therefore these walls are essentially retaining walls during the service life of the project.

The in-situ material along the wall alignment is generally uncontrolled fill and Atlantic Muck, overlying Gatun Sandstone. The overlying materials have friction angles less than 25 degrees, with the Atlantic Muck material having a friction angle of only 19 degrees. These materials are not suitable backfill materials for a 25 m high retaining wall because of the magnitude of the active and dynamic earth pressures generated by the horizontal seismic coefficient of 0.31g. The lower the friction angle, the higher the generated force on the retaining structure. It is therefore recommended that all material within 10 m of the back of the wall be removed and replaced with a well graded structural backfill material with a friction angle of no less than 35 degrees. The Atlantic Muck would have to be cut at a slope of approximately one vertical to eight horizontal to maintain stability within the excavation.

2.12.2. Results of Analyses

The results of the analyses indicate that a continuous retaining structure with a maximum moment capacity of approximately 33.38 MN-m/m of wall will have to be designed to retain the backfill against the east side of the entrance walls. The soils at the Atlantic entrance wall site are weak and the wall to be constructed is high. The ACP desires that the design of all features take into consideration a possible Fourth Lane adjacent to the Third Lane. Thus the use of inclined soil or bedrock anchors will not be possible. The wall would therefore have to be either a gravity structure or essentially a cantilever wall. The high groundwater table combined with weak soil conditions would provide an excellent opportunity to construct either a secant pile wall or a reinforced slurry diaphragm wall in order to provide the required moment resistance.

2.12.2.1.Secant Pile Wall Analyses

Secant pile walls provide a continuous, unbroken line of drilled shafts. These walls are constructed so that there is an intersection of one pile with another, the usual practice being to construct alternate piles along the line of the wall leaving a clear space of a little under the diameter of the required primary or "male" piles. The exact spacing is determined by the construction tolerances that can be achieved; the height of the wall is a major determinant. The initially placed "female" piles do not necessarily have to be constructed to the same depth as the "male" piles that follow, depending on the way in which the wall has been designed and reinforced. The concrete may also be chosen to have a slower rate of strength development in order to ease the problem of cutting one pile into another. The wall is constructed from the top down to the bottom, which is an ideal situation for the Atlantic wall.

The male piles are usually formed through a heavy temporary casing that can be rotated by an oscillator device, the cutting edge of the casing being toothed in a way that enables the casing to cut into the concrete of the female piles on either side.

The maximum depth to which Secant piles can be bored to is on the order of 30 m but the difficulties of construction greatly increase as pile depth increases above about 20 m. This is especially true in soils where the piles cannot be made dry during construction. Where the ground embedded length of wall is in dense or medium dense sands and gravel's, in stiff clay, or in soft rocks, walls of up to about 10 m in retained height have been constructed as cantilevers, but this requires concrete walls of perhaps 1.2 m or more in thickness. Commonly 500 mm or 600 mm diameter contiguous cantilevered pile walls can be used for retained heights of approximately 5 m. A literature search has turned up information regarding an 880 mm diameter hard/hard secant pile wall in London, England with a maximum depth of 23 m. The wall consisted of 23 m long female piles reinforced with 533 x 210 x 101 mm Universal Beams. Male piles were shorter at 16 m long and reinforced with a traditional circular cage. Due to the great height of the proposed walls (over 25 m) combined with the relatively high seismic accelerations and low soil and bedrock strengths at the site, the application of this technology for the Panama Third Lane entrance walls would seem to be pushing the envelope of the standard of practice in the industry to the present time.

There are different alternatives in the execution of secant pile walls depending on the static requirements. Either only alternate shafts are reinforced or every shaft is reinforced. For the Third Lane entrance walls, it is assumed that all shafts would have to be reinforced, for the reasons outlined in the preceding paragraph.

In order to guarantee the required overcut between the piles of the wall a concrete guide wall is built. This guide wall has exactly the shape of the plan view of the wall seen from the top.

Analysis with the commercial computer program LPILE and the Corps computer program "M-Phi" was completed to determine the capacity of various reinforced shaft sizes for the secant pile wall. The results of each analysis indicate that the maximum yield moment capacity of a 3.0 m diameter drilled shaft (without casing) is far less than the moment capacity required to cover the 3.0 m of wall that the shaft would fill. The analysis confirmed that if an uncased secant pile wall were selected, it would have to be constructed with all shafts heavily reinforced. All shafts would require diameters greater than 4.0 m.

It is concluded that a secant pile wall is not practical for the entrance walls. The required diameter and reinforcement would make such a wall uneconomical.

2.12.2.2.Slurry Diaphragm Wall Analyses

The technology for this type of wall construction has developed to the point that walls with heights greater than 50 m have been constructed from the top down in soft soil sites. Walls higher than about 10 m have all been tied-back, or anchored walls. However, a limitation on this project is that it will not be possible to utilize earth or rock anchors for the Third Lane Atlantic entrance walls. A new technique now being developed utilizes the construction of two parallel slurry diaphragm walls with slurry wall panels oriented perpendicular to and connecting the two parallel walls. The effect is to construct very large reinforced beams. This technology would permit the construction of reinforced concrete cantilever beams of nearly unlimited moment capacity. The Corps has discussed this alternate wall type with the Trevi Icos Company of Boston, Massachussetts, U.S.A., a construction firm that constructed many of the deep slurry wall diaphragm walls for the Boston Central Artery Project in the U.S.A. According to Mr. Nino Catalano of Trevi Icos, the Corps idea appears to be a feasible application of the diaphragm wall concept.

It is beyond the scope of this study to design such a set of walls, because new design methodologies will have to be developed. However, the Corps estimates that this wall must have a design yield moment capacity of no less than approximately 33.38 MN·m/m of wall. A preliminary simplified analysis was completed for a reinforced "Tee Beam" type diaphragm wall, constructed using the slurry wall technique. The results indicate that a structure of this type, designed to resist both the seismic and static load demands, is feasible. The completed design indicated that two concrete diaphragm walls, each 0.6 m wide, would be required. Center-to-center spacing of these walls would be 4.0 m, with 1.0 m wide "web" diaphragms spaced at 2.4 m, center-to-center.

2.12.3. Conclusions and Recommendations

The cost of any type of retaining wall system would be considerable for the entrance walls. The seismic design forces imposed on the wall would be greater than those permitted by conventional cantilever wall design methodologies. The construction of gravity wall sections is certainly feasible, but the unit length costs would be approximately the same or greater than the costs of the lock chamber walls. The least expensive retaining wall alternative would likely be the reinforced "Tee Beam" type diaphragm wall, constructed using the slurry wall technique, as described in the previous section.

Deleting the requirement for placement of backfill behind the walls would eliminate the costs of all of these wall types. This would be accomplished by excavating the areas behind the entrance walls so that open water areas existed in elevations above the Gatun Sandstone. The cross sections for the entrance walls shown on the report plates have assumed that there is no backfill behind the walls.

2.13. Cap Beam Design

2.13.1. General Description

The visible surface of the Panama Canal Third Lane Atlantic entrance wall is designated herein as the cap beam. The cap beam would support the Ship Positioning System locomotives and transmit vessel impact force from the energy-absorbing fender system to the drilled shaft foundations. The cap beam has been designed assuming that there would be paired 2.44 m diameter drilled shaft foundation elements spaced at between 15 m and 30 m. The central goal of this portion of the Design was to maximize the spacing of the shafts to minimize construction costs.

2.13.2. Geometry and Load Assumptions

The following information was used in the analysis. The dimensions of the cap beam shall be generally 11.80 m wide; this distance provides sufficient space for two locomotive (standard gauge) railroad tracks and a safe passage between for laborers to walk on the top of the wall. At the southern terminus of the Gatun Lake wall, the wall width will be increased to approximately 22.50 m to permit the ship positioning rail lines to crossover. This design is for only the portion of the beam that is 11.80 m wide. The cap beam is assumed to be a height of 5.00 m, which permits the selected fender system to be attached to the surface with all connections above mean water elevations.

For the purpose of this Concept Design, the cap beam is assumed to be solid, conventional reinforced concrete with a rectangular in cross-section. It is anticipated that in the next level of design, the cap beam geometry would be optimized to reduce the dead load of the beam and reduce concrete volume. The use of post-tensioning, pre-stressed precast elements and high strength concrete will all be evaluated to optimize the cap beam.

The loading consists of both vertical and horizontal factored loads. The vertical loads include the self-weight of the cap beam and the weight of the ship positioning locomotives. Each locomotive is assumed to weigh approximately 155.85 t; this was based on scaling the existing locomotives up by comparing existing Panamax vessel maximum displacement versus the anticipated Third Lane vessel maximum displacement. The design considered the case where two locomotives pass each other at the center of the span. It is assumed that the axles are spaced 15 m apart. An assumed deck live load of 4788.03 N/m^2 was also added. This loading exceeds the maximum live load in AASHTO paragraph 3.14.1.1 for bridges by more than 50%.

The horizontal load evaluated was the result of the Container Ship extreme impact case. This impact energy was reduced by the energy absorption of the selected fender system, and the resulting reaction force at the back of the fenders was applied to the cap beam. The reaction force utilized in this computation is a factored load, and these calculations therefore do not apply an additional load factor. The reaction force at the rear of the fenders would be distributed by a steel plate that would be installed between the fender and the cap beam; thus the load is distributed over the area of the steel plate. This plate is approximately 2.13 m long.

The design team is assuming that the cap beam would be cast-in-place; therefore, it is assumed that the ends (at the drilled shaft supports) would be fixed and continuous. Assumed materials consist of a 27.6 MPa concrete mix reinforced with steel reinforcement with a yield strength of 413.6 Mpa.

2.13.3. Results

Various spans were analyzed and a recommended length of 30 m was confirmed. A model of the cap beam with two drilled shafts was developed in the analysis program *Dr. Frame*. More precise moment values were calculated. These moments were then input into a *MathCAD* file that analyzes concrete beams in accordance with ACI 318-99. The tensile reinforcement steel required for a 30 m span was computed. However, based on the cross-sectional area of the cap beam alone, the minimum steel required from ACI 318-99 paragraph 10.5.1 is considered excessive. Paragraph10.5.3 states that supplying this minimum percentage of steel is not required if the amount is excessive. The minimum area of tensile reinforcement provided can be a maximum of one-third greater than that required by analysis. The cracking moment capacity of the Cap beam turned out to be larger than the factored moment that resulted from the impact of the approaching vessel. All of these results lead to the conclusion that the cap beam should be optimized in the next phase of the Design of the Panama Canal Third Lane Atlantic Locks entrance walls.

2.13.4. Sheet Pile Cut-off Wall

The Bow Thruster is a feature utilized on most, if not all of the design vessels that will transit the new Third Lane. On modern bulbous bow ships, the thruster tunnels are located within a meter of the keel, and as close to the bulbous bow as possible. Use of these thrusters will create very strong flows under the cap beam and may result in dangerous turbulence in the open water on the non-navigation side of the entrance wall. The Panama Canal Authority has specifically requested therefore that a cut-off wall be installed under the Gatun Lake entrance wall.

2.13.4.1.Bow Thruster Considerations

Research into bow thrusters yielded the following information, courtesy of Mr. Richard Welch, a representative for Ships Machinery International of Miami, Florida. This company sells and installs bow thrusters manufactured by Brunvoll AS of Norway. The tunnel thrusters used in ships of Post-Panamax size can be expected to generate power greater than 1500 kW each, and a large vessel may have up to three thrusters. Because the vessels for the Third Lane project will have such deep draft, and the thrusters will be located almost at keel level, Mr. Welch believes a limit of about 0.14 kN of thrust can be generated for each kilowatt of power. Significantly higher thrust, up to 15% greater, can be generated for thrusters located higher in the water column. The tunnel diameter can be as large as 2.65 m. Using these figures as representative numbers, an average pressure of approximately 0.039 mPa could be exerted against the sheet pile wall. For the 2.65 m tunnel, the computed total force against the wall would be approximately 213.5 kN.

2.13.4.2.Wall Design

The wall is modeled as a beam that is fixed at the upper end and hinged at the bottom. A spreadsheet was developed that allows a comparison of the total force against the sheet pile wall for various thrust magnitudes and at various bow thruster elevations. For the purpose of this concept level analysis, the centerline of the bow thruster is assumed to be located at elevation 12.7; this is 2 m above the keel, which is assumed to be at a draft of 15.2 m below the average Gatun Lake elevation of 25.908 m.

The resulting maximum bending moment on the sheet pile will occur at the upper connection to the cap beam, and is approximately 1107 kN-m for the full width of the bow thruster tunnel. Normalized per meter of wall, the moment demand is approximately 410 kN-m. Using these criteria, the required section modulus should be no less than 1971 cm^3/m. Sheet pile sections that provide an excess to this capacity include both the PZ-35 and PZ-40 sheets manufactured by Chaparral Steel in the U.S.; and both the AZ-26 and AZ-36 sheets manufactured by Profil Arbed S.A. of Luxembourg. There are many other possibilities available in both hot-rolled and cold-rolled. For purposes of this concept level report, the PZ-40 pile section is shown on the plates.

The connection between the sheets and the cap beam will have to be accomplished above water to permit replacement of damaged or corroded sheet piling in the future. In order to provide sufficient fixity at this connection, a high capacity wale with steel anchors grouted into the cap beam should be provided. This connection has not been studied in detail for this concept level report but a simple detail has been shown on the plans.

2.13.4.3.References:

1. AASHTO Standard Specifications for Highway Bridges 16th Edition (1996)
2. ACI 318-99 Building Code Requirements

2.14. Nose Piers

2.14.1. Introduction

The nose piers are the principal fixed structures that protect the entrance walls from a direct, head-on vessel impact. For the purposes of this design submittal, it was assumed that the nose piers would be designed to resist an impact equal to the Extreme vessel impact load cases for the entrance walls. The nose piers are subject to direct forces arising from wind, current, earthquake loads, and tie-off forces from vessels.

There are four nose piers. The two Atlantic entrance wall nose piers are 24.777 m wide and each pier protects the 24.777 m wide entrance wall cap beam from errant vessels up to above the maximum Atlantic Ocean elevation (El. +6.46). The two Gatun Lake entrance wall nose piers are 24.777 m wide and each pier protects the 24.777 m wide entrance wall cap beam from errant vessels up to above the maximum Gatun Lake elevation (El. +26.82).

Both of the Atlantic entrance wall nose piers and the Gatun Lake south entrance wall nose pier can be constructed in the dry. It is assumed that the Gatun Lake north entrance wall nose pier would be constructed in the wet. The design and construction method of the nose pier that is constructed in the wet would have to accommodate possible misalignments of the large-diameter drilled shafts. This misalignment can be compensated by the correct placement of the superstructure element over the shafts.

2.14.2. Components

A series of drilled shafts would support each nose pier. The drilled shafts would be designed as heavily reinforced 2.44 m diameter concrete shafts with 50 mm steel casings. All steel casings are assumed to have a yield strength of $F_y = 345$ MPa. Higher grade steel ($F_y = 483$ MPa) may be more economical and it may be used for the final steel casing grade.

The shafts would be installed such that their top (cut-off) elevation extends vertically to an elevation just above Gatun Lake normal water elevation, and Atlantic Ocean high tide elevation, respectively. The shafts would be enclosed by a base shell superstructure that sits down on top of the shafts. After installation on the shafts, the fabricated steel base shell would be filled with tremie concrete. Above the top of the base shell, precast concrete wall segments continue to the same elevation as the top of the entrance wall cap beams. For the nose piers to be constructed in the dry, the top concrete segments could be constructed with conventional cast-in-place methods, and the Base Shell superstructure could be replaced with conventional cast-in-place reinforced concrete.

The superstructures would have a built-in fuse to change their response to earthquake loads. The fuse design provides a monolithic response to low level lateral loads, and a segregated response to higher-level loads. This is proposed to reduce the axial tension in the shafts. This concept prevents shaft pullout and increases the moment capacity of the shaft.

The fuse is comprised of three, 3 m diameter sleeves that are placed to enclose the top of each nose pier shaft. The sleeves have a bearing plate at the top that transfers the superstructure vertical load to the shafts. The annular gap between the sleeves and shafts would be filled with grout. The grout would be designed to disintegrate under tension. Lateral loads would be transferred through the confined grout and through friction at the bearing plates. There is some moment fixity at the sleeve due to the snugness of fit and the length of the sleeve. The fuse is intended to remain intact at low-level loads due to wind, wave, and current, but is designed to release under extreme vessel impact collision or an MDE seismic event.

2.14.3. Fendering at Knuckles and Ends

The knuckles of the entrance walls are located where the nose piers transition to the cap beams, and at the extreme ends of the piers. These knuckles would be protected with Wheel Fenders. Wheel Fenders are already in use at Gatun Locks, and it is the Corps' understanding that they have provided satisfactory protection of the existing knuckles.

The energy absorbing capacity of the largest commercially available Wheel Fenders is similar to the energy absorbing capacity of the linear fender system specified for the new entrance walls. However, the maximum deflections of the two systems will be designed to be compatible with each other. The specified wheel fenders will be Fentek Wheel Fender No. 290-110WF or the Metso 3750 mm. The wheels of these fender systems are approximately 2.90 to 3.0 m in diameter. Each wheel fender can absorb approximately 880 kN-m, and exert a maximum reaction force of about 1300 kN against the nose pier. By comparison, the maximum energy absorption of a single panel unit of the proposed Metso/Trellex MV1450 x 1000A system that is to be used along the entrance walls is approximately 1046 kN-m. However the maximum rated deflection of the MV1450 x 1000A system is about 0.9 m, and the maximum rated deflection of the two wheel fenders evaluated is about 1.16 to 1.20 m.

The selected wheel fenders would be stacked two high for the Gatun Lake nose piers to protect the knuckle through the full range of the lake elevations. Each Wheel Fender is approximately 0.9 to 1.1 m high, the casing is approximately 1.7 m high, and the maximum range of possible Gatun Lake water surface elevations is about 2.89 m.

Only a single wheel fender would be required at the Atlantic Ocean nose piers, as the maximum tidal range is only about 0.95 m.

The specified Wheel Fenders would have either a sliding axle with rear idler rollers, or the wheel of the fender would be mounted between two idler rollers that allow the wheel to rotate even when compressed. Maintenance-free bearings enable the wheel to rotate at relatively high speeds without generating significant friction against the hull, and permit absorption of the greatest possible energy. All Wheel Fenders would be specified to have zero maintenance composite bearings and steel casings.

The extreme ends of the nose piers have the potential to be exposed to the most severe vessel collisions on the Third Lane project. Therefore the Corps recommends that ACP consider protection with the highest capacity fender system available. The system with the highest energy absorbing capacity is the Bridgestone C3000H Super Cell Fender. Each fender has the rated capacity to absorb up to 720.0 t·m of energy. These fenders are 3.00 m in depth, measured between the outsides of flanges, and weigh 18 500 kg. These fenders have a cylindrical shape and have steel mounting plates permanently bonded to the main rubber column during the vulcanization process. The fenders absorb energy by buckling; the effect is that the total fender bulges as it collapses. Custom-designed frontal frames would be mounted on the fenders to increase the contact area on the vessel hull.

Two of the selected fenders could be mounted side-by-side to provide “wrap around” protection to the front face of the nose piers to protect the end. The height of one fender is large enough to provide protection through the full range of the Gatun Lake elevations. Each Super Cell Fender is 3.35 m high, and the maximum range of possible Gatun Lake water surface elevations is about 2.89 m. The height of a single Super Cell Fender would also be adequate for the Atlantic Ocean nose piers, as the maximum tidal range is only about 0.95 m. The masonry outline of the nose piers are designed such that these fenders, in their uncompressed state, would align to project from the concrete an equal distance as the Metso MI2000 fender system that would be mounted on the sides of the nose piers. Thus no projecting edges would stick out to catch the edges of the vessels as they arrive.

Another alternative is to place Wheel Fenders at the extreme ends, although direct impact is not their ideal application. Because Wheel Fenders are already included as components of the proposed nose piers, the Concept drawings with this submittal show the same fenders at the extreme ends. At later stages of design development, it is recommended that the shape and fendering in the nose piers be analyzed more closely.

PANAMA CANAL CONCEPT DESIGN

Atlantic Locks Structure

Third Lane Lock

Appendix G

Valve and Valve Bulkheads

Prepared for

Canal Capacity Projects Office

By

US Army Corps
of Engineers

Final Report
23 July 2003

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1. CULVERT VALVES

1.1. Filling and Emptying Valve Type and Size

The filling and emptying valves would be bonnetted wheel gates, and would be operated by a hydraulic cylinder. Each valve unit would include a vertical leaf with fixed main wheels, counter hold and guide rollers, upstream and downstream frame sections, a culvert liner continuous from the upstream bulkhead to the downstream bulkhead, a bonnet and a bonnet cover which would also act as the support for the operating cylinder. The valve culvert and conduit clear opening would be 8 m high and 6 m wide for the Bottom Interlaced Lateral Filling and Emptying System. The filling and emptying valves for the In-Chamber Longitudinal Culvert Filling and Emptying System would be bifurcated to two 4 m x 7m valves and transition to 7 m high by 8 m wide culverts.

1.2. Valve Design Concept

The valve leaf would be designed as a weld fabricated and stress relieved structural steel with skin plate on the upstream and downstream sides and rubber seals installed on the downstream side of the skin plate. The side seals would be of hollow music note (J-seals) type to allow adequate seal deflection for proper sealing at the low operating hydrostatic head. The top (lintle) seal would be of hollow center bulb (double stem) type and the bottom seal would be of the rectangular bearing type.

The valve leaf would be provided with main wheels to transfer the hydrostatic load on the leaf to the downstream-embedded frame and the monolith structure. The wheels would have stainless steel cylindrical rims and self-lubricating bearings. The wheel axles would also be of stainless steel and supported on the side of the valve leaf. The main wheels would be designed such that they can be removed and be replaced easily. The valve leaf would be provided with four guide rollers to center (laterally locate) the leaf in the culvert. Two of the guide rollers on one side would be spring loaded to prevent any possibility of lateral jamming of the leaf. The valve upstream and downstream frames, bonnet, and bonnet cover would be designed as a welded and stress relieved steel fabrication. Frames and bonnet halves would be flanged, doweled and bolted together. Stainless steel seal seats would be provided on the frames and would be extended into the bonnet. Stainless steel wheel tracks would be provided on both bonnet halves and would extend into the bonnet so that the valve leaf would be supported under all transient and operating conditions. In addition, stainless steel wheel tracks for the guide rollers would be provided on the upstream frame and bonnet half to guide the valve leaf on the sides.

The bonnet cover would be flanged and bolted to the valve bonnet with stainless steel studs and then doweled to assure permanent alignment. A bronze stuffing box, packed with V-shaped chevron packing and a packing gland for the cylinder-operating rod, would be provided to control leakage past the cylinder rod. The packing gland would be adjustable from the top. A rod scraper would also be provided on the underside of the bonnet cover.

1.3. Valve Materials

The following materials would be used for the major valve components:

- Valve Leaf, Frames, Bonnets, Bonnet Covers and Culvert Liners ASTM A 36 or A 572M Grade 345

- Wheel and Roller Tracks ASTM A 564, UNS Designation S17400, Type 630, Condition 1150
- Seal Seats ASTM A 276, UNS Designation S31600
- Steel Bolts and Nuts ASTM A 307, A 325, A 490
- Fluoro-Carbon Clad Rubber Seals Rubber seal would be of molded neoprene compound or copolymer of butadiene and styrene or a blend of both. A fluorocarbon sheath would be bonded to the rubber on the sealing surface
- Corrosion Resistant Steel for Bolts, Nuts and Bars ASTM A 276, Type 316, ASTM A 564, Type 630
- Wheel Axles and Roller Pins ASTM A 564, Type 630
- Wheel Rims ASTM A 564, Type XM-25
- Concrete Anchor Studs Concrete anchor studs and stud welding per requirements of Section 7 of AWS D1.1.

1.4. Valve Function and Operation Criteria

The filling and emptying valves would be used to raise and lower the water elevation in the lock chamber for lockage operation.

1.5. Valve Minimum Dimensions

The minimum plate thickness of structural members would be at least 9.5 mm, except the parts that would be embedded in concrete, which would be at least 12.7 mm thick. The minimum fillet weld size would be at least 5 mm along the leg of the weld.

1.6. Valve Design Loads

The following table indicates the maximum design head for each valve type:

Table G-1-1 Valve Design Head

Valves Location	Normal Operating Head (m)	Design Head (with 1.5 increase) (m)
Upper and Lower Lock Filling Valves	13.53	20.29
Valves Between the Locks	27.05	40.58
Conduit Valves	10.14	10.14

Valves would be designed for the following sources of loading:

- Hydrostatic loads (H).
- Dead Loads (D) would include the applicable weight of the valve components and attachments.

- Buoyancy would be calculated using the volume of the valve leaf and its attachments.
- Down pull would be calculated using classical methods.
- Seismic loading was considered and did not control the design.
- The friction forces for seals would be computed by summing the friction caused by hydrostatic water load acting on the seal and the seal pre-compression force. The friction coefficient of 0.25 would be used for fluorocarbon sheathed rubber seal on stainless steel seal seats.
- The friction forces for the valve leaf main and guide rollers would be calculated using maximum normal force on the wheels and a rolling resistance of 0.05.
- The wheel loads would be calculated as simple reaction forces to the hydrostatic load on the gate. The wheels would be sized to have a rated capacity of at least 15 percent greater than the calculated wheel load.

1.6.1. Filling and Emptying Valve Allowable Stresses

The allowable stresses for structural steel under normal operating (usual load) conditions would be limited to 75 percent of the allowable stresses given in the AISC "Specification for the Design, Fabrication and Erection of Structural Steel for Buildings".

For unusual (head increased by 1.5) conditions, the allowable stresses given for normal operating condition would be increased by 33.3 percent, to 100% of AISC valves, except that the bearing stress will be limited to 90 percent of the yield strength.

Equivalent stress resulting from combining biaxial or triaxial stresses would be allowed to be 25 percent higher than the allowable uniaxial stress, but for all operating conditions not more than 80 percent of the yield strength.

In order to establish a permissible level for contact (Hertzian) stresses for the design of the wheels and wheel track plates the following two sources were used.

1) The Corps of Engineers Engineering Manual EM 1110-2-2703, "Locks Gates and Operating Equipment", allows contact stresses up to twice the yield strength (0.5 safety factor) of the material having the lower yield strength.
2) In Chapter 7 of "Hydraulic Gates and Valves", by Jack Lewin, based on DIN 19704, permissible contact stresses up to 1.6 times the ultimate tensile strength (of the lower tensile strength material) is recommended for frequently operated gates and locks. For rollers and wheels permanently immersed in water and making 2,000 to 20,000 revolutions per year, it recommends that the permissible contact stresses be reduced by 30 percent. This results in a permissible contact stress equal to 112 percent of the ultimate tensile strength. As a result of the review of the above references, and to be on the conservative side, a permissible contact stress equal to the ultimate tensile strength of the lower strength material would be used for sizing the wheels and wheel track plates under normal operating (usual load condition) design head. For operation under maximum operating (unusual load condition) design head only, with valve

closed, downstream bulkhead in position and downstream culvert dewatered for inspection) the permissible contact stresses would be allowed to increase up to twice the yield strength.

The maximum stresses in the mechanical components for normal operating conditions would be limited to 20 percent of the ultimate strength or 33 percent of the yield point of the materials involved. The maximum stresses for unusual operating conditions would be allowed to increase to 80 percent of the minimum yield strength or elastic limit of the materials used.

1.7. Valve Deflections

Each valve leaf would be designed to limit the deflection at the normal operating condition (without the 1.5 increase in head) to a value equal to the center-to-center dimension of the leaf side seals divided by 800. The rotation at the end of the valve body was minimized in consideration of the roller design.

2. VALVE BULKHEADS TYPE AND SIZE

A bulkhead would be provided at both the upstream and downstream sides of each filling and emptying valve in order to facilitate the isolation and dewatering of the valve culvert for inspection and maintenance of the valve, embedded metal and seals.

2.1. Valve Bulkheads Design Concept

The bulkheads would be a single piece welded structural steel fabrication with downstream skin plate and rubber seals installed on the downstream side of the skin plate. The side and top seals would be of music note (J-seals) type and the bottom seals would be of the rectangular rubbed. Continuous bearing areas on each side of the bulkhead frame, on the dewatered side, would be provided to transfer and distribute the hydrostatic load to the emptying valve structure through embedded stainless steel bearing plates.

Additionally, each bulkhead would be provided with two guide shoes on each side, which would guide the bulkhead in each bulkhead slot and would prevent it from jamming in the slot during its removal or placement. Since bulkheads are placed and removed under balanced head conditions, a small filling valve that is installed on the bulkhead and operated (opened) by the bulkhead-lifting beam would be provided on each bulkhead to fill the culvert prior to removal of the bulkhead. When not in use, each bulkhead would be stored in its own slot near the top of monolith. Two dogging devices would be provided for each bulkhead. An operator stationed at top of wall would set the dogging devices. One lifting beam would also be provided to facilitate the placement and removal of the bulkheads. The lifting beam would have a mechanism that would lock and unlock the beam to the bulkhead. The lifting beam would be stored in one of the bulkhead slots.

2.2. Valve Bulkheads Materials

The following materials would be used for the major bulkhead components:

- Structural Components ASTM A 572M
- Embedded Seal Seat Plates ASTM A 240, UNS Designation S31600
- Guide and Bearing Bars and Other Embedments ASTM A 240, UNS Designation S31600
- Steel Bolts and Nuts ASTM A 307M, A 325M, A 490M
- Concrete Anchor Studs Concrete anchor studs and stud welding per requirements of Section 7 of AWS D1.1.
- Fluoro-Carbon Clad Rubber Seals Rubber seal would be of molded neoprene compound or copolymer of butadiene and styrene or a blend of both. A fluorocarbon sheath would be bonded to the rubber on the culvert and conduit sealing surface.

2.3. Valve Bulkheads Function and Operation Criteria

The function of the bulkheads is to isolate the lock emptying culvert or conduits for dewatering in order to gain access to the valve parts (which would otherwise be submerged) for inspection or maintenance. The design head for the upstream and downstream valves and conduit valve bulkheads are approximately the same. These bulkheads are designed for a head of 28 m. The common design has advantages of interchangeability and ease of maintenance. The central valve bulkheads are designed for a head of 40 m. All bulkheads would be placed and removed under balanced head conditions.

2.4. Valve Bulkheads Minimum dimensions

The minimum dimensions for the bulkheads would be the same as for the valves; except for the embedded plates it would be 9.5 mm.

2.5. Valve Bulkheads Design Loads

The following design loads would be considered as applicable.

1. Hydrostatic loads (H), H=28 and 40 m.
2. Dead Loads (D) would include the weight of the bulkhead, lifting beam, and the hoist connection parts bearing on the bulkhead.
3. Buoyancy would be calculated using the volume of the bulkhead and its attachments.
4. Silt and debris load would be computed assuming silt built up on the flanges of the horizontal members except, where large holes are present in the webs, silt would be assumed to accumulate on a 1V:2H slope away from the holes.
5. A hydrodynamic water pressures resulting from the Operational Basis Earthquake would be added to hydrostatic pressures.
6. Seal sliding friction forces would be computed using a maximum coefficient of friction of Fluoro-Carbon on corrosion resistant steel of 0.25 and the normal force between the seal plates and the side and top seals. Since bulkheads are installed and removed under balanced head conditions, the only force on the seals would be the preset force in the seal.
7. Guiding forces for the bulkheads (when it is not submerged), to counteract the tendency of the bulkhead swinging, would be considered as 5 percent of the weight or a surface loading of 191Pa on the bulkhead, whichever is higher, in either horizontal directions. The effect of water turbulence on the bulkhead guiding components would be computed on the basis of 487 Pa surface loading on the bulkhead. The bulkhead area to be considered would be the projected area of the bulkhead outline.
8. Blocking/jamming forces in the lowering direction occur when the bulkhead moving downward is stopped by a resistance (blocking force) at one lower fixed guide. Acting forces (blocking force) would be the weight of the bulkhead and the lifting beam.
9. Block/jamming forces in the raising direction occur when the bulkhead moving upward is stopped by a resistance (blocking force) at one upper fixed guide. Acting forces (blocking force) would be computed using 300 percent of the weight of the bulkhead.

2.6. Valve Bulkheads Allowable Stresses

Bulkheads would be designed in accordance with EM 1110-2-2105 Design of Hydraulic Steel Structures. Allowable stresses will be1.1 times those permitted by AISC (1989). Bulkheads would be designed to resist expected pool elevations for dewatering applications.

2.7. Valve Bulkheads Deflections

The bulkheads would be designed to limit the deflection at the top of the bulkhead to 9.5 mm under normal operating design head.

PANAMA CANAL CONCEPT DESIGN

Atlantic Locks Structure

Third Lane Lock

Appendix H

Electrical and Mechanical Lock Operating Systems

Prepared for

ACP
AUTORIDAD DEL CANAL DE PANAMA

Canal Capacity Projects Office

By

US Army Corps
of Engineers®

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1. OPERATING MACHINERY

1.1. Miter Gate Machinery

1.1.1. General

The miter machinery will be the direct-connected hydraulic cylinder type, similar to those being installed on the existing locks. This arrangement is simpler and easier to maintain than either the Panama or Ohio River type linkages.

1.1.1.1. Design Loads

The miter gate machinery loads are based on guidance outlined in EM 1110-2-2703, Lock Gates and Operating Equipment, 29 February 1984. This guidance recommends that miter gate machinery be designed to withstand normal operating loads during movement in water as well as temporal loads, which are short duration loads from impact or wave surge. The temporal load recommendation for direct connected type machinery has been recently updated to a 0.2286 m differential head superimposed on the gates at the mitered and recessed positions. The gate cylinders are sized to hold position against the surge loads or equivalent impact loads. The cylinder rods are designed to resist column failure at full extension with 2.5 times the maximum (temporal) loading. Any load that exceeds this design parameter will open a hydraulic system relief valve to limit the force on the rod. Loads are investigated for three conditions in each direction of gate movement. Theses loads are not additive:

1) Operating loads while swinging the gate are predicted using the scale factor procedures outlined in the EM for the Waterways Experiment Station (WES) Claiborne Lock Model. They represent the forces required to move the leaf through the water in both opening and closing cycles. These forces vary greatly with gate position, with the maximum operating loads just after the start of each cycle. A variable volume hydraulic pump is used to adjust the system output as the load changes.
2) The temporal load is calculated by superimposing a 0.2286 m differential head on the gates at the mitered and recessed positions. The EM requires the cylinder to hold this additional load to prevent unanticipated gate movement when fully opened or fully closed. Calculations show this load to be the maximum of any predicted gate machinery load. Therefore, the temporal load is used as the basis for cylinder selection and design. The miter gate machinery is not required to move the gate during a temporal load condition; it is only required to hold the gate in either the open or closed position. Check valves are used to isolate the hydraulic pumps from reverse flow and excessive back pressure and relief valves are used to limit the pressures generated by the surge. By limiting the pressures, the loads on the gate and operating equipment are limited to predicted values. If relief valve settings are exceeded, the cylinder will allow controlled movement of the gate in the direction of the force. Due to different effective piston areas in the

head and rod ends of the cylinder, separate relief valves with different settings are required for each end of the cylinder.

3) The maximum gate stall load is calculated by applying the full system pressure to the effective piston area. Gate stall occurs when an obstruction such as a log prevents the gate from moving.

1.1.1.2. Component Stresses

A factor of safety of not less than five, based on the ultimate strength of material, is used in all design calculations at normal loads. At maximum available loads, stresses will not exceed 75% of the material yield point. Rods in compression will be designed for 2.5 times their critical column loads.

1.1.2. Miter Gate Cylinders

The cylinder is supported in the miter gate machinery recess by a trunnion/cardon ring assembly (or gimbal) and the piston rod is connected to the gate pin type clevis. Each cylinder will be equipped with rod scrapers, wipers, zero leakage seals, and stop tubes as required. Greaseless bearings are used for the cylinder trunnion, cardanic ring, and rod clevis. All miter gate cylinders will be identical to minimize spare part requirements. Each cylinder will have a 711 mm bore, 508 mm rod, and 10,491mm stroke.

1.1.3. Hydraulic Power Unit

A separate hydraulic power unit operates each miter gate cylinder. The power units and most control components are located in the operating gallery adjacent to each gate. The interconnecting hydraulic piping to the cylinders is stainless steel tubing. Each power unit includes an 1800L stainless steel reservoir, two independent motor-pump groups, relief valves, check valves, flow control valves, filters, and gages. A sealed breather system utilizing two 227L reservoir isolators and a filtered vacuum relief valve is required to prevent water contamination from operating in Panama's humid environment. The hydraulic system will have a design pressure of 17.2 MPa with a peak allowable of 24.1 MPa. With a 4-minute operating time a 56 kW motor is required to drive each of the two hydraulic pump groups.

1.1.4. Maintenance Access

Access for inspection and maintenance of the bearings, hoses, seals and position transducer will be provided. Since the locomotive tracks must pass over the miter gate machinery room, the access tunnel to the operating gallery continues across the gallery and through the back side of the lock wall where it opens to a platform. This arrangement allows the cylinder to be removed by the following procedure: the miter gate is pinned in the recess position with the cylinder retracted, hydraulic extension hoses are installed to the cylinder, track rollers are secured under the cardanic ring, and the cardanic ring pins are removed. At this point the cylinder is extended to propel itself through the access tunnel. A second retract/extend cycle is required to push the cylinder shell onto the platform where it can be removed by a crane.

1.1.5. Environmental Measures

Environmental protection measures will include: pressure switches to automatically shut off the working pumps (and oil flow) in case of hose or pipe rupture; zero leakage cylinder rod seals with protective scraper/wiper; self lubricating bearings to eliminate the need for grease and an oil containment system for each HPU.

1.2. Valve Machinery

1.2.1. General

The valve machinery for both the culvert and conduit fixed wheel type bonneted valves will incorporate a vertically mounted hydraulic cylinder connected directly to the valve. This arrangement takes up less room than other valve types such as reverse tainter valves, which is an especially important consideration due to the requirement for back-up valves and miter gates at each location.

1.2.1.1. Design Loading

Design loads considered for the valve cylinder are from the forces due to flowing water, weight of the submerged valve, friction of the side seals and wheel bearings, and forces associated with the head differential across the top seal. Since the valves normally start closing under low to nearly balanced head conditions, the cylinder rods are in tension most of the time.

1.2.1.2. Component Stresses

A factor of safety of not less than five, based on the ultimate strength of material, is used in all design calculations at normal loads. At maximum available loads, stresses will not exceed 75% of the material yield point.

1.2.2. Valve Cylinders

The valve cylinders will have a flange type mount on the rod end and will be installed vertically to a support frame directly above the valve bonnet cover. The cylinder rod will pass through a stuffing box type bonnet seal to prevent water from intruding into the machinery room due to the differential head pressure. The cylinder will be attached directly to the valve with a spherical bearing type rod clevis. Each cylinder will be equipped with rod scrapers, wipers, zero leakage seals, and stop tubes as required. A Self-lubricating spherical bearing will be used for the rod clevis. Conduit valve cylinders with slightly smaller bore and rod diameters than the culvert valve cylinders could be utilized. But since the stroke requirements are the same for both valve types, having them all identical will minimize spare part requirements. Therefore, each valve cylinder will have a 457mm bore, 165mm rod, and 8,229mm stroke.

1.2.3. Hydraulic Power Unit

A separate hydraulic power unit operates each valve cylinder. The power units and most control components for the culvert valves are located in the operating gallery adjacent to each valve. The power units and control components for the conduit valves are located in the same machinery room as the cylinders for each set of water saving basins. The interconnecting hydraulic piping to the cylinders is stainless steel tubing. Each power unit includes a 4542L stainless steel reservoir, two independent motor-pump groups, relief valves, check valves, flow control valves, filters, and gages. A sealed breather system utilizing four 379L reservoir isolators and a filtered vacuum relief valve is required to prevent water contamination from operating in Panama's humid environment. The hydraulic system will have a design pressure of 17.2 MPa with a peak allowable of 24.1 MPa. A 75 kW motor is required to drive each of the two hydraulic pump groups.

1.2.4. Valve Rollers

The reaction rollers for all valves are designed as a crowned roller on a flat race. The maximum compressive stress is calculated, based upon the actual operating head, using Formulas for Stress and Strain by Roark and Young, 5th Edition, page 518, case 4. This approach is consistent with that recommended in DIN Standard 19704-1, 1998, Hydraulic Steel Structures, Para 10.22. The allowable resistance of the tread material has been calculated according to Din 19704-1 taking into account the number of cycles of stress repetition. For purposes of this design, it has been assumed that there will be 20 lockages per day for twenty years. This would amount to approximately 460,000 cycles of stress for the culvert valve. The fact that the load on the wheels will be reduced as the valve is opened was not taken into consideration and makes the result conservative. The calculated level of stress is also within that recommended in U.S. Army Corps of Engineers Engineer Manual 1110-2-2703, Design of Lock Gates and Operating Machinery. The width of the roller and the crown radius have been selected to minimize peak compressive stresses and to insure that the compression ellipse falls well within the confines of the tread under the maximum gate deflection and resulting rotation of the neutral axis. In the case of the conduit valve, a larger diameter roller was used in conjunction with embedded roller tracks on both walls of the gate recess. A small clearance will be provided between the roller and the track when the roller is in contact with the track on the other side of the recess. This arrangement will allow the gate to take the load and seal with the load in either direction. In this case, the resulting stresses were lower due to the larger roller diameter and lower head; consequently, the roller width was adjusted accordingly.

The reaction rollers will be constructed of cast steel, ASTM A148, Gr. 80-40 with a hardened, ¼" finished thickness, stainless steel, welded overlay on the tread. The weld overlay will be made in multiple passes to minimize dilution of the base metal into the corrosion resistant tread surface.

The roller axles are designed as cantilever beams. Axles will be machined from ASTM A564, Gr XM25, Grade H1150. Allowable stresses are in accordance with recommendations of EM 2703 for machine components. The axle centerline will be eccentric to the bearing seat centerline by 4mm to allow for adjustment of the roller treads to a common plane to insure proper load distribution. Once adjusted, the axle will be pinned to maintain its position.

Reaction roller bearing will be maintenance free and self-lubricating utilizing a "Lubron AQ" film specifically developed for underwater use. Bearings will be fabricated of alpha aluminum bronze, a high strength alloy most suited for marine environments.

1.2.5. Maintenance Access

Access for inspection and maintenance of the bearings, hoses, seals and position transducer will be provided. Access covers are provided at each end of the bonnet cover plate to install dogging beams that support the valve in the fully raised position. With the valve dogged off, the rod clevis pin can be removed and the hydraulic cylinder and support frame can be lifted off. After the bonnet cover is removed, the valve itself can be lifted out of its slot

1.2.6. Environmental Measures:

Environmental protection measures will include: pressure switches to automatically shut off the working pumps (and oil flow) in case of hose or pipe rupture; zero leakage cylinder rod seals with protective scraper/wiper; self lubricating bearings to eliminate the need for grease and an oil containment system for each HPU.

2. LOCK LIGHTING

2.1. Design analysis and evaluation procedure.

The analysis and evaluation of the proposed lighting system was performed using Visual Professional software from Holophane. The software performed all of the necessary calculations to determine an adequate illumination level in the chambers and on the lock walls. A three-dimensional model of the lock was created and used to determine pole locations, adjust pole heights, add and/or subtract the number of luminaries, and switch the types of luminaries to determine the optimum illumination levels and patterns. The recommended lighting design showing the various light levels is included with the electrical drawings.

The objective for the lighting design was to provide adequate uniform lighting in the chamber, lock walls, and approach areas. There are no standards or IES recommendations for lock chambers or locks of this magnitude. The standard utilized within USACE is to provide an average of 21.52 lx minimum at low pool within the lock chambers. Therefore, the lock lighting drawings indicate the 21.52 lx cutoff point.

2.2. Considerations

2.2.1. Area vs. Floodlight luminaries.

Area type luminaries are favorable when compared to floodlight types in a high mast lighting application. Considering the size of the locks and the various lighting objectives, utilizing a floodlight design would require extensive and precise aiming. The aiming would be difficult to maintain because of the necessary eventual re-lamping procedures and environmental slippage thereby affecting the original design parameters. Therefore, flood light type luminaries were dismissed from consideration.

2.2.2. Metal Halide vs. High pressure sodium lamps

There are tradeoffs in lamp characteristics to consider when selecting high intensity discharge (HID) lamps. The advantages of using high-pressure sodium (HPS) lamps is their high efficacy (140 lm/W for a 1000 W lamp), they offer the longest life (24,000 hours) and best lumen maintenance characteristics of all HID sources. The major disadvantage of HPS lamps is the color appearance, or chromaticity. Sodium, the major element used, produces a golden color. Metal Halide (MH) lamps are less efficient (110 lm/W for a 1000 W lamp) and have up to a 50 percent shorter life. Another concern is the restarting time for metal halide, which can take up to 12 minutes for the lamps to return to its full output. The advantage of MH is the good color appearance, chromaticity, or white color produced. Often the decision for selecting the type of lamp lies with the user. Weighing the advantages and disadvantages of each, HPS lamps are recommended for this application.

2.2.3. Pole Spacing and Height

Several software iterations were performed with various pole heights and spacing. Illumination calculations with poles at 30.5 m in height, and spacing at 150 m, resulted in acceptable levels of light within the chamber. However, light levels less than 21.52 lx were evident consistently between the poles. Adding fixtures to this configuration only added to the non-uniformity. Compensating by providing additional poles with closer spacing would add cost. It was also apparent that with pole heights of 30.5 m, light contributions from luminaries located on opposite walls were limited. At this point poles were raised to 45.7 m. By raising the pole height to 45.7 m a more uniform distribution could be attained. Less poles and luminaries can be utilized at this height. Contributions from adjacent poles increase and the overall light distribution improves to average illuminance levels well above the 21.52 lx level at low pool and at the top of lock walls. Uniformity also increases at this pole height. Thus the 45.7 m pole became the recommended pole height.

It is the opinion of the design team that one of the contributing factors of the shadows at the existing Panama locks is the pole configuration. Poles on the east, middle and west walls are located in most cases directly across from on another. This contributes to the shadows and the dark spot between the poles. A staggered configuration using the 45.7 m pole height provides a more uniform distribution.

To meet the 21.52 lx at low pool at the upstream and downstream approach areas, a spacing of 125 m was required and the number of fixtures required was increased from six to eight.

2.2.4. Luminaries

Two luminaries were considered for the high mast lock lighting design. One being Holophanes standard high mast fixture (HMST) and the other a cutoff fixture (HMSC). Cutoff luminaries, restrict light trespass, reduce glare, provide good light throw away, and direct most of the downward. Cutoff luminaries by definition allow less than 2.5 percent of the lumen output above 90 degrees. Comparing the two luminaries with the lighting model, with all parameters such as spacing, pole height, and wattages being equal, the cutoff fixture had superior results. Therefore the cutoff luminaries were selected. The HMSC cutoff luminaries is suitable for coastline applications and other outdoor environments. Luminaires with a wide asymmetric light pattern was utilized.

2.3. Recommendations

2.3.1. General

The lock chambers and walls would be illuminated by a high mast lighting system with cutoff style luminaires. Each high mast pole would be provided with a lowering ring on which the luminaires are mounted. Lamp changing and luminaire maintenance could be performed at lock top of wall level. A portable powered winch would be utilized for lowering and raising the fixture support ring. Galvanized steel poles, 45.7 m high would be set back 6 m from the face of the lock walls and pole spacing would be 150 m in a staggered configuration. Each pole would be provided with six or eight luminaires depending on location as shown on the drawings. The luminaires selected would be cutoff type each with a 1000 W high pressure sodium lamp and a wide asymmetric optical pattern. Since there are no walls to mount poles opposite of the entrance walls, pole spacing would be decreased to 125 m and the number of fixtures increased from six to eight on the upper and lower entrance walls. Luminaires, lowering mechanism and the high-mast poles would be designed for a 129 km/h wind or lateral load with a gust factor of 1.3. The east and west walls would contain 19 and 10 poles respectively.

2.4. Definitions

2.4.1. Illuminance

Illuminance is the most common metric used by the lighting industry for system performance verification. Loosely defined, illuminance is the amount of light falling onto an area. Thus, illuminance is a density. The footcandle is the English unit for illuminance and represents the number of lumens (light) incident on an area per ft^2 of that area. Lux is the metric equivalent of the footcandle and represents the number of lumens incident on an area per square meter of that area. In exterior lighting models the inter-reflected component of illuminance is most often considered insignificant and therefore the additional calculation time that would be necessary to calculate this component is unjustified. By default, the Visual software does not calculate the inter-reflected component of illuminance for exterior models.

2.4.2. Average/min Ratio

The ratio of the average value to the minimum value of illuminance found within a statistical or calculation zone. This ratio is typically used as an indicator of lighting uniformity. Vision is enhanced by uniformity in illumination when average-to-min ratios are kept to approx. 4:1 or better. An average to minimum ratio of 4:1 represents for a given target area the lowest level of illuminance is no less than ¼ or 25 percent of the average level of illuminance.

2.4.3. Max/min Ratio

The ratio of the maximum value to the minimum value of illuminance found within a statistical or calculation zone. Typically used as an indicator of lighting uniformity.

2.4.4. Uniformity Gradient

A statistic that measures the rate of change of illuminance over a Calculation or Statistical Zone expressed as a ratio between the illuminance levels of adjacent calculation points.

2.5. Summary Of Design Results

2.5 General

Statistical results for the recommended high mast lighting design are contained in Table H-2-1 and can also be found on the electrical drawings.

Table H-2-1 Lock Lighting Results

Description	Avg	Max	Min	Max/min	Avg/Min	UG
West top of wall – lower	52.72 lx	98.99 lx	24.75 lx	4.0:1	2.1:1	1.5
East top of wall – lower	59.18 lx	121.59 lx	112.91 lx	9.4:1	4.6:1	1.5
Atlantic Ocean pool	37.66 lx	104.37 lx	12.91 lx	8.1:1	2.9:1	1.6

Description	Avg	Max	Min	Max/min	Avg/Min	UG
West top of wall – middle	51.65 lx	98.99 lx	25.82 lx	3.8:1	2.0:1	1.5
East top of wall – middle	47.34 lx	100.07 lx	22.60 lx	4.4:1	2.1:1	1.5
Lower chamber – low pool	39.81 lx	60.26 lx	13.99 lx	4.3:1	2.9:1	2.0
West top of wall – upper	48.42 lx	97.92 lx	22.60 lx	4.3:1	2.1:1	1.5
East top of wall – upper	55.95 lx	121.59 lx	21.52 lx	5.7:1	2.6:1	1.6
Upper chamber low pool	39.81 lx	59.18 lx	18.29 lx	3.2:1	2.2:1	1.9
Gatun lake pool	37.66 lx	93.61 lx	fc	7.9:1	3.2:1	1.6

2.6. Supplemental Lock Lighting

2.6.1. General

Supplemental lock lighting systems are proposed to enhance the illumination of critical areas within the lock chamber. Critical areas requiring additional lighting are the miter gates and the area where the water meets the chamber walls. Through the use of the Visual three-dimensional model, it was quite evident that supplemental lighting systems are required to increase lighting levels in these areas. Using the lighting model, illumination levels were determined in the chamber. The model created, symbolized a ship of the Post Panamax variety in the chamber. Lighting levels provided by the high mast system is somewhat compromised within the chamber due to the size of the ships. Solutions must overcome various restrictions such as the locomotives, ship size, access to proposed fixtures for maintenance, etc., that limit the possible solutions for lighting these areas. Therefore, the design team proposes supplemental lighting in the form of chamber lighting and miter gate lighting, which are discussed below.

2.6.2. Chamber Lighting (where water meets vertical walls)

The most feasible solution for chamber lighting, incorporates the use of a floodlight and providing a .76 by .76 m slot from the top of the wall to the water level. The slot would occur every 30.5 m and the floodlight at the top of wall would be aimed at the water. The design was modeled using the Predator luminaire manufactured by Holophane. The floodlight would be accessible at this location and can be replaced by rotating the fixture 180 degrees. The recommended floodlight contains a 400 W high pressure sodium lamp with wide horizontal and wide vertical beam optical options. A representative light pattern and calculations for this arrangement is shown for a typical chamber length on the electrical drawings. The additional lighting will assist the ship operators in knowing where the lock wall is and how close the ship is to the lock wall.

2.6.3. Miter Gate Lighting

Consideration was given to lighting the miter gates by installing luminaires on the top of the gates and aiming them towards the water surface. However, for the luminaires to be effective, they would have to protrude beyond the vertical surface of the gates. In this configuration, clearance issues with ships and when the gates are moved into the recess become an issue. Therefore, installing any lighting fixtures [illegible] the gates is not a feasible option and was removed from the list of miter gate lighting considerations. Another option considered was to illuminate the miter gates from the top of the lock walls using floodlights mounted on a separate pole. The proposed arrangement utilizes 9 m poles each with 2 floodlights per pole and setback 6 m from the face of the wall. The luminaires used in the design model are Holophane Prismbeam with a 750 W high pressure sodium lamp. The fixtures are aimed at the face of the gates for maximum illumination as shown on the electrical drawings. The floodlights aimed at the upstream face of the gates utilize a NEMA 6 x 5 beam spread and floodlights aimed at the downstream face utilize a NEMA 3 x 3 beam spread. Different beam spreads are required depending on the location and aiming of the fixtures. The light patterns and calculations for this arrangement are shown on the electrical drawings. This arrangement provides an additional benefit, which became evident from the lighting model. By adding miter gate floodlights, additional chamber lighting at water level near the gates is realized. The additional level of illumination is also shown on the electrical drawings.

3. ELECTRICAL POWER DISTRIBUTION AND CONTROLS

3.1. Lock Power Distribution

3.1.1. Assumptions

It should be stated that loads for the locomotives were not available for this effort and that assumptions were made to permit the conceptual design of the lock distribution system. Actual load information is critical to any power distribution design and results presented and shown on the drawings could be greatly impacted. Loads also play a key role in the selection of proper voltage level. The load assumption for the locomotives was based on the existing track rooms at Gatun Locks, which are furnished with 225 kVA transformers. The proposed design assumes a load of 500 kVA for each track room for the new lock.

3.1.2. General Description

The objective of any power distribution system design is to provide a design that insures safe, reliable, and flexible service. Supplying multiple connection paths to the loads served can increase service continuity and reliability. These statements are the basis for this conceptual design. To assure reliability, a degree of redundancy was incorporated into the lock power distribution system. Redundancy insures flexibility and provisions to quickly isolate faults or failed components and ability to quickly restore power to operating equipment.

The proposed medium voltage power distribution system would be configured as a redundant loop primary system. The proposed system would distribute 6.9 kV primary power in a loop configuration to all the transformer rooms through the tunnels. The power distribution system would consist of two main switch rooms and 22 transformer rooms distributed throughout the lock. The switch rooms would be located on the north and south ends of the locks. The switch rooms would each contain medium voltage metal clad switchgear. Loop feeders would connect the main switch rooms with the transformer rooms. There would be separate loop feeders for the east wall, west wall, and the water saving basins. To insure reliable electrical service to all operating equipment a redundant loop from each switch room would be included to each transformer room. Transformer rooms would contain sectionalizing switches, redundant transformers, and low voltage switchgear. Transformer rooms could be fed from the north and south switch room. Sectionalizing switches would be located in each transformer room to isolate the feeds for maintenance or should problems occur. The transformer rooms would be located near the operating machinery where loads are concentrated to provide load segmentation. Each transformer room would be provided with redundant transformers sized to carry the entire load. The transformer secondary would terminate into doubled ended low voltage switchgear.

The proposed 6.9 kV electrical distribution system, in addition to the basic power carrying system of power cables, circuit breakers, switches, and transformers, would feature a fully integrated network protection scheme to facilitate protection, remote monitoring and control from the control room or location designated by the user.

3.1.3. Loop primary method of distribution

The loop primary method of distribution has many advantages. Greater reliability, flexibility, and service continuity would be realized. Single sections of primary cable could be isolated for repair or maintenance without the need to interrupt power to the loads. Furthermore, the close-coupled construction of isolating devices and bus would make short circuit faults less likely.

Each primary loop would be configured such that one of the sectionalizing switches would be kept open to prevent parallel operation of the sources. With this proposed method of distribution, when a primary feeder conductor fails, the associated breaker opens and interrupts service to all loads up to the normally open primary loop sectionalizing load break switch. Once it has been determined which section of primary cable has faulted, then the loop sectionalizing switches on each side of the faulted conductor can be opened, the loop sectionalizing switch previously left opened then closed and service restored to all transformer rooms. If a fault would occur directly on the load side of one of the loop breakers, the loop breaker would be kept open after tripping and the next load side loop sectionalizing switch opened so that the faulted conductor could be sectionalized and replaced. Under this condition all transformer rooms would be supplied from the other loop feeder circuit breaker, and thus all conductors around the loop must be sized to carry the entire load. Should a transformer fault or overload occurs, the transformer primary fuses would blow, and then the transformer primary switch opened thereby disconnecting the transformer from the loop, and leaving all other transformer room loads unaffected.

Since it is not desirable to have a transformer room without service even for a minimal time while locating a faulted conductor, or when a transformer fault occurs, a redundant loop would be included to all transformer rooms to reduce the extent of an outage from a conductor fault. This would obviously increase system investment, however, service continuity would be gained. Additionally, the existing locks utilize the loop primary method of distribution thereby realizing gains in maintenance and making this type of distribution system the logical choice. Redundant loop feeders would be provided for the transformer rooms located on each wall and the water saving basins. The proposed method of distributing power throughout the locks is shown on the one line drawing.

3.1.4. Switchrooms

Switchrooms would be located on the north and south ends of the lock on the west wall.

The switchrooms would house the medium voltage switchgear. Switchgear would be Vacuum type, and rated for 15 kV, 2000 A. Switchgear rated for 1200 A is sufficient for the load; however, additional capacity and cells would be added to accommodate future growth. Vacuum switchgear assemblies are a worldwide application trend for medium voltage applications. This switchgear would contain the control devices for checking and regulating the flow of power, switching and interrupting devices to turn power on and off, metering devices to measure the flow of electrical power and protective devices to protect power service from interruption and prevent damage to equipment. Microprocessor based relays would provide multiple relay protection functions as well as metering, alarming, monitoring, and control, all in one assembly and therefore require less space than individual relays and associated peripherals. The plan would be to control and monitor the switchgear from the control room. Each switchgear assembly would be configured to accept two incoming feeders. A provision for a third incoming feeder would be configured for the south switch room for standby power. A plan drawing showing a general layout of the switch room is shown on the drawings.

3.1.5. Transformer Rooms

The proposed transformer room locations are configured as follows:

Table H-3-1 Transformer Rooms

Location	No. of Transformer Rooms	Track Rooms	Machinery Rooms
East Wall	10	7	3
West Wall	8	5	3
WSB's	4	-	4

Machinery transformer rooms and their associated distribution equipment would be located near areas of load concentration. As a result, secondary cables can be kept to minimum lengths. Other obvious advantages include efficient space utilization, increased flexibility, and reduced exposure to low voltage faults, reduced power losses and improved voltage regulation. Segmentation of the load permits the use of smaller transformers. There would be a total of 10 machinery transformer rooms placed throughout the system, one near each set of gates and culvert valves and one for each water saving basin.

Track transformer rooms are shown, however their proposed locations should be revisited once locomotive decisions and associated loads are finalized.

Transformer rooms would be accessible from the electrical tunnel. Controlled access to the transformer rooms is recommended and could be further defined during later phases of the design. Rooms must be provided with roof access for equipment installation or replacement. Each transformer room would contain sectionalizing switches for the redundant north and south loop feeders, redundant transformers, and the low voltage switchgear. Suitable wall space would be provided for additional equipment. A plan drawing showing the proposed major items of equipment located in the transformer rooms is shown on the drawings.

3.1.6. Sectionalizing switches

Sectionalizing switches, load break type, would be added to each transformer room to facilitate equipment isolation for maintenance purposes or should a fault occur on a section of primary. The switches would be rated 15 kV, 600 A and include provisions for motor operators.

A microprocessor relay option with directional capability would be available for the loop switches which would assist operators in locating faults along the various sections of the primary should they occur. Various options associated with the switches exist including provisions for remote control, addressable relays for reading the switch position remotely, etc. User needs and preferences must be considered to determine to what extent these features should be incorporated, all of which could be better defined during the feasibility or plans and specifications phase.

3.1.7. Power Transformers

Transformers would be subject to large load swings and would undoubtedly operate below rated current most of the time. However, during operation, capacity must be sufficient for the machinery motor loads. Redundant power transformers would be provided which feed the double-ended 480-volt low voltage switchgear. Each power transformers would be sized to supply the total simultaneous load. Loss of single transformer would not affect lock operations. The proposed power transformers are dry type, and rated for 750 kVA. With the proposed arrangement, true transformer redundancy would result in a transformer loading of 50 percent of it secondary rated capacity.

3.1.8. Loop feeders

Redundant loop feeders from the north and south switchrooms would be provided for the east wall and west wall transformer rooms. Additionally, separate redundant feeders would be provided for the conduit valves for the water saving basins. Medium voltage cable would be required to be specified at the 133 percent insulation level per TM-5-811-1, which permits greater margin for voltage surges, insulation deterioration, and fault clearing time. Cable would be shielded and the recommended insulation for long life requirement is EPR (ethylene propylene). Recommended jacket is chlorosulfonated polyethylene, which is mechanically rugged, flame and oil resistant. Conductors larger than 500 kcmil are not economical and therefore parallel conductors would be utilized for ampacity requirements greater than 500 kcmil.

3.1.9. Low voltage switchgear

The proposed low voltage switchgear was sized based on the loads, which resulted in a 1600 A rated bus. Since redundant feeds supply power to the switchgear a doubled ended unit was selected. Power circuit breakers were selected do to the critical loads they serve, available selectivity, repetitive duty, extended life and high current in-rush. The main breakers would each utilize a microprocessor-based relay for bus protection, metering, remote control, alarming and indication. Providing means for indicating the status of the main breakers is recommended so that a tripped main does not go unnoticed. Digital trip units are proposed for the feeder breakers.

Because there are redundant sources providing power to the switchgear, bus metering provisions would be included for each source. This would aid maintenance personnel in determining if all voltage has been removed prior to working on the switchgear.

3.1.10. Power System Monitoring and Control

One of the ongoing changes in the power industry has been the movement of electronics and solid state devices into industrial applications. Today's protection systems are microprocessor based and can combine monitoring, metering, protection, and control capabilities into one assembly. The extent to which control and/or monitoring of the power system from a remote location would be further defined during the plans and specifications phase. User needs and preferences must be considered to determine to what extent these features should be incorporated. Major items of distribution equipment shown in this conceptual phase can all be operated and monitored remotely. It would seem logical and feasible to provide a power system with this capability, which would result in attaining efficiencies in operations.

3.1.11. Lock Load Discussion

The sum of the power ratings of the load equipment is referred to as the connected load. Because most of the equipment operates intermittently or at less than full load, the actual demand on the power source is much less than the connected load.

Based on feeder load computations (see appendix), the distribution system would need to deliver 1090 A at 6.9 kV. This current would require 13.011 M or a transformer capacity of 15 mVA. However, these loads assume a 500 kVA load for each track room. Also, all gates and valves would not operate simultaneously. The National Electrical Code permits, where it is unlikely that two or more noncoincident loads will be in use simultaneously, that only the largest loads in use at one time may be used in computing the total load. In reviewing the various operating machinery scenarios and valve sequences, the largest demand on the distribution system occurs when utilizing the water saving basin conduit valves during equalization between the upper and lower lock. During this stage, 8 conduit valves (12-93 kW motors) would be required to operate at one time. During this time, if we assume that 16 locomotives are also operating, the max demand of the locks would be approx 617 A at 6.9 kV (See appendix). Based on the above assumptions this current would require a demand of 7.365 MVA. Allowing 20 percent increase for future growth and rounding the result to a standard transformer size would result in a transformer bank capable of providing a capacity of 10 MVA. It should be understood that the locomotive loads are a significant portion of this estimated load. For example, without the locomotives, the demand would drop significantly to approximately 2.59 MVA.

The system would be configured at the 6.9 kV distribution level because of the existing Gatun Locks. Although the load demand and the available capacity of the existing sources that feed Gatun are not known, operating efficiencies could be gained since the new and existing locks are in close proximity of each other. Supplemental feeders could be configured between the new and existing locks. Once locomotive loads are determined voltage levels should be revisited. Since existing utility information was not available, further studies are needed to determine available power on the existing transmission system.

3.2. Controls

3.2.1. Communications

3.2.1.1. General

Wherever possible, all control system communications would be accomplished using fiber optic cable of the latest technology and maximum bandwidth. While it is not possible to precisely determine what the "optimum" fiber optic cable features would be when this project is formerly designed, the following features, based on year 2002 features, are offered for comparison. In general, the proposed system would have as its backbone a redundant 36-fiber cable routed in a large "Figure 8" arrangement reaching all machinery rooms, transformer rooms, track rooms, and other areas where breakout communications needs may be identified.

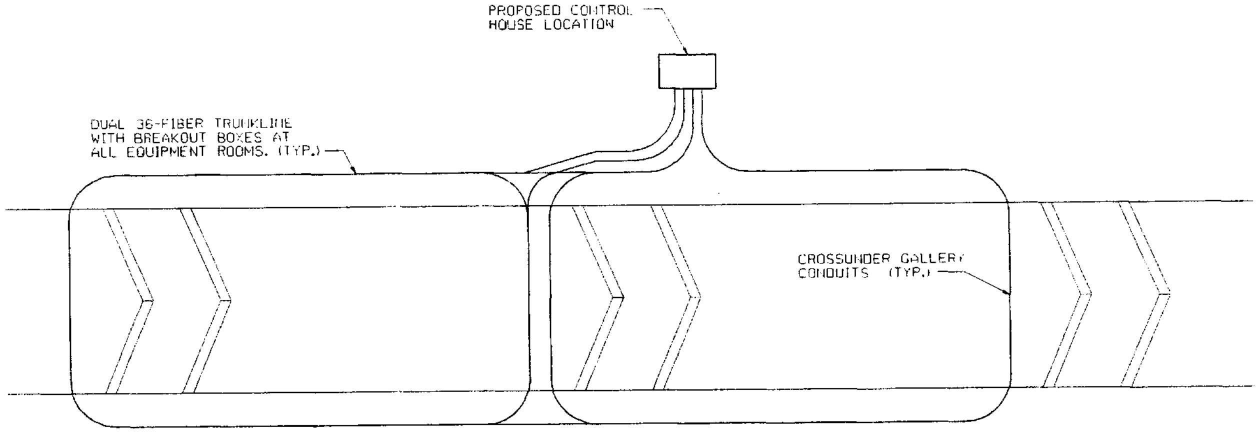


Figure H-3-1 Proposed Fiber Optic Trunk Line Routing

The Fiber Optic trunk line will be routed in RGS conduit within the lock wall galleries to provide as much physical protection as possible. Redundant 36-fiber cable will be routed on opposite sides of the gallery wherever possible to provide as much true redundancy as possible. As proposed, each PLC I/O rack will be connected to the redundant fault tolerant fiber communication rings as access to the network. It would take multiple failures in different exact locations for the system to fail.

3.2.1.2. Hardware

The general items of communication hardware that follow are proposed for use at the new locks. As stated, all hardware would be specified at the time of design to be the latest technology. Redundancy, reliability, and security would be primary issues when specifying this equipment at the design phase.

Ethernet fiber optic communication modules would be utilized for communications to the distributed PLC chassis and remote I/O chassis. Communications for controlling the miter gate and valve hydraulic power units would be achieved using a fault tolerant, self-healing ethernet communications network. This configuration would allow for diagnostic monitoring of the communication signal waveforms at each node on the network. In addition, the fault tolerant, self-healing network would provide high-speed detection, isolation, and correction of points of communication failure anywhere on the network grid. The fiber optic Ethernet modules would redirect network data communications around a point of failure.

The Ethernet network would have fault predictive communication functionality to provide diagnostic monitoring and detection of impending communication failures resulting from the gradual degradation on the communication link itself. The Ethernet network would monitor impending fault conditions by continuously measuring the actual in-line signal strength of the data communications at each receive input on the network. The actual signal strength would be continuously compared to reference levels where valid network communications would still be assured, but impending communication failures can be accurately predicted. If the signal strength were below the reference levels, the network would automatically detect and annunciate the impending failure condition before a communication failure actually occurs. Remote status monitoring of the communications link would enable maintenance personnel to perform predictive maintenance on the fiber optic network.

3.2.1.2.1. Fiber Optic Cable

The fiber optic cable proposed for use in this section would be for communication between PLC and other components specified as part of the proposed control system. It is intended that the main fiber trunk line can be used for other communications such as, Power Management Products, PA, WAN, and CCTV systems. Proposed fiber optic cable would be FDDI-grade heavy-duty type using the water blocking gel-filled loose buffer tube construction with inner core 62.5 microns and outer clad 125 microns. Single and duplex fiber cable would be used each having fibers contained in plastic tubes that are encased in braided Kevlar material strands. All Multi-fiber cable would be specified to have a fiberglass epoxy rod strength member. Cable would be rated for max attenuation of 3.5 db/km at 850 nm and 1.0 db/km at 1300 nm and min bandwidth 200 MHz at 850 nm and 500 MHz at 1300 nm. As proposed herein, fiber optic cable specifications would include a stranded core covered with an inner jacket made of heavy duty Poly-vinyl Chloride, a Kevlar Braid, and an outer jacket made of black Polyethylene.

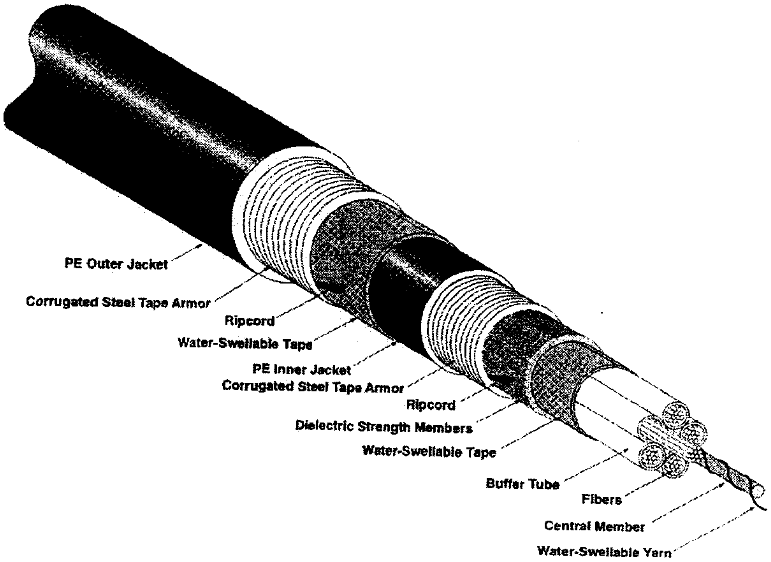


Figure H-3-2 Fiber Optic Cable Cross Section

3.2.1.2.2. Repeaters

The PLC control system as proposed would have fiber optic repeaters at each processor and Input/Output rack. The current proposal, subject to change with technology, would have the fiber optic repeaters for the PLC specified as plug-in modules with in the I/O racks. The proposal at present would use an Allen Bradley PLC system with Phoenix Digital 100Mbit Ethernet Optical Communication Modules. The Ethernet would be TCP/IP – Transmission Control Protocol/Internet Protocol and remote devices such as laptops could be used to access network data at each I/O rack.

3.2.1.2.3. Breakout Boxes

The fiber optic backbone would be accessible at each machinery/transformer/ track room by means of a fiber optic breakout boxes. At these points each fiber from both 36-fiber trunk lines would be accessible for use by the PLC system and other communication needs. Patch cables would be used to provide access as well as continuation of the fiber communication rings. Figure H-3-3 shows a typical breakout box proposed for use on this project. Patch cables are shown here but would be used only within the local machinery room.

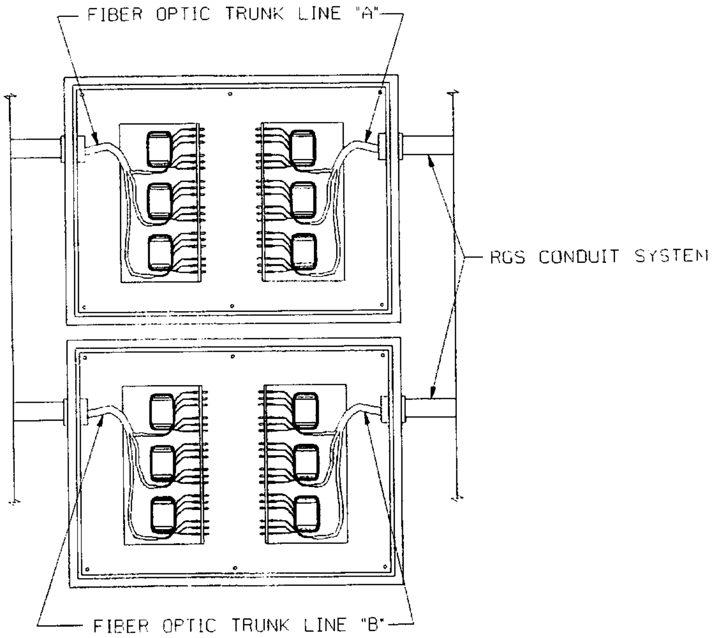


Figure H-3-3 Typical Fiber Optic Breakout Box

3.2.2. Programmable Logic Controller

3.2.2.1. General

For this project it proposed to use a modern state-of-the-art high powered off the shelf programmable logic controller system such as the Allen Bradley ControlLogix® PLC system. The PLC type system was selected over a PC-based control system for the following reasons:

- Reliable, deterministic, safe data retention
- Time-proven performance
- Product hardware lines are supported for many years
- Operation of the locks is too critical to risk interruption of the control process execution with a multi-tasking environment.
- Enhanced long-term support

A primary processor, with redundant back-up, would be located in the control room to provide all high level automation as well as buffer communications to the PC network and the HMI (Human Machine Interface) software database. Each of five strategic areas around the project would have a secondary processor, with redundant back-up, to perform local I/O servicing. The distributed PLC processor in the five areas would be located in a separate enclosure and be independent all other equipment. The five areas would be the lake side gates and valves (upper lock area), the middle gates and valves (middle area), the ocean side gates and valves (lower lock area), upper water saving basin, and lower water saving basin. Each gate and valve machinery room would have an I/O rack located in the HPU electronics enclosure. As stated in paragraph 3.2.1, all communications are proposed to be Ethernet. This will be re-evaluated during the design phase to verify the exact network requirements.

3.2.2.2. Hardware

3.2.2.3.

The hardware design will definitely change by the design phase because of the desire to specify the most advanced technology available. The current proposed design would use the hardware as described below. The Allen Bradley PLC hardware was chosen because of its share of the world-wide market and its reputation in the automation field. The existing Gatun Locks are also being retrofitted with a new automated control system using an Allen Bradley PLC system and keeping the system compatible is desired.

3.2.2.3.1. Processors

The ControlLogix® 5550 processor would be the heart of the PLC system for controlling the lock equipment. At each location with a processor, a redundant processor and chassis would be synchronized with the primary controller to provide bumpless switchover for any outputs controlled by logic in the highest priority task. The switchover of any controller needs to be transparent to any devices networked to the redundant controller chassis to insure continuous, uninterrupted service. The 5550 processor has an extensive instruction set that includes symbolic, IEC 1131-3 compliant programming. The symbol names create by the programmer are loaded into the controller's memory, making it easy for other controllers or operator interface units to read the controller's data without having to know physical memory locations. This is critical in a multi-processor system as proposed herein. While it would likely be possible that a single processor could control the entire project, it is desirable that all functionality of the system be segmented to allow a redundant component to assume responsibility of its execution. Namely, the primary controller and back-up are responsible for high level automation, but in the unlikely event of total control room network communication loss, the remote processors at each area of the project would be responsible for orderly shut-down of automation processes in such an event. The five distributed processors would then be responsible for any operation made locally at each HPU and would be able to maintain communication with the HMI control network of PCs. The following diagram provides a general description of the proposed PLC processor arrangement. Exact routing of the fiber cable is not detailed nor are the machinery room breakout boxes. Specific details are shown on the drawings that accompany this proposal.

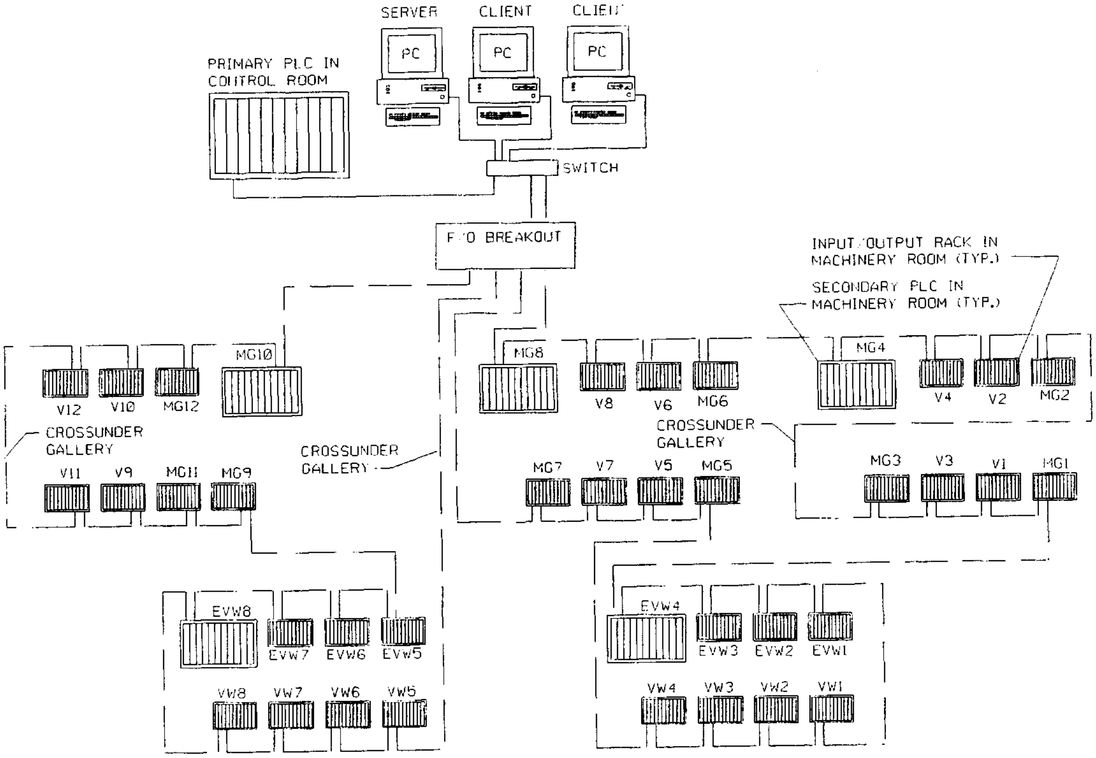


Figure H-3-4 **Abbreviated Sketch of Proposed PLC Architecture**

3.2.2.3.2. Communication Cards

Each I/O rack would have a fiber optic Ethernet switch type card mounted in the chassis. Currently the proposal is recommending the use of a Phoenix Digital Ethernet modem intended to be used with a fault tolerant ring. Only one module or modem would be necessary in each rack to achieve a redundant and fault tolerant communication network architecture throughout the project. Each rack would also have an Ethernet interface card directly connected to the fiber optic modules. Locations having a processor would also have a ControlNet® communications module. The ControlNet® communications module would interface with the redundant processors and a system redundancy module would keep the processors synchronized. With this arrangement every I/O point on the system would have a redundant processor system at the machinery room level assigned to servicing it. Each rack would also have a dual fault tolerant fiber ring connecting it to every other processor on the system including the redundant primary processor system at the control house. With this arrangement it would be nearly impossible to lose the PLC control system. The use of Allen Bradley DeviceNet® cards is considered for communications with soft start modules, overload relays, Adjustable Speed Drives (locomotives), and other intelligent devices. In general, all equipment would be specified with Ethernet communication capability to avoid an alternate protocol.

3.2.2.3.3. I/O Cards

Currently it is anticipated that only simple I/O cards will be required for the system. These include Digital 120-volt input/output, Analog Input/Output, and high speed counter cards. The digital input cards would be used to read the status of dry contact limit switches, remote pushbuttons, and control relays. The digital output cards would control motor starters, traffic lights, pilot relays, remote pilot lights, and other devices. The Analog input cards would read the status of position transducers, water level sensing devices, temperature sensing devices, and other such analog signals. The Analog output cards would provide a reference signal for the hydraulic power unit proportional valves. The High Speed Counter cards would be used to track the position of the hydraulic cylinder position measuring system, currently proposed to be Rexroth's CIMS (Ceramic Integrated Measuring System) transducer which produces a high speed digital pulse count.

3.2.2.3.4. Programming Software

The PLC processors would be programmed from designated (during the design phase) PCs using Allen Bradley's RSLogix5000®. The software would make use of traditional Ladder logic control as well as IEC 1131-3 advanced programming languages such as Function Blocks and Structured Text. Each Processor would have identical programming. The program would be in segments allowing each processor to assume normal responsibility of only certain portions of the program while having the capability to provide back-up for any other processor that fails. This is in the unlikely event that communication to a machinery room or the control house is completely lost (both sides of both rings) making the local ControlLogix® Redundant Processor unavailable to back-up the primary processor in that location. As long as the remote racks on that segment have access to one of the fiber trunk lines, another processor on the system would simply assume responsibility for the roles of those in the room that is lost until the problem is fixed. If the primary processors in the control room were lost, remote PCs, perhaps laptops, could be used as necessary to resume full automated control by accessing the data from one of the remote machinery room processors.

3.2.3. PC Network

3.2.3.1. General

Of the all the control system parts the PC network is the hardware that is most difficult to positively identify at this point in the study phase. This is due to the rapid developments in the PC world. An attempt will be made in this study to propose types of equipment but specific equipment would be specified in the design phase. At the design and construction phases research should be done to insure that the most recent and most applicable technology is used in the PC portion of the control system. It is worth considering specifying the PC hardware after construction of the project to insure the latest technology possible upon start-up.

3.2.3.2. Hardware

As stated the hardware proposed for use herein should be re-evaluated at the design and construction phases and is shown here only for comparison with other control system proposals.

3.2.3.2.1. Processor Chassis

Use of Industrial Personal Computers was considered for this proposal but found not to be the PC of choice for this application. Desktop PC's such as Dell's OptiPlex® are recommended for this project for the following reasons:

- The cost of a desktop PC ($2000) is considerable less that of a comparably equipped Industrial PC ($7500)
- The added life expectancy of an Industrial PC probably exceeds its technically useful life expectancy making it cheaper, even in the long run to buy desktop units and replace them as they either fail or more likely the case become outdated.
- The control room surroundings will not be that harsh to warrant the hefty environment rating associated with an Industrial PC.
- Most Desktop PCs have a service plan that includes up to 3 years of service. After 3 years most PCs will have to be replaced.
- All software has been tested to run on a Desktop system such as a Dell® or Gateway®, while cases exist of software that has problems on Industrial PCs.

The PC's should be specified with the fastest processor available at the time of construction.

3.2.3.2.2. Memory and Storage

In general, all desktop PCs should be specified with as much memory and storage as is available at the time of construction. PC servers would need this with the amount of data they will be storing. Data logging and Condition Monitoring are two areas that could consume a lot of storage space on a server.

3.2.3.2.3. Peripheral Devices

The PCs should be specified with floppy disk drives, CD-RW drives, DVD-drives, quality sound cards and speakers, high resolution video cards, microphones, Fast Ethernet NICs, and other peripheral devices as needs are identified at the design and construction phases of the project.

3.2.3.2.4. Monitor System

The monitor system is another area where change is rapid, although not as rapid as the processors. The monitors should be 21" flat screen color LCD type with the best resolution available at the time. Because they could also be used for a CCTV system the monitors simply should be the absolute top of the line available at the construction phase.

3.2.3.3. Software

An attempt has been made herein to describe the type of software proposed for use on this project. Specific versions and releases would not be determined until the design and/or construction phases. Basically the software necessary for this project consists of three general categories: The PC operating system, The PLC Programming Software, and The HMI Software. Each of these topics includes various software packages.

3.2.3.3.1. Operating System

The PCs specified in paragraph 3.2.3.2 should be ordered with the standard available operating system. For illustration and comparison purposes such software has been delineated herein. However, extensive research would be required at the design and construction phases of this project to insure that all software needs have been identified and that the optimal software packages are ordered. Since it appears that the Microsoft® operating system will be the world-wide standard for some time to come all software would be required to meet that standard.

a Microsoft Windows NT2000® (Client/Server)

Currently, the state of the art operating system as available from Microsoft® is the Windows NT2000 package. Computers identified as Servers would have the Windows NT2000 Server packages installed and others would have the Workstation versions. It is important to note that it is not necessary for the Windows NT2000 Server to be the HMI software Server. In fact, there may be some benefit to dividing the database and operating system maintenance between different computers. In that fashion the operating system features, such as virus software, can be upgraded without affecting the database.

b Microsoft Office 2000®

The PCs should be shipped with a deluxe Microsoft® Office package installed. Research should be done to determine standards of operating for the ACP so software such as Microsoft Outlook® or other E-mail packages can be configured properly for use in their network. It is critical that E-mail capabilities exist on all PCs for maintenance purposes as the HMI software will be configured to generate E-mails for alarms, failures, and other maintenance needs that will be identified later. Internet access, as available by the ACP servers would also be a necessity for the PCs at the locks.

3.2.3.3.2. PLC Programming Software

The PLC processor programming software would be specified to be provided by the PLC manufacturer. The PLC programming software should have provisions for configuring I/O rack addresses, simulating program execution for debugging, and downloading to the PLC processors. The programming software should conform to part 3 of IEC 1131, the standard for PLC programming languages, should operate on a Microsoft Windows NT2000® platform, and should include the following editors:

- Function Block Diagram. This editor depicts process data flow suited for discrete and continuous control application functions and should include predefined elementary function blocks as well as user-definable function blocks. Language written in other editors, as listed below, can be nested within the Function Block Diagram. In FBD, control sequences are programmed as blocks which are "wired" together in a manner resembling a traditional control circuit with "flow" from right to left. See Figure H-3-5 for a basic illustration of a Function Block Editor.

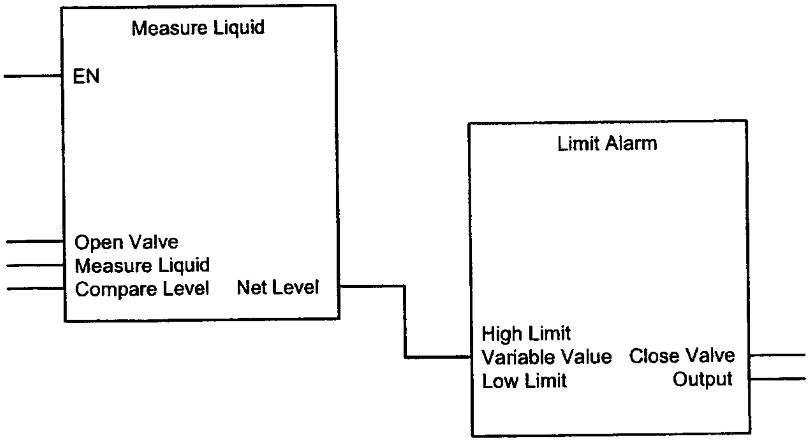


Figure H-3-5 Function Block Diagram Edito

- Ladder Diagram. This language allows programming in the familiar left to right contact and coil arrangement in an order that is familiar to most electricians and maintenance personnel. The ladder logic editor should allow the use of other editors such as Function Block and Structured Text to be incorporated into the ladder programming. This would simplify the programming as electricians and maintenance personnel will not have to be familiar with the complex logic of the other editors. The Function Block or Structured Text editors simply perform predetermined logic within the body of the ladder diagram. These can be grouped in subroutines to simplify the appearance of traditional ladder logic. See Figure Below.

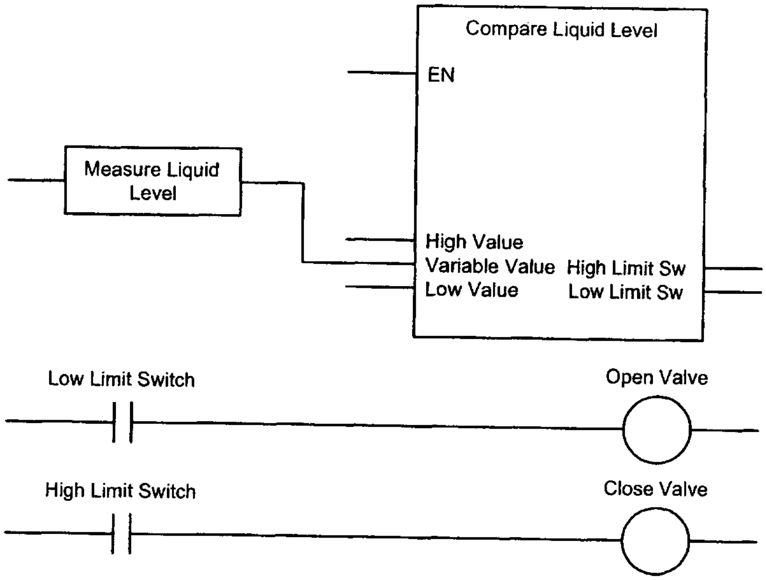


Figure H-3-6 Traditional Ladder Logic Editor

- Sequential Function Chart. This editor provides a graphical method of organizing a control program using programming from other editors nested within. The SFC editor should include three main components: steps, transitions, and actions. See Figure H-3-7. Steps are individual control *tasks* comprised of programmed logic operators used to perform a particular control function. Actions are the individual *operators* of that task. Transitions are merely mechanisms to move from one task to another. With SFC the processor continues to perform the actions in a step until the transition conditions is true, i.e. repeat the **step** containing the **action** of *filling a tank* until the **transition** condition of *comparing level against "full"* is true then move to **step** of *close the valve.*

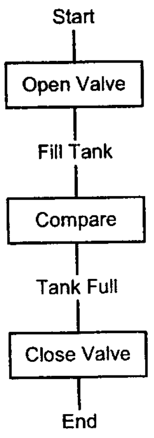


Figure H-3-7 Sequential Function Chart Editor

- Structured Text. The Structured Text editor is a high-level language resembling Pascal or Basic used to perform control logic programming. Structured Text often proves to be the easiest way for the novice to write and understand control logic because of its inherent resemblance to sentences. See the following figure.

```
LET LowLimit = Low_Limit
LET HighLimit = High_Limit
LET Value = Liquid_Level
WHILE Value < HighLimit
   IF Value < LowLimit THEN
      DO Open_Valve
   END IF
END WHILE
DO Close_Valve
```

Figure H-3-8 Structured Text Editor

- Instruction List. Instruction List editor is a text based Boolean language. The basic Boolean operators can be used to create more complex control applications. Similar to Assembly Language, the Instruction List editor is a low-level language that is very useful for simple control processes whose logic is repeated often. Instruction List allows the logic for these processes to be programmed once and then recalled in latter instances in the program. The figure that follows illustrated this type of editor.

```
    Start:          LD    Liquid_Level   :Move value of liquid level into
  argument
                    GT    Low_Limit      :Compare with Low Level Limit
ST  Open_Valve      :Move (1 or 0, based on above) into output
GT  High_Limit      :Compare with High Level Limit
ST  Close_Valve     :Move (1 or 0, based on above) into output
    End:
```

Figure H-3-9 Instruction List Editor

Of these editors the Function Block, structured Text, and Ladder Logic are likely to be the most commonly used on this project. It is important to specify the PLC programming software in sufficient detail using the IEC 1131.3 standard because this will insure that the Contractor provides a quality software package that complies with worldwide industry accepted standards.

3.2.3.3.3. HMI Software.

The primary means of operating the locks would be via the PCs in the central control room using the Human Machine Operating Software. The HMI software would be a graphics oriented command issue package running on all server and client PCs and communicating to the PLC processors. It would have functionality in general as described herein.

a Operating System

The operating system would be Microsoft Windows NT2000®. The software would exhibit strong compliance with Microsoft's Windows DNA standards, such as in its use of dialog boxes and menus. The system must support running as a service under Windows NT, making it independent of the NT2000 user login limitations.

b Size

The system software shall be provided with capacity for unlimited database tag counts.

c Database Tag Configuration

The system HMI software would include database tags which are configurable in several ways, as follows:

1) Directly from the graphics editor, so that tags can be configured as graphics are developed.
2) Via an interactive spreadsheet-style database builder program that uses a fill-in-the-blank menu methodology including the following editing functions:
    a) Cut/Copy/Paste tags
    b) Duplicate tags

c) Generate multiple tags from a given pattern

d) Sort tags

e) Query tags

f) Display tags in user-configurable formats

3) Via the importation of a Comma Separated Value (CSV) text file developed in another program as input for tag creation. The database builder program would also be able to export the current tag listing for modification by the external program

d I/O Device Communications

The system must support fast Ethernet communication with the programmable logic controller. The HMI would include the Ethernet driver for the provided PLC processor system. Sequel Server (SQL) and OPC process control communications would be supported by the HMI software package for outputting data to other project applications.

e Networking And Distributed Operation

The system must have a distributed; client/server system architecture based on OPC and Component Object Technology (COM). This architecture would employ a local area network (LAN) as the method for communicating among workstations. Data would be available to all computers and individuals on the network that have been provided access and assigned privileges. Real-time data would be available directly across the network from the computer that acquired it from the PLC.

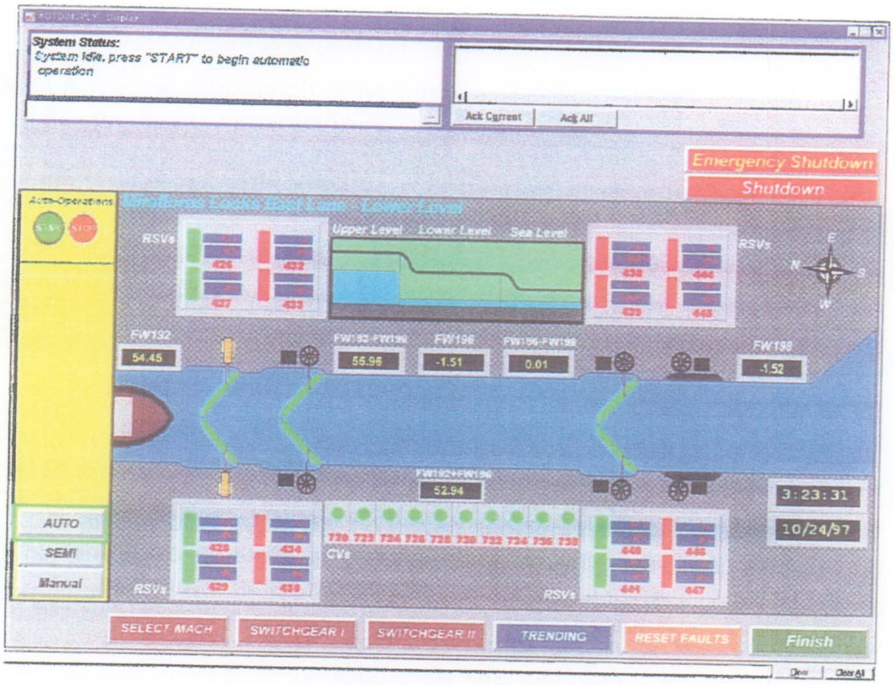
f OLE OPC and Active X Support

The HMI proposed for this system would support third-party objects and controls to be plugged in via OLE, OPC and Active X support.

g Graphics Capabilities

The HMI software would have graphics package which provides a means of creating and displaying color object-oriented graphic displays that would be used by the operator to monitor and control the lock equipment and processes. The graphics package would include:

- Graphic Creation.
- The proposed system would have an interactive object-oriented editor or workspace that allows creation of graphic displays using a mouse. The editor would have the capability to toggles between the graphic building and graphic runtime modes to speed display animation verification and testing during the development process. Figure H-3-10 illustrates a typical operating screen as might be developed for this project.



System Status:
System idle, press "START" to begin automatic operation

Figure H-3-10 Typical Operating Graphics Screen

- Browser.
- Once an object is created, it would automatically be placed on a tree similar to the browser in Microsoft's Internet Explorer for easy access during all phases of software development.
- Properties Window.
- A properties window, exposing all properties for an object would be included with the package's workspace.
- Active X Support.
- The graphic screens must be an active X document and have the ability to have third party active X OCX, controls dropped in.
- Graphic Animation.
- Every display created would have the ability to dynamically update elements in the picture. The update would be true animation based on the condition of tags in the database.
- Bitmaps.
- The HMI software would allow for bitmaps created by other packages to be imported into the graphics and animated. Supported types would be as a minimum .bmp, .msp, .jpg, wmf, pcx, ico, cur, psd, epr, and wpg.

- Support of Microsoft Excel and Word Documents.
- Microsoft Excel and Word documents would be able to live within a graphic screen. The documents would run within the graphic, not as an external call. The Microsoft Excel or Word toolbars would get inserted as part of the graphic toolbars for editing.
- Command/Scripting Language.
- The scripting language used by the system HMI would be true Microsoft Visual Basic for Applications (VBA). Scripts can be simple or complex and allow users to automate operator tasks, and create automations solutions.
- Alarm And Message Handling.
- The proposed system HMI software would be capable of detecting alarm conditions based on the states and values of the various sensed variables. The system would allow numerous different ways to display the alarms and alert operators including on screen messaging and E-mail generating. All alarms would be date and time stamped fro archiving.
- Trending And Reporting.
- The proposed software system would be provided with a facility for automatically collecting, storing and recalling data. Recalled data would be made available to a trend display program, a report generation program and to user-written programs.
- Security Management.
- The software would provide a user-based security system to allow for the creation of users with certain rights and/or privileges.
- Redundancy.
- The software system as proposed for use would support server backup and LAN redundancy.

3.2.4. Network

It is important to review the fundamentals of networks and network protocols before discussing their application to this project. A network is a group of two or more computer systems linked together. There are many types of computer networks, including local-area networks (LANs) and wide-area networks (WANs). With LANs the computers are geographically close together (that is, in the same building or group of buildings). With WANs the computers are farther apart and are connected by telephone lines or radio waves. In addition to these types, the following characteristics are also used to categorize different types of networks.

3.2.4.1. Topology

The geometric arrangement of a computer system. See Figure H-3-11 for the three principal topologies used in a local area network.

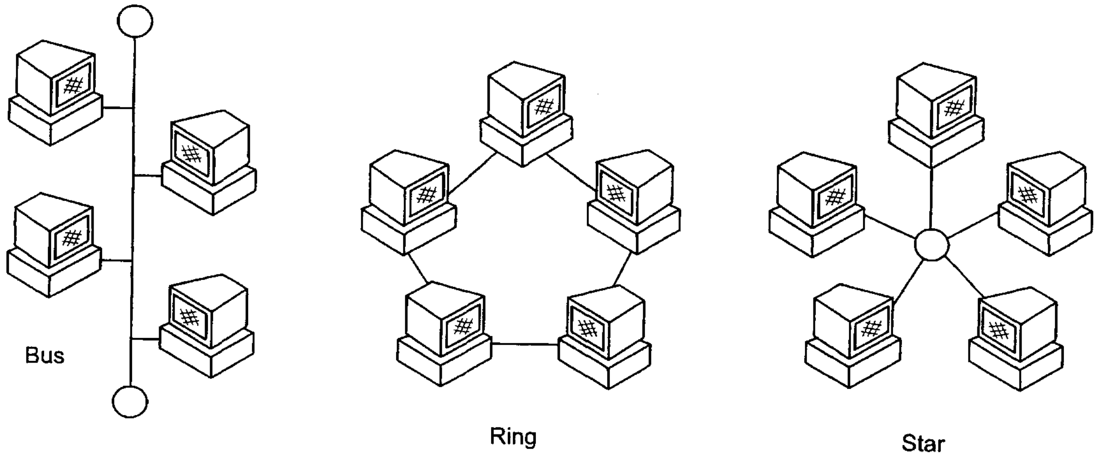


Figure H-3-11 Principal LAN Topologies

- Bus Topology: All devices are connected to a central cable, called a bus or backbone. Bus networks are relatively inexpensive and easy to install. Ethernet systems use a bus topology.
- Ring Topology: All devices are connected to one another in the shape of a closed loop, so that each device is connected directly to two other devices, one on either side of it. Ring topologies are relatively expensive and difficult to install, but they offer high bandwidth and can span large distances.
- Star Topology: All devices are connected to a central hub. Star networks are relatively easy to install and manage, but bottlenecks can occur because all data must pass through the hub.

Variations on these topologies exist. The bus and star topologies, for example, can be combined to form a hybrid LAN. This arrangement is useful where several remote IPCs need to be networked to a central LAN, such as in a control room. The remote IPCs connect back in a star configuration to a network hub that is connected to a local bus. See Figure h-3-12 for an example of a hybrid LAN. This hybrid type topology is proposed for use on this project. The computers in the control room would be connected to a bus with remote devices (I/O racks, Processors, ..etc.) connected to the fiber trunk line and hence connected as a star.

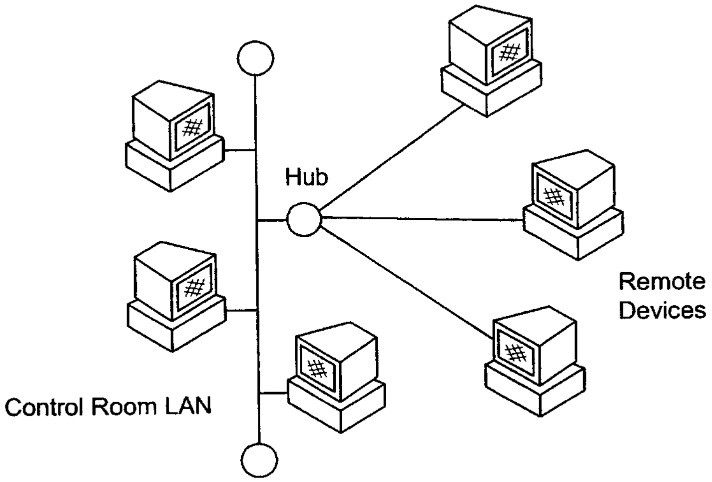


Figure H-3-12 Hybrid Bus and Star LAN Topology

3.2.4.2. Protocol

The protocol defines a common set of rules and signals that computers and other devices on the network use to communicate. One of the most popular and widely used protocols for LANs is called Ethernet. Ethernet was developed by Xerox Corporation in cooperation with DEC and Intel in 1976. Ethernet supports a bus topology and supports data transfer rates of 10 Megabits per second (Mbps). The Ethernet specification served as the basis for the IEEE 802.3 standard, which specifies the physical and lower software layers. Different physical layer versions include 10BASE-2 (ThinNet coaxial cable), 10BASE-5 (ThickNet coaxial cable), 10BASE-T (twisted-pair wires), and 10BASE-FL (fiber optic cable). A new version of Ethernet, called Fast Ethernet, supports data transfer rates up to 100 Mbps. The IEEE standard for Fast Ethernet is 802.3u. Different physical layer versions include 100BASE-TX (two pairs of high quality twisted-pair wires), 100BASE-T4 (four pairs of normal-quality twisted-pair wires), and 100BASE-FX (fiber optic cable). An even newer standard, called Gigabit Ethernet, supports data rates of 1 Gigabit per second (Gbps). There are two IEEE standards for Gigabit Ethernet: 802.3z for fiber and 802.3ab for copper wires. Different physical layer versions include 1000BASE-SX, 1000BASE-LX, and 1000BASE-T. For this project it is proposed that fast Ethernet adhering to the TCP/IP – Transmission Control Protocol/Internet Protocol – standard be used. All devices specified for the network should conform to this widely accepted standard.

3.2.4.3. Architecture

Networks can be broadly classified as using either a peer-to-peer or client/server architecture.

- In a peer-to-peer network each workstation has equivalent capabilities and responsibilities. Peer-to-peer networks are generally simpler and less expensive, but they do not offer the same performance under heavy loads.

- In a client-server network each computer or process on the network is either a client or a server. Servers are powerful computers or processes dedicated to managing disk drivers (file servers), printers (print servers), or network traffic (network servers). Clients are PCs or workstations on which users run applications. Clients rely on servers for resources, such as files, devices, and even processing power.

For use on this project it is proposed that a client/server architecture be used. The server PCs would be polling the PLC processors for data and performing any data logging or trending functions. The client PCs would be used to operate the equipment.

3.2.4.4. Network Considerations

For this project the following considerations were applied to the design of the proposed network. They include reliability, availability of management and troubleshooting tools, scalability, and cost.

- Reliability. Highly reliable networks are critical to the success of a network at the project, so ease of installation and support are primary considerations in the choice of network technology. Ethernet networks are by far the most widely used, representing more than 83 percent of all installed networks by the end of 1996. Because of this popularity, equipment and wiring systems have become increasingly reliable. They are also relatively simple to understand and administer. Many hardware manufactures go to great expense to insure their equipment meets the Ethernet standard.
- Availability Of Management And Troubleshooting Tools. Management tools for Ethernet, made possible by widespread adoption of management standards including Simple Network Management Protocol (SNMP) and its successors, allow an administrator to view the status of all desktops and network elements, including redundant elements, from a central station. Ethernet troubleshooting tools span a range of capabilities, from simple link indicator lights to sophisticated network analyzers. As a result of Ethernet's popularity, large numbers of people have been trained on its installation, maintenance, and troubleshooting.
- Scalability. The Fast Ethernet standard, approved in1995, established Ethernet as a scalable technology. Now, the development of Gigabit Ethernet extends the scalability of Ethernet even further. Independent market research has indicated a strong interest among network users in adopting Gigabit Ethernet technology, specifically Fast Ethernet hubs and switches with Gigabit Ethernet uplinks, Gigabit Ethernet switches and repeaters, and Gigabit Ethernet server network interface cards (NICs).
- Cost. Prices for Fast Ethernet hubs, switches, and NICs have decreased rapidly overall. Although initially expensive, Gigabit Ethernet technology is expected to track the rapid decrease in price of Fast Ethernet technology.

3.2.4.5. Network Design

To design a reliable network, it is important to understand some of the limitations of the different technologies available and to decide which features are required for this application.

- Distance. An important design consideration for this project is the size of the facility. For a facility this large distance becomes a critical factor in the design of the network. Figure H-3-13 delineates some of the maximum design distances for several Ethernet network technologies.

	Ethernet **10BASE-T**	**Fast Ethernet** **100BASE-T**	**Gigabit Ethernet** **1000BASE-X**
Data Rate	10 Mbps	100 Mbps	1 Gbps
Cat 5 Unshielded Twisted Pair	100 m (min)	100 m	100 m
Shielded Twisted Pair/Coax	500 m	100 m	25 m
Multi-mode Fiber	2 km	412 m (half duplex) 2 km (full duplex)	500 m
Single-mode Fiber	25 km	20 km	3 km

Figure H-3-13 Rules for Maximum Network Distance

From the table it can be seen that Fast Ethernet and Gigabit Ethernet may only be implemented at large facilities with widely separate control points using fiber optic cable. In most instances, this technology will also require repeaters at strategic points.

- Noise. Another important consideration in network design is noise from radio and electromagnetic interference. Locks can be extremely noisy environments, especially with large motors, variable speed drives, and so forth. Lightning and surge protection is another important consideration. Fiber is naturally suited to protect against noise, lightning, and surges because it is non-conductive, using glass as the media of transmission instead of copper.
- Operating Plan. During design of the network an operating plan must be developed, a network topology based on the operating plan must be selected, a suitable network protocol must be selected, and the network architecture must be selected. The operating plan includes selection of

operating locations, number of control points at each location, and primary versus secondary control points.

- Operating Locations. The operating locations will include a central control room with backup control points situated at strategic locations at opposite ends of the lock chambers. At each of these control points the total number of operating workstations must be determined. The central control room used for normal operation, will likely have 6 to 8 workstations. Secondary, or backup, operating points may have only one workstation, possibly a laptop computer, depending on how critical and how frequently that location is used. Each I/O rack has an Ethernet switch and should be considered as a possible back-up control point.
- Operating Points. Using the maximum network distances as a guideline, the operating points have been "grouped" by distance of separation. The clear network topology of choice is a combination of bus and star topology.
- Protocol Selection. Next, the network protocol was selected. Ethernet is the industrial protocol of choice, and the majority of manufacturers of electronic equipment requiring communications have/are making strides to conform to Ethernet technology and standards. However, some consideration was given to shortcomings of Ethernet that may affect this design effort. Foremost is the fact that it is a non-deterministic protocol. This means there is no guaranteed time in which communication between two or more nodes has been completed. This is not a problem on small intranets used for lock and dam control because the amount of data transferred falls far short of the available bandwidth of Ethernet and the system becomes essentially deterministic. However, for some large networks, requiring the transmission of significant amounts of data, the non-deterministic nature of Ethernet can be noticeable. This is the reason why traditional PLC communications are of a proprietary deterministic protocol such as Allen Bradley's Data highway. The speeds of these networks, however, are far less than that available from Ethernet. The tradeoff may lead to the decision that 100Mbps non-deterministic (message may take longer than one scan time to send) is still faster than 1 or 5 Mbps deterministic. Currently, it is felt for the scope of this project that a combination of fast Ethernet (communications to the I/O racks) and Gigabit Ethernet (Client/Server communications) is the optimal protocol. However, during the design phase another hard look should be given to all network requirements and this choice reevaluated with the possibility of looking at a reflective memory network. This more costly approach would give true deterministic networking speeds of 1.25 Gbps between PLC processors.
- Architecture Selection.
- Finally, the network architecture must be selected. The client-server model is the architecture of choice and has been selected for this proposal. One key benefit is simple network administration. The server

provides user authentication so that a common user profile can be used for all users. A common user profile insures that all IPCs present the same interface for each user who is configured to use the profile. This means that if the user makes changes while logged in or accidentally deletes icons or reconfigures the system, it reverts back to the original configuration the next time they log in. This type of administration also represents a lesser security risk because all virus software can be updates and maintained in a common location. Another benefit is the ability of clients to access shared resources on the server, such as databases, printers, or modems. A third benefit of client-server systems is scalability. They can be scaled horizontally or vertically. Horizontal scaling means adding or removing client workstations with only a slight performance impact. Vertical scaling means migrating to a larger and faster server machine or multi-servers. This could be an issue if the existing Gatun Locks or other facilities are combined with this network

3.2.5. HPU Units

The hydraulic power unit mechanical equipment is discussed elsewhere in the study.

3.2.5.1. General

The miter gates and valves would be operated by hydraulic cylinders as shown on the drawings. The HPU (Hydraulic Power Unit) motor horsepower ratings range in size from 56 kW to 93 kW. For such large motor sizes it is proposed that solid state soft start motor contactor be used to provide a means of ramping the motor starting current draw. The operating of all equipment would be via the Programmable Logic Controller system. All equipment provided by the HPU manufacturer would be specified to be compatible with the PLC manufacturers equipment.

3.2.5.2. Starters

As stated solid state current ramping motor starters are proposed for use with all the hydraulic power units. The soft starters would be provided as part of the hydraulic power unit skids. Included on the skids would be means for operating the cylinder from the starter in a hardwired fashion using pushbuttons and selector switches. The starters would have two means for communicating with the PLC system. The first would be via dry contact start/stop I/O from the local I/O rack. The second would be Ethernet communications would which would allow remote monitoring and programming of all parameters inherent to the starter. These would include current and voltage in all three phases, power factor, ramp parameters, current limiting values, control times, temperature, vibration, and others as provided by the starter manufacturer.

3.2.5.3. Position Tracking

The position of the hydraulic cylinders would be tracked by a measuring system inherent to the cylinder itself and provided by the cylinder manufacturer. Currently it is proposed the Rexroth CIMS (Ceramic Integrated Measuring System) system be used. The interface to the PLC would be a high speed counter module used to count the impregnated rings in the cylinder ceramic coating. In addition to the CIMS system, dry contact limit switches would be used as end-of-travel indications for the PLC.

3.2.6. Lighting System

The lighting system equipment is discussed elsewhere in this study.

3.2.6.1. General

This study proposes that the lock lighting system be controlled from the central control room using the HMI operator interface and the PLC system.

3.2.6.2. Contactors

The high mast lights, gate recess lights, and lock wall lights would be energized from contactors located around the project in the transformer and switchgear equipment rooms. The contactor switchboard buckets can be operated locally using pushbuttons or, as they normally would, from local PLC I/O rack inputs and outputs.

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PANAMA CANAL CONCEPT DESIGN

Atlantic Locks Structure

Third Lane Lock

Appendix I

Electrical and Mechanical Reference Drawings

Prepared for

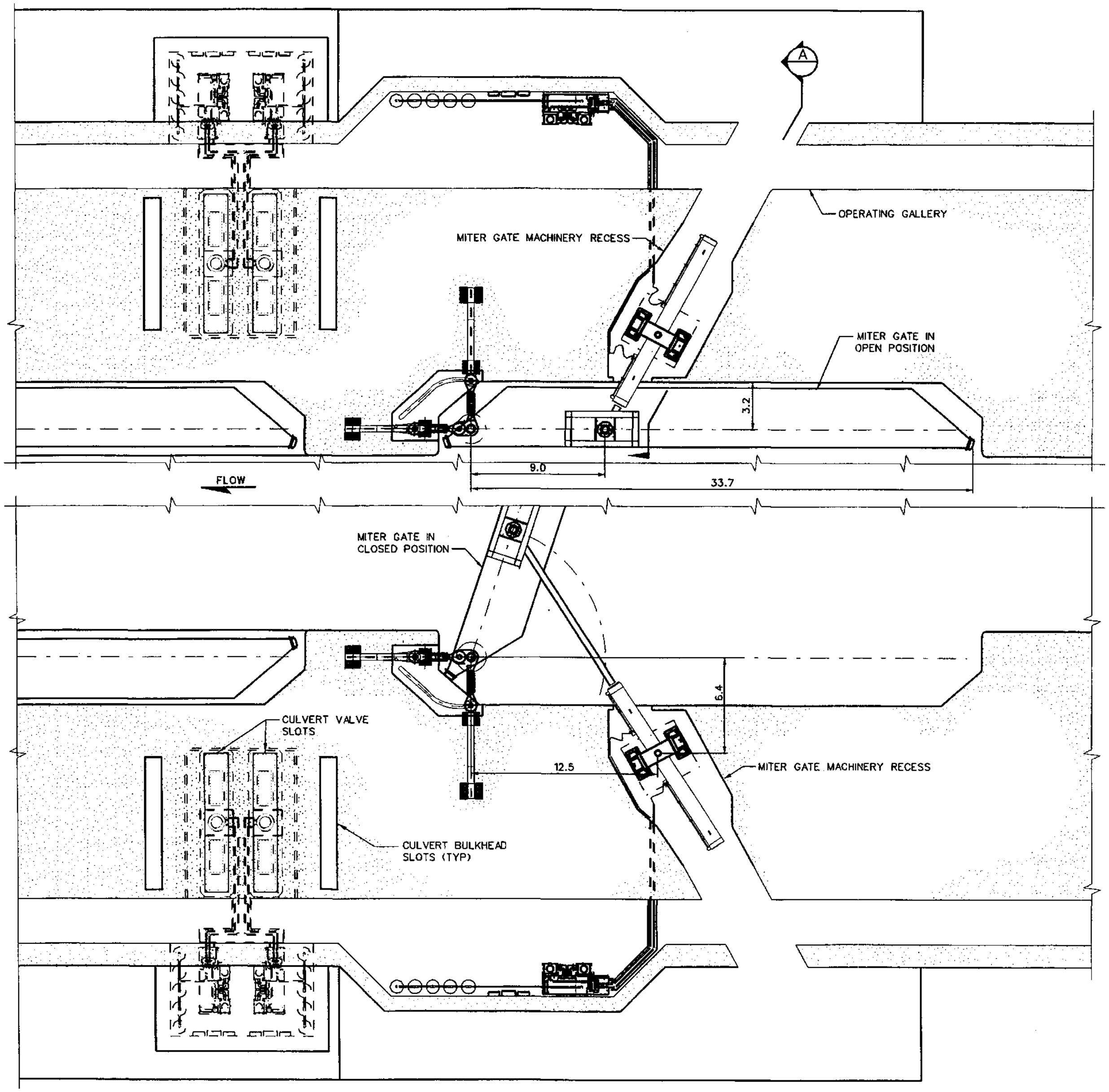
Canal Capacity Projects Office

By

US Army Corps of Engineers

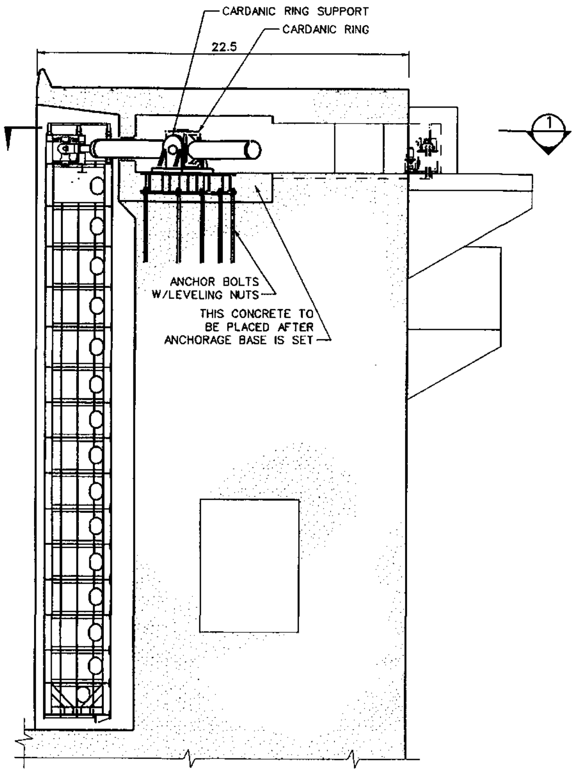
Revised Draft Report

23 July 2003



MACHINERY RECESS PLAN ①

SCALE: 1-150



SECTION Ⓐ

SCALE: 1-150

UPPER MITER GATE MACHINERY SHOWN, MIDDLE AND LOWER MITER GATE MACHINERY IS SIMILAR.

ALL DIMENSIONS AND/OR DIMENSIONS SHOWN IN CALLOUTS/NOTES ARE IN METERS UNLESS OTHERWISE NOTED.

US Army Corps of Engineers
Pittsburgh District

Submitted by: FRANK ZOVACK
SECTION CHIEF

Design by: D. BUCCINI
Dwn by: PETERS
Ckd by: X
Submission Date: OCT 2002
Revision Date: X
FB NO.: DACW59
Sheet X of X

ACP
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Pen Table
Color Table

Symbol	Description	Date	Appr.
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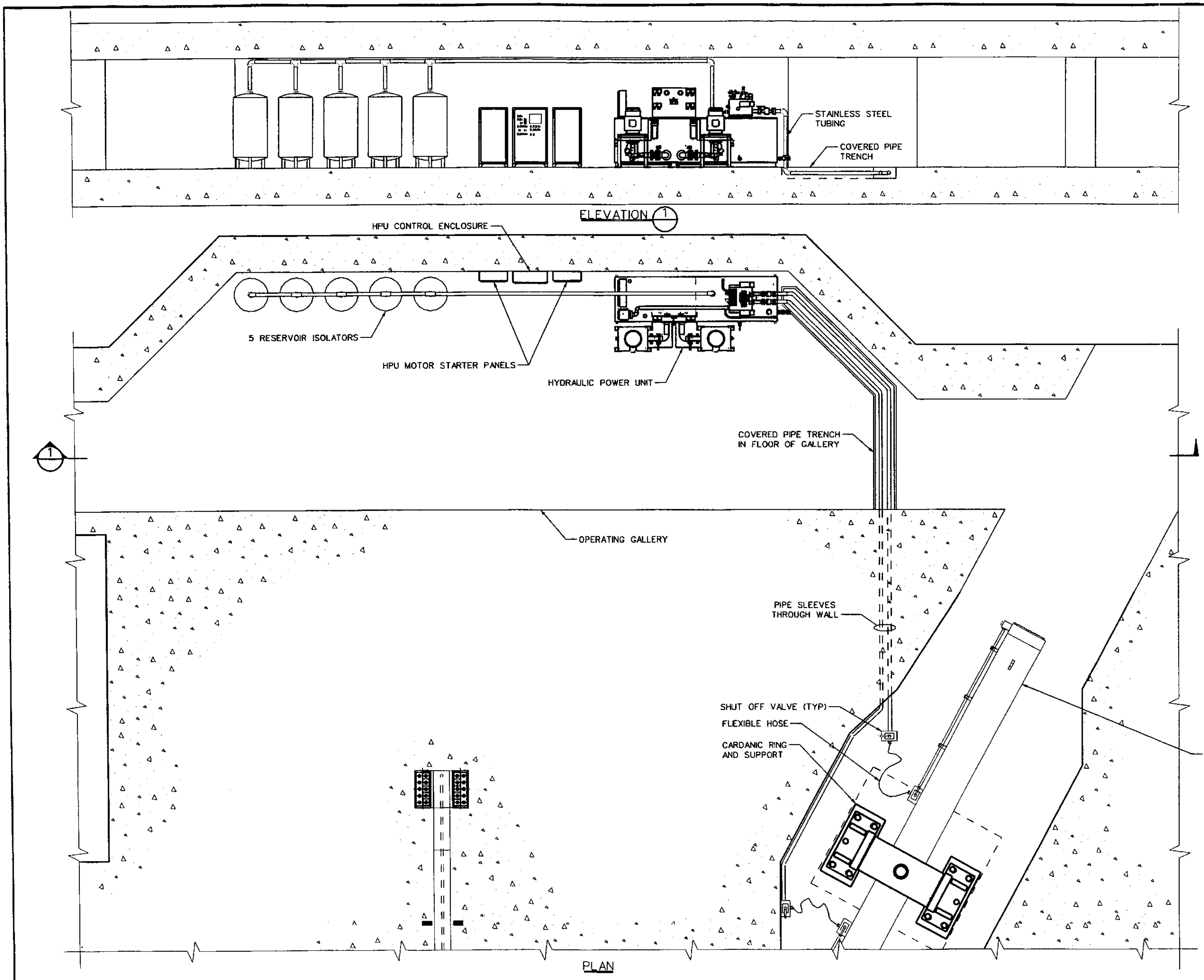
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
MITER GATE OPERATING MACHINERY
ASSEMBLY
PLAN AND SECTION

Drawing Number: ACP-R-22/1



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Sheet X of X

ACP
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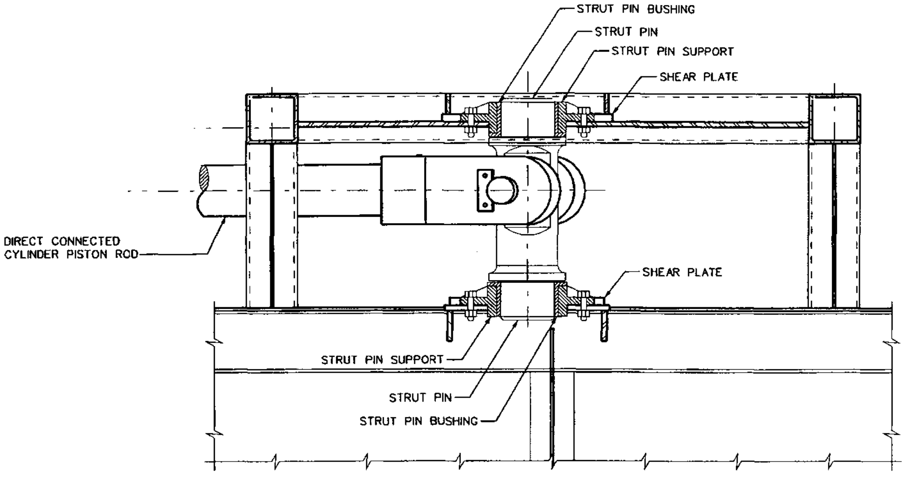
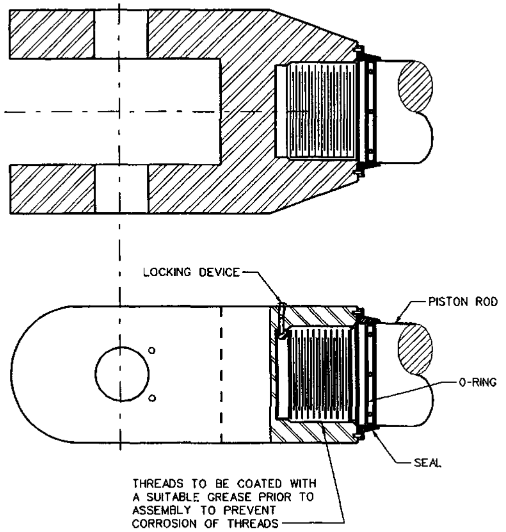
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
MITER GATE OPERATING MACHINERY
HYDRAULIC POWER UNIT
INSTALLATION

Drawing Number: ACP-R-22/2



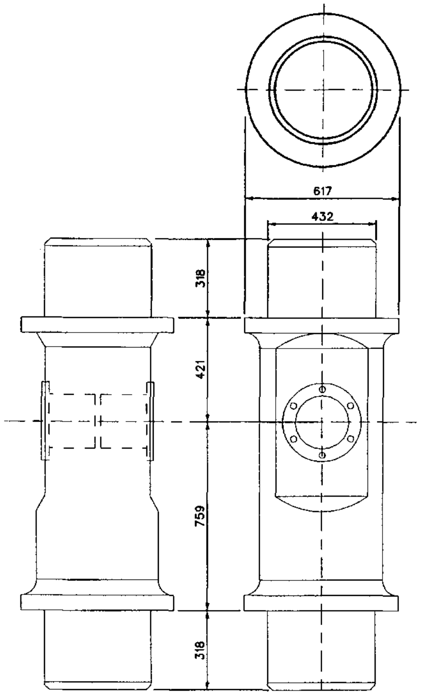
GATE CONNECTION

SCALE: 1=20



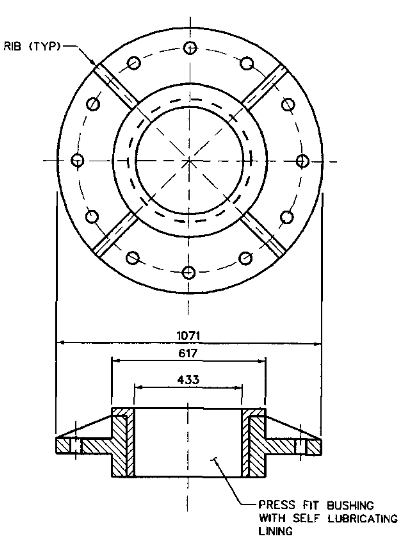
ROD END CLEVIS

SCALE: 1=10



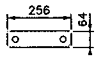
STRUT PIN

STAINLESS STEEL - ASTM A276 TYPE 410 COND. H
SCALE: 1=10



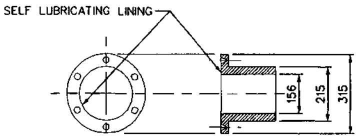
STRUT PIN SUPPORT

CAST STEEL - ASTM A27 GRADE 70-40
SCALE: 1=10



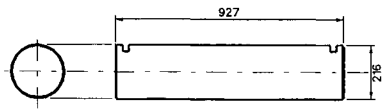
KEEPER PLATE

STRUCTURAL STEEL - ASTM A36
SCALE: 1=10



CYLINDER PIN BUSHING

NICKEL ALUM BRONZE - ASTM B148-906 ALLOY C9550
SCALE: 1=10



ROD CLEVIS PIN

STAINLESS STEEL - ASTM A276 TYPE 410 COND. H
SCALE: 1=10

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US Army Corps
of Engineers
Pittsburgh District

Submitted by:
FRANK ZOVACK
SECTION CHIEF

Design by:
D. BUCCINI

Dwn by:
PETERS

Ckd by:
X

Submission Date:
OCT 2002

Revision Date:
X

IFB NO.:
DACW59

Sheet X of X

ACP
AUTORIDAD DEL CANAL DE PANAMA

User: Haskosh
Date: 20-OCT-2002 22:41
Plot Scale: 2.765340:1.000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
X	X	X	X

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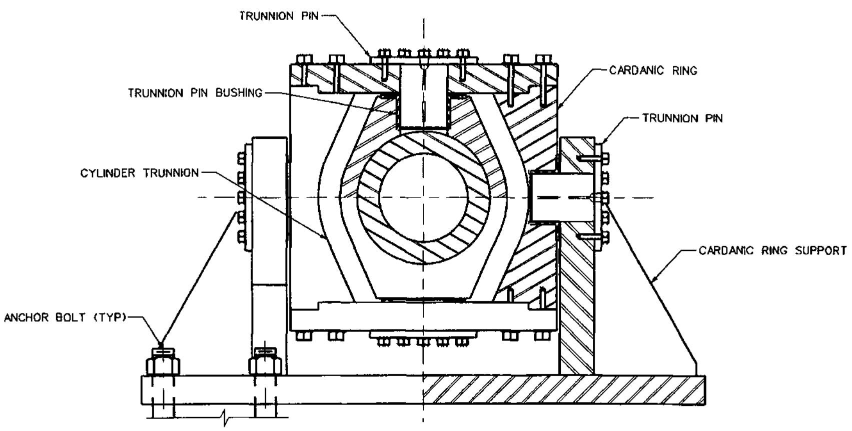
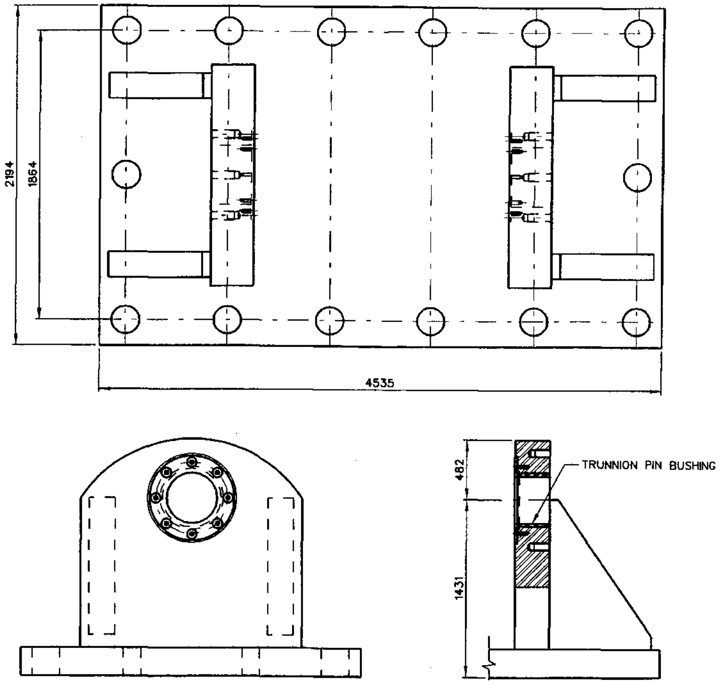
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
MITER GATE OPERATING MACHINERY
HYDRAULIC CYLINDER
GATE CONNECTION DETAILS

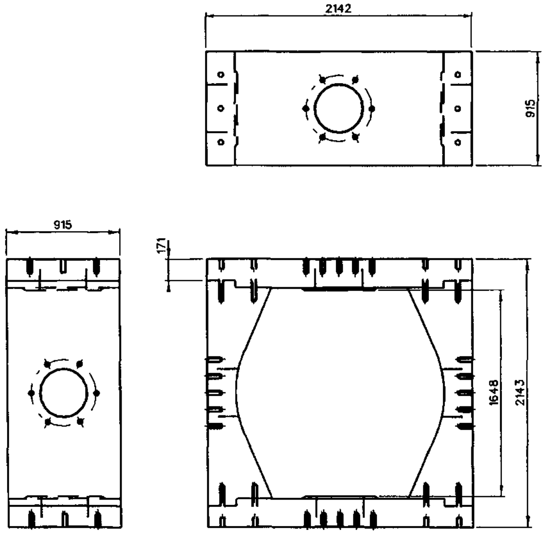
Drawing Number:
ACP-R-22/3



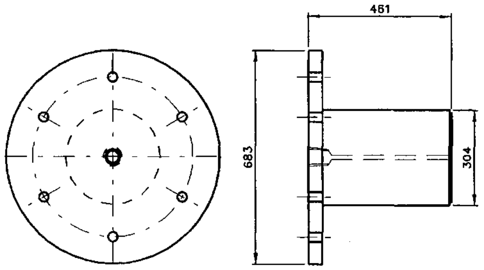
CYLINDER SUPPORT
SCALE: 1-20



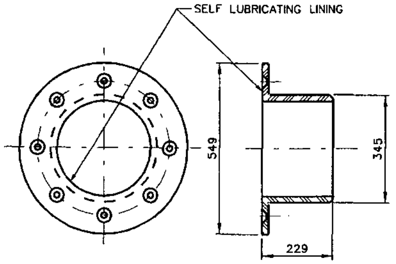
CARDANIC RING SUPPORT
STRUCT. STEEL - ASTM A36
SCALE: 1-20



CARDANIC RING
CARBON STEEL - ASTM A576
GRADE 1045 ANNEALED
SCALE: 1-20



TRUNNION PIN
STAINLESS STEEL - ASTM A276 TYPE 410 COND. H
SCALE: 1-10



TRUNNION PIN BUSHING
NICKEL ALUM BRONZE ASTM B148-906 ALLOY C9550
SCALE: 1-10

ALL DIMENSIONS AND/OR DIMENSIONS
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US Army Corps
of Engineers
Pittsburgh District

Submitted by:
FRANK ZOVACK
SECTION CHIEF
IFB NO.:
DACW59
Sheet X of X

Design by:
D. BUCCINI
Dwn by:
PETERS
Ckd by:
X
Submission Date:
OCT 2002
Revision Date:
X

ACP
AUTORIDAD DEL CANAL DE PANAMA
User: Rankash
Date: 20-OCT-2002 22:41
Plot Scale: 2.715340:1.000000
Pen Table:
Color Table

Symbol	Description	Date	Appr.
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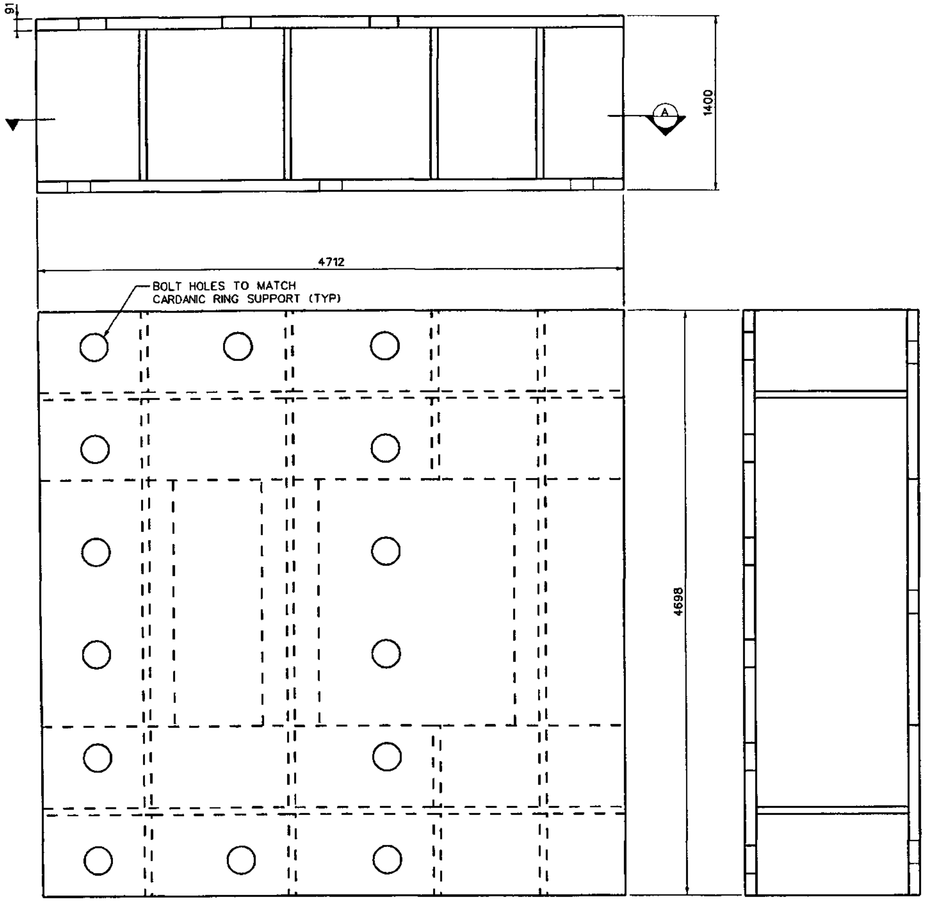
F:\ACP\mech\Cardanic Ring.s01

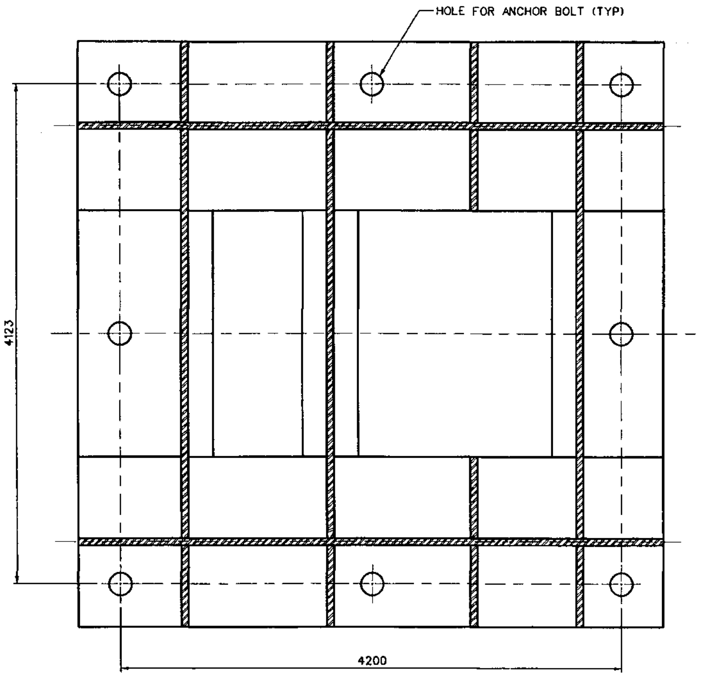
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
MITER GATE OPERATING MACHINERY
HYDRAULIC CYLINDER
SUPPORT DETAILS

Drawing Number:
ACP-R-22/4



ANCHORAGE BASE

HIGH STRENGTH LOW ALLOY STEEL - ASTM A572 GRADE 50
SCALE: 1-20



SECTION A

SCALE: 1-20

ALL DIMENSIONS AND/OR DIMENSIONS SHOWN IN CALLOUTS/NOTES ARE PRELIMINARY AND ARE IN MILLIMETERS UNLESS OTHERWISE NOTED.

US Army Corps
of Engineers
Pittsburgh District

Design by: D. BUCCINI		Submitted by: FRANK ZOVACK SECTION CHIEF
Dwn by: PETERS	Ckd by: X	
Submission Date: OCT 2002	Revision Date: X	IFB NO.: DACW59
		Sheet X of X

ACP
AUTORIDAD DEL CANAL DE PANAMA

User: jtankosh
Date: 20-OCT-2002 22:41
Plot Scale: 2.715340:1.000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
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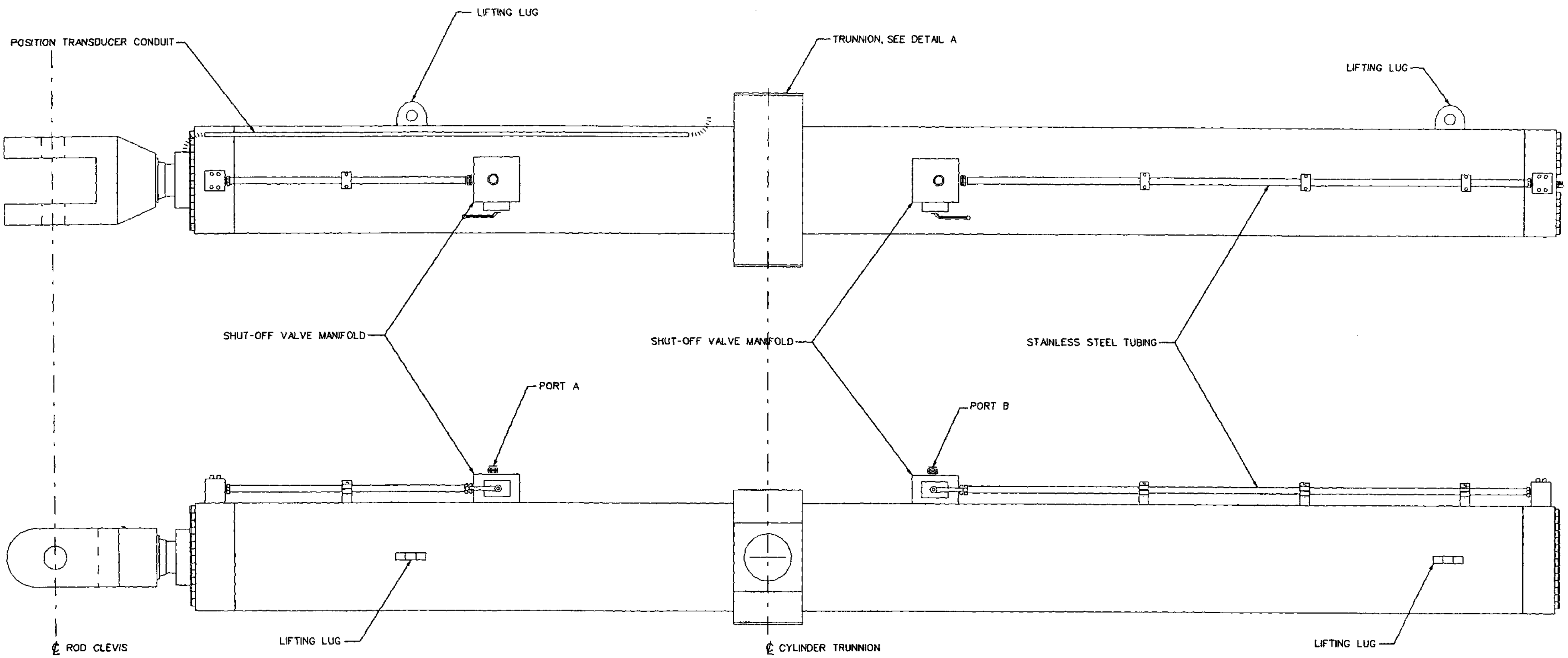
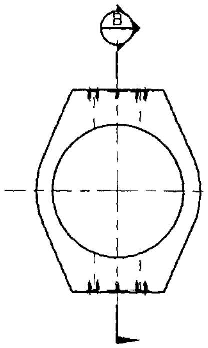
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
MITER GATE OPERATING MACHINERY
HYDRAULIC CYLINDER
ANCHORAGE BASE

Drawing Number: ACP-R-22/5

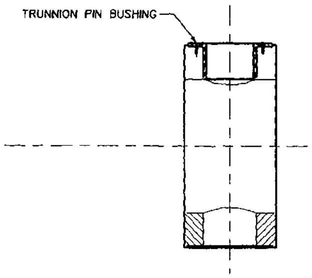


CYLINDER PIPING

SCALE: 1=20



DETAIL A



DETAIL B

US Army Corps
of Engineers
Pittsburgh District

Submitted by:
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SECTION CHIEF

Design by:
D. BUCCINI

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PETERS

Ckd by:
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Submission Date:
OCT 2002

Revision Date:
X

FB NO.:
DACW59

Sheet X of X

ACP
AUTORIDAD DEL CANAL DE PANAMA

User: Rankash
Date: 20-OCT-2002 22:41
Plot Scale: 2.765340:1.000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
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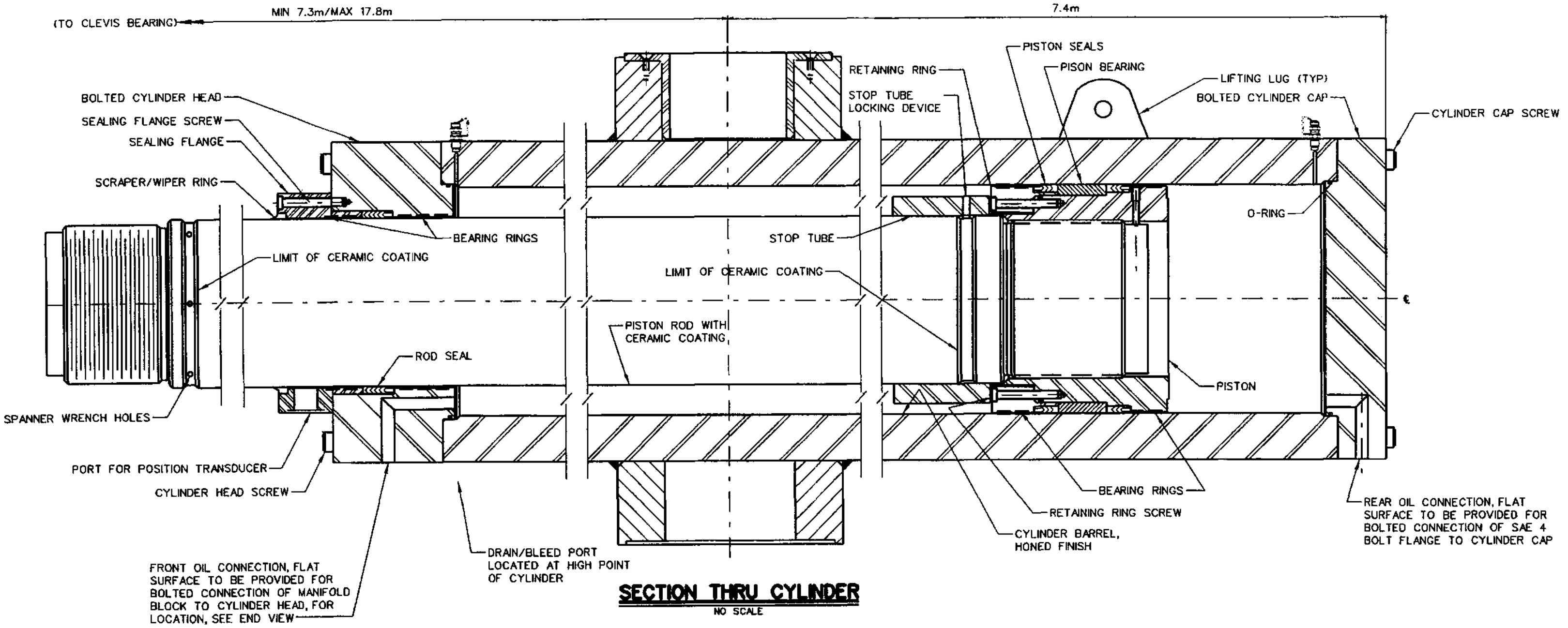
F:\ACP\mech\CylinderPiping.s01

PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
MITER GATE OPERATING MACHINERY
HYDRAULIC CYLINDER
DETAILS



SECTION THRU CYLINDER

NO SCALE

CYLINDER DATA	
BORE DIA	711 mm
ROD DIA	508 mm
REQUIRED STROKE LENGTH	10491 mm
DESIGN PRESSURE	17.2 MPa
TEST PRESSURE (MAX.)	24.1 MPa
SPEED: MOVING "IN"	2623 mm/min
MOVING "OUT"	2623 mm/min
OPERATING PRESSURE: NORMAL OPENING	10.8 MPa
NORMAL CLOSING	5.8 MPa
MATERIAL: ROD	AISI 4340 (DIN 34CrNiMo6)
CYLINDER	ASTM A542 CL3 (DIN 20 MnV6)
SURFACE CONDITION: BORE	HONED
ROD	CERAMIC

ALL DIMENSIONS AND/OR DIMENSIONS SHOWN IN CALLOUTS/NOTES ARE IN METERS UNLESS OTHERWISE NOTED.

US Army Corps of Engineers
Pittsburgh District

Submitted by: FRANK ZOVACK
SECTION CHIEF
FB NO.: DACW59
Sheet X of X

Design by: D. BUCCINI
Dwn by: PETERS
Ckd by: X
Submission Date: OCT 2002
Revision Date: X

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User: Rankosh
Date: 20-OCT-2002 22:41
Plot Scale: 2.715340:1.000000
Pen Table:
Color Table

Symbol	Description	Date	Appr.
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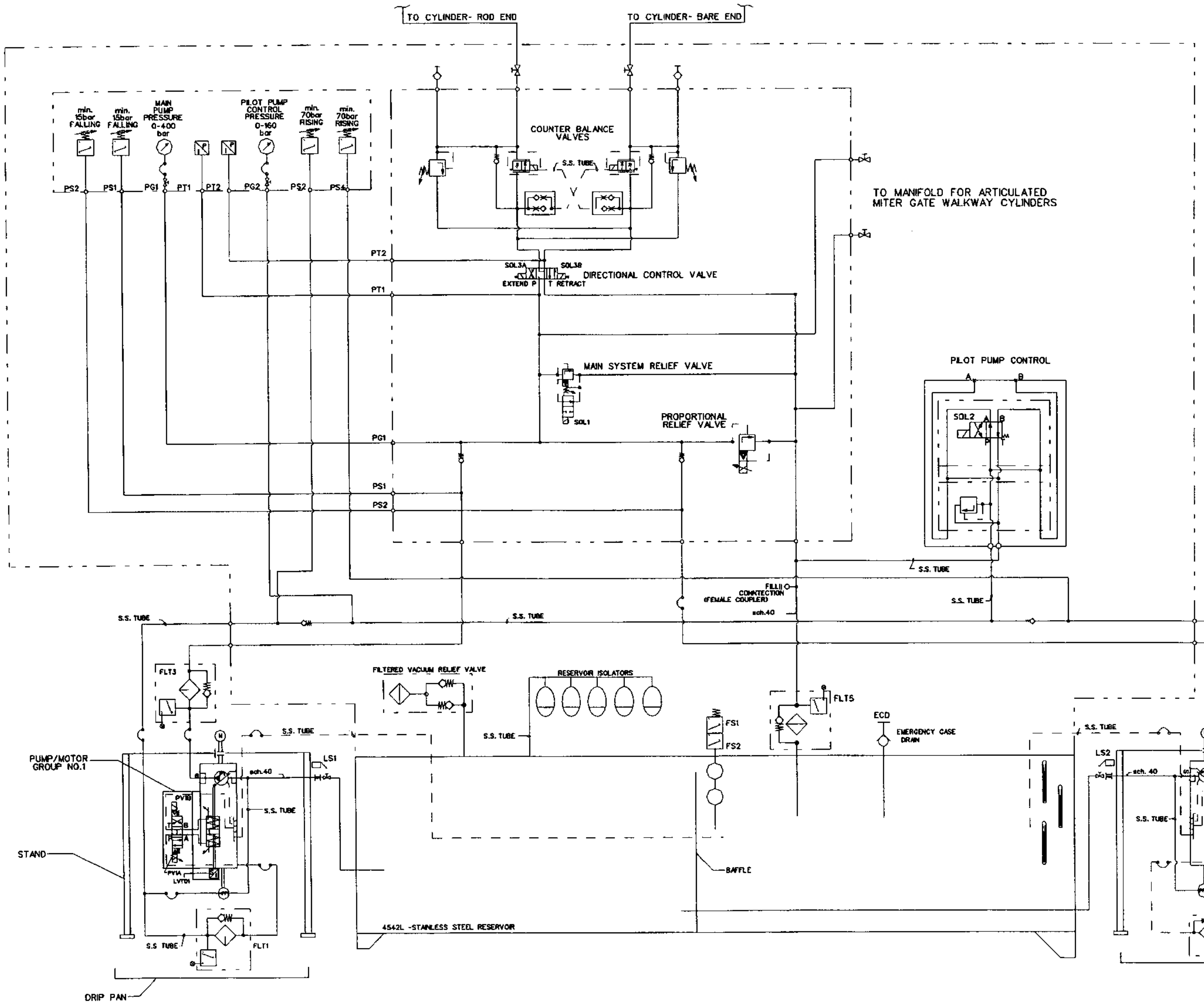
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
MITER GATE OPERATING MACHINERY
HYDRAULIC CYLINDER
SECTION

Drawing Number: ACP-R-22/7



LEGEND

FLT- FILTER
FS- FLOAT SWITCH
PS- PRESSURE SWITCH
LS- LIMIT SWITCH
PT- PRESSURE TRANSDUCER
PV- PROPORTIONAL VALVE
SOL- SOLENOID
P- MAIN PUMP
PP- PILOT PUMP
M- MOTOR (75HP)
SS- STAINLESS STEEL

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US Army Corps
of Engineers
Pittsburgh District

Submitted by:
FRANK ZOVACK
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FB NO.:
DACW59
Sheet X of X

Design by:
D. BUCCINI
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PETERS
Ckd by:
X
Submission Date:
OCT 2002
Revision Date:
X

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AUTORIDAD DEL CANAL DE PANAMA

User: Rankosh
Date: 20-OCT-2002 22:41
Plot Scale: 2.715340:1.000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
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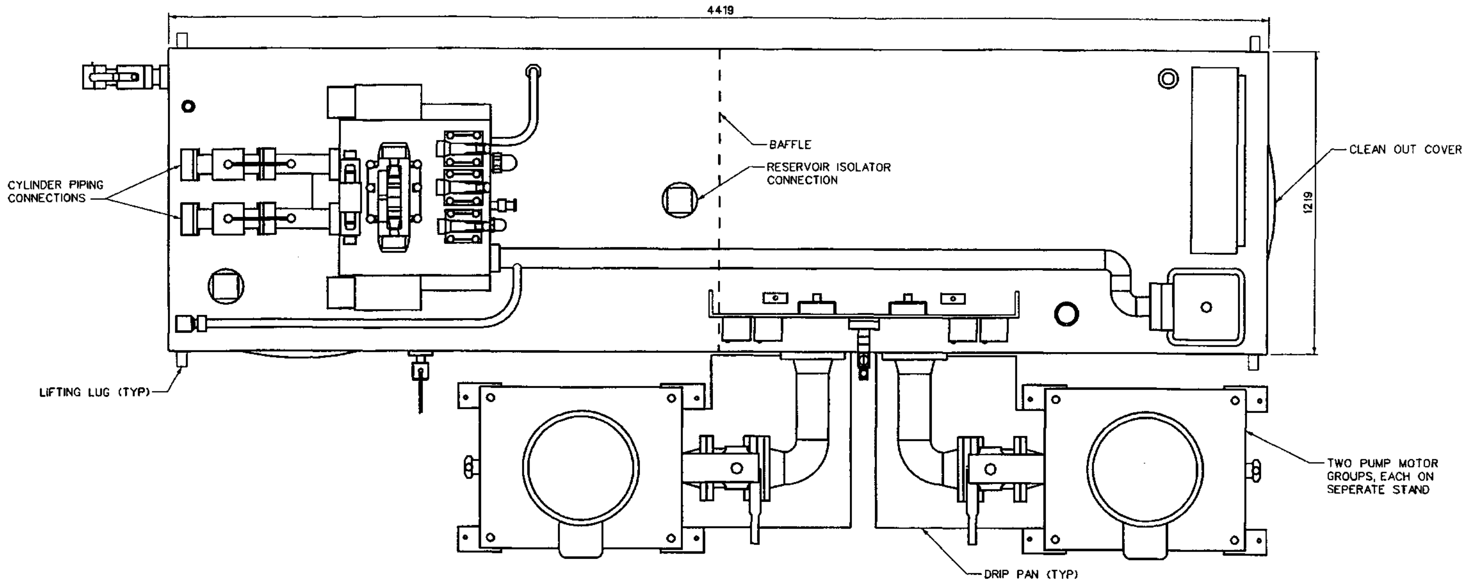
F:\ACP\mech\HPU Schematic_Gate.s01

PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
MITER GATE OPERATING MACHINERY
HYDRAULIC POWER UNIT
SCHEMATIC DIAGRAM

Drawing Number:
ACP-R-22/8



HPU PLAN
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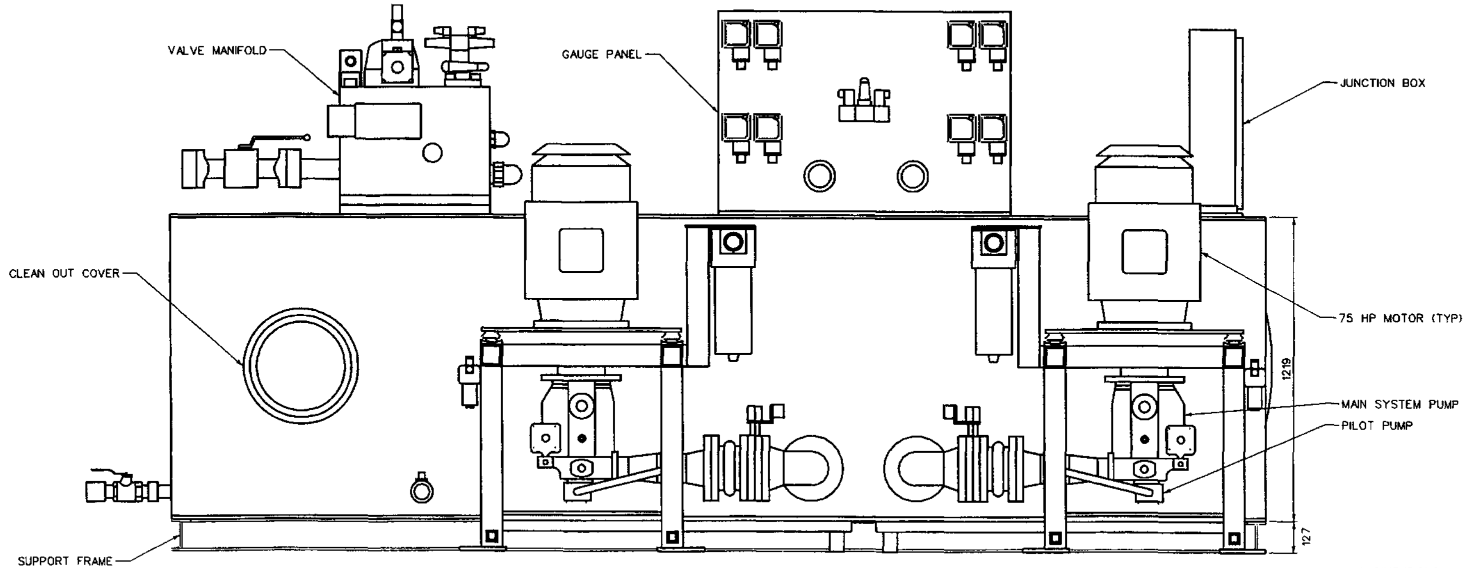

HPU SIDE ELEVATION
SCALE: 1:10

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Pittsburgh District

Submitted by:
FRANK ZOVACK
SECTION CHIEF
FB NO.:
DACW59
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Design by:
D. BUCCINI
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Revision Date:
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AUTORIDAD DEL CANAL DE PANAMA
User: Rankoh
Date: 20-OCT-2002 22:41
Plot Scale: 2.715340:1.000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
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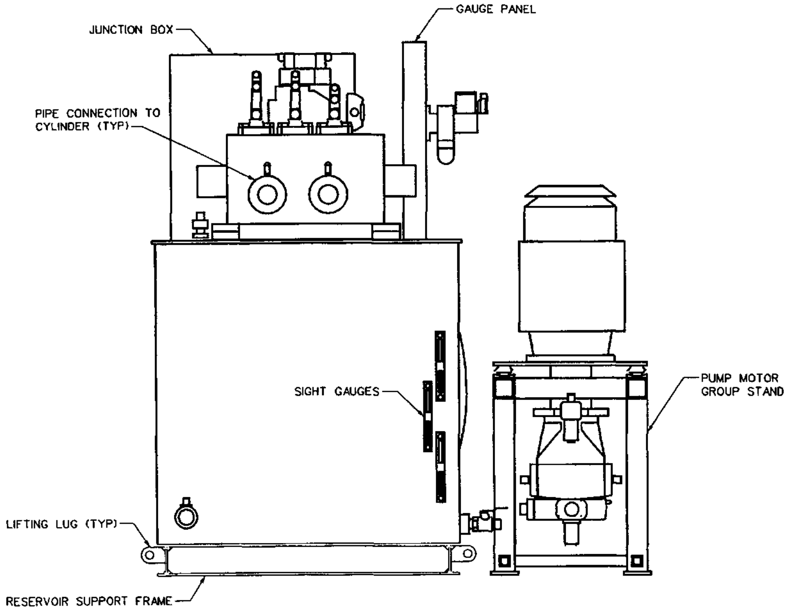
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
MITER GATE OPERATING MACHINERY
HYDRAULIC POWER UNIT
PLAN AND ELEVATION

Drawing Number:
ACP-R-22/9



HPU FRONT ELEVATION
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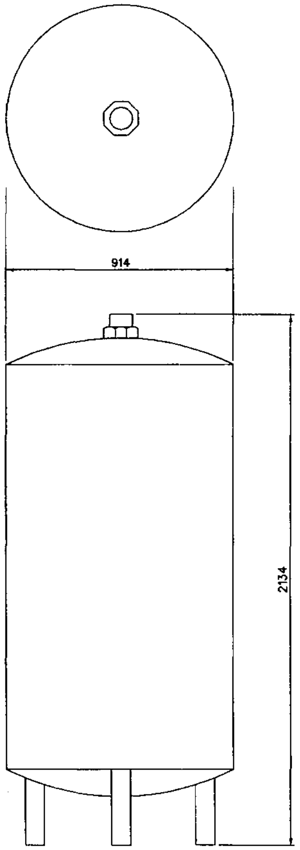

HYDRAULIC RESERVOIR ISOLATOR
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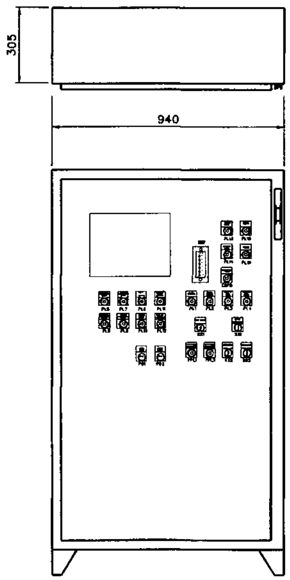

HPU CONTROL ENCLOSURE
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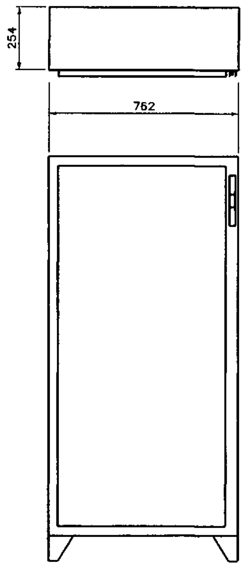

MOTOR STARTER ENCLOSURE
SCALE: 1=10

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US Army Corps of Engineers
Pittsburgh District

Submitted by:
FRANK ZOVACK
SECTION CHIEF

FB NO.: DACW59
Sheet X of X

Design by: D. BUCCINI
Dwn by: PETERS
Ckd by: X
Submission Date: OCT 2002
Revision Date: X

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AUTORIDAD DEL CANAL DE PANAMA
User: kconkoah
Date: 20-OCT-2002 22:41
Plot Scale: 2.715340:1.000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
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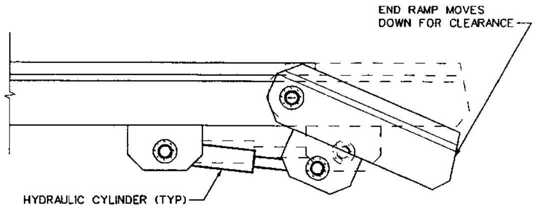
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
MITER GATE OPERATING MACHINERY
HYDRAULIC POWER UNIT
DETAILS

Drawing Number:
ACP-R-22/10



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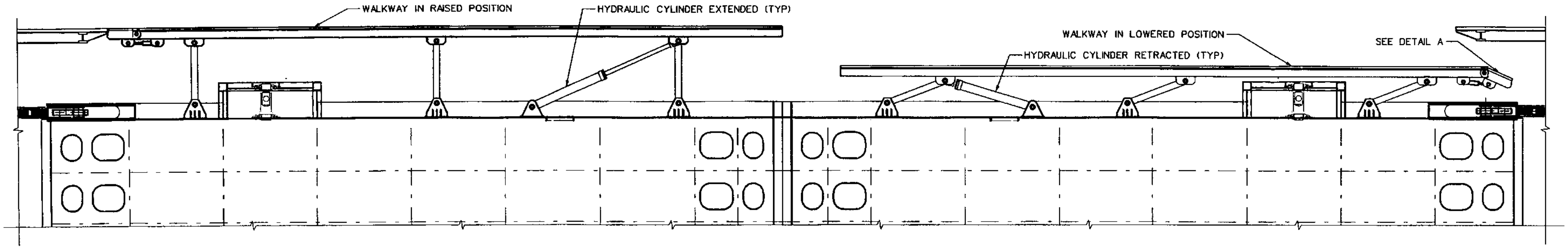
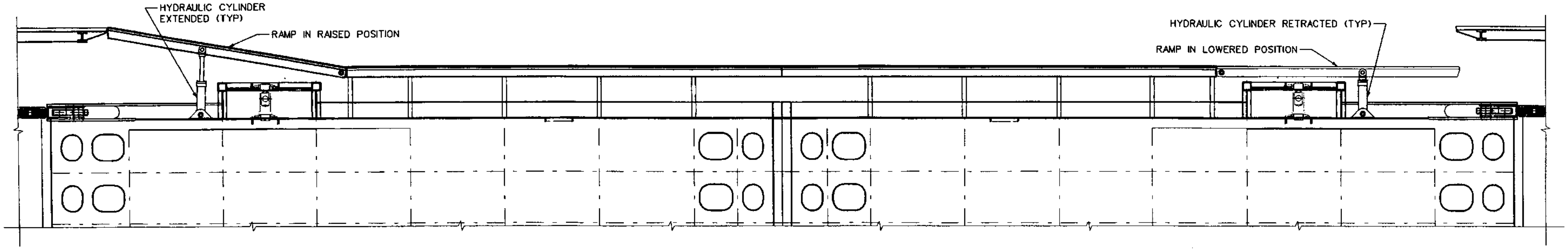


ARTICULATED WALKWAY
SCALE: 1=100



ARTICULATED RAMP
SCALE: 1=100

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US Army Corps
of Engineers
Pittsburgh District

Submitted by:
FRANK ZOVACK
SECTION CHIEF

Design by:
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Dwn by:
PETERS

Ckd by:
X

Submission Date:
OCT 2002

Revision Date:
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DACW59

Sheet X of X

ACP
AUTORIDAD DEL CANAL DE PANAMA

User: Jtankah
Date: 20-OCT-2002 22:41
Plot Scale: 2.715340:1.000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
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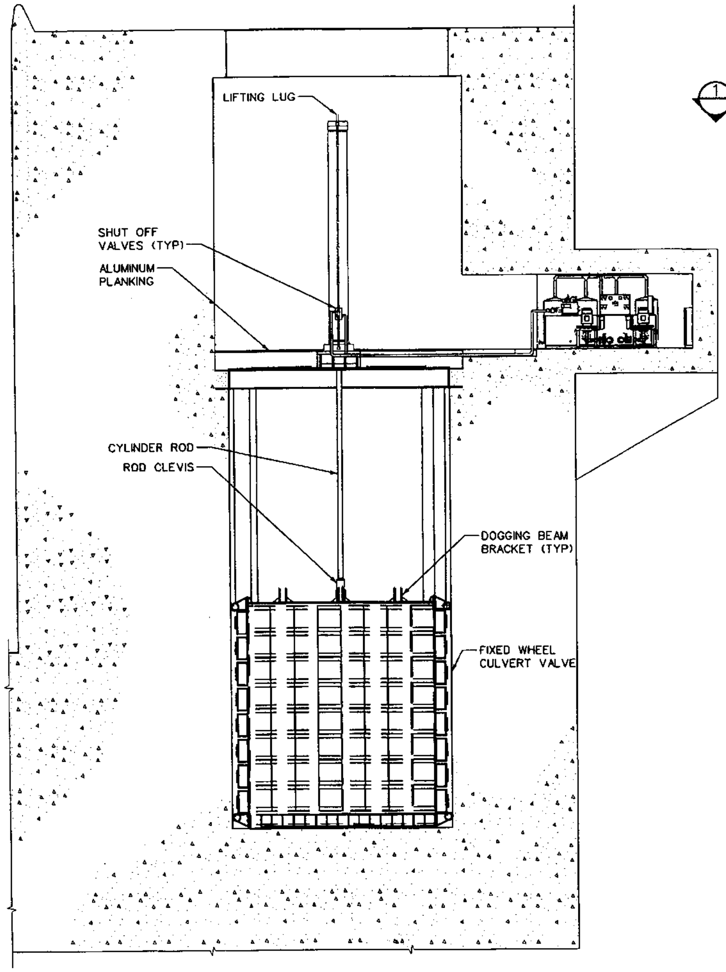
F:\ACP\mech\Walkway.s01

PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
MITER GATE OPERATING MACHINERY
MITER GATE WALKWAY
ACTUATOR SCHEMES

Drawing Number:
ACP-R-22/11



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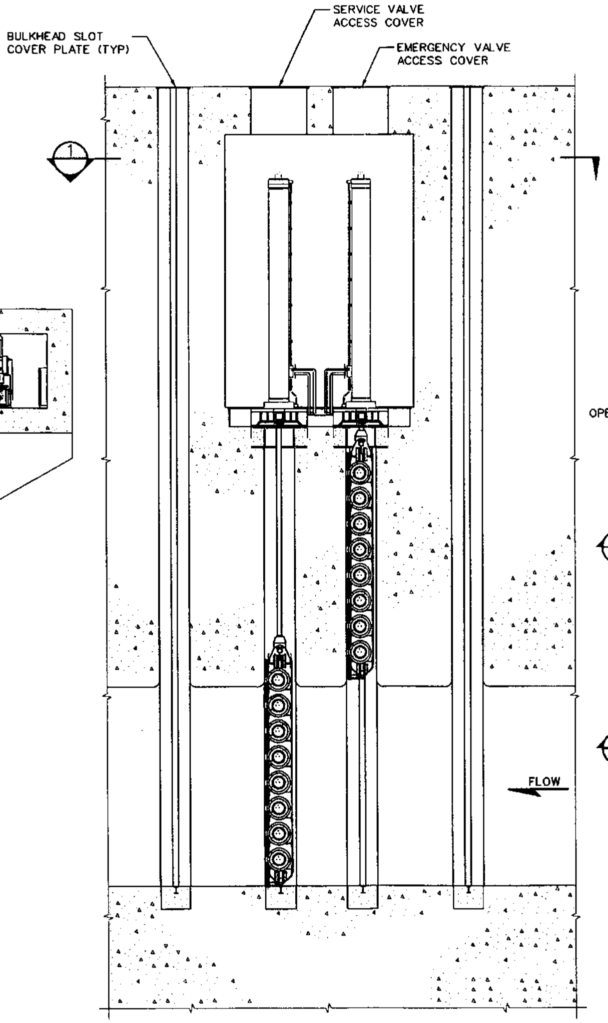

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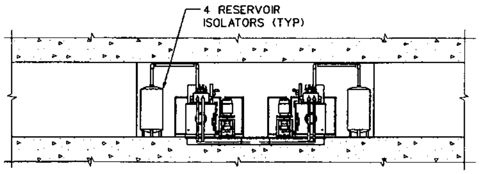

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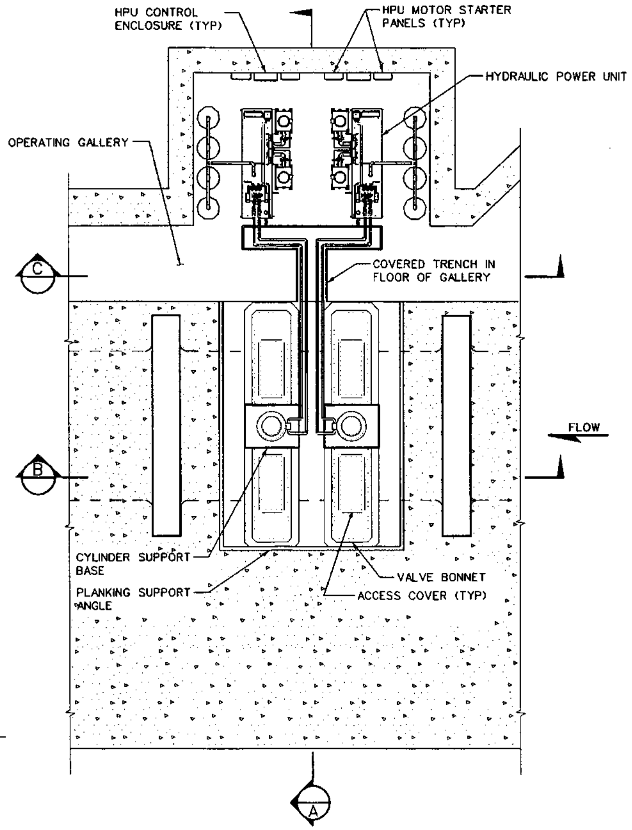

LOWER CULVERT VALVES ①
SCALE: 1=100

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US Army Corps of Engineers
Pittsburgh District

Submitted by: FRANK ZOVACK
SECTION CHIEF
PB NO.: DACW59
Sheet X of X

Design by: D. BUCCINI
Dwn by: PETERS
Ckd by: X
Submission Date: OCT 2002
Revision Date: X

ACP
AUTORIDAD DEL CANAL DE PANAMA
User: jkankosh
Date: 20-OCT-2002 22:41
Plot Scale: 2.715340:1.000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
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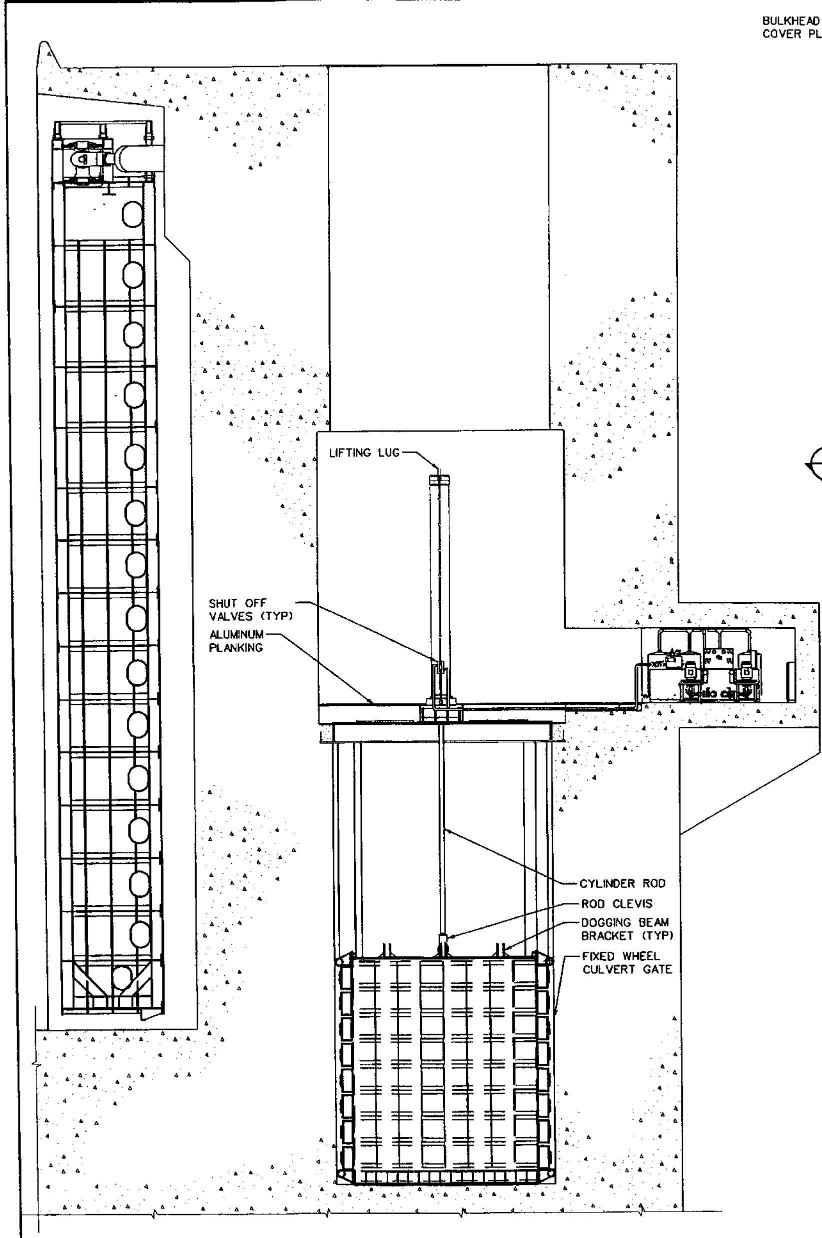
F:\ACP\mech\Culvert Valves_Lower.s01

PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
VALVE OPERATING MACHINERY
LOWER CULVERT VALVES
PLAN AND SECTIONS

Drawing Number: ACP-R-28/1



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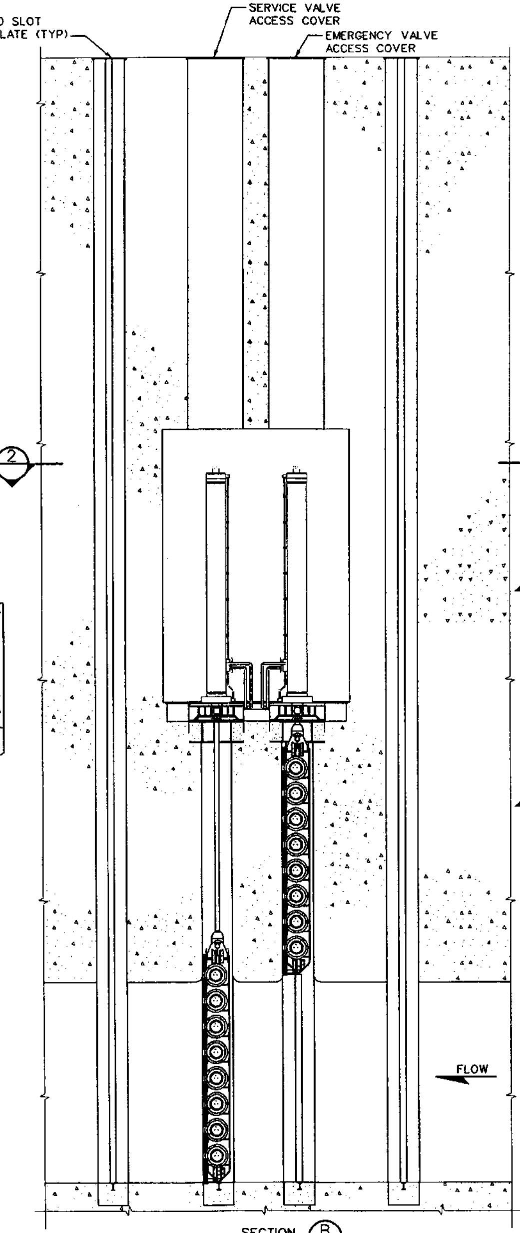

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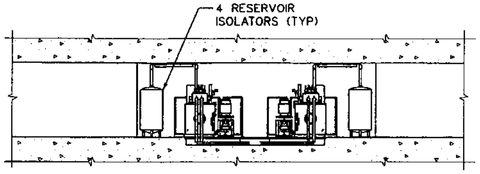

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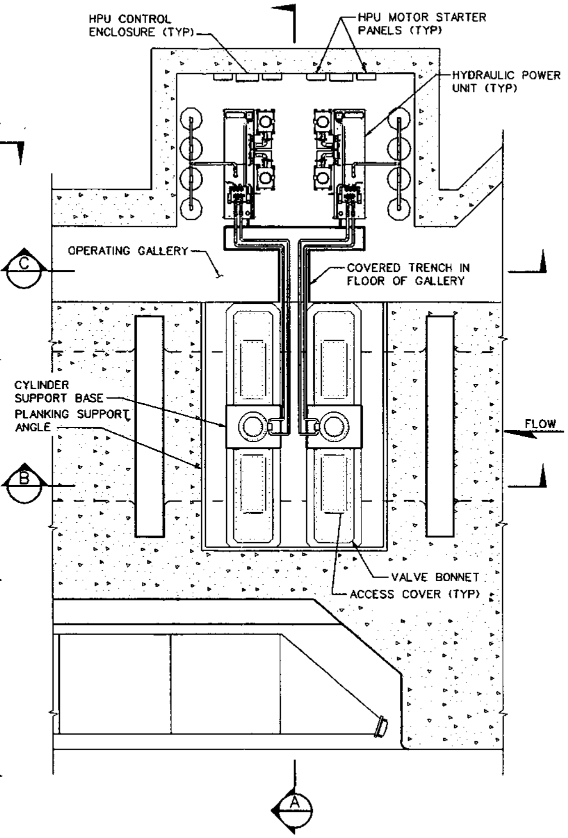

MIDDLE CULVERT VALVES (2)
SCALE: 1-100

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US Army Corps of Engineers
Pittsburgh District

Submitted by: FRANK ZOVACK
SECTION CHIEF
PB NO.: DACW59
Sheet X of X
Design by: D. BUCCINI
Dwn by: PETERS
Ckd by: X
Submission Date: OCT 2002
Revision Date: X

ACP
AUTORIDAD DEL CANAL DE PANAMA
User: Hankosh
Date: 20-OCT-2002 22:41
Plot Scale: 2.715340:1.000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
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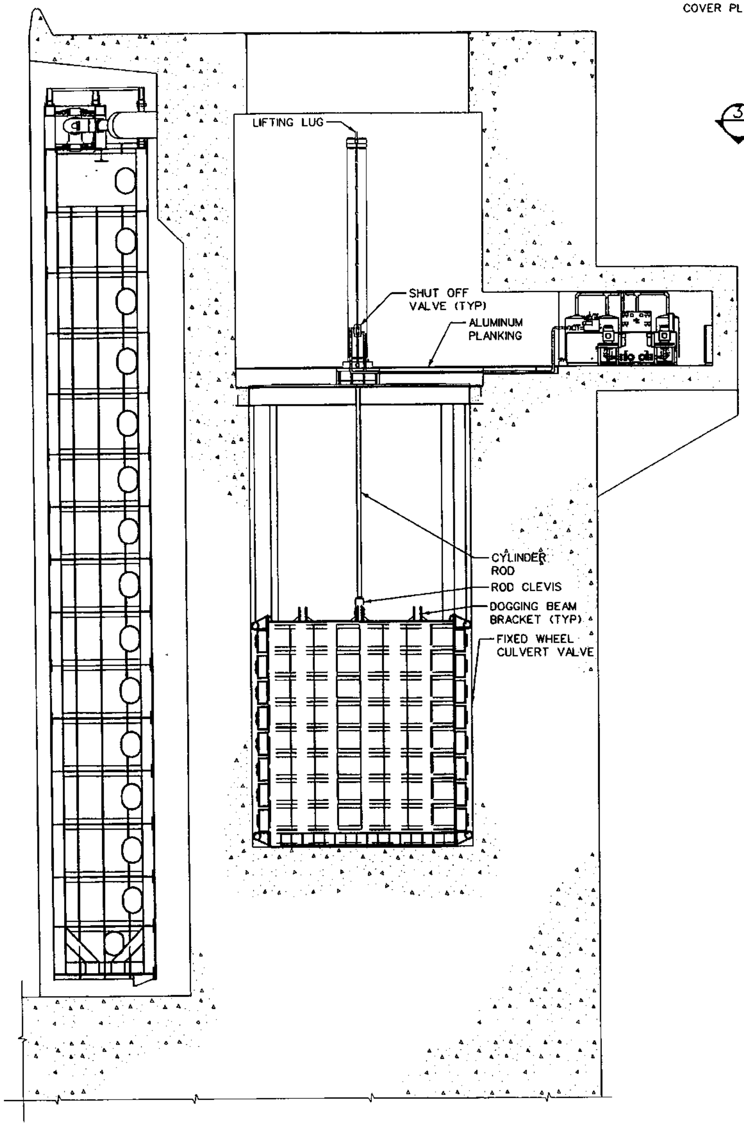
F:\ACP\mech\Culvert Valves_Middle.s01

PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
VALVE OPERATING MACHINERY
MIDDLE CULVERT VALVES
PLAN AND SECTIONS

Drawing Number: ACP-R-28/2



SECTION A
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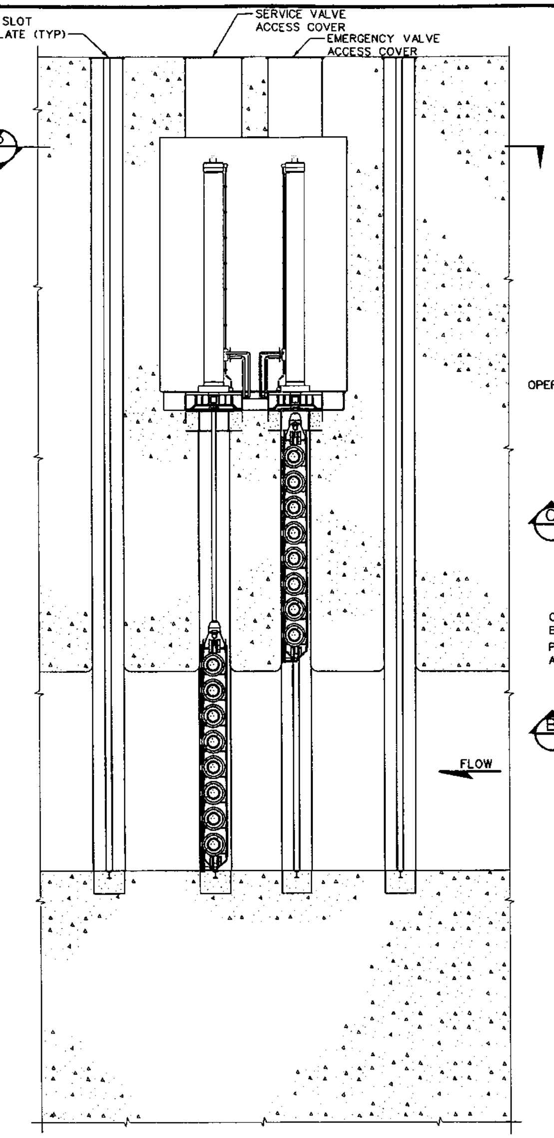
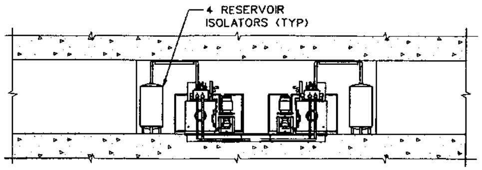
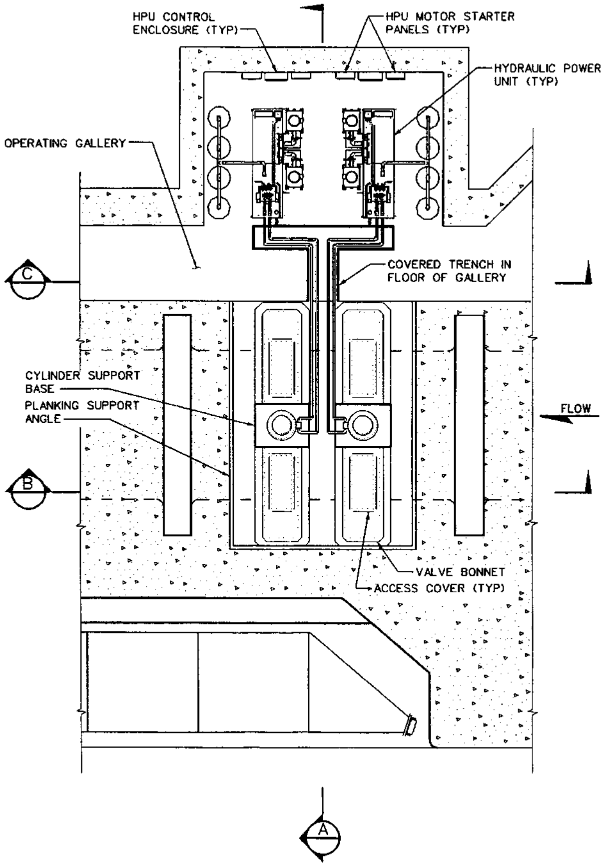


SECTION B
SCALE: 1=100



SECTION C



UPPER CULVERT VALVES 3
SCALE: 1=100

ALL DIMENSIONS AND/OR DIMENSIONS
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US Army Corps
of Engineers
Pittsburgh District

Submitted by:
FRANK ZOVACK
SECTION CHIEF
FB NO.:
DACW59
Sheet X of X

Design by:
D. BUCCINI
Dwn by:
PETERS
Ckd by:
X
Submission Date:
OCT 2002
Revision Date:
X

ACP
AUTORIDAD DEL CANAL DE PANAMA

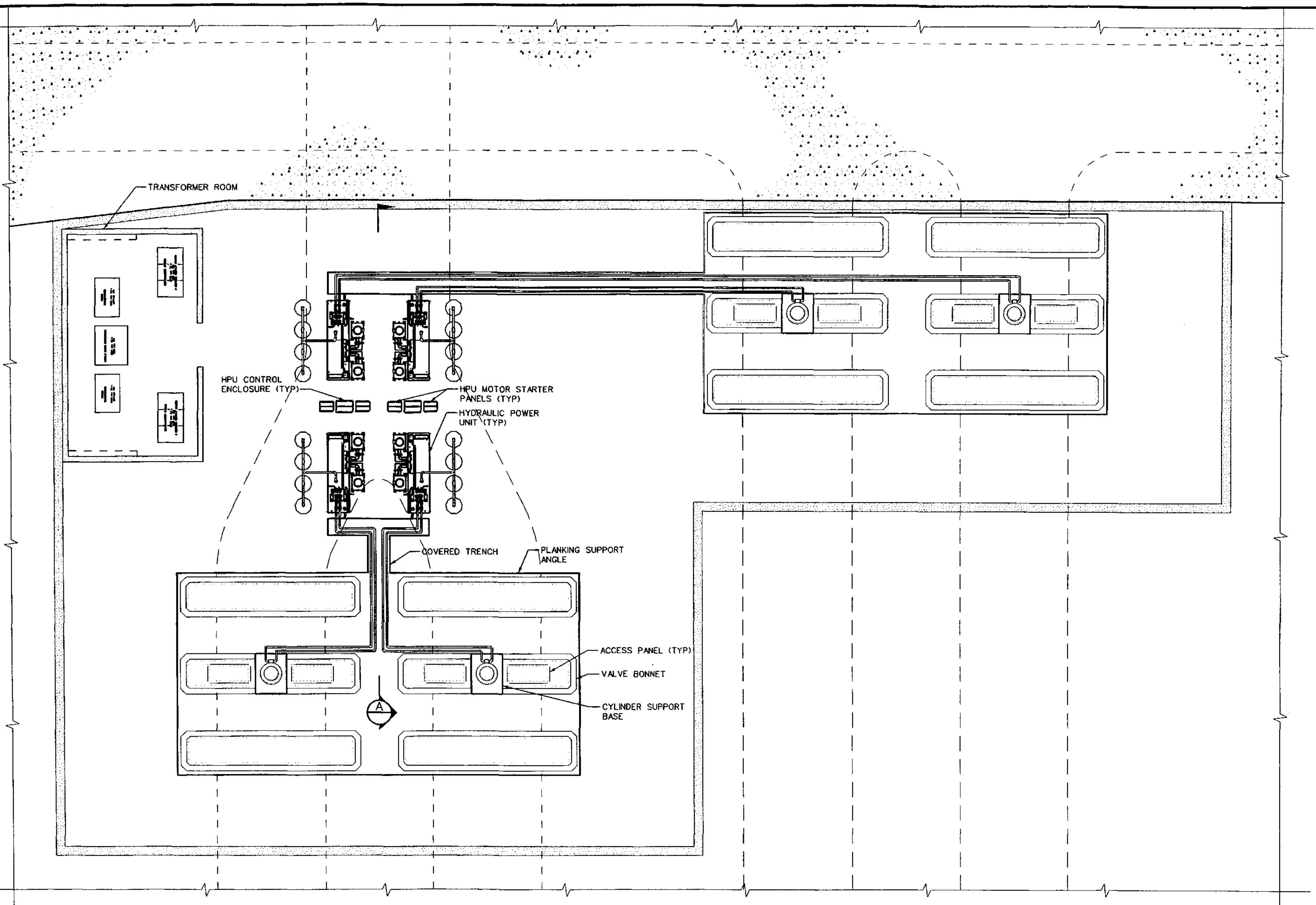
User: jbankosh
Date: 20-OCT-2002 22:41
Plot Scale: 2.715340:1.000000
Pen Table:
Color Table

Symbol	Description	Date	Appr.
X	X	X	X

F:\ACP\mech\Culvert Valves_Upper.s01

PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
VALVE OPERATING MACHINERY
UPPER CULVERT VALVE
PLAN AND SECTIONS

Drawing Number:
ACP-R-28/3



CONDUIT VALVE BUILDING PLAN

SCALE: 1-100

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of Engineers
Pittsburgh District

Submitted by:
FRANK ZOVACK
SECTION CHIEF

FB NO.: DACW59

Sheet X of X

Design by: D. BUCCINI

Dwn by: PETERS

Ckd by: X

Submission Date: OCT 2002

Revision Date: X

ACP
AUTORIDAD DEL CANAL DE PANAMA

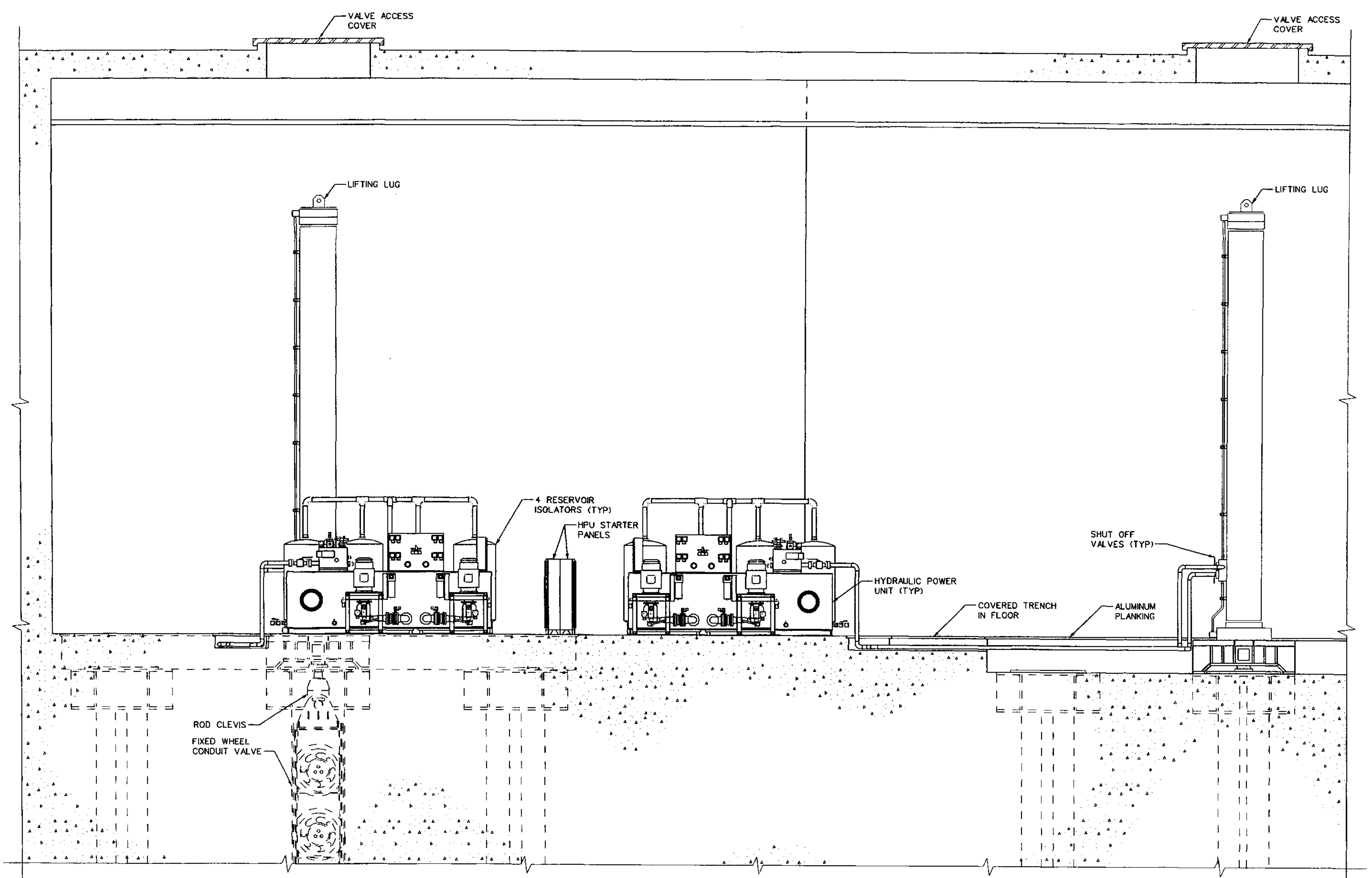
User: lkenkosh
Date: 20-OCT-2002 22:41
Plot Scale: 2.715340:1.000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
X	X	X	X

F:\ACP\mech\Valve Building.s01

PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
VALVE OPERATING MACHINERY
CONDUIT VALVE
PLAN

Drawing Number:
ACP-R-28/4



CONDUIT VALVE BUILDING ELEVATION
SCALE: 1-40

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US Army Corps
of Engineers
Pittsburgh District

Submitted by: FRANK ZOVACK
SECTION CHIEF
PB NO.: DACW59
Sheet X of X

Design by: D. BUCCINI
Dwn by: PETERS
Ckd by: X
Submission Date: OCT 2002
Revision Date: X

ACP
AUTORIDAD DEL CANAL DE PANAMA

User: Rankosh
Date: 20-OCT-2002 22:42
Plot Scale: 2.715340:1.000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
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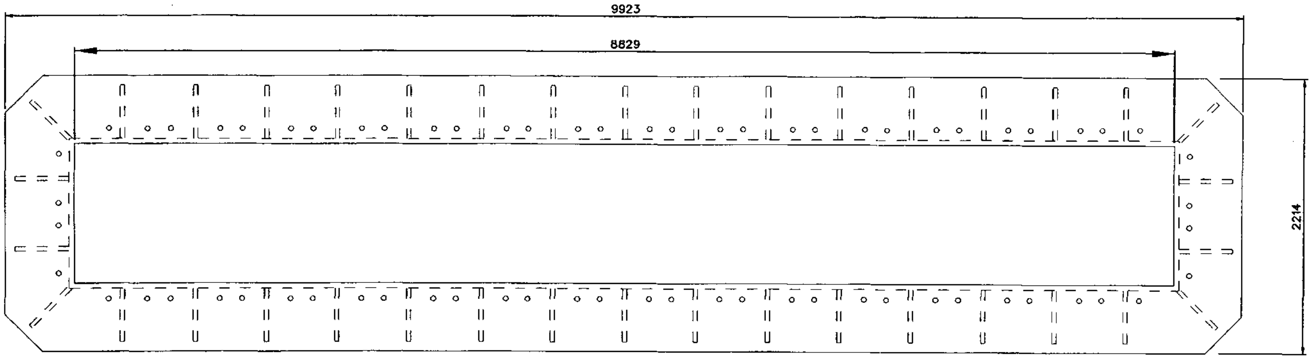
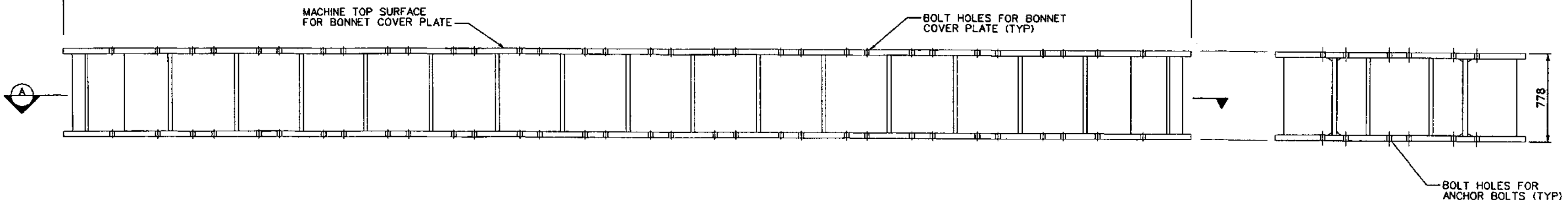
F:\ACP\mech\Valve BuildingElev.s01

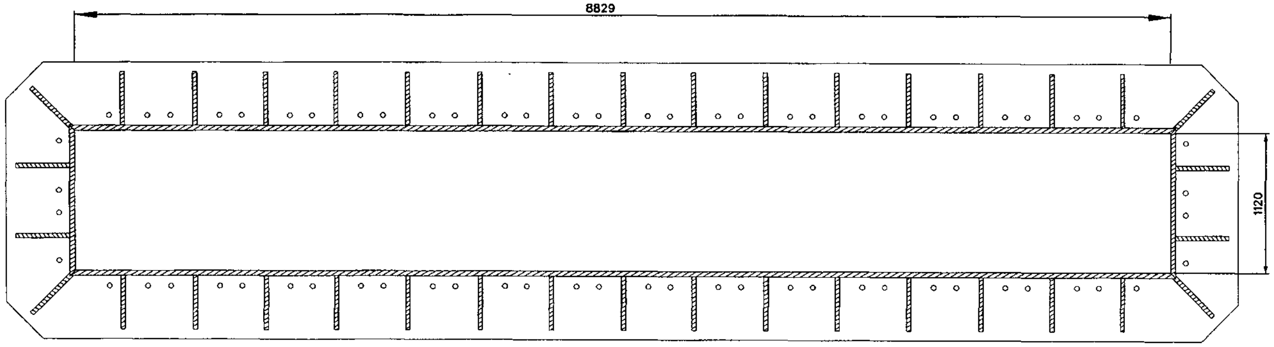
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
VALVE OPERATING MACHINERY
CONDUIT VALVE
ELEVATION

Drawing Number: ACP-R-28/5



VALVE BONNET BASE
SCALE: 1=20





SECTION (A)
SCALE: 1=20

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US Army Corps of Engineers
Pittsburgh District

Submitted by: FRANK ZOVACK
SECTION CHIEF

Design by: D. BUCCINI
Dwn by: PETERS
Ckd by: X
Submission Date: OCT 2002
Revision Date: X
FB NO.: DACW59
Sheet X of X

ACP
AUTORIDAD DEL CANAL DE PANAMA

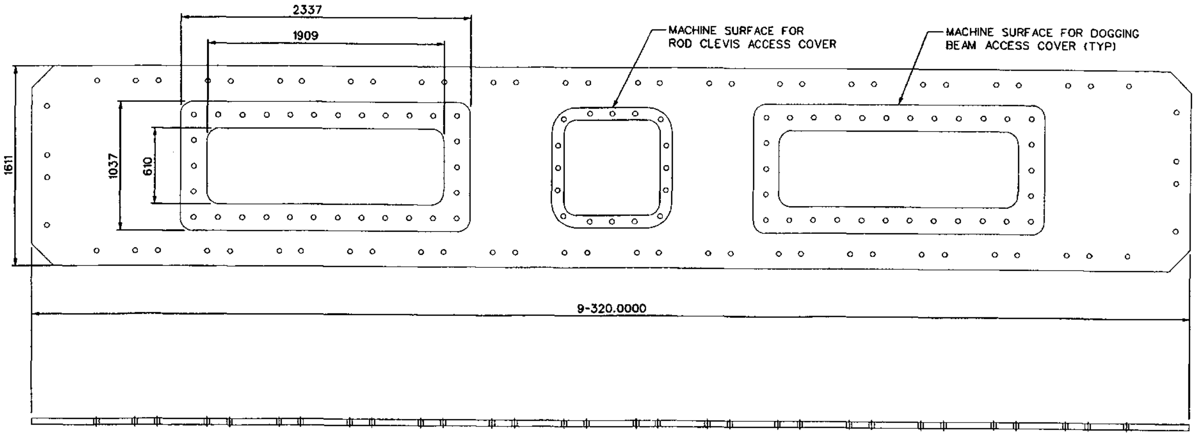
User: Rankash
Date: 20-OCT-2002 22:42
Plot Scale: 2.7753401.000000
Pen Table:
Color Table

Symbol	Description	Date	Appr.
X	X	X	X

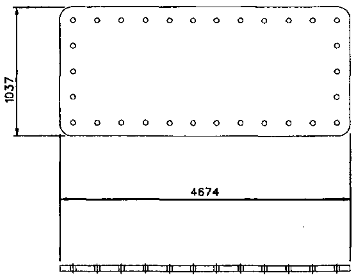
F:\ACP\mech\Bonnet_Valve.s01

PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
VALVE OPERATING MACHINERY
VALVE BONNET
ANCHORAGE BASE

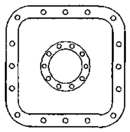
Drawing Number: ACP-R-28/6



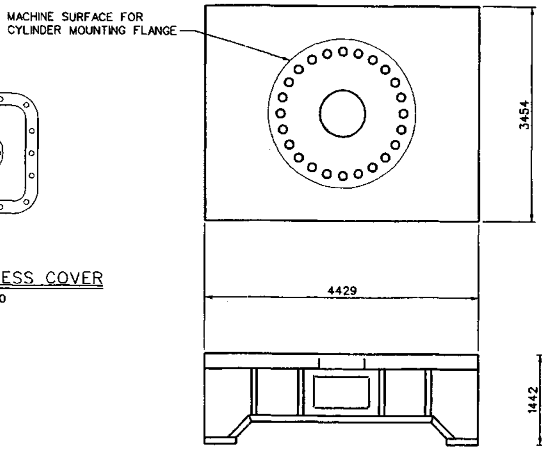
BONNET COVER PLATE
SCALE: 1=20



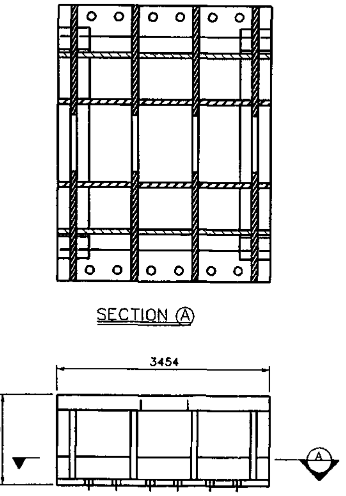
DOGGING BEAM ACCESS COVER
SCALE: 1=20



ROD CLEVIS ACCESS COVER
SCALE: 1=20



CYLINDER SUPPORT BASE
SCALE: 1=20



SECTION Ⓐ

ALL DIMENSIONS AND/OR DIMENSIONS SHOWN IN CALLOUTS/NOTES ARE IN MILLIMETERS UNLESS OTHERWISE NOTED.

US Army Corps of Engineers
Pittsburgh District

Submitted by:
FRANK ZOVACK
SECTION CHIEF

Design by: D. BUCCINI
Dwn by: PETERS
Ckd by: X
Submission Date: OCT 2002
Revision Date: X
FB NO.: DACW59
Sheet X of X

ACP
AUTORIDAD DEL CANAL DE PANAMA

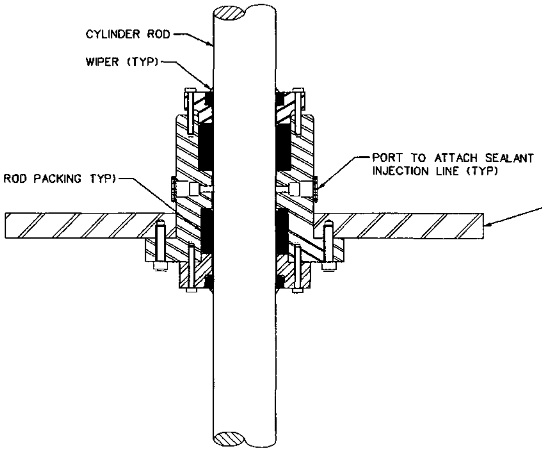
User: jkankash
Date: 20-OCT-2002 22:42
Plot Scale: 2.7153400:1.000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
X	X	X	X

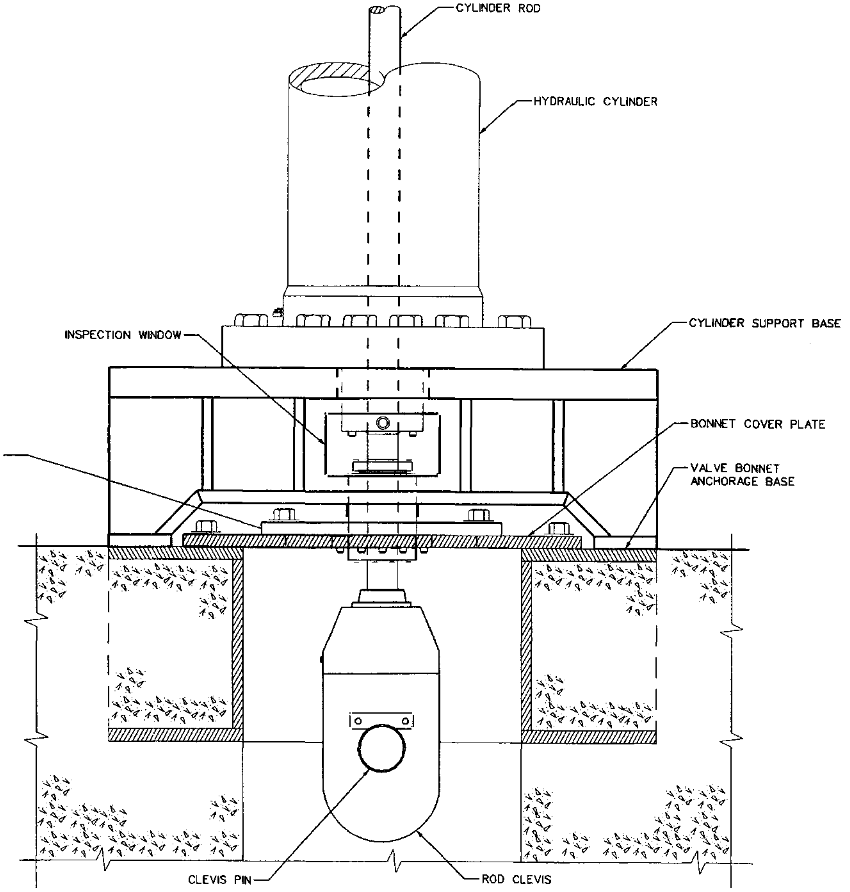
F:\ACP\mech\BonnetCover Plate.s01

PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
VALVE OPERATING MACHINERY
BONNET AND CYLINDER SUPPORT BASE
DETAILS

Drawing Number:
ACP-R-28/7



BONNET SEAL
SCALE: 1-20



CYLINDER BASE ASSEMBLY
SCALE: 1-10

ALL DIMENSIONS AND/OR DIMENSIONS
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US Army Corps
of Engineers
Pittsburgh District

Submitted by:
FRANK ZOVACK
SECTION CHIEF

Design by:
D. BUCCINI

Dwn by:
PETERS

Ckd by:
X

Submission Date:
OCT 2002

Revision Date:
X

FB NO.:
DACW59

Sheet X of X

ACP
AUTORIDAD DEL CANAL DE PANAMA

User: jlankosh
Date: 20-OCT-2002 22:42
Plot Scale: 2.716340:1.000000
Pen Table:
Color Table

Symbol	Description	Date	Appr.
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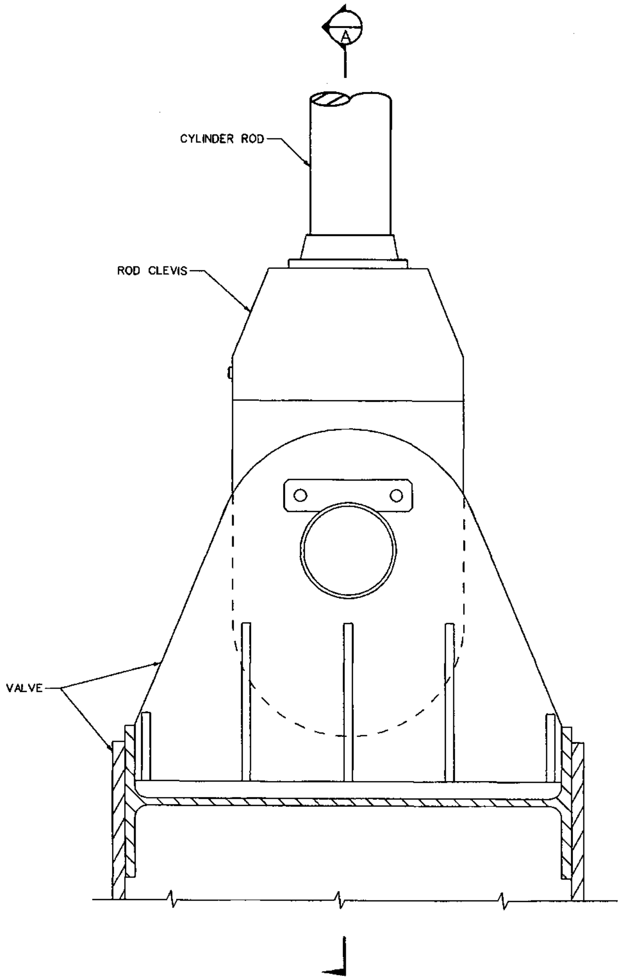
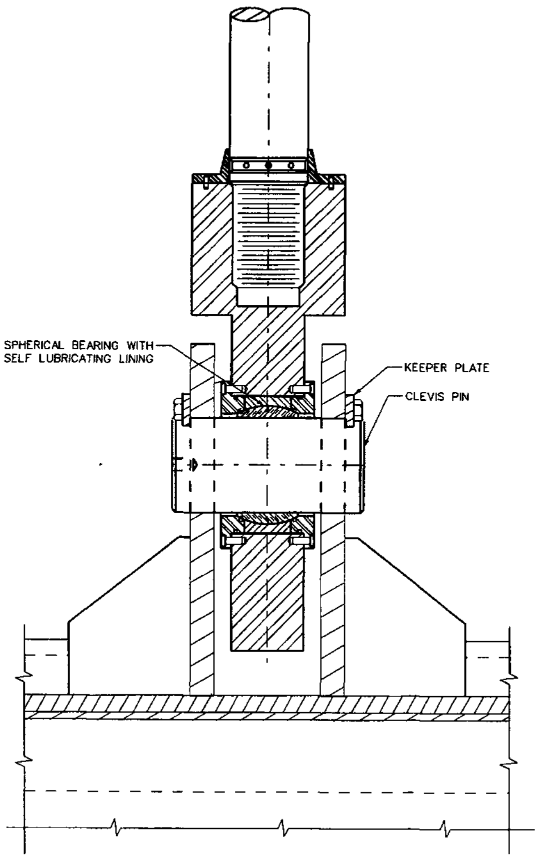
F:\ACP\mech\BaseAssembly.s01

PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
VALVE OPERATING MACHINERY
BONNET SEAL AND CYLINDER BASE ASSEMBLY
DETAILS

Drawing Number:
ACP-R-28/8



CYLINDER CONNECTION
SCALE: 1-5



SECTION (A)
SCALE: 1-5

ALL DIMENSIONS AND/OR DIMENSIONS SHOWN IN CALLOUTS/NOTES ARE IN MILLIMETERS UNLESS OTHERWISE NOTED.

US Army Corps of Engineers
Pittsburgh District

Symbol	Description	Date	Appr.
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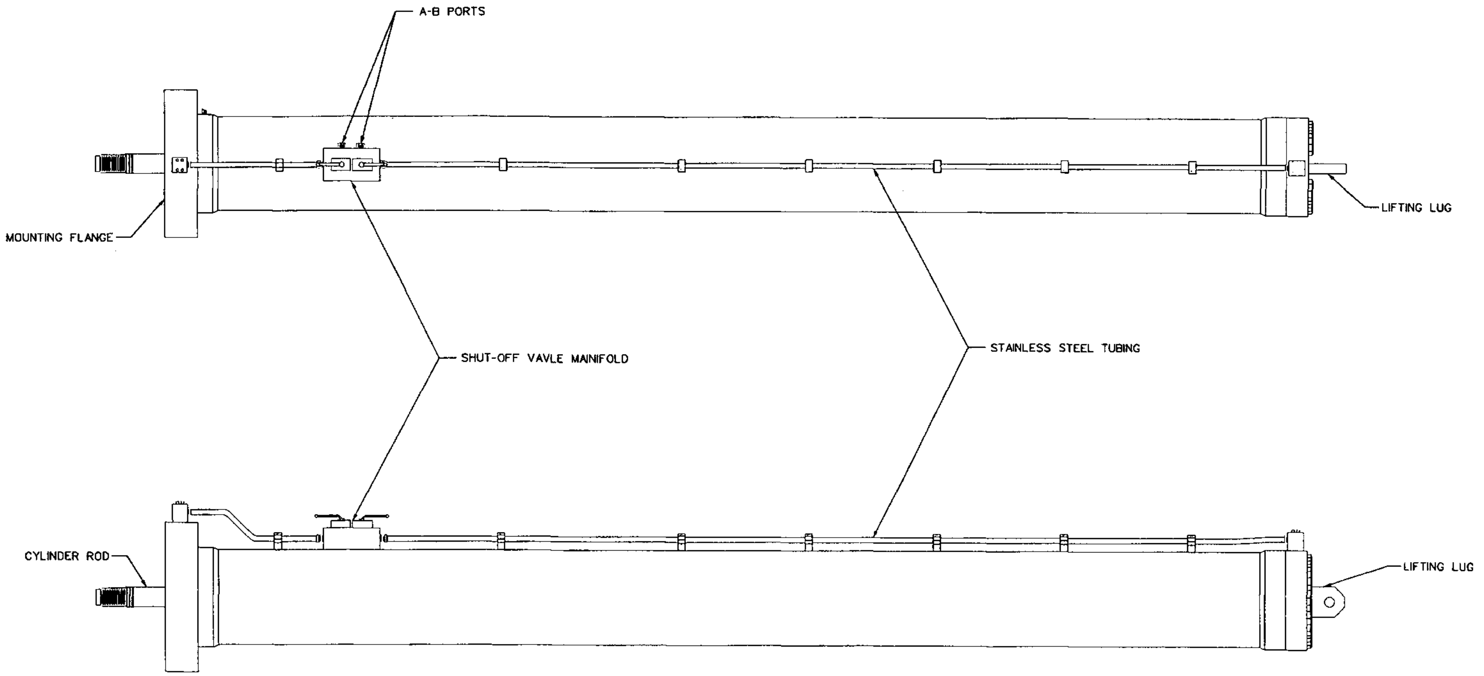
F:\ACP\mech\ValveGateConnection.s01

ACP
AUTORIDAD DEL CANAL DE PANAMA
User: jtonkosh
Date: 20-OCT-2002 22:42
Plot Scale: 2.715340:1.000000
Pen Table:
Color Table

Design by: D. BUCCINI
Dwn by: PETERS
Ckd by: X
Submission Date: OCT 2002
Revision Date: X
Submitted by: FRANK ZOVACK
SECTION CHIEF
IFB NO.: DACW59
Sheet X of X

PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
VALVE OPERATING MACHINERY
CYLINDER CLEVIS AND VALVE CONNECTION
DETAILS

Drawing Number: ACP-R-28/9



CYLINDER PIPING

SCALE: 1" - 1'-0"

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US Army Corps
of Engineers
Pittsburgh District

Submitted by:
FRANK ZOVACK
SECTION CHIEF
FB NO.:
DACW59
Sheet X of X

Design by:
D. BUCCINI
Dwn by:
PETERS
Ckd by:
X
Submission Date:
OCT 2002
Revision Date:
X

ACP
AUTORIDAD DEL CANAL DE PANAMA
User: lbankoh
Date: 20-OCT-2002 22:42
Plot Scale: 2.7163401.000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
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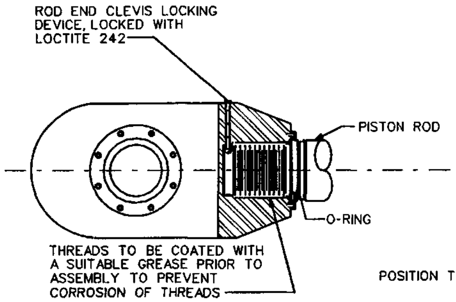
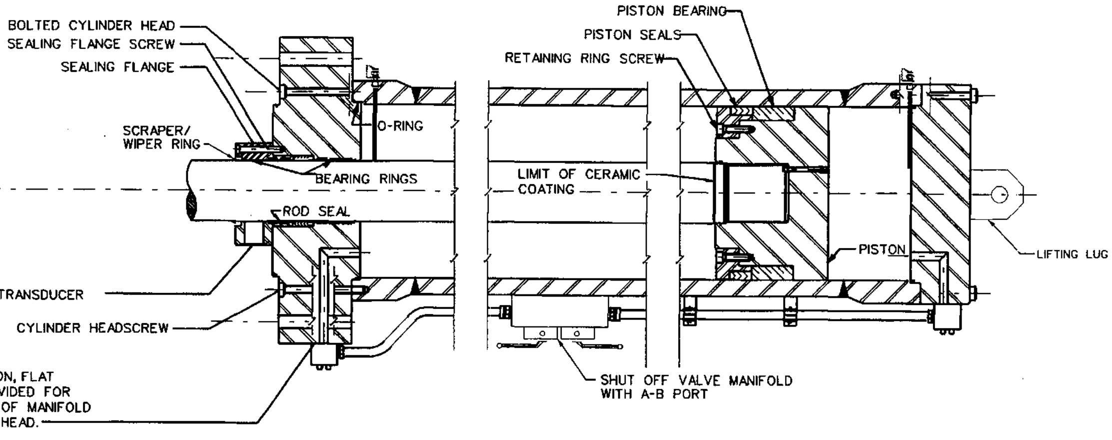
F:\ACP\mech\HydraulicCylinder_Vdve.s01

PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
VALVE OPERATING MACHINERY
HYDRAULIC CYLINDER
PIPING ARRANGEMENT

Drawing Number:
ACP-R-28/10



ROD END CLEVIS



HYDRAULIC CYLINDER

CYLINDER DATA

BORE DIA		457 mm
ROD DIA		165 mm
REQUIRED STROKE LENGTH		8229 mm
DESIGN PRESSURE		17.2 MPa
TEST PRESSURE (MAX.)		24.1 MPa
SPEED: (MAX)	MOVING "IN"	8226 mm/min
	MOVING "OUT"	8226 mm/min
MATERIAL: ROD		AISI 4340 (DIN 34CrNiMo6)
CYLINDER		ASTM A542 CL3 (DIN 20 MnV6)
SURFACE CONDITION: BORE		HONED
ROD		CERAMIC

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US Army Corps of Engineers
Pittsburgh District

Submitted by: FRANK ZOVACK
SECTION CHIEF
FB NO.: DACW59
Sheet X of X

Design by: D. BUCCINI
Dwn by: PETERS
Ckd by: X
Submission Date: OCT 2002
Revision Date: X

ACP
AUTORIDAD DEL CANAL DE PANAMA
User: Kantash
Date: 20-OCT-2002 22:42
Plot Scale: 2.715340:1.000000
Pen Table
Color Table

Symbol	Description	Date	Appr.
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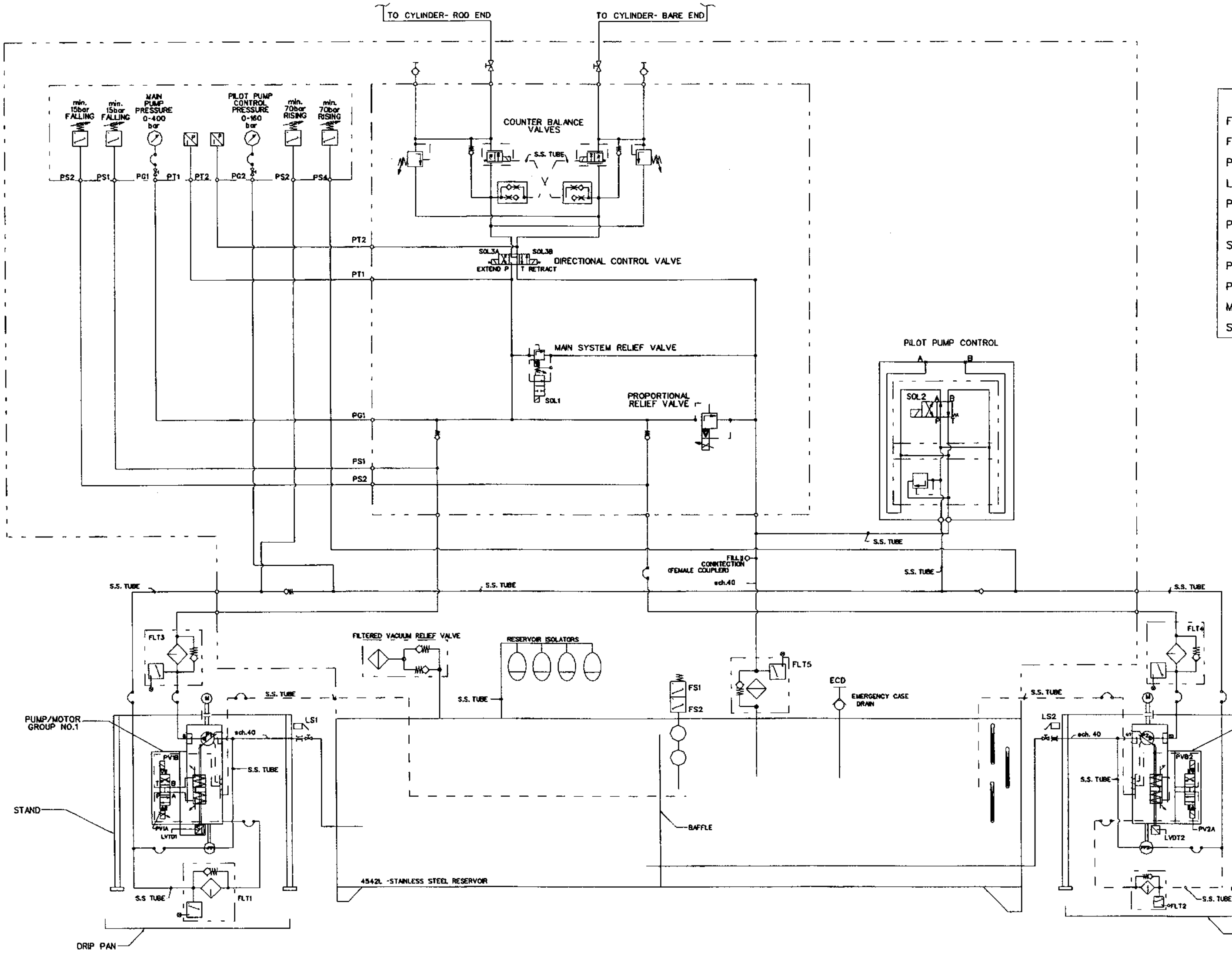
X			

F:\ACP\mech\HydraulicCylinderSection2.s01

PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
VALVE OPERATING MACHINERY
HYDRAULIC CYLINDER
SECTION

Drawing Number: ACP-R-28/11



LEGEND

FLT- FILTER
FS- FLOAT SWITCH
PS- PRESSURE SWITCH
LS- LIMIT SWITCH
PT- PRESSURE TRANSDUCER
PV- PROPORTIONAL VALVE
SOL- SOLENOID
P- MAIN PUMP
PP- PILOT PUMP
M- MOTOR (100HP)
SS- STAINLESS STEEL

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US Army Corps
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Pittsburgh District

Submitted by: FRANK ZOVACK
SECTION CHIEF
FB NO.: DACW59
Sheet X of X

Design by: D. BUCCINI
Dwn by: PETERS
Ckd by: X
Submission Date: OCT 2002
Revision Date: X

ACP
AUTORIDAD DEL CANAL DE PANAMA

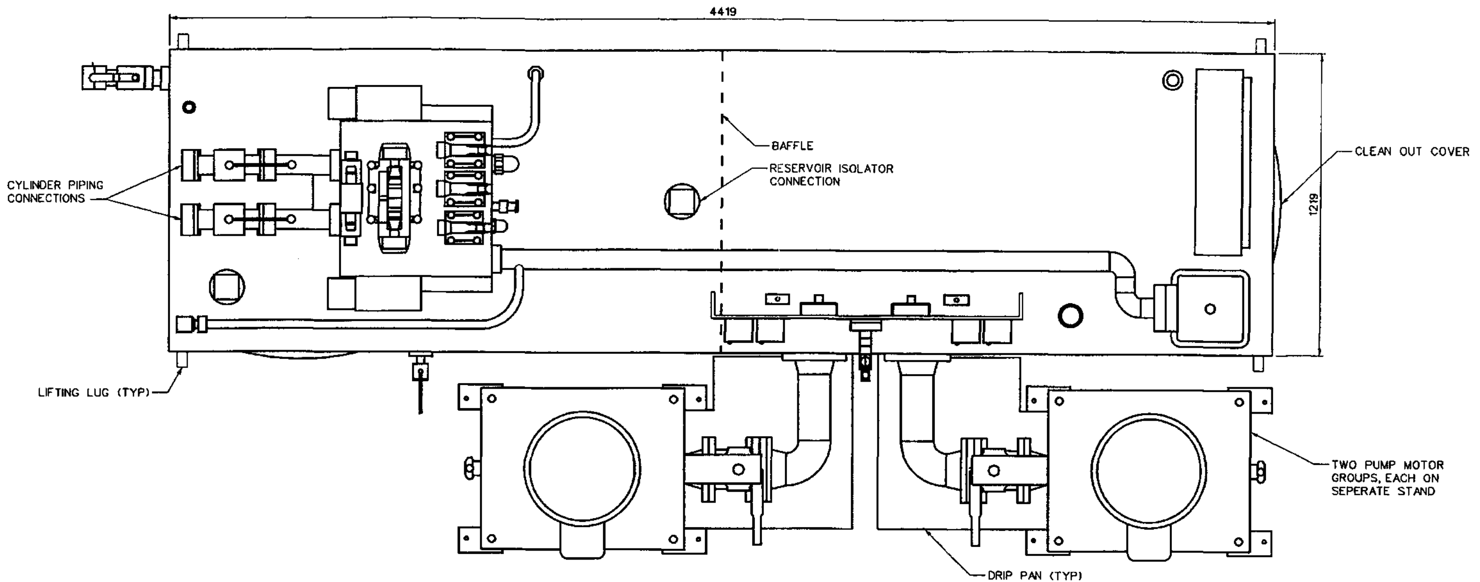
User: Rankoph
Date: 20-OCT-2002 22:42
Plot Scale: 2.7853401:000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
X		X	X

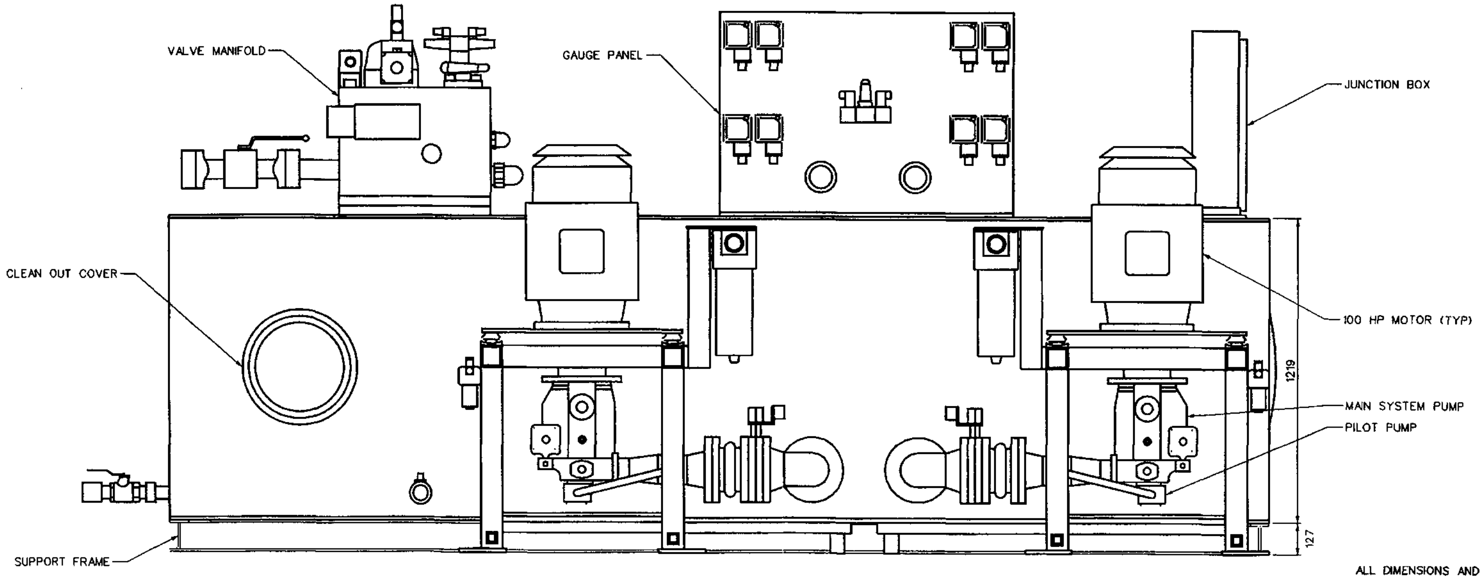
F:\ACP\mech\HPU Schematic_Culvert.s01

PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
CULVERT VALVE OPERATING MACHINERY
HYDRAULIC POWER UNIT
SCHEMATIC DIAGRAM

Drawing Number: ACP-R-28/12



HPU PLAN



HPU SIDE ELEVATION

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Pittsburgh District

Submitted by:
FRANK ZOVACK
SECTION CHIEF

PB NO.:
DACW59

Sheet X of X

Design by:
D. BUCCINI

Dwn by:
PETERS

Ckd by:
X

Submission Date:
OCT 2002

Revision Date:
X

ACP
AUTORIDAD DEL CANAL DE PANAMA

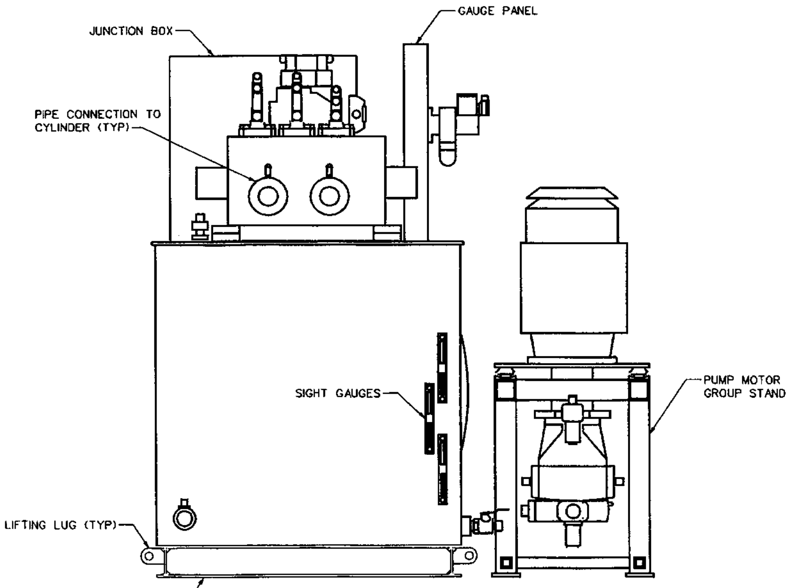
User: Rankosh
Date: 20-OCT-2002 22:42
Plot Scale: 2.715340:1.000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
X	X	X	X

F:\ACP\mech\HPU_Valve.s01

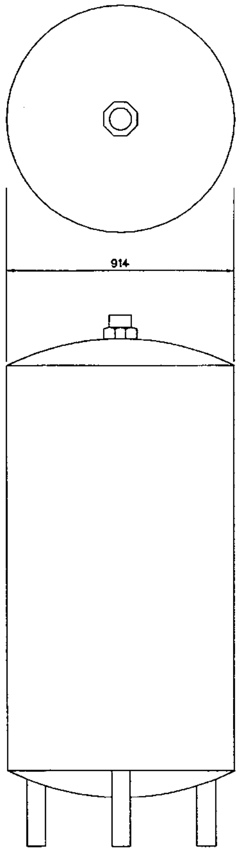
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
VALVE OPERATING MACHINERY
HYDRAULIC POWER UNIT
PLAN AND ELEVATION

Drawing Number:
ACP-R-28/13



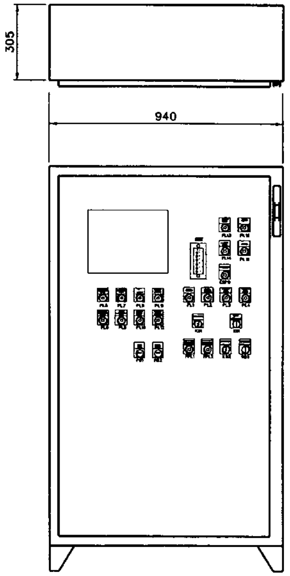
HPU FRONT ELEVATION

SCALE: 1=10



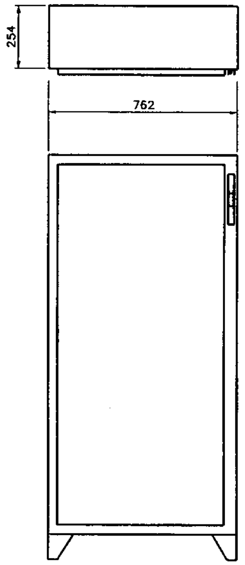
HYDRAULIC RESERVOIR ISOLATOR

SCALE: 1=10



HPU CONTROL ENCLOSURE

SCALE: 1=10



MOTOR STARTER ENCLOSURE

SCALE: 1=10

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US Army Corps
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Pittsburgh District

ACP
AUTORIDAD DEL CANAL DE PANAMA

User: Rankesh
Date: 20-OCT-2002 22:42
Plot Scale: 2.715340:1.000000
Pen Table:
Color Table:

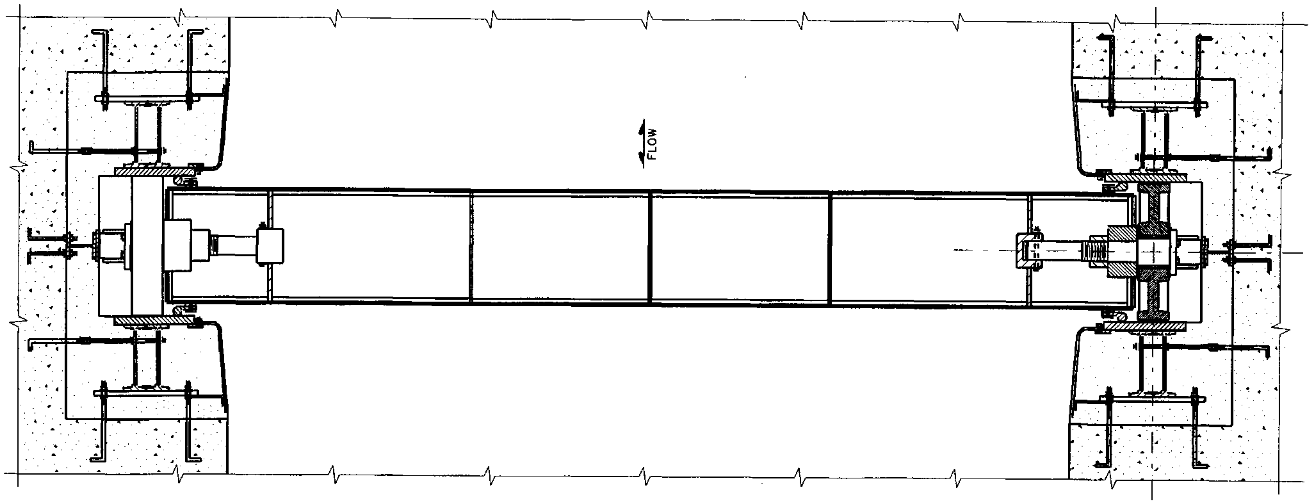
Design by: D. BUCCINI
Dwn by: PETERS
Ckd by: X
Submission Date: OCT 2002
Revision Date: X
Submitted by: FRANK ZOVACK
SECTION CHIEF
PN NO.: DACW59
Sheet X of X

Symbol	Description	Date	Appr.
X	X	X	X

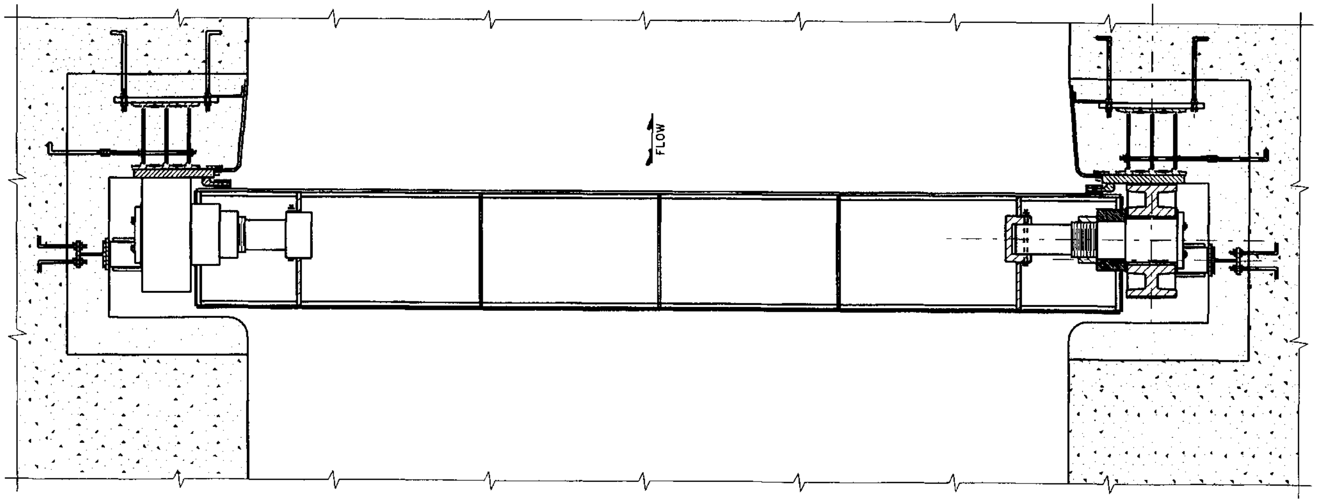
F:\ACP\mech\HPU_Valve frontview.s01

PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
VALVE OPERATING MACHINERY
HYDRAULIC POWER UNIT
DETAILS

Drawing Number: ACP-R-28/14



CONDUIT VALVE WHEELS



CULVERT VALVE WHEELS

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US Army Corps
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Pittsburgh District

Submitted by: FRANK ZOVACK
SECTION CHIEF

FB NO.: DACW59

Sheet X of X

Design by: RPW/DLB

Dwn by: JLF/JJP

Ckd by: X

Submission Date: OCT 2002

Revision Date: X

ACP
AUTORIDAD DEL CANAL DE PANAMA

User: Ronkosh
Date: 20-OCT-2002 22:42
Plot Scale: 2.715340:1.000000
Pen Table:
Color Table:

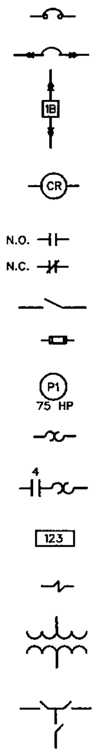
Symbol	Description	Date	Appr.
X	X	X	X

F:\ACP\mech\GateWheels.s01

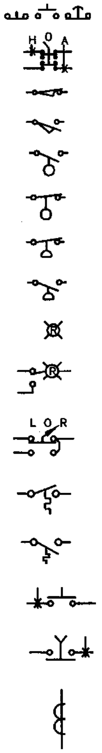
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
VALVE OPERATING MACHINERY
CULVERT AND CONDUIT VALVES
FIXED WHEEL ASSEMBLIES

Drawing Number: ACP-R-28/15

ELECTRICAL SYMBOLS



- CIRCUIT BREAKER - THERMAL MAGNETIC
- CIRCUIT BREAKER - DRAWOUT
- DRAWOUT VACUUM BREAKERS CUBICLE 1B
- COILS
  - CONTROL RELAY - CR
  - MOTOR STARTER - M
- CONTACTS
  - N.O. NORMALLY OPEN CONTACT
  - N.C. NORMALLY CLOSED CONTACT
- NON-FUSIBLE DISCONNECT SWITCH
- FUSE
- PUMP 1 MOTOR - 75 HORSEPOWER
- MOTOR OVERLOAD
- NON-REVERSIBLE STARTER W/OVERLOAD (NUMBER DENOTES NEMA SIZE 4)
- TERMINAL BLOCK (123 - TERMINAL NUMBER (TYP))
- SOLENOID VALVE
- POWER TRANSFORMER
- LOAD BREAK SECTIONALIZING SWITCH



- PUSHBUTTON - NORMALLY CLOSED, NORMALLY OPEN AND MAINTAINED (EMERG. STOP) SHOWN
- LOCAL-OFF-REMOTE 3-POSITION SWITCH
- LIMIT SWITCH, NORMAL CLOSE
- LIMIT SWITCH, NORMAL OPEN
- FLOAT SWITCH, NORMAL OPEN
- FLOAT SWITCH, NORMAL CLOSE
- PRESSURE SWITCH, NORMAL CLOSE
- PRESSURE SWITCH, NORMAL OPEN
- LIGHT - INDICATOR (PILOT), R-RED, G-GREEN, W-WHITE, A-AMBER. BOTH SYMBOLS INDICATE PUSH-TO TEST LIGHTS
- LIGHT - INDICATOR (PILOT), R-RED, G-GREEN, W-WHITE, A-AMBER. BOTH SYMBOLS INDICATE PUSH-TO TEST LIGHTS
- LOCAL-OFF-REMOTE 3 POSITION SELECTOR SWITCH
- THERMAL SWITCH - NORMALLY CLOSED
- THERMAL SWITCH - NORMALLY OPEN
- PUSHBUTTON, MOMENTARY
- TWO-POSITION SELECTOR SWITCH
- CURRENT TRANSFORMER

ABBREVIATIONS

A	AMPERE	LED	LIGHT EMITTING DIODE CLUSTER LAMP
AC	ALTERNATING CURRENT	LS	LIMIT SWITCH (PROXIMITY TYPE)
AFF	ABOVE FINISHED FLOOR	LP	LIGHTING PANELBOARD
AI	ANALOG INPUT	LTG	LIGHTING
AIC	AMPERE INTERRUPTING CAPACITY	MFR	MANUFACTURER
AO	ANALOG OUTPUT	MIN	MINIMUM
AUX	AUXILIARY	N, NTRL	NEUTRAL
AWG	AMERICAN WIRE GAUGE	NC, NO	NORMALLY CLOSED, NORMALLY OPEN
BKR	BREAKER	NF	NOT FUSED
BLDG	BUILDING	NTS	NOT TO SCALE
C	CONDUIT	OIT	OPERATOR INTERFACE TERMINAL
CB	CIRCUIT BREAKER	OL	OVERLOAD
CKT	CIRCUIT	P	POLE
CNTRL	CONTROL	PB	PUSH BUTTON
CP	CONTROL PANEL	IPC	INDUSTRIAL PERSONAL COMPUTER
CSPE	CHLOROSULFINATED POLYETHYLENE	PH	PHASE
CT	CURRENT TRANSFORMER	PNL	PANEL
CU	COPPER	POS	POSITIVE
DC	DIRECT CURRENT	POT	POTENTIOMETER
DI	DIGITAL INPUT	PR	PAIR
DIA	DIAMETER	PS	POWER SUPPLY
DO	DIGITAL OUTPUT	PL	PILOT LIGHT
DISC. SW.	DISCONNECT SWITCH	PLC	PROGRAMMABLE LOGIC CONTROLLER
D/S OR D.S	DOWNSTREAM	PPL	PUSH/PULL PUSHBUTTON WITH PILOT LIGHT
DWG	DRAWING	PS1	PRESSURE SWITCH 1
EL	ELEVATION	PVC	POLYVINYL CHLORIDE
EPR	ETHYLENE-PROPYLENE RUBBER	PWR	POWER TERMINAL
ESPB	EMERGENCY STOP PUSHBUTTON	RGS	RIGID GALVANIZED STEEL CONDUIT
FB	FUSE BOX	RTN	RETURN TERMINAL
FCBN	FULL CAPACITY BELOW NORMAL	RT	RETURN TRACK
FDR	FEEDER	SH, SHLD	SHIELDED
FL	FLOOR	SOL	SOLENOID OPERATOR VALVE
FS	FLOAT SWITCH	SS	SELECTOR SWITCH
FU	FUSE	SW	SWITCH
FVNR	FULL VOLTAGE NON REVERSING	T, XFMR	TRANSFORMER
GALV	GALVINIZED	TB	TERMINAL BLOCK
GEN	GENERATOR	TFT	THIN FILM TRANSISTOR
GFI	GROUND FAULT CIRCUIT INTERRUPTER	TH	THERMOSTAT
G/GND/GRD	GROUND	TPDT	THREE POLE, DOUBLE THROW SW.
HOA	HAND-OFF-AUTOMATIC	TR	TRANSFORMER ROOM
HP	HORSEPOWER	TT	TOW TRACK
HPU	HYDRAULIC POWER UNIT	TYP	TYPICAL
I/O	INPUT/OUTPUT	UL	UNDERWRITERS LABORATORIES
JB	JUNCTION BOX	V	VOLTS
KS	KEY SWITCH	VAC	VOLTS ALTERNATING CURRENT
KVA	KILOVOLT AMPS	VDC	VOLTS DIRECT CURRENT
KW	KILOWATT	W	WATTS
L	LINE, POWER	WP	WEATHERPROOF

NOTES:
1. ADDITIONAL SYMBOLS MAY BE IDENTIFIED WITHIN THE DRAWING SET.

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Ckd by: X
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Sheet X of X

ACP
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Date: 20-OCT-2002 22:42
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Symbol	Description	Date	Appr.
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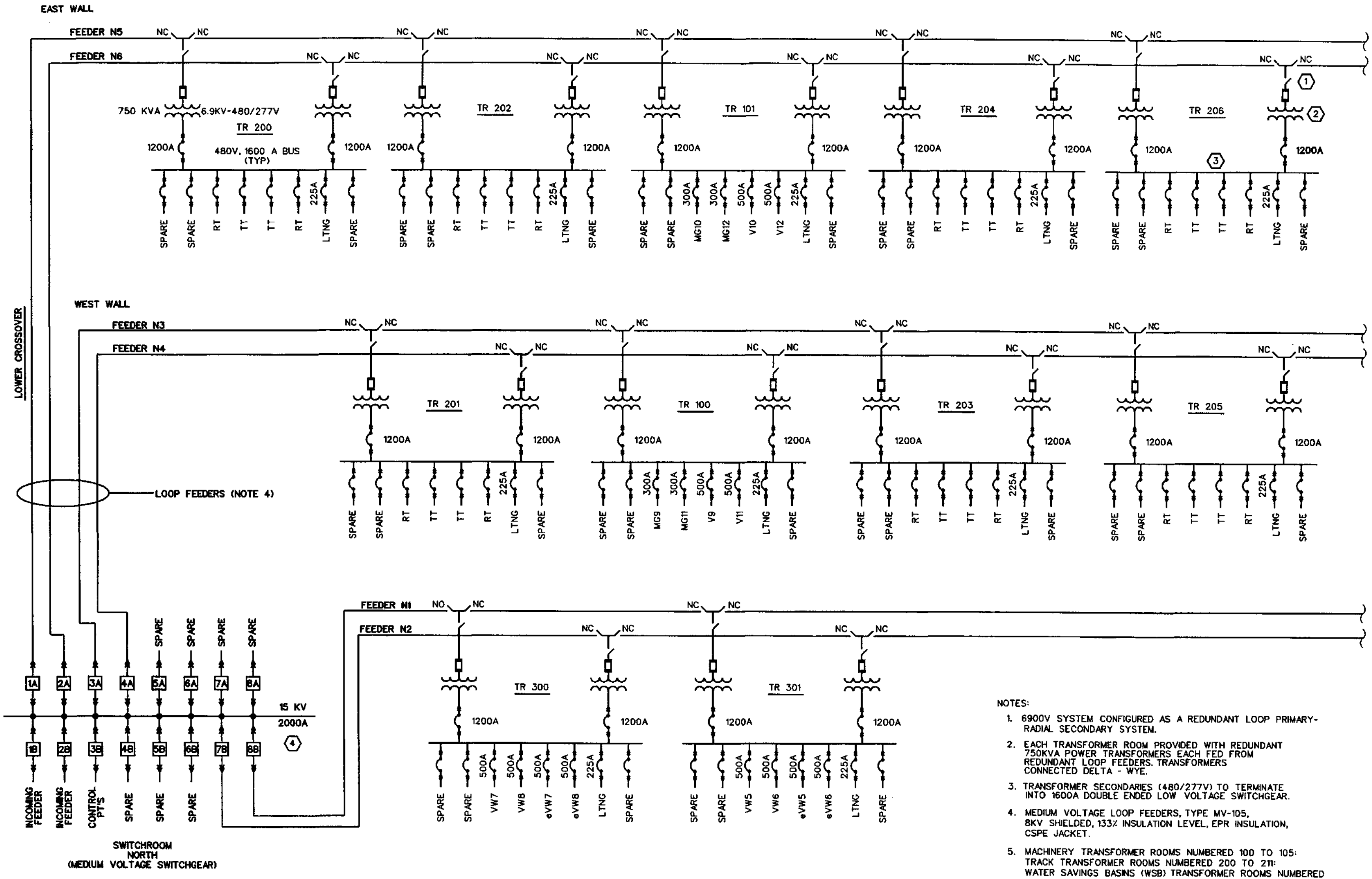
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
SYMBOLS AND ABBREVIATIONS

Drawing Number:
ACP-R-29/1



ONE LINE DIAGRAM

NO SCALE

NOTES:

1. 6900V SYSTEM CONFIGURED AS A REDUNDANT LOOP PRIMARY-RADIAL SECONDARY SYSTEM.
2. EACH TRANSFORMER ROOM PROVIDED WITH REDUNDANT 750KVA POWER TRANSFORMERS EACH FED FROM REDUNDANT LOOP FEEDERS. TRANSFORMERS CONNECTED DELTA - WYE.
3. TRANSFORMER SECONDARIES (480/277V) TO TERMINATE INTO 1600A DOUBLE ENDED LOW VOLTAGE SWITCHGEAR.
4. MEDIUM VOLTAGE LOOP FEEDERS, TYPE MV-105, 8KV SHIELDED, 133% INSULATION LEVEL, EPR INSULATION, CSPE JACKET.
5. MACHINERY TRANSFORMER ROOMS NUMBERED 100 TO 105: TRACK TRANSFORMER ROOMS NUMBERED 200 TO 211: WATER SAVINGS BASINS (WSB) TRANSFORMER ROOMS NUMBERED 300 TO 303.
6. REFER TO 29/3 FOR ONE LINE EQUIPMENT SCHEDULE.

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Pittsburgh District

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Revision Date: X
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Color Table:

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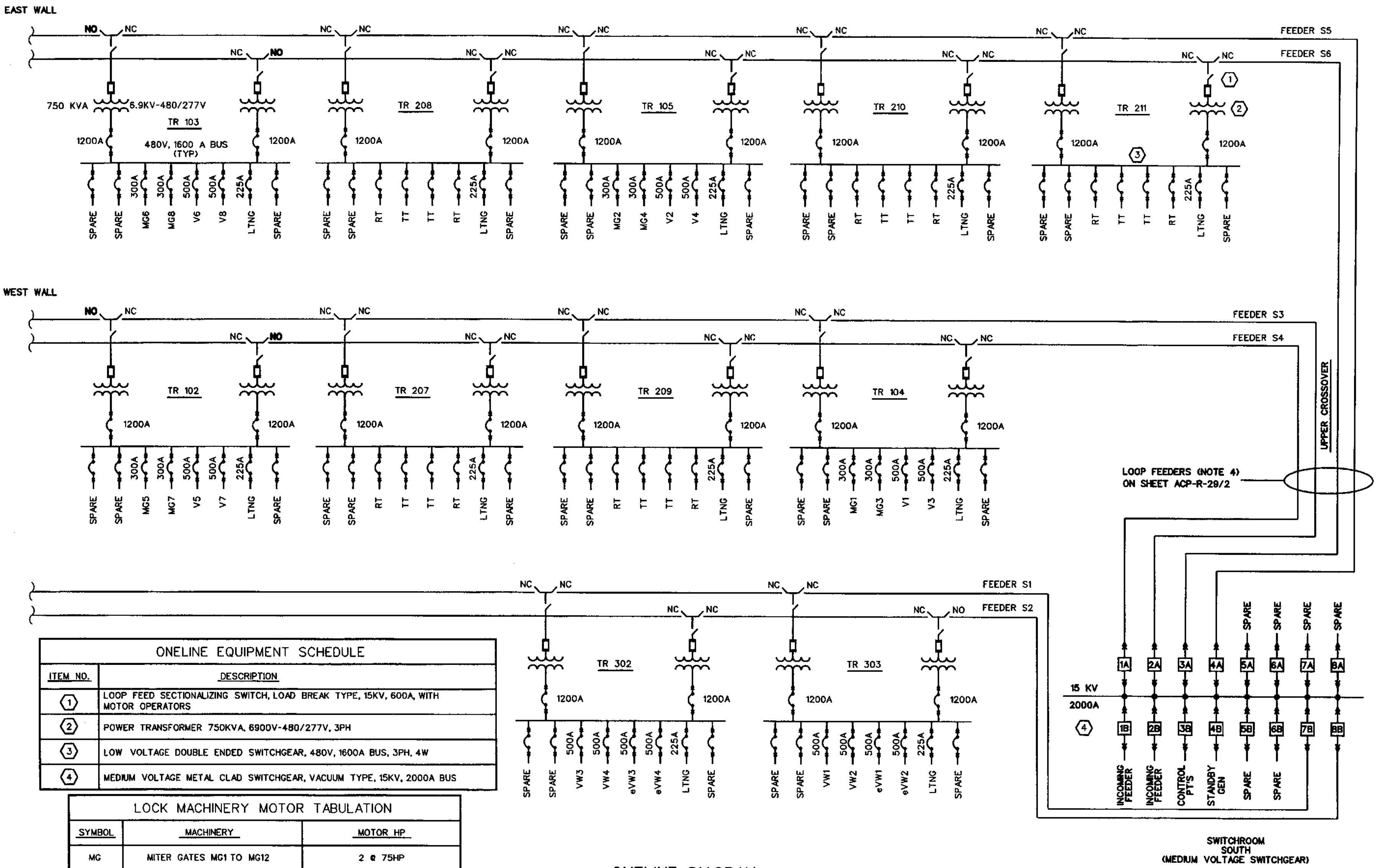
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
ONE-LINE DIAGRAM
LOWER END

Drawing Number:
ACP-R-29/2



ONELINE EQUIPMENT SCHEDULE	
ITEM NO.	DESCRIPTION
①	LOOP FEED SECTIONALIZING SWITCH, LOAD BREAK TYPE, 15KV, 600A, WITH MOTOR OPERATORS
②	POWER TRANSFORMER 750KVA, 6900V-480/277V, 3PH
③	LOW VOLTAGE DOUBLE ENDED SWITCHGEAR, 480V, 1600A BUS, 3PH, 4W
④	MEDIUM VOLTAGE METAL CLAD SWITCHGEAR, VACUUM TYPE, 15KV, 2000A BUS

LOCK MACHINERY MOTOR TABULATION		
SYMBOL	MACHINERY	MOTOR HP
MG	MITER GATES MG1 TO MG12	2 @ 75HP
V	CULVERT VALVE V1 TO V12	2 @ 125HP
VW	CONDUIT VALVES (WSB) VW1 TO VW8	2 @ 125HP
eVW	CONDUIT VALVES (WSB) eVW1 TO eVW8	2 @ 125HP

ONELINE DIAGRAM

NO SCALE

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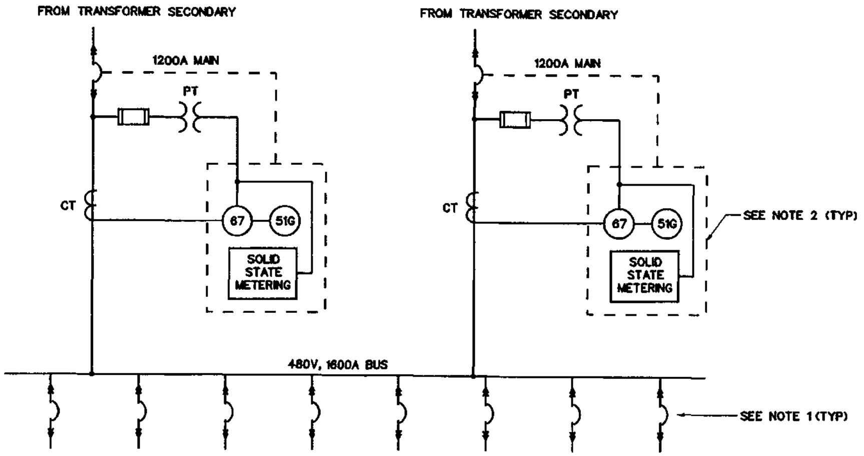
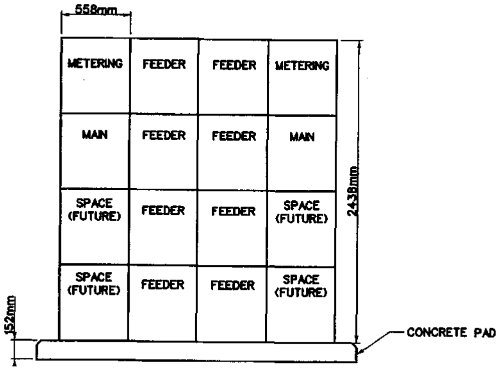
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
ONE-LINE DIAGRAM
UPPER END

Drawing Number:
ACP-R-29/3



ONELINE DIAGRAM

NO SCALE



ELEVATION

NO SCALE

DEVICES

67	DIRECTIONAL OVERCURRENT RELAY
51G	GROUND FAULT PROTECTION

LOW VOLTAGE SWITCHGEAR

NO SCALE

NOTES:

1. ALL FEEDER BREAKERS TO BE PROVIDED WITH DIGITAL TRIP UNITS.
2. MICROPROCESSOR BASED PROTECTION RELAY WITH COMPLETE METERING AND COMMUNICATIONS CAPABILITY FOR CONTROL, ALARMING, AND MONITOR TO BE FURNISHED FOR MAIN BREAKERS.

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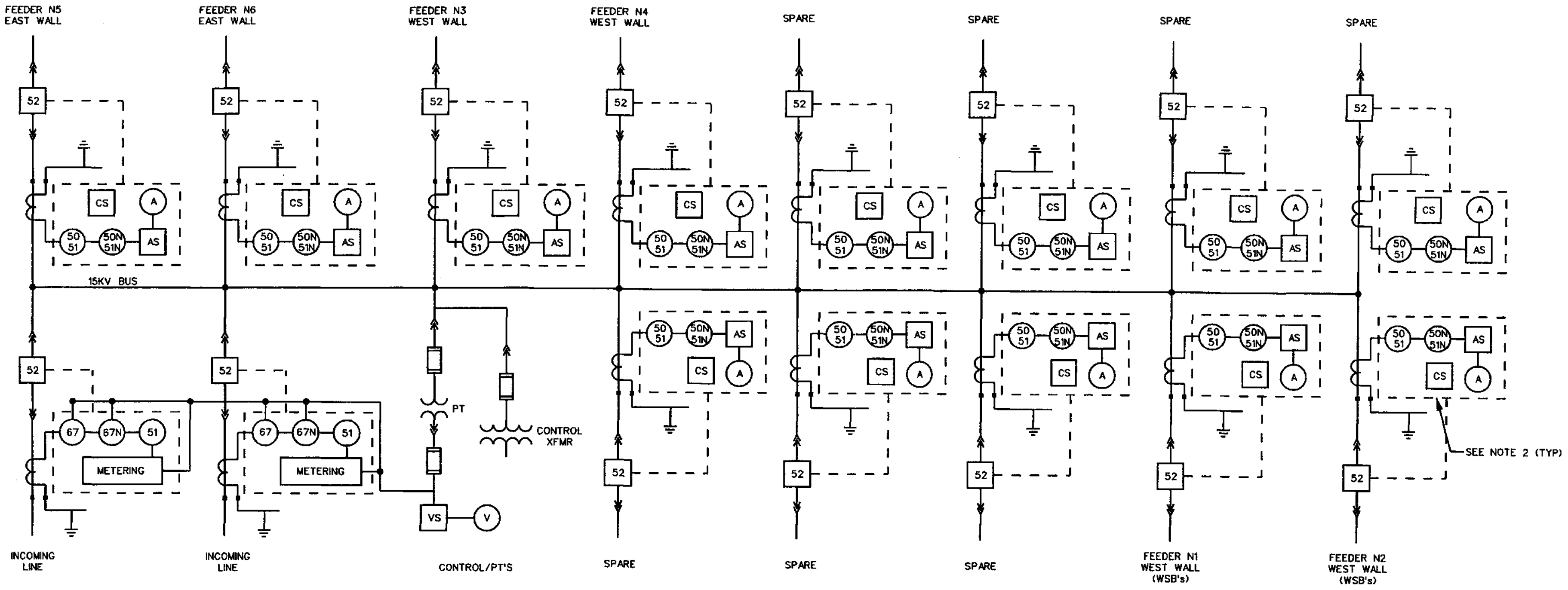
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL DESIGN
LOW VOLTAGE SWITCHGEAR
ONELINE DIAGRAM & ELEVATION

Drawing Number: ACP-R-29/4



ONE-LINE DIAGRAM

(SWITCHROOM NORTH)

LEGEND

DEVICE	
50/51	INSTANTANEOUS AND TIME OVERCURRENT RELAY
50/51N	GROUND OVERCURRENT RELAY
67	DIRECTIONAL OVERCURRENT RELAY
67N	DIRECTIONAL GROUND OVERCURRENT RELAY
52	AC CIRCUIT BREAKER
A	AMMETER
AS	AMMETER SWITCH
CS	CONTROL SWITCH

SWITCHROOM NORTH

CUBICLE NO.	FEEDER NO.	LOAD
1A	N5	EAST WALL TRANSFORMER ROOMS
1B	-	INCOMING FEEDER
2A	N6	EAST WALL TRANSFORMER ROOMS
2B	-	INCOMING FEEDER
3A	N3	WEST WALL TRANSFORMER ROOMS
3B	-	CONTROL AND POTENTIAL TRANSFORMERS
4A	N4	WEST WALL TRANSFORMER ROOMS
4B	-	SPARE
5A	-	SPARE
5B	-	SPARE
6A	-	SPARE
6B	-	SPARE
7A	-	SPARE
7B	N2	WEST WALL (WSB's)
8A	-	SPARE
8B	N1	WEST WALL (WSB's)

NOTES

1. MEDIUM VOLTAGE METAL CLAD SWITCHGEAR, VACUUM TYPE, 15KV, 8 CELL.
2. MICROPROCESSOR BASED RELAYS TO BE FURNISHED FOR ALL INCOMING AND FEEDER BREAKERS. RELAYS TO INCLUDE COMPLETE PROTECTION, METERING AND COMMUNICATIONS CAPABILITY FOR REMOTE CONTROL AND MONITORING IN ONE ASSEMBLY.

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Pittsburgh District

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PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
ONE-LINE DIAGRAM
SWITCHROOM NORTH

Drawing Number:
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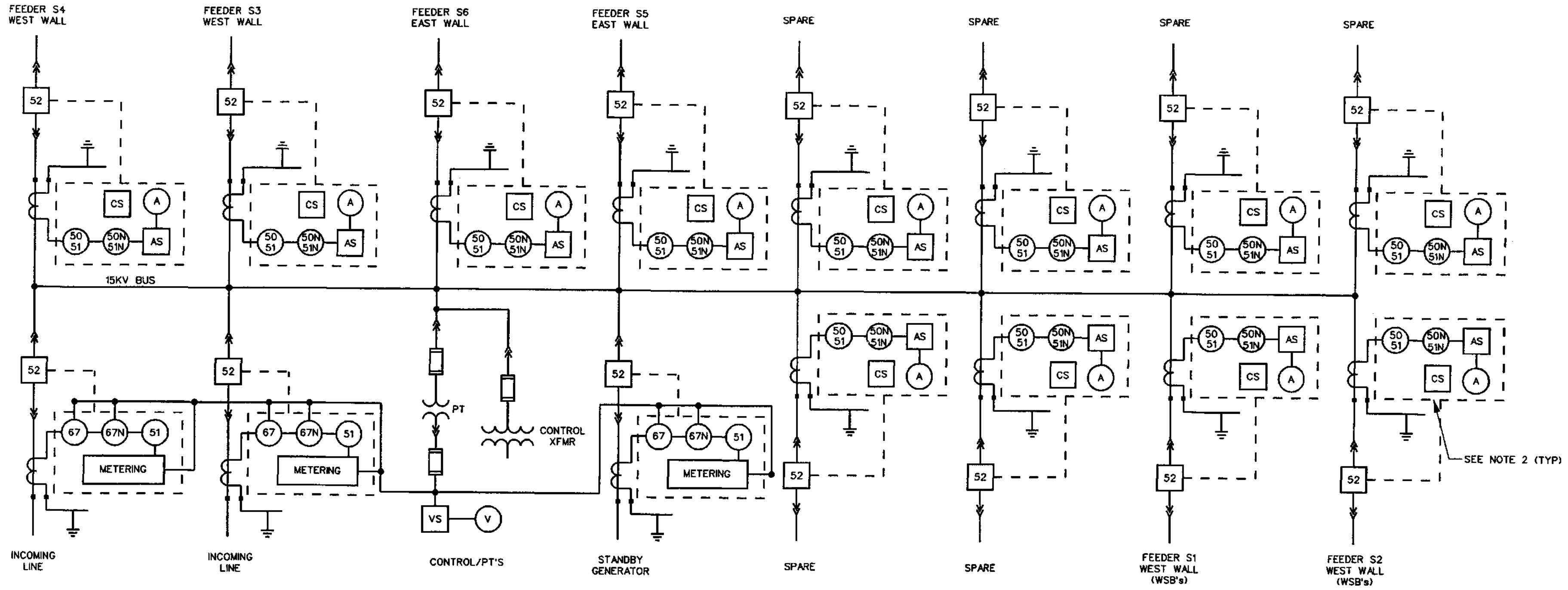

ONE-LINE DIAGRAM

(SWITCHROOM SOUTH)

LEGEND

DEVICE

50/51	INSTANTANEOUS AND TIME OVERCURRENT RELAY
50/51N	GROUND OVERCURRENT RELAY
67	DIRECTIONAL OVERCURRENT RELAY
67N	DIRECTIONAL GROUND OVERCURRENT RELAY
52	AC CIRCUIT BREAKER
A	AMMETER
AS	AMMETER SWITCH
CS	CONTROL SWITCH

SWITCHROOM SOUTH

CUBICLE NO.	FEEDER NO.	LOAD
1A	S4	WEST WALL TRANSFORMER ROOMS
1B	-	INCOMING FEEDER
2A	S3	WEST WALL TRANSFORMER ROOMS
2B	-	INCOMING FEEDER
3A	S6	EAST WALL TRANSFORMER ROOMS
3B	-	CONTROL AND POTENTIAL TRANSFORMERS
4A	S5	EAST WALL TRANSFORMER ROOMS
4B	-	STANDBY GENERATOR
5A	-	SPARE
5B	-	SPARE
6A	-	SPARE
6B	-	SPARE
7A	-	SPARE
7B	S1	WEST WALL (WSB's)
8A	-	SPARE
8B	S2	WEST WALL (WSB's)

NOTES

1. MEDIUM VOLTAGE METAL CLAD SWITCHGEAR, VACUUM TYPE, 15KV, 8 CELL
2. MICROPROCESSOR BASED RELAYS TO BE FURNISHED FOR ALL INCOMING AND FEEDER BREAKERS. RELAYS TO INCLUDE COMPLETE PROTECTION, METERING AND COMMUNICATIONS CAPABILITY FOR REMOTE CONTROL AND MONITOTING IN ONE ASSEMBLY.

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PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
ONE-LINE DIAGRAM
SWITCHROOM SOUTH

Drawing Number:
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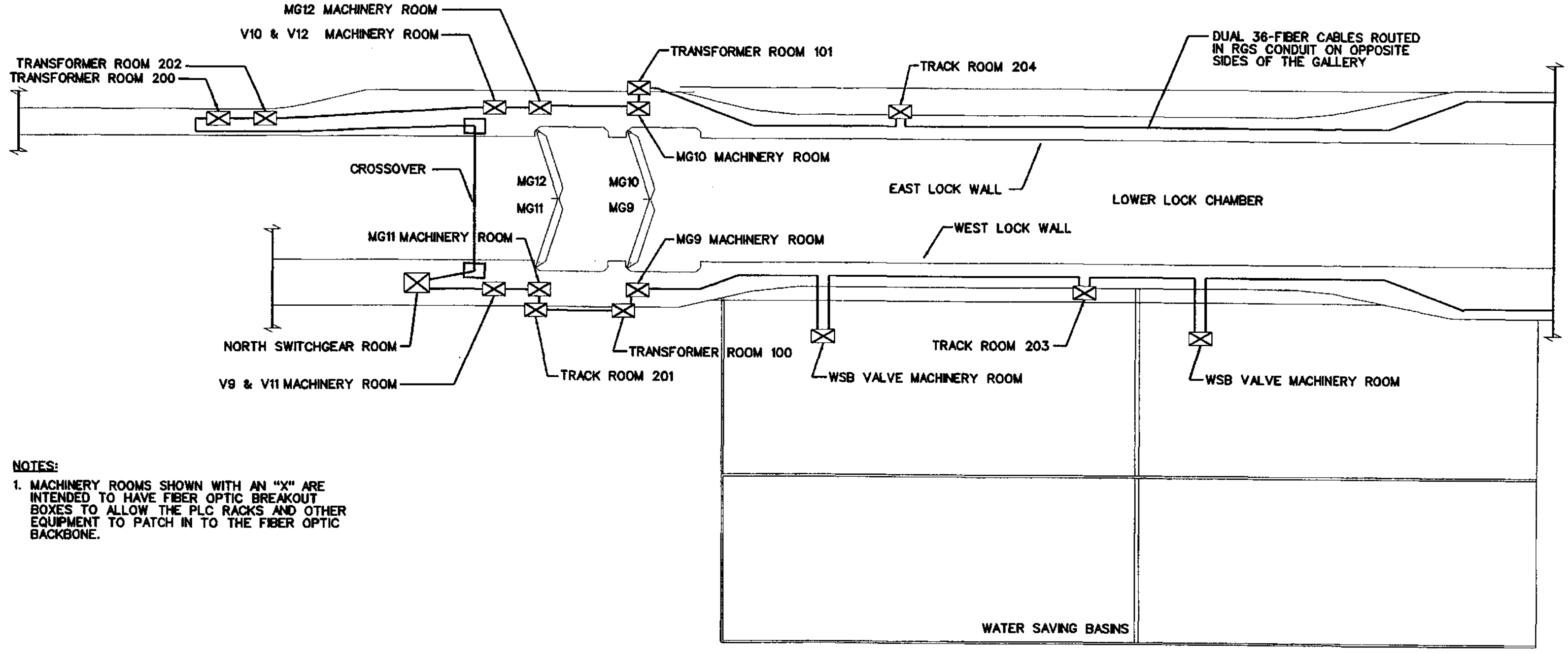

NOTES:

1. MACHINERY ROOMS SHOWN WITH AN "X" ARE INTENDED TO HAVE FIBER OPTIC BREAKOUT BOXES TO ALLOW THE PLC RACKS AND OTHER EQUIPMENT TO PATCH IN TO THE FIBER OPTIC BACKBONE.

LOWER LOCK FIBER OPTIC ARCHITECTURE

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PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
LOWER LOCK FIBER OPTIC ARCHITECTURE

Drawing Number:
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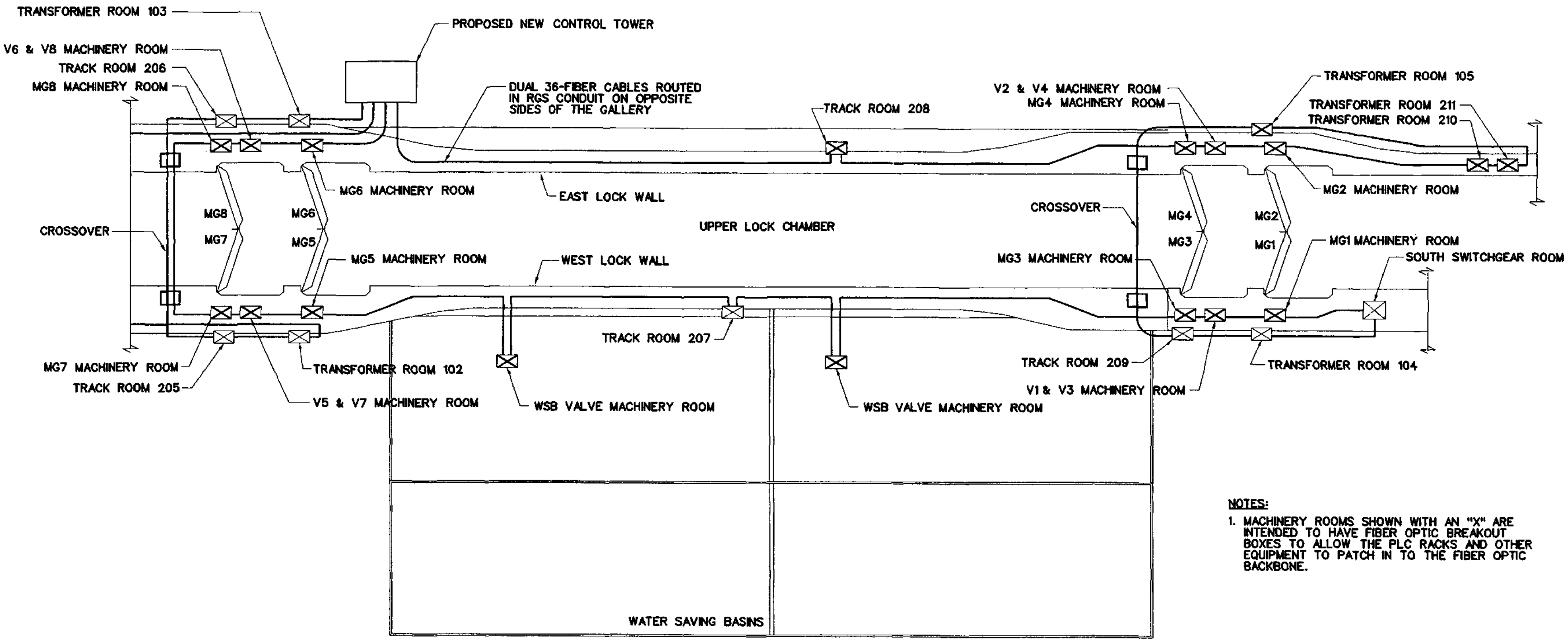

NOTES:

1. MACHINERY ROOMS SHOWN WITH AN "X" ARE INTENDED TO HAVE FIBER OPTIC BREAKOUT BOXES TO ALLOW THE PLC RACKS AND OTHER EQUIPMENT TO PATCH IN TO THE FIBER OPTIC BACKBONE.

UPPER LOCK FIBER OPTIC ARCHITECTURE

US Army Corps
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Pittsburgh District

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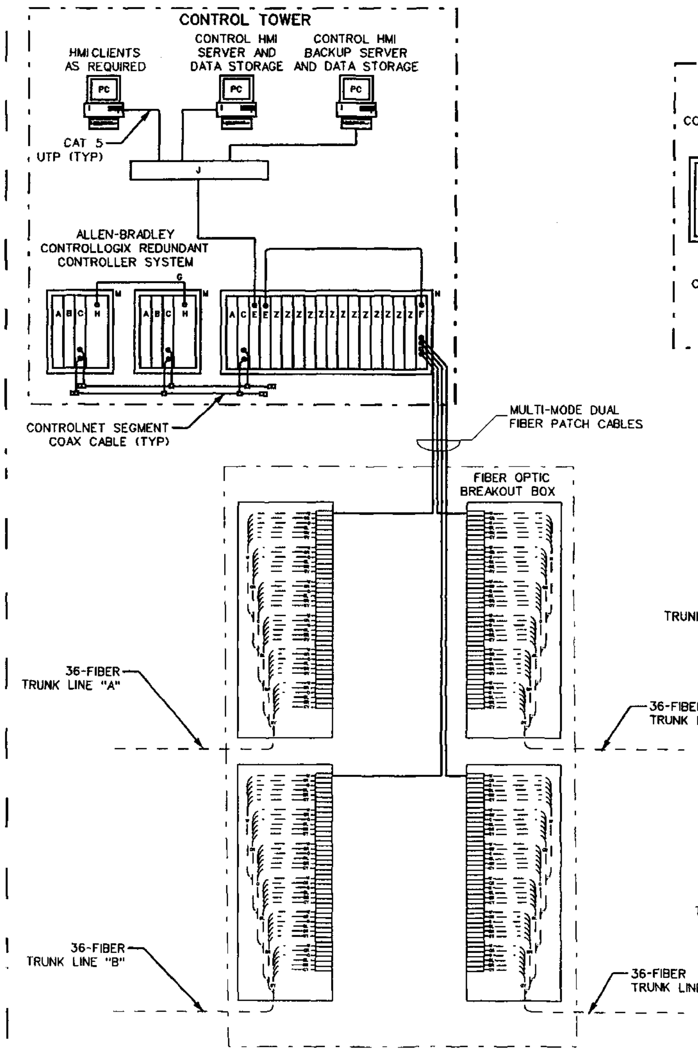
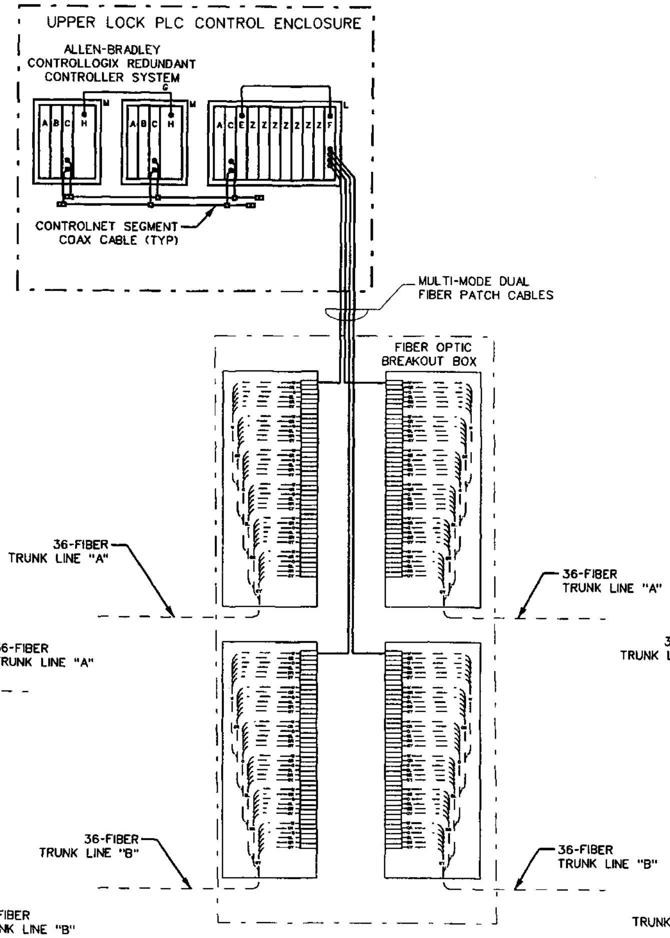
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
UPPER LOCK FIBER OPTIC ARCHITECTURE

Drawing Number:
ACP-R-29/8

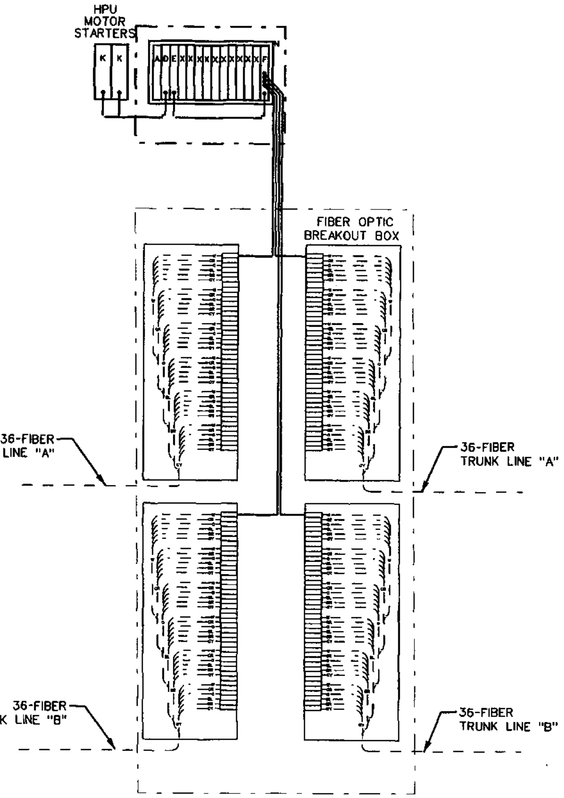


CONTROL HOUSE MAIN
PROCESSOR COMMUNICATION DIAGRAM



TYPICAL REMOTE
PROCESSOR COMMUNICATION DIAGRAM

TYPICAL OF 5 LOCATIONS



TYPICAL REMOTE
RACK COMMUNICATION DIAGRAM

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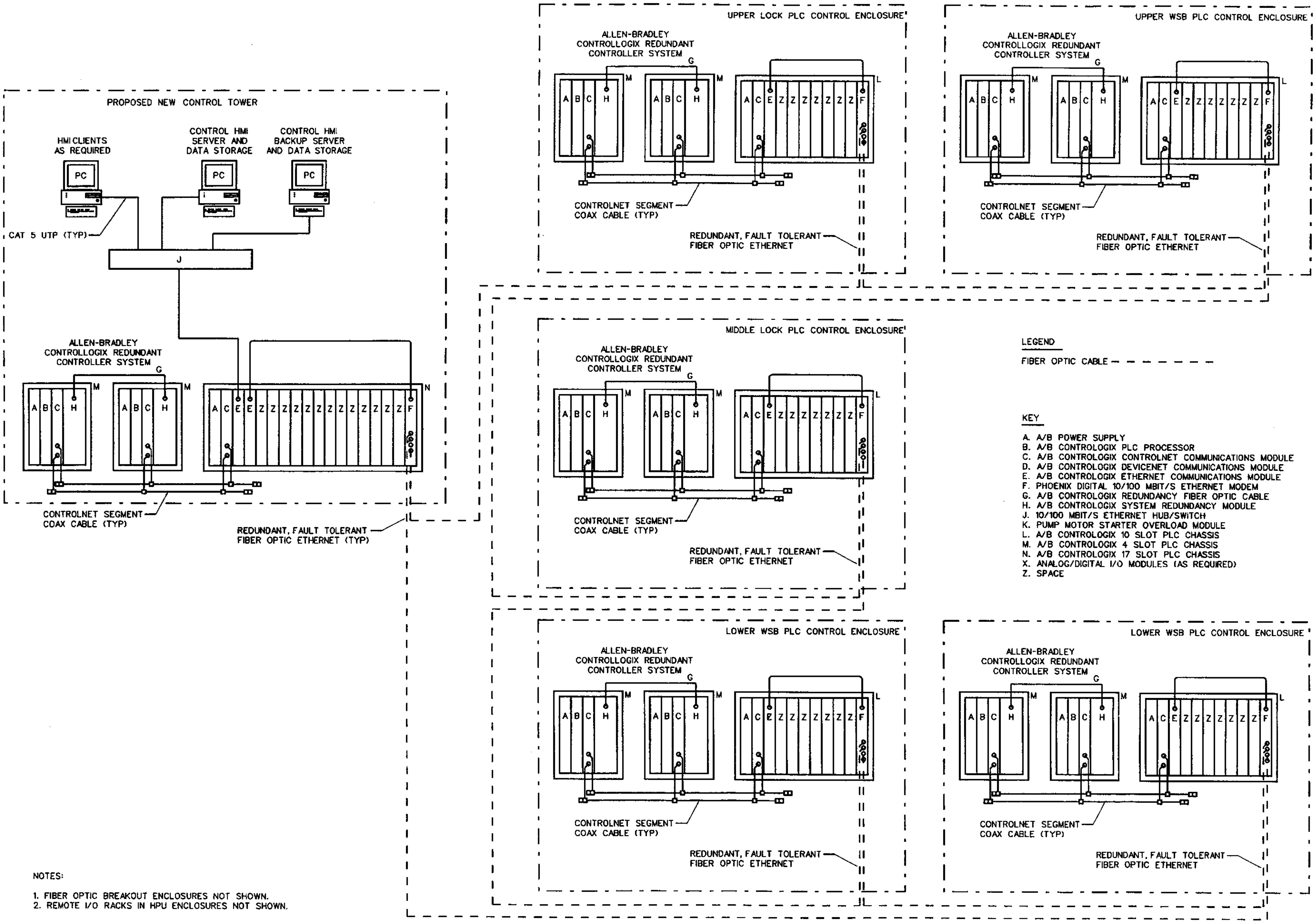
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
PROCESSOR COMMUNICATION DIAGRAMS

Drawing Number:
ACP-R-29/9



LEGEND

FIBER OPTIC CABLE — — — — — —

KEY

A. A/B POWER SUPPLY
B. A/B CONTROLOGIX PLC PROCESSOR
C. A/B CONTROLOGIX CONTROLNET COMMUNICATIONS MODULE
D. A/B CONTROLOGIX DEVICENET COMMUNICATIONS MODULE
E. A/B CONTROLOGIX ETHERNET COMMUNICATIONS MODULE
F. PHOENIX DIGITAL 10/100 MBIT/S ETHERNET MODEM
G. A/B CONTROLOGIX REDUNDANCY FIBER OPTIC CABLE
H. A/B CONTROLOGIX SYSTEM REDUNDANCY MODULE
J. 10/100 MBIT/S ETHERNET HUB/SWITCH
K. PUMP MOTOR STARTER OVERLOAD MODULE
L. A/B CONTROLOGIX 10 SLOT PLC CHASSIS
M. A/B CONTROLOGIX 4 SLOT PLC CHASSIS
N. A/B CONTROLOGIX 17 SLOT PLC CHASSIS
X. ANALOG/DIGITAL I/O MODULES (AS REQUIRED)
Z. SPACE

NOTES:

1. FIBER OPTIC BREAKOUT ENCLOSURES NOT SHOWN.
2. REMOTE I/O RACKS IN HPU ENCLOSURES NOT SHOWN.

PLC CONTROL SYSTEM NETWORK ARCHITECTURE

NO SCALE

US Army Corps
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Pittsburgh District

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Revision Date: X
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Sheet X of X

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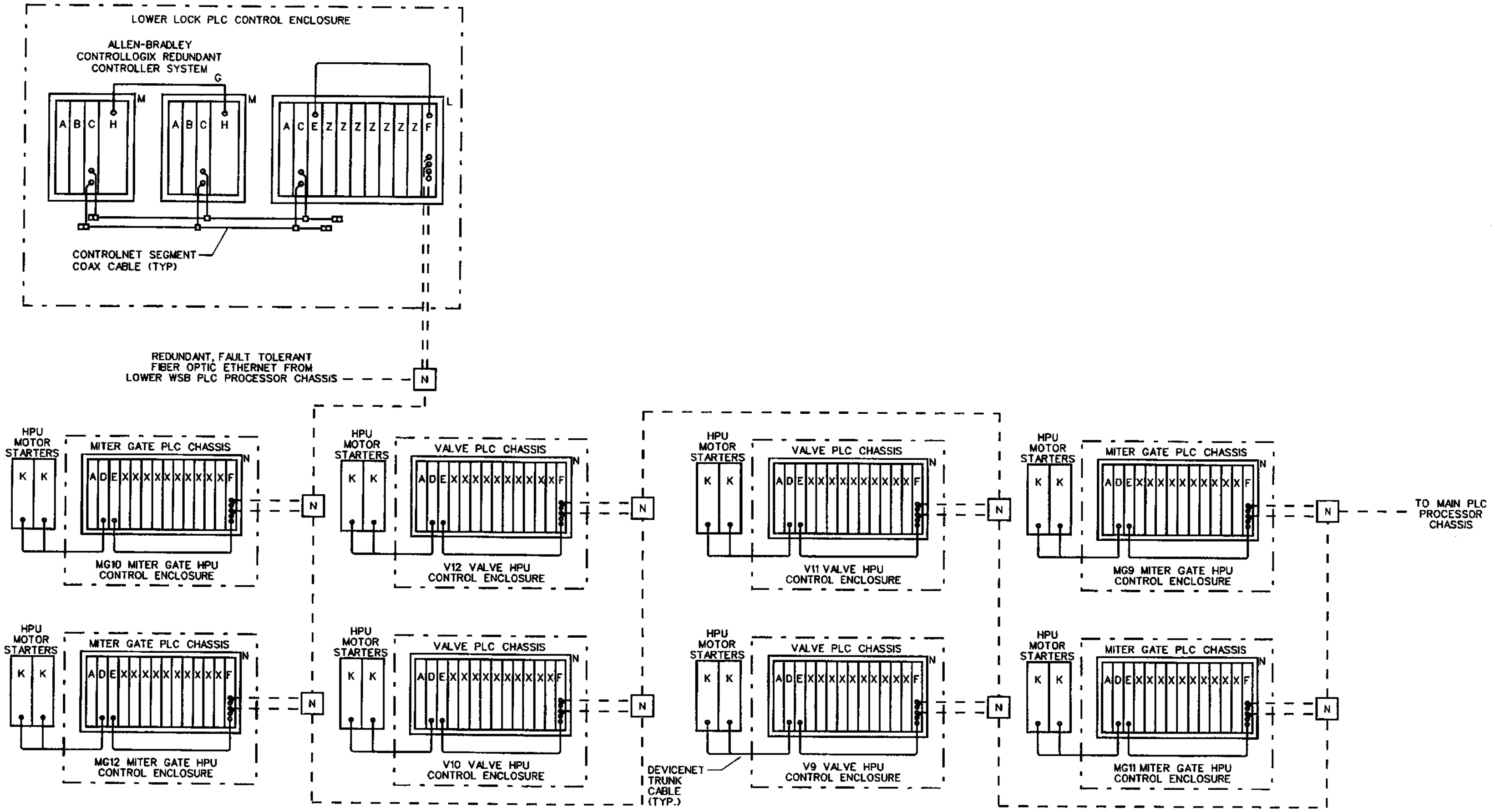
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
PLC CONTROL SYSTEM NETWORK ARCHITECTURE

Drawing Number:
ACP-R-29/10



KEY ⟨1⟩

A. POWER SUPPLY
B. PLC CONTROLLOGIX PROCESSOR
C. CONTROLNET COMMUNICATIONS MODULE
D. DEVICENET COMMUNICATIONS MODULE
E. ETHERNET COMMUNICATIONS MODULE
F. PHOENIX DIGTIAL 10/100 MBIT/S ETHERNET MODEM
G. REDUNDANCY FIBER OPTIC CABLE
H. SYSTEM REDUNDANCY MODULE
K. PUMP MOTOR STARTER
L. 10 SLOT PLC CHASSIS
M. 4 SLOT PLC CHASSIS
N. 13 SLOT PLC CHASSIS
P. FIBER OPTIC CABLE BREAKOUT ENCLOSURE
X. ANALOG/DIGITAL I/O MODULES (AS REQUIRED)
Z. SPACE

LOWER LOCK PLC CONTROL SYSTEM NETWORK ARCHITECTURE

NO SCALE

LEGEND

FIBER OPTIC CABLE — — — — — — —

CAT 5 UTP CABLE ————————

⟨1⟩NOTES:

1. ALL PLC EQUIPMENT SHOWN IS BASED ON ALLEN-BRADLEY CONTROLLOGIX PLATFORM UNLESS NOTED.
2. ALL FIBER OPTIC BREALOUT ENCLOSURES AND LOCATIONS ARE NOT SHOWN.

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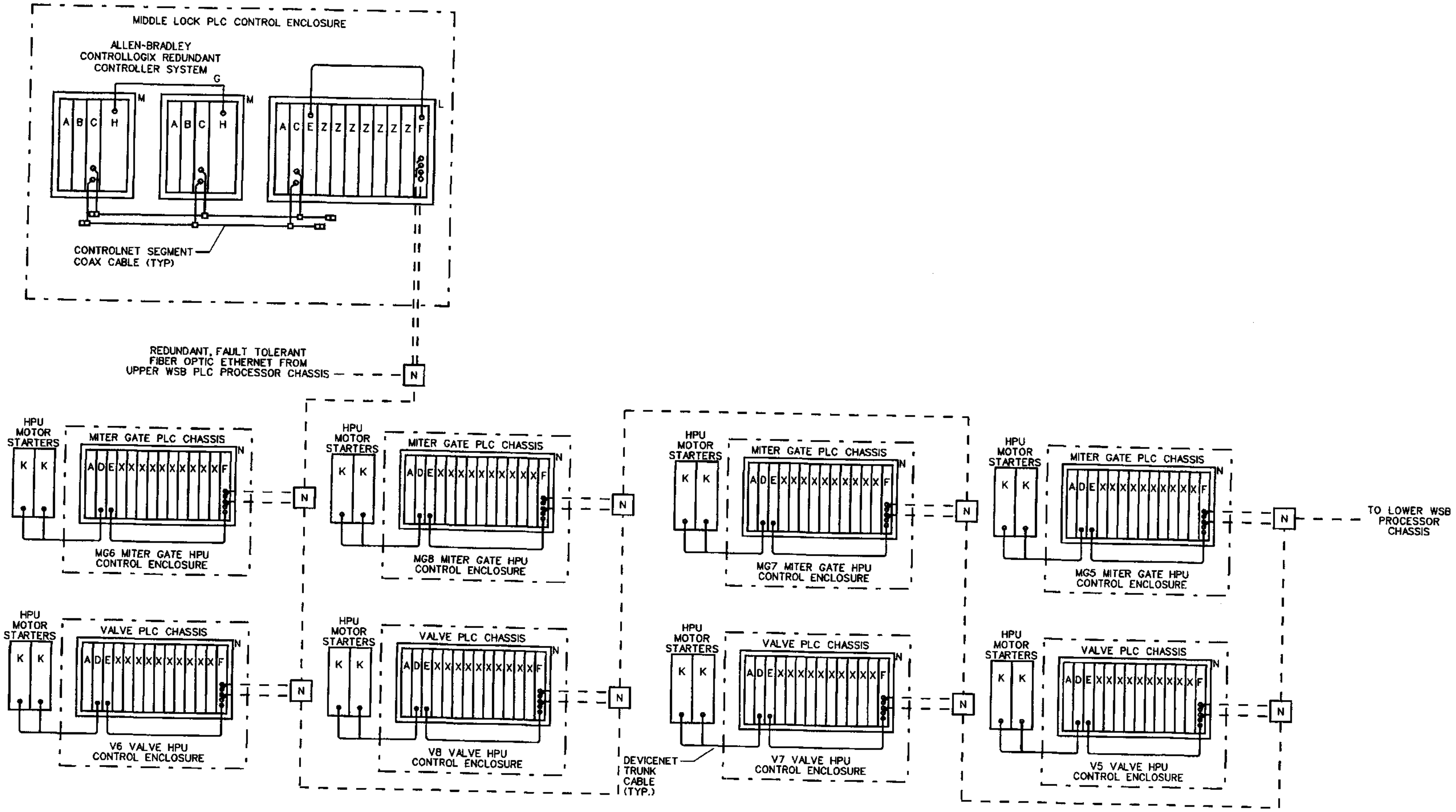
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
LOWER LOCK PLC
CONTROL SYSTEM NETWORK ARCHITECTURE

Drawing Number:
ACP-R-29/11



KEY ◊1

A. POWER SUPPLY
B. PLC CONTROLLOGIX PROCESSOR
C. CONTROLNET COMMUNICATIONS MODULE
D. DEVICENET COMMUNICATIONS MODULE
E. ETHERNET COMMUNICATIONS MODULE
F. PHOENIX DIGTIAL 10/100 MBIT/S ETHERNET MODEM
G. REDUNDANCY FIBER OPTIC CABLE
H. SYSTEM REDUNDANCY MODULE
K. PUMP MOTOR STARTER
L. 10 SLOT PLC CHASSIS
M. 4 SLOT PLC CHASSIS
N. 13 SLOT PLC CHASSIS
P. FIBER OPTIC CABLE BREAKOUT ENCLOSURE
X. ANALOG/DIGITAL I/O MODULES (AS REQUIRED)
Z. SPACE

MIDDLE LOCK PLC CONTROL SYSTEM NETWORK ARCHITECTURE

NO SCALE

LEGEND

FIBER OPTIC CABLE - - - - - - -

CAT 5 UTP CABLE ————————

◊NOTES:

1. ALL PLC EQUIPMENT SHOWN IS BASED ON ALLEN-BRADLEY CONTROLLOGIX PLATFORM UNLESS NOTED.
2. ALL FIBER OPTIC BREAKOUT ENCLOSURES AND LOCATIONS ARE NOT SHOWN.

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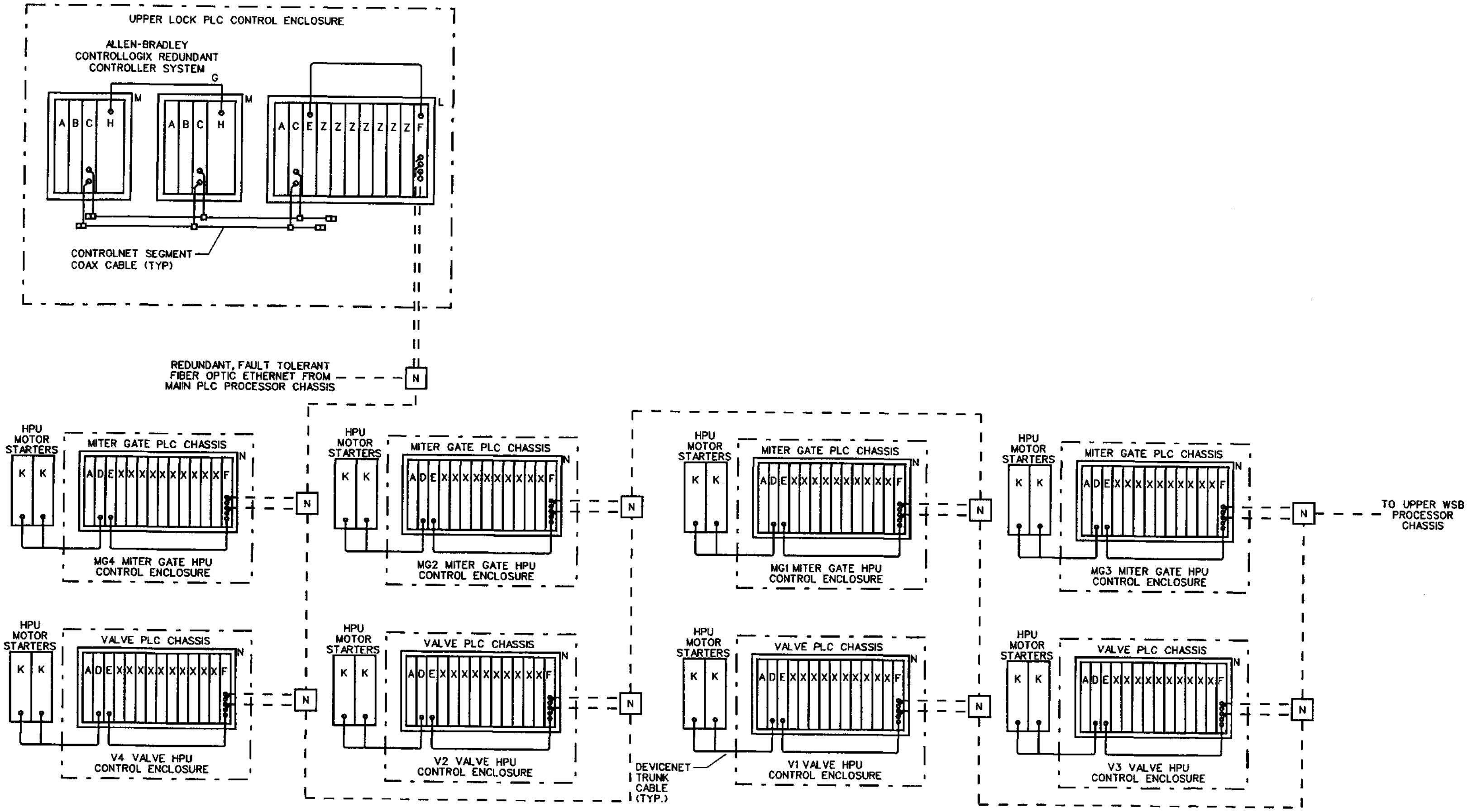
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
MIDDLE LOCK PLC
CONTROL SYSTEM NETWORK ARCHITECTURE

Drawing Number:
ACP-R-29/12



UPPER LOCK PLC CONTROL SYSTEM NETWORK ARCHITECTURE

NO SCALE

KEY ◊1

A. POWER SUPPLY
B. PLC CONTROLLOGIX PROCESSOR
C. CONTROLNET COMMUNICATIONS MODULE
D. DEVICENET COMMUNICATIONS MODULE
E. ETHERNET COMMUNICATIONS MODULE
F. PHOENIX DIGTIAL 10/100 MBIT/S ETHERNET MODEM
G. REDUNDANCY FIBER OPTIC CABLE
H. SYSTEM REDUNDANCY MODULE
K. PUMP MOTOR STARTER
L. 10 SLOT PLC CHASSIS
M. 4 SLOT PLC CHASSIS
N. 13 SLOT PLC CHASSIS
P. FIBER OPTIC CABLE BREAKOUT ENCLOSURE
X. ANALOG/DIGITAL I/O MODULES (AS REQUIRED)
Z. SPACE

LEGEND

FIBER OPTIC CABLE – – – – – – –

CAT 5 UTP CABLE ————

◊ NOTES:

1. ALL PLC EQUIPMENT SHOWN IS BASED ON ALLEN-BRADLEY CONTROLLOGIX PLATFORM UNLESS NOTED.
2. ALL FIBER OPTIC BREAKOUT ENCLOSURES AND LOCATIONS ARE NOT SHOWN.

US Army Corps
of Engineers
Pittsburgh District

Submitted by: X
SECTION CHIEF
Design by: X
Dwn by: X
Ckd by: X
Submission Date: X
Revision Date: X
DB NO.: DACW59
Sheet X of X

ACP
AUTORIDAD DEL CANAL DE PANAMÁ

User: jbenkosh
Date: 20-OCT-2002 22:42
Plot Scale: 2.7162261:1.000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
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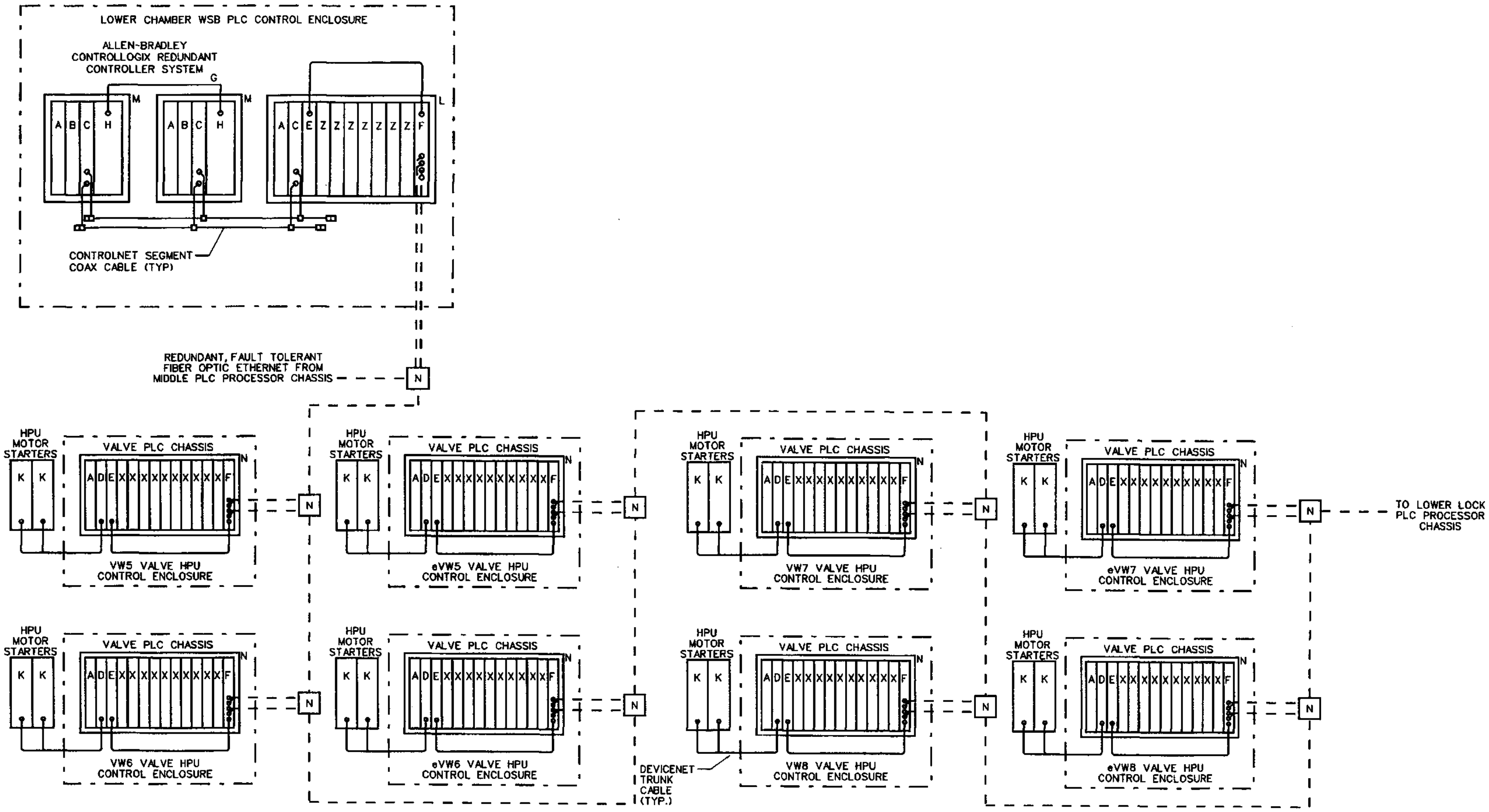
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
UPPER LOCK PLC
CONTROL SYSTEM NETWORK ARCHITECTURE

Drawing Number:
ACP-R-29/13



KEY ◊1

A. POWER SUPPLY
B. PLC CONTROLLOGIX PROCESSOR
C. CONTROLNET COMMUNICATIONS MODULE
D. DEVICENET COMMUNICATIONS MODULE
E. ETHERNET COMMUNICATIONS MODULE
F. PHOENIX DIGTIAL 10/100 MBIT/S ETHERNET MODEM
G. REDUNDANCY FIBER OPTIC CABLE
H. SYSTEM REDUNDANCY MODULE
K. PUMP MOTOR STARTER
L. 10 SLOT PLC CHASSIS
M. 4 SLOT PLC CHASSIS
N. 13 SLOT PLC CHASSIS
P. FIBER OPTIC CABLE BREAKOUT ENCLOSURE
X. ANALOG/DIGITAL I/O MODULES (AS REQUIRED)
Z. SPACE

LOWER CHAMBER WSB VALVE PLC CONTROL SYSTEM NETWORK ARCHITECTURE

NO SCALE

LEGEND

FIBER OPTIC CABLE — — — — — —

CAT 5 UTP CABLE ————————

◊NOTES:

1. ALL PLC EQUIPMENT SHOWN IS BASED ON ALLEN-BRADLEY CONTROLLOGIX PLATFORM UNLESS NOTED.
2. ALL FIBER OPTIC BREAKOUT ENCLOSURES AND LOCATIONS ARE NOT SHOWN.

US Army Corps
of Engineers
Pittsburgh District

Submitted by: X
SECTION CHIEF

Design by: X
Dwn by: X
Ckd by: X
Submission Date: X
Revision Date: X
IFB NO.: DACW59
Sheet X of X

ACP
AUTORIDAD DEL CANAL DE PANAMA
User: jkantosh
Date: 20-OCT-2002 22:42
Plot Scale: 2.7162261.000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
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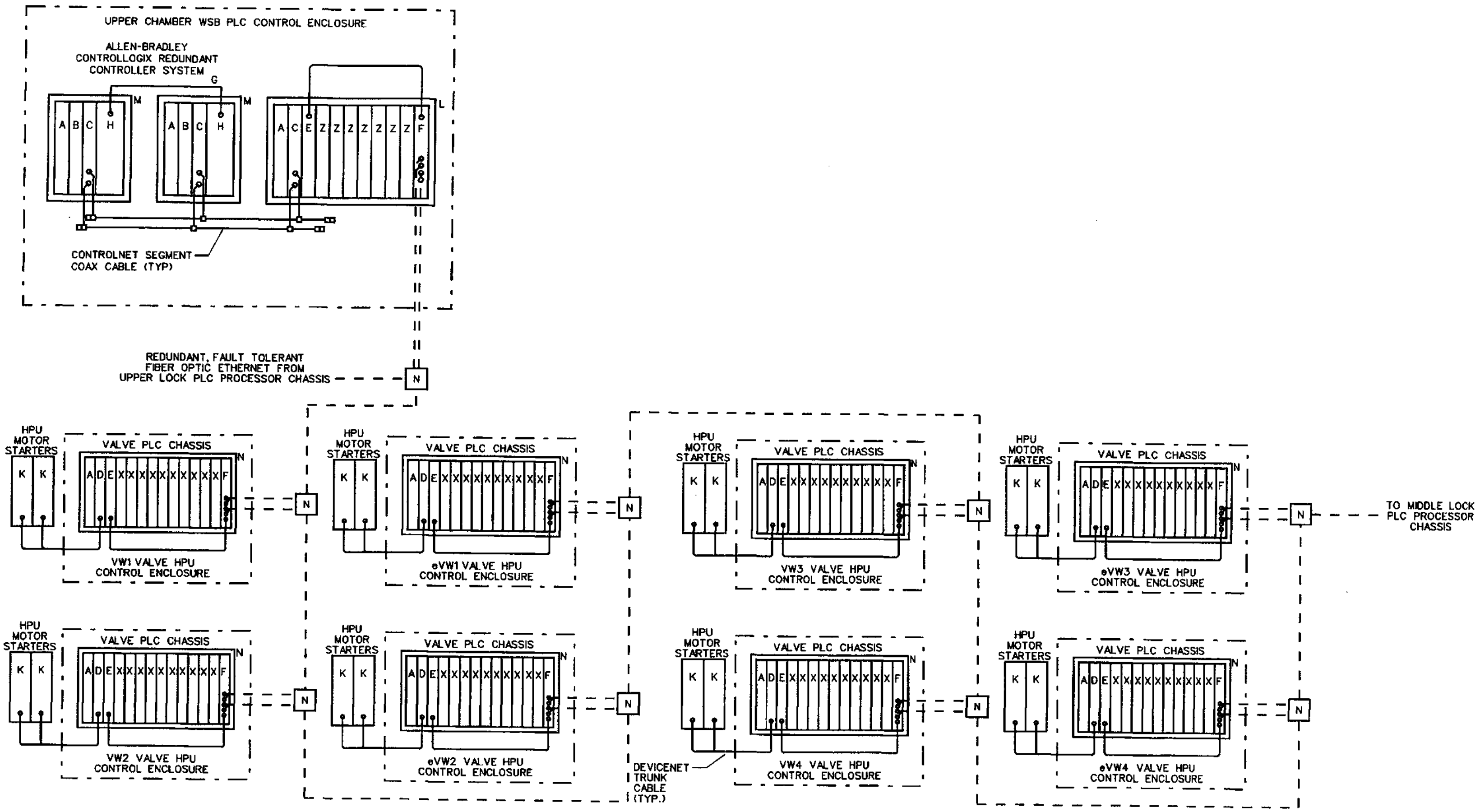
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
LOWER CHAMBER WSB VALVE PLC
CONTROL SYSTEM NETWORK ARCHITECTURE

Drawing Number:
ACP-R-29/14



KEY ◇1

A. POWER SUPPLY
B. PLC CONTROLLOGIX PROCESSOR
C. CONTROLNET COMMUNICATIONS MODULE
D. DEVICENET COMMUNICATIONS MODULE
E. ETHERNET COMMUNICATIONS MODULE
F. PHOENIX DIGTIAL 10/100 MBIT/S ETHERNET MODEM
G. REDUNDANCY FIBER OPTIC CABLE
H. SYSTEM REDUNDANCY MODULE
K. PUMP MOTOR STARTER
L. 10 SLOT PLC CHASSIS
M. 4 SLOT PLC CHASSIS
N. 13 SLOT PLC CHASSIS
P. FIBER OPTIC CABLE BREAKOUT ENCLOSURE
X. ANALOG/DIGITAL I/O MODULES (AS REQUIRED)
Z. SPACE

UPPER CHAMBER WSB VALVE PLC CONTROL SYSTEM NETWORK ARCHITECTURE

NO SCALE

LEGEND

FIBER OPTIC CABLE – – – – – – –

CAT 5 UTP CABLE ————————

◇ NOTES:

1. ALL PLC EQUIPMENT SHOWN IS BASED ON ALLEN-BRADLEY CONTROLLOGIX PLATFORM UNLESS NOTED.
2. ALL FIBER OPTIC BREAKOUT ENCLOSURES AND LOCATIONS ARE NOT SHOWN.

US Army Corps
of Engineers
Pittsburgh District

Design by:	Dwn by:	Ckd by:	Submitted by:
X	X	X	X SECTION CHIEF
Submission Date: X		Revision Date: X	FB NO.: DACW59
			Sheet X of X

ACP
AUTORIDAD DEL CANAL DE PANAMA
User: jkonkosh
Date: 20-OCT-2002 22:42
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Pen Table:
Color Table
601

Symbol	Description	Date	Appr.
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X		X	X

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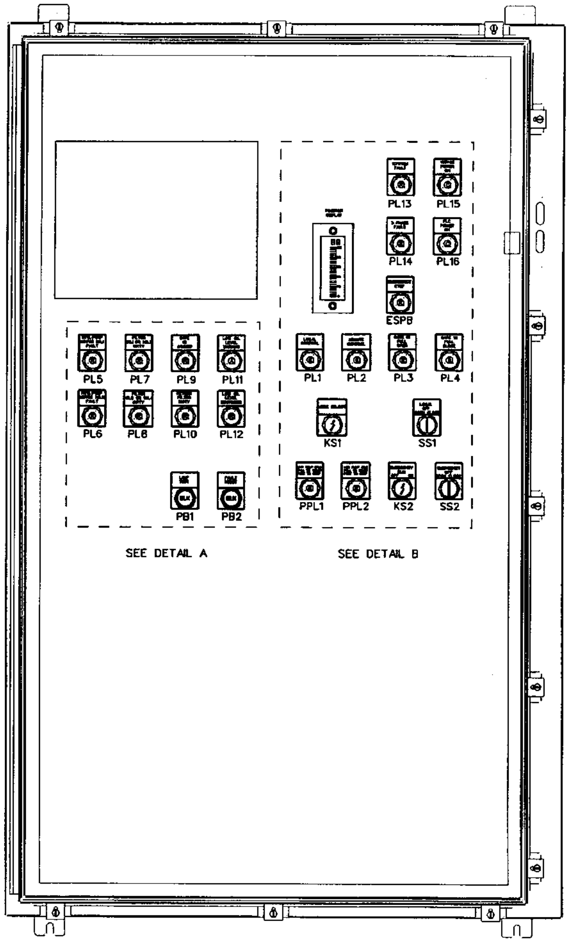
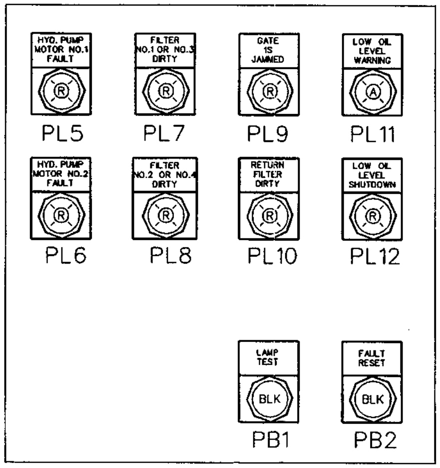
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
UPPER CHAMBER WSB VALVE PLC
CONTROL SYSTEM NETWORK ARCHITECTURE

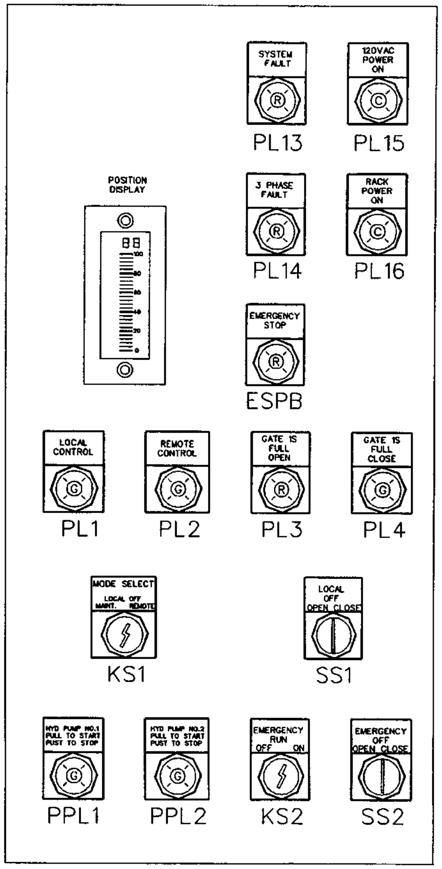
Drawing Number:
ACP-R-29/15



GATE HPU CONTROL ENCLOSURE



DETAIL A



DETAIL B

NOTES:

1. ONE CONTROL ENCLOSURE PER GATE LOCATED WITH GATE HYDRAULIC POWER UNITS.

US Army Corps
of Engineers
Pittsburgh District

Submitted by:
X
SECTION CHIEF

Design by: X
Dwn by: X
Ckd by: X
Submission Date: X
Revision Date: X
IFB NO.: DACW59
Sheet X of X

ACP
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User: [illegible]
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Plot Scale: 2.7162261.000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
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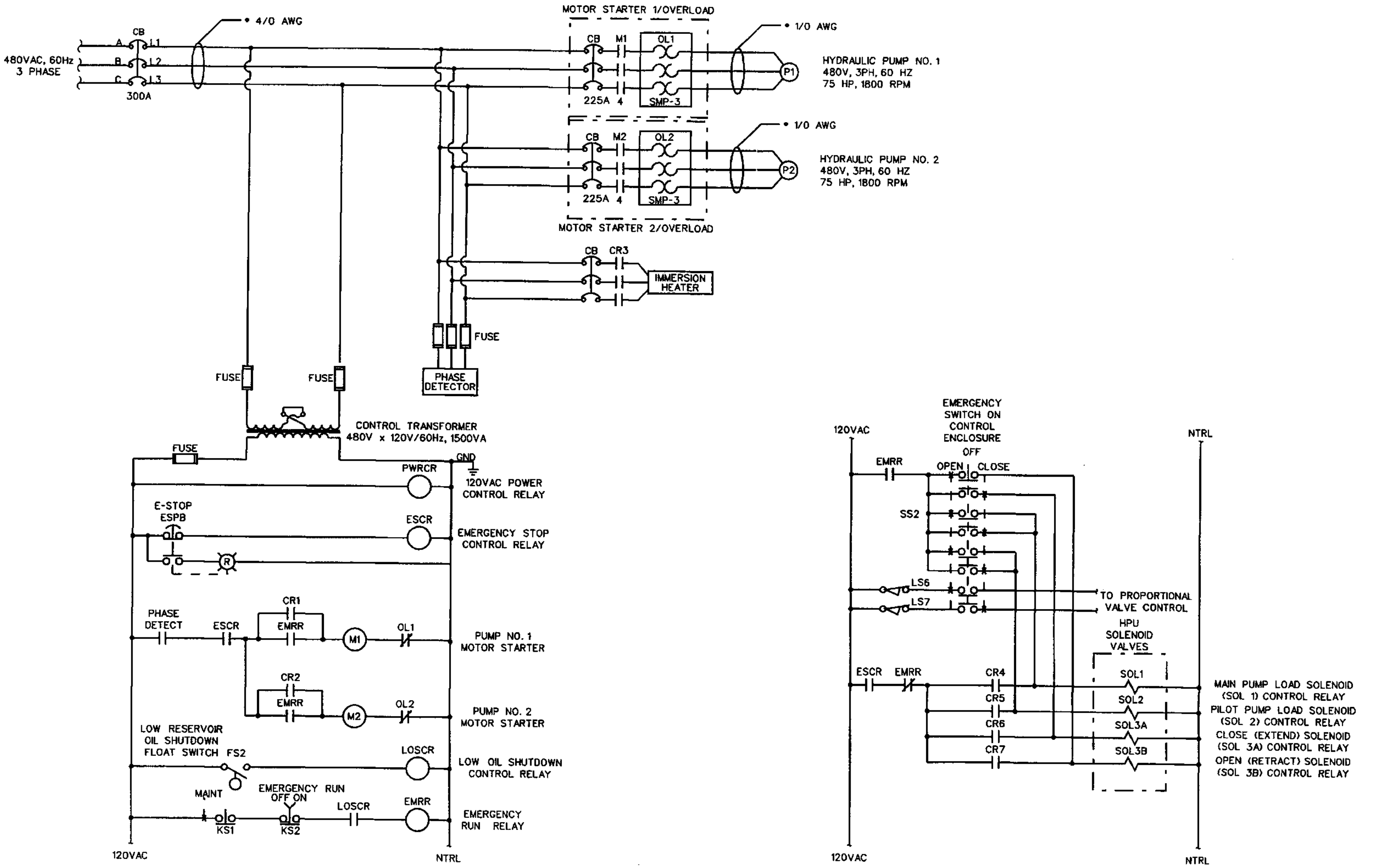
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
GATE HPU CONTROL ENCLOSURE

Drawing Number:
ACP-R-29/16



MITER GATE HPU CONTROL WIRING DIAGRAM

NO SCALE

NOTES:

1. HPU MOTOR STARTER PANELS TO BE SOLID STATE SOFT START TYPE AND LOCATED WITH HYDRAULIC POWER UNITS.

US Army Corps of Engineers
Pittsburgh District

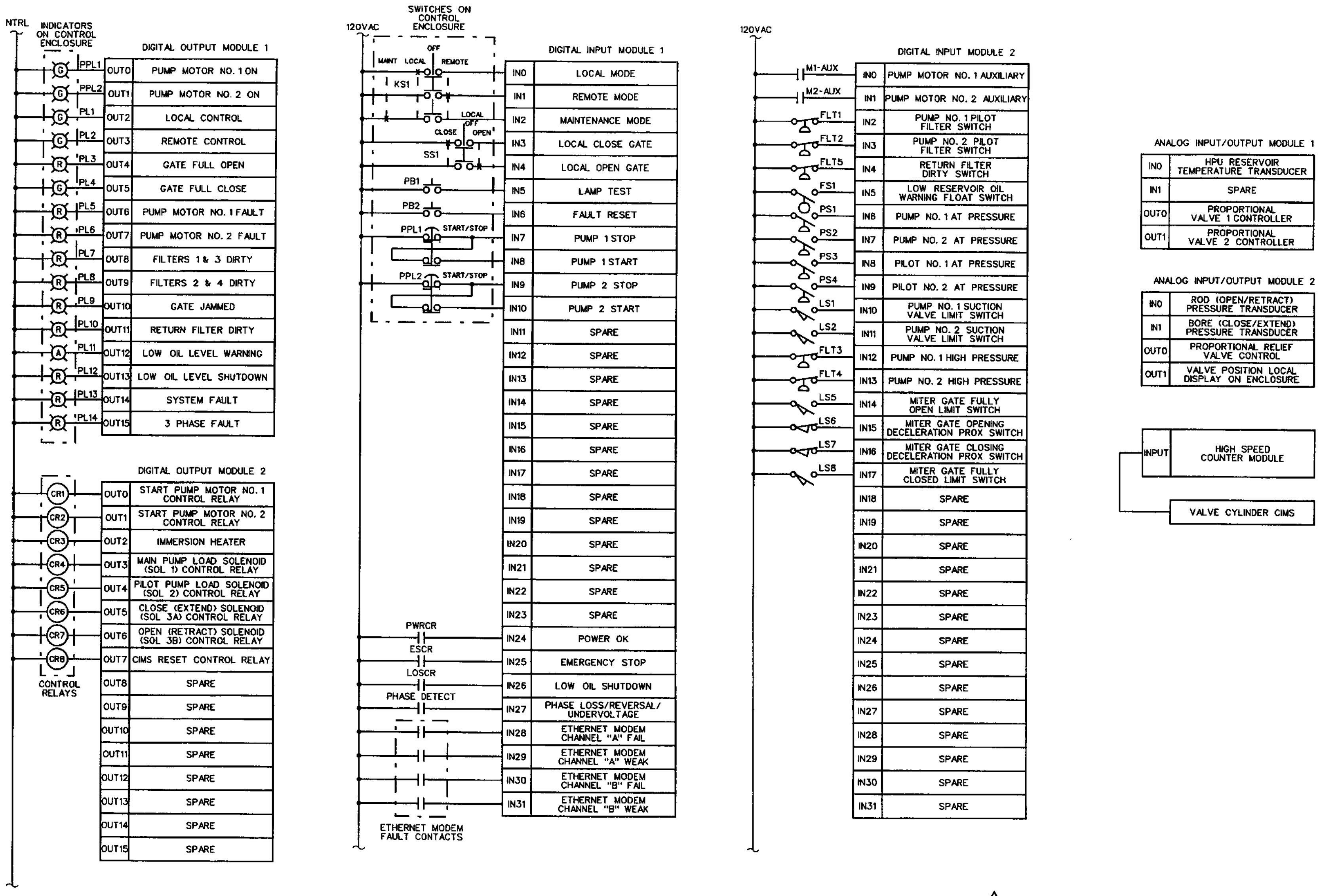
Submitted by: X
SECTION CHIEF
DACW59
Sheet X of X

ACP
AUTORIDAD DEL CANAL DE PANAMA

F:\ACP\sheet\Miter_Gate_HPU_Control_Wiring_Diagram.s01

PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
MITER GATE HPU CONTROL WIRING DIAGRAM

Drawing Number:
ACP-R-29/17



DIGITAL OUTPUT MODULE 1

OUT0	PUMP MOTOR NO. 1 ON
OUT1	PUMP MOTOR NO. 2 ON
OUT2	LOCAL CONTROL
OUT3	REMOTE CONTROL
OUT4	GATE FULL OPEN
OUT5	GATE FULL CLOSE
OUT6	PUMP MOTOR NO. 1 FAULT
OUT7	PUMP MOTOR NO. 2 FAULT
OUT8	FILTERS 1 & 3 DIRTY
OUT9	FILTERS 2 & 4 DIRTY
OUT10	GATE JAMMED
OUT11	RETURN FILTER DIRTY
OUT12	LOW OIL LEVEL WARNING
OUT13	LOW OIL LEVEL SHUTDOWN
OUT14	SYSTEM FAULT
OUT15	3 PHASE FAULT

DIGITAL OUTPUT MODULE 2

OUT0	START PUMP MOTOR NO. 1 CONTROL RELAY
OUT1	START PUMP MOTOR NO. 2 CONTROL RELAY
OUT2	IMMERSION HEATER
OUT3	MAIN PUMP LOAD SOLENOID (SOL 1) CONTROL RELAY
OUT4	PILOT PUMP LOAD SOLENOID (SOL 2) CONTROL RELAY
OUT5	CLOSE (EXTEND) SOLENOID (SOL 3A) CONTROL RELAY
OUT6	OPEN (RETRACT) SOLENOID (SOL 3B) CONTROL RELAY
OUT7	CIMS RESET CONTROL RELAY
OUT8	SPARE
OUT9	SPARE
OUT10	SPARE
OUT11	SPARE
OUT12	SPARE
OUT13	SPARE
OUT14	SPARE
OUT15	SPARE

DIGITAL INPUT MODULE 1

IN0	LOCAL MODE
IN1	REMOTE MODE
IN2	MAINTENANCE MODE
IN3	LOCAL CLOSE GATE
IN4	LOCAL OPEN GATE
IN5	LAMP TEST
IN6	FAULT RESET
IN7	PUMP 1 STOP
IN8	PUMP 1 START
IN9	PUMP 2 STOP
IN10	PUMP 2 START
IN11	SPARE
IN12	SPARE
IN13	SPARE
IN14	SPARE
IN15	SPARE
IN16	SPARE
IN17	SPARE
IN18	SPARE
IN19	SPARE
IN20	SPARE
IN21	SPARE
IN22	SPARE
IN23	SPARE
IN24	POWER OK
IN25	EMERGENCY STOP
IN26	LOW OIL SHUTDOWN
IN27	PHASE LOSS/REVERSAL/ UNDERVOLTAGE
IN28	ETHERNET MODEM CHANNEL "A" FAIL
IN29	ETHERNET MODEM CHANNEL "A" WEAK
IN30	ETHERNET MODEM CHANNEL "B" FAIL
IN31	ETHERNET MODEM CHANNEL "B" WEAK

DIGITAL INPUT MODULE 2

IN0	PUMP MOTOR NO. 1 AUXILIARY
IN1	PUMP MOTOR NO. 2 AUXILIARY
IN2	PUMP NO. 1 PILOT FILTER SWITCH
IN3	PUMP NO. 2 PILOT FILTER SWITCH
IN4	RETURN FILTER DIRTY SWITCH
IN5	LOW RESERVOIR OIL WARNING FLOAT SWITCH
IN6	PUMP NO. 1 AT PRESSURE
IN7	PUMP NO. 2 AT PRESSURE
IN8	PILOT NO. 1 AT PRESSURE
IN9	PILOT NO. 2 AT PRESSURE
IN10	PUMP NO. 1 SUCTION VALVE LIMIT SWITCH
IN11	PUMP NO. 2 SUCTION VALVE LIMIT SWITCH
IN12	PUMP NO. 1 HIGH PRESSURE
IN13	PUMP NO. 2 HIGH PRESSURE
IN14	MITER GATE FULLY OPEN LIMIT SWITCH
IN15	MITER GATE OPENING DECELERATION PROX SWITCH
IN16	MITER GATE CLOSING DECELERATION PROX SWITCH
IN17	MITER GATE FULLY CLOSED LIMIT SWITCH
IN18	SPARE
IN19	SPARE
IN20	SPARE
IN21	SPARE
IN22	SPARE
IN23	SPARE
IN24	SPARE
IN25	SPARE
IN26	SPARE
IN27	SPARE
IN28	SPARE
IN29	SPARE
IN30	SPARE
IN31	SPARE

ANALOG INPUT/OUTPUT MODULE 1

IN0	HPU RESERVOIR TEMPERATURE TRANSDUCER
IN1	SPARE
OUT0	PROPORTIONAL VALVE 1 CONTROLLER
OUT1	PROPORTIONAL VALVE 2 CONTROLLER

ANALOG INPUT/OUTPUT MODULE 2

IN0	ROD (OPEN/RETRACT) PRESSURE TRANSDUCER
IN1	BORE (CLOSE/EXTEND) PRESSURE TRANSDUCER
OUT0	PROPORTIONAL RELIEF VALVE CONTROL
OUT1	VALVE POSITION LOCAL DISPLAY ON ENCLOSURE

INPUT	HIGH SPEED COUNTER MODULE

VALVE CYLINDER CIMS

◊NOTES:

1. HARDWIRED INPUT/OUTPUTS ARE NOT SHOWN

MITER GATE HPU ANALOG/DIGITAL INPUT/OUTPUT WIRING DIAGRAM

NO SCALE

US Army Corps of Engineers
Pittsburgh District

Submitted by: X
SECTION CHIEF

Design by: X
Ckd by: X
Dwn by: X
Submission Date: X
Revision Date: X
FB NO.: DACW59
Sheet X of X

ACP
AUTORIDAD DEL CANAL DE PANAMA
User: jtarkosh
Date: 20-OCT-2002 22:43
Plot Scale: 2.7152261:1.000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
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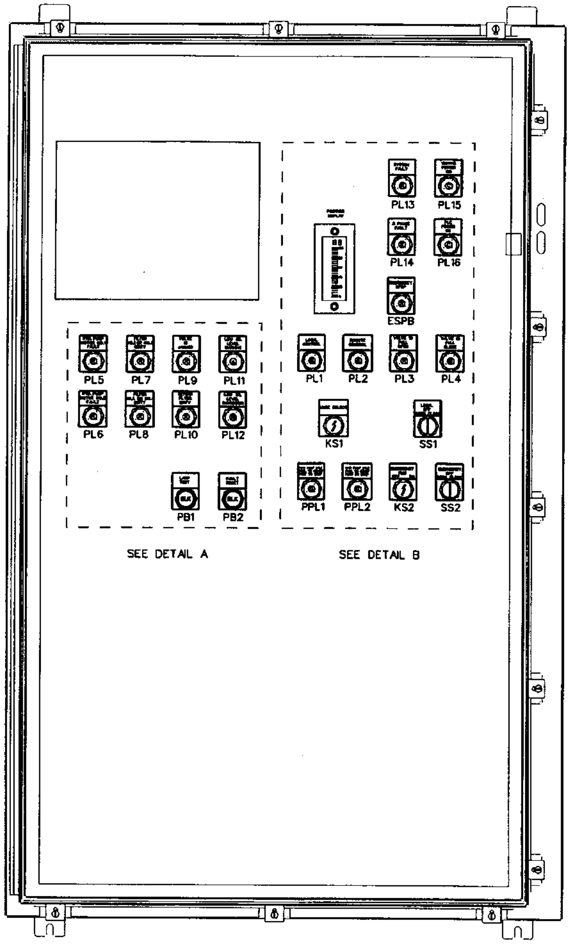
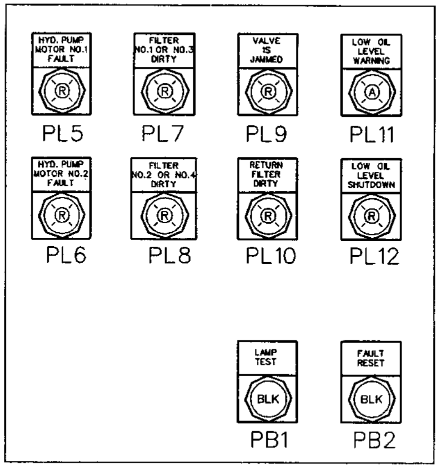
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
MITER GATE HPU ANALOG/DIGITAL
INPUT/OUTPUT WIRING DIAGRAM

Drawing Number: ACP-R-29/18



VALVE HPU CONTROL ENCLOSURE



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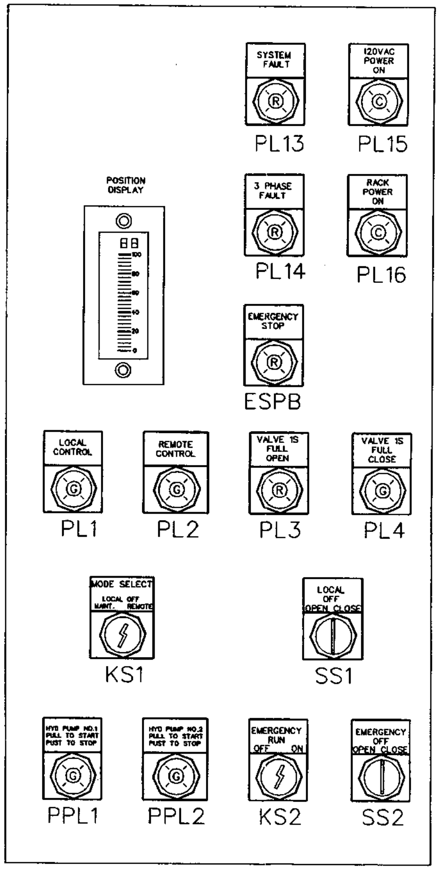

DETAIL B

NOTES:

1. ONE CONTROL ENCLOSURE PER VALVE LOCATED WITH VALVE HYDRAULIC POWER UNITS.

US Army Corps of Engineers
Pittsburgh District

Submitted by: X
SECTION CHIEF
IFB NO.: DACW59
Sheet X of X

Design by: X
Ckd by: X
Dm by: X
Submission Date: X
Revision Date: X

ACP
AUTORIDAD DEL CANAL DE PANAMA
User: jtorkosh
Date: 20-OCT-2002 22:43
Plot Scale: 2.715226:1.000000
Pen Table:
Color Table:

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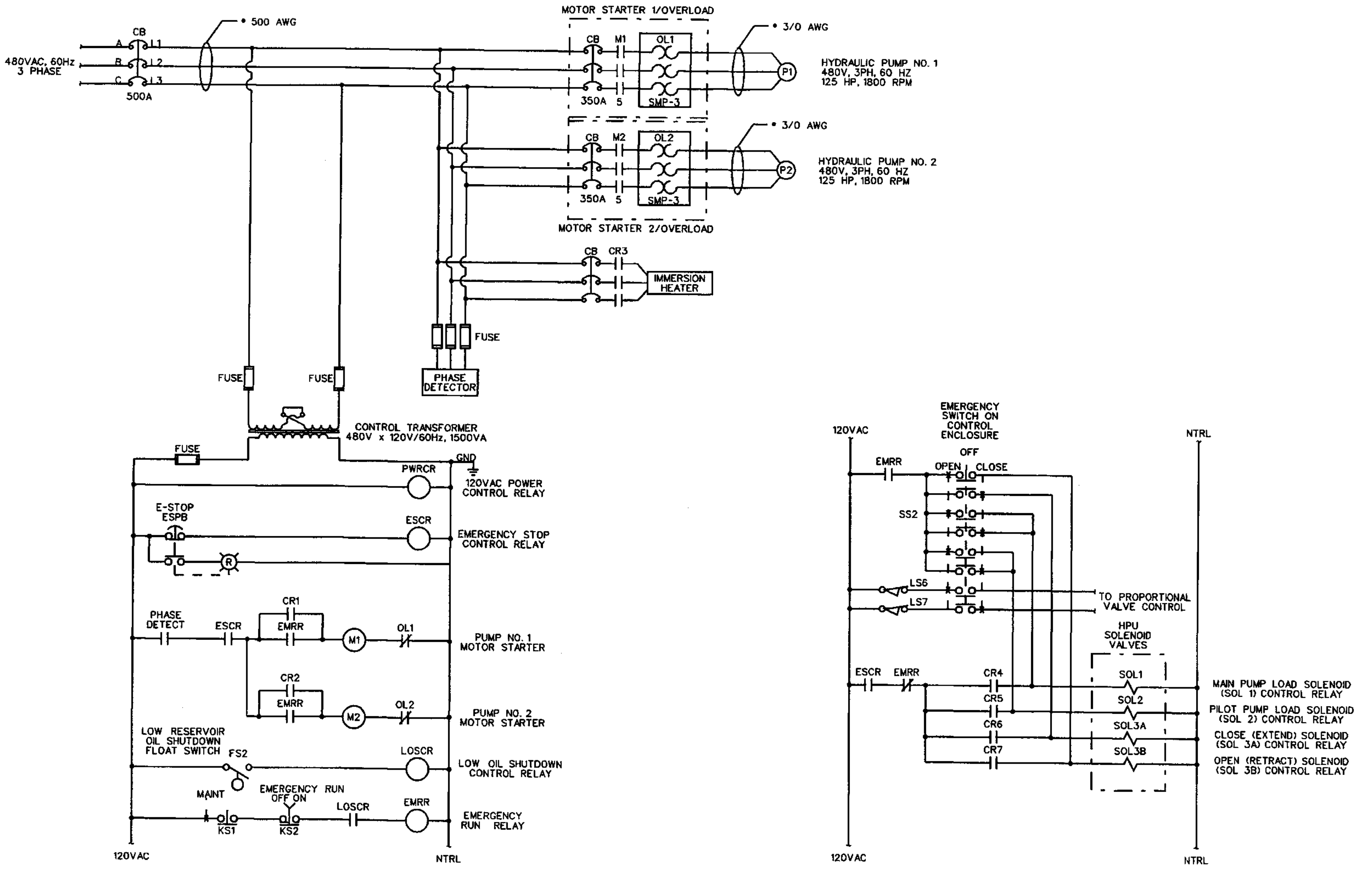
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
VALVE HPU CONTROL ENCLOSURE

Drawing Number:
ACP-R-29/19



VALVE HPU CONTROL WIRING DIAGRAM

NO SCALE

NOTES:

1. HPU MOTOR STARTER PANELS TO BE SOLID STATE SOFT START TYPE AND LOCATED WITH HYDRAULIC POWER UNITS.

US Army Corps
of Engineers
Pittsburgh District

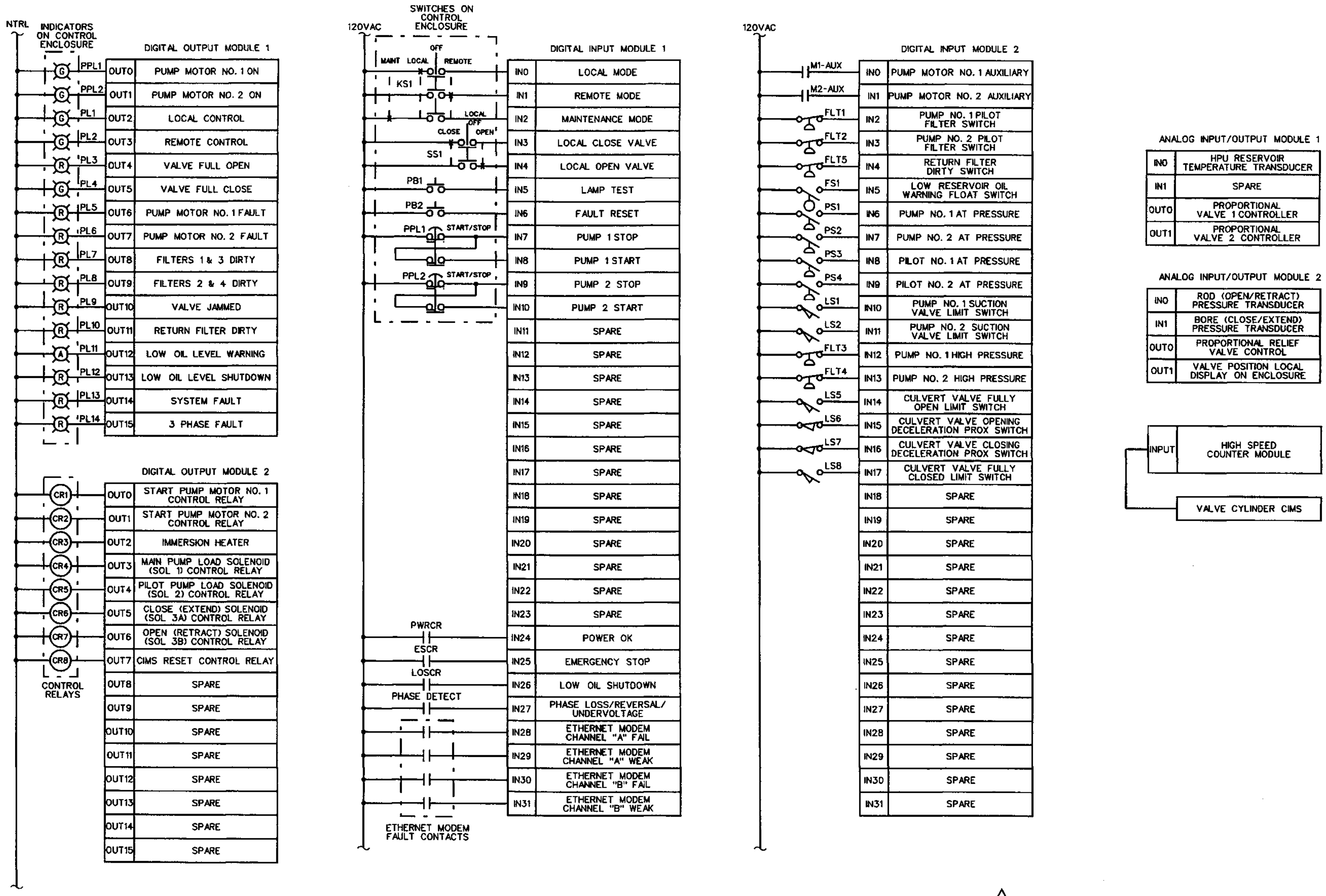
ACP
AUTORIDAD DEL CANAL DE PANAMA

Design by: X
Dwn by: X
Submission Date: X
Submitted by: X
SECTION CHIEF
Ckd by: X
Revision Date: X
IFB NO.: DACW59
Sheet X of X

F:\ACP\sheet\Valve_HPU_Control_Wiring_Diagram.s01

PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
VALVE HPU CONTROL WIRING DIAGRAM

Drawing Number:
ACP-R-29/20



DIGITAL OUTPUT MODULE 1

OUT0	PUMP MOTOR NO. 1 ON
OUT1	PUMP MOTOR NO. 2 ON
OUT2	LOCAL CONTROL
OUT3	REMOTE CONTROL
OUT4	VALVE FULL OPEN
OUT5	VALVE FULL CLOSE
OUT6	PUMP MOTOR NO. 1 FAULT
OUT7	PUMP MOTOR NO. 2 FAULT
OUT8	FILTERS 1 & 3 DIRTY
OUT9	FILTERS 2 & 4 DIRTY
OUT10	VALVE JAMMED
OUT11	RETURN FILTER DIRTY
OUT12	LOW OIL LEVEL WARNING
OUT13	LOW OIL LEVEL SHUTDOWN
OUT14	SYSTEM FAULT
OUT15	3 PHASE FAULT

DIGITAL OUTPUT MODULE 2

OUT0	START PUMP MOTOR NO. 1 CONTROL RELAY
OUT1	START PUMP MOTOR NO. 2 CONTROL RELAY
OUT2	IMMERSION HEATER
OUT3	MAIN PUMP LOAD SOLENOID (SOL 1) CONTROL RELAY
OUT4	PILOT PUMP LOAD SOLENOID (SOL 2) CONTROL RELAY
OUT5	CLOSE (EXTEND) SOLENOID (SOL 3A) CONTROL RELAY
OUT6	OPEN (RETRACT) SOLENOID (SOL 3B) CONTROL RELAY
OUT7	CIMS RESET CONTROL RELAY
OUT8	SPARE
OUT9	SPARE
OUT10	SPARE
OUT11	SPARE
OUT12	SPARE
OUT13	SPARE
OUT14	SPARE
OUT15	SPARE

DIGITAL INPUT MODULE 1

IN0	LOCAL MODE
IN1	REMOTE MODE
IN2	MAINTENANCE MODE
IN3	LOCAL CLOSE VALVE
IN4	LOCAL OPEN VALVE
IN5	LAMP TEST
IN6	FAULT RESET
IN7	PUMP 1 STOP
IN8	PUMP 1 START
IN9	PUMP 2 STOP
IN10	PUMP 2 START
IN11	SPARE
IN12	SPARE
IN13	SPARE
IN14	SPARE
IN15	SPARE
IN16	SPARE
IN17	SPARE
IN18	SPARE
IN19	SPARE
IN20	SPARE
IN21	SPARE
IN22	SPARE
IN23	SPARE
IN24	POWER OK
IN25	EMERGENCY STOP
IN26	LOW OIL SHUTDOWN
IN27	PHASE LOSS/REVERSAL/ UNDERVOLTAGE
IN28	ETHERNET MODEM CHANNEL "A" FAIL
IN29	ETHERNET MODEM CHANNEL "A" WEAK
IN30	ETHERNET MODEM CHANNEL "B" FAIL
IN31	ETHERNET MODEM CHANNEL "B" WEAK

DIGITAL INPUT MODULE 2

IN0	PUMP MOTOR NO. 1 AUXILIARY
IN1	PUMP MOTOR NO. 2 AUXILIARY
IN2	PUMP NO. 1 PILOT FILTER SWITCH
IN3	PUMP NO. 2 PILOT FILTER SWITCH
IN4	RETURN FILTER DIRTY SWITCH
IN5	LOW RESERVOIR OIL WARNING FLOAT SWITCH
IN6	PUMP NO. 1 AT PRESSURE
IN7	PUMP NO. 2 AT PRESSURE
IN8	PILOT NO. 1 AT PRESSURE
IN9	PILOT NO. 2 AT PRESSURE
IN10	PUMP NO. 1 SUCTION VALVE LIMIT SWITCH
IN11	PUMP NO. 2 SUCTION VALVE LIMIT SWITCH
IN12	PUMP NO. 1 HIGH PRESSURE
IN13	PUMP NO. 2 HIGH PRESSURE
IN14	CULVERT VALVE FULLY OPEN LIMIT SWITCH
IN15	CULVERT VALVE OPENING DECELERATION PROX SWITCH
IN16	CULVERT VALVE CLOSING DECELERATION PROX SWITCH
IN17	CULVERT VALVE FULLY CLOSED LIMIT SWITCH
IN18	SPARE
IN19	SPARE
IN20	SPARE
IN21	SPARE
IN22	SPARE
IN23	SPARE
IN24	SPARE
IN25	SPARE
IN26	SPARE
IN27	SPARE
IN28	SPARE
IN29	SPARE
IN30	SPARE
IN31	SPARE

ANALOG INPUT/OUTPUT MODULE 1

IN0	HPU RESERVOIR TEMPERATURE TRANSDUCER
IN1	SPARE
OUT0	PROPORTIONAL VALVE 1 CONTROLLER
OUT1	PROPORTIONAL VALVE 2 CONTROLLER

ANALOG INPUT/OUTPUT MODULE 2

IN0	ROD (OPEN/RETRACT) PRESSURE TRANSDUCER
IN1	BORE (CLOSE/EXTEND) PRESSURE TRANSDUCER
OUT0	PROPORTIONAL RELIEF VALVE CONTROL
OUT1	VALVE POSITION LOCAL DISPLAY ON ENCLOSURE

INPUT	HIGH SPEED COUNTER MODULE

VALVE CYLINDER CIMS

◊ NOTES:

1. HARDWIRED INPUT/OUTPUTS ARE NOT SHOWN

VALVE HPU ANALOG/DIGITAL INPUT/OUTPUT WIRING DIAGRAM

NO SCALE

US Army Corps
of Engineers
Pittsburgh District

Submitted by: X
SECTION CHIEF

FB NO.: DACW59

Sheet X of X

Design by: X
Dwn by: X
Ckd by: X
Submission Date: X
Revision Date: X

ACP
AUTORIDAD DEL CANAL DE PANAMA

User: jlankeah
Date: 20-OCT-2002 22:43
Plot Scale: 2.715228:1.000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
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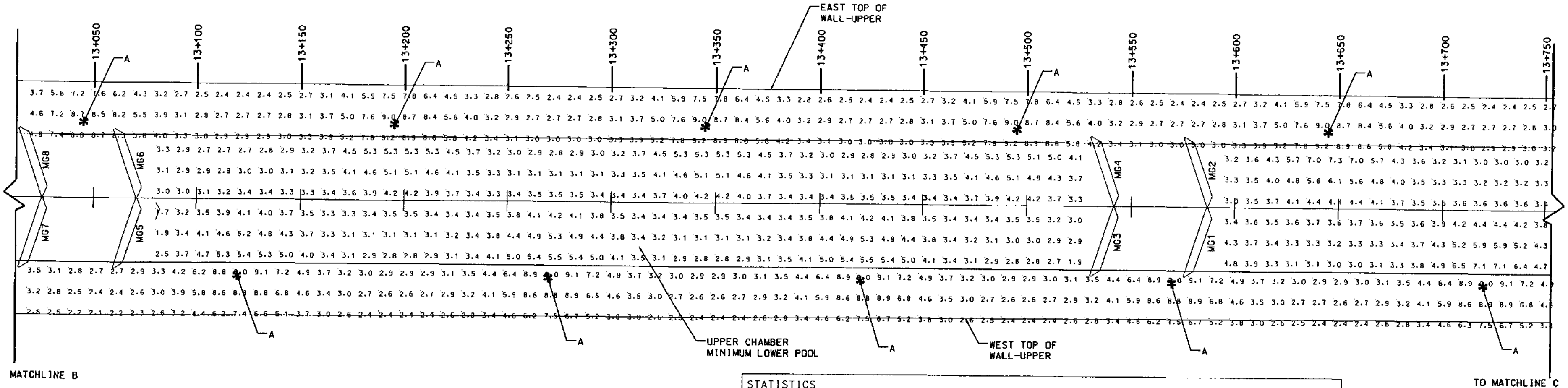
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
VALVE HPU ANALOG/DIGITAL
INPUT/OUTPUT WIRING DIAGRAM

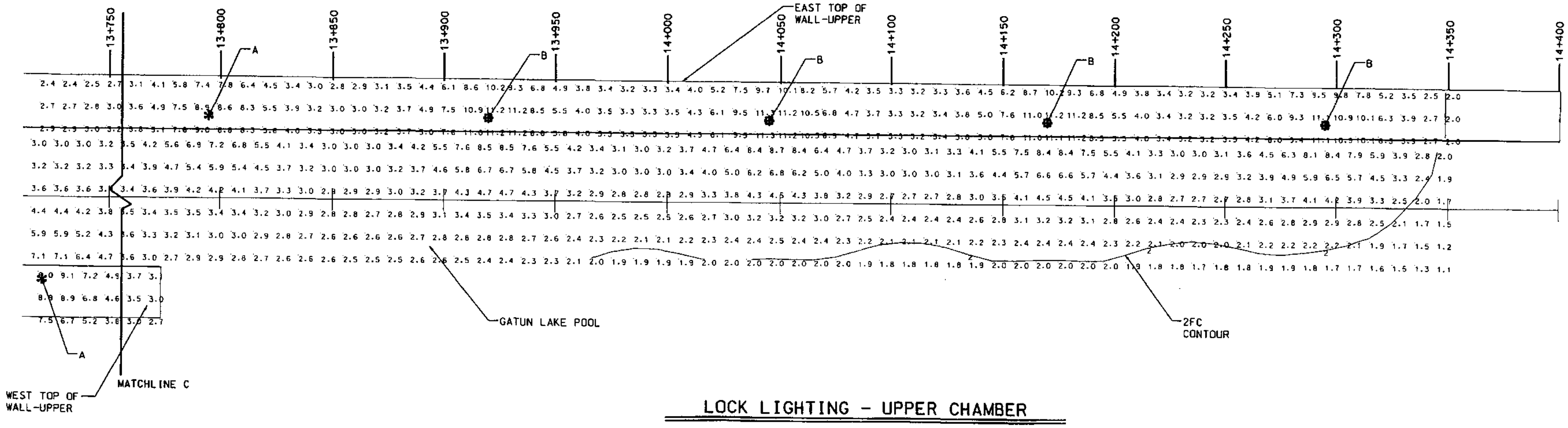
Drawing Number:
ACP-R-29/21



LUMINAIRE SCHEDULE								
Symbol	Label	Qty	Catalog Number	Description	Lamp	Lumens	LLF	Watts
✳	A	21	HMSCC10HP00B7	HIGHMAST CUTOFF	1000W CLEAR HPS	140000	1.00	6450
❋	B	8	HMSCC10HP00B7	HIGHMAST CUTOFF	1000W CLEAR HPS	140000	1.00	8600

NOTES:
1. DESIGN BASED ON LUMINAIRES MANUFACTURED BY HOLOPHANE.
2. POLE HEIGHT IS 45.7 METERS.
3. LABEL A REPRESENTS 6 FIXTURES PER POLE; LABEL B REPRESENTS 8 FIXTURES PER POLE.
4. POLES SPACED AT 150M IN CHAMBER AREAS AND 125M AT APPROACH WALLS.
5. POLE SETBACK IS 6 METERS FROM VERTICAL FACE OF WALL.
6. LIGHT LEVELS SHOWN IN FOOT CANDLES.

STATISTICS						
Description	Avg	Max	Min	Max/Min	Avg/Min	UG
WEST TOP OF WALL - LOWER	4.9 fc (52.72 LUX)	9.2 fc (98.99 LUX)	2.3 fc (24.75 LUX)	4.0:1	2.1:1	1.5
EAST TOP OF WALL - LOWER	5.5 fc (59.18 LUX)	11.3 fc (121.59 LUX)	1.2 fc (12.91 LUX)	9.4:1	4.6:1	1.6
EAST TOP OF WALL - MIDDLE	4.4 fc (47.34 LUX)	9.3 fc (100.07 LUX)	2.1 fc (22.60 LUX)	4.4:1	2.1:1	1.5
EAST TOP OF WALL - UPPER	5.2 fc (55.95 LUX)	11.3 fc (121.59 LUX)	2.0 fc (21.52 LUX)	5.7:1	2.6:1	1.6
WEST TOP OF WALL - MIDDLE	4.8 fc (51.65 LUX)	9.2 fc (98.99 LUX)	2.4 fc (25.82 LUX)	3.8:1	2.0:1	1.5
WEST TOP OF WALL - UPPER	4.5 fc (48.42 LUX)	9.1 fc (97.92 LUX)	2.1 fc (22.60 LUX)	4.3:1	2.1:1	1.5
GATUN LAKE POOL	3.5 fc (37.66 LUX)	8.7 fc (93.61 LUX)	1.1 fc (11.84 LUX)	7.9:1	3.2:1	1.6
UPPER CHAMBER MINIMUM LOWER POOL	3.7 fc (39.81 LUX)	5.5 fc (59.18 LUX)	1.7 fc (18.29 LUX)	3.2:1	2.2:1	1.9
ATLANTIC OCEAN POOL	3.5 fc (37.66 LUX)	9.7 fc (104.37 LUX)	1.2 fc (12.91 LUX)	8.1:1	2.9:1	1.6
LOWER CHAMBER MINIMUM LOWER POOL	3.7 fc (39.81 LUX)	5.6 fc (60.26 LUX)	1.3 fc (13.99 LUX)	4.3:1	2.9:1	2.0



LOCK LIGHTING - UPPER CHAMBER

SCALE = 1:1000

US Army Corps of Engineers
Pittsburgh District

Submitted by: X
SECTION CHIEF
FB NO.: DACW59
Sheet X of X
Design by: X
Ckd by: X
Dwn by: X
Submission Date: X
Revision Date: X

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User: lbanbash
Date: 20-OCT-2002 22:43
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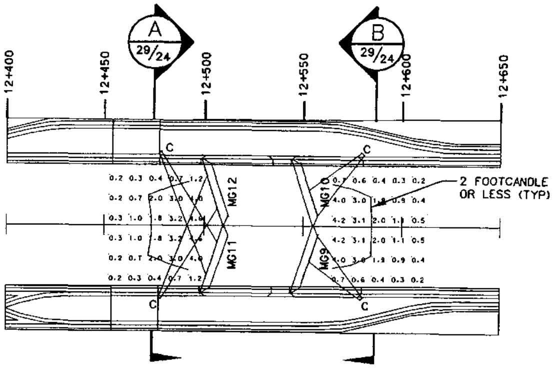
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
LOCK LIGHTING
UPPER CHAMBER

Drawing Number
ACP-R-29/23



GATE LIGHTING PLAN (MG9-MG12)

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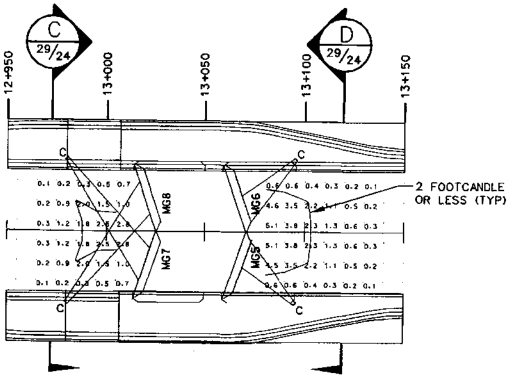

GATE LIGHTING PLAN (MG5-MG8)

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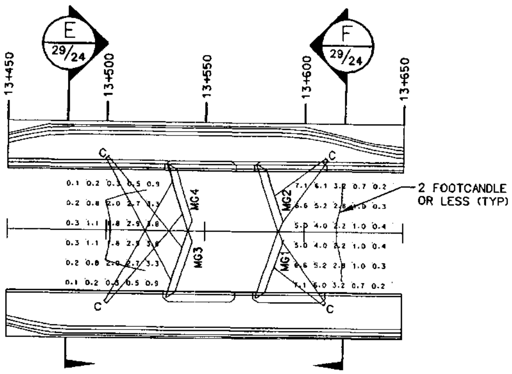

GATE LIGHTING PLAN (MG1-MG4)

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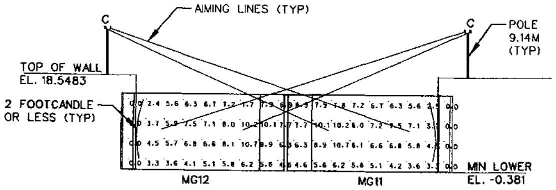

SECTION A 29/24

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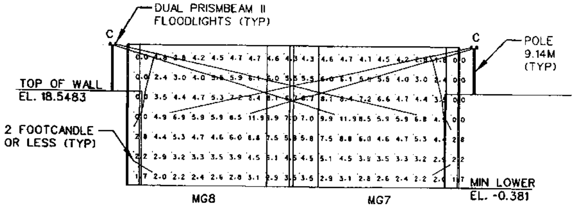

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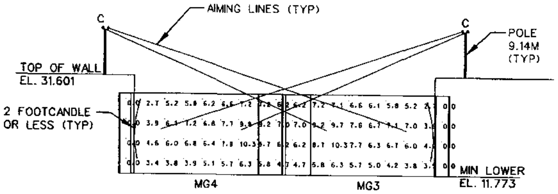

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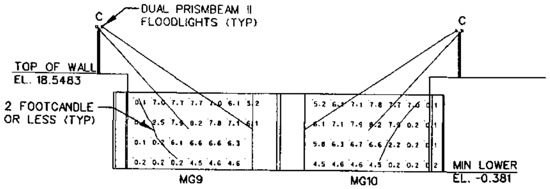

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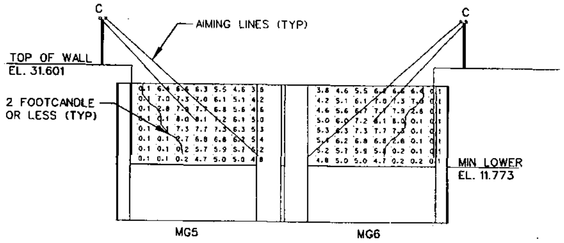

SECTION D 29/24

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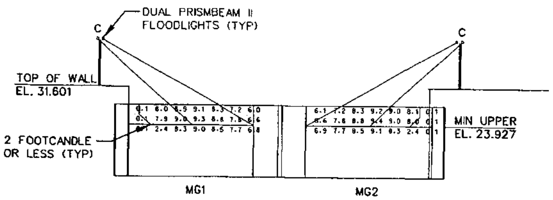

SECTION F 29/24

SCALE: 1:500

NOTES:

1. DESIGN BASED ON PRISMBEAM II LUMINAIRES MANUFACTURED BY HOLOPHANE.
2. BEAM SPREAD FOR U.S. FACE OF GATE IS NEMA TYPE 6 (H) x NEMA TYPE 5 (V). BEAM SPREAD FOR D.S. FACE OF GATE IS NEMA TYPE 3 (H) x NEMA TYPE 3 (V).
3. POLE HEIGHT IS 9.14 METERS.
4. LABEL C DESIGNATES 2 FLOODLIGHT LUMINAIRES EACH WITH A 750 WATT HIGH PRESSURE SODIUM LAMPS.
5. POLE SETBACK IS 6 METERS FROM VERTICAL FACE OF WALL.
6. LIGHT LEVEL SHOWN IN FOOTCANDLES.

US Army Corps of Engineers
Pittsburgh District

Submitted by: X
SECTION CHIEF
DACW59
Sheet X of X

Design by: X | Ckd by: X | Dwn by: X | Revision Date: X | Submission Date: X | Plt NO.:

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User: jlankosh
Date: 20-OCT-2002 22:43
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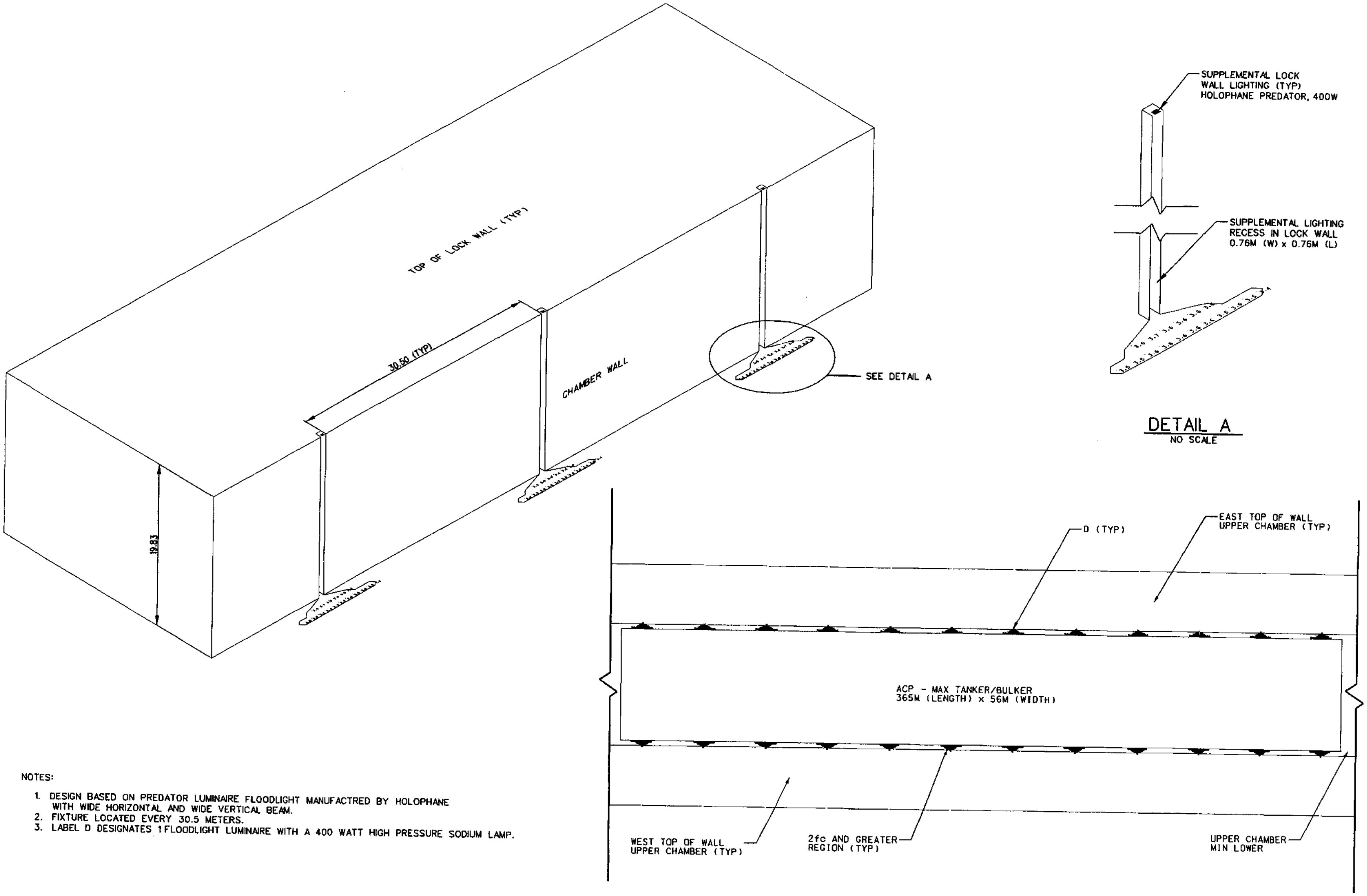
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
SUPPLEMENTAL LOCK LIGHTING
MITER GATES

Drawing Number:
ACP-R-29/24



NOTES:

1. DESIGN BASED ON PREDATOR LUMINAIRE FLOODLIGHT MANUFACTRED BY HOLOPHANE WITH WIDE HORIZONTAL AND WIDE VERTICAL BEAM.
2. FIXTURE LOCATED EVERY 30.5 METERS.
3. LABEL D DESIGNATES 1 FLOODLIGHT LUMINAIRE WITH A 400 WATT HIGH PRESSURE SODIUM LAMP.

SUPPLEMENTAL LOCK LIGHTING
SCALE: 1:1000

US Army Corps
of Engineers
Pittsburgh District

Submitted by:	X SECTION CHIEF
Design by:	X
Dsn by:	X
Ckd by:	X
Submission Date:	X
Revision Date:	X
IFB NO.:	DACW59
	Sheet X of X

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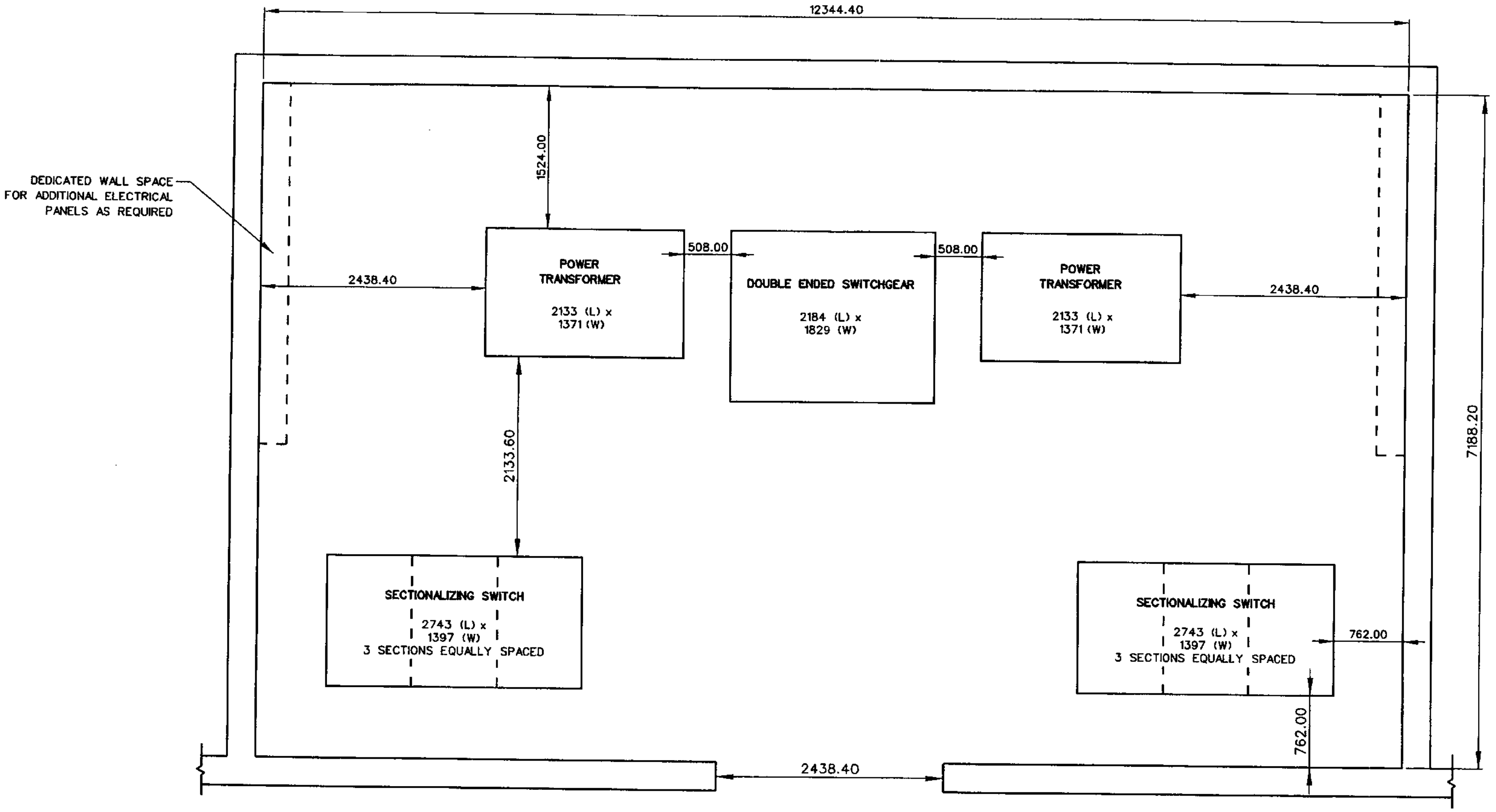
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
SUPPLEMENTAL LOCK LIGHTING

Drawing Number:
ACP-R-29/25



TRANSFORMER ROOM - PLAN (TYPICAL)

SCALE = 1:25

NOTES:

ALL DIMENSIONS AND/OR DIMENSIONS SHOWN IN CALLOUTS/NOTES ARE IN MILLIMETERS UNLESS OTHERWISE NOTED.

US Army Corps of Engineers
Pittsburgh District

Submitted by:
X
SECTION CHIEF

Design by: X
Dwn by: X
Ckd by: X
Submission Date: X
Revision Date: X
I/B NO.: DACW59
Sheet X of X

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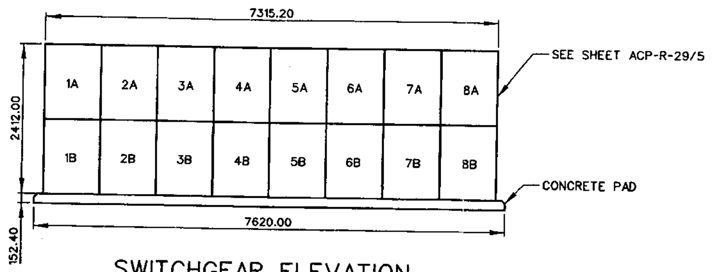
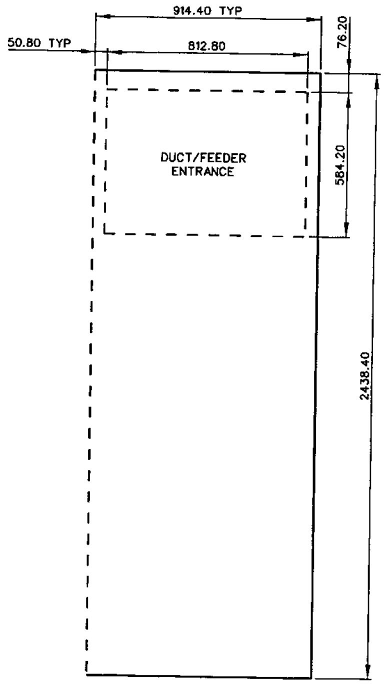
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
TRANSFORMER ROOM - PLAN

Drawing Number:
ACP-R-29/26



SWITCHGEAR ELEVATION

SCALE: 1:40



DETAIL A 29/27

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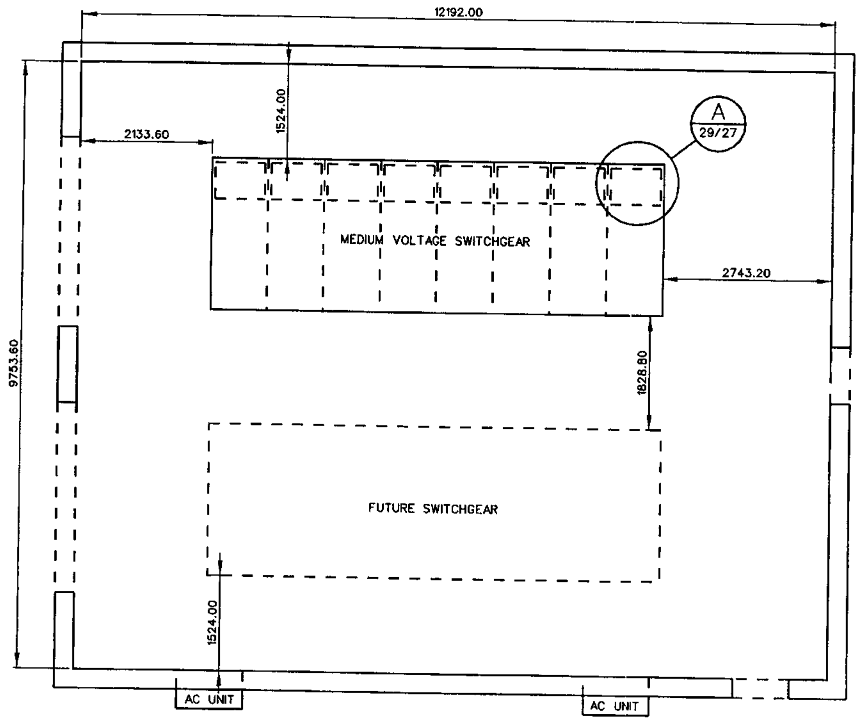

SWITCHROOM PLAN - TYPICAL

SCALE: 1:40

NOTES:

ALL DIMENSIONS AND/OR DIMENSIONS SHOWN IN CALLOUTS/NOTES ARE IN MILLIMETERS UNLESS OTHERWISE NOTED.

US Army Corps
of Engineers
Pittsburgh District

Submitted by: X
SECTION CHIEF

Design by: X
Dwn by: X
Ckd by: X
Submission Date: X
Revision Date: X
FB NO.: DACW59
Sheet X of X

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PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
ELECTRICAL SYSTEM
SWITCHROOM PLAN

Drawing Number:
ACP-R-29/27

PANAMA CANAL CONCEPT DESIGN

Atlantic Locks Structure

Third Lane Lock

Appendix J

Filling and Emptying System Screening Study

Prepared for

Canal Capacity Projects Office

By

US Army Corps
of Engineers

Final Report
23 July 2003

NOTE:

THE TEXT IN THIS APPENDIX IS FROM THE ORIGINAL SCREENING STUDY REPORT SUBMITTED FEBRUARY 20, 2003. REVISED COST INFORMATION IS REFLECTED IN THE MAIN REPORT AND APPENDIX M COST ESTIMATES.

Table of Contents

Table of Contents

1. EXECUTIVE SUMMARY

This screening study compares four cost saving alternatives for the Concept Design of the Atlantic Locks. The alternatives are changes to the Scope of Work and are identified as such in Modification No. 2 to IAPWO No. SAA-80640, Changes to the Scope of Work.

The above modification states "Revise and resubmit the double-lift configuration draft report to include the revised Interlaced Lateral System and either the Side Port or the ICLS filling and emptying system that was identified as the most advantageous in the above screening studies."

All of the alternatives studied fell within a narrow cost range as shown in Table 1-1:

Table 1-1 Estimated Construction Cost

Alternative No.	Description	Construction Cost
1	Modified Interlaced Bottom Lateral System	$1,040,000,000
2	Side Port System with Water Saving Basins on One Side	$1,052,000,000
3	Side Port System with Water Saving Basins on Both Sides	$1,034,000,000
4	In-Chamber Longitudinal Culvert System with Water Saving Basins on Both Sides, Anchored Walls	$1,019,000,000
4a	In-Chamber Longitudinal Culvert System with Water Saving Basins on Both Sides, Gravity Walls	$1,027,000,000

As a result, cost is not a deciding factor in recommending an alternative. Alternative 1 is already included in resubmittal of the Double-Lift configuration, leaving the choice between Alternatives 2, 3, 4 and 4a. Of these, Alternative 4a is the recommended alternative due to better hydraulic performance characteristics compared to the other filling and emptying systems and a structural configuration that allows maximum use of roller compacted concrete (RCC).

2. INTRODUCTION

The Corps of Engineers submitted the concept level design for the double-lift configuration for the Atlantic Locks as a draft report on October 25, 2002. The construction cost of the draft design submitted was estimated to be approximately $1,800,000,000. At a meeting held in Pittsburgh on December 4, 5 and 6, 2002, the ACP advised the Corps of Engineers that they could not finance a project with a cost of $1,800,000,000.

In an effort to mitigate the cost, the Corps of Engineers received ACP approval to contract with a contractor with significant international construction experience to review the estimate.

Arrangements were also made for the cost team to travel to Panama and meet with suppliers and contractors to obtain additional cost data. Based on new unit pricing developed to date, the construction costs of the concept designs submitted in October 2002 have been reduced to approximately $1,300,000,000.

This report presents the results of a screening level study of four alternative filling and emptying systems identified in the modification to change the Scope of Work approved by the ACP. One of the alternatives, In-Chamber Longitudinal Culvert System with Water Saving Basins on Both Sides, has been evaluated with both anchored walls and gravity walls, resulting in a total of five alternatives. Significant reduction of feature quantities (and costs) is anticipated for these changes in the Scope of Work requirements.

This screening study was formally authorized by Modification No. 2 to IAPWC No. SAA-90640, "Changes to the Scope of Work". A copy of the modification is included as Attachment A. Two of the five alternatives identified will be advanced to revise the Double-Lift draft report. They will be Modified Interlaced Bottom Lateral System (Alternative 1) and one of the remaining four alternatives. Alternative 4a, In Chamber Longitudinal Culvert with Gravity Walls, is recommended as the second alternative.

3. ASSUMPTIONS

The following assumptions were used in the screening study.

- Simplified design procedures are used to size masonry structures. Load Case 2G, Maximum Design Earthquake, is used to proportion typical sections along the lock. The maximum design earthquake (MDE) is set equal to the peak ground acceleration of 0.313g associated with the maximum credible earthquake and is used to size all earth retaining structures. A 1/3 reduction in ground acceleration is used to size reaches of wall that do not retain earth and areas that are not subjected to placement of backfill behind the wall to achieve final grades. The designs developed will be investigated for higher seismic loading using more rigorous analytical tools during feasibility study or following engineering activities.
- The application of these simplified design procedures has been found to result in larger structures when compared to time history based analysis. A more refined analysis would permit optimizing these structures.
- The excavation required to construct one set of large water saving basins (WSB) to the west side of the lock is comparable to excavation necessary to construct WSB of one-half the size placed symmetrically about the lock centerline.
- The arrangement and differences associated with the layout of conduits to transfer water from the WSB to the lock is considered in the evaluation of split WSB designs.
- Lock excavation quantities determined from previous studies are proportioned from excavation lines based on new typical sections to determine cost differential between options.
- The lock wall design assumes a ship positioning system similar to that in current use. Other ship positioning systems, such as tug-assisted, could have an effect on optimizing the wall design.

4. COST COMPARISONS

The purpose of the cost estimates prepared for this report is to assist in the evaluation of the five alternatives. The construction costs presented are not to be considered the final cost estimates. The unit costs used to develop these comparison estimates will be further refined as the study progresses and more cost data becomes available. The construction cost estimate for each alternative as well as a summary explanation of the changes made to unit costs since the submission of the draft Double-Lift report are included in Attachment G.

The cost comparison of the five alternatives did not result in one alternative standing out above the rest. The construction costs of all of the alternatives were within $33,000,000 of each other. Considering the current total construction cost of over $1,000,000,000, the cost difference between the five alternatives is approximately three percent which is essentially negligible considering the numerous unknown factors at the concept level of design. Due to the cost difference being insignificant, the recommendation of which alternatives to advance should not be based solely on construction cost.

5. ALTERNATIVES CONSIDERED

The contract modification to eliminate consideration of future construction in the design of the Third Lane lock has been incorporated into all of the alternatives considered. This change has revised the design of the miter gate monoliths from U-Frame construction as described in the initial draft Double-Lift Design report to gravity structures. The east wall design has been optimized for each alternative without consideration of future adjacent construction. Roller compacted concrete is used more extensively in lock walls and reaches of entrance wall constructed in dry excavations resulting in lower construction costs as well as reducing construction duration. These changes are common to all alternatives considered in this study and reduce the volume of cast-in-place concrete, excavation, and reinforcing steel. Additional cost saving measures such as an alignment through the 1939 excavation, use of emergency closures in lieu of redundant gates, and shorter entrance walls are not included in the scope of this study.

5.1. Alternative 1 – Modified Interlaced Bottom Lateral System

The interlaced bottom lateral system originally proposed in the draft Double-Lift concept design report allowed adjacent excavation for construction of a future adjacent twin lock without modification or stabilization. This concept would have reduced future construction costs to built a future Fourth Lane. Further optimization of this east wall and refinement of the U-Frame gate monolith design would have likely resulted in additional cost saving. However, the ACP Locks Team determined that a clear separation of lanes is a preferred arrangement due to the configurations lower initial costs.

Alternative 1 includes a reconfiguration of the east Wall and miter gate monoliths to serve only as a lock wall for the Third Lane lock. A clear separation or other stabilization measures would be required for future Fourth Lane construction. The entrance walls and upper lock chamber would be backfilled to allow land access to top of wall in these areas. The lower lock chamber would have a 14.5 m grade differential (+/-) from a final grade of 4 m to the top of wall, elevation 18.55.

Other design revisions that have been adopted to reduce cost include replacement of the 5 m thick floor slab with paving between bottom laterals; the bottom laterals would now be constructed within a localized trench excavation, and a reinforced concrete toe would be added to the lock monoliths. Conventional cast in place concrete would be placed in the lower portions of lock walls to facilitate construction of culverts and laterals. Upper reaches of the wall would be constructed of roller compacted concrete. Reinforcing steel would be necessary in the toe and along the back face of the lock walls. General reinforcement would be placed around culverts and galleries for crack control; other areas would be generally unreinforced mass concrete. The general arrangement of this alternative is shown on drawing ACP-SS-PL1 and ACP-SS-PL2.

This interlaced bottom lateral system is a proven design that would be similar to the system used for existing locks. It would perform well in the range of the design lift and provide safe and efficient equalizations with acceptable water surface slopes. Criteria for equalization time (12-15 minutes) and water surface slope (<0.8/1000) would be met with this system. An additional advantage of this system would be the ability to operate under most maintenance conditions. The system would provide good performance with or without use of the water saving basins.

5.2. Alternative 2 – Side Port System with Water Saving Basins on One Side

As with Alternative 1, the entrance walls and upper lock chamber would be backfilled to allow land access to top of wall within these reaches. The lower lock chamber would have a 14.5 m grade differential from a final grade of 4 m to the top of wall, elevation 18.55.

The lock floor would be 4.34 m lower than Alternative 1 to accommodate the side port filling system. The founding elevation of the lock walls would be approximately 2 m below the lock floor. Reinforcement and concrete placements are similar to Alternative 1. The general arrangement of this alternative is shown on drawing ACP-SS-PL3 and ACP-SS-PL4.

The side port filling and emptying system is a proven design generally recommended for lifts less than 9 m; however, designs for simple lifts in the 12 m range are feasible. Hydraulic performance would be acceptable under normal operating conditions for heads up to the recommended maximum (9 m). Safe and efficient equalizations would be achieved, but hawser forces would be somewhat higher than the bottom lateral type system. Surface turbulence during equalizations would also be more significant with this system. Additional submergence would be required under the design ship to minimize the effects of turbulence. This generally results in a lower chamber floor elevation. A side port system would require a significant increase in equalization time under most maintenance conditions and would not tolerate unsynchronized valve operations. The system would provide acceptable performance with use of water saving basins, but could require a longer equalization time for operations without water saving basins due to the higher initial head. With water saving basins on one side of the lock, there are concerns over the even distribution of flow from the basins to each lock culvert. A method to provide a reasonably balanced distribution could be determined through physical modeling.

A side port filling and emptying system was not recommended in the initial evaluation of alternatives for two primary reasons.

- The maximum head differential for lock-to-lock equalization (27 m) exceeds the maximum design lift recommended by Corps guidance (9 m). This would result in more turbulence and higher hawser forces during equalizations.

- The system would not provide satisfactory hydraulic performance under most maintenance conditions.

Revisions to design criteria facilitated reconsideration of the side port system. The first change in design criteria was the operating assumptions. Equalizations with the water saving basins would be considered the primary mode of operation. This change in operating assumptions would reduce the maximum initial effective head for with water saving basin operations to 6.8 m, which is within the recommended range. The maximum head differential for lock-to-lock operations would be reduced to 13.5 m, which is closer to the feasible range. The additional submergence that would exist because the lock would already be half filled would reduce the concern associated with the head differential for lock-to-lock operations. Operations without water saving basins would be considered unusual, for which longer valve times and equalization times may be required due to the higher heads. The second change in design criteria was a reduced emphasis on performance under maintenance conditions. Bifurcating the lock culvert valves would reduce the maintenance concerns.

5.3. Alternative 3 - Side Port System with Water Saving Basins on Both Sides

The general configuration and arrangement of lock walls and lock floor is similar to Alternative 2. Land access to top of walls would be more restricted in this configuration due to the presence of water saving basins located behind both the east and west walls. The backfill loads imposed on the east wall would be eliminated with placement of the water saving basin behind east wall monoliths. This resulted in a reduction of concrete volumes and excavation quantities. The general arrangement of this alternative is shown on drawing ACP-SS-PL5 and ACP-SS-PL6.

Basic design considerations for a side port system with water saving basins on both sides were the same as those described in Section 5.2. By placing the water saving basins on both sides, flow would be more likely to be evenly distributed to each lock culvert. Overall hydraulic performance would be improved with this arrangement compared to the side port system with water saving basins on one side.

5.4. Alternative 4 – In-Chamber Longitudinal Culvert System with Water Saving Basins on Both Sides, Anchored Walls

The in-chamber longitudinal culvert system (ILCS) removes significant reaches of culvert from the lock walls, which allows more freedom in selection of wall types. In Alternative 4 the water saving basins would be placed symmetrically about the lock centerline. The thickness of lock walls would be reduced to a minimum dimension with supplementary external stability provided by post-tensioning tendons that would be incorporated in the water saving basin floors. The tendons would extent from the lock wall to a concrete dead man located under the separation wall between upper and lower basins. The floor slab of the lower water saving basin located adjacent to the lock wall would be thickened to encapsulate the tendons and increase compressive resistance for seismic conditions. The lock wall foundation elevations would be the lowest with this design due to the depth and proximity of longitudinal culverts. As with Alternatives 1, 2, and 3, the lower portions of the lock wall would be made from cast-in-place concrete, and upper reaches would be made from roller compacted concrete. Because of the risk related to structural acceptability of the anchored wall concept without more refined time-history based seismic analysis, this design concept should be considered as having a higher performance risk than the other alternatives at this time. The general arrangement of this alternative is shown on drawing ACP-SS-PL7 and ACP-SS-PL8.

The in-chamber longitudinal culvert system (ILCS) is a proven design generally recommended for lifts less than 12 m. Performance would be hydraulically acceptable under normal operating conditions in the range of the recommended lift. Safe and efficient equalizations would be achieved, but hawser forces may be higher than the bottom lateral type system and lower than the side port system. Surface turbulence could also be more than the bottom lateral system. The system would not perform well under most maintenance conditions and would require increases in equalization time for safe operation. The system would provide acceptable performance with use of water saving basins, but may require a longer equalization time for operations without water saving basins due to the higher initial head. The system would be compatible with water saving basins on both sides of the lock.

An ILCS filling and emptying system was not recommended in the initial evaluation of alternatives described in the initial Double-Lift Design draft report for two primary reasons.

- The maximum head differential for lock-to-lock equalization (27 m) exceeds the maximum design lift suggested by Corps studies (12 m).
- The system would not provide satisfactory hydraulic performance under most maintenance conditions.

Revisions to design criteria facilitated reconsideration of the ILCS system. The first change in design criteria was the operating assumptions. Equalizations with the water saving basins would be considered the primary mode of operation. This change in operating assumptions would reduce the maximum initial effective head for water saving basin operations to 6.8 m, which is within the recommended range. The maximum head differential for lock-to-lock operations would be reduced to 13.5 m, which is closer to the recommended range. The additional submergence that would exist because the lock would already be half filled would reduce the concern associated with the head differential for lock-to-lock operations. Operations without water saving basins would be considered an unusual operating condition, for which equalization times could exceed 12-15 minutes to achieve safe equalization due to the higher initial head. The second change in design criteria was a reduced emphasis on performance under maintenance conditions. Bifurcating the lock culvert valves would reduce the maintenance concerns.

5.5. Alternative 4a – In-Chamber Longitudinal Culvert System with Water Saving Basins on Both Sides, Gravity Walls

The filling and emptying system presented in Alternative 4 is adopted in Alternative 4a, see Section 5.4. However, the tie-back wall system is replaced with gravity structures. The primary advantage of this configuration lies in concrete placements used to build the lock walls. Roller compacted concrete could be used extensively, approaching 100% of the concrete in the walls. This would allow the use of lower cost and higher production construction procedures. The general arrangement of this alternative is shown on drawing ACP-SS-PL9 and ACP-SS-PL10.

6. FINDINGS

6.1. Alternative 1 – Modified Interlaced Bottom Lateral System

6.1.1. Features

The arrangement of the filling and emptying system presented in this report is based on conventional cast in place concrete construction. It would be possible to speed construction by precasting three basic components concurrently with civil/site activities. These components include the filling culvert, lower lock wall face, and bottom lateral culverts. This would significantly reduce on-site forming and stripping activities and allow for rapid in-fill concrete placements up to the beginning of roller compacted concrete construction. The bottom lateral length could be divided with tongue and groove joints into approximately six pieces. These pieces would be placed and positioned into trenches cut into rock then encapsulated in a grout placement. Standard precast concrete panels could be used as formwork for the lock face and culvert walls and ceiling.

Further cost savings may be realized by splitting the water saving basins similar to Alternatives 3, 4, and 4a. Splitting the water saving basins would eliminate backfill placements behind the east wall and reduce overturning moments on the lock wall. This would save construction costs by reducing the wall size and width of excavation. Additional savings in construction of hydraulic features include elimination of two cross-under culverts. A split basin arrangement would also improve the distribution of flow to each lock culvert. These potential cost saving measures would need to compared to and evaluated with impacts resulting from reduced access to the top of wall along the east side of the lock.

Designs for the interlaced bottom lateral system were primarily based upon the existing locks and the Third Lane lock model tests completed in 1942.* An upstream intake and downstream outlet manifold would connect to 6 m wide by 8 m high culverts located in each lock wall. Within the lock chamber, the culverts would connect to transverse lateral culverts that extend across the lock chamber. There would be twelve laterals per culvert arranged in an alternating pattern for a total of twenty-four laterals per lock. Two laterals, one from each culvert, would be used to serve the areas between miter gates. Each lateral would have an area of 8 m^2. Ports would be distributed along the lateral to minimize transverse water surface differentials. The total port area would be 8.16 m^2 per lateral. Redundant valves in series located upstream and downstream of the laterals would control flow. The valves would be 6 m wide by 8 m high. There would be four conduits connecting each water saving basin to its corresponding lock chamber. Each conduit would be 6 m wide by 8 m high with a valve of the same dimensions. Two conduits from each basin would connect to the lock culvert on the basin side of the lock. The other two conduits would pass under the lock chamber through a crossover conduit and connect to the lock culvert opposite the basins.

The lateral to culvert area ratio (2.0) for the design would be higher than the existing system (1.8) but should be acceptable. The total port to culver area ratio of (2.04) would be less than the existing system and within acceptable limits. The port to conduit ratio of 1.0 would provide efficient operation with use of the water saving basins.

6.1.2. Performance

The system would be able to safely meet equalization time (12-15 minutes) and water surface slope criteria (<0.8/1000). Of the five alternatives under consideration, the interlaced bottom lateral system has the advantage of producing the lowest hawser forces. Overall, the system would provide the best hydraulic performance with or without use of water saving Cost

The estimated construction cost associated with this alternative is $1,040,000,000.

6.2. Alternative 2 – Side Port System with Water Saving Basins on One Side

6.2.1. Features

Lowering of the culvert with the intent of using more roller compacted concrete was considered. However, the west wall would need to be widened to provide adequate clearance to excavated rock. This would result in additional excavation and concrete quantities. Further design and cost analysis would be needed to explore if additional cost savings are possible. As with Alternative 1, the use of precast concrete components is a feasible method to reduce the duration lock construction.

Hydraulic designs for this system were primarily based upon guidance contained in EM 1110-2-1604, Hydraulic Design of Navigation Locks. Additional design information was obtained from model tests completed in 1961 for the side port systems of the Snell and Eisenhower ship locks on the Saint Lawrence Seaway. An upstream intake and downstream outlet manifold would connect to 8 m wide by 7 m high culverts located in each lock wall. Ports along the bottom of the culverts would connect to a vertical shaft before turning 90 degrees to connect directly with the lock chamber. The ports would enter the chamber near the midpoint of the submergence zone beneath the design ship. This port design would allow the culvert to be raised, which should facilitate a more narrow wall base and reduce the volume of concrete. Another advantage created by the longer port length would be a reduction in the downstream component of flow exiting the port. Each culvert would have 26 ports for a total of 52 ports per lock. Ports from one culvert would be staggered with respect to ports from the other culvert to reduce and dissipate turbulence. The ports would extend along 85% of the chamber length, which would be somewhat more than the 50%-60% referenced in the Corps guidance. The additional coverage would be required to meet equalization time criteria while maintaining the recommended port size and spacing. The ports would have an area of 2.85 m^2 each and be spaced at 16 m on center. Two laterals, one from each culvert, would be used to serve the areas between miter gates. Each lateral would have an area of 8 m^2. Ports would be distributed along the lateral with a total port area of 7.0 m^2 per lateral. Submergence equal to one-half the port spacing (8m) is provided beneath the design ship in the concept design in accordance with Corps' guidance. The guidance suggests that a 20% reduction in submergence will cause a 20% increase in filling time. The standard guidance is based on hydraulic modeling of mainly shallow draft, low to medium lift locks, with limited data on ship locks and high lift locks. The purpose of the submergence zone is to allow the jet to expand vertically, spread across the chamber, and dissipate before impinging on the hull of the vessel. The proposed lock floor elevation with the side port would be approximately 5 m lower compared to the other alternative filling systems. The submergence provided by this lower floor would still be less than that available at the Snell and Eisenhower ship locks on a scaled up basis (11-14 m); however, we expect the 8 m will be sufficient because of reduced head and lower discharge per unit volume under the ship. Even if the precise submergence requirement could be determined analytically, which is doubtful, such analysis is not warranted at the concept level. Ultimately, if this option is selected for final design, physical modeling will determine the minimum acceptable submergence, which may be greater or less than that recommended here. Redundant valves in parallel would be provided by bifurcation of the lock culvert into two 4 m wide by 7 m high culverts. There would be four conduits connecting each water saving basin to its corresponding lock chamber. Each conduit would be 6 m wide by 7 m high with a valve of the same dimensions. Two conduits from each basin would connect to the lock culvert on the basin side of the lock. The other two conduits would pass under the lock chamber through a crossover conduit and connect to the lock culvert opposite the basins.

The port to culvert area ratio (1.45) for the design would be higher than that typically recommended for a side port system. The port to conduit ratio (0.97) would conform to Corps guidance. Design emphasis was placed on the importance of the port to conduit area ratio since the water saving basin operations occur first and during filling operations the submergence beneath a ship would be a minimum.

6.2.2. Performance

The system would be able to safely meet equalization time (12-15 minutes) and water surface slope (<0.8/1000) criteria for the revised operating assumptions. Of the three filling and emptying system types under consideration, the side port systems have the disadvantage of producing the highest hawser forces and most turbulence during equalizations. Overall, the system would provide acceptable hydraulic performance with use of water saving basins. Longer equalization times could be required without water saving basins. Poor performance under most maintenance conditions would result in longer equalization times.

6.2.3. Cost

The estimated construction cost associated with this alternative is $1,052,000,000.

6.3. Alternative 3 - Side Port System with Water Saving Basins on Both Sides

6.3.1. Features

Lowering of the culvert with the intent of using more roller compacted concrete was considered. However, both the east and west walls would need to be widened to provide adequate clearance to excavated rock. This would result in additional excavation and concrete quantities. Further design and cost analysis would be needed to explore if additional cost savings are possible. As with Alternative 1, the use of precast concrete components is a feasible method to reduce the duration lock construction.

Basic design features for the side port filling and emptying system with water saving basins on both sides were the same as those described in Section 6.2. By placing the water saving basins on both sides, crossover conduits under the lock chamber floor would be eliminated. There would be two basins on each side of the lock with each basin having a surface area equal to one-half of the lock chamber area. Each basin would have two 6 m wide by 7 m high conduits connecting to the adjacent lock culvert.

6.3.2. Performance

The system would be able to safely meet equalization time (12-15 minutes) and water surface slope (<0.8/1000) criteria for the revised operating assumptions. Of the three filling and emptying system types under consideration, the side port systems have the disadvantage of producing the highest hawser forces and most turbulence during equalizations. Hydraulic performance should improve slightly with water saving basins on both sides of the lock. Overall, the system would provide acceptable hydraulic performance with use of water saving basins. Longer equalization times could be required without water saving basins. Poor performance under maintenance conditions would result in longer equalization times.

6.3.3. Cost

The estimated construction cost associated with this alternative is $1,034,000,000.

6.4. Alternative 4 – In-Chamber Longitudinal Culvert System with Water Saving Basins on Both Sides, Anchored Walls

6.4.1. Features

There is design risk associated with the adequacy of the tied-back system and water saving basin floor details due to the uncertainty inherent with simplified analysis used in its development. Concerns with the rocking motion of lock walls and possibilities of buckling the lower water saving basin floor slab during an earthquake has not been evaluated as part of this concept study. Some skepticism exists with this design concept.

Hydraulic designs for this system were primarily based upon previous studies conducted by the Coastal and Hydraulics Laboratory of the Corps Engineer Research and Development Center (ERDC). An upstream intake and downstream outlet manifold would connect to 8 m wide by 7 m high culverts. At the intake, outlet, and valves, the lock culverts would be located in the lock walls. Within the lock chamber the culverts would transition to an 8 m wide by 8 m high section and run longitudinally along the floor with transitions at the upstream and downstream sections. The additional culvert area should help in meeting equalization time criteria for the operations with water saving basins. The elevation of the top of the culverts would be set equal to the sill elevation to provide the required clearance. The lock floor adjacent to the culverts would be slightly lower to allow sufficient space for the ports. The centerline of the longitudinal culverts would be located at the transverse quarter points of the chamber. Ports would be located on both sides of the longitudinal culverts just below the culvert roof. Two groupings of ports would be centered at the longitudinal one-third points of the chamber. Each culvert would have 32 pairs of ports spaced in a staggered arrangement at 5.5 m on center for a total of 128 ports per lock. Each port has an area of 0.975 m^2. The distance between the upstream and downstream most port would be approximately 50% of the pintle-to-pintle distance in accordance with research findings. Additional features related to the ports would include a culvert roof overhang to redirect the jet and a wall baffle to diffuse the jet. Two laterals, one from each culvert, would be used to serve the areas between miter gates. Each lateral would have an area of 8 m^2. Ports would be distributed along the lateral with a total port area of 7.0 m^2 per lateral. Redundant valves in parallel would be provided by bifurcation of the lock culvert into two 4 m wide by 7 m high valves. There would be two water saving basins on each side of the lock with each basin having a surface area equal to one-half of the lock chamber area. Each basin would have two 6 m wide by 7 m high conduits connecting to the adjacent lock culvert.

The port to culvert area ratio (0.975) for the design would be consistent with research findings and previous designs. The port to conduit ratio (0.74) would be somewhat low but within reasonable limits. The port arrangement could be reconfigured if necessary to increase the ratio.

6.4.2. Performance

The system would be able to safely meet equalization time (12-15 minutes) and water surface slope criteria (<0.8/1000) for the revised operating assumptions. Hydraulic performance is expected to be slightly better than a side port system. Hawser forces are expected to be slightly higher than the interlaced bottom lateral system. Overall, the system would provide acceptable hydraulic performance with use of water saving basins under normal conditions. Longer equalization times may be required without water saving basins. Performance under maintenance conditions would be better than a side port system but not as good as a bottom lateral system.

6.4.3. Cost

The estimated construction cost associated with this alternative is $1,019,000,000.

6.5. Alternative 4a – In-Chamber Longitudinal Culvert System with Water Saving Basins on Both Sides, Gravity Walls

6.5.1. Features and Performance

Hydraulic design features and performance of the side port filling and emptying system with water saving basins incorporated into the lock walls are the same as those described in Section 6.4.

An advantage of gravity walls is that the construction duration would be reduced by the extensive use of roller compacted concrete. This should result is savings in construction costs and interest paid on borrowed money.

6.5.2. Cost

The estimated construction cost associated with this alternative is $1,027,000,000.

7. RECOMMENDATIONS

The construction costs of all alternatives are essentially the same. Recommendations are based on the merits of filling and emptying systems and advantages offered by processes used for construction. A comparison of these attributes is shown in Table 7-1. Based on this evaluation, Alternative 4a, In-Chamber Longitudinal Culvert System with WSB on Both Sides, Gravity Walls is recommended as the second filling system for the double-lift lock configuration for the following reasons:

- The nature of the filling system reduces the potential for side-to-side movements of ships within the lock chamber.

- Removal of culverts from the lock walls over significant reaches of lock wall allows for faster construction through the use of more roller compacted concrete.

Table 7-1 Comparison of Alternatives

ALTERNATIVE	COST	HYDRAULIC	STRUCTURAL	CONSTRUCTION
Modified Interlaced Bottom Lateral System	$1,040,000	• Lowest hawser forces • Good performance with or without WSBs • Good performance for maintenance condition	• The higher foundation elevation reduces over turning moments and results in less massive walls. • There are no unusual design issues.	• Bottom laterals require more complex forming. • Culverts in the wall reduce percentage of RCC
Side Port System with WSB on One Side	$1,082,000	• Highest hawser forces • Acceptable performance with WSBs. May require longer times without WSBs • Poor performance for maintenance conditions	• The foundation elevation is lower than Interlace Bottom Lateral system resulting in higher over turning moments that leads to an increase in wall dimensions. The result is a need for larger concrete volumes and more extensive excavation.	• Simplified floor construction • Culverts in the wall reduce percentage of RCC
Side Port System with WSB on Both Sides	$1,034,000	• Relatively high hawser forces • Acceptable performance with WSBs. May require longer times without WSBs • Poor performance for maintenance conditions	• The foundation elevation is lower than Interlace Bottom Lateral system resulting in higher over turning moments that leads to an increase in wall dimensions. The result is a need for larger concrete volumes and more extensive excavation.	• Simplified floor construction • Culverts in the wall reduce percentage of RCC

ALTERNATIVE	COST	HYDRAULIC	STRUCTURAL	CONSTRUCTION
In-Chamber Longitudinal Culvert System with WSB on Both Sides, Anchored Walls	$1,019,000	• Relatively moderate hawser forces • Acceptable performance with WSBs. May require longer times without WSBs • Acceptable performance for maintenance conditions	• Deepest foundations • Long-term performance of anchorage system is questionable. • Rigorous structural analysis is required prior to selection of this alternative to demonstrate adequate performance in seismic conditions.	• Potential time savings due to increased percentage of RCC, and least overall concrete quantity • Least amount of excavation • Use of post-tensioning increases risk and difficulty of construction. • Culverts out of walls eases construction.
In-Chamber Longitudinal Culvert System with WSB on Both Sides, Gravity Walls	$1,027,000	• Relatively moderate hawser forces • Acceptable performance with WSBs. May require longer times without WSBs • Acceptable performance for maintenance conditions	• Deeper foundations result in more massive wall sections. • Does not rely on external stability systems. • Conventional design procedures can be applied.	• Potential time and cost savings due to increased percentage of RCC, and least overall concrete quantity • Culverts out of walls eases construction

8. ATTACHMENTS

Attachment A	Modification No. 2 to Implementing Agreement Relating to Project Work Order (IAPWO), IAPWO No. SAA-80640
Attachment B	Alternative 1 – Modified Interlaced Bottom Lateral
Attachment C	Alternative 2 - Side Port System with Water Saving Basins on One Side
Attachment D	Alternative 3 – Side Port System with Water Saving Basins on Both Sides
Attachment E	Alternative 4 - In-Chamber Longitudinal Culvert System with Water Saving Basins on Both Sides, Anchored Walls
Attachment F	Alternative 4a - In-Chamber Longitudinal Culvert System with Water Saving Basins on Both Sides, Gravity Walls
Attachment G	Cost Estimate
Attachment H	Revised Miter Gate and Entrance Wall Drawings

Attachment 1

Modification No. 2 to Implementing Agreement Relating to Project Work Order (IAPWO), IAPWO No. SAA-80640

MODIFICATION NO. 2

TO

IMPLEMENTING AGREEMENT RELATING TO PROJECT WORK ORDER (IAPWO)

FOR THE

AGREEMENT BETWEEN THE DEPARTMENT OF THE ARMY OF THE UNITED STATES OF AMERICA AND THE PANAMA CANAL AUTHORITY OF THE GOVERNMENT OF THE REPUBLIC OF PANAMA CONCERNING PROVISION OF EQUIPMENT, MATERIAL, TRAINING AND SERVICES TO THE PANAMA CANAL AUTHORITY, 13 DECEMBER 2000

IAPWO NO. SAA-80640

1. Reference IAPWO NO. SAA-80640 and Modification No. 1 to IAPWO NO. SAA-80640.

2. Pursuant to paragraph 10 of IAPWO NO. 80640 and Article XV of the Memorandum of Agreement between the Panama Canal Authority and the Department of the Army dated 13 December 2000, the referenced Work Order is being amended as follows:

   Scope of Work – The Scope of Work is amended as detailed on the attached "Changes to the Scope of Work".

   Schedule – The schedule for deliverables is amended as per the attached "Changes to the Scope of Work".

   Funding – The total estimated cost for USACE technical assistance required for this Work Order is increased by $292,500.00 for a new total estimated cost of $2,242,500.00. The additional funds are to cover additional studies as detailed on the attached "Changes to the Scope of Work".

3. All other terms and conditions of the Memorandum of Agreement and Work Order remain the same, and have the same force and effect as in the original.

For the Panama Canal Authority:

Alberto Aleman Zubieta

For the Department of the Army:

Bruce A. Smith
Assistant for Interagency and
International Affairs
Secretary of the Army (Civil Works)

MODIFICATION NO. 2
TO
IAPWO NO. SAA-80640

CHANGES TO THE SCOPE OF WORK

The Scope of Work for Work Order IAPWO NO. SAA-80640, Concept Design of Atlantic Side Locks, is amended as follows.

1. Add additional screening studies to identify advantages, disadvantages and "rough order of magnitude" costs for the following Filling and Emptying Systems alternatives in the two-lift lock configuration as submitted in October 2002.

   a. Interlaced Lateral System without the consideration of a fourth lane.
   b. In Chamber Longitudinal System (ICLS) with water savings basins on both sides incorporated into the lock walls
   c. Side Port System with water savings basins on both sides incorporated into the lock walls.
   d. Side Port System with water savings basins on both sides but not incorporated into the lock walls.

The ACP will work closely with the USACE design team during the above screening studies and the subsequent studies of the three-lift configuration and participate in decision making to identify opportunities for selecting lock system features that meet cost effectiveness objectives.

ACP personnel will participate with the USACE design team in the Pittsburgh District offices as necessary for coordination and review. USACE will provide office support at no additional cost. This effort will accomplish the technology transfer requirement of the original scope of work.

2. The assumption is make that if a fourth lane of locks is constructed in the future that there will be sufficient distance between the third and fourth lane that construction of the fourth lane will not affect the design of the third lane locks.

3. Revise and resubmit the two-lift configuration draft report to include the revised Interlaced Lateral System and either the Side Port or the ICLS filling and emptying system that was identified as the most advantageous in the above screening studies.

4. Produce a concept level design for a three-lift configuration lock using components that are scaled from those selected for the two-lift configuration. Only one filling and emptying system will be presented for the three-lift alternative. The system selected from the screening study in paragraph 1 above will be presented in the three-lift configuration. Minimal new analysis will be performed for this alternative and only to the level that a reasonable determination can be made as to the adequacy of the component for safety and operability and to set general dimensions for project quantities. The purpose of this effort will be to produce a reasonable cost estimate for comparison to the two-lift configuration.

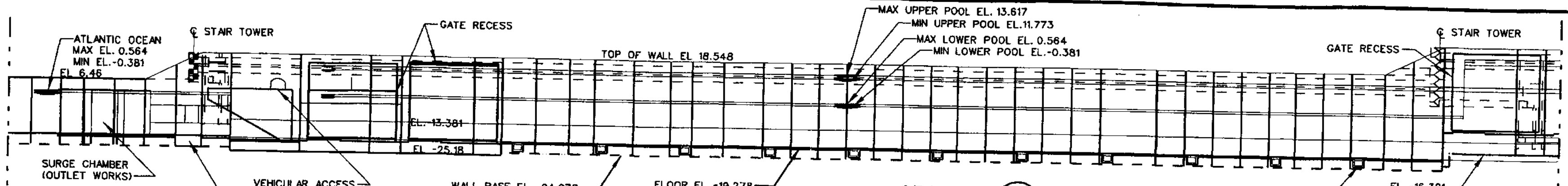
5. Additional coordination trips will be made to ACP by the design team as required to coordinate the completion of this Work Order. As a minimum the USACE will travel to Panama to present the completed final report.

6. The schedule for submittals is revised as follows.

Submit draft revised two-lift configuration	21 Mar 2003
Submit draft three-lift configuration	16 May 2003
Submit Draft final report	16 Jun 2003
Submit final report	23 Jul 2003

Attachment 2

Alternative 1 – Modified Interlaced Bottom Lateral System



SECTION P

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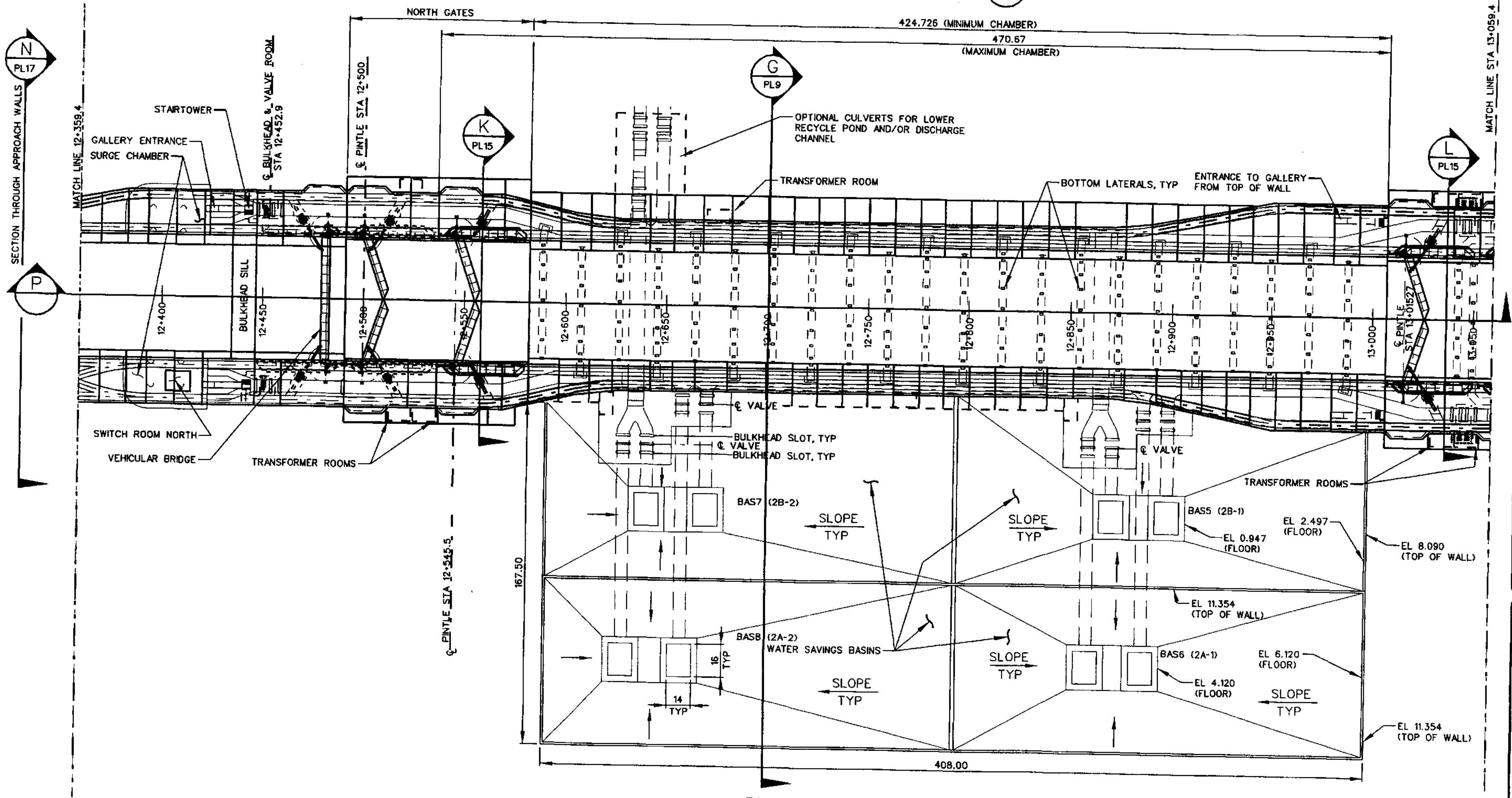

PLAN - LOWER LOCK CHAMBER

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US Army Corps of Engineers
Pittsburgh District

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Dwn by: JET
Ckd by:
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Submission Date:
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Sheet X of X

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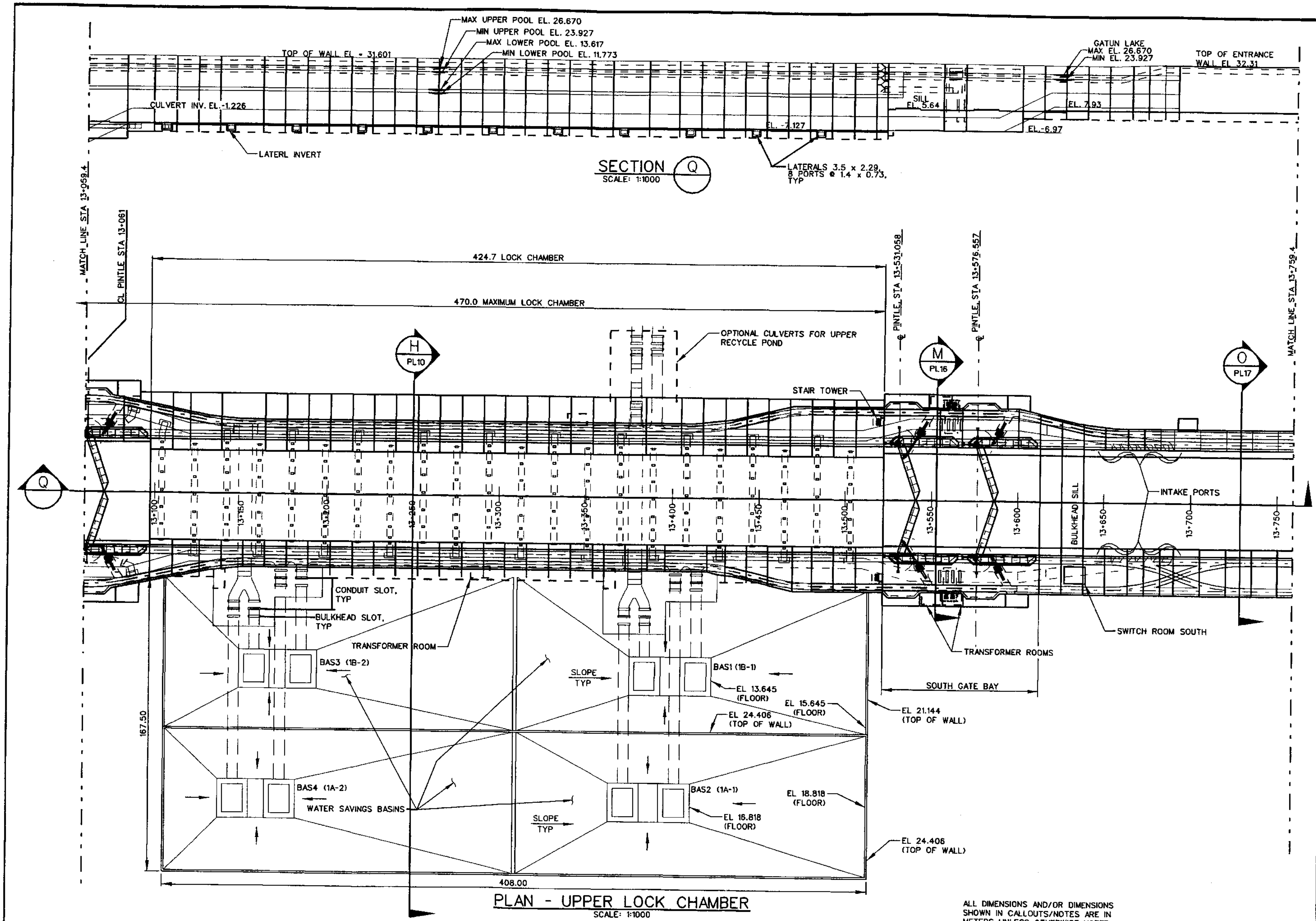
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
DOUBLE LIFT LOCK - SCREENING STUDY
ALTERNATIVE #1 - BOTTOM INTERLACED LATERALS
PLAN AND ELEVATION

Drawing Number: ACP-SS-PL1



SECTION Q
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PLAN - UPPER LOCK CHAMBER
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Submitted by: A. HARKNESS
TECHNICAL LEAD

Sheet X of X

Design by: A.HARKNESS
Dwn by: JET
Ckd by: RA
Submission Date:
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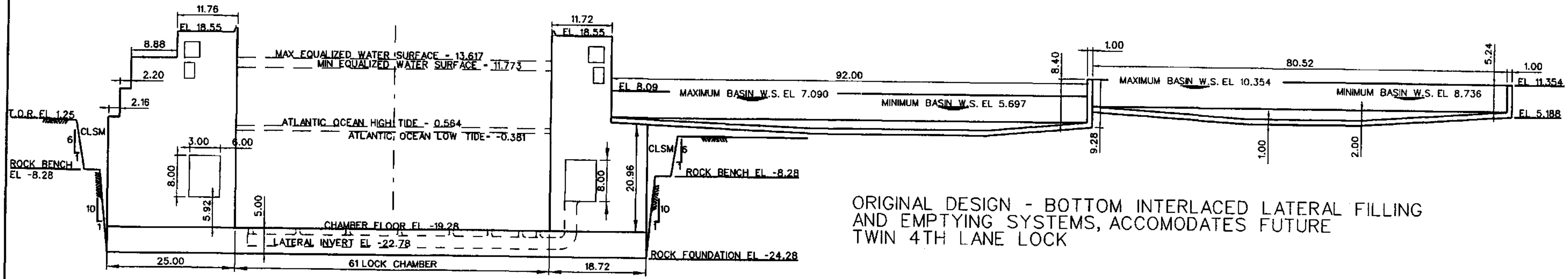
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
DOUBLE LIFT LOCK - SCREENING STUDY
ALTERNATIVE #1 - BOTTOM INTERLACED LATERAL
PLAN AND ELEVATION

Drawing Number: ACP-SS-PL2



ORIGINAL DESIGN - BOTTOM INTERLACED LATERAL FILLING AND EMPTYING SYSTEMS, ACCOMODATES FUTURE TWIN 4TH LANE LOCK

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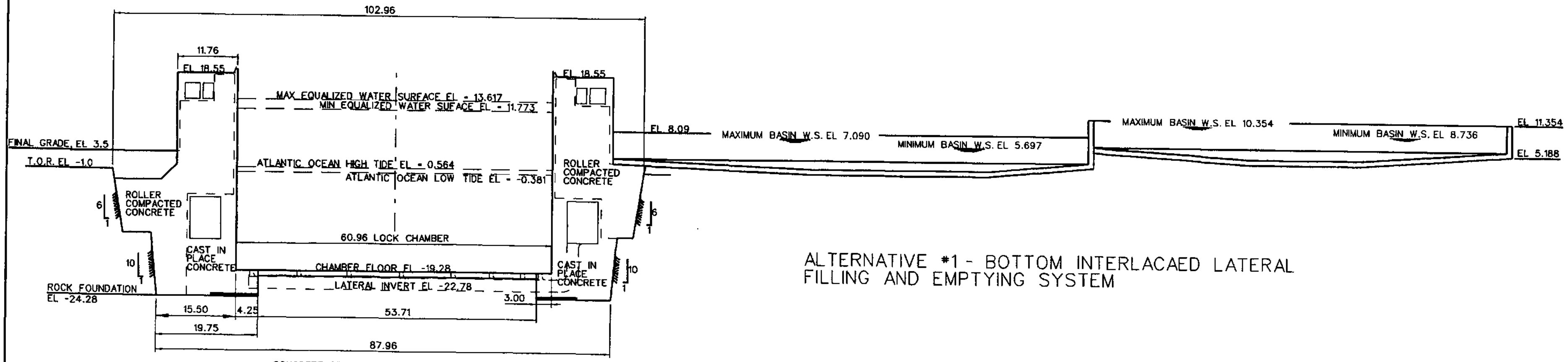
STA 12+700



CONCRETE CROSS SECTIONAL AREA - 1232 m^2

ALTERNATIVE #1 - BOTTOM INTERLACAED LATERAL FILLING AND EMPTYING SYSTEM

SECTION G
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SCALE: 1:400
STA 12+700

W.S- WATER SURFACE

US Army Corps of Engineers
Pittsburgh District

Submitted by:
A. HARKNESS
TECHNICAL LEAD

Sheet X of X

Design by: A HARKNESS
Dwn by: JT
Ckd by: RA
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Revision Date: X
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PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
DOUBLE LIFT LOCK - SCREENING STUDY
ALTERNATIVE #1
SECTIONS G - ORIGINAL AND H DESIGN

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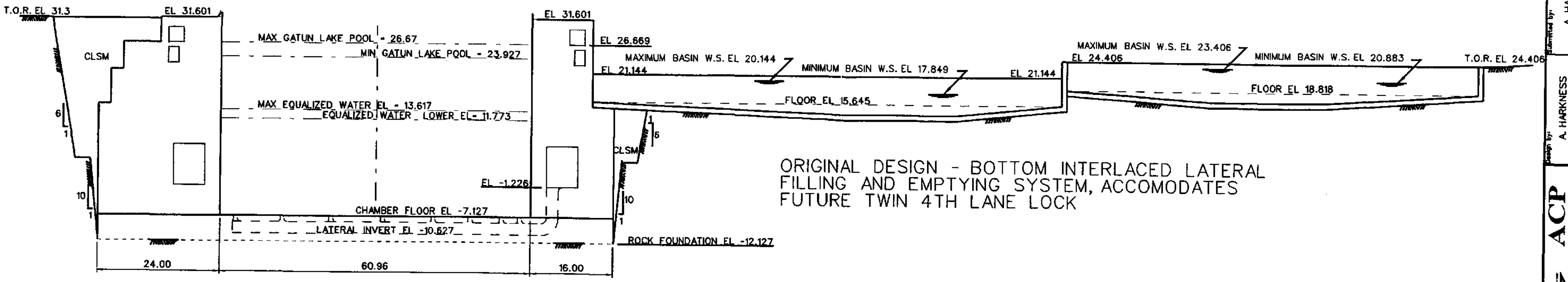

ORIGINAL DESIGN - BOTTOM INTERLACED LATERAL FILLING AND EMPTYING SYSTEM, ACCOMODATES FUTURE TWIN 4TH LANE LOCK

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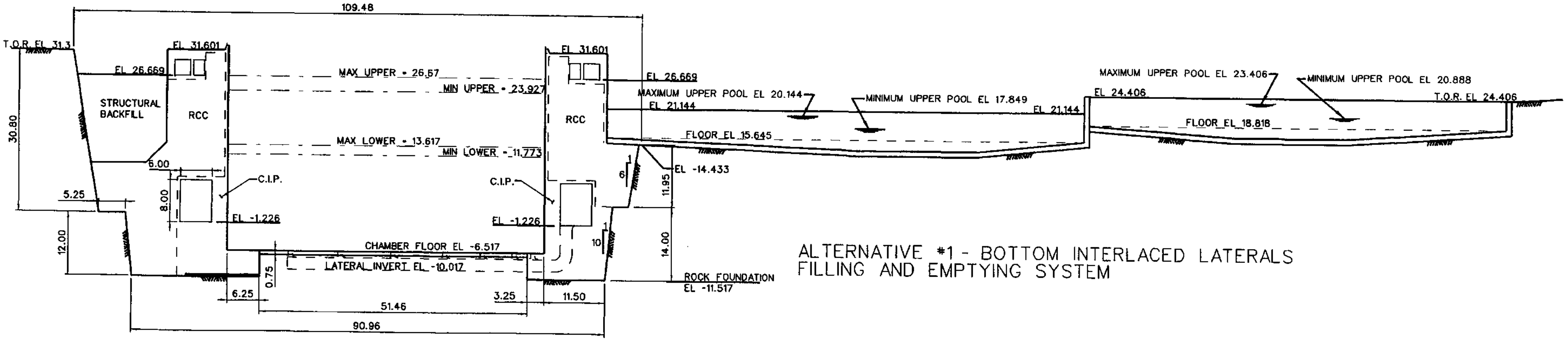
(UPPER CHAMBER)



ALTERNATIVE #1 - BOTTOM INTERLACED LATERALS FILLING AND EMPTYING SYSTEM

SECTION (H / PL2)
SCALE: 1:400
STA 13+250
(UPPER CHAMBER)

US Army Corps
of Engineers
Pittsburgh District

Submitted by: A. HARKNESS
TECHNICAL LEAD

Design by: A. HARKNESS
Dwn by: JT
Ckd by: RA
Submission Date: X
Revision Date: X
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Sheet X of X

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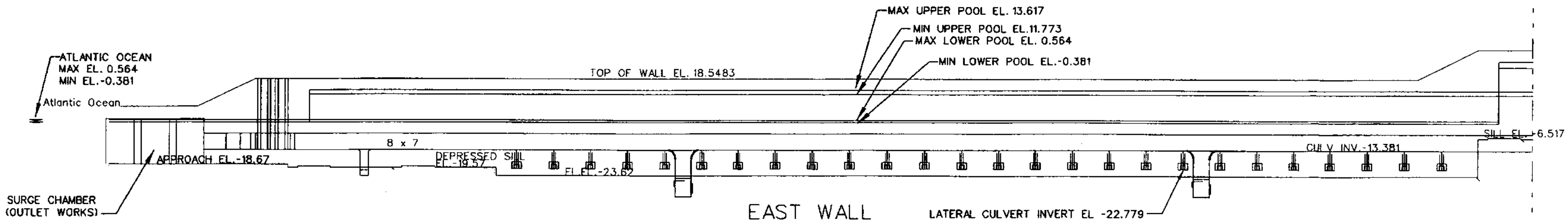
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
PRELIMINARY DOUBLE LIFT - SCREENING STUDY
ALTERNATIVE #1 SIDE PORT IWSB
SECTIONS G AND H ALTERNATIVE #1

Drawing Number:
ACP-SS-PL10

Attachment 3

Alternative 2 - Side Port System with Water Saving Basins on One Side



EAST WALL ELEVATION

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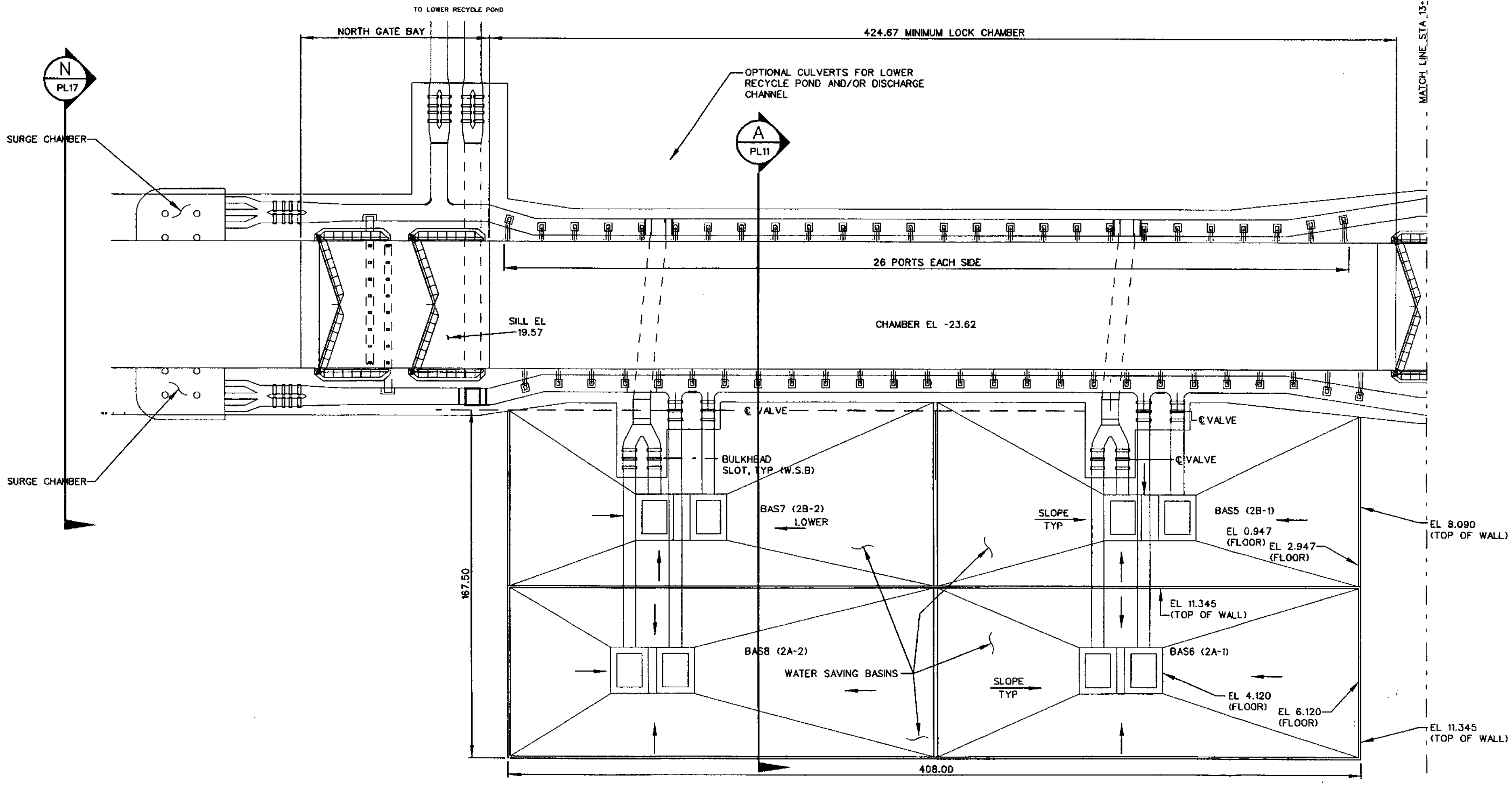

PLAN - LOWER LOCK CHAMBER

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US Army Corps of Engineers
Pittsburgh District

Submitted by: A HARKNESS
TECHNICAL LEAD

Sheet X of X

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Design by: A HARKNESS
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Submission Date: X
Revision Date: X

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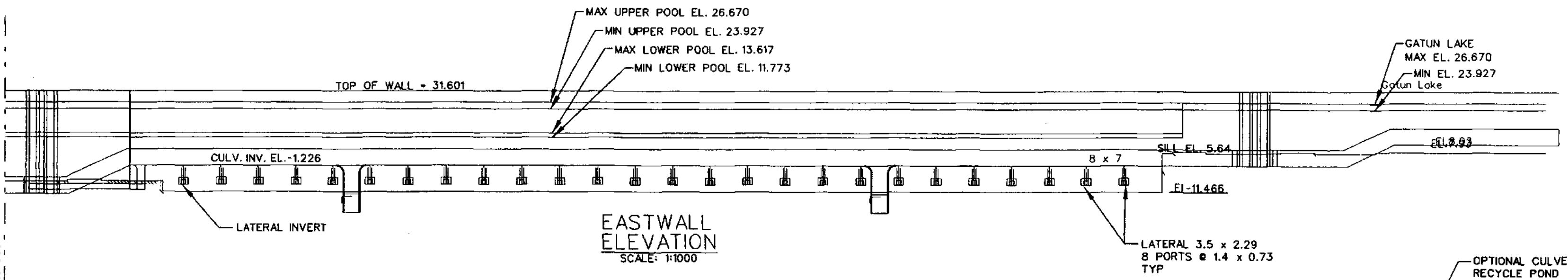
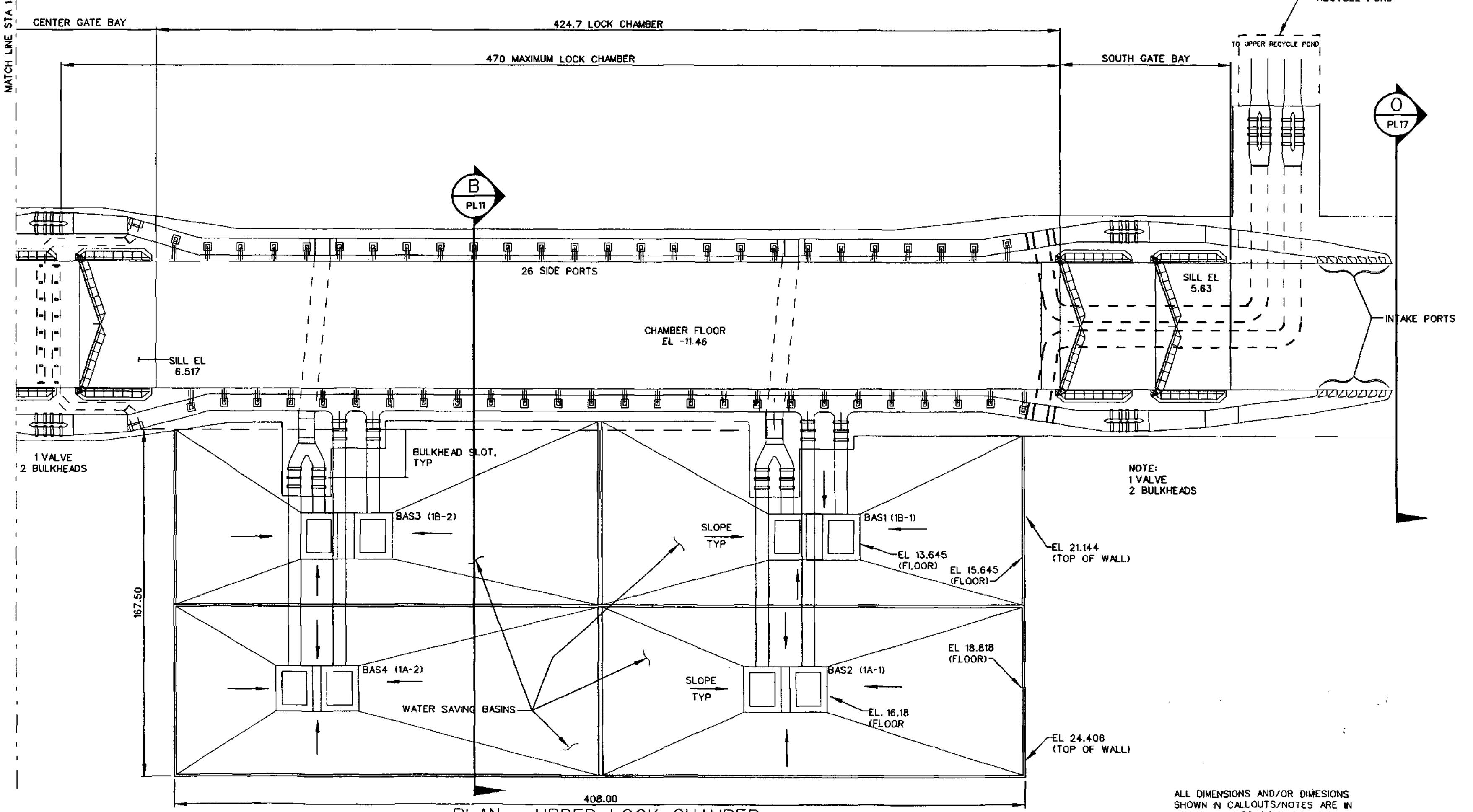
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
DOUBLE LIFT LOCK - SCREENING STUDY
ALTERNATIVE #2 - SIDE PORT IWSB
PLAN AND ELEVATION

Drawing Number: ACP-SS-PL3



EASTWALL ELEVATION

SCALE: 1:1000



PLAN - UPPER LOCK CHAMBER

SCALE: 1:1000

ALL DIMENSIONS AND/OR DIMESIONS SHOWN IN CALLOUTS/NOTES ARE IN METERS UNLESS OTHERWISE NOTED.

US Army Corps
of Engineers
Pittsburgh District

Submitted by:
A HARKNESS
TECHNICAL LEAD

Sheet X of X

Design by: A HARKNESS
Ckd by: RA
Dwn by: JT
Submission Date: X
Revision Date: X
PB NO.:

ACP
AUTORIDAD DEL CANAL DE PANAMA

User: dmarcial
Date: 10-FEB-2003 15:39
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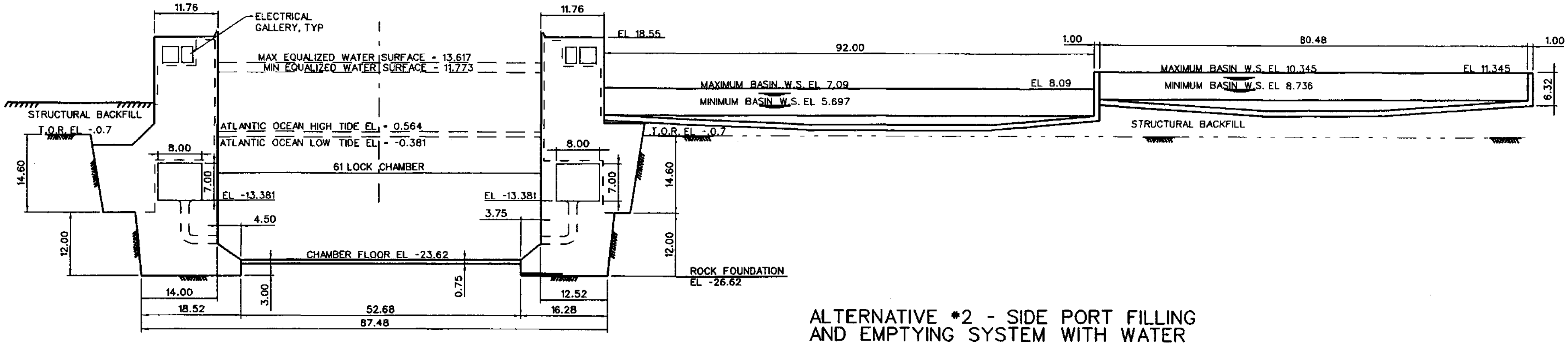
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
DOUBLE LIFT LOCK - SCREENING STUDY
ALTERNATIVE #2 - SIDE PORT, IWSB
PLAN AND ELEVATION

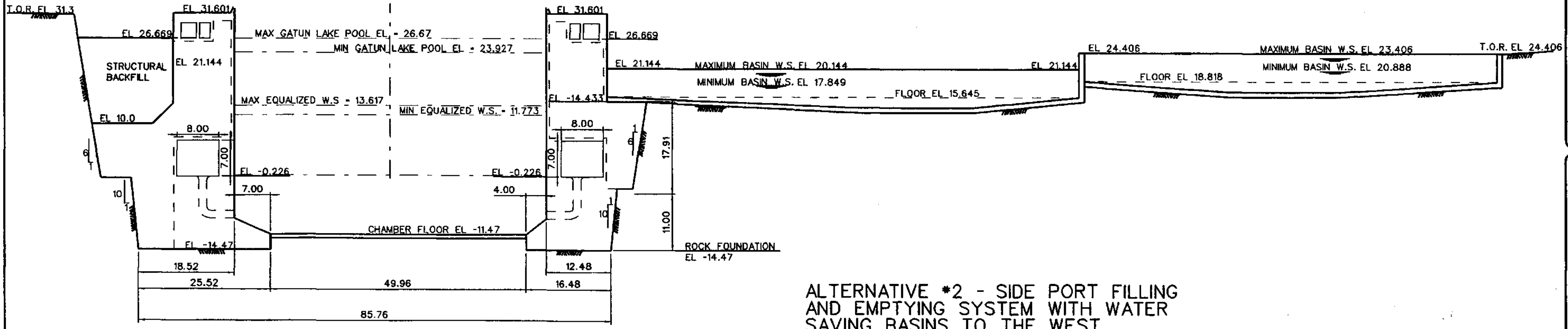
Drawing Number:
ACP-SS-PL4



ALTERNATIVE #2 - SIDE PORT FILLING AND EMPTYING SYSTEM WITH WATER SAVING BASINS TO THE WEST

SECTION A PL3
SCALE: 1:400

(LOWER LOCK CHAMBER)



ALTERNATIVE #2 - SIDE PORT FILLING AND EMPTYING SYSTEM WITH WATER SAVING BASINS TO THE WEST

SECTION B PL4
SCALE: 1:400

(UPPER LOCK CHAMBER)

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US Army Corps of Engineers
Pittsburgh District

Submitted by: A HARKNESS
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Sheet X of X

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Submission Date: X
Revision Date: X
FB NO.:

ACP
AUTORIDAD DEL CANAL DE PANAMA

User: Gnardini
Date: 19-FEB-2003 15:38
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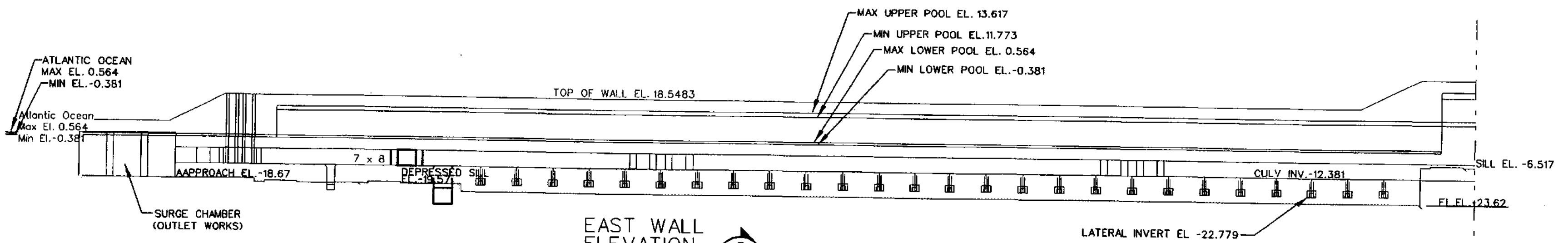
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
DOUBLE LIFT LOCK - SCREENING STUDY
ALTERNATIVE #2
SECTIONS A & B

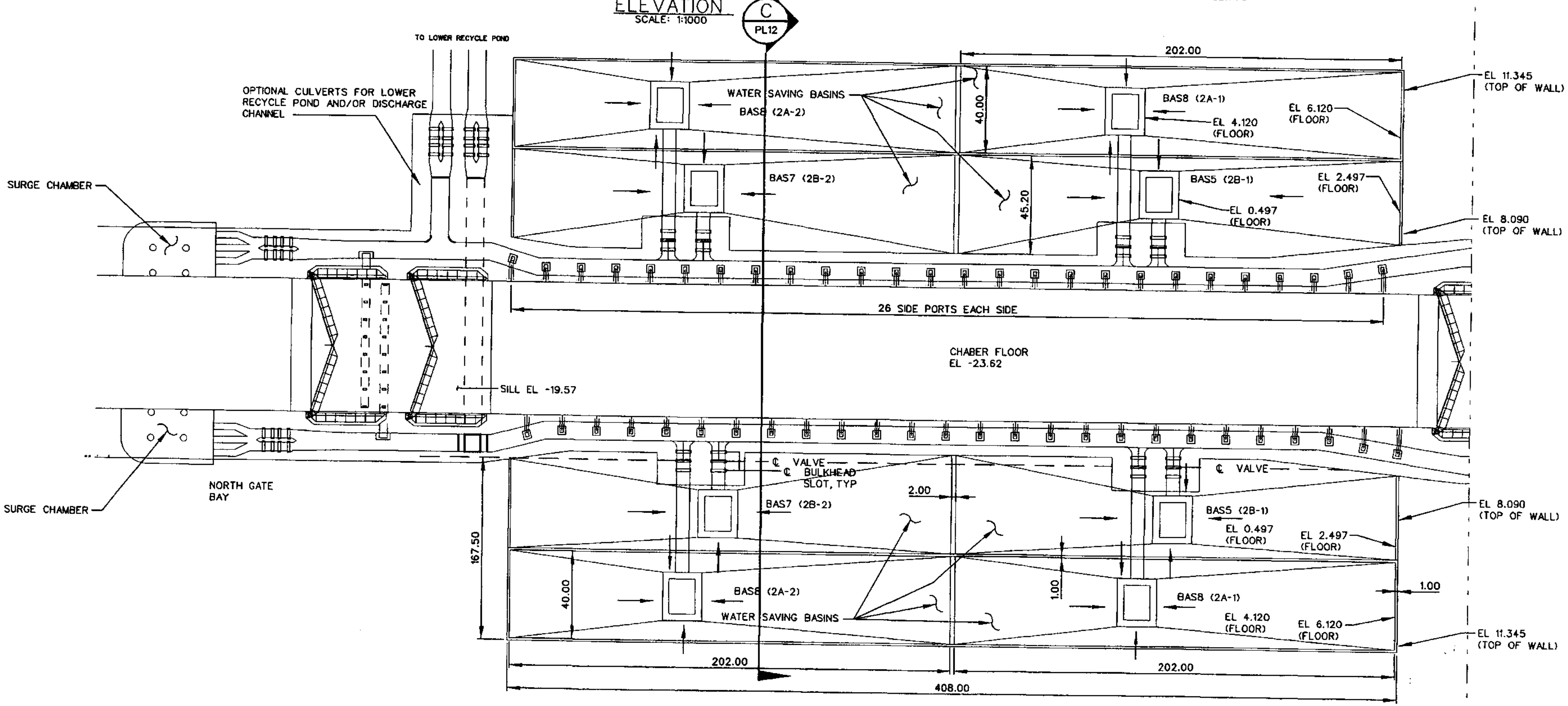
Drawing Number: ACP-SS-PL11

Attachment 4

Alternative 3 – Side Port System with Water Saving Basins on Both Sides



EAST WALL ELEVATION
SCALE: 1:1000



PLAN - LOWER LOCK CHAMBER
SCALE: 1:1000

ALL DEMENSIONS AND/OR DIMENSIONS
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Pittsburgh District

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Submission Date: X
Revision Date: X
Sheet X of X

ACP
AUTORIDAD DEL CANAL DE PANAMA

User: dmarani
Date: 19-FEB-2003 15:38
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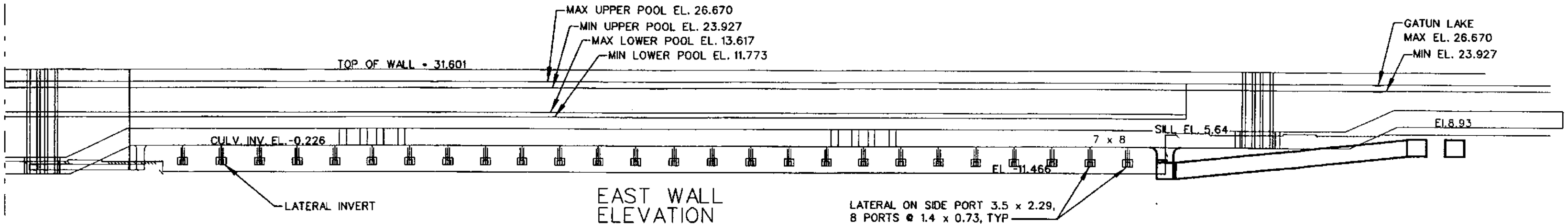
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
DOUBLE LIFT LOCK - SCREENING STUDY
ALTERNATIVE #3 - SIDE PORT WITH SPLIT WSB
PLAN AND ELEVATION

Drawing Number: ACP-SS-PL5



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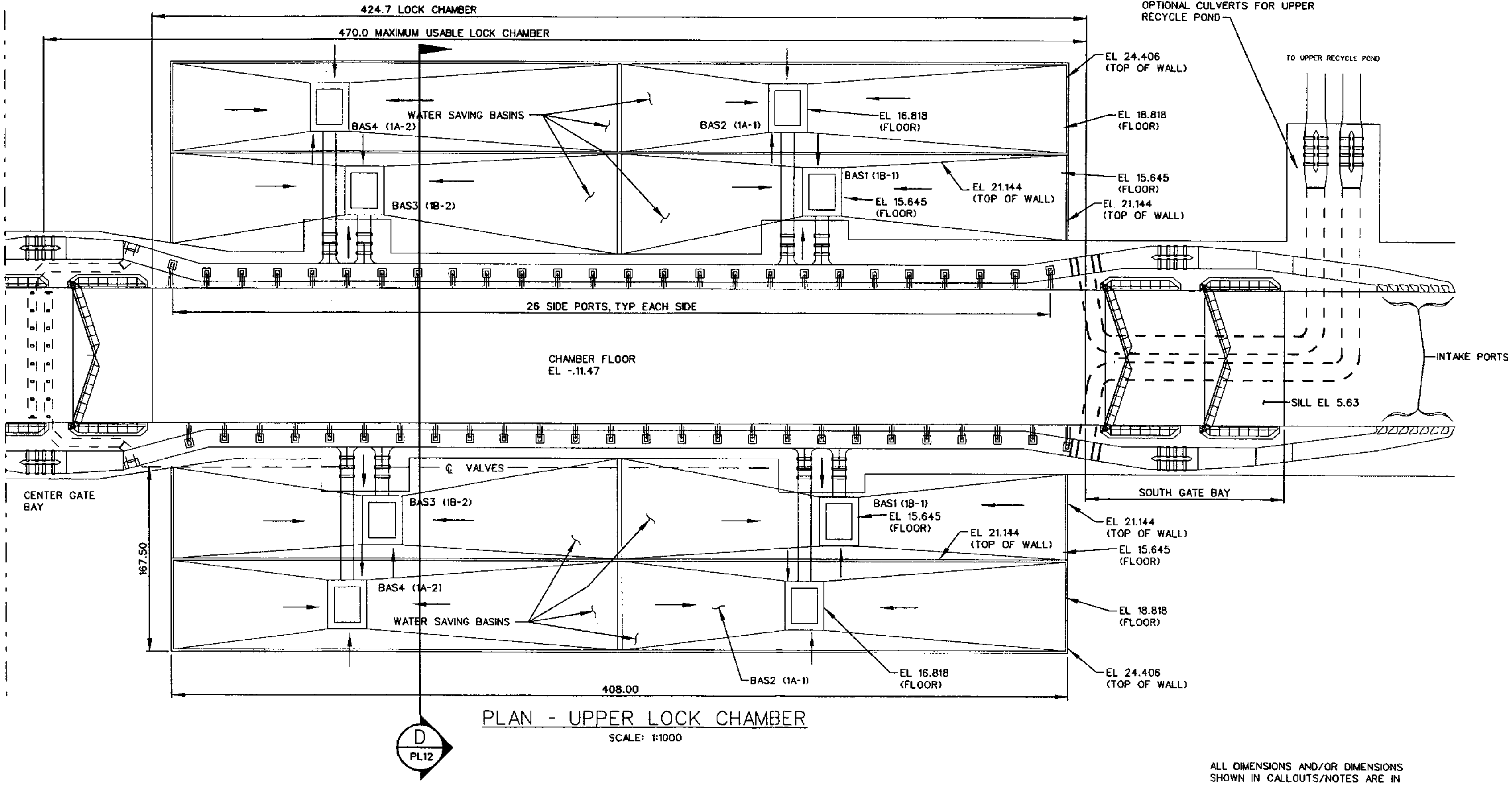

PLAN - UPPER LOCK CHAMBER

SCALE: 1:1000

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Pittsburgh District

Submitted by: A HARKNESS
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Sheet X of X

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Ckd by: RA
Submission Date: X
Revision Date: X
PB NO.:

ACP
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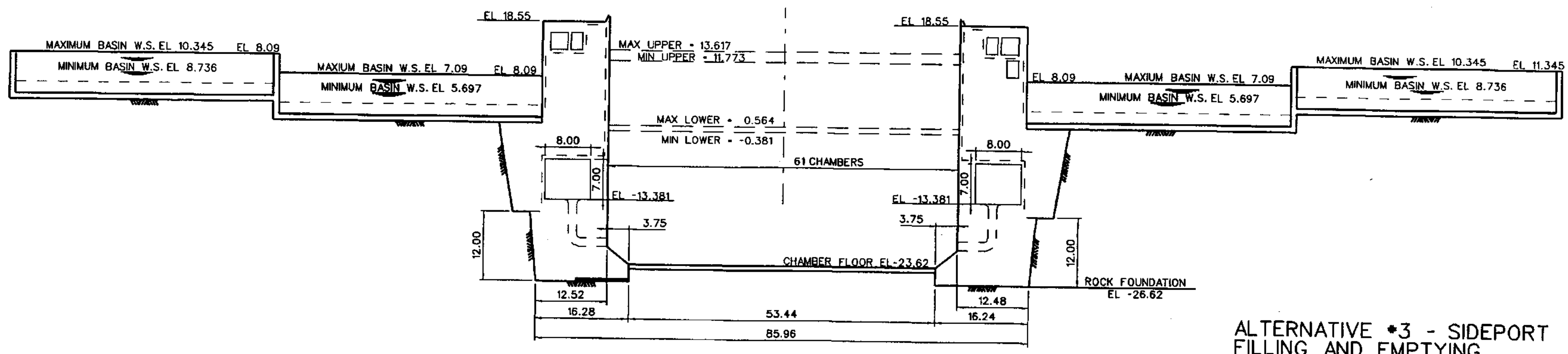
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
DOUBLE LIFT LOCK - SCREENING STUDY
ALTERNATIVE #3 - SIDE PORT WITH SPLIT WSB
PLAN AND ELEVATION

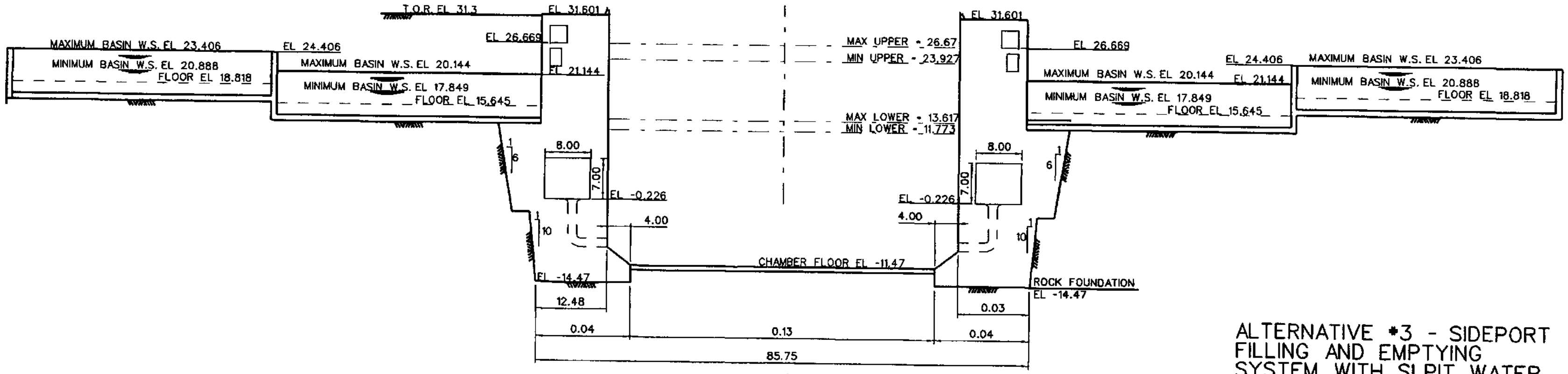
Drawing Number:
ACP-SS-PL6



SECTION C
SCALE: 1:400
PL5

(LOWER LOCK CHAMBER)

ALTERNATIVE •3 - SIDEPORT FILLING AND EMPTYING SYSTEM WITH SLPIT WATER SAVING BASINS



SECTION D
SCALE: 1:400
PL6

(UPPER LOCK CHAMBER)

ALTERNATIVE •3 - SIDEPORT FILLING AND EMPTYING SYSTEM WITH SLPIT WATER SAVING BASINS

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US Army Corps
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Pittsburgh District

Submitted by: A. HARKNESS
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Sheet X of X

Design by: A. HARKNESS
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Ckd by: RA
Submission Date: X
Revision Date: X
FB NO.:

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AUTORIDAD DEL CANAL DE PANAMA

User: dmarohn
Date: 19-FEB-2003 15:40
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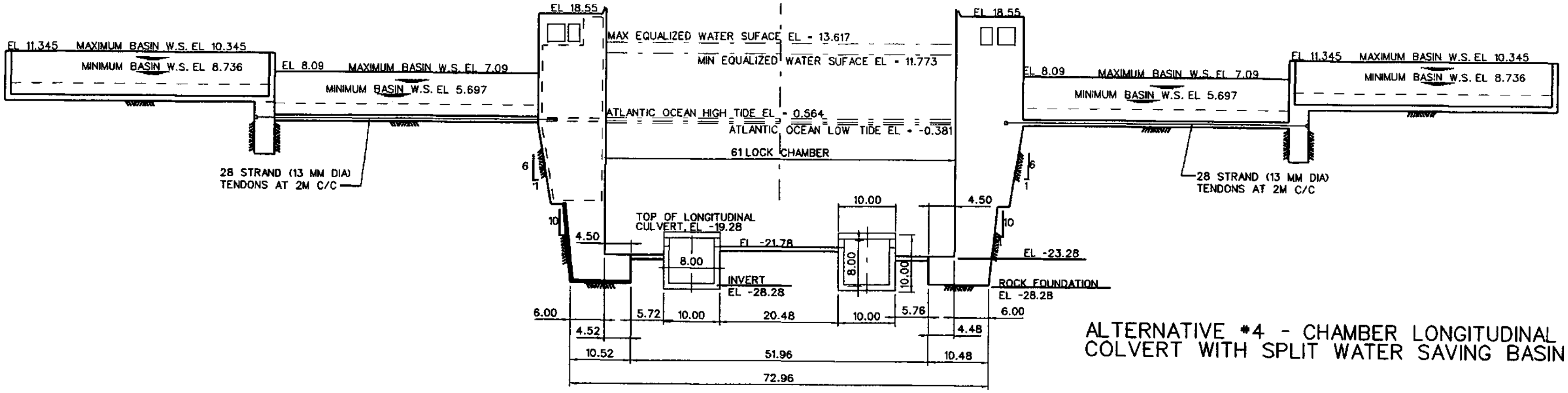
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
DOUBLE LIFT LOCK - SCREENING STUDY
ALTERNATIVE •3 SIDEPORT, SPLIT W.S.B
SECTIONS C & D

Drawing Number: ACP-SS-PL12

Attachment 5

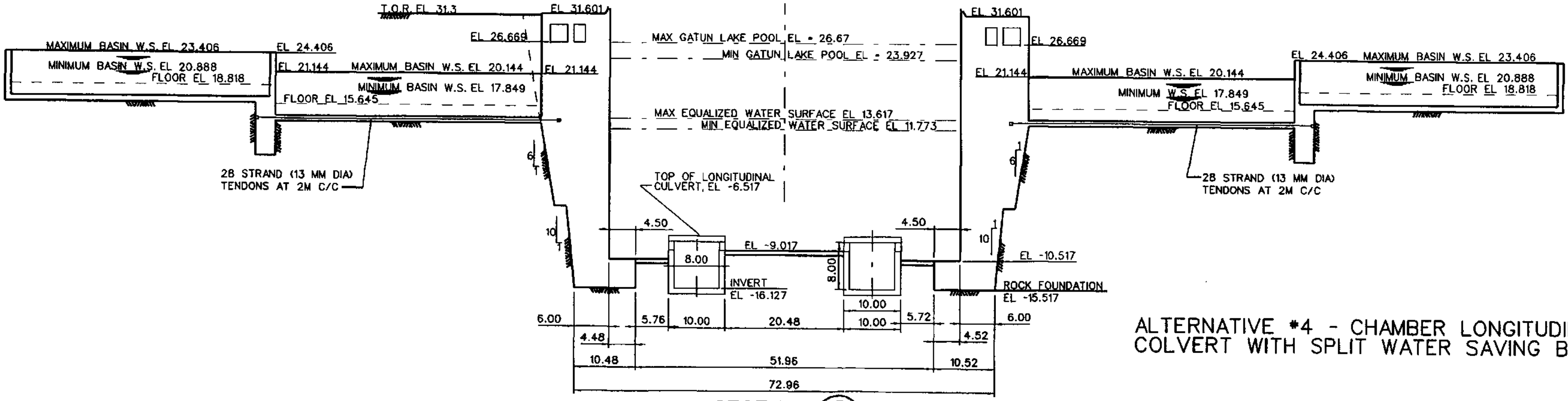
Alternative 4 - In-Chamber Longitudinal Culvert System with Water Saving Basins on Both Sides, Anchored Walls



ALTERNATIVE #4 - CHAMBER LONGITUDINAL COLVERT WITH SPLIT WATER SAVING BASIN

SECTION E
SCALE: 1:400
PL7

(LOWER LOCK CHAMBER)



ALTERNATIVE #4 - CHAMBER LONGITUDINAL COLVERT WITH SPLIT WATER SAVING BASIN

SECTION F
SCALE: 1:400
PL8

(UPPER LOCK CHAMBER)

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US Army Corps
of Engineers
Pittsburgh District

ACP
AUTORIDAD DEL CANAL DE PANAMA

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Dwn by:	JT
Ckd by:	RA
Submission Date:	X
Revision Date:	X
Submitted by:	A HARKNESS TECHNICAL LEAD
PB NO.:	
Sheet X of X	

User: dmazani
Date: 19-FEB-2003 15:40
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Color Table

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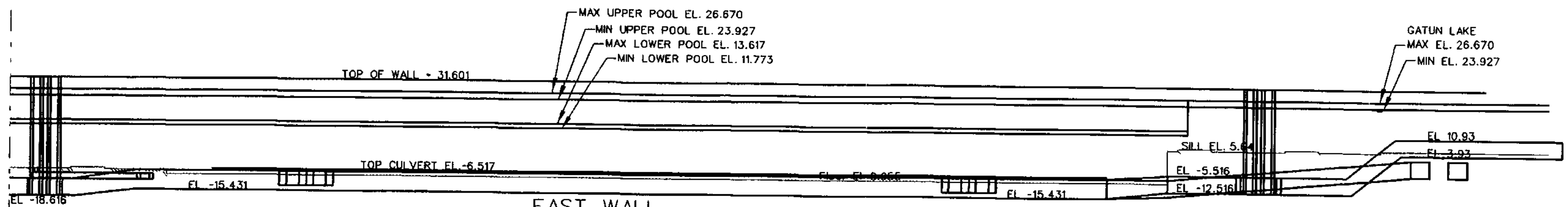
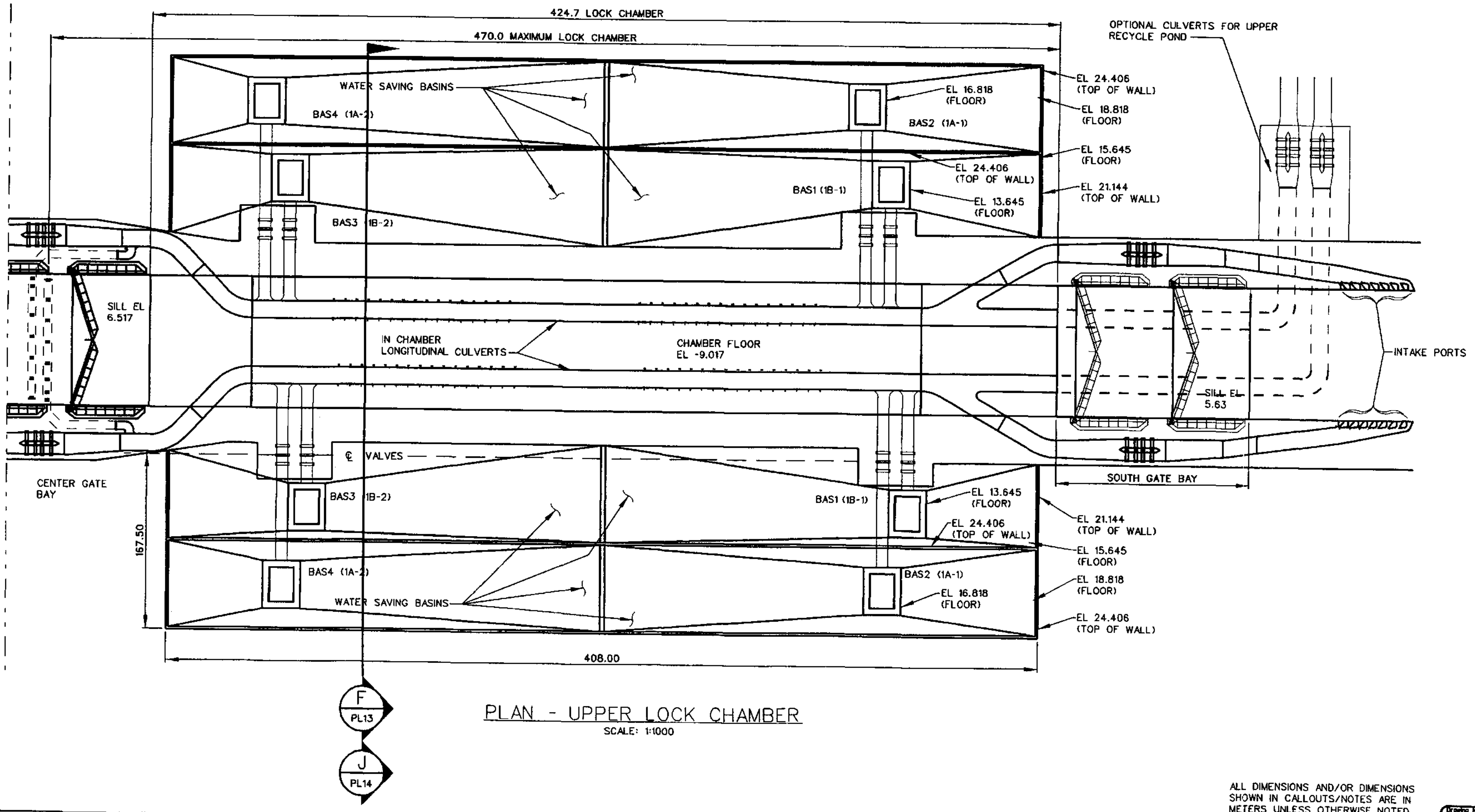
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
PRELIMINARY DOUBLE LIFT - SCREENING STUDY
ALTERNATIVE #4 ICLC SPLIT W.S.B
SECTIONS E & F

Drawing Number
ACP-SS-PL13



EAST WALL ELEVATION

SCALE: 1:1000



PLAN - UPPER LOCK CHAMBER

SCALE: 1:1000

ALL DIMENSIONS AND/OR DIMENSIONS SHOWN IN CALLOUTS/NOTES ARE IN METERS UNLESS OTHERWISE NOTED.

US Army Corps of Engineers
Pittsburgh District

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Sheet X of X
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Ckd by: RA
Submission Date: X
Revision Date: X
PB NO.:

ACP
AUTORIDAD DEL CANAL DE PANAMA

User: dmerwin
Date: 19-FEB-2003 15:39
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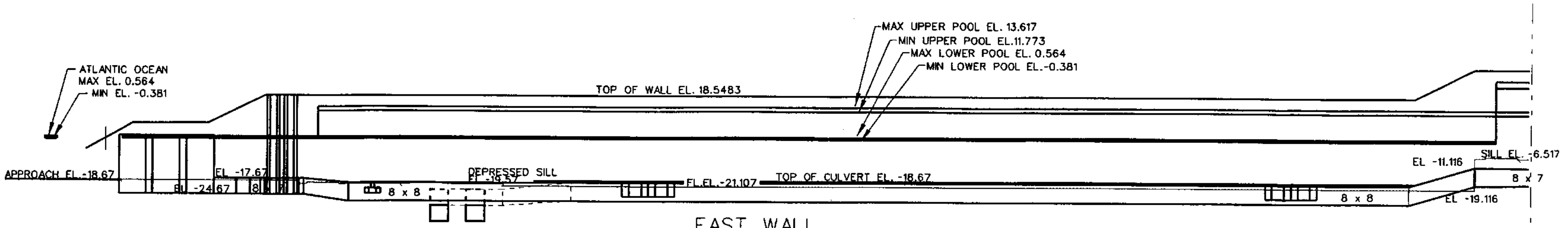
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
DOUBLE LIFT LOCK - SCREENING STUDY
ALTERNATIVE #4
PLAN AND ELEVATION

Drawing Number:
ACP-SS-PL8



EAST WALL ELEVATION

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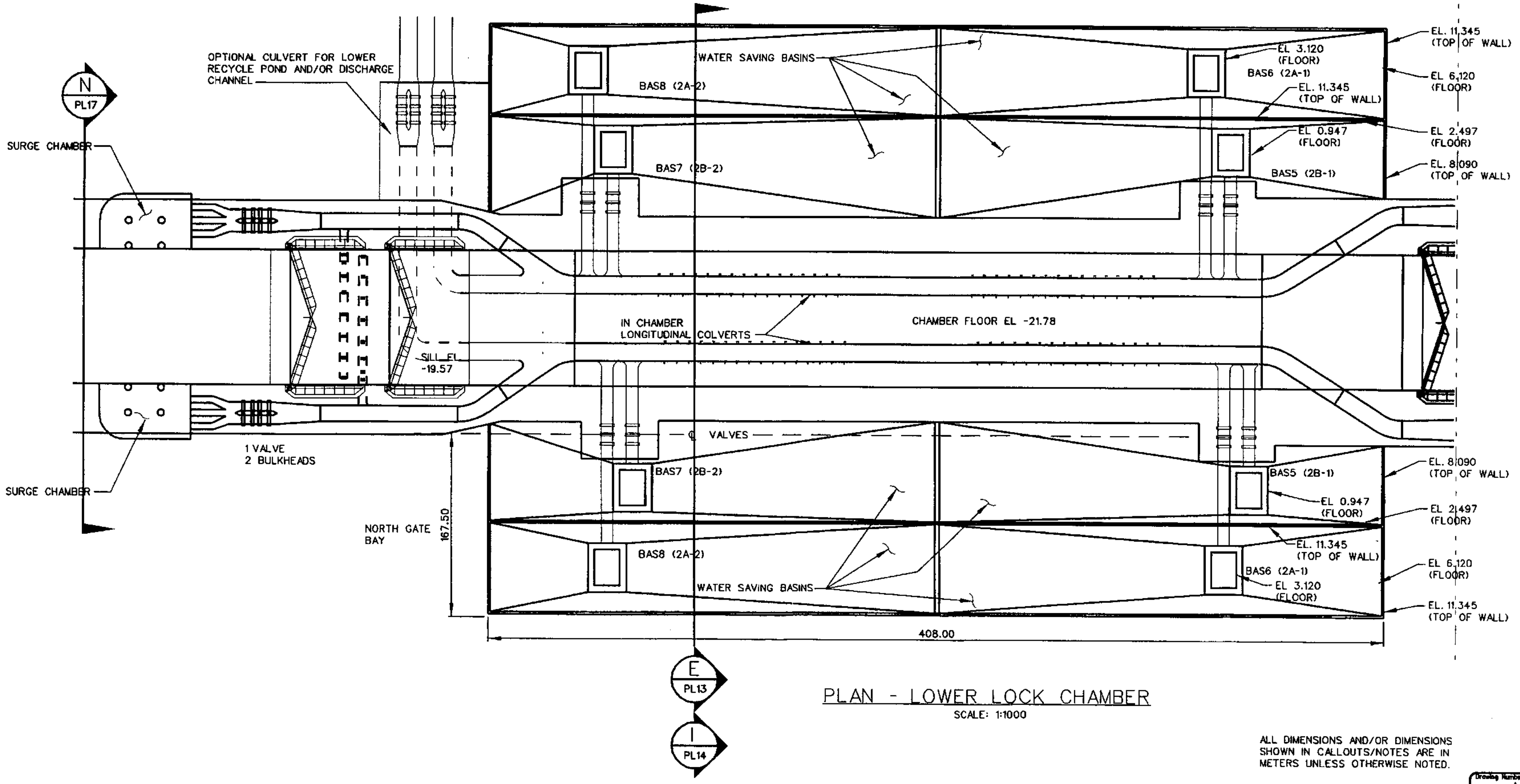

PLAN - LOWER LOCK CHAMBER

SCALE: 1:1000

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METERS UNLESS OTHERWISE NOTED.

US Army Corps
of Engineers
Pittsburgh District

Submitted by: A HARKNESS
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Sheet X of X

Design by: A HARKNESS
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Ckd by: RA
Submission Date: X
Revision Date: X
P/B NO.:

ACP
AUTORIDAD DEL CANAL DE PANAMA

User: dmorcini
Date: 19-FEB-2003 15:38
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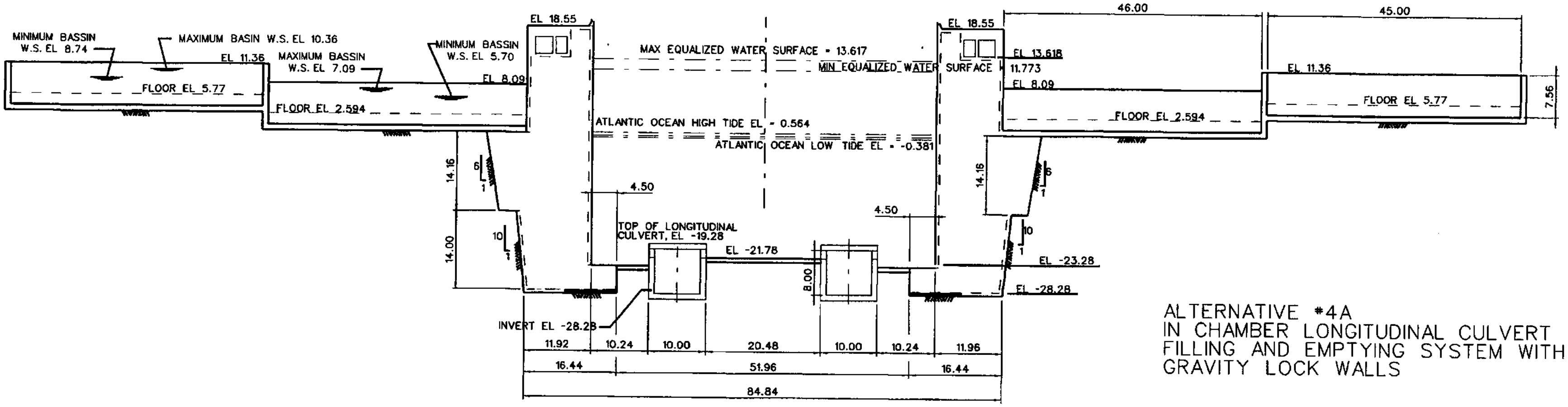
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
DOUBLE LIFT LOCK - SCREENING STUDY
ALTERNATIVE #4 - ICLC WITH SPLIT WSB
PLAN AND ELEVATION

Drawing Number:
ACP-SS-PL7

Attachment 6

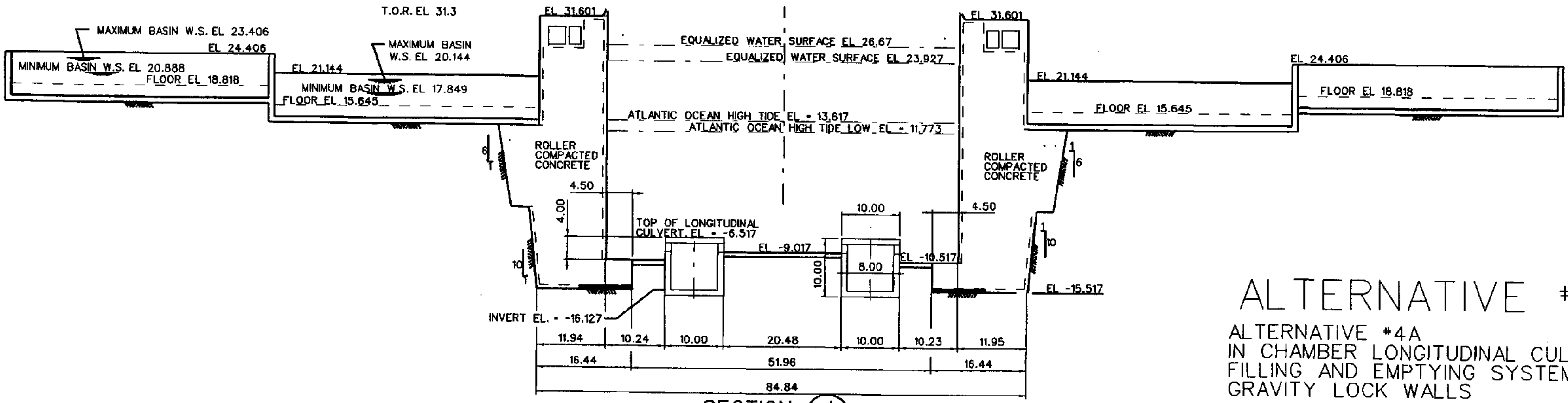
Alternative 4a - In-Chamber Longitudinal Culvert System with Water Saving Basins on Both Sides, Gravity Walls



ALTERNATIVE #4A
IN CHAMBER LONGITUDINAL CULVERT
FILLING AND EMPTYING SYSTEM WITH
GRAVITY LOCK WALLS

SECTION I PL8
SCALE: 1:400

(LOWER LOCK CHAMBER)



ALTERNATIVE #4b

ALTERNATIVE #4A
IN CHAMBER LONGITUDINAL CULVERT
FILLING AND EMPTYING SYSTEM WITH
GRAVITY LOCK WALLS

SECTION J PL8
SCALE: 1:400

(UPPER LOCK CHAMBER)

US Army Corps
of Engineers
Pittsburgh District

Design by: A HARKNESS
Dwn by: JT
Ckd by: RA
Submission Date: X
Revision Date: X
Submitted by: A HARKNESS
TECHNICAL LEAD
PB NO.:
Sheet X of X

ACP
AUTORIDAD DEL CANAL DE PANAMA
User: dmargain
Date: 18-FEB-2003 16:40
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PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
DOUBLE LIFT LOCK - SCREENING STUDY
ALTERNATIVE #4B
SECTION I& J

Drawing Number:
ACP-SS-PL14

Attachment 7

Cost Estimates

1. GENERAL

The purpose of these cost estimates is to assist in the evaluation of the five alternatives for the Two-Lift lock design. The total costs presented in this report are not the final cost estimates for each of the alternatives. The unit costs used to develop these comparison estimates will be further refined as the study continues and will be applied to the final design quantities of the two alternatives selected for further study. It is anticipated that this refinement of unit costs will lead to changes in the total construction cost of the chosen alternatives.

The unit costs presented in these cost estimates are unit costs revised from the initial Two-Lift submission. The unit costs have been refined to reflect the labor rates in Panama, international market material pricing, price quotations, reduced prime contractor markup, and some contract cost data furnished by the ACP. Although most of the unit costs were adjusted for this report, the main focus was on the following items: concrete, reinforcing steel, miter gates, valves, excavation, and backfill. The other items were adjusted to take into account the reduction in the prime contractor's markup and the reduction in labor rates.

2. UNIT COST COMPARISON

Item	Original Unit Cost	Updated Unit Cost
Cast in Place Concrete	\$200 - \$210 / m^3	\$145 - \$150 / m^3
Roller Compacted Concrete	\$160.00 / m^3	\$80.00 / m^3
Reinforcing Steel	\$2.20 / kg	\$1.15 / kg
Miter Gates Fabrication	\$12,800 / t	\$8,130 / t
Miter Gate Installation	\$2,000 / t	\$1,420 / t
Valve Fabrication	\$12,800 / t	\$13,900 / t
Valve Installation	\$2,000 / t	\$730 / t
Common Excavation	\$6.35 / m^3	\$4.00 / m^3
Rock Excavation	\$10.00 / m^3	\$7.50 / m^3
Structural Backfill	\$39.00 / m^3	\$20.00 / m^3
CLSM (Backfill)	\$220.00 / m^3	\$70.00 / m^3

The concrete unit cost reductions reflect material cost information (cement, sand, aggregate) received during a recent visit to Panama. These cost will be further refined once additional cost information is received from the cement suppliers introduced by ACP personnel during a recent visit. Also, the ACP is working with the rail company to obtain information on the cost of rail freight to transport aggregate from the Pacific side excavation to the Atlantic Lock site.

The costs for fabrication of the Miter Gates and Valves were adjusted based on a quote received from a Japanese fabricator. The machinery cost has not been adjusted for this screening study. These cost will be further refined once any additional cost information is received from the Brazilian fabricators that were contacted with assistance from the ACP.

The cost for reinforcing steel was adjusted to reflect international steel market costs as well as labor rates for Panama.

The cost for excavation was adjusted based upon contract cost data and ACP cost data received on a recent trip to Panama.

The structural backfill was adjusted to reflect local stone prices as well as labor rates for Panama.

For the final cost submission, the unit costs used to prepare the larger cost items will be refined and the basis for these costs will be presented in greater detail. The costs will be based upon crew development unless quotes or local contract information is available. The smaller cost items will only include minimal refinement, as their percentage of the overall cost does not merit a detailed investigation at the concept level of design.

Overall unit cost refinements resulted in a cost reduction of approximately $475,000,000 from the original design. The changes in the approach wall design resulted in another $130,000,000 in cost savings. The elimination of the Fourth Lane considerations and redesign of the lock walls resulted in approximately $175,000,000 in cost savings. The cost reduction associated with split WSB's versus WSB's just on the West side is approximately $18,000,000.

The five alternatives are all just over $1,000,000,000 in estimated cost. The cost difference between the least cost and greatest cost alternative is only $33,000,000. At this level of design detail, and considering the relative scale of this cost difference, cost should not be the decisive factor in selecting which alternatives to advance in the concept design study.

Panama Canal Concept Design
Atlantic Locks Structure
Third Lane
Double-Lift Lock Screening Study

Construction Cost Estimate Comparison

Price Level: October 2002

Alternative #	Description	Construction Cost	Concrete (m^3) RCC	Concrete (m^3) Conventional	(kg) Reinforcing Steel	Excavation Reduction Rock	Excavation Reduction Overburden
1	Modified Interlaced Bottom Lateral Filling System	$1,040,000,000	1563906	1029866	29971274	11.0%	9.0%
2	Side Port Filling System with WSB's to the West	$1,052,000,000	1565457	1084306	30778371	10.0%	8.0%
3	Side Port Filling System with Split WSB's	$1,034,000,000	1474280	1101164	28747528	14.0%	13.0%
4	ILCS with Anchored Split WSB's	$1,019,000,000	1386329	1012812	37770904	25.0%	26.0%
4a	ILCS Gravity Monoliths with Split WSB's	$1,027,000,000	1979873	717345	33797168	9.0%	11.0%
Original	Interlaced Bottom Lateral Filling System with 4th Lane Considerations	$1,214,000,000	1751397	1317342	83115565	0.0%	0.0%

Note: The total construction costs listed above all include a reduction in the approach walls cost of approximately $130 million from the original submission.

Panama Canal Concept Design

Atlantic Locks Structure

Third Lane

Double Lift Lock Screening Study

Construction Cost Estimate (Alternative 1 - Modified Interlaced Bottom Lateral Filling System)

Price Level: October 2002

ITEM #	Description	Quantity	Unit	Unit Price	Amount	Contin-gencies	Total
01-07	**Lock Structure**						
01-07001	Concrete for Lock Walls, (Conv)	558842	m^3	$145.00	$81,032,090.00	20.0%	$97,238,508.00
	Concrete for Lock Walls, (RCC)	789282	m^3	$80.00	$63,142,560.00	20.0%	$75,771,072.00
01-07004	Concrete in Place, Gate Monoliths	257720	m^3	$145.00	$37,369,400.00	20.0%	$44,843,280.00
01-07007	Concrete for Lock Gate Monoliths, RCC	210528	m^3	$80.00	$16,842,240.00	20.0%	$20,210,688.00
01-070010	Concrete for Lock Floors/Sills, (Conv)	40643	m^3	$150.00	$6,096,450.00	20.0%	$7,315,740.00
01-070013	Concrete for Lock Floors, (RCC)	112846	m^3	$80.00	$9,027,680.00	20.0%	$10,833,216.00
01-070016	Reinforcing Steel, Wall Monoliths	9661804	kg	$1.15	$11,111,074.60	20.0%	$13,333,289.52
01-070017	Reinforcing Steel, Floor/Sills	1893131	kg	$1.15	$2,177,100.65	20.0%	$2,612,520.78
01-070018	Reinforcing Steel, Gate Monoliths	4890764	kg	$1.15	$5,624,378.60	20.0%	$6,749,254.32
				Subtotals	**$232,423,000.00**		**$278,908,000.00**
01-08	**Lock Gates & Operating Machinery**						
01-08001	Furnish & Install Lower Miter Gates	2	sets	$0.00	$61,540,000.00	10.0%	$67,694,000.00
01-08002	Furnish & Install Center Miter Gates	2	sets	$0.00	$77,200,000.00	10.0%	$84,920,000.00
01-08003	Furnish & Install Upper Miter Gates	2	sets	$0.00	$45,220,000.00	10.0%	$49,742,000.00
01-08004	Furnish and Install Operating Machinery	12	ea	$900,000.00	$10,800,000.00	15.0%	$12,420,000.00
01-08005	Embedded Metals (Stainless Steel)	38000	kg	$15.00	$570,000.00	15.0%	$655,500.00
01-08006	Gate Anchorage (Structural steel)	391600	kg	$8.30	$3,250,280.00	15.0%	$3,737,822.00
01-08007	Bridges over recesses	12	ea	$450,000.00	$5,400,000.00	20.0%	$6,480,000.00
				Subtotals	**$203,980,000.00**		**$225,649,000.00**

Panama Canal Concept Design

Atlantic Locks Structure
Third Lane
Double Lift Lock Screening Study
Construction Cost Estimate (Alternative 1 - Modified Interlaced Bottom Lateral Filling System)

Price Level: October 2002

ITEM #	Description	Quantity	Unit	Unit Price	Amount	Contin-gencies	Total
01-09	**Culvert Valves and Operating Machinery**						
01-09001	Upper Lock Filling Valves	4	ea	$1,245,000.00	$4,980,000.00	10.0%	$5,478,000.00
01-09002	Valves Between Locks	4	ea	$1,360,000.00	$5,440,000.00	10.0%	$5,984,000.00
01-09003	Lower Lock Emptying Valves	4	ea	$1,245,000.00	$4,980,000.00	10.0%	$5,478,000.00
01-09004	Embedded Metals (Stainless Steel)	1900	kg	$15.00	$28,500.00	15.0%	$32,775.00
01-09005	Valve Anchorage	19580	kg	$8.30	$162,514.00	15.0%	$186,891.10
01-09006	Bulkheads	10	ea	$480,000.00	$4,800,000.00	15.0%	$5,520,000.00
01-09007	Valves Operating Machinery	12	ea	$600,000.00	$7,200,000.00	15.0%	$8,280,000.00
				Subtotals	**$27,591,000.00**		**$30,960,000.00**
01-10	**Piping System**				$1,500,000.00	30.0%	$1,950,000.00
01-11	**Power and Lighting Systems**				$23,000,000.00	20.0%	$27,600,000.00
01-12	**Associated General Items**				$4,147,000.00	20.0%	$4,769,000.00
01-13	**Building, Project Operations**				$450,000.00	25.0%	$563,000.00
01-14	**Miscellaneous Items**				$14,410,000.00	16.0%	$16,682,000.00
01-15	**Maintenance Facility (Gates)**				$2,770,000.00	25.0%	$3,463,000.00

Panama Canal Concept Design

Atlantic Locks Structure
Third Lane
Double Lift Lock Screening Study

Construction Cost Estimate (Alternative 1 - Modified Interlaced Bottom Lateral Filling System)

Price Level: October 2002

ITEM #	Description	Quantity	Unit	Unit Price	Amount	Contin-gencies	Total
01-16	**Water Savings Basins**						
01-16001	Overburden Excavation	1250943	m^3	$4.00	$5,003,772.00	15.0%	$5,754,337.80
01-16002	Rock Excavation	1048947	m^3	$7.50	$7,867,102.50	15.0%	$9,047,167.88
01-16003	Concrete (Conventional)	88911	m^3	$150.00	$13,336,650.00	15.0%	$15,337,147.50
01-16006	Reinforcing Steel	4493075	kg	$1.15	$5,167,036.25	20.0%	$6,200,443.50
01-16007	Handrailing	1370	m	$80.00	$109,600.00	20.0%	$131,520.00
				Subtotals	**$31,484,000.00**		**$36,471,000.00**
01-17	**Conduits**						
01-17001	Overburden Excavation	11700	m^3	$4.00	$46,800.00	15.0%	$53,820.00
01-17002	Rock Excavation	23400	m^3	$7.50	$175,500.00	15.0%	$201,825.00
01-17003	Concrete (Conventional CIP)	60000	m^3	$150.00	$9,000,000.00	15.0%	$10,350,000.00
01-17006	Reinforcing Steel	6540000	kg	$1.15	$7,521,000.00	20.0%	$9,025,200.00
				Subtotals	**$16,743,000.00**		**$19,631,000.00**
01-18	**Crossovers (Including with Lock Floor Costs)**						
01-19	**Conduit Valves and Operating Mach.**						
01-19001	Valves	16	ea	$860,000.00	$13,760,000.00	10.0%	$15,136,000.00
01-19002	Embedded Metals (Stainless Steel)	2000	kg	$15.00	$30,000.00	15.0%	$34,500.00
01-19003	Valve Anchorage (Structural Steel)	20000	kg	$8.30	$166,000.00	15.0%	$190,900.00
01-19004	Valve Operating Machinery	16	ea	$600,000.00	$9,600,000.00	15.0%	$11,040,000.00
01-19005	Electrical System/Controls	1	job	$2,000,000.00	$2,000,000.00	20.0%	$2,400,000.00
				Subtotals	**$25,556,000.00**		**$28,801,000.00**

Totals	**$883,095,000.00**	**$1,039,666,000.00**
Rounded	**$883,000,000.00**	**$1,040,000,000.00**

Panama Canal Concept Design
Atlantic Locks Structure
Third Lane
Double-Lift Lock Screening Study
Construction Cost Estimate (Alternative 2 - Side Port Filling System with WSB's on One Side)

Price Level: October 2002

ITEM #	Description	Quantity	Unit	Unit Price	Amount	Contin-gencies	Total
01-01001	**Mobilization & Demobilization (1.25%)**	1	job	$11,200,000.00	$11,200,000.00	10.0%	$12,320,000.00
01-01	**Preparatory Work**				$10,882,000.00	20.0%	$13,059,000.00
01-02	**Relocations**				$968,000.00	27.0%	$1,227,000.00
01-03	**Care & Diversion of Water**				$11,462,000.00	20.0%	$13,754,000.00
01-04	**Earthwork for Structures**						
01-04001	Exploratory Drilling	1	job	$1,800,000.00	$1,800,000.00	20.0%	$2,160,000.00
01-04002	Common Excavation (Dry)	4894400	m^3	$4.00	$19,577,600.00	20.0%	$23,493,120.00
01-04003	Rock Excavation (Dry)	5643000	m^3	$7.50	$42,322,500.00	20.0%	$50,787,000.00
01-04004	Common Excavation (In the Wet)	0	m^3	$6.30	$0.00	20.0%	$0.00
01-04005	Rock Excavation (In the Wet)	130000	m^3	$34.15	$4,439,500.00	20.0%	$5,327,400.00
01-04006	Pervious (Structural) Backfill	427000	m^3	$20.00	$8,540,000.00	25.0%	$10,675,000.00
01-04007	Controlled Low Strength Material	0	m^3	$70.00	$0.00	20.0%	$0.00
01-04008	Foundation Prep	125000	m^2	$80.00	$10,000,000.00	20.0%	$12,000,000.00
				Subtotals	**$86,680,000.00**		**$104,443,000.00**
01-05	**Sitework**				$1,687,000.00		$2,026,000.00
01-06	**Guard & Guide Walls, Upper & Lower**						
01-06001	In-the-wet Section (All inclusive)	600	m	$200,000.00	$120,000,000.00	25.0%	$150,000,000.00
01-06002	Conventional CIP	23750	m^3	$145.00	$3,443,750.00	20.0%	$4,132,500.00
01-06003	RCC	451250	m^3	$80.00	$36,100,000.00	20.0%	$43,320,000.00
01-06004	Reinforcing Steel (Dry Section)	2492500	kg	$1.15	$2,866,375.00	20.0%	$3,439,650.00
01-06008	Fenders	1	job	$15,115,000.00	$15,115,000.00	20.0%	$18,138,000.00
				Subtotals	**$177,525,000.00**		**$219,030,000.00**

Panama Canal Concept Design
Atlantic Locks Structure
Third Lane
Double-Lift Lock Screening Study
Construction Cost Estimate (Alternative 2 - Side Port Filling System with WSB's on One Side)

Price Level: October 2002

ITEM #	Description	Quantity	Unit	Unit Price	Amount	Contin-gencies	Total
01-07	**Lock Structure**						
01-07001	Concrete for Lock Walls, (Conv)	636469	m^3	$145.00	$92,288,005.00	20.0%	$110,745,606.00
	Concrete for Lock Walls, (RCC)	777516	m^3	$80.00	$62,201,280.00	20.0%	$74,641,536.00
01-07004	Concrete in Place, Gate Monoliths	257720	m^3	$145.00	$37,369,400.00	20.0%	$44,843,280.00
01-07007	Concrete for Lock Gate Monoliths, RCC	210528	m^3	$80.00	$16,842,240.00	20.0%	$20,210,688.00
01-070010	Concrete for Lock Floors/Sills, (Conv)	17456	m^3	$150.00	$2,618,400.00	20.0%	$3,142,080.00
01-070013	Concrete for Lock Floors, (RCC)	126163	m^3	$80.00	$10,093,040.00	20.0%	$12,111,648.00
01-070016	Reinforcing Steel, Wall Monoliths	10276000	kg	$1.15	$11,817,400.00	20.0%	$14,180,880.00
01-070017	Reinforcing Steel, Floor/Sills	2050420	kg	$1.15	$2,357,983.00	20.0%	$2,829,579.60
01-070018	Reinforcing Steel, Gate Monoliths	4926376	kg	$1.15	$5,665,332.40	20.0%	$6,798,398.88
				Subtotals	**$241,253,000.00**		**$289,504,000.00**
01-08	**Lock Gates & Operating Machinery**						
01-08001	Furnish & Install Lower Miter Gates	2	sets	$0.00	$61,540,000.00	10.0%	$67,694,000.00
01-08002	Furnish & Install Center Miter Gates	2	sets	$0.00	$77,200,000.00	10.0%	$84,920,000.00
01-08003	Furnish & Install Upper Miter Gates	2	sets	$0.00	$45,220,000.00	10.0%	$49,742,000.00
01-08004	Furnish and Install Operating Machinery	12	ea	$900,000.00	$10,800,000.00	15.0%	$12,420,000.00
01-08005	Embedded Metals (Stainless Steel)	38000	kg	$15.00	$570,000.00	15.0%	$655,500.00
01-08006	Gate Anchorage (Structural steel)	391600	kg	$8.30	$3,250,280.00	15.0%	$3,737,822.00
01-08007	Bridges over recesses	12	ea	$450,000.00	$5,400,000.00	20.0%	$6,480,000.00
				Subtotals	**$203,980,000.00**		**$225,649,000.00**

SUPERCEDED SEE NOTE AT BEGINNING OF APPENDIX J

Panama Canal Concept Design
Atlantic Locks Structure
Third Lane
Double Lift Lock Screening Study
Construction Cost Estimate (Alternative 2 - Side Port Filling System with WSB's on One Side)

Price Level: October 2002

ITEM #	Description	Quantity	Unit	Unit Price	Amount	Contin-gencies	Total
01-09	**Culvert Valves and Operating Machinery**						
01-09001	Upper Lock Filling Valves	4	ea	$1,245,000.00	$4,980,000.00	10.0%	$5,478,000.00
01-09002	Valves Between Locks	4	ea	$1,360,000.00	$5,440,000.00	10.0%	$5,984,000.00
01-09003	Lower Lock Emptying Valves	4	ea	$1,245,000.00	$4,980,000.00	10.0%	$5,478,000.00
01-09004	Embedded Metals (Stainless Steel)	1900	kg	$15.00	$28,500.00	15.0%	$32,775.00
01-09005	Valve Anchorage	19580	kg	$8.30	$162,514.00	15.0%	$186,891.10
01-09006	Bulkheads	10	ea	$480,000.00	$4,800,000.00	15.0%	$5,520,000.00
01-09007	Valves Operating Machinery	12	ea	$600,000.00	$7,200,000.00	15.0%	$8,280,000.00
				Subtotals	**$27,591,000.00**		**$30,960,000.00**
01-10	**Piping System**				$1,500,000.00	30.0%	$1,950,000.00
01-11	**Power and Lighting Systems**				$23,000,000.00	20.0%	$27,600,000.00
01-12	**Associated General Items**				$4,147,000.00	20.0%	$4,769,000.00
01-13	**Building, Project Operations**				$450,000.00	25.0%	$563,000.00
01-14	**Miscellaneous Items**				$14,410,000.00	16.0%	$16,682,000.00
01-15	**Maintenance Facility (Gates)**				$2,770,000.00	25.0%	$3,463,000.00

Panama Canal Concept Design
Atlantic Locks Structure
Third Lane
Double-Lift Lock Screening Study
Construction Cost Estimate (Alternative 2 - Side Port Filling System with WSB's on One Side)

Price Level: October 2002

ITEM #	Description	Quantity	Unit	Unit Price	Amount	Contin-gencies	Total
01-16	**Water Savings Basins**						
01-16001	Overburden Excavation	1250943	m^3	$4.00	$5,003,772.00	15.0%	$5,754,337.80
01-16002	Rock Excavation	1048947	m^3	$7.50	$7,867,102.50	15.0%	$9,047,167.88
01-16003	Concrete (Conventional)	88911	m^3	$150.00	$13,336,650.00	15.0%	$15,337,147.50
01-16006	Reinforcing Steel	4493075	kg	$1.15	$5,167,036.25	20.0%	$6,200,443.50
01-16007	Handrailing	1370	m	$80.00	$109,600.00	20.0%	$131,520.00
				Subtotals	**$31,484,000.00**		**$36,471,000.00**
01-17	**Conduits**						
01-17001	Overburden Excavation	11700	m^3	$4.00	$46,800.00	15.0%	$53,820.00
01-17002	Rock Excavation	23400	m^3	$7.50	$175,500.00	15.0%	$201,825.00
01-17003	Concrete	60000	m^3	$150.00	$9,000,000.00	15.0%	$10,350,000.00
01-17006	Reinforcing Steel	6540000	kg	$1.15	$7,521,000.00	20.0%	$9,025,200.00
				Subtotals	**$16,743,000.00**		**$19,631,0[illegible]**
01-18	**Crossovers (Including with Lock Floor Costs)**						
01-19	**Conduit Valves and Operating Mach.**						
01-19001	Valves	16	ea	$860,000.00	$13,760,000.00	10.0%	$15,136,000.00
01-19002	Embedded Metals (Stainless Steel)	2000	kg	$15.00	$30,000.00	15.0%	$34,500.00
01-19003	Valve Anchorage (Structural Steel)	20000	kg	$8.30	$166,000.00	15.0%	$190,900.00
01-19004	Valve Operating Machinery	16	ea	$600,000.00	$9,600,000.00	15.0%	$11,040,000.00
01-19005	Electrical System/Controls	1	job	$2,000,000.00	$2,000,000.00	20.0%	$2,400,000.00
				Subtotals	**$25,556,000.00**		**$28,801,000.00**

Totals	**$893,288,000.00**	**$1,051,902,000.00**
Rounded	**$893,000,000.00**	**$1,052,000,000.00**

Panama Canal Concept Design
Atlantic Locks Structure
Third Lane
Double-Lift Lock Screening Study
Construction Cost Estimate (Alternative 3 Side Port Filling System w/ Split WSB's)

Price Level: October 2002

ITEM #	Description	Quantity	Unit	Unit Price	Amount	Contin-gencies	Total
01-01001	**Mobilization & Demobilization (1.25%)**	1	job	$11,000,000.00	$11,000,000.00	10.0%	$12,100,000.00
01-01	**Preparatory Work**				$10,882,000.00	20.0%	$13,059,000.00
01-02	**Relocations**				$968,000.00	27.0%	$1,227,000.00
01-03	**Care & Diversion of Water**				$11,462,000.00	20.0%	$13,754,000.00
01-04	**Earthwork for Structures**						
01-04001	Exploratory Drilling	1	job	$1,800,000.00	$1,800,000.00	20.0%	$2,160,000.00
01-04002	Common Excavation (Dry)	4628400	m^3	$4.00	$18,513,600.00	20.0%	$22,216,320.00
01-04003	Rock Excavation (Dry)	5392200	m^3	$7.50	$40,441,500.00	20.0%	$48,529,800.00
01-04004	Common Excavation (In the Wet)	0	m^3	$6.30	$0.00	20.0%	$0.00
01-04005	Rock Excavation (In the Wet)	130000	m^3	$34.15	$4,439,500.00	20.0%	$5,327,400.00
01-04006	Pervious (Structural) Backfill	230000	m^3	$20.00	$4,600,000.00	25.0%	$5,750,000.00
01-04007	Controlled Low Strength Material	0	m^3	$70.00	$0.00	20.0%	$0.00
01-04008	Foundation Prep	125000	m^2	$80.00	$10,000,000.00	20.0%	$12,000,000.00
				Subtotals	**$79,795,000.00**		**$95,984,000.00**
01-05	**Sitework**				$1,687,000.00		$2,026,000.00
01-06	**Guard & Guide Walls, Upper & Lower**						
01-06001	In-the-wet Section (All inclusive)	600	m	$200,000.00	$120,000,000.00	25.0%	$150,000,000.00
01-06002	Conventional CIP	23750	m^3	$145.00	$3,443,750.00	20.0%	$4,132,500.00
01-06003	RCC	451250	m^3	$80.00	$36,100,000.00	20.0%	$43,320,000.00
01-06004	Reinforcing Steel (Dry Section)	2492500	kg	$1.15	$2,866,375.00	20.0%	$3,439,650.00
01-06008	Fenders	1	job	$15,115,000.00	$15,115,000.00	20.0%	$18,138,000.00
				Subtotals	**$177,525,000.00**		**$219,030,000.00**

Panama Canal Concept Design
Atlantic Locks Structure
Third Lane
Double-Lift Lock Screening Study
Construction Cost Estimate (Alternative Side Port Filling System w/ Split WSB's)

Price Level: October 2002

ITEM #	Description	Quantity	Unit	Unit Price	Amount	Contin-gencies	Total
01-07	**Lock Structure**						
01-07001	Concrete for Lock Walls, (Conv)	663732	m^3	$145.00	$96,241,140.00	20.0%	$115,489,368.00
	Concrete for Lock Walls, (RCC)	686339	m^3	$80.00	$54,907,120.00	20.0%	$65,888,544.00
01-07004	Concrete in Place, Gate Monoliths	257720	m^3	$145.00	$37,369,400.00	20.0%	$44,843,280.00
01-07007	Concrete for Lock Gate Monoliths, RCC	210528	m^3	$80.00	$16,842,240.00	20.0%	$20,210,688.00
01-070010	Concrete for Lock Floors/Sills, (Conv)	17456	m^3	$150.00	$2,618,400.00	20.0%	$3,142,080.00
01-070013	Concrete for Lock Floors, (RCC)	126163	m^3	$80.00	$10,093,040.00	20.0%	$12,111,648.00
01-070016	Reinforcing Steel, Wall Monoliths	9598400	kg	$1.15	$11,038,160.00	20.0%	$13,245,792.00
01-070017	Reinforcing Steel, Floor/Sills	2050420	kg	$1.15	$2,357,983.00	20.0%	$2,829,579.60
01-070018	Reinforcing Steel, Gate Monoliths	4926376	kg	$1.15	$5,665,332.40	20.0%	$6,798,398.88
				Subtotals	**$237,133,000.00**		**$284,559,000.00**
01-08	**Lock Gates & Operating Machinery**						
01-08001	Furnish & Install Lower Miter Gates	2	sets	$0.00	$61,540,000.00	10.0%	$67,694,000.00
01-08002	Furnish & Install Center Miter Gates	2	sets	$0.00	$77,200,000.00	10.0%	$84,920,000.00
01-08003	Furnish & Install Upper Miter Gates	2	sets	$0.00	$45,220,000.00	10.0%	$49,742,000.00
01-08004	Furnish and Install Operating Machinery	12	ea	$900,000.00	$10,800,000.00	15.0%	$12,420,000.00
01-08005	Embedded Metals (Stainless Steel)	38000	kg	$15.00	$570,000.00	15.0%	$655,500.00
01-08006	Gate Anchorage (Structural steel)	391600	kg	$8.30	$3,250,280.00	15.0%	$3,737,822.00
01-08007	Bridges over recesses	12	ea	$450,000.00	$5,400,000.00	20.0%	$6,480,000.00
				Subtotals	**$203,980,000.00**		**$225,649,000.00**

Panama Canal Concept Design
Atlantic Locks Structure
Third Line
Double-Lift Lock Screening Study
Construction Cost Estimate (Alternative [illegible] Side Port Filling System w/ Split WSB's)

Price Level: October 2002

ITEM #	Description	Quantity	Unit	Unit Price	Amount	Contin- gencies	Total
01-09	**Culvert Valves and Operating Machinery**						
01-09001	Upper Lock Filling Valves	4	ea	$1,245,000.00	$4,980,000.00	10.0%	$5,478,000.00
01-09002	Valves Between Locks	4	ea	$1,360,000.00	$5,440,000.00	10.0%	$5,984,000.00
01-09003	Lower Lock Emptying Valves	4	ea	$1,245,000.00	$4,980,000.00	10.0%	$5,478,000.00
01-09004	Embedded Metals (Stainless Steel)	1900	kg	$15.00	$28,500.00	15.0%	$32,775.00
01-09005	Valve Anchorage	19580	kg	$8.30	$162,514.00	15.0%	$186,891.10
01-09006	Bulkheads	10	ea	$480,000.00	$4,800,000.00	15.0%	$5,520,000.00
01-09007	Valves Operating Machinery	12	ea	$600,000.00	$7,200,000.00	15.0%	$8,280,000.00
				Subtotals	**$27,591,000.00**		**$30,960,000.00**
01-10	**Piping System**				$1,500,000.00	30.0%	$1,950,000.00
01-11	**Power and Lighting Systems**				$23,000,000.00	20.0%	$27,600,000.00
01-12	**Associated General Items**				$4,147,000.00	20.0%	$4,769,000.00
01-13	**Building, Project Operations**				$450,000.00	25.0%	$563,000.00
01-14	**Miscellaneous Items**				$14,410,000.00	16.0%	$16,682,000.00
01-15	**Maintenance Facility (Gates)**				$2,770,000.00	25.0%	$3,463,000.00

Panama Canal Concept Design
Atlantic Locks Structure

Third Lane
Double-Lift Lock Screening Study
Construction Cost Estimate (Alternative [illegible] Side Port Filling System w/ Split WSB's)

Price Level: October 2002

ITEM #	Description	Quantity	Unit	Unit Price	Amount	Contin-gencies	Total
01-16	**Water Savings Basins**						
01-16001	Overburden Excavation	1250943	m^3	$4.00	$5,003,772.00	15.0%	$5,754,337.80
01-16002	Rock Excavation	1048947	m^3	$7.50	$7,867,102.50	15.0%	$9,047,167.88
01-16003	Concrete (Conventional)	108506	m^3	$150.00	$16,275,900.00	15.0%	$18,717,285.00
01-16006	Reinforcing Steel	6409832	kg	$1.15	$7,371,306.80	20.0%	$8,845,568.16
01-16007	Handrailing	1370	m	$80.00	$109,600.00	20.0%	$131,520.00
				Subtotals	**$36,628,000.00**		**$42,496,000.00**
01-17	**Conduits**						
01-17001	Overburden Excavation	6000	m^3	$4.00	$24,000.00	15.0%	$27,600.00
01-17002	Rock Excavation	12000	m^3	$7.50	$90,000.00	15.0%	$103,500.00
01-17003	Concrete	30000	m^3	$150.00	$4,500,000.00	15.0%	$5,175,000.00
01-17006	Reinforcing Steel	3270000	kg	$1.15	$3,760,500.00	20.0%	$4,512,600.00
				Subtotals	**$8,375,000.00**		**$9,819,000.00**
01-18	**Crossovers (Including with Lock Floor Costs)**						
01-19	**Conduit Valves and Operating Mach.**						
01-19001	Valves	16	ea	$860,000.00	$13,760,000.00	10.0%	$15,136,000.00
01-19002	Embedded Metals (Stainless Steel)	2000	kg	$15.00	$30,000.00	15.0%	$34,500.00
01-19003	Valve Anchorage (Structural Steel)	20000	kg	$8.30	$166,000.00	15.0%	$190,900.00
01-19004	Valve Operating Machinery	16	ea	$600,000.00	$9,600,000.00	15.0%	$11,040,000.00
01-19005	Electrical System/Controls	1	job	$2,000,000.00	$2,000,000.00	20.0%	$2,400,000.00
				Subtotals	**$25,556,000.00**		**$28,801,000.00**
				Totals	**$878,859,000.00**		**$1,034,491,000.00**
				Rounded	**$879,000,000.00**		**$1,034,000,000.00**

Panama Canal Concept Design
Atlantic Locks Structure
Third Lane
Double-Lift Lock Screening Study
Construction Cost Estimate (Alternative 4 - ILCS with Anchored Split WSB's)

Price Level: October 2002

ITEM #	Description	Quantity	Unit	Unit Price	Amount	Contin-gencies	Total
01-01001	**Mobilization & Demobilization (1.25%)**	1	job	$10,800,000.00	$10,800,000.00	10.0%	$11,880,000.00
01-01	**Preparatory Work**				$10,882,000.00	20.0%	$13,059,000.00
01-02	**Relocations**				$968,000.00	27.0%	$1,227,000.00
01-03	**Care & Diversion of Water**				$11,462,000.00	20.0%	$13,754,000.00
01-04	**Earthwork for Structures**						
01-04001	Exploratory Drilling	1	job	$1,800,000.00	$1,800,000.00	20.0%	$2,160,000.00
01-04002	Common Excavation (Dry)	3936800	m^3	$4.00	$15,747,200.00	20.0%	$18,896,640.00
01-04003	Rock Excavation (Dry)	4702500	m^3	$7.50	$35,268,750.00	20.0%	$42,322,500.00
01-04004	Common Excavation (In the Wet)	0	m^3	$6.30	$0.00	20.0%	$0.00
01-04005	Rock Excavation (In the Wet)	130000	m^3	$34.15	$4,439,500.00	20.0%	$5,327,400.00
01-04006	Pervious (Structural) Backfill	230000	m^3	$20.00	$4,600,000.00	25.0%	$5,750,000.00
01-04007	Controlled Low Strength Material	0	m^3	$70.00	$0.00	20.0%	$0.00
01-04008	Foundation Prep	125000	m^2	$80.00	$10,000,000.00	20.0%	$12,000,000.00
				Subtotals	**$71,855,000.00**		**$86,457,000.00**
01-05	**Sitework**				$1,687,000.00		$2,026,000.00
01-06	**Guard & Guide Walls, Upper & Lower**						
01-06001	In-the-wet Section (All inclusive)	600	m	$200,000.00	$120,000,000.00	25.0%	$150,000,000.00
01-06002	Conventional CIP	23750	m^3	$145.00	$3,443,750.00	20.0%	$4,132,500.00
01-06003	RCC	451250	m^3	$80.00	$36,100,000.00	20.0%	$43,320,000.00
01-06004	Reinforcing Steel (Dry Section)	2492500	kg	$1.15	$2,866,375.00	20.0%	$3,439,650.00
01-06008	Fenders	1	job	$15,115,000.00	$15,115,000.00	20.0%	$18,138,000.00
				Subtotals	**$177,525,000.00**		**$219,030,000.00**

Panama Canal Concept Design
Atlantic Locks Structure
Third Lane
Double-Lift Lock Screening Study
Construction Cost Estimate (Alternative 4 - ILCS with Anchored Split WSB's)

Price Level: October 2002

ITEM #	Description	Quantity	Unit	Unit Price	Amount	Contin- gencies	Total
01-07	**Lock Structure**						
01-07001	Concrete for Lock Walls, (Conv)	461804	m^3	$145.00	$66,961,580.00	20.0%	$80,353,896.00
	Concrete for Lock Walls, (RCC)	629325	m^3	$80.00	$50,346,000.00	20.0%	$60,415,200.00
01-07004	Concrete in Place, Gate Monoliths	249952	m^3	$145.00	$36,243,040.00	20.0%	$43,491,648.00
01-07007	Concrete for Lock Gate Monoliths, RCC	204179	m^3	$80.00	$16,334,320.00	20.0%	$19,601,184.00
01-070010	Concrete for Lock Floors/Sills, (Conv)	78440	m^3	$150.00	$11,766,000.00	20.0%	$14,119,200.00
01-070013	Concrete for Lock Floors, (RCC)	101575	m^3	$80.00	$8,126,000.00	20.0%	$9,751,200.00
01-070016	Reinforcing Steel, Wall Monoliths	11686400	kg	$1.15	$13,439,360.00	20.0%	$16,127,232.00
01-070017	Reinforcing Steel, Floor/Sills	8758660	kg	$1.15	$10,072,459.00	20.0%	$12,086,950.80
01-070018	Reinforcing Steel, Gate Monoliths	4926376	kg	$1.15	$5,665,332.40	20.0%	$6,798,398.88
				Subtotals	**$218,954,000.00**		**$262,745,000.00**
01-08	**Lock Gates & Operating Machinery**						
01-08001	Furnish & Install Lower Miter Gates	2	sets	$0.00	$61,540,000.00	10.0%	$67,694,000.00
01-08002	Furnish & Install Center Miter Gates	2	sets	$0.00	$77,200,000.00	10.0%	$84,920,000.00
01-08003	Furnish & Install Upper Miter Gates	2	sets	$0.00	$45,220,000.00	10.0%	$49,742,000.00
01-08004	Furnish and Install Operating Machinery	12	ea	$900,000.00	$10,800,000.00	15.0%	$12,420,000.00
01-08005	Embedded Metals (Stainless Steel)	38000	kg	$15.00	$570,000.00	15.0%	$655,500.00
01-08006	Gate Anchorage (Structural steel)	391600	kg	$8.30	$3,250,280.00	15.0%	$3,737,822.00
01-08007	Bridges over recesses	12	ea	$450,000.00	$5,400,000.00	20.0%	$6,480,000.00
				Subtotals	**$203,980,000.00**		**$225,649,000.00**

Panama Canal Concept Design
Atlantic Locks Structure
Third Lane
Double-Lift Lock Screening Study
Construction Cost Estimate (Alternative 4 - ILCS with Anchored Split WSB's)

Price Level: October 2002

ITEM #	Description	Quantity	Unit	Unit Price	Amount	Contin-gencies	Total
01-09	**Culvert Valves and Operating Machinery**						
01-09001	Upper Lock Filling Valves	4	ea	$1,245,000.00	$4,980,000.00	10.0%	$5,478,000.00
01-09002	Valves Between Locks	4	ea	$1,360,000.00	$5,440,000.00	10.0%	$5,984,000.00
01-09003	Lower Lock Emptying Valves	4	ea	$1,245,000.00	$4,980,000.00	10.0%	$5,478,000.00
01-09004	Embedded Metals (Stainless Steel)	1900	kg	$15.00	$28,500.00	15.0%	$32,775.00
01-09005	Valve Anchorage	19580	kg	$8.30	$162,514.00	15.0%	$186,891.10
01-09006	Bulkheads	10	ea	$480,000.00	$4,800,000.00	15.0%	$5,520,000.00
01-09007	Valves Operating Machinery	12	ea	$600,000.00	$7,200,000.00	15.0%	$8,280,000.00
				Subtotals	**$27,591,000.00**		**$30,960,000.00**
01-10	**Piping System**				$1,500,000.00	30.0%	$1,950,000.00
01-11	**Power and Lighting Systems**				$23,000,000.00	20.0%	$27,600,000.00
01-12	**Associated General Items**				$4,147,000.00	20.0%	$4,769,000.00
01-13	**Building, Project Operations**				$450,000.00	25.0%	$563,000.00
01-14	**Miscellaneous Items**				$14,410,000.00	16.0%	$16,682,000.00
01-15	**Maintenance Facility (Gates)**				$2,770,000.00	25.0%	$3,463,000.00

Panama Canal Concept Design
Atlantic Locks Structure
Third Lane
Double-Lift Lock Screening Study
Construction Cost Estimate (Alternative 4 - ILCS with Anchored Split WSB's)

Price Level: October 2002

ITEM #	Description	Quantity	Unit	Unit Price	Amount	Contin-gencies	Total
01-16	**Water Savings Basins**						
01-16001	Overburden Excavation	1250943	m^3	$4.00	$5,003,772.00	15.0%	$5,754,337.80
01-16002	Rock Excavation	1048947	m^3	$7.50	$7,867,102.50	15.0%	$9,047,167.88
01-16003	Concrete (Conventional)	168866	m^3	$150.00	$25,329,900.00	15.0%	$29,129,385.00
01-16006	Reinforcing Steel	6636968	kg	$1.15	$7,632,513.20	20.0%	$9,159,015.84
01-16007	Handrailing	1370	m	$80.00	$109,600.00	20.0%	$131,520.00
	Post Tensioning	800	EA	$5,300.00	$4,240,000.00	25.0%	$5,300,000.00
				Subtotals	**$50,183,000.00**		**$58,521,000.00**
01-17	**Conduits**						
01-17001	Overburden Excavation	6000	m^3	$4.00	$24,000.00	15.0%	$27,600.00
01-17002	Rock Excavation	12000	m^3	$7.50	$90,000.00	15.0%	$103,500.00
01-17003	Concrete	30000	m^3	$150.00	$4,500,000.00	15.0%	$5,175,000.00
01-17006	Reinforcing Steel	3270000	kg	$1.15	$3,760,500.00	20.0%	$4,512,600.00
				Subtotals	**$8,375,000.00**		**$9,819,000.00**
01-18	**Crossovers (Including with Lock Floor Costs)**						
01-19	**Conduit Valves and Operating Mach.**						
01-19001	Valves	16	ea	$860,000.00	$13,760,000.00	10.0%	$15,136,000.00
01-19002	Embedded Metals (Stainless Steel)	2000	kg	$15.00	$30,000.00	15.0%	$34,500.00
01-19003	Valve Anchorage (Structural Steel)	20000	kg	$8.30	$166,000.00	15.0%	$190,900.00
01-19004	Valve Operating Machinery	16	ea	$600,000.00	$9,600,000.00	15.0%	$11,040,000.00
01-19005	Electrical System/Controls	1	job	$2,000,000.00	$2,000,000.00	20.0%	$2,400,000.00
				Subtotals	**$25,556,000.00**		**$28,801,000.00**
				Totals	**$866,095,000.00**		**$1,018,955,000.00**
				Rounded	**$866,000,000.00**		**$1,019,000,000.00**

Panama Canal Concept Design
Atlantic Locks Structure
Third Lane
Double-Lift Lock Screening Study
Construction Cost Estimate (Alternative 4a - LCS Gravity Monoliths with Split WSB's)

Price Level: October 2002

ITEM #	Description	Quantity	Unit	Unit Price	Amount	Contin- gencies	Total
01-01001	**Mobilization & Demobilization (1.25%)**	1	job	$10,900,000.00	$10,900,000.00	10.0%	$11,990,000.00
01-01	**Preparatory Work**				$10,882,000.00	20.0%	$13,059,000.00
01-02	**Relocations**				$968,000.00	27.0%	$1,227,000.00
01-03	**Care & Diversion of Water**				$11,462,000.00	20.0%	$13,754,000.00
01-04	**Earthwork for Structures**						
01-04001	Exploratory Drilling	1	job	$1,800,000.00	$1,800,000.00	20.0%	$2,160,000.00
01-04002	Common Excavation (Dry)	4734800	m^3	$4.00	$18,939,200.00	20.0%	$22,727,040.00
01-04003	Rock Excavation (Dry)	5705700	m^3	$7.50	$42,792,750.00	20.0%	$51,351,300.00
01-04004	Common Excavation (In the Wet)	0	m^3	$6.30	$0.00	20.0%	$0.00
01-04005	Rock Excavation (In the Wet)	130000	m^3	$34.15	$4,439,500.00	20.0%	$5,327,400.00
01-04006	Pervious (Structural) Backfill	230000	m^3	$20.00	$4,600,000.00	25.0%	$5,750,000.00
01-04007	Controlled Low Strength Material	0	m^3	$70.00	$0.00	20.0%	$0.00
01-04008	Foundation Prep	125000	m^2	$80.00	$10,000,000.00	20.0%	$12,000,000.00
				Subtotals	**$82,571,000.00**		**$99,316,000.00**
01-05	**Sitework**				$1,687,000.00		$2,026,000.00
01-06	**Guard & Guide Walls, Upper & Lower**						
01-06001	In-the-wet Section (All inclusive)	600	m	$200,000.00	$120,000,000.00	25.0%	$150,000,000.00
01-06002	Conventional CIP	23750	m^3	$145.00	$3,443,750.00	20.0%	$4,132,500.00
01-06003	RCC	451250	m^3	$80.00	$36,100,000.00	20.0%	$43,320,000.00
01-06004	Reinforcing Steel (Dry Section)	2492500	kg	$1.15	$2,866,375.00	20.0%	$3,439,650.00
01-06008	Fenders	1	job	$15,115,000.00	$15,115,000.00	20.0%	$18,138,000.00
				Subtotals	**$177,525,000.00**		**$219,030,000.00**

Panama Canal Concept Design
Atlantic Locks Structure

Third Lane
Double-Lift Lock Screening Study
Construction Cost Estimate (Alternative 4a - RCC Gravity Monoliths with Split WSB's)
Price Level: October 2002

ITEM #	Description	Quantity	Unit	Unit Price	Amount	Contin-gencies	Total
01-07	**Lock Structure**						
01-07001	Concrete for Lock Walls, (Conv)	226697	m^3	$145.00	$32,871,065.00	20.0%	$39,445,278.00
	Concrete for Lock Walls, (RCC)	1222869	m^3	$80.00	$97,829,520.00	20.0%	$117,395,424.00
01-07004	Concrete in Place, Gate Monoliths	249952	m^3	$145.00	$36,243,040.00	20.0%	$43,491,648.00
01-07007	Concrete for Lock Gate Monoliths, RCC	204179	m^3	$80.00	$16,334,320.00	20.0%	$19,601,184.00
01-070010	Concrete for Lock Floors/Sills, (Conv)	78440	m^3	$150.00	$11,766,000.00	20.0%	$14,119,200.00
01-070013	Concrete for Lock Floors, (RCC)	101575	m^3	$80.00	$8,126,000.00	20.0%	$9,751,200.00
01-070016	Reinforcing Steel, Wall Monoliths	7939800	kg	$1.15	$9,130,770.00	20.0%	$10,956,924.00
01-070017	Reinforcing Steel, Floor/Sills	8758660	kg	$1.15	$10,072,459.00	20.0%	$12,086,950.80
01-070018	Reinforcing Steel, Gate Monoliths	4926376	kg	$1.15	$5,665,332.40	20.0%	$6,798,398.88
				Subtotals	**$228,039,000.00**		**$273,646,000.00**
01-08	**Lock Gates & Operating Machinery**						
01-08001	Furnish & Install Lower Miter Gates	2	sets	$0.00	$61,540,000.00	10.0%	$67,694,000.00
01-08002	Furnish & Install Center Miter Gates	2	sets	$0.00	$77,200,000.00	10.0%	$84,920,000.00
01-08003	Furnish & Install Upper Miter Gates	2	sets	$0.00	$45,220,000.00	10.0%	$49,742,000.00
01-08004	Furnish and Install Operating Machinery	12	ea	$900,000.00	$10,800,000.00	15.0%	$12,420,000.00
01-08005	Embedded Metals (Stainless Steel)	38000	kg	$15.00	$570,000.00	15.0%	$655,500.00
01-08006	Gate Anchorage (Structural steel)	391600	kg	$8.30	$3,250,280.[illegible]	[illegible]	$3,737,822.00
01-08007	Bridges over recesses	12	ea	$450,000.00	$5,400,000.0[illegible]	[illegible]	$6,480,000.00
				Subtotals	**$203,980,000.00**		**$225,649,000.00**

Panama Canal Concept Design
Atlantic Locks Structure
Third Lane
Double-Lift Lock Screening Study
Construction Cost Estimate (Alternative 4a - LCS Gravity Monoliths with Split WSB's)

Price Level: October 2002

ITEM #	Description	Quantity	Unit	Unit Price	Amount	Contin-gencies	Total
01-09	**Culvert Valves and Operating Machinery**						
01-09001	Upper Lock Filling Valves	4	ea	$1,245,000.00	$4,980,000.00	10.0%	$5,478,000.00
01-09002	Valves Between Locks	4	ea	$1,360,000.00	$5,440,000.00	10.0%	$5,984,000.00
01-09003	Lower Lock Emptying Valves	4	ea	$1,245,000.00	$4,980,000.00	10.0%	$5,478,000.00
01-09004	Embedded Metals (Stainless Steel)	1900	kg	$15.00	$28,500.00	15.0%	$32,775.00
01-09005	Valve Anchorage	19580	kg	$8.30	$162,514.00	15.0%	$186,891.10
01-09006	Bulkheads	10	ea	$480,000.00	$4,800,000.00	15.0%	$5,520,000.00
01-09007	Valves Operating Machinery	12	ea	$600,000.00	$7,200,000.00	15.0%	$8,280,000.00
				Subtotals	**$27,591,000.00**		**$30,960,000.00**
01-10	**Piping System**				$1,500,000.00	30.0%	$1,950,000.00
01-11	**Power and Lighting Systems**				$23,000,000.00	20.0%	$27,600,000.00
01-12	**Associated General Items**				$4,147,000.00	20.0%	$4,769,000.00
01-13	**Building, Project Operations**				$450,000.00	25.0%	$563,000.00
01-14	**Miscellaneous Items**				$14,410,000.00	16.0%	$16,682,000.00
01-15	**Maintenance Facility (Gates)**				$2,770,000.00	25.0%	$3,463,000.00

Panama Canal Concept Design
Atlantic Locks Structure
Third Lane
Double-Lift Lock Screening Study
Construction Cost Estimate (Alternative 4a - ILCS Gravity Monoliths with Split WSB's)

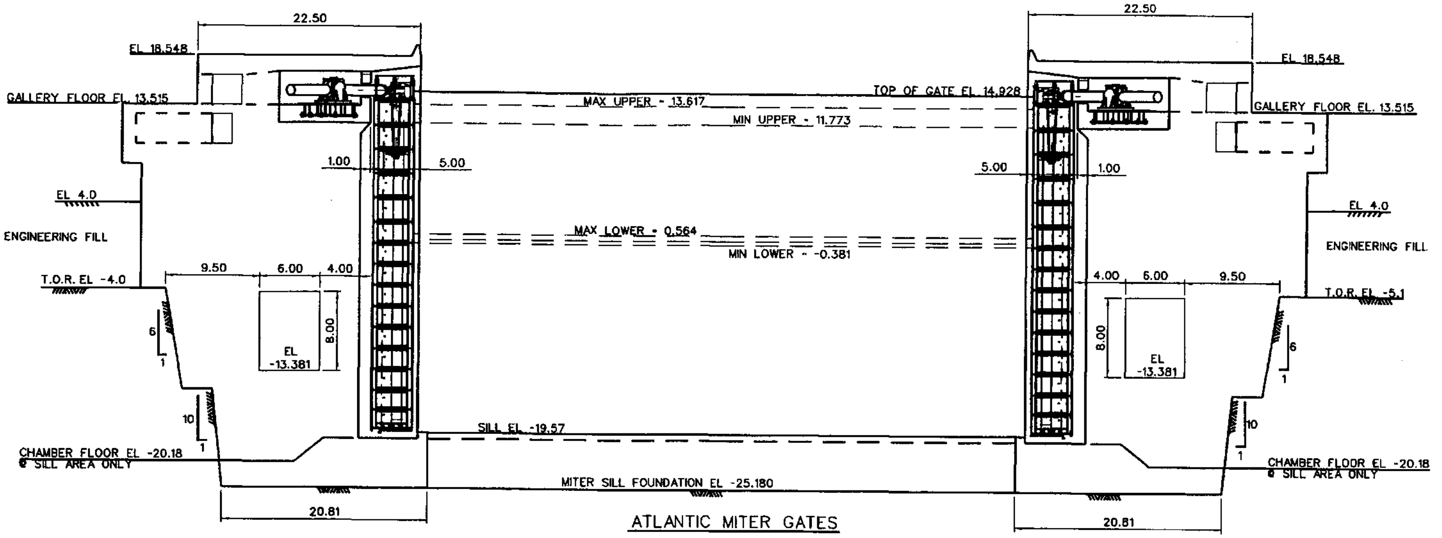
Price Level: October 2002

ITEM #	Description	Quantity	Unit	Unit Price	Amount	Contin-gencies	Total
01-16	**Water Savings Basins**						
01-16001	Overburden Excavation	1250943	m^3	$4.00	$5,003,772.00	15.0%	$5,754,337.80
01-16002	Rock Excavation	1048947	m^3	$7.50	$7,867,102.50	15.0%	$9,047,167.88
01-16003	Concrete (Conventional)	108506	m^3	$150.00	$16,275,900.00	15.0%	$18,717,285.00
01-16006	Reinforcing Steel	6409832	kg	$1.15	$7,371,306.80	20.0%	$8,845,568.16
01-16007	Handrailing	1370	m	$80.00	$109,600.00	20.0%	$131,520.00
				Subtotals	**$36,628,000.00**		**$42,496,000.00**
01-17	**Conduits**						
01-17001	Overburden Excavation	6000	M3	$4.00	$24,000.00	15.0%	$27,600.00
01-17002	Rock Excavation	12000	M3	$7.50	$90,000.00	15.0%	$103,500.00
01-17003	Concrete	30000	M3	$150.00	$4,500,000.00	15.0%	$5,175,000.00
01-17006	Reinforcing Steel	3270000	kg	$1.15	$3,760,500.00	20.0%	$4,512,600.00
				Subtotals	**$8,375,000.00**		**$9,819,000.00**
01-18	**Crossovers (Including with Lock Floor Costs)**						
01-19	**Conduit Valves and Operating Mach.**						
01-19001	Valves	16	ea	$860,000.00	$13,760,000.00	10.0%	$15,136,000.00
01-19002	Embedded Metals (Stainless Steel)	2000	kg	$15.00	$30,000.00	15.0%	$34,500.00
01-19003	Valve Ancho[illegible]tructural Steel)	20000	kg	$8.30	$166,000.00	15.0%	$190,900.00
01-19004	Valve Opera[illegible]chinery	16	ea	$600,000.00	$9,600,000.00	15.0%	$11,040,000.00
01-19005	Electrical System/Controls	1	job	$2,000,000.00	$2,000,000.00	20.0%	$2,400,000.00
				Subtotals	**$25,556,000.00**		**$28,801,000.00**

Totals	**$872,441,000.00**	**$1,026,800,000.00**
Rounded	**$873,000,000.00**	**$1,027,000,000.00**

Attachment 8

Revised Miter Gate and Entrance Wall Drawings



ATLANTIC MITER GATES

SECTION K
PL1
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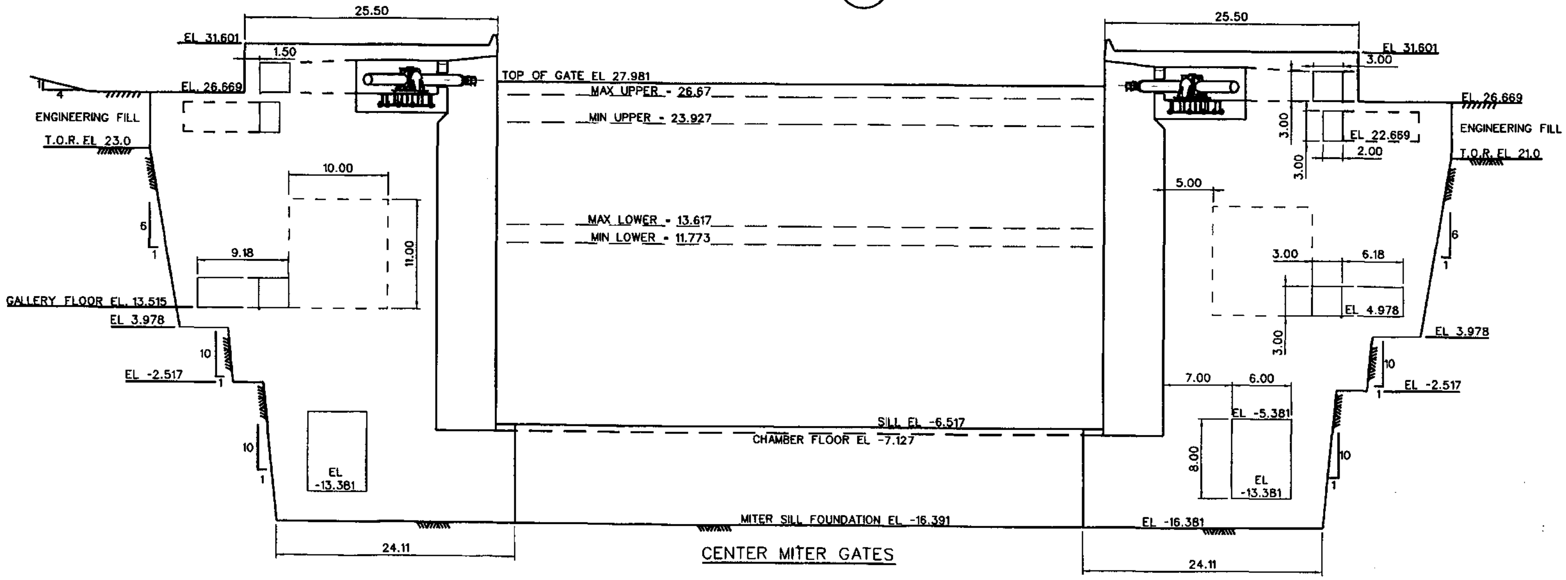

CENTER MITER GATES

SECTION L
PL1
SCALE: 1:250

US Army Corps
of Engineers
Pittsburgh District

Submitted by:
A HARKNESS
TECHNICAL LEAD

Sheet X of X

Design by: R ALLOWES
Dwn by: FT
Ckd by: AH
Submission Date: X
Revision Date: X
FB NO.:

ACP
AUTORIDAD DEL CANAL DE PANAMA

User: dmarcini
Date: 19-FEB-2003 15:40
Plot Scale: 2.880404410000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
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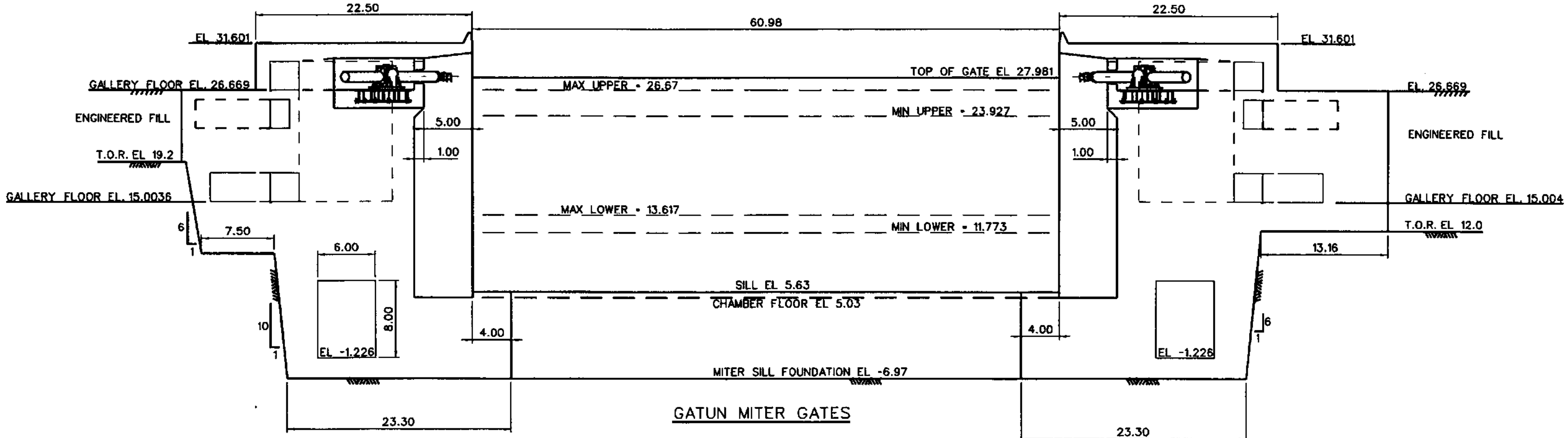
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
DOUBLE LIFT LOCK - SCREENING STUDY
MITER GATE MONOLITHS
SECTIONS K & L

Drawing Number:
ACP-SS-PL15



GATUN MITER GATES

SECTION (M / PL2)
SCALE: 1:250

US Army Corps
of Engineers
Pittsburgh District

Submitted by: A HARKNESS
TECHNICAL LEAD

Sheet X of X

Design by: R ALLOWES
Dwn by: JT
Ckd by: AH
Submission Date: X
Revision Date: X
FB NO.:

ACP
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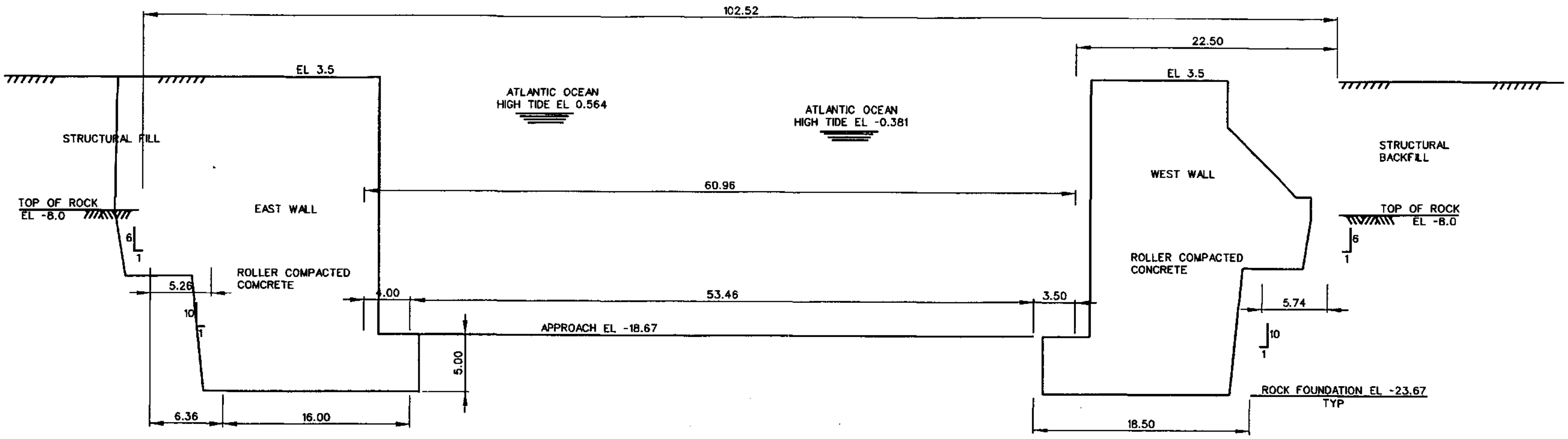
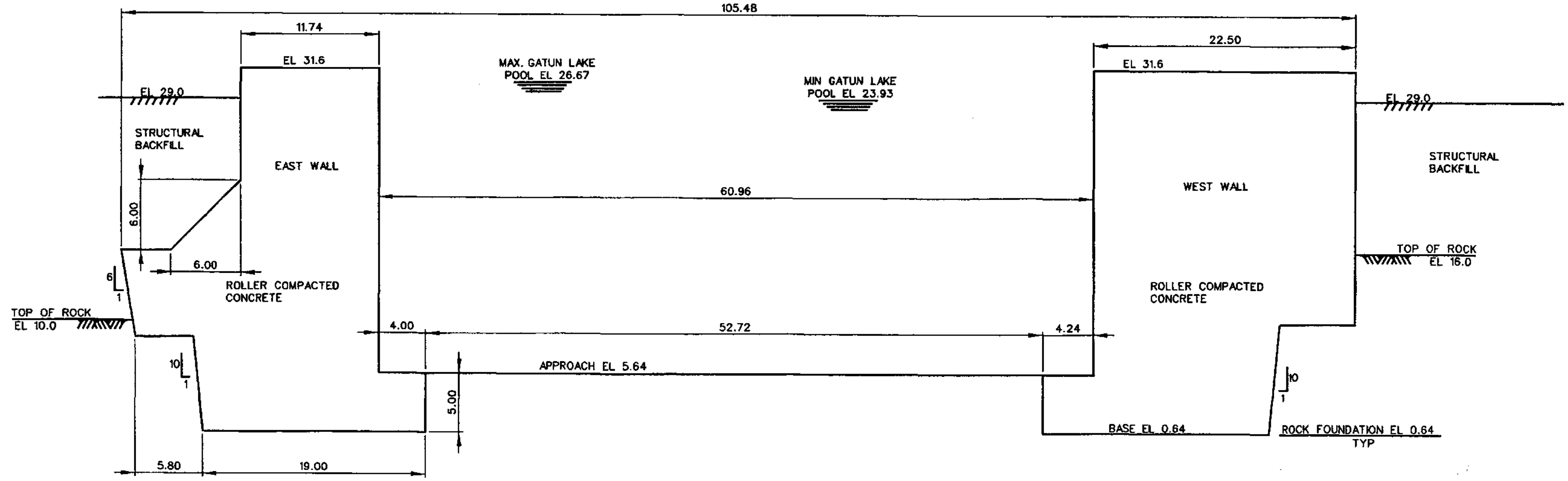
PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
DOUBLE LIFT LOCK - SCREENING STUDY
MITER GATE MONOLITHS
SECTION M

Drawing Number:
ACP-SS-PL16



SECTION N
SCALE: 1:200



SECTION O
SCALE: 1:200

ALL DIMENSIONS AND/OR DIMENSIONS SHOWN IN CALLOUTS/NOTES ARE IN METERS UNLESS OTHERWISE NOTED.

US Army Corps of Engineers
Pittsburgh District

Submitted by: A HARKNESS
TECHNICAL LEAD

Sheet X of X

Design by: HARKNESS
Dwn by: JT
Ckd by: RA
Submission Date: X
Revision Date: X
FB NO.:

ACP
AUTORIDAD DEL CANAL DE PANAMA

User: dnardini
Date: 19-FEB-2003 15:40
Plot Scale: 2.880404:1.000000
Pen Table:
Color Table:

Symbol	Description	Date	Appr.
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PANAMA CANAL
ATLANTIC LOCKS CONCEPT DESIGN
DOUBLE LIFT LOCK - SCREENING STUDY
ENTRANCE WALLS
ATLANTIC & GATUN SECTIONS

Drawing Number: ACP-SS-PL17