Inner Harbor Navigational Canal Lock Replacement- Shallow Draft GRR

Annex 5: Sector Gate versus Miter Gate Analysis

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1.0 BACKGROUND

1.1 General

The original study, dated March 1997, investigated the feasibility of replacing the existing IHNC Lock with either a 110 foot wide barge lock with a sill elevation (-) 22.0 feet NGVD and a 900 foot usable chamber length or a 110 foot wide ship lock with a sill elevation (-) 40.0 feet NGVD (gate sill at El. –36.0) and a 1200 foot usable chamber length. Both options utilized a conventional miter-gated structure, with two sets of gates (one set having an upstream pair of gates and a downstream pair of gates): one set of direct head gates and one set of reverse head gates. Subsequent to the original study, CEMVN-OD requested the investigation of a sector gate alternative for the 110-foot by 1200-foot ship lock, which is the primary focus of this Annex. The sector gate can operate under a reverse head; therefore, the reverse head gates were eliminated. Furthermore, CEMVN-OD prefers the durability of the sector gate over the slender miter gates.

1.2 Physical Model Study

On 11 April 1997, the Headquarters, U.S. Army Corps of Engineers, at the request of U.S. Army Engineer District, New Orleans (MVN), approved a physical model study of the 110-foot by 1200-foot ship lock, to be performed by ERDC. The main objectives of this study were:

1. To determine the filling and emptying times for various valve speeds for lifts up to 19.6 feet.
2. To determine hawser forces on barges and a ship in the chamber for varying operating conditions.
3. To determine intake and outlet performance.
4. To determine pintle torque loads on the sector gates.
5. To make modifications if necessary to improve hydraulic performance.

While a more detailed discussion of the results of this study and their impacts on the design can be found in the *Inner Harbor Navigation Canal Replacement Lock Filling and Emptying System, Inner Harbor Navigation Canal, Louisiana*, report by John E. Hite, Jr., the results affecting this appendix the most are:

1. The pintle torque results verified that the sector gate and recess designs were satisfactory for a 110-foot wide lock,
2. The side port filling and emptying system were incorporated into the design to assist the end filling system, as the end filling system alone was

inadequate. Ultimately, only the culvert system was considered in the filling and emptying system.

3. The lock geometry was optimized to produce the configuration shown herein.

2.0 DESIGN

2.1 General:

Although there are differences in the gate bay monoliths of a sector-gated structure as compared to a miter-gated structure, the chambers essentially remain the same. Consequently, all design performed as a part of this appendix focuses entirely on the gate bay monoliths, with the exception of some minor adjustments made to the chamber monoliths' layout to optimize the graving site.

2.1.1 Design/Construction Philosophy:

The overall construction philosophy presented in the Evaluation Report has not been altered. The modules are still to be partially constructed in the government-furnished graving site and, upon completion, floated to the work platform located at the Galvez Street staging area for final outfitting and set down. The float out draft was limited to the available IHNC channel bottom elevation at EL –30.0 NGVD. The outfitting area was placed over the excavated foundation area; available draft on the excavated slope is approximately 48'.

2.2 Structural Design

2.2.1 References:

The EM's, ETL's, technical publications, and material weights referenced in Volume 3 of 9, Appendix B, of the 1997 Evaluation Report were utilized in all computations performed as part of this appendix, with the following exceptions:

1. American Concrete Institute, Building Code Requirements for Reinforced Concrete, (ACI 318R-99).

2. Muckle, W. Muckle's Naval Architecture, Second Edition

2.2.2 Load Cases:

2.2.2.1 Gate Bay Module Design Load Cases:

The transportation case, lightship condition was investigated for the gate bay module post-tensioning design about the longitudinal and transverse axis. Both a static and static plus wave case were considered, the wave height of 6'(crest to trough) was used thus limiting transport to an inland waterway. A simplified hogging and sagging curve were used to calculate shear and moments, the method is described in para. 2.2.3.1. Allowable stress levels were increased for the temporary static plus wave load condition. The gate bay shell was also analyzed in the set down condition, in the transverse direction.

Member dimensions are comparable to the miter gate sections, sizes were increased as required to overcome the transport analysis.

2.2.2.2 <u>Gate Bay Foundation Design Load Cases:</u>

The load cases, as defined in the Evaluation Report, investigated herein for the foundation design are:

1. Normal Operation
2. Maximum Operation A
3. Maximum Operation B
4. Maintenance Dewatering
5. Hurricane

2.2.2.3 <u>Sector Gate Design Load Cases:</u>

For the sector gate design, load cases 1, 2, and 4 of the above Foundation Design Load cases were used. The following load cases, defined in the Evaluation Report as well, were also investigated:

1A. Normal Operation + Boat Impact
2A. Maximum Operation A + Boat Impact
2B. Maximum Operation A + Freeboard (4.8 ft)

2.2.3 <u>Gate Bay Design:</u>

For cost-comparison purposes, the design philosophy for the gate bay monoliths remains the same as that presented in the 1997 Evaluation Report: a precast, post-tensioned, float-in concrete lock, as shown on PLATE S-08. Post tensioning was used in the base section in both directions. The post tensioning reinforces the base girder system, conventional reinforcement is used in the panel design. The panel design does not consider the positive effects of the global post tensioning. The panels were designed as beam-columns with the post-tensioning applying an axial load. The top of the replacement lock walls remain at elevation 22.4 feet NGVD, and the lock chamber remains 110 feet in width. The lock culvert geometry is also unchanged at 15’-0” wide by 18’-3” high, flaring out to 32’-0” wide at each end.

2.2.3.1 <u>Naval Analysis:</u>

The gate bay was analyzed for the lightship condition using the simplified hogging and sagging method presented in <u>Muckle’s Naval Architecture.</u> The assumptions made for the simplified naval analyses are:

1. The hogging and sagging analysis is a 2-d analysis with separate analyses performed for the transverse and longitudinal directions.

2. The loads across the full width of the structure are collapsed and averaged into linear loads acting at the centerline of the structure.

3. Since the base is a non-rectangular shape, the width is averaged to simplify the calculation of buoyancy forces and average draft.

4. Temporary end dams are present and no water weight is allowed in the culverts or the chamber/gate recesses.

5. The wave loadings have a sinusoidal shape rather than the more accurate trochoidal shape to greater simplify calculations.

6. Although an uneven mass distribution would cause the structure to list and displace more water to achieve equilibrium with the buoyancy forces, this analysis assumes no listing of the structure and a linearly varying buoyancy pressure, trapezoidal in shape, to simplify the analysis.

Based upon the use of this analysis on a similar structure, the resulting shears and moments calculated are conservative. Also, the lightship condition has been shown to govern in the past for the longitudinal direction and is, consequently, the only loading condition analyzed herein. The transverse direction post-tensioning was designed based on the transport condition; operating conditions shall be analyzed in the future as needed by the Design Team. No ballasting phases or normal operating conditions have been analyzed for the concrete design.

2.2.3.2 <u>Module Design</u>:

Using the geometry shown on plates S-08 through S-12, and the shears and moments computed in the hogging and sagging analysis, a rough post-tensioning design was performed. The design assumed 6000 psi, normal-weight concrete, with 160 ksi threaded prestressing bars (although the Corps has begun to allow tendons in lieu of bars, bars were used in this design to maintain consistency with the original Evaluation Report). The same methodology and the same allowable stresses provided in the Evaluation Report were used for design, herein. That is, the base was designed as a series of post-tensioned I-beams spanning both the 320'-0" and the 218'-8" directions. Although the base post-tensioning was designed to take the transport condition full moment, an allowance was left in the cost-estimate for temporary struts, which should be provided for additional capacity. The infill was <u>not</u> considered as acting compositely with the shell; future designs will provide the most economical combination of shell and ballast. The ballast must be a solid cementitious fill, shell interior rebar cover requirements can be reduced accordingly. Similar to the miter gate design, sufficient infill shall be added such that dead load alone will provide 105% negative buoyancy for the greater of the dewatering and set down condition. Pile tension capacity is used to obtain the minimum flotation Factor of Safety of 1.3. However, as a minimum infill will be included up above the culvert walls, voided compartments below water were considered as a maintenance problem. The modules are supported independent of each other; there was no load transfer, gravity or lateral, between adjacent modules.

2.2.3.3 <u>Other Checks</u>:

Draft and structure geometry were investigated to determine the feasibility of transporting the structure from the government-furnished graving site to the Galvez Street staging area. The voided base structure will have 21.4 feet of draft which is approximately 1'-7" less than the maximum draft of the miter-gated structure. The width and draft of the structure were also compared to the channel constriction at the new Florida Avenue Bridge and was determined to have adequate clearance. The fully constructed gate bay module requires a draft of 48 feet; this is significantly greater than the miter-gated module, which required only 38.5 feet.

The structure geometry was also checked graphically via plates S-04 and S-05 to determine if any adjustment to the bypass channel would be necessary. Adequate clearance is provided between the gate bay and the bypass channel guide wall, so no adjustment to the bypass channel is required. Two-110 foot bypass lanes can be constructed on the east side.

2.2.3.4 <u>Foundation Design:</u>

The pile foundation is shown on plate S-07 and utilizes the piles used in the preliminary design as presented in the original Evaluation Report - 48" x $^5/_8$" steel pipe piles. As with the miter gate monoliths' foundations, the majority of the piles are compression-only piles connected to the monolith by a 4-foot thick tremie concrete cap. Some of these compression-only piles are located in the three setting pads under each monolith. The three setting pads are in keeping with the Evaluation Report design and are used for those same reasons. The tension piles are anchored to the monoliths using the same methodology as the Evaluation Report. There are five tension piles per transverse row for both gate bays (with the exception of the rows containing setting pads) and three tension piles per transverse row for all chamber monoliths. The entire underbase width is grouted; a piping system was included in the base design. The weight of the grout was included in the pile compressive load and conservatively ignored in the dewatered case. Lateral load is minimal, the resistance is assumed transferred through the base into the pile foundation by friction.

2.2.4 <u>Chamber Design:</u>

The overall chamber modules' design presented in the 1997 Evaluation Report was not altered. The geometry, however, was adjusted as shown on plate S-08 to provide the requisite 1200 feet of usable chamber length. The pintle to pintle distance is 1270 feet.

2.2.5 <u>Sector Gate Design:</u>

The sector gates, shown on plates S-13 through S-20, have a pintle-to-skin plate radius of 52'-6", an overall height of 62.4 ft, and is composed of three vertical trusses and four horizontal frames. The gate was analyzed with the traditional 2-d approach using C-FRAME. The main members were designed using the C-FRAME results and checked as a 3-dimensional space frame and a 3-dimensional space truss using STAAD. The main members selected were all wide-flanges, however, pipe sections shall be investigated in the next phase of design.

3.0 COST

3.1 General:

Included, as APPENDIX A and APPENDIX B, are the cost estimates for the sector-gated structure and the miter-gated structure respectively. For consistency, the line items in the sector-gated structure's cost estimate are the same as those for the miter-gated structure. Some quantities were unaffected by changing the structure to a sector –gated lock, and were left unchanged. All others were revised accordingly. The unit costs and lump sum costs were all updated from 1997 prices to 2002 prices.

Worthy of note is the fact that for the sector gate option, CEMVN-OD has authorized the elimination of the emergency crane, which is a $1,350,000 savings.

The overall cost for the miter gate option (2002 prices) is $260,300,000 and the cost for the sector gate option (2002 prices) is $248,800,000.

4.0 SECTOR VS. MITER COMPARISON

4.1 Design Issues:

Considerations that set the two gate types apart are:

- The existence of a reverse head at various times of the year.
- Durability.
- Gate geometry.
- Gate Bay Monolith Geometry.
- Construction time.
- Culvert Maintenance.
- Overall costs.

4.1.1 <u>Reverse Head:</u>

Miter gates are not designed to operate against a reverse head. To deal with this condition, either a second set of gates must be installed or the lock must be shut down for the duration of the reverse head. Since the latter is not an option, a second set of gates must be included along with the appurtenant machinery. To accommodate the second set of gates, the gate bay monolith must be lengthened accordingly.

A single set of sector gates, by design, can handle both a direct head and a reverse head without the need for more gates or more machinery.

4.1.2 <u>Durability:</u>

Miter gates do not stand up to damage as well as sector gates. Additionally, if a miter gate leaf is damaged such that there is a flow of water into the chamber, flooding of the downstream side could occur and/or the undamaged gates cannot be operated. Consequently, a $1.4 million emergency crane must be provided to lift the emergency bulkheads into place to stem the flow.

Sector gates, on the other hand have no problem operating against a flow and can thus temporarily stem the flow until the emergency bulkheads can be placed. Since placement of the emergency bulkheads is no longer imperative, the emergency crane can be eliminated.

4.1.3 Gate Geometry:

Miter gates are routinely built for the rough channel geometry of 110’ wide by 60’ tall. If built, the sector gates would be atypical and would be among the largest constructed. However, the large couple (distance between pintle and hinge) distance greatly reduces thrust on the hinge and pintle and large main chords minimize deflection. Gate deflection due to dead load is mostly cambered out during fabrication. Wheels and flotation tanks were considered in the preliminary design but discounted.

4.1.4 Gate Bay Monolith Geometry:

The miter gates’ gate bay monolith is rectangular in shape, roughly 180’ wide by 436’ long. The sector gates’ gate bay monolith is 218’-8” long by 320’ wide at the widest point tapered down to 180’ wide at the gate bay – chamber interface. While in transit, the gate bay will be subjected to wave loadings, the most critical of which is the hogging case (the structure is essentially supported in the center by the wave while the ends behave as cantilevers). While the miter gate structure has significant moments induced during transport, the additional 70’ of width on the sector gate structure increases the moment drastically, thus requiring more prestress. To eliminate the need for so much prestress, these high moments can be reduced by selective ballasting and/or the addition of tension struts spanning the 110’ width.

The other area potentially affected by the additional 70’ of width is the bypass channel. However, the original clearance between the limits of the bypass channel and the edge of the gate bay concrete of 110’ has been reduced to 40’. This distance is more than sufficient, so no adjustment to the bypass channel would be necessary.

4.1.5 Construction Time:

The initial plan for construction and float-out of the miter gate monolith calls for four 450’(±) long sections to be constructed at the government-furnished graving site and floated into position. Since the 320’ width is required for the gate recesses, the 218’-8” longitudinal dimension of the sector gate monolith becomes the least dimension. At the new Florida Avenue Bridge, the width and depth restrictions do not allow a longer section. Therefore, the configuration of the graving site was changed, thus necessitating the construction of five sections instead of four. Although the five smaller sections would be more manageable and the graving site smaller and more cost-effective, this option would require the graving site to be flooded and dewatered one additional time, thus increasing construction time. If a shorter construction time is more desirable than cost-savings, the graving site can be enlarged, thus permitting the construction of multiple modules simultaneously.

4.1.6 Culvert Maintenance

Miter gates cannot operate without culverts to fill and empty the chamber. Sector gates, on the other hand are capable of filling and emptying the chamber in a sufficient time frame when there is a small head differential. Although the sector gate was shown to need the culverts for high head differentials, the gates are capable of operating without them during periods of low differentials. Being able to end-fill during those times would enable the culverts to be dewatered for maintenance without closing the lock to marine traffic.

4.1.7 Costs

Excluding spare gates for either option, the sector gate option is roughly $12 million cheaper than the miter gate option.

5.0 CONCLUSIONS

5.1 General:

In light of the comparison above, the costs turned out to be roughly comparable and were, therefore, a non-issue. In light of its preference for a sector-gated structure, and the data presented herein, CEMVN-OD elected to pursue the sector gate option and also authorized the elimination of the emergency bulkhead crane.

LIST OF REFERENCES

American Concrete Institute, Building Code Requirements for Reinforced Concrete, (ACI 318R-99).

Inner Harbor Navigation Canal Replacement Lock Filling and Emptying System, Inner Harbor Navigation Canal, Louisiana, Report, John E. Hite, Jr.

Muckle’s Naval Architecture, Second Edition, W. Muckle.