Calvin College Senior Design: ENGR 340

Lock System
for the River Siem Reap

Team Members:
Michael Bratt
Aaron Svacha
Nate Voigt
Matt Vredevoogd

© Calvin College and Michael Bratt, Aaron Svacha, Nate Voigt, Matt Vredevoogd
Lock System for the River Siem Reap

**TABLE OF CONTENTS**

2  Executive Summary  
3  Introduction  
3  Challenges  
5  Solutions  
7  Discussion of Solutions  
11  Conclusions  
11  Recommendations  
12  Acknowledgements  
13  Appendix
Executive Summary

The goal of this project was to design a system of locks for the Siem Reap River in Siem Reap, Cambodia. Due to time restrictions, we designed only the main components of the lock. These components include the culverts, valves, gates, opening mechanisms, side bumpers, and dewatering wells.
Introduction

Cambodia has undergone dramatic political and social changes during the last twenty-five years. The four-year rule of Pol Pot and the Khmer Rouge left the entire country in a degraded state and with a population one-half of what it had been. Recently, the country reopened its borders to tourists and it has much to offer. Cambodia claims Angkor Wat, one of the seven wonders of the ancient world, which resides in a cluster of ancient temples just outside the city of Siem Reap. When tourism was once welcomed to Cambodia, the area found itself unprepared for the sudden rush of tourists and in need of urban development. From Handong Global University in South Korea, Professor Hackchul Kim prepared his Master Plan to aid in the reconstruction of the area and further development of the city. Professor Kim’s plan includes the construction of a pier and canal that will allow for tourists to approach the city by water from the capital city of Phnom Penh. The city is located across the Tonle Sap Lake, a body of water that undergoes a dramatic change in volume due to seasonal swelling. The channel is meant to maintain a constant river level through the city and to promote tourism and trade. To help out, we commissioned ourselves to design a lock system to allow free transport between the river channel and the lake.

Challenges

The project contained a wide variety of challenges. Several became design considerations as the project progressed, while others occasionally slowed our project to an agonizing crawl.

Project Description

Cambodia experiences a tropical climate with a monsoon season and an equally severe dry season. These conditions create water level fluctuations of approximately 21 feet in the Tonle Sap Lake. In order to keep the new canal navigable, Professor De Rooy proposed incorporating a lock system. This lock system would allow the water level of the river to be kept constant while the water level of the Tonle Sap could continue to fluctuate naturally with the seasons.
Lock System for the River Siem Reap

Communication

Professor Hackchul Kim, architect of the master plan, was located over 6,000 miles away, and the project location itself was located over 8,000 miles away from Grand Rapids, Michigan. There was little or no information provided at the onset of the project and very little technical information was readily available about the area due to Cambodia’s recent history. Communications were few and far between since correspondence was limited mainly to e-mail and one visit to the area where the project was to take place.

Design Norms

We kept several ideas and concepts, called design norms, in mind during our design process. These norms helped to maintain our focus on designing from a Christian standpoint. The norms that we emphasized the most were cultural appropriateness, stewardship, justice, and trust.

- Cultural Appropriateness
  
  As a result of its recent history, Cambodia has undergone severe cultural changes. The implementation of the lock system, as well as the entire master plan, could contribute to even greater unwanted cultural changes that the people in the area do not want to see. In our design, we took care to draw from and protect the deep history of the area.

- Stewardship
  
  The purpose of the locks is to serve people in the area. We attempted to incorporate technology and resources that the people presently have. Also, we hoped to minimize impedance on the people’s daily lives.

- Justice
  
  We tried to design the locks to accommodate future growth in the area and larger commercial vessels. However, we wanted to make the locks accessible to all traffic types and sizes. We needed to keep the locks accessible for traffic
ranging from canoes to tourist boats to houseboats that might travel from nearby floating villages.

➢ Trust

As a developing country, Cambodia does not have a significant amount of money to spend. The design must fit the country’s needs and in an appropriate manner. The country must have a quality, long-lasting design if any significant sum of money is to be invested. The final design must also be able to accommodate any expected future growth.

Solution

The design process had two main steps, a preliminary design and a final design. The first design was based on many assumptions and contained very few specific details. Our team used this as a starting point. After gaining more information and input from Professor Kim, we determined that two identical locks were necessary in the final design. The second lock was added for aesthetics, redundancy, and to accommodate the expected volume of boat traffic. Lock sizing was another very important step since the dimensions dictated the size of the culverts. This size was based both on the anticipated largest vessel sizes as well as traffic volumes. We optimized the lock dimensions based on operating times of the components of the lock cycle: closing the gates, filling the lock with water, moving vessels in and out, and so on. Culvert dimensions proved to be the controlling factor in how fast the water would either raise or lower in a single operation. For our final design, we settled on a 120m x 25m x 17.5m lock channel. With these dimensions, each lock cycles twice per hour. Boat traffic volumes and lock dimension calculations are included in Appendix B. In order to minimize the effects of water currents entering the locks, we chose to incorporate a diffusing grid between the culverts and the lock area.

Once we knew the basic dimensions of the locks, we began to design the gates, valves, and bumper system. We relied heavily on the aid of the United States Army Corps of Engineers (USACE) Design Manuals for gate load considerations and calculations. Our gates and their mountings were modeled after the Macarthur Lock at Sault Ste Marie. However, we felt that the gates would benefit from a custom design in the opening and closing mechanisms to make it
culturally adaptive and for simplicity. We implemented another unique design with the special
bumper system located on the lock walls. It is unique in that most lock systems do not have
bumpers. The bumpers are not fixed to the walls, but instead raise and lower with the water level
inside the locks. We used butterfly valves upstream and downstream because of their simple
design and ease of operation. These can be manufactured relatively easily and should be easier
to repair, due to their simple geometries.

In order to allow for maintenance and possible emergency repairs of any of the
aforementioned lock components, we added dewatering gates to each end of the lock. This
design requires dewatering wells to dewater, or empty the locks. Our design includes two
dewatering wells adjacent to either lock for the sake of redundancy and to expedite the
dewatering process.

Microsoft Excel was a valuable tool in the analysis and design process for our solution.
All calculations done in Excel were checked by hand for accuracy. Copies of our spreadsheets
and hand calculations can be seen in Appendix D of this report.

For display purposes, we constructed a semi-operable model. A picture of the model may
be seen in Appendix B.

Pricing our project was a difficult task. We found little information on current material
prices such as concrete or steel in Cambodia. Also, labor costs have no set minimum or standard
in Cambodia. We compiled an estimate of steel and concrete requirements and found an
estimate in U.S. dollars. The cost of construction in Siem Reap should be significantly lower,
but we do not have a good method of cost conversion. Our current estimate only for steel and
concrete is $20 million USD. Additional expenses include labor costs and construction
overhead, pumps, motors, shafts, lock control structures, Programmable Logic Controllers
(PLCs), excavation, and so on. As far as our design and model needs were concerned, we did
stretch our budget. Our few expenses can be traced to a trip to the Sault Ste. Marie locks and
model materials. We budgeted $100 for the trip and $100 for the model, but spent approximately
$180 on the model and $100 on the Sault Ste Marie trip.

At the onset of the project, we set a schedule for ourselves and agreed upon it as a team.
For comparison, Appendix A also includes a copy of our actual schedule. Under examination, it
turned out that many of the important dates that we set for ourselves were pushed closer to the
end of the schedule. Unfortunately many of the items on the original schedule were either
greatly delayed or never started. These occurrences are partly a result of our learning as the project continued. New and more significant items replaced those that were thought to be important at the beginning of the project. Also, the Sault Ste. Marie trip was delayed because of security clearance issues.

As a team we learned much throughout the duration of this project. The biggest lesson that we learned from working as a team was to meet often, but work separately. Our original approach to the project was to treat it as a group project. Often, we had too many opinions and not enough work for everyone. As time progressed, we divided the tasks and talked frequently with one another to keep each other updated and to get new ideas. We all worked well in our separate roles once the tasks were delegated. One change that would be important in the planning of our project would be to do a greater amount of research or to consult with a person familiar with the design process before setting the schedule in place.

**Discussion of Solution**

We have included a set of drawings of our lock schematic with this submission. For items that we did not have time or ability to design, we referenced the USACE design guides. These design guides are included in Appendix C.

**Design Materials**

We based all of our concrete designs on 3,000 psi concrete. This is a lower grade concrete that we felt would be accessible in Cambodia. Also, we hoped to use lower grade steel when possible. In the United States, several components of a lock require at least 50 ksi steel. For these members, such as the horizontal leaf girders and quoin posts, we based our calculations on the higher strength steel. For other items such as rebar and valves, we used lower strength steel, usually 30 or 36 ksi.

**Motor Sizing**

The mechanical engineers took on the task of determining the best type of motor available to control the linkage for opening and closing the gates and for controlling the shaft that the valves would be attached to. We decided that a DC motor would be the
best option for the area. This seemed to be a better option than a hydraulic or fuel powered motor due to the simplicity of use and lower energy costs.

Once we had decided on the type of motor, we determined what specifications the motor would have to achieve. In the case of the linkage operation, we required a motor that would be able to achieve a very large torque, upwards of 5,500,000 foot-pounds for the downstream gates and 4,000,000 foot-pounds for the upstream gates. Fortunately, we only needed the gate leafs to move through an angle of 72 degrees in ninety seconds, making it possible to find an electric motor for our application. For the valve operation, we only needed a torque of approximately 150,000 foot-pounds, but we wanted the valves to open in about six seconds, turning through an angle of 90 degrees.

After searching through a variety of manufacturer's websites, we found one company that produced electric DC motors large enough to operate our gates. The motor we selected was the Portescap 28LT12-416E-164. The company produces this motor at a variety of speeds and torques, and the speeds and torques we required fell within the ranges that the company produced, in most cases with a very large safety factor. The calculations used to determine our torques, speeds, and safety factors for both sets of gates and the culvert valves can be found in Appendix D.

**Bumper System Buoyancy**

In order to ensure that our bumper system would float and ascend and descend as the elevation of the water changed, we performed calculations to determine how many buoys would be needed based on the amount of tires that would be used. The density of rubber is slightly greater than that of water, so we began by assuming that the tires would not float on their own. We then determined the weight of a tire in air, as well as the weight of the tire in water. These results determined the amount of buoys necessary to counteract the weight of the tires in water. All of the calculations can be found in Appendix D.

**Valve FEA Calculations**

We determined the force on the surface of the valves due to the water by finding the weight of the water between the gates and spreading it over the surface of the floor to
give a force in pounds per square inch. The valves were designed using standard structural steel to make up the walls. The shaft about which the valves would rotate was designed using standard sized steel pipe.

Also, we performed finite element analysis on the initial valve design to determine if it would be able to withstand the force from the water as well as the vibrations from boats passing through the lock system. We tested the valves in both the open and closed positions, and verified the FEA solutions with hand calculations. Although our initial valve model was good enough, the safety factor was quite small. Therefore, we redesigned the valves and tested again.

The updated design of the butterfly valves consisted of the original valves with ribs added on either side of the shaft to increase the strength and stiffness of the valve. The valves were once again tested using FEA and hand calculations in both the open and closed positions. These calculations can be found in Appendix D. A summary of the process and results, as well as some 3D drawings of the valves analyzed can be found in Appendix D.

Pump Selection

Although the main lock operation is gravity-driven to increase simplicity, we had to use pumps to empty the dewatering wells because the level of the water in the wells is below that of the surface of the lake. When choosing which pumps would best achieve our goals, we looked at two main criteria: the flow rate of water through the pumps and the head that the pumps could produce. Our goal was to have the ability to empty the locks within an hour using two pumps, one in each of the two dewatering wells. We found numerous pumps that would work for our design, but decided on the CPP-21 Model, a horizontal pump from Phoenix Pumps. We could have used a larger pump to empty the locks faster, but this was unnecessary, and it would likely incur a greater cost. The pumps that we chose from for our system can be found in Appendix D.

Dewatering Well Gates

When designing the gates to our dewatering wells, we wanted the gates to be designed in such a way that they could be opened manually. The two gates weighed
approximately 1100 pounds each. Therefore, we needed to design a system of gear reductions to reduce this weight to an amount that would be manageable for an average human being.

The gate-lifting mechanism consists of a foot long shaft, upon which a cable attached to the top of the gate will coil. A system of gears is attached to the shaft to reduce the torque needed to turn a crank while increasing the number of revolutions necessary to raise the gate to its fully open position.

Although fatigue will not likely be a major issue because the dewatering wells will only be used on occasions when there are problems with the locks, we also did calculations to ensure that the shaft would not fail due to fatigue from numerous opening and closing cycles. Finally, the shaft diameter is large enough to prevent failure due to the transverse shear and torsional forces supplied by the cable. We used the Distortion Energy Failure Theory method for this calculation. Since $s_e$ is less than the yield strength of the steel (36 ksi), the shaft will not fail. These calculations can be found in Appendix D. As a method of checking the failure theory, we utilized MD Solids. See Appendix D.

By reducing the rotation speed from 10 rpm at the original shaft to 0.2778 rpm at the crank, we were able to reduce the torque from around 1100 ft-lbs to 30.97 ft-lbs for the gate. Based on a cranking speed of 10 rpm, the time required to lift the gate would be about 9 minutes, as the shaft attached to the cable would have to revolve 2.5 times and the crank would have to revolve about 90 times. These calculations can be found in Appendix D.

Also, we checked the forces on the shaft in order to determine that it would be able to support the weight of the gates with minimal deflection. These calculations are also found in Appendix D.

Opening/Closing Linkage

We checked three members of the linkage to verify their strength and resistance to failure during gate opening/closing operations. First, we checked the shaft that the gear is mounted on to ensure it would not fail due to the shear force put on it from the 300,000 lb reaction force from the gate leaf. These calculations are found in Appendix D.
Then, the two linkage members were checked via buckling failure theory. They are both capable of supporting the load generated by the gate leaf as well. These calculations are found in Appendix D.

Conclusions

For this project, we have met our goal of designing most of the major components. This proved to be a difficult task with many assumptions built into the design. However, we feel that the designs comply with the design norms and will benefit the people of Cambodia.

Presently, the Master Plan will not be implemented for at least several years. In that time, the plans will change to adapt to the needs of the people. It is not likely that our design will be built as we have specified in this report. However, we do feel that our design is solid and fits the Master Plan as of January 2005. This schematic can be changed and updated as the Master Plan or local standards require. For the local people, funding will likely be the largest issue involved in attempts to implement this project.

Recommendations

As this project is very large and still requires several years to completely finish, we left out many components of lock design. In addition to the under-channel walkways, electric wiring, shaft seals and so on, we strongly recommend adding the following:

1. Bubblers- Bubblers are mounted in the lock wall inside the recess for a gate leaf and blow air into the water to reduce sediment buildup. This forced air creates turbulence in the water to pick up sediment and send it out the downstream valves. We have several ideas for bubblers, one of which would operate with the force of the opening gate.

2. Electric generators- Energy is a precious resource in Cambodia and a lock system requires a large amount. To alleviate some or all of the electricity demand, we recommend placing turbines in the culverts. These turbines could run generators, which would produce electricity that could operate various gate components and possibly provide power to some areas of the pier.
Acknowledgements

As a team we would like to acknowledge those who have helped along the way in our design process. Without their aid, we would not have been able to produce our final design.

Special thanks to:
Leonard De Rooy – Professor of Engineering at Calvin College
Dr. Gayle Ermer – Professor of Engineering at Calvin College
Ezra Hackchul Kim – Professor of Architecture at Handong Global University
Steve Rose – Assistant to Area Engineer, Sault Ste. Marie USACE
Kevin Sprague – Sault Ste. Marie USACE
Roger Lamer – Industrial Consultant
Scott Vredevoogd – Shop assistance
Mike Zuiderveen – Materials and shop assistance
USACE – Gate and Operating Equipment Design Manual
Appendices

Appendix A: Schedule and Budget
Appendix B: Our Design Guides
Appendix C: USACE Design Guides
  Gate Mounting
  Anchorage
  Gate Leaf
  Connections
  Gate Linkage
  Electrical Systems
Appendix D: Design Verification and Failure Theory
  Linkage
  Dewatering Well/Valve/Gate Operation
  Gate Leaf Design
  Concrete Beams
  Bumper System
Appendix A: Schedule & Budget
<table>
<thead>
<tr>
<th>Task</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research / Project Milestones</td>
<td>21.00</td>
</tr>
<tr>
<td>Presentation 3</td>
<td>5.50</td>
</tr>
<tr>
<td>Culverts</td>
<td>20.50</td>
</tr>
<tr>
<td>Doors</td>
<td>59.75</td>
</tr>
<tr>
<td>Pumps</td>
<td>4.50</td>
</tr>
<tr>
<td>Bumpers</td>
<td>10.50</td>
</tr>
<tr>
<td>Final Report</td>
<td>98.75</td>
</tr>
<tr>
<td>Presentation 4</td>
<td>9.00</td>
</tr>
<tr>
<td>Door Closing Mechanisms</td>
<td>21.00</td>
</tr>
<tr>
<td>Minutes</td>
<td>1.00</td>
</tr>
<tr>
<td>Model</td>
<td>126.50</td>
</tr>
<tr>
<td>Valves</td>
<td>12.00</td>
</tr>
<tr>
<td>Well Gates</td>
<td>8.50</td>
</tr>
<tr>
<td>Final Presentation</td>
<td>18.25</td>
</tr>
<tr>
<td>Design Night Prep</td>
<td>38.00</td>
</tr>
<tr>
<td>Date</td>
<td>Mike Bratt</td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
</tr>
<tr>
<td>31-Jan</td>
<td>0.50</td>
</tr>
<tr>
<td>2-Feb</td>
<td>1.00</td>
</tr>
<tr>
<td>4-Feb</td>
<td>1.00</td>
</tr>
<tr>
<td>11-Feb</td>
<td>1.00</td>
</tr>
<tr>
<td>16-Feb</td>
<td>1.00</td>
</tr>
<tr>
<td>18-Feb</td>
<td>1.00</td>
</tr>
<tr>
<td>22-Feb</td>
<td>1.00</td>
</tr>
<tr>
<td>23-Mar</td>
<td>4.00</td>
</tr>
<tr>
<td>7-Mar</td>
<td>1.00</td>
</tr>
<tr>
<td>9-Mar</td>
<td>1.00</td>
</tr>
<tr>
<td>16-Mar</td>
<td>1.00</td>
</tr>
<tr>
<td>23-Mar</td>
<td>1.00</td>
</tr>
<tr>
<td>29-Mar</td>
<td>1.50</td>
</tr>
<tr>
<td>1-Apr</td>
<td>2.00</td>
</tr>
<tr>
<td>4-Apr</td>
<td>2.00</td>
</tr>
<tr>
<td>5-Apr</td>
<td>2.00</td>
</tr>
<tr>
<td>6-Apr</td>
<td>1.00</td>
</tr>
<tr>
<td>7-Apr</td>
<td>1.50</td>
</tr>
<tr>
<td>7-Apr</td>
<td>2.00</td>
</tr>
<tr>
<td>7-Apr</td>
<td>2.00</td>
</tr>
<tr>
<td>8-Apr</td>
<td>0.50</td>
</tr>
<tr>
<td>11-Apr</td>
<td>2.50</td>
</tr>
<tr>
<td>11-Apr</td>
<td>1.50</td>
</tr>
<tr>
<td>12-Apr</td>
<td>0.50</td>
</tr>
<tr>
<td>12-Apr</td>
<td>0.50</td>
</tr>
<tr>
<td>13-Apr</td>
<td>2.00</td>
</tr>
<tr>
<td>13-Apr</td>
<td>0.50</td>
</tr>
<tr>
<td>14-Apr</td>
<td>0.50</td>
</tr>
<tr>
<td>14-Apr</td>
<td>1.50</td>
</tr>
<tr>
<td>15-Apr</td>
<td>0.50</td>
</tr>
<tr>
<td>16-Apr</td>
<td>1.00</td>
</tr>
<tr>
<td>18-Apr</td>
<td>1.00</td>
</tr>
<tr>
<td>19-Apr</td>
<td>2.00</td>
</tr>
<tr>
<td>20-Apr</td>
<td>3.50</td>
</tr>
<tr>
<td>21-Apr</td>
<td>1.00</td>
</tr>
<tr>
<td>21-Apr</td>
<td>6.00</td>
</tr>
<tr>
<td>21-Apr</td>
<td>0.50</td>
</tr>
<tr>
<td>22-Apr</td>
<td>0.50</td>
</tr>
<tr>
<td>22-Apr</td>
<td>1.50</td>
</tr>
<tr>
<td>23-Apr</td>
<td>1.50</td>
</tr>
<tr>
<td>23-Apr</td>
<td>0.50</td>
</tr>
<tr>
<td>23-Apr</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Team Poster
Team Blurb
Calculations
Presentation
Calcs
Calcs/Presentation
Culvert Sizing
Norm Presentation
Culvert Sizing
Class (lock dims/bumpers)
Design Norms
Pumps and AutoCAD and Gates
AutoCAD and Gates
CAD/research
Gates
Industrial Consultant
Model Shopping
Butterfly Valves
Bumpers/CAD and model
Motor Sizing
Webpage Update and patents
Valves
Valve Drawings
Motor Selection
Pump Selection
Bumpers
<table>
<thead>
<tr>
<th>Date</th>
<th>Activity</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>23-Apr</td>
<td>2</td>
<td>2.00</td>
</tr>
<tr>
<td>23-Apr</td>
<td>5.5</td>
<td>5.25</td>
</tr>
<tr>
<td>24-Apr</td>
<td>4.00</td>
<td>4.00</td>
</tr>
<tr>
<td>25-Apr</td>
<td>4.00</td>
<td>3.00</td>
</tr>
<tr>
<td>25-Apr</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>25-Apr</td>
<td>2.5</td>
<td>2.00</td>
</tr>
<tr>
<td>26-Apr</td>
<td>6.50</td>
<td>6.50</td>
</tr>
<tr>
<td>26-Apr</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>26-Apr</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>27-Apr</td>
<td>4.00</td>
<td>4.00</td>
</tr>
<tr>
<td>27-Apr</td>
<td>9.00</td>
<td>9.00</td>
</tr>
<tr>
<td>27-Apr</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>28-Apr</td>
<td>2.50</td>
<td>2.50</td>
</tr>
<tr>
<td>28-Apr</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>29-Apr</td>
<td>4.00</td>
<td>4.00</td>
</tr>
<tr>
<td>29-Apr</td>
<td>3.50</td>
<td>3.50</td>
</tr>
<tr>
<td>29-Apr</td>
<td>7.50</td>
<td>7.50</td>
</tr>
<tr>
<td>30-Apr</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>30-Apr</td>
<td>3.50</td>
<td>3.50</td>
</tr>
<tr>
<td>1-May</td>
<td>4.75</td>
<td>4.75</td>
</tr>
<tr>
<td>2-May</td>
<td>4.00</td>
<td>4.00</td>
</tr>
<tr>
<td>2-May</td>
<td>5.50</td>
<td>5.50</td>
</tr>
<tr>
<td>2-May</td>
<td>1.50</td>
<td>1.50</td>
</tr>
<tr>
<td>3-May</td>
<td>4.75</td>
<td>4.75</td>
</tr>
<tr>
<td>3-May</td>
<td>7.00</td>
<td>7.00</td>
</tr>
<tr>
<td>3-May</td>
<td>10.50</td>
<td>10.50</td>
</tr>
<tr>
<td>4-May</td>
<td>11.50</td>
<td>11.50</td>
</tr>
<tr>
<td>4-May</td>
<td>4.75</td>
<td>4.75</td>
</tr>
<tr>
<td>4-May</td>
<td>4.00</td>
<td>4.00</td>
</tr>
<tr>
<td>5-May</td>
<td>9.00</td>
<td>5.00</td>
</tr>
<tr>
<td>5-May</td>
<td>5.00</td>
<td>6.00</td>
</tr>
<tr>
<td>5-May</td>
<td>2.50</td>
<td>2.50</td>
</tr>
<tr>
<td>6-May</td>
<td>3.00</td>
<td>9.50</td>
</tr>
<tr>
<td>6-May</td>
<td>9.50</td>
<td>10.50</td>
</tr>
<tr>
<td>6-May</td>
<td>3.50</td>
<td>3.50</td>
</tr>
<tr>
<td>7-May</td>
<td>3.00</td>
<td>3.00</td>
</tr>
<tr>
<td>7-May</td>
<td>9.50</td>
<td>6.00</td>
</tr>
<tr>
<td>9-May</td>
<td>3.50</td>
<td>3.50</td>
</tr>
<tr>
<td>9-May</td>
<td>9.50</td>
<td>7.00</td>
</tr>
<tr>
<td>11-May</td>
<td>4.00</td>
<td>2.50</td>
</tr>
<tr>
<td>11-May</td>
<td>2.50</td>
<td>4.50</td>
</tr>
<tr>
<td>11-May</td>
<td>2.50</td>
<td>2.50</td>
</tr>
<tr>
<td>12-May</td>
<td>5.50</td>
<td>1.00</td>
</tr>
<tr>
<td>12-May</td>
<td>1.00</td>
<td>4.00</td>
</tr>
</tbody>
</table>

**Engineering**

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>101.50</td>
<td>88.00</td>
<td>95.25</td>
<td>79.00</td>
<td>361.75</td>
</tr>
</tbody>
</table>

**Shop Work**

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>47.00</td>
<td>0.00</td>
<td>47.00</td>
<td>94.00</td>
</tr>
</tbody>
</table>

**Total**

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>101.50</td>
<td>133.00</td>
<td>95.25</td>
<td>126.00</td>
<td>456.75</td>
</tr>
</tbody>
</table>

**Second Semester Cost** $41,815.00

**First Semester Cost** $12,466.00

**Total Cost** $54,281.00
<table>
<thead>
<tr>
<th>Task</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doors</td>
<td>59.75</td>
</tr>
<tr>
<td>Project Milestones</td>
<td>21.00</td>
</tr>
<tr>
<td>Culverts</td>
<td>20.50</td>
</tr>
<tr>
<td>Bumpers</td>
<td>10.50</td>
</tr>
<tr>
<td>Presentation 3</td>
<td>5.50</td>
</tr>
<tr>
<td>Pumps</td>
<td>4.50</td>
</tr>
<tr>
<td>Final Report</td>
<td>98.75</td>
</tr>
<tr>
<td>Presentation 4</td>
<td>9.00</td>
</tr>
<tr>
<td>Door Closing Mechanisms</td>
<td>21.00</td>
</tr>
<tr>
<td>Minutes</td>
<td>1.00</td>
</tr>
<tr>
<td>Model</td>
<td>126.50</td>
</tr>
<tr>
<td>Valves</td>
<td>12.00</td>
</tr>
<tr>
<td>Design Night</td>
<td>38.00</td>
</tr>
<tr>
<td>Well Gates</td>
<td>8.50</td>
</tr>
<tr>
<td>Final Presentation</td>
<td>18.25</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>454.75</strong></td>
</tr>
</tbody>
</table>

**Tallies**

<table>
<thead>
<tr>
<th>Task</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Milestones</td>
<td>120.75</td>
</tr>
<tr>
<td>Presentations</td>
<td>61.75</td>
</tr>
<tr>
<td>Website</td>
<td>10.00</td>
</tr>
<tr>
<td>PPFS</td>
<td>16.25</td>
</tr>
<tr>
<td>Sault Ste Marie</td>
<td>12.00</td>
</tr>
<tr>
<td>Culverts</td>
<td>20.50</td>
</tr>
<tr>
<td>Hours Management</td>
<td>4.00</td>
</tr>
<tr>
<td>Doors</td>
<td>59.75</td>
</tr>
<tr>
<td>Bumpers</td>
<td>10.50</td>
</tr>
<tr>
<td>Pumps</td>
<td>4.50</td>
</tr>
<tr>
<td>Final Report</td>
<td>98.75</td>
</tr>
<tr>
<td>Presentation 4</td>
<td>9.00</td>
</tr>
<tr>
<td>Door Closing Mechanisms</td>
<td>21.00</td>
</tr>
<tr>
<td>Model</td>
<td>126.50</td>
</tr>
<tr>
<td>Valves</td>
<td>12.00</td>
</tr>
<tr>
<td>Design Night</td>
<td>38.00</td>
</tr>
<tr>
<td>Well Gates</td>
<td>8.50</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>633.75</strong></td>
</tr>
</tbody>
</table>
Concrete

Under Upstream Face: $9,000 m^3$ - from AutoCAD

Diffusing Grid: $(80 m)(0.5 m)(25 m) + (29 EA)(1 m^2)(0.5 m) + (9 m)(25 m)(0.5 m) \approx 1,100 m^3$

Culverts: $(2,237.5 m)(15 m)(8 EA)(1 m) + (23.7613 m)(2,237.5 m)(1 m) + (8.7613 m)(2,237.5 m)(1 m)(2 EA) + (9 m)(1 m)(2.604 m)(5 EA) \approx 430 m^3$

Dewatering Well and Channel Bottom:
$= (55 m^3)(25 m) + (151.6 m)(25 m)(1 m) + (55.2 m)(3 m)(5 m) + (2 m)(16 m)(16 m) \approx 6500 m^3$

Walls: $(2 EA)(230.7 m)(19.5 m)(7 m) + (6 EA)(24.5 m)(16 m)(7 m) \approx 79,500 m^3$

Total Volume:
$= (9,000 m^3) + (1,100 m^3) + (430 m^3) + (6500 m^3) + (79,500 m^3)$
$= 96,530 m^3 \approx 100,000 m^3$

Approximate cost concrete = 60 USD/CYD

$$\frac{60 \text{ USD}}{\text{CYD}} \cdot \frac{1 \text{ CYD}}{23 \text{ KFT}} \cdot \left(\frac{3.2808 \text{ LFT}}{1 \text{ m}}\right)^3 = 78.5 \text{ USD/m}^3$$

Cost Concrete: $(100,000 m^3)(78.5 \text{ USD/m}^3) = 7,850,000 \text{ USD}$
Steel

Downstream Gate (One Leaf)
\[
W \times 40 \times 215 = (11.3 \text{ m})(9 \text{ EA}) = 101.7 \text{ m} \\
W \times 40 \times 183 = (11.3 \text{ m})(1 \text{ EA}) = 11.3 \text{ m} \\
W \times 40 \times 149 = (11.3 \text{ m})(2 \text{ EA}) = 27.6 \text{ m}
\]

Upstream Gate (One Leaf)
\[
W \times 40 \times 215 = (11.3 \text{ m})(5 \text{ EA}) = 56.5 \text{ m} \\
W \times 40 \times 149 = (11.3 \text{ m})(2 \text{ EA}) = 22.6 \text{ m}
\]

Intercostals (One Leaf)
\[
\text{Upstream} = 9.5 \text{ m}(6 \text{ EA}) = 57 \text{ m} \quad \text{(W 40 x 149)} \\
\text{Downstream} = 17.5 \text{ m}(6 \text{ EA}) = 105 \text{ m} \quad \text{(W 40 x 149)}
\]

Tallies (All Gates)
\[
W \times 40 \times 215 = (101.7 \text{ m} + 56.5 \text{ m})(4 \text{ EA}) = 632.8 \text{ m} \\
W \times 40 \times 183 = (11.3 \text{ m})(4 \text{ EA}) = 45.2 \text{ m} \\
W \times 40 \times 149 = (22.6 \text{ m} + 22.6 \text{ m} + 57 \text{ m} + 105 \text{ m})(4 \text{ EA}) = 828.8 \text{ m}
\]

Skin Plate (All Gates)
\[
\text{Upstream} = (9.5 \text{ m})(11.6 \text{ m})(0.0254 \text{ m})(4 \text{ EA}) = 11.2 \text{ m}^3 \\
\text{Downstream} = (17.5 \text{ m})(11.6 \text{ m})(0.0254 \text{ m})(4 \text{ EA}) = 20.6 \text{ m}^3
\]

Rebar
\[
(35 \text{ EA})(25 \text{ m})(3.2808 \text{ ft})(12 \frac{\text{in}}{\text{ft}})(35 \text{ in}^2) = 1.21 \times 10^6 \text{ in}^3 \\
(5 \text{ EA})(80 \text{ m})(3.2808 \text{ ft})(12 \frac{\text{in}}{\text{ft}})(35 \text{ in}^2) = 0.55 \times 10^6 \text{ in}^3 \\
1.76 \times 10^6 \text{ in}^3 \\
(1.76 \times 10^6 \text{ in}^3)(12 \frac{\text{ft}}{\text{in}})^3(\frac{m}{3.2808 \text{ ft}})^3 = 28.8 \text{ m}^3
\]
Cost Calculations

Quoin/Miter (One Leaf)

Up stream = \((52.8 \text{ in}^2) \times (2 \text{ EA}) \left(\frac{1}{2} \times \frac{1}{12} \times \left(\frac{m}{3.2808 \text{ ft}}\right)^2 \times 9.5 \text{ m}\right)\)
= 0.6 m³

Down stream = \((52.8 \text{ in}^2) \times (2 \text{ EA}) \left(\frac{1}{2} \times \frac{1}{12} \times \left(\frac{m}{3.2808 \text{ ft}}\right)^2 \times 17.5 \text{ m}\right)\)
= 1.2 m³

Tally (All Gates)
= \((0.6 \text{ m}^3 + 1.2 \text{ m}^3) \times (4 \text{ EA})\) = 7.2 m³
Cost Calculations

Diagonals (One Leaf)

\[
\text{Upstream} = (525 \text{ in}^3)(13.0 \text{ in}^2 + 9.0 \text{ in}^2) = 11,550 \text{ in}^3
\]

\[
\text{Downstream} = (760 \text{ in}^3)(26.0 \text{ in}^2 + 20 \text{ in}^2) = 34,960 \text{ in}^3
\]

\[
\text{Tally} = \left(\frac{61,510 \text{ in}^3}{12 \text{ in}^3}\right)\left(\frac{1}{3.2808 \text{ ft}^3}\right)^3 \text{(4EA)} = 3,0 \text{ m}^3
\]

Total weight

\[
W \text{ 40 \times 215} = (632.8 \text{ m})(215 \frac{\text{ft}}{\text{m}})(3.2808 \frac{\text{ft}}{\text{m}}) = 446,359 \text{ lbs}
\]

\[
W \text{ 40 \times 183} = (45.2 \text{ m})(183 \frac{\text{ft}}{\text{m}})(3.2808 \frac{\text{ft}}{\text{m}}) = 27,138 \text{ lbs}
\]

\[
W \text{ 40 \times 149} = (828.8 \text{ m})(149 \frac{\text{ft}}{\text{m}})(3.2808 \frac{\text{ft}}{\text{m}}) = 405,150 \text{ lbs}
\]

\[
\text{Skin Plate} = (11.2 \text{ m}^3 + 20.6 \text{ m}^3)(490 \frac{\text{lb}}{\text{ft}^2})(3.2808 \frac{\text{ft}}{\text{m}}) = 550,253 \text{ lbs}
\]

\[
\text{Rebar} = (28.8 \text{ m}^3)(490 \frac{\text{lb}}{\text{ft}^2})(3.2808 \frac{\text{ft}}{\text{m}}) = 498,342 \text{ lbs}
\]

\[
\text{Diagonal} = (3.0 \text{ m}^3)(490 \frac{\text{lb}}{\text{ft}^2})(3.2808 \frac{\text{ft}}{\text{m}}) = 51,911 \text{ lbs}
\]

\[
\text{Quoin/Miter} = (7.2 \text{ m}^3)(490 \frac{\text{lb}}{\text{ft}^2})(3.2808 \frac{\text{ft}}{\text{m}}) = 4124,586 \text{ lbs}
\]

\[
(2.1 \times 10^6 \text{ lbs}) \times \frac{1 \text{ ton}}{2000 \text{ lbs}} \times \frac{1 \text{ USD}}{1 \text{ ton}} = 51,000,000 \text{ USD}
\]

Two Locks

Total Cost = \((7,850,000 + 1,000,000) \times 2 \text{ EA}) = \$20,000,000 \text{ USD}\]
Appendix B: Our Design Guides
Assumptions

A) Inside gate dimensions
- Minimum: Length: 30m Width: 15m Depth: 5m
- Maximum: Length: 120m Width: 30m Depth: 20m

B) Boat Sizes
- Max: Length: 25m Width: 10m Draft: 3m
- Min: Length: 2m Width: 1m Draft: .5m

C) Traffic volume/lock cycles
- Min: 60 boats per hour, 20-40 feet each
  + 35 canoe-sized boats
- Max: 90/hr. + 45 canoes

D) River Channel Dimensions
- Actual: 20-25m x 1.5m
- New Channel: 50-200m x 7m

E) 2 locks operating simultaneously
- both operate in both directions
<table>
<thead>
<tr>
<th>Width</th>
<th>Length</th>
<th>Depth</th>
<th>Capacity</th>
<th>Slope Year</th>
<th>Site Name</th>
<th>Culvert</th>
<th>Area Req'd</th>
<th>Volume</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>20</td>
<td>5</td>
<td>200</td>
<td>5</td>
<td>23</td>
<td>9.7</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>15</td>
<td>25</td>
<td>7</td>
<td>300</td>
<td>7</td>
<td>23</td>
<td>9.7</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>20</td>
<td>30</td>
<td>10</td>
<td>400</td>
<td>10</td>
<td>23</td>
<td>9.7</td>
<td>400</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>25</td>
<td>35</td>
<td>15</td>
<td>500</td>
<td>15</td>
<td>23</td>
<td>9.7</td>
<td>500</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>30</td>
<td>40</td>
<td>20</td>
<td>600</td>
<td>20</td>
<td>23</td>
<td>9.7</td>
<td>600</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>35</td>
<td>45</td>
<td>25</td>
<td>700</td>
<td>25</td>
<td>23</td>
<td>9.7</td>
<td>700</td>
<td>700</td>
<td>700</td>
</tr>
<tr>
<td>40</td>
<td>50</td>
<td>30</td>
<td>800</td>
<td>30</td>
<td>23</td>
<td>9.7</td>
<td>800</td>
<td>800</td>
<td>800</td>
</tr>
<tr>
<td>45</td>
<td>55</td>
<td>35</td>
<td>900</td>
<td>35</td>
<td>23</td>
<td>9.7</td>
<td>900</td>
<td>900</td>
<td>900</td>
</tr>
<tr>
<td>50</td>
<td>60</td>
<td>40</td>
<td>1000</td>
<td>40</td>
<td>23</td>
<td>9.7</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
</tr>
</tbody>
</table>

*Note: Calculations based on the formula for rectangular culverts.*
### Computation of Polar Moment of Inertia J

#### Horizontal Girders

<table>
<thead>
<tr>
<th>Number of</th>
<th>l(ln)</th>
<th>c(ln)</th>
<th>nlc&lt;sup&gt;3&lt;/sup&gt; (vert)</th>
<th>nlc&lt;sup&gt;3&lt;/sup&gt; (horz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>US Flange</td>
<td>2</td>
<td>11.8</td>
<td>2.09</td>
<td>215.5</td>
</tr>
<tr>
<td>W 40X149 Web</td>
<td>2</td>
<td>36.5</td>
<td>0.63</td>
<td>18.3</td>
</tr>
<tr>
<td>DS Flange</td>
<td>2</td>
<td>11.8</td>
<td>0.83</td>
<td>13.5</td>
</tr>
<tr>
<td>US Flange</td>
<td>1</td>
<td>11.8</td>
<td>2.48</td>
<td>180.0</td>
</tr>
<tr>
<td>W 40X183 Web</td>
<td>1</td>
<td>36.6</td>
<td>0.85</td>
<td>10.1</td>
</tr>
<tr>
<td>DS Flange</td>
<td>1</td>
<td>11.8</td>
<td>1.22</td>
<td>21.4</td>
</tr>
<tr>
<td>US Flange</td>
<td>9</td>
<td>15.8</td>
<td>2.48</td>
<td>2169.0</td>
</tr>
<tr>
<td>W 40X215 Web</td>
<td>9</td>
<td>36.6</td>
<td>0.85</td>
<td>90.5</td>
</tr>
<tr>
<td>DS Flange</td>
<td>9</td>
<td>15.8</td>
<td>1.22</td>
<td>258.2</td>
</tr>
<tr>
<td>Skin</td>
<td>1</td>
<td>511.4</td>
<td>0.63</td>
<td>127.9</td>
</tr>
</tbody>
</table>

#### Vertical Girders

<table>
<thead>
<tr>
<th>Number of</th>
<th>l(ln)</th>
<th>c(ln)</th>
<th>nlc&lt;sup&gt;3&lt;/sup&gt; (vert)</th>
<th>nlc&lt;sup&gt;3&lt;/sup&gt; (horz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>US Flange</td>
<td>6</td>
<td>11.8</td>
<td>2.09</td>
<td>--</td>
</tr>
<tr>
<td>W 40X149 Web</td>
<td>6</td>
<td>36.5</td>
<td>0.83</td>
<td>--</td>
</tr>
<tr>
<td>DS Flange</td>
<td>6</td>
<td>11.8</td>
<td>0.83</td>
<td>--</td>
</tr>
</tbody>
</table>

#### Quoin/Miter Posts

<table>
<thead>
<tr>
<th>Area</th>
<th>x</th>
<th>y</th>
<th>xA</th>
<th>yA</th>
<th>J&lt;sub&gt;x&lt;/sub&gt;</th>
<th>J&lt;sub&gt;y&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Web</td>
<td>2</td>
<td>16.2</td>
<td>1.00</td>
<td></td>
<td>32.4</td>
<td></td>
</tr>
<tr>
<td>Flange</td>
<td>2</td>
<td>13.1</td>
<td>1.00</td>
<td></td>
<td>26.2</td>
<td></td>
</tr>
<tr>
<td>Block</td>
<td>2</td>
<td>8.0</td>
<td>2.63</td>
<td></td>
<td>291.1</td>
<td></td>
</tr>
</tbody>
</table>

#### Location of Shear Center

<table>
<thead>
<tr>
<th>Area</th>
<th>x</th>
<th>y</th>
<th>xA</th>
<th>yA</th>
<th>I&lt;sub&gt;x&lt;/sub&gt;</th>
<th>I&lt;sub&gt;y&lt;/sub&gt;</th>
<th>mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam 1</td>
<td>43.80</td>
<td>275.59</td>
<td>688.97</td>
<td>12070.72</td>
<td>30176.80</td>
<td>6342147</td>
<td>1108845</td>
</tr>
<tr>
<td>Beam 2</td>
<td>53.80</td>
<td>275.59</td>
<td>590.54</td>
<td>14826.59</td>
<td>31771.27</td>
<td>21898806</td>
<td>1362006</td>
</tr>
<tr>
<td>Beam 3</td>
<td>63.40</td>
<td>275.59</td>
<td>521.65</td>
<td>17472.23</td>
<td>33072.43</td>
<td>12505647</td>
<td>1605041</td>
</tr>
<tr>
<td>Beam 4</td>
<td>63.40</td>
<td>275.59</td>
<td>452.75</td>
<td>17472.23</td>
<td>28704.38</td>
<td>5732185</td>
<td>1605041</td>
</tr>
<tr>
<td>Beam 5</td>
<td>63.40</td>
<td>275.59</td>
<td>393.70</td>
<td>17472.23</td>
<td>24960.33</td>
<td>2005806</td>
<td>1605041</td>
</tr>
<tr>
<td>Beam 6</td>
<td>63.40</td>
<td>275.59</td>
<td>334.64</td>
<td>17472.23</td>
<td>21216.28</td>
<td>201605</td>
<td>1605041</td>
</tr>
<tr>
<td>Beam 7</td>
<td>63.40</td>
<td>275.59</td>
<td>275.59</td>
<td>17472.23</td>
<td>17472.23</td>
<td>319581</td>
<td>1605041</td>
</tr>
<tr>
<td>Beam 8</td>
<td>63.40</td>
<td>275.59</td>
<td>216.53</td>
<td>17472.23</td>
<td>13728.18</td>
<td>2359735</td>
<td>1605041</td>
</tr>
<tr>
<td>Beam 9</td>
<td>63.40</td>
<td>275.59</td>
<td>157.48</td>
<td>17472.23</td>
<td>9984.13</td>
<td>6322067</td>
<td>1605041</td>
</tr>
<tr>
<td>Beam 10</td>
<td>63.40</td>
<td>275.59</td>
<td>98.42</td>
<td>17472.23</td>
<td>6240.08</td>
<td>12206577</td>
<td>1605041</td>
</tr>
<tr>
<td>Beam 11</td>
<td>63.40</td>
<td>275.59</td>
<td>39.37</td>
<td>17472.23</td>
<td>2496.03</td>
<td>20013265</td>
<td>1605041</td>
</tr>
<tr>
<td>Beam 12</td>
<td>43.80</td>
<td>275.59</td>
<td>0.00</td>
<td>12070.72</td>
<td>0.00</td>
<td>26278699</td>
<td>1108845</td>
</tr>
</tbody>
</table>

Centroid: 
\[
\begin{align*}
x &= 275.59 \\
y &= 308.74
\end{align*}
\]

Radius of Gyration = 403.96
### Distance Y

<table>
<thead>
<tr>
<th>( I_N ) (in(^4))</th>
<th>( y ) (in)</th>
<th>( I_N'y ) (in(^3) x 10(^6))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam 1</td>
<td>9800</td>
<td>380.23</td>
</tr>
<tr>
<td>Beam 2</td>
<td>13300</td>
<td>281.81</td>
</tr>
<tr>
<td>Beam 3</td>
<td>13300</td>
<td>212.91</td>
</tr>
<tr>
<td>Beam 4</td>
<td>16700</td>
<td>144.01</td>
</tr>
<tr>
<td>Beam 5</td>
<td>16700</td>
<td>84.96</td>
</tr>
<tr>
<td>Beam 6</td>
<td>16700</td>
<td>25.90</td>
</tr>
<tr>
<td>Beam 7</td>
<td>16700</td>
<td>-33.15</td>
</tr>
<tr>
<td>Beam 8</td>
<td>16700</td>
<td>-92.21</td>
</tr>
<tr>
<td>Beam 9</td>
<td>16700</td>
<td>-151.26</td>
</tr>
<tr>
<td>Beam 10</td>
<td>16700</td>
<td>-210.31</td>
</tr>
<tr>
<td>Beam 11</td>
<td>16700</td>
<td>-269.37</td>
</tr>
<tr>
<td>Beam 12</td>
<td>9800</td>
<td>-308.74</td>
</tr>
</tbody>
</table>

\[ Y = -6.1 \text{ in} \]

### Distance X

<table>
<thead>
<tr>
<th>( a ) (in(^3))</th>
<th>( y ) (in)</th>
<th>( Y ) (in)</th>
<th>( ayyr ) (in(^3) x 10(^6))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam 1</td>
<td>22.1</td>
<td>380.23</td>
<td>386.31</td>
</tr>
<tr>
<td>Beam 2</td>
<td>27.1</td>
<td>281.81</td>
<td>287.89</td>
</tr>
<tr>
<td>Beam 3</td>
<td>31.9</td>
<td>212.91</td>
<td>218.99</td>
</tr>
<tr>
<td>Beam 4</td>
<td>31.9</td>
<td>144.01</td>
<td>150.09</td>
</tr>
<tr>
<td>Beam 5</td>
<td>31.9</td>
<td>84.96</td>
<td>91.04</td>
</tr>
<tr>
<td>Beam 6</td>
<td>31.9</td>
<td>25.90</td>
<td>31.99</td>
</tr>
<tr>
<td>Beam 7</td>
<td>31.9</td>
<td>-33.15</td>
<td>-27.07</td>
</tr>
<tr>
<td>Beam 8</td>
<td>31.9</td>
<td>-92.21</td>
<td>-86.12</td>
</tr>
<tr>
<td>Beam 9</td>
<td>31.9</td>
<td>-151.26</td>
<td>-145.18</td>
</tr>
<tr>
<td>Beam 10</td>
<td>31.9</td>
<td>-210.31</td>
<td>-204.23</td>
</tr>
<tr>
<td>Beam 11</td>
<td>31.9</td>
<td>-269.37</td>
<td>-263.29</td>
</tr>
<tr>
<td>Beam 12</td>
<td>22.1</td>
<td>-308.74</td>
<td>-302.66</td>
</tr>
</tbody>
</table>

\[ X = 4.93 \text{ in} \]

### Load Torque Areas

<table>
<thead>
<tr>
<th>Force (lb)</th>
<th>M arm (in)</th>
<th>( z ) (in)</th>
<th>( T_z ) (in(^3)lb x 10(^6))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead Load</td>
<td>285366</td>
<td>29.7</td>
<td>267</td>
</tr>
<tr>
<td>Mud</td>
<td>50000</td>
<td>29.7</td>
<td>267</td>
</tr>
<tr>
<td>Water</td>
<td>70523</td>
<td>467.2</td>
<td>271</td>
</tr>
</tbody>
</table>

\[ -2261 \]
\[ -396 \]
\[ -8932 \]
\[ -11589 \]

Downstream 2 of 5
\[ R_o = \pm \frac{2wT}{v(w^2 + h^2)^{1/2}} \]

- \( w \) (in) = 443.7  Width of panel
- \( t \) (in) = 40.9  Center of skin plate to center of diagonal
- \( v \) (in) = 542.2  Pintle to extreme miter end
- \( h \) (in) = 689.0  Height of panel enclosing diagonal

\[ R_o = 0.0817 \]

\[
A = -\sum \frac{T_s}{sR_o hv}
\]

- \( T_s \) (in² lb) = -1.2E+10  Torque area
- \( s \) (in) = 18000.0  Unit stress in diagonal
- \( R_o = 0.0817 \)  Ratio of change in length of diagonal to deflection when diagonal offers no resistance
- \( v \) (in) = 542.2  Pintle to extreme miter end
- \( h \) (in) = 689.0  Height of panel enclosing diagonal

\[ A = 21.1 \text{ in}^2 \]

\[
A = -\sum \frac{T_s}{sR_o hv}
\]

- \( T_s \) (in² lb) = -9.E+09  Torque area
- \( s \) (in) = 18000.0  Unit stress in diagonal
- \( R_o = 0.0817 \)  Ratio of change in length of diagonal to deflection when diagonal offers no resistance
- \( v \) (in) = 542.2  Pintle to extreme miter end
- \( h \) (in) = 689.0  Height of panel enclosing diagonal

\[ A = 16.3 \text{ in}^2 \]
For design purposes, we will assume a safe values of the diagonal areas as follows:

\[ U_{iL_1} = 26 \text{ in}^2 \]  
\[ U_{iL_0} = 20 \text{ in}^2 \]  
Boosted in order to meet minimum stress values

\[ Q = \frac{RR}{EAvh} \]

\[ R_o = 0.0817 \] Ratio of change in length of diagonal to deflection when diagonal offers no resistance

\[ E = 29000000 \] Modulus of elasticity

\[ v (\text{in}) = 542.2 \] Pintle to extreme miter end

\[ h (\text{in}) = 689.0 \] Height of panel enclosing diagonal

\[ L = 760 \] Length of diagonals

\[ A' (\text{in}^3) = 21.9 \] Stiffness of the leaf in deforming the diagonal

<table>
<thead>
<tr>
<th>( A (\text{in}^2) )</th>
<th>( R )</th>
<th>( Q(\text{in lb x 10}^6) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>0.0373</td>
<td>1131</td>
</tr>
<tr>
<td>20</td>
<td>0.0427</td>
<td>994</td>
</tr>
</tbody>
</table>

**Deflection of Leaf**

\[ \Delta = \frac{\sum T_z}{Q_o + \sum Q} \]

\[ T_z (\text{in}^2 \text{lb}) = 1.2E+10 \] Torque area

\[ Q_o (\text{in lb}) = 1.36E+08 \] Elasticity constant of leaf without diagonals

\[ Q (\text{in lb x 10}^6) = 2.6E+09 \] Elasticity constant of diagonal

\[ \Delta = 5.13 \text{ in} \]

**Gate Closing**

\[ \Delta = \frac{\sum T_z}{Q_o + \sum Q} \]

\[ T_z (\text{in}^2 \text{lb}) = -1.2E+10 \] Torque area

\[ Q_o (\text{in lb}) = 1.36E+08 \] Elasticity constant of leaf without diagonals

\[ Q (\text{in lb x 10}^6) = 2.6E+09 \] Elasticity constant of diagonal

\[ \Delta = -4.95 \text{ in} \]
Prestressed Deflections and Stresses in Diagonals

\[
(D - \Delta)_{\text{max}} = \frac{sL}{RE}
\]

s (in) = 18000.0  Unit stress in diagonal
L = 760  Length of diagonals
E = 29000000  Modulus of elasticity

\[
\begin{array}{|c|c|}
\hline
R & (D-\Delta)_{\text{max}} \\
\hline
U_L L_i & 0.0373 \quad 12.6 \\
U_L L_o & 0.0427 \quad -11.0 \\
\hline
\end{array}
\]

Positive  Negative

\[
\begin{array}{|c|c|}
\hline
R & 0.0373 \quad 0.0427 \\
Q & 1131 \quad 994 \\
D_{\text{min}} & 5.13 \quad -4.95 \\
(D-\Delta)_{\text{max}} & 12.6 \quad -11.0 \\
D_{\text{max}} & 7.50 \quad -6.10 \\
D_{\text{effective}} & 7.00 \quad -5.65 \\
QO & 7914.57 \quad -5617.67 \\
\hline
\end{array}
\]

Sum = 2297  in^2 lb x 10^5

Stress (ksi)

\[
\begin{array}{|c|c|c|}
\hline
& \text{Gates Stationary} & \text{Gates Being Opened} & \text{Gates Being Closed} \\
\hline
\Delta & 10.0 \quad 9.2 & 2.7 \quad 17.6 & 17.0 \quad 1.1 \\
\hline
\end{array}
\]

\Delta = 0
\Delta = 5.13
\Delta = 4.95
### COMPUTATION OF POLAR MOMENT OF INERTIA J

<table>
<thead>
<tr>
<th>Girders</th>
<th>Number of</th>
<th>l (in)</th>
<th>c (in)</th>
<th>( \pi c^2 ) (vert)</th>
<th>( \pi c^2 ) (horiz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US Flange</td>
<td>2</td>
<td>11.8</td>
<td>2.09</td>
<td>215.5</td>
<td>---</td>
</tr>
<tr>
<td>W 40X149 Web</td>
<td>2</td>
<td>36.5</td>
<td>0.63</td>
<td>18.3</td>
<td>---</td>
</tr>
<tr>
<td>DS Flange</td>
<td>2</td>
<td>11.8</td>
<td>0.63</td>
<td>13.5</td>
<td>---</td>
</tr>
<tr>
<td>US Flange</td>
<td>5</td>
<td>15.8</td>
<td>2.48</td>
<td>1205.0</td>
<td>---</td>
</tr>
<tr>
<td>W 40X215 Web</td>
<td>5</td>
<td>36.6</td>
<td>0.65</td>
<td>50.2</td>
<td>---</td>
</tr>
<tr>
<td>DS Flange</td>
<td>5</td>
<td>15.8</td>
<td>1.22</td>
<td>143.5</td>
<td></td>
</tr>
<tr>
<td>Skin</td>
<td>5/8</td>
<td>1</td>
<td>586.4</td>
<td>0.63</td>
<td>146.6</td>
</tr>
<tr>
<td>Vertical Girders</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US Flange</td>
<td>6</td>
<td>11.8</td>
<td>2.09</td>
<td></td>
<td>641.7</td>
</tr>
<tr>
<td>Web</td>
<td>6</td>
<td>36.5</td>
<td>0.63</td>
<td></td>
<td>54.8</td>
</tr>
<tr>
<td>DS Flange</td>
<td>6</td>
<td>11.8</td>
<td>0.63</td>
<td></td>
<td>40.5</td>
</tr>
<tr>
<td>Quoin/Miter Posts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Web</td>
<td>2</td>
<td>16.2</td>
<td>1.00</td>
<td></td>
<td>32.4</td>
</tr>
<tr>
<td>Flange</td>
<td>2</td>
<td>13.1</td>
<td>1.00</td>
<td></td>
<td>26.2</td>
</tr>
<tr>
<td>Block</td>
<td>2</td>
<td>8.0</td>
<td>2.63</td>
<td></td>
<td>291.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1792.5</td>
<td>1086.7</td>
</tr>
</tbody>
</table>

### Upstream

<table>
<thead>
<tr>
<th>Area</th>
<th>x</th>
<th>y</th>
<th>xA</th>
<th>yA</th>
<th>( l_x )</th>
<th>( l_y )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam 1</td>
<td>43.80</td>
<td>7.00</td>
<td>374.01</td>
<td>306.60</td>
<td>16381.69 ( \pi c^2 ) (vert)</td>
<td>1943954 ( \pi c^2 ) (horiz)</td>
</tr>
<tr>
<td>Beam 2</td>
<td>63.40</td>
<td>7.00</td>
<td>275.59</td>
<td>443.80</td>
<td>17472.23 ( \pi c^2 ) (vert)</td>
<td>807960 ( \pi c^2 ) (horiz)</td>
</tr>
<tr>
<td>Beam 3</td>
<td>63.40</td>
<td>7.00</td>
<td>216.53</td>
<td>443.80</td>
<td>13728.18 ( \pi c^2 ) (vert)</td>
<td>192523 ( \pi c^2 ) (horiz)</td>
</tr>
<tr>
<td>Beam 4</td>
<td>63.40</td>
<td>7.00</td>
<td>157.48</td>
<td>443.80</td>
<td>9984.13 ( \pi c^2 ) (vert)</td>
<td>19291 ( \pi c^2 ) (horiz)</td>
</tr>
<tr>
<td>Beam 5</td>
<td>63.40</td>
<td>7.00</td>
<td>98.42</td>
<td>443.80</td>
<td>6240.08 ( \pi c^2 ) (vert)</td>
<td>288265 ( \pi c^2 ) (horiz)</td>
</tr>
<tr>
<td>Beam 6</td>
<td>63.40</td>
<td>7.00</td>
<td>39.37</td>
<td>443.80</td>
<td>2496.03 ( \pi c^2 ) (vert)</td>
<td>999443 ( \pi c^2 ) (horiz)</td>
</tr>
<tr>
<td>Beam 7</td>
<td>43.80</td>
<td>7.00</td>
<td>0.00</td>
<td>306.60</td>
<td>0.00 ( \pi c^2 ) (vert)</td>
<td>1185997 ( \pi c^2 ) (horiz)</td>
</tr>
<tr>
<td></td>
<td>404.60</td>
<td>2832.20</td>
<td>66302</td>
<td>5437432 ( \pi c^2 ) (vert)</td>
<td>10242895 ( \pi c^2 ) (horiz)</td>
<td></td>
</tr>
</tbody>
</table>

Centroid:
\[ x = 7.00 \]
\[ y = 163.87 \]

Radius of Gyration = 115.93
### Distance Y

<table>
<thead>
<tr>
<th>Beam</th>
<th>( I_y )</th>
<th>( Y )</th>
<th>( I_{yY} \times 10^4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam 1</td>
<td>9800</td>
<td>210.14</td>
<td>2.06</td>
</tr>
<tr>
<td>Beam 2</td>
<td>16699</td>
<td>151.09</td>
<td>2.52</td>
</tr>
<tr>
<td>Beam 3</td>
<td>16699</td>
<td>92.03</td>
<td>1.54</td>
</tr>
<tr>
<td>Beam 4</td>
<td>16700</td>
<td>32.98</td>
<td>0.55</td>
</tr>
<tr>
<td>Beam 5</td>
<td>16700</td>
<td>-26.08</td>
<td>-0.44</td>
</tr>
<tr>
<td>Beam 6</td>
<td>16700</td>
<td>-85.13</td>
<td>-1.42</td>
</tr>
<tr>
<td>Beam 7</td>
<td>16700</td>
<td>-124.50</td>
<td>-2.08</td>
</tr>
<tr>
<td></td>
<td><strong>109998</strong></td>
<td><strong>2.73</strong></td>
<td></td>
</tr>
</tbody>
</table>

\[ Y = 24.9 \text{ in} \]

### Distance X

<table>
<thead>
<tr>
<th>Beam</th>
<th>( a ) (in²)</th>
<th>( y ) (in)</th>
<th>( Y_n ) (in)</th>
<th>( aY_n ) (in³ x 10⁴)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam 1</td>
<td>22</td>
<td>210.14</td>
<td>185.29</td>
<td>0.85</td>
</tr>
<tr>
<td>Beam 2</td>
<td>32</td>
<td>151.09</td>
<td>128.24</td>
<td>0.60</td>
</tr>
<tr>
<td>Beam 3</td>
<td>32</td>
<td>92.03</td>
<td>67.18</td>
<td>0.20</td>
</tr>
<tr>
<td>Beam 4</td>
<td>32</td>
<td>32.98</td>
<td>8.13</td>
<td>0.01</td>
</tr>
<tr>
<td>Beam 5</td>
<td>32</td>
<td>-26.08</td>
<td>-50.93</td>
<td>0.04</td>
</tr>
<tr>
<td>Beam 6</td>
<td>32</td>
<td>-85.13</td>
<td>-109.98</td>
<td>0.30</td>
</tr>
<tr>
<td>Beam 7</td>
<td>22</td>
<td>-124.50</td>
<td>-149.35</td>
<td>0.41</td>
</tr>
</tbody>
</table>

\[ X = 17.41 \text{ in} \]

### Load Torque Areas

<table>
<thead>
<tr>
<th></th>
<th>Upstream</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Force (lb)</td>
<td>M arm (in)</td>
<td>z (in)</td>
<td>( T_z ) (in²lb x 10⁶)</td>
<td></td>
</tr>
<tr>
<td>Dead Load</td>
<td>182210</td>
<td>29.7</td>
<td>267</td>
<td>-1444</td>
</tr>
<tr>
<td>Mud</td>
<td>50000</td>
<td>29.7</td>
<td>267</td>
<td>-396</td>
</tr>
<tr>
<td>Water</td>
<td>32911</td>
<td>257.2</td>
<td>271</td>
<td>-2295</td>
</tr>
</tbody>
</table>

\[ \text{Upstream 2 of 5} \]
\[ R_o = \pm \frac{2wt}{v(w^2 + h^2)^{1/2}} \]

- \( w \) (in) = 443.7 Width of panel
- \( t \) (in) = 40.9 Center of skin plate to center of diagonal
- \( v \) (in) = 542.2 Pintle to extreme miter end
- \( h \) (in) = 374.0 Height of panel enclosing diagonal

\[ R_o = 0.1154 \]

\[ A = -\sum \frac{T_z}{sR_o hv} \]

- \( T_z \) (in^2 lb) = -4.1E+09 Torque area
- \( s \) (in) = 18000.0 Unit stress in diagonal
- \( R_o = 0.1154 \) Ratio of change in length of diagonal to deflection when diagonal offers no resistance
- \( v \) (in) = 542.2 Pintle to extreme miter end
- \( h \) (in) = 374.0 Height of panel enclosing diagonal

\[ A = 9.8 \text{ in}^2 \]

\[ A = -\sum \frac{T_z}{sR_o hv} \]

- \( T_z \) (in^2 lb) = -2.8E+09 Torque area
- \( s \) (in) = 18000.0 Unit stress in diagonal
- \( R_o = 0.1154 \) Ratio of change in length of diagonal to deflection when diagonal offers no resistance
- \( v \) (in) = 542.2 Pintle to extreme miter end
- \( h \) (in) = 374.0 Height of panel enclosing diagonal

\[ A = 5.4 \text{ in}^2 \]
For design purposes, we will assume a safe values of the diagonal areas as follows:

\[
\begin{align*}
U_{iL_1} &= 13.0 \text{ in}^2 \quad \rightarrow \quad 1 \times 12 \text{ in}^2 \\
U_{iL_2} &= 9.0 \text{ in}^2 \quad \rightarrow \quad 1 \times 8 \text{ in}^2
\end{align*}
\]

\[
Q = \frac{RR_o EAvh}{L}
\]

- \(R_o = 0.1154\) Ratio of change in length of diagonal to deflection when diagonal offers no resistance
- \(E = 29000000\) Modulus of elasticity
- \(v\) (in) = 542.2 Pintle to extreme miter end
- \(h\) (in) = 374.0 Height of panel enclosing diagonal
- \(L = 525\) Length of diagonals
- \(A'\) (in\(^2\)) = 21.9 Stiffness of the leaf in deforming the diagonal

<table>
<thead>
<tr>
<th>(U_{iL_1}) (in(^2))</th>
<th>(R)</th>
<th>(Q) (in lb x 10(^6))</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.0</td>
<td>0.0724</td>
<td>1216</td>
</tr>
<tr>
<td>9</td>
<td>0.0818</td>
<td>951</td>
</tr>
</tbody>
</table>

\[
\text{Collection of Leaf}
\]

\[
\Delta = \frac{\sum T_x}{Q_o + \sum Q}
\]

- \(T_x\) (in\(^2\) lb) = 4.1E+09 Torque area
- \(Q_o\) (in lb) = 1.37E+08 Elasticity constant of leaf without diagonals
- \(Q\) (in lb x 10\(^6\)) = 2.0E+09 Elasticity constant of diagonal

\[
\Delta = 1.79 \text{ in}
\]

\[
\Delta = \frac{\sum T_x}{Q_o + \sum Q}
\]

- \(T_x\) (in\(^2\) lb) = -4.1E+09 Torque area
- \(Q_o\) (in lb) = 1.37E+08 Elasticity constant of leaf without diagonals
- \(Q\) (in lb x 10\(^6\)) = 2.0E+09 Elasticity constant of diagonal

\[
\Delta = -1.62 \text{ in}
\]
\[ (D - \Delta)_{\text{max}} = \frac{sL}{RE} \]

- \( s \) (in) = 18000.0  Unit stress in diagonal
- \( L = 525 \)  Length of diagonals
- \( E = 29000000 \)  Modulus of elasticity

<table>
<thead>
<tr>
<th>( U_{\text{L}_1} )</th>
<th>( U_{\text{L}_0} )</th>
<th>((D-\Delta)_{\text{max}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0724</td>
<td>0.0818</td>
<td>4.5</td>
</tr>
<tr>
<td>-4.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>( U_{\text{L}_1} )</td>
<td>( U_{\text{L}_0} )</td>
</tr>
<tr>
<td>0.0724</td>
<td>0.0818</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Stress (ksi)**

<table>
<thead>
<tr>
<th>Gates Stationary</th>
<th>Gates Being Opened</th>
<th>Gates Being Closed</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0</td>
<td>8.6</td>
<td>12.3</td>
</tr>
<tr>
<td>7.4</td>
<td>16.7</td>
<td>1.3</td>
</tr>
</tbody>
</table>

\( \Delta = 0 \)
\( \Delta = 1.79 \)
\( \Delta = 1.62 \)
## Lower Gate

<table>
<thead>
<tr>
<th>Item</th>
<th>Weight (LBS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight Horiz Beams</td>
<td>109684</td>
</tr>
<tr>
<td>Weight Intercostals</td>
<td>51328</td>
</tr>
<tr>
<td>Skin Plate</td>
<td>53841</td>
</tr>
<tr>
<td>Mud Load</td>
<td>50000</td>
</tr>
<tr>
<td>Quoin Post</td>
<td>10257</td>
</tr>
<tr>
<td>Miter Post</td>
<td>10257</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>285 kips</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1269 kN</strong></td>
</tr>
</tbody>
</table>

Density of steel: \[ 490 \text{ lbs/ft}^3 \]

## Upper Gate

<table>
<thead>
<tr>
<th>Item</th>
<th>Weight (LBS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight Horiz Beams</td>
<td>63982</td>
</tr>
<tr>
<td>Weight Intercostals</td>
<td>27864</td>
</tr>
<tr>
<td>Skin Plate</td>
<td>29228</td>
</tr>
<tr>
<td>Mud Load</td>
<td>50000</td>
</tr>
<tr>
<td>Quoin Post</td>
<td>5568</td>
</tr>
<tr>
<td>Miter Post</td>
<td>5568</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>182 kips</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>811 kN</strong></td>
</tr>
</tbody>
</table>
### Centroid of Upstream Gate Leaf

<table>
<thead>
<tr>
<th>Area</th>
<th>x</th>
<th>y</th>
<th>xA</th>
<th>yA</th>
<th>( I_x )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom Left Plate</td>
<td>3.00</td>
<td>1.19</td>
<td>2.77</td>
<td>3.56</td>
<td>8.30</td>
</tr>
<tr>
<td>Base Plate</td>
<td>11.51</td>
<td>12.85</td>
<td>2.69</td>
<td>147.85</td>
<td>30.94</td>
</tr>
<tr>
<td>Bottom Right Plate</td>
<td>3.00</td>
<td>24.68</td>
<td>2.77</td>
<td>74.04</td>
<td>8.30</td>
</tr>
<tr>
<td>Web</td>
<td>16.21</td>
<td>12.93</td>
<td>11.04</td>
<td>209.66</td>
<td>179.04</td>
</tr>
<tr>
<td>Top Left Plate</td>
<td>3.00</td>
<td>5.67</td>
<td>16.22</td>
<td>17.02</td>
<td>48.67</td>
</tr>
<tr>
<td>Top Plate</td>
<td>13.10</td>
<td>12.93</td>
<td>19.65</td>
<td>169.41</td>
<td>257.40</td>
</tr>
<tr>
<td>Top Right Plate</td>
<td>3.00</td>
<td>20.19</td>
<td>16.22</td>
<td>60.58</td>
<td>48.67</td>
</tr>
<tr>
<td></td>
<td>52.82</td>
<td>682.13</td>
<td>581.32</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Centroid:
- X = 12.91
- Y = 11.01

### Radius of Gyration
- 9.51

### Miscellaneous:
- Angle: 18.43
- z': 18.00
- z: 17.08
- k': 4.00
- k: 4.00
- Ds = 21.81
- Dt = 20.43

<table>
<thead>
<tr>
<th>Area</th>
<th>x</th>
<th>y</th>
<th>xA</th>
<th>yA</th>
<th>( I_x )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total bottom area</td>
<td>136.73</td>
<td>8.32</td>
<td>0.00</td>
<td>1137.47</td>
<td>10958.30 in(^4)</td>
</tr>
<tr>
<td></td>
<td>130.73</td>
<td>8.32</td>
<td>0.00</td>
<td>1087.56</td>
<td>10459.38 in(^4)</td>
</tr>
<tr>
<td></td>
<td>267.46</td>
<td>0.00</td>
<td>49.91</td>
<td></td>
<td>498.92</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Area</th>
<th>x</th>
<th>y</th>
<th>xA</th>
<th>yA</th>
<th>( I_x )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total top area</td>
<td>85.36</td>
<td>5.10</td>
<td>0.00</td>
<td>435.20</td>
<td>3140.94 in(^4)</td>
</tr>
<tr>
<td></td>
<td>79.36</td>
<td>5.10</td>
<td>0.00</td>
<td>404.61</td>
<td>2063.44 in(^4)</td>
</tr>
<tr>
<td></td>
<td>164.72</td>
<td>0.00</td>
<td>30.59</td>
<td></td>
<td>1077.50</td>
</tr>
</tbody>
</table>
\[ S = \frac{\sigma_{y}}{1.3} \]
\[ V = 300000 \text{ [lb]} \]
\[ R = 9.5 \text{ [in]} \]
\[ T = 3.24 \times 10^7 \text{ [IN-LB_f]} \]
\[ d = 2 \cdot R \]
\[ A = \pi \cdot R^2 \]
\[ S_u = 50000 \text{ [psi]} \text{ assumed} \]
\[ \tau = \frac{16 \cdot T}{\pi \cdot d^3} \text{ torsion} \]

**Distortion Energy Failure Theory**

\[ \sigma_y = 4 / 3 \cdot \frac{V}{A} \text{ transverse shear} \]

\[ \sigma_x = 0 \text{ zero bending} \]

\[ \sigma_e = \left( \sigma_x^2 + \sigma_y^2 - \sigma_x \cdot \sigma_y + 3 \cdot \tau^2 \right)^{0.5} \]

**SOLUTION**

Unit Settings: [kJ]/[kJ]/[kPa]/[kmol]/[degrees]

\[ A = 283.5 \text{ [in}^2\text{]} \]
\[ d = 19 \text{ [in]} \]
\[ R = 9.5 \text{ [in]} \]
\[ \sigma_e = 41693 \text{ [psi]} \]
\[ \sigma_x = 0 \text{ [psi]} \]
\[ \sigma_y = 1411 \text{ [psi]} \]
\[ S_u = 50000 \text{ [psi]} \]
\[ T = 3.240E+07 \text{ [IN-LB_f]} \]
\[ \tau = 24058 \text{ [psi]} \]
\[ V = 300000 \text{ [lb]} \]

No unit problems were detected.
Cylinder design verification page

Input page

Rod parameters
Geometric (inches)

<table>
<thead>
<tr>
<th>ID</th>
<th>8</th>
<th>Column load conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>OD</td>
<td>9</td>
<td>fixed-pinned</td>
</tr>
<tr>
<td>length</td>
<td>108</td>
<td></td>
</tr>
<tr>
<td>rod material</td>
<td>Steel-Best</td>
<td></td>
</tr>
</tbody>
</table>

Column Parameters Inches

<table>
<thead>
<tr>
<th>ID</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>OD</td>
<td>2.4</td>
</tr>
<tr>
<td>Length</td>
<td>9</td>
</tr>
<tr>
<td>Material</td>
<td>Steel-Mild</td>
</tr>
</tbody>
</table>

Cylinder Performance

| Pressure | 2500 |
| Retracted length | 10.8 |
| Extended length  | 15.1 |
| Stroke           | 4.3  |

Material

<table>
<thead>
<tr>
<th>Material</th>
<th>E</th>
<th>Sy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel-Best</td>
<td>3.00E+07</td>
<td>8.50E+04</td>
</tr>
<tr>
<td>Steel-Mild</td>
<td>3.00E+07</td>
<td>3.60E+04</td>
</tr>
<tr>
<td>Aluminum</td>
<td>1.06E+07</td>
<td>3.00E+04</td>
</tr>
<tr>
<td>Timber</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Aaron Svacha in collaboration with
Ren Tubbergen
Rod Buckling  

First, check slenderness ratio  

Slenderness = length effective / radius of gyration  

radius of gyration = square root ( section modulus / section area )  

<table>
<thead>
<tr>
<th>area</th>
<th>13.35</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>120.94</td>
</tr>
<tr>
<td>radius of gyration</td>
<td>3.01</td>
</tr>
<tr>
<td>slenderness ratio</td>
<td>25.11</td>
</tr>
</tbody>
</table>

For this to be considered a long column the slenderness ratio for Steel-Best should be 89  

Euler Formula  

Critical load for buckling = \( \frac{P^2}{2 \cdot E \cdot I} \) / (effective length^2)  

Young's modulus \( 3.00E+07 \)  

Yield Strength \( 8.50E+04 \)  

End conditions, fixed-pinned, gives length multiplier of 0.7  

Critical load \( 6.26E+06 \)  

Applied load based on bore and working pressure \( 7850 \)  

SF = \( 7.97E+02 \)  

This result does not apply because the column is not long  

Intermediate-Range Code No. 1 - Struct. Steel  


<table>
<thead>
<tr>
<th>Cc</th>
<th>83.47</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress max allowed</td>
<td>45691.81</td>
</tr>
<tr>
<td>SF</td>
<td>1.78</td>
</tr>
</tbody>
</table>

Critical load \( 609757.24 \)  

This result applies because the column is intermediate  

Block analysis  

Block fails in shear due to load exceeding shear strength of piece.  

Critical load \( 1134325 \)  

Safety factor \( 144.5 \)  

This result always applies but will often fail in another mode first  

\( \frac{(f_a/F_a)+((C_m\cdot f_b)/(1-f_a)/F_b)}{\text{equal to } 1} \) when \( (f_a/F_a)>0.15 \)  

\( \frac{(f_a/F_a)+f_b/F_b}{\text{equal to } 1} \) when \( (f_a/F_a)<0.15 \)  

\( F_b=TR/J \)  

\( F_a=\text{allowable value of } P/A \text{ for the member considered as a concentrically loaded colt} \)  

\( F_b=\text{allowable value of compressive fiber stress for the member considered as a beam} \)  

\( f_a=P/A=\text{average compressive stress due to the axial load } P \)  

\( f_b=\text{computed max bending stress due to the transverse loads, applied couples, or a } \)  

\( L=\text{Unbraced length in plane of bending} \)  

\( L/r=\text{slenderness ratio for buckling in that plane} \)  

\( C_m=0.85 \)
Cylinder design verification page  
[US std units; in., psi, unless otherwise noted]

**Input page**

### Rod parameters

<table>
<thead>
<tr>
<th>Geometric</th>
<th>Column load conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID 8</td>
<td>free-free</td>
</tr>
<tr>
<td>OD 9</td>
<td>fixed-free</td>
</tr>
<tr>
<td>Length 189</td>
<td>fixed-pinned</td>
</tr>
<tr>
<td>Rod material</td>
<td>Steel-Best</td>
</tr>
</tbody>
</table>

### Column Parameters

<table>
<thead>
<tr>
<th>ID</th>
<th>OD</th>
<th>Length</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2.4</td>
<td>9</td>
<td>Steel-Mild</td>
</tr>
</tbody>
</table>

### Cylinder Performance

- Pressure: 2500
- Retracted length: 10.8
- Extended length: 15.1
- Stroke: 4.3

Aaron Svacha in collaboration with Ren Tubergen

<table>
<thead>
<tr>
<th>Material</th>
<th>E</th>
<th>Sy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel-Best</td>
<td>3.00E+07</td>
<td>8.50E+04</td>
</tr>
<tr>
<td>Steel-Mild</td>
<td>3.00E+07</td>
<td>3.60E+04</td>
</tr>
<tr>
<td>Aluminum</td>
<td>1.06E+07</td>
<td>3.00E+04</td>
</tr>
<tr>
<td>Timber</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Rod Buckling (15')

First, check slenderness ratio

Slenderness = length effective / radius of gyration

radius of gyration = square root (section modulus / section area)

area 13.35
I 129.94
radius of gyration 3.01
slenderness ratio 43.95

For this to be considered a long column the slenderness ratio for Steel-Best should be 89.

Euler Formula

Critical load for buckling = Pr^2/E*I/(Effective length^2)

Young's modulus 3.00E+07
Yield Strength 8.50E+04
End conditions, fixed-pinned, gives length multiplier of 0.7

Critical load 2.04E+06

Applied load based on bore and working pressure 7850
SF= 2.60E+02

This result does not apply because the column is not long


Cc 83.47
Stress max allowed 36665.76
SF 1.85
Critical load 529339.51

This result applies because the column is intermediate

Block analysis

Block fails in shear due to load exceeding shear strength of piece.

Critical load 1134325
Safety factor 144.5

This result always applies but will often fail in another mode first

\[ F_{a} = \text{allowable value of } P/A \text{ for the member considered as a concentrically loaded column} \]

\[ F_{b} = \text{allowable value of compressive fiber stress for the member considered as a beam under beam} \]

\[ f_{a} = P/A = \text{average compressive stress due to the axial load } P \]

\[ f_{b} = \text{computed max bending stress due to the transverse loads, applied couples, or a combination} \]

\[ L = \text{Unbraced length in plane of bending} \]

\[ L_{s} = \text{slenderness ration for buckling in that plane} \]

\[ C_{m} = 0.85 \]

\[ (f_{a} - F_{a}) + (C_{m} - 1)(f_{b} - F_{b}) \text{ equal to 1 when } (f_{a} - F_{a}) > 0.15 \]

\[ (f_{a} - F_{a}) + (f_{b}/F_{b}) \text{ equal to 1 when } (f_{a} - F_{a}) < 0.15 \]

\[ F_{b} = TRJ/J \]
Horizontal - Gate Leaf Design

Moment Design

Shown equations and defined variables are for this table at the end of this section.

Depth = Distance to center of horizontal girder to rise of water level when the lock is full.

\( Y = \text{unit weight of water} = 9.81 \, \text{KN/m}^3 \)

\( A_1 = \frac{1}{2} \) the distance between the girder immediately above and immediately below the selected girder.

\( W = \text{Force of water load acting on girder per horizontal meter} = YA_1 \text{ Depth} \)

\( W = \text{total force applied to girder by water load} = \omega (\text{Length of girder}) \)

\( R = \text{Reaction of girder at wall and miter blocks} = 1.58 \, W \)

\( N = \text{Component of R perpendicular to gate leaf} = \frac{W}{2} \)

\( P_1 = \text{Component of R parallel to gate leaf} = 0.5 \, W \)

\( P_2 = \text{Water force at the end of each girder} = \frac{W}{t} \)

\( t = \text{distance from Work line to outside of damming surface} \)

\( P = P_1 + P_2 \)

\( M_{w1} = \text{Moments experienced at the center line of the selected girder} = \frac{NL}{2} - \frac{Wl^2}{8} + \frac{P_1t}{2} \)

This resulted in a metric Moment of \( \text{KN-m}. \) This value was then converted to English units and the LRFD manual was used to determine beam sizing.
Horizontal - Gate Leaf Design

Ex.) Will calculate moment on gate located at 8.0 m below water surface.

\[ w = (1.18 \text{ kN/m}^3) \left( \frac{9.5 - 6.5}{2} \right) (9 \text{ m}) = 117.72 \text{ kN/m} \]

\[ W = (117.72 \text{ kN/m}) (14 \text{ m}) = 1648.08 \text{ kN} \]

\[ N = (0.5) (1648.08 \text{ kN}) = 824.04 \text{ kN} \]

\[ P_2 = \frac{(1.07 \text{ m})(1648.08 \text{ kN})}{(114 \text{ m})} = 125.96 \text{ kN} \]

\[ R = (1.58)(1648.08 \text{ kN}) = 2602.97 \text{ kN} \]

\[ M_4 = \frac{(824.04 \text{ kN})(14 \text{ m}) - (117.72 \text{ kN/m})(4 \text{ m})^2 + (125.96 \text{ kN})(1.07 \text{ m})}{2} \]

\[ = \frac{2951.53 \text{ kN.m}}{2} - \frac{3280.8 \text{ kN}}{1 \text{ m}} + \frac{125.96 \text{ kN}}{4.44 \text{ kN/m}} = 2176.91 \text{ ft.kips} \]

Safety factor included as a result of boat impact, will assume an impact of 200 kips at 35° from quoin point. This is a safety load as recommended by USACE.

Additional moment = (200 kips)(35°) = 7,000 ft.kips with a vessel capable of creating such a force would impact at least three beams at once on \( \frac{2000}{2} = 2333 \text{ ft.kips} \)

Beam designed by taking the greater moment of:

The most heavily loaded beam or the third submerged beam with impact loading,

\[ M_{3400} = 3400 \text{ ft.kips} \]

**Binder: WHO X 215**
### Downstream

<table>
<thead>
<tr>
<th>Depth</th>
<th>ω</th>
<th>W</th>
<th>N</th>
<th>P₁</th>
<th>P₂</th>
<th>P</th>
<th>R</th>
<th>M_{CL} (kN\cdot m)</th>
<th>M_{CL} (ft\cdot kip)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>1.75</td>
<td>30.04</td>
<td>420.60</td>
<td>210.30</td>
<td>630.91</td>
<td>32.15</td>
<td>663.05</td>
<td>664.55</td>
<td>753.25</td>
<td>555.57</td>
</tr>
<tr>
<td>3.50</td>
<td>55.79</td>
<td>781.12</td>
<td>390.56</td>
<td>1171.68</td>
<td>59.70</td>
<td>1231.38</td>
<td>1234.17</td>
<td>1398.90</td>
<td>1031.76</td>
</tr>
<tr>
<td>5.00</td>
<td>73.58</td>
<td>1030.05</td>
<td>515.03</td>
<td>1545.08</td>
<td>78.73</td>
<td>1623.80</td>
<td>1627.48</td>
<td>1844.71</td>
<td>1360.57</td>
</tr>
<tr>
<td>6.50</td>
<td>95.63</td>
<td>1339.07</td>
<td>669.53</td>
<td>2008.60</td>
<td>102.34</td>
<td>2110.94</td>
<td>2115.72</td>
<td>2398.12</td>
<td>1768.74</td>
</tr>
<tr>
<td>8.00</td>
<td>117.72</td>
<td>1648.08</td>
<td>824.04</td>
<td>2472.12</td>
<td>125.96</td>
<td>2598.08</td>
<td>2603.97</td>
<td>2951.53</td>
<td>2176.91</td>
</tr>
<tr>
<td>9.50</td>
<td>139.79</td>
<td>1957.10</td>
<td>978.55</td>
<td>2935.64</td>
<td>149.58</td>
<td>3085.22</td>
<td>3092.21</td>
<td>3504.94</td>
<td>2585.08</td>
</tr>
<tr>
<td>11.00</td>
<td>161.87</td>
<td>2266.11</td>
<td>1133.06</td>
<td>3399.17</td>
<td>173.20</td>
<td>3572.36</td>
<td>3580.45</td>
<td>4058.35</td>
<td>2993.25</td>
</tr>
<tr>
<td>12.50</td>
<td>183.94</td>
<td>2575.13</td>
<td>1287.56</td>
<td>3862.69</td>
<td>196.81</td>
<td>4059.50</td>
<td>4068.70</td>
<td>4611.76</td>
<td>3401.42</td>
</tr>
<tr>
<td>14.00</td>
<td>206.68</td>
<td>2884.51</td>
<td>1442.17</td>
<td>4329.53</td>
<td>220.34</td>
<td>4546.78</td>
<td>4556.02</td>
<td>5164.33</td>
<td>3822.09</td>
</tr>
<tr>
<td>15.00</td>
<td>233.38</td>
<td>3193.86</td>
<td>1596.79</td>
<td>4796.57</td>
<td>243.88</td>
<td>5034.00</td>
<td>5043.32</td>
<td>5726.93</td>
<td>4252.52</td>
</tr>
</tbody>
</table>

### Upstream

<table>
<thead>
<tr>
<th>Depth</th>
<th>ω</th>
<th>W</th>
<th>N</th>
<th>P₁</th>
<th>P₂</th>
<th>P</th>
<th>R</th>
<th>M_{CL} (kN\cdot m)</th>
<th>M_{CL} (ft\cdot kip)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>1.50</td>
<td>22.07</td>
<td>309.02</td>
<td>154.51</td>
<td>463.52</td>
<td>23.62</td>
<td>487.14</td>
<td>488.24</td>
<td>553.41</td>
<td>408.17</td>
</tr>
<tr>
<td>3.00</td>
<td>44.15</td>
<td>618.03</td>
<td>309.02</td>
<td>927.05</td>
<td>47.24</td>
<td>974.28</td>
<td>976.49</td>
<td>1106.82</td>
<td>818.34</td>
</tr>
<tr>
<td>4.50</td>
<td>66.22</td>
<td>927.05</td>
<td>463.52</td>
<td>1390.57</td>
<td>70.85</td>
<td>1461.42</td>
<td>1464.73</td>
<td>1660.23</td>
<td>1224.51</td>
</tr>
<tr>
<td>6.00</td>
<td>73.58</td>
<td>1030.05</td>
<td>515.03</td>
<td>1545.08</td>
<td>78.73</td>
<td>1623.80</td>
<td>1627.48</td>
<td>1844.71</td>
<td>1360.57</td>
</tr>
<tr>
<td>7.00</td>
<td>34.34</td>
<td>480.69</td>
<td>240.35</td>
<td>721.04</td>
<td>36.74</td>
<td>757.77</td>
<td>759.49</td>
<td>860.86</td>
<td>634.93</td>
</tr>
</tbody>
</table>
Diagonal - Gate Leaf Design

\( A' = \text{function of top and lower horizontal girders as well as vertical end posts.} \)

\[ A' = \frac{1}{8} (4 \times \text{Area of beams}) = \frac{1}{8} (4) (43.8 \text{ in}^2) = 21.9 \text{ in}^2 \]

\( Q_0 = \text{elasticity constant of leaf without diagonals} \)

\[ Q_0 = K E_0 \left( \frac{d}{h} + \frac{J}{V} \right) \]

- \( K = \text{constant} = 4 \) pg 3-1 of manual
- \( E_0 = \text{Shearing modulus of elasticity} = 11.2 \times 10^6 \) LRFD
- \( J = \text{Polar Moment} \)
- \( h = \text{height of panel encircling diagonal} = 689 \text{ in} \)
- \( V = \text{center line of flange to extreme outer end} = 524'' \)

\[ J_x = (nlc^3), \quad J_y = (nlc^3) \]

- \( n = \text{number of members} \)
- \( l = \text{large dimension of rectangular cross-section} \)
- \( c = \text{smaller dimension of rectangular cross-section} \)

<table>
<thead>
<tr>
<th>Horizontal</th>
<th>( n )</th>
<th>( l )</th>
<th>( c )</th>
<th>( nlc^3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>W 40 x 149</td>
<td>2</td>
<td>11.8''</td>
<td>2.04''</td>
<td>215.5 in^4</td>
</tr>
<tr>
<td></td>
<td>[Flange (US)]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Web</td>
<td>2</td>
<td>36.5''</td>
<td>0.63''</td>
</tr>
<tr>
<td></td>
<td>[Flange (OS)]</td>
<td></td>
<td></td>
<td>13.5 in^4</td>
</tr>
<tr>
<td>W 40 x 183</td>
<td>1</td>
<td>11.8''</td>
<td>2.48''</td>
<td>1800 in^4</td>
</tr>
<tr>
<td></td>
<td>[Flange (US)]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Web</td>
<td>1</td>
<td>36.6''</td>
<td>0.65''</td>
</tr>
<tr>
<td></td>
<td>[Flange (OS)]</td>
<td></td>
<td></td>
<td>21.4 in^4</td>
</tr>
<tr>
<td>W 40 x 215</td>
<td>9</td>
<td>15.8''</td>
<td>2.48''</td>
<td>2169.0 in^4</td>
</tr>
<tr>
<td></td>
<td>[Flange (US)]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Web</td>
<td>9</td>
<td>36.6''</td>
<td>0.65''</td>
</tr>
<tr>
<td></td>
<td>[Flange (OS)]</td>
<td></td>
<td></td>
<td>233.2 in^4</td>
</tr>
<tr>
<td>Skin</td>
<td>5/8''</td>
<td>1</td>
<td>51.4''</td>
<td>0.63''</td>
</tr>
</tbody>
</table>

\[ J_y = \text{Total} = 3104.2 \text{ in}^4 \]
Diagonal Gate Leaf Design

Vertical

| W 40 x 149 | Flange (OS) | 6 | 11.8'' | 2.09'' |
| W 40 x 149 | Web | 6 | 3/8'' | 0.63'' |
| W 40 x 149 | Flange (OS) | 6 | 11.8'' | 0.83'' |

Quan./Miler

| Web | 2 | 16'' | 1.00'' |
| Flange | 2 | 13.1'' | 1.00'' |
| Block | 2 | 70'' | 2.63'' |

\[ J_y = \text{Total} = 10.913 \text{ in}^4 \]

Special consideration for the value of \( C \) on the

Upstream Flange: \( C = 0.83'' + 0.63'' + 0.63'' = 2.09'' \)

\[ Q_0 = (4)(11.2 \times 10^6 \text{ psi}) \left( \frac{3104.2 \text{ in}^4}{3 \times 489 \text{ in}^3} + \frac{1091.3 \text{ in}^4}{3 \times 324 \text{ in}^3} \right) = 48.3 \times 10^6 \text{ in}^6 \]

Centroid: \( x \) component determined by dividing width by 2.

This can be assumed solely due to uniformity of the gate along the \( x \) axis. \( \bar{x} = 275.6 \text{ in} \)

\( y \) component determined by multiplying the cross-sectional area of each beam by the distance from the centroid of the lowest beam and then dividing the total by the sum of the areas.

\( \bar{y} \)

Beam 1

\( A = 4380 \text{ in}^2 \quad y = 689 \text{ in} \quad \bar{y}A = 30,178 \text{ in}^3 \)

\[ \bar{y} = \frac{A_1}{A} \]

\[ \bar{y}A = \frac{219,822 \text{ in}^3}{712 \text{ in}^2} = 308.7 \text{ in} \]

*Centroid location is relative to lower left-hand corner of gate.*
Diagonal - Gate Leaf Design

Horizontal shear center: \( (Y) \)

\[
Y = \frac{\sum (I_n y_n)}{\sum I_n}
\]

\( I_n \) = The moment of inertia of an individual beam.
\( y \) = Vertical location of a beam relative to the centroid.

Ex) Beam 1

\[
I_n = 9800 \text{ in}^4 \quad y = 380.2 \text{ in} \quad I_n y = 3.75 \times 10^6 \text{ in}^5
\]

\[
\sum I_{n1} = 179800 \text{ in}^4 \quad \sum I_{n1} y = -1.09 \times 10^6 \text{ in}^5
\]

It will encounter some negative numbers on beams located lower than the centroid.

\[
Y = \frac{-1.09 \times 10^6 \text{ in}^5}{179800 \text{ in}^4} = \frac{-1.09 \times 10^6}{179800} \text{ in} = -6.0 \text{ in} \quad \text{(relative to centroid)}
\]

Vertical shear center:

\[
x = \frac{b}{2} \sum (a y_n)
\]

\( b \) = Distance from \& skin plate to the flange of a horizontal girder
\( a \) = the area of a beam located outside the midpoint of the flange and the skin plate.

\( y_n \) = Vertical location of a beam relative to the centroid

Ex) Beam 1

\[
a = (93.8 \times \frac{1}{2}) + (\frac{1}{2})(0.63)(0.63) = 22.1 \text{ in}^2
\]

\( y_n = 689 - (308.7 - 61) = 386.4 \text{ in} \)

\( y = 689 - (308.7) = 380.3 \text{ in} \)

\( b = \text{depth of flange} + \frac{1}{2} \text{ skin plate} \) : \( (39'' + \frac{5}{16}'') = 39.3'' \)

will assume this value for all beams.
### Diagonal - Cable Loop Design

\[ a_{yn} = (221 \text{ in})(380.3 \text{ in})(386.4 \text{ in}) = 3.24 \times 10^6 \text{ in}^2 \]

\[ \Sigma a_{yn} = 14.58 \times 10^6 \text{ in}^2 \]

\[ X = \left( \frac{39.3''}{116 \times 10^4 \text{ in}^2} \right) (14.58 \times 10^6 \text{ in}^2) = [4.9 \text{ in}] \]

#### Load Torque Area

- A function of the dead loads acting on the leaf.

\[ T_x = (\text{Force})(\text{Momemi arm})(\text{distance from load to pivot}) = FMZ \]

<table>
<thead>
<tr>
<th></th>
<th>( F )</th>
<th>( M )</th>
<th>( Z )</th>
<th>( T_x )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead load</td>
<td>285,366 lb</td>
<td>29.7 in</td>
<td>267 in</td>
<td>2263 in(^2) lb x 10(^6)</td>
</tr>
<tr>
<td>Mud</td>
<td>50,000 lb</td>
<td>24.7 in</td>
<td>267 in</td>
<td>396 in(^2) lb x 10(^6)</td>
</tr>
<tr>
<td>Water</td>
<td>70,523 lb</td>
<td>29.7 in</td>
<td>271 in</td>
<td>8924 in(^2) lb x 10(^6)</td>
</tr>
</tbody>
</table>

\[ \Sigma = 11.588 \text{ in}^2 \text{ lb x 10}^6 \]

- **F** = Summation of mass of hogs, jirdons, intercostals, skin plate, quoin post and mite post.
- **Mud** = suggested loading for mud and ice by USACE, due to extremely dusty conditions, we assume in full value of 50,000 lbs for mud.
- **From** = \( \frac{1}{2}(\%)(\text{submerged area}) = \frac{1}{2}(62.4)(14 \times 15)(3.2808^2) = 70,523 \text{ lb} \)
- **M_{DL}** = Mud x (0.75)(thickness of leaf) as specified by USACE Monzel = (0.75)(39.3 + 0.15) = 29.7 in
- **M_{DL} =** \( \text{Monzel} \times (0.75)(39.3 + 0.15) = 29.7 \text{ in} \)
- **M_{DL} =** \( \left( \frac{9}{4} \right) \text{(height of gate)} = \left( \frac{9}{4} \right)(17.5)(3.2808)(12) + \frac{1}{2}(118) + \frac{1}{2}(118) \)
  \[ = 271'' \text{ in addition}, (118)(\frac{9}{4}) \text{ was added to account for the additional flange width on the top and bottom of the gate,} \]
- **Z_{DL} =** Z_{mud} + 26.7 in
- **Z_{water} =** 29.7 in
Diagonal-Gate Leaf Design

Evaluation of $R_c$, $R$, $Q$

$$R_c = \pm \frac{2wt}{\nu(w^2 + h^2)^{1/2}}$$

$w$ (in) = 443.7 Width of panel
$t$ (in) = 40.9 Center of skin plate to center of diagonal
$v$ (in) = 542.2 Pintel to extreme miter end
$h$ (in) = 689.0 Height of panel enclosing diagonal

$R_c = 0.0817$

Quoin

Miter

$U_{l1}$

$$A = -\sum \frac{T_c}{sR_c h v}$$

$T_c$ (in² lb) = -1.2E+10 Torque area
$s$ (in) = 18000.0 Unit stress in diagonal
$R_c = 0.0817$ Ratio of change in length of diagonal to deflection when diagonal offers no resistance
$v$ (in) = 542.2 Pintel to extreme miter end
$h$ (in) = 689.0 Height of panel enclosing diagonal

$A = 21.1$ in²

$U_{l0}$

$$A = -\sum \frac{T_c}{sR_c h v}$$

$T_c$ (in² lb) = -9.8E+09 Torque area
$s$ (in) = 18000.0 Unit stress in diagonal
$R_c = 0.0817$ Ratio of change in length of diagonal to deflection when diagonal offers no resistance
$v$ (in) = 542.2 Pintel to extreme miter end
$h$ (in) = 689.0 Height of panel enclosing diagonal

$A = 16.3$ in²
For design purposes, we will assume a safe values of the diagonal areas as follows:

\[ U_{i_{11}} = 28 \text{ in}^2 \quad \Rightarrow \quad 2 \times 13 \text{ in}^2 \quad \text{Boosted in order to meet minimum stress values} \]
\[ U_{i_{10}} = 20 \text{ in}^2 \quad \Rightarrow \quad 2 \times 10 \text{ in}^2 \quad \text{Boosted in order to meet minimum stress values} \]

\[ Q = \frac{RR}{EAh} \frac{c}{L} \]

- \[ R_b = 0.0817 \quad \text{Ratio of change in length of diagonal to deflection when diagonal offers no resistance} \]
- \[ E = 29000000 \quad \text{Modulus of elasticity} \]
- \[ v (\text{in}) = 542.2 \quad \text{Pintle to extreme miter end} \]
- \[ h (\text{in}) = 689.0 \quad \text{Height of panel enclosing diagonal} \]
- \[ L = 750 \quad \text{Length of diagonals} \]

\[ A' (\text{in}^2) = 21.9 \quad \text{Stiffness of the leaf in deforming the diagonal} \]

<table>
<thead>
<tr>
<th>( U_{i_{11}} )</th>
<th>( A' ) (\text{in}^2)</th>
<th>( P )</th>
<th>( Q (\text{in lb } \times 10^6) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>0.0373</td>
<td>1131</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.0427</td>
<td>994</td>
<td></td>
</tr>
</tbody>
</table>

\[ \Delta = \frac{\sum T_z}{Q_z + \sum Q} \]

- \( T_z (\text{in}^2 \text{ lb}) = 1.2E+10 \quad \text{Torque area} \)
- \( Q_z (\text{in lb}) = 1.36E+08 \quad \text{Elasticity constant of leaf without diagonals} \)
- \( Q (\text{in lb } \times 10^6) = 2.1E+09 \quad \text{Elasticity constant of diagonal} \)

\( \Delta = 5.13 \quad \text{in} \)

\[ \Delta = \frac{\sum T_z}{Q_z + \sum Q} \]

- \( T_z (\text{in}^2 \text{ lb}) = -1.2E+10 \quad \text{Torque area} \)
- \( Q_z (\text{in lb}) = 1.36E+08 \quad \text{Elasticity constant of leaf without diagonals} \)
- \( Q (\text{in lb } \times 10^6) = 2.1E+09 \quad \text{Elasticity constant of diagonal} \)

\( \Delta = -4.95 \quad \text{in} \)
Prostressed Deflections and Stresses in Diagonals

\[(D-\Delta)_{\text{max}} = \frac{sL}{RE}\]

\[s \text{ (in)} = 18000.0 \quad \text{Unit stress in diagonal}\]
\[L = 760 \quad \text{Length of diagonals}\]
\[E = 29000000 \quad \text{Modulus of elasticity}\]

<table>
<thead>
<tr>
<th>(U_{\text{LT}})</th>
<th>(U_{\text{L0}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0373</td>
<td>12.6</td>
</tr>
<tr>
<td>0.0427</td>
<td>-11.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Positive (U_{\text{LT}})</th>
<th>Negative (U_{\text{L0}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0373</td>
<td>0.0427</td>
</tr>
<tr>
<td>Q</td>
<td>Q</td>
</tr>
<tr>
<td>1131</td>
<td>994</td>
</tr>
<tr>
<td>((D-\Delta)_{\text{max}})</td>
<td>((D-\Delta)_{\text{max}})</td>
</tr>
<tr>
<td>5.13</td>
<td>-4.95</td>
</tr>
<tr>
<td>(D_{\text{max}})</td>
<td>(D_{\text{max}})</td>
</tr>
<tr>
<td>12.6</td>
<td>-11.0</td>
</tr>
<tr>
<td>(D_{\text{reduced}})</td>
<td>(D_{\text{reduced}})</td>
</tr>
<tr>
<td>7.50</td>
<td>-6.10</td>
</tr>
<tr>
<td>(QD)</td>
<td>(QD)</td>
</tr>
<tr>
<td>7914.57</td>
<td>-5617.67</td>
</tr>
</tbody>
</table>

\[\text{Sum} = 2297 \quad \text{in}^2 \text{ lb x} 10^6\]
\[\text{2261}\]

<table>
<thead>
<tr>
<th>Stress (ksi)</th>
<th>(\Delta)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gates Stationary</td>
<td>10.0</td>
</tr>
<tr>
<td>Gates Being Opened</td>
<td>2.7</td>
</tr>
<tr>
<td>Gates Being Closed</td>
<td>17.0</td>
</tr>
</tbody>
</table>
INTERCOGAL: TRAINGULAR LOADING

\[ F_{EM} = \frac{9(\%G)(3.2/y^2)}{24} = \frac{9SG(3-2y^2)}{48} \]

\[ S_{BM} = \frac{25y^2}{412} + \frac{2SF}{8} \]

G = 1.5 m
S = 1.0987 m
F = 1.013 m
\( q = 22,000 \text{ kN/m} \)

\[ F_{LM} = \frac{(2.00N/m)(1.0987m)(1.0m)[3 - 2 \times (\frac{1.0987m}{2}(1.5m))^2]}{48} = 2,100 \text{ N.m} \]

= 1.550 ft-lb \( \rightarrow \text{W40x149 OK} \)
Concrete Beam Capacity (without Steel Reinforcement)

Assume

\[ f_r = 7.5 \sqrt{f_c'} = 7.5 \sqrt{3000} = 410.8 \text{ psi} \]

\[ z = 19.69 \text{ in} - 2(3.28 \text{ in}) = 13.13 \text{ in} \]

\[ C = \frac{1}{2} \left( \frac{4108 \text{ ksi}}{\text{in}^2} \right) (59.06 \text{ in}) (19.69 \text{ in}) = 119 \text{ kip} \]

\[ M_{cr} = CZ = TZ = \left( 119 \text{ kip} \right) (13.13 \text{ in}) = \frac{130 \text{ ftkip}}{12\text{ in}} = 176 \text{ kN.m} \]

Check

\[ f = \frac{M_c}{I} \quad C = 9.84 \text{ in} \quad f = f_r = 410.8 \text{ psi} \quad M = M_{cr} \]

\[ I = \frac{bh^3}{12} = \frac{(59.06 \text{ in})(19.69 \text{ in})^3}{12} = 37,570 \text{ in}^4 \]

\[ M_{cr} = \left( \frac{410.8 \text{ psi}}{9.84 \text{ in}} \right) \left( \frac{1 \text{ ft}}{12 \text{ in}} \right) \left( \frac{1 \text{ kip}}{1 \text{ ksi}} \right) = 130 \text{ ftkip} = 176 \text{ kN.m} \]

if \( L_b = 6 \text{ m} \)

\( M_{max} \) is at 3 m = 9.84 ft

\[ \text{Max Load} = \frac{130 \text{ ftkip}}{9.84 \text{ ft}} \quad \text{13 kip} = 57 \text{ kN} \]

M/\( K \) LICKITAT

10 kip \( \frac{ft}{k} \) \( \rightarrow \) OK
CONCRETE BEAM CAPACITY (WITH TENSION STEEL ONLY)

Assume:

\[ a = 0.85 c = 0.85(9.84\text{ in}) = 8.37\text{ in} \]
\[ Z = d - \frac{a}{2} = 16\text{ in} - \frac{8.37\text{ in}}{2} = 11.81\text{ in} \]
\[ C = 0.85 f'_c a b = 0.85(3,000\text{ psi})(8.37\text{ in})(59.06\text{ in}) = 1,260\text{ kip} \]
\[ M_{cr} = C Z = T Z = \frac{(1,260\text{ psi})(11.81\text{ in})}{(12\text{ in}^2)} \]

\[ T = C = A_s f_y = 1,260\text{ kip} = A_s (36\text{ ksi}) \]
\[ A_s = 35\text{ in}^2 \]

\[ \rightarrow 9\#18 \text{ or } 16\#14 \text{ or } 21\#11 \]

\[ IF \quad M_{max} \text{ is at } \frac{L_b}{2} = 9.84\text{ ft} \]

\[ \frac{M_{max}}{\text{load}} = \frac{1240\text{ ft-kip}}{9.84\text{ ft}} = 126\text{ kip} = 560\text{ kN} \]

M/V Klickitat

1370 tons (Gross)

\[ \frac{256\text{ ft}}{10\text{ kip/ft}} \rightarrow \text{OK} \]
Concrete beam capacity (No steel reinforcement)

Bottom of lock $L_b = 6$ m

Assume:

![Diagram of beam with dimensions and forces]

$f_c' = 3,000$ psi

$f_r = 7.5 f_c' = 7.5 \sqrt{3,000} = 410.8$ psi

$Z = 39.37$ in - 2(6.56 in) = 26.25 in

$C = T = \frac{T}{2} (0.4108 \text{ kip})(39.37 \text{ in}) = 238 \text{ kip}$

$M_cr = CEZ = \frac{(240 \text{ kip})(26.25 \text{ in})}{12 \text{ ft}} = 522 \text{ ft.kip} = 707 \text{ kN.m}$

Flexure Formula

$f = \frac{Mc}{I}$

$M_r = M_{cr} = \frac{f_c(I)}{C}$

$I = \frac{bh^3}{12} = \frac{(59.06 \text{ in})(39.37 \text{ in})^3}{12} = 300337$ in$^4$

$M_{cr} = \frac{(410.8 \text{ psi})(300337 \text{ in}^4)}{19.69 \text{ in}} \left( \frac{1 \text{ ksi}}{1000 \text{ psi}} \right) \left( \frac{1 \text{ ft}}{12 \text{ in}} \right) = 522 \text{ ft.kip} = 707 \text{ kN.m}$

If $L_b = 6$ m

$M_{max} @ 3m = 9.84$ ft

$Max \ Load = \frac{522 \text{ ft.kip}}{9.84 \text{ ft}} = 53 \text{ kip} = 235 \text{ kN}$
Concrete Beam Capacity (with Tension Steel Reinforcement)

**Assume:**
- $f' = 3000 \text{ psi}$
- $f_y = 36,000 \text{ psi}$
- $A_s = ?$
- $L_o = 6 \text{ m}$

\[ a = 0.85c = 0.85(19.69 \text{ in}) = 16.74 \text{ in} \]
\[ Z = d - \frac{a}{2} = 35" - \frac{16.74"}{2} = 26.63" \]
\[ C = 0.85f' A_o = 0.85(3,000 \text{ psi})(16.74 \text{ in})(64.06 \text{ in}) = 2,521 \text{ kip} \]
\[ T = A_s f_y = 2521 \text{ kip} = A_s \left( \frac{36 \text{ksi}}{12 \text{ in}} \right) = 70 \text{ in}^2 \]

\[ 18\#18 = 72 \text{ in}^2 \quad \text{or} \quad 32\#14 \quad \text{or} \quad 45\#11 \]

\[ M_{cr} = CZ = 2520 \text{ kip}(26.63 \text{ in})(\frac{144}{12} \text{ in}) \]

\[ M_{cr} = 5590 \text{ ft.kip} \]

\[ \frac{M_{max}}{M_{cr}} \text{ is at } \frac{L_o}{2} = 3m = 9.84 \text{ ft} \]

\[ \text{Max Load} = \frac{5590 \text{ ft.kip}}{9.84 \text{ ft}} = 568 \text{ kip} = 2,525 \text{ kN} \]

\[ M/V \text{ Klickitat} \]

1370 (Gross) Tons > 10 kip

256 ft long $\frac{f}{f_{+}}$ -> OK
V=1115 [lb_f]  "heaviest of two dewatering gates"
R=2.5 [in]
T=V*R
d=2*R
A=PI*R^2
S_u=36000 [psi]  "assumed"
tau=(16*T)/(PI*(d^3))  "torsion"

"Fatigue"
SN_ratio=tau/S_u  "figure 8.11"
S_n_prime=0.29*S_u  "endurance limit"

"Distortion Energy Failure Theory"
sigma_y=(4/3)*(V/A)
sigma_x=0  "zero bending"
sigma_e=(sigma_x^2+sigma_y^2-sigma_x*sigma_y+3*tau^2)^0.5

SOLUTION

Unit Settings: [kJ]/[K]/[kPa]/[kmol]/[degrees]
A = 19.63 [in^2]  
\( \sigma_e = 210.8 \text{ [psi]} \)  
SN_ratio = 0.003155  
T = 2788 [in-lb_f]  
\( \sigma_x = 0 \text{ [psi]} \)  
\( S_n,prime = 10440 \text{ [psi]} \)  
\( \tau = 113.6 \text{ [psi]} \)  
R = 2.5 [in]  
\( \sigma_y = 75.72 \text{ [psi]} \)  
S_u = 36000 [psi]  
V = 1115 [lb_f]  

No unit problems were detected.
V=1115 [lb_f]  "heaviest of two dewatering gates"
R=2.5 [in]
T=V*R
d=2*R
A=PI*R^2
S_u=36000 [psi]  "assumed"
tau=(16*T)/(PI*(d^3))  "torsion"

"Fatigue"
SN_ratio=tau/S_u  "figure 8.11"
S_n_prime=0.29*S_u  "endurance limit"

"Distortion Energy Failure Theory"
sigma_y=(4/3)*(V/A)  "zero bending"
sigma_x=0
sigma_e=(sigma_x^2+sigma_y^2-sigma_x*sigma_y+3*tau^2)^0.5

SOLUTION
Unit Settings: [kJ]/[K]/[kPa]/[kmol]/[degrees]
σ_e = 210.8 [psi]  σ_x = 0 [psi]  σ_y = 75.72 [psi]
SN_ratio = 0.003155  S_n_prime = 10440 [psi]  S_u = 36000 [psi]
T = 2788 [in-lb_f]  τ = 113.6 [psi]  V = 1115 [lb_f]

No unit problems were detected.
$\sigma_1 = 157.6 \text{ psi}$

$\sigma_2 = -81.9 \text{ psi}$

$\tau_{xy} \text{ Max} = 119.7 \text{ psi}$

$108.43^\circ$

Principal Stress Orientation

Max In-plane Shear Stress Orientation

The material does not fail

$FS = 170.7554$

Yield Stress

$p$si

-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90

Failure Theories

Ductile Materials

- Maximum-Shear-Stress Theory (Tresca)
- Maximum-Distortion-Energy Theory (Huber/Von Mises/Hencky)

Brittle Materials

- Maximum-Normal-Stress Theory (Rankine)
- Mohr's Failure Criterion
"Bouyancy Forces in Bumper System"

\[ \text{gravity} = 9.81 \text{ [m/s}^2\text{]} \]
\[ \text{Volume}_\text{tire} = 0.003 \text{ [m}^3\text{]} \]
\[ \text{Diameter}_\text{tire} = 0.35 \text{ [m]} \]
\[ \rho_{\text{water}} = 997 \text{ [kg/m}^3\text{]} \]
\[ \rho_{\text{rubber}} = 1150 \text{ [kg/m}^3\text{]} \]
\[ \text{Weight}_\text{tire,air} = \rho_{\text{rubber}} \times \text{gravity} \times \text{Volume}_\text{tire} \]
\[ \text{Force}_\text{Buoyant, tire} = \rho_{\text{water}} \times \text{gravity} \times \text{Volume}_\text{tire} \]
\[ \text{Weight}_\text{tire, underwater} = \text{Weight}_\text{tire, air} - \text{Force}_\text{Buoyant, tire} \]
\[ \text{NO, Tires} = 100 \]
\[ \text{Weight}_\text{Tires, total} = \text{NO, Tires} \times \text{Weight}_\text{tire, underwater} \]
\[ \text{Force}_\text{Buoyant, Float} = 30 \text{ [N]} \]
\[ \text{Buoyants, needed} = \frac{\text{Weight}_\text{Tires, total}}{\text{Force}_\text{Buoyant, Float}} \]

"Bouy Specs"

"Bouyancy = 7 lbs = 30 N"
"Diameter = 6 in"
"Hole Diameter = 1 3/8 or 2 in"
"# per Package = 46"

SOLUTION

Unit Settings: [kJ]/[K]/[kPa]/[kmol]/[degrees]

Buoyanted = 15.01

\[ \text{Force}_\text{Buoyant, Float} = 30 \text{ [N]} \]
\[ \text{gravity} = 9.81 \text{ [m/s}^2\text{]} \]
\[ \rho_{\text{rubber}} = 1150 \text{ [kg/m}^3\text{]} \]
\[ \text{Volume}_\text{tire} = 0.003 \text{ [m}^3\text{]} \]
\[ \text{Weight}_\text{tire,air} = 33.64 \text{ [N]} \]

Diameter_tire = 0.35 [m]

Force_Buoyant_tire = 29.34 [N]

\[ \text{NO, Tires} = 100 \]
\[ \rho_{\text{water}} = 997 \text{ [kg/m}^3\text{]} \]
\[ \text{Weight}_\text{Tires, total} = 450.3 \text{ [N]} \]
\[ \text{Weight}_\text{tire, underwater} = 4.503 \text{ [N]} \]

No unit problems were detected.
"Speed requirements:
Gates: 90 seconds
Culvert Valves: 6 seconds"

"Motor Specs:
Gates - Manufacturer: Portescap Part # - 28LT12-416E-164
Culvert Valves - Manufacturer: Portescap Part # - 28LT12-416E-164"

\[
\begin{align*}
\text{Torque}_{\text{reqd,gates}} &= 5625000 \text{ [ft-lbf]} \\
\text{Torque}_{\text{reqd,smallgates}} &= 4162500 \text{ [ft-lbf]} \\
\text{Torque}_{\text{culvertvalves}} &= 154600 \text{ [ft-lbf]} \\
\text{Speed}_{\text{reqd,gates}} &= 1.6 \text{ [deg/sec]} \\
\text{Speed}_{\text{culvertvalves}} &= 15 \text{ [deg/sec]}
\end{align*}
\]

"Culvert Valves"
\[
\begin{align*}
\text{CulvertValve\_Torque} &= 970781 \text{ [ft-lbf]} \\
\text{CulvertValve\_Speed} &= 28 \text{ [deg/sec]} \\
\text{Torque}_{\text{culvertvalves}} &= \text{CulvertValve\_Torque} / (\text{Speed}_{\text{reqd,culvertvalves}} / \text{CulvertValve\_Speed}) \\
\text{SafetyFactor}_{\text{CulvertValves}} &= \text{Torque}_{\text{culvertvalves}} / \text{Torque}_{\text{reqd,culvertvalves}}
\end{align*}
\]

"Large Gate Valves"
\[
\begin{align*}
\text{LargeGate\_Torque} &= 99608 \text{ [ft-lbf]} \\
\text{LargeGate\_Speed} &= 322 \text{ [deg/sec]} \\
\text{Torque}_{\text{largegate}} &= \text{LargeGate\_Torque} / (\text{Speed}_{\text{reqd,gates}} / \text{LargeGate\_Speed}) \\
\text{SafetyFactor}_{\text{LargeGate}} &= \text{Torque}_{\text{largegate}} / \text{Torque}_{\text{reqd,largegates}}
\end{align*}
\]

"Small Gate Valves"
\[
\begin{align*}
\text{SmallGate\_Torque} &= 99608 \text{ [ft-lbf]} \\
\text{SmallGate\_Speed} &= 322 \text{ [deg/sec]} \\
\text{Torque}_{\text{smallgate}} &= \text{SmallGate\_Torque} / (\text{Speed}_{\text{reqd,gates}} / \text{SmallGate\_Speed}) \\
\text{SafetyFactor}_{\text{SmallGate}} &= \text{Torque}_{\text{smallgate}} / \text{Torque}_{\text{reqd,smallgates}}
\end{align*}
\]

SOLUTION

Unit Settings: [kJ]/[K]/[kPa]/[kmol]/[degrees]
\[
\begin{align*}
\text{CulvertValve\_Speed} &= 28 \text{ [deg/sec]} \\
\text{LargeGate\_Speed} &= 322 \text{ [deg/sec]} \\
\text{SafetyFactor}_{\text{CulvertValves}} &= 11.72 \\
\text{SafetyFactor}_{\text{SmallGate}} &= 4.816 \\
\text{SmallGate\_Torque} &= 99608 \text{ [ft-lbf]} \\
\text{Speed}_{\text{reqd,gates}} &= 1.6 \text{ [deg/sec]} \\
\text{Torque}_{\text{largegate}} &= 2.005E+07 \text{ [ft-lbf]} \\
\text{Torque}_{\text{culvertvalves}} &= 5.625E+06 \text{ [ft-lbf]} \\
\text{Torque}_{\text{smallgate}} &= 2.005E+07 \text{ [ft-lbf]}
\end{align*}
\]

No unit problems were detected.
Mitre Gate Design

Fit into recessed wall
Bottom of recess should extend beyond bottom of gate to account for debris. 2.5-3.5 ft is good
structural grade carbon steel (36 ksi) should be used, except for diagonals and skin plate

Operating time- 90 sec 44

Gate weight 71
Ohio Linkage 39,41
Ohio Linkage Ass'y 168

Strut 44
Strut Ass'y 171, 172

Sector Gear Anchorage 168

Design loads 44
Load analysis 45

temporal load 46

percent closed/open 242, 244

effect of submergence on torque 232

operating machinery control 49, 51

lock filling/emptying sequence 52

Machinery stops 168

Automatic lubrication schematic 53,54, 131 sect. A

Automatic Latches 53, 192?, 143, 144, 145

mitre gate guide 37, 138, 139
## Model

<table>
<thead>
<tr>
<th>Scale</th>
<th>Lock Length [ft]</th>
<th>Width [th]</th>
<th>Length [m]</th>
<th>Width [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0000</td>
<td>1</td>
<td>574.15</td>
<td>229.66</td>
<td>175.00</td>
</tr>
<tr>
<td>0.5000</td>
<td>1/2</td>
<td>287.07</td>
<td>114.83</td>
<td>87.50</td>
</tr>
<tr>
<td>0.2500</td>
<td>1/4</td>
<td>143.54</td>
<td>57.41</td>
<td>43.75</td>
</tr>
<tr>
<td>0.1250</td>
<td>1/8</td>
<td>71.77</td>
<td>28.71</td>
<td>21.88</td>
</tr>
<tr>
<td>0.0625</td>
<td>1/16</td>
<td>35.88</td>
<td>14.35</td>
<td>10.94</td>
</tr>
<tr>
<td>0.0313</td>
<td>1/32</td>
<td>17.94</td>
<td>7.18</td>
<td>5.47</td>
</tr>
<tr>
<td>0.0156</td>
<td>1/64</td>
<td>8.97</td>
<td>3.59</td>
<td>2.73</td>
</tr>
<tr>
<td>0.0143</td>
<td>1/70</td>
<td>8.20</td>
<td>3.28</td>
<td>2.50</td>
</tr>
<tr>
<td>0.0133</td>
<td>1/75</td>
<td>7.66</td>
<td>3.06</td>
<td>2.33</td>
</tr>
<tr>
<td>0.0125</td>
<td>1/80</td>
<td>7.18</td>
<td>2.87</td>
<td>2.19</td>
</tr>
<tr>
<td>0.0118</td>
<td>1/85</td>
<td>6.75</td>
<td>2.70</td>
<td>2.06</td>
</tr>
<tr>
<td>0.0111</td>
<td>1/90</td>
<td>6.38</td>
<td>2.55</td>
<td>1.94</td>
</tr>
<tr>
<td>0.0105</td>
<td>1/95</td>
<td>6.04</td>
<td>2.42</td>
<td>1.84</td>
</tr>
<tr>
<td>0.0104</td>
<td>1/96</td>
<td>5.98</td>
<td>2.39</td>
<td>1.82</td>
</tr>
<tr>
<td>0.0100</td>
<td>1/100</td>
<td>5.74</td>
<td>2.30</td>
<td>1.75</td>
</tr>
<tr>
<td>0.0078</td>
<td>1/128</td>
<td>4.49</td>
<td>1.79</td>
<td>1.37</td>
</tr>
<tr>
<td>0.0067</td>
<td>1/150</td>
<td>3.83</td>
<td>1.53</td>
<td>1.17</td>
</tr>
<tr>
<td>0.005</td>
<td>1/200</td>
<td>2.87</td>
<td>1.15</td>
<td>0.88</td>
</tr>
<tr>
<td>0.004</td>
<td>1/250</td>
<td>2.30</td>
<td>0.92</td>
<td>0.70</td>
</tr>
<tr>
<td>0.0033</td>
<td>1/300</td>
<td>1.91</td>
<td>0.77</td>
<td>0.56</td>
</tr>
</tbody>
</table>

Dewatering well

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3.15</td>
<td>3.15</td>
<td>4.82</td>
<td>0.08</td>
</tr>
<tr>
<td>[at 1/200 scale]</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Y-dir [m]</th>
<th>Height [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.08</td>
<td>0.1225</td>
</tr>
</tbody>
</table>

## Research:

- waterproof wood
- caulk? Epoxy?
"Conversion Factors"
LengthConversion=.0833333333 [ft/in]
AreaConversion=.0069444444 [ft^2/in^2]
VolumeConversion=.000578703703704 [ft^3/in^3]

"Material Properties"
E_steel=30000000 [psi]
ν_steel=0.30
rho_steel=.283 [lbf/in^3]
Cost_steel=.839 [$/lbf]

"Dimensions: Short Gate"
Height_ShortGate=39.372 [in]
Width_ShortGate=160.079 [in]
Thickness_ShortGate=.625 [in]

"Dimensions: Tall Gate"
Height_TallGate=59.055 [in]
Width_TallGate=98.425 [in]
Thickness_TallGate=.625 [in]

"Volumes"
Volume_ShortGate=Height_ShortGate*Width_ShortGate*Thickness_ShortGate
Volume_TallGate=Height_TallGate*Width_TallGate*Thickness_TallGate

"Weights"
Weight_ShortGate=Volume_ShortGate*rho_steel
Weight_TallGate=Volume_TallGate*rho_steel

"Torques"
Crank_Distance=1.0 [ft]
Torque_Required=40 [ft-lbf]
Torque_ShortGate=Weight_ShortGate*Crank_Distance
Torque_TallGate=Weight_TallGate*Crank_Distance
ScaleDownFactor_ShortGate=Torque_ShortGate/Torque_Required
ScaleDownFactor_TallGate=Torque_TallGate/Torque_Required

"Dimensions: Shaft and Gears"
ShaftDiameter=5 [in]
ShaftWallThickness=.375 [in]
ShaftLength=12 [in]
ShaftRadius=.20833333 [ft]
Gear_Radius_Shft=1.25 [ft]
Gear_Radius_2=.20833333 [ft]
Gear_Radius_3= 1.25 [ft]
Gear_Radius_4=.20833333 [ft]

"Reduced Torques"
Torque_ShortGate_Gear_2=Torque_ShortGate*(Gear_Radius_2/Gear_Radius_Shft)
Torque_ShortGate_Gear_3=Torque_ShortGate_Gear_2*(Gear_Radius_3/Gear_Radius_2)
Torque_ShortGate_Gear_4=Torque_ShortGate_Gear_3*(Gear_Radius_4/Gear_Radius_3)

Torque_TallGate_Gear_2=Torque_TallGate*(Gear_Radius_2/Gear_Radius_Shft)
Torque_TallGate_Gear_3=Torque_TallGate_Gear_2
Torque_TallGate_Gear_4=Torque_TallGate_Gear_3*(Gear_Radius_4/Gear_Radius_3)
"Shaft Speeds"
Omega_Gear_4=10 [rpm]
Omega_Gear_3=Omega_Gear_4*(Gear_Radius_4/Gear_Radius_3)
Omega_Gear_2=Omega_Gear_3
Omega_Gear_1=Omega_Gear_2*(Gear_Radius_2/Gear_Radius_Shaf)  

"Shaft Deflections"
D_o=5 [in]
D_i=4.625 [in]
l=\left(\frac{\pi}{64}\right)\left((D_o^4)-(D_i^4)\right)
delta_{max}\text{ShortGate}=\left(\frac{\text{Weight}_\text{ShortGate}}{(Shaft\text{Length})^3}\right)\left(48\times(E_{\text{steel}})^3\times(l)\right)
delta_{max}\text{TailGate}=\left(\frac{\text{Weight}_\text{TailGate}}{(Shaft\text{Length})^3}\right)\left(48\times(E_{\text{steel}})^3\times(l)\right)

Lift\_OneRotation=\pi\times\text{ShaftDiameter}

TURNS\_reqd\_ShortGate=\frac{\text{Height}_\text{ShortGate}}{(Lift\_OneRotation)}

TURNS\_reqd\_TailGate=\frac{\text{Height}_\text{TailGate}}{(Lift\_OneRotation)}

Lift\_Time\_ShortGate=TURNS\_reqd\_ShortGate/Omega\_Gear_1
Lift\_Time\_TailGate=TURNS\_reqd\_TailGate/Omega\_Gear_1

SOLUTION
Unit Settings: [kJ]/[K]/[kPa]/[kmol]/[degrees]
AreaConversion = 0.006944 [ft^2/in^2]
CrankDistance = 1 [ft]
\delta_{max,\text{TailGate}} = 0.0001501 [in]
D_o = 5 [in]
Gear_Radius_2 = 0.2083 [ft]
Gear_Radius_4 = 0.2083 [ft]
Height_ShafGate = 39.37 [in]
l = 8.219 [in^3]
Lift\_OneRotation = 15.71 [in/rev]
Lift\_Time\_TailGate = 13.53 [min]
\omega_{\text{gear,}2} = 1.667 [rpm]
\omega_{\text{gear,}4} = 10 [rpm]
Scale\_Down\_Factor\_ShortGate = 27.87
ShaftDiameter = 5 [in]
ShaftRadius = 0.2083 [ft]
Thickness\_ShortGate = 0.625 [in]
Torque\_\text{Required} = 40 [ft-lbf]
Torque\_\text{ShortGate,} Gear_2 = 185.8 [ft-lbf]
Torque\_\text{ShortGate,} Gear_4 = 30.97 [ft-lbf]
Torque\_\text{TailGate,} Gear_2 = 171.3 [ft-lbf]
Torque\_\text{TailGate,} Gear_4 = 28.56 [ft-lbf]
TURNS\_reqd\_TailGate = 3.76 [rev]
Volume\_\text{ShortGate} = 3939 [in^3]
V_{\text{steel}} = 0.3
Weight\_\text{TailGate} = 1028 [lbf]
Width\_\text{TailGate} = 98.43 [in]

Cost_{\text{steel}} = 0.839 [$/lbf]
\delta_{\text{max,ShortGate}} = 0.0001628 [in]
D_i = 4.625 [in]
E_{\text{steel}} = 3.000E+07 [psi]
Gear\_Radius_2 = 1.25 [ft]
Gear\_Radius_4 = 1.25 [ft]
Height\_\text{TailGate} = 59.06 [in]
LengthConversion = 0.08333 [ft/in]
LIFT\_Time\_ShortGate = 9.023 [min]
\omega_{\text{gear,1}} = 0.2778 [rpm]
\omega_{\text{gear,3}} = 1.667 [rpm]
\rho_{\text{steel}} = 0.283 [lbf/in^3]
Scale\_Down\_Factor\_TailGate = 25.7
Shaft\_\text{Length} = 12 [in]
Shaft\_Wall\_\text{Thickness} = 0.375 [in]
Thickness\_\text{TailGate} = 0.625 [in]
Torque\_\text{ShortGate} = 1115 [ft-lbf]
Torque\_\text{ShortGate,} Gear_2 = 185.8 [ft-lbf]
Torque\_\text{TailGate} = 1028 [ft-lbf]
Torque\_\text{TailGate,} Gear_3 = 171.3 [ft-lbf]
TURNS\_reqd\_\text{TailGate} = 2.506 [rev]
VolumeConversion = 0.0005787 [ft^3/in^3]
Volume\_\text{TailGate} = 3633 [in^3]
Weight\_\text{ShortGate} = 1115 [lbf]
Width\_\text{ShortGate} = 160.1 [in]

1 potential unit problem was detected.
"!Conversion Factors"
LengthConversion=.0833333333 [ft/in]
AreaConversion=.0069444444 [ft^2/in^2]
VolumeConversion=.000578703703704 [ft^3/in^3]

"!Material Properties"
E_steel=3000000000 [psi]
v_steel=0.30
rho_steel=.283 [lb/ft^3]
Cost_steel=.839 [$/lbf]

"!Lock Dimensions at Maximum Capacity"
LockHeight=45 [ft]
LockWidth=100 [ft]
LockLength=300 [ft]
LockVolume=LockHeight*LockWidth*LockLength
LockFloorArea=LockLength*LockWidth

"!Lock Forces at Maximum Capacity"
rhoWater=62 [lbf/ft^3]
WaterForce=LockVolume*rhoWater
LockFloorPressure=(WaterForce/LockFloorArea)*AreaConversion

"!Valve Dimensions"
ValveLength=10 [ft]
ValveWidth=6 [ft]
ValveDepth=1 [ft]
ValveWallThickness=.0833333333 [ft]
ValveWeight=(SurfaceArea_Valve_Closed*(ValveWallThickness/LengthConversion))*rho_steel

"Valve Dimensions-Closed"
ValveLengthClosed=10 [ft]
ValveWidthClosed=6 [ft]
ValveThicknessClosed=.0833333333 [ft]
SurfaceArea_Valve_Closed=ValveLengthClosed*ValveWidthClosed/AreaConversion

"ValveDimensions-Open"
ValveLengthOpen=1 [ft]
ValveWidthOpen=6 [ft]
ValveThicknessOpen=.0833333333 [ft]
SurfaceArea_Valve_Open=ValveLengthOpen*ValveWidthOpen/AreaConversion

"ShaftDimensions"
ShaftLength=8 [ft]
Diameter_Outside=8.625 [in]
Diameter_Inside=7.981 [in]
Thickness_ShaftWall=.322 [in]

"Initial Valve Model"
"Closed - Stress Calculations"
BETA[1]=0.47
alpha[1]=0.0255
MaxStress_Init_Closed=(BETA[1]*LockFloorPressure*ValveWidth^2)/(ValveWallThickness^2)
MaxDeflection_Init_Closed=(alpha[1]*LockFloorPressure*(ValveWidth/LengthConversion)^4)/(E_steel*(ValveWallThickness /LengthConversion)^3)
"Closed - Modal Analysis"

\[
K[1] = 25.9 \\
g = 386.4 \text{ [in/sec}^2]\]

\[
D[1] = (E_{\text{steel}} \times (\text{ValveWallThickness/LengthConversion})^3)/(12^2 (1 - \text{v_steel}^2)) \\
\text{Frequency}_{\text{Initial Closed}} = (K[1]/(2^\pi))^3 \times \text{SQRT}((D[1] \times g)/(\text{ValveWeight} \times \text{ValveWidth}^4))
\]

"Open - Stress Calculations"

\[
\text{BETA}[2] = .75 \\
\alpha[2] = 0.1421 \\
\gamma[2] = 0.500 \\
\text{MaxStress}_{\text{Initial Open}} = (\text{BETA}[2] \times \text{LockFloorPressure} \times \text{ValveWidth}^2)/(2^\pi \times \text{ValveWallThickness}^2) \\
\text{MaxDeflection}_{\text{Initial Open}} = (\alpha[2] \times \text{LockFloorPressure} \times \text{ValveWidth} \times \text{LengthConversion})^4 / (E_{\text{steel}} \times (2^\pi \times \text{ValveWallThickness} \times \text{LengthConversion})^3)
\]

"Open - Modal Analysis"

\[
K[2] = 22.8 \\
D[2] = (E_{\text{steel}} \times (2^\pi \times \text{ValveWallThickness} \times \text{LengthConversion})^3)/(12^2 (1 - \text{v_steel}^2)) \\
\text{Frequency}_{\text{Initial Open}} = (K[2]/(2^\pi))^3 \times \text{SQRT}((D[2] \times g)/(\text{ValveWeight} \times \text{ValveLengthOpen} \times \text{LengthConversion})^4))
\]

"Ribbed Valve Model"

"Rib Dimension"

\[
\text{RibHeight} = .45 \text{ [ft]} \\
\text{RibWidth} = .083333333 \text{ [ft]} \\
\text{RibDepth} = .583333333 \text{ [ft]} \\
\text{RibVolume} = \text{RibHeight} \times \text{RibWidth} \times \text{RibDepth} \\
\text{RibWeight} = (\text{RibVolume} \times \text{VolumeConversion}) \times \rho_{\text{steel}} \\
\text{RibbedValveWeight} = \text{ValveWeight} + (2 \times \text{RibWeight})
\]

"Cost Comparison"

\[
\text{Cost}_{\text{Initial Model}} = \text{ValveWeight} \times \text{CostSteel} \\
\text{Cost}_{\text{Ribbed Model}} = \text{RibbedValveWeight} \times \text{CostSteel} \\
\text{Cost Increase} = (\text{Cost}_{\text{Ribbed Model}} - \text{Cost}_{\text{Initial Model}}) / \text{Cost}_{\text{Ribbed Model}} \times 100
\]

**SOLUTION**

<table>
<thead>
<tr>
<th>Unit Settings: [kJ][K]/[kJ][Pa]/[kmol][degrees]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AreaConversion = 0.006944 [ft$^2$/in$^2$]</td>
</tr>
<tr>
<td>Cost$\text{Initial Model} = 2051$ [S]</td>
</tr>
<tr>
<td>Cost$\text{steel} = 0.839$ [$$/lbf]</td>
</tr>
<tr>
<td>Diameter$\text{Outside} = 8.625$ [in]</td>
</tr>
<tr>
<td>Frequency$\text{Initial Closed} = 75.45$ [Hz]</td>
</tr>
<tr>
<td>( \text{g} = 386.4 \text{ [in/sec}^2])</td>
</tr>
<tr>
<td>\text{LockFloorArea} = 30000 [ft$^2$]</td>
</tr>
<tr>
<td>LockHeight = 45 [ft]</td>
</tr>
<tr>
<td>\text{LockVolume} = 1.350E+06 [ft$^3$]</td>
</tr>
<tr>
<td>\text{MaxDeflection}_{\text{Initial Closed}} = 0.4426 [in]</td>
</tr>
<tr>
<td>\text{MaxStress}_{\text{Initial Closed}} = 47207 [psi]</td>
</tr>
<tr>
<td>\text{rhoWater} = 62 [/lbf/ft$^3$]</td>
</tr>
<tr>
<td>\text{RibbedValveWeight} = 2659 [/lbf]</td>
</tr>
<tr>
<td>RibHeight = 0.45 [ft]</td>
</tr>
<tr>
<td>RibWeight = 107 [/lbf]</td>
</tr>
<tr>
<td>ShaftLength = 8 [ft]</td>
</tr>
<tr>
<td>SurfaceArea$\text{ValveClosed} = 864$ [in$^2$]</td>
</tr>
<tr>
<td>ValveDepth = 1 [ft]</td>
</tr>
</tbody>
</table>

\[
\text{Cost Increase} = 8.05 \% \\
\text{Cost}_{\text{Ribbed Model}} = 2231 \text{ [S]} \\
\text{Diameter}_{\text{valve}} = 7.881 \text{ [in]} \\
\text{E}_{\text{steel}} = 3.000E+07 \text{ [psi]} \\
\text{Frequency}_{\text{Initial Open}} = 46.55 \text{ [Hz]} \\
\text{LengthConversion} = 0.08333 \text{ [ft/in]} \\
\text{LockFloorPressure} = 19.37 \text{ [psi]} \\
\text{LockLength} = 300 \text{ [ft]} \\
\text{LockWidth} = 100 \text{ [ft]} \\
\text{MaxDeflection}_{\text{Initial Open}} = 0.3083 \text{ [in]} \\
\text{MaxStress}_{\text{Initial Open}} = 37665 \text{ [psi]} \\
\text{\rho}_{\text{steel}} = 0.283 \text{ [lb/lb/ft$^3$]} \\
\text{RibDepth} = 5.833 \text{ [ft]} \\
\text{RibVolume} = 0.2187 \text{ [ft$^3$]} \\
\text{RibWidth} = 0.08333 \text{ [ft]} \\
\text{SurfaceArea}_{\text{ValveClosed}} = 8640 \text{ [in$^2$]} \\
\text{Thickness}_{\text{Shaft}} = 0.322 \text{ [in]} \\
\text{ValveLength} = 10 \text{ [ft]} \\
\]
ValveLengthClosed = 10 [ft]
ValveThicknessClosed = 0.08333 [ft]
ValveWallThickmess = 0.08333 [ft]
ValveWidth = 6 [ft]
ValveWidthOpen = 6 [ft]

ValveLengthOpen = 1 [ft]
ValveThicknessOpen = 0.08333 [ft]
ValveWeight = 2445 [lbf]
ValveWidthClosed = 6 [ft]
VolumeConversion = 0.0005787 [ft³/in³]
WaterForce = 8.370E+07 [lbf]

3 potential unit problems were detected.

<table>
<thead>
<tr>
<th></th>
<th>α</th>
<th>β</th>
<th>D₀</th>
<th>γ</th>
<th>K₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0255</td>
<td>0.47</td>
<td>2.747E+06</td>
<td></td>
<td>25.9</td>
</tr>
<tr>
<td>2</td>
<td>0.1421</td>
<td>0.75</td>
<td>2.198E+07</td>
<td>0.5</td>
<td>22.6</td>
</tr>
<tr>
<td>Name</td>
<td>Flow Rate [m³/hr]</td>
<td>Head [m]</td>
<td>De-Water Time [hr]</td>
<td>2 Pumps De-Water Time [hr]</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>-------------------</td>
<td>----------</td>
<td>---------------------</td>
<td>-----------------------------</td>
<td></td>
</tr>
<tr>
<td>CPP - 21</td>
<td>1150</td>
<td>235</td>
<td>43.5</td>
<td>21.7 Horizontal</td>
<td></td>
</tr>
<tr>
<td>VLT/VMT</td>
<td>1600</td>
<td>1060</td>
<td>31.3</td>
<td>15.6 Vertical</td>
<td></td>
</tr>
<tr>
<td>DSV</td>
<td>11364</td>
<td>244</td>
<td>4.4</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>SCE</td>
<td>2050</td>
<td>335</td>
<td>24.4</td>
<td>12.2</td>
<td></td>
</tr>
<tr>
<td>SVN</td>
<td>2500</td>
<td>510</td>
<td>20.0</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>J/HVN</td>
<td>4200</td>
<td>518</td>
<td>11.9</td>
<td>6.0</td>
<td></td>
</tr>
</tbody>
</table>

http://www.phoenixpumps.com/ruhr.htm
thermo ex 12-6 p. 535