Final Design Report (Phase 4 report)

APSC-100: Written submission checklist

Check this checklist before submitting the assignment.

☒Assignment instructions read, and all requirements met

☒ Computer spell check/grammar check run on document

☒ Complete document reviewed and proofread by all team members

☒ Grading rubric attached at end of document and self-assessed

☒ Team members reviewed the academic integrity expectations

☒ *"We do hereby verify that this written report is our own individual work and contains our own original ideas, concepts, and designs. No portion of this report has been copied in whole or in part from another source, with the possible exception of properly referenced material."*

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Executive Summary

In 1987, a mechanical failure of a mine gate at the Levack mine in Sudbury, Ontario resulted in the deaths of four employees. The goal of this project is to create an improved mine gate design that will reduce the risk of failure and withstand over 20 tons (short ton) of static load. Initially, the three possible design solutions included the Undercut-Arcing Gate, Pinching Gate and Drill Gate. The Undercut-Arcing design is an arced gate that will distribute the load like an arched bridge. The pinching gate design consists of two doors that exit from the ore-pass walls and pinch together with interlocking teeth. The final design is the drill gate which consists of multiple inter-locking drill bits that can clear rock when closing. All designs were evaluated using an evaluation matrix with points being awarded for how designs meet the client criteria. The final design chosen was initially the Undercut Design. The design was chosen because of its feasibility, simplicity and effective force distribution. The disadvantages of the design are that rocks could block the gate from closing by blocking the path of motion since it requires more room than the other gate designs. As the project continued, the group discovered that the feasibility of the Undercut-Arcing gate was over-estimated. The biggest problem with this design was that its arc made it difficult for the gate to retract into the ore pass. To overcome this obstacle, the group came up with a new design. The new gate design is a hollow rectangle allowing for bending moment resistivity, less material, and space for electronics. The gate model was visualized with solid edge. A force analysis on the control gate was done to determine the stress distribution on the gate under 20 tons of loading. A financial analysis was made to determine the cost of the project and to justify the selection of certain materials. The total cost of the mine gate itself would be approximately $168,993.40 (CAD). In addition, the cost of the installation is estimated to be $100,000.00-$200,000.00 (CAD).

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Part 1: Key Information for Clients

Section 1.1: Problem Statement and Scope Definition

Minerva Canada Incorporated is a non-profit organization that provides health and safety education to create ideal workplaces around the world. Due to the 1987 accident at the Levack Mine where a fatal failure occurred, Minerva has requested three new possible mining control gate designs for which incidents like these would be prevented. The new gate must meet all the safety requirements that Minerva has provided and remain within a $1M budget. The gate must also be capable of withstanding at least 20 US-tons of rock. The final design proposal will include a failure mode and effects analysis which includes force calculations, a model of the design using CAD software, and orthographic drawings. Minerva requested to incorporate automated systems, water management systems and proper failsafe mechanisms into the new gate system. Suggestions on current mining safety and management systems must also be provided.

Section 1.2: Background Information

Control Protection chains and doglegs can be placed in the ore pass before gates to reduce impact and degradation [1]. A dogleg in an ore pass is an abrupt change in the angle at the bottom of the ore pass. Doglegs increase collisions of material, which reduce the impact velocity of the rocks. Control Protection chains slow down and limit material flow by absorbing the kinetic energy of the falling rocks. The chains can be made any length to fit the dimensions of the ore pass.

Strain-gage load cells are sensors that are mounted to surfaces and convert the load it senses from compression and tension into electrical signals to calculate the forces acting on the surface. This system can be mounted onto the gate to monitor the unevenly distributed forces. This is an effective method to predict potential failures due to heavy loading, which would improve the overall safety of the gate system [2].

Pressure sensors, which through a quartz crystal that senses a charge from pressure, force, and acceleration exerted on it can measure the pressure of water. These sensors can be mounted to the holes in the gate to measure the pressure of the water flowing through the gate [3]. Water drainage hazards can be prevented by maintaining drainage holes and lines, making sure the workplace is aware of the dangers of improper monitoring of water, and ensuring that pumping systems are functional and can remove excess water.

Operational tactics that can be used to prevent injury include lockout/tagout, personal protective equipment (PPE), electronic key sensors to regulate personnel in specified zones of the mine, and operation procedure manuals for employees performing given tasks. Lockout/tagout is a safety procedure whereby equipment or machinery is disabled to prevent hazards during inspection, which often requires putting a lock or tag on the equipment [4].

Mining Life Equipment and Mining Technologies International are two businesses that could provide communication systems that would greatly improve the efficiency, safety, and overall communication in a mine. Systems they could provide include the Mine Radio System Underground Communication and wireless locator devices. The Mine Radio System Underground Communication is a system that allows two-way data, voice, and video communication through wireless technology. Employees will carry a key card with a small Bluetooth device on their waste-belt that would be capable of transmitting the location of employees throughout the mine [5].

Section 1.3: Design Solution

In contrast to designs previously proposed, the final design solution is more practical, allowing for an in-depth quantitative analysis. The gate design is a hollow rectangular design with guide rails made from Titanium 6AL4V ELI. This titanium was chosen due to its strength and wide use in industry such as aerospace, automotive, chemical plants and many others. The gate is powered by hydraulic actuators a top of the gate (these actuators would be concealed by the ore-pass – seen in Figure 3. Also note that the power channel in Figure 1 is figurative and only recognizes that the system is powered externally.). The hollowness is an ideal shape for resisting bending moments and saving on material costs. Additionally, the hollow space is where strain-gage load cells and internal electronics would be housed as mention in Section 1.2: Background Information. The cells are a part of the gates monitoring system, which would help to identify over loading on the gate. A hatch and hole for wiring on the top are included for installation. The design also includes drainage holes that allow for water monitoring by measuring the flow and pressure – the location of the holes would need to vary to adjust to the allowable water capacity of different ore-passes. A draft view and rendering are shown in Figure 1 and Figure 2.

The failsafe for this design is self-contained, meaning no external mechanisms are needed. In the chance of a power outage, the power supply to the gate would cease, and the actuators would release their pressure allowing for the gate to close, stopping the flow of rock. If a material failure were to occur, the rock would puncture the gate allowing for rock to flow through it. The effects of this type of failure would include cost of replacing the door and any other equipment that gets damaged during the failure, and potentially the harm of workers. Consequences could include loss of revenue from production delays and legal setbacks. However, in the case of the material failure, the second control gate of the entire system would prevent rock from travelling into the mine shaft. Furthermore, with the monitoring systems mentioned previously in place, preventative measures can be taken to ensure material failure does not occur, making this functional failure unlikely and low risk.

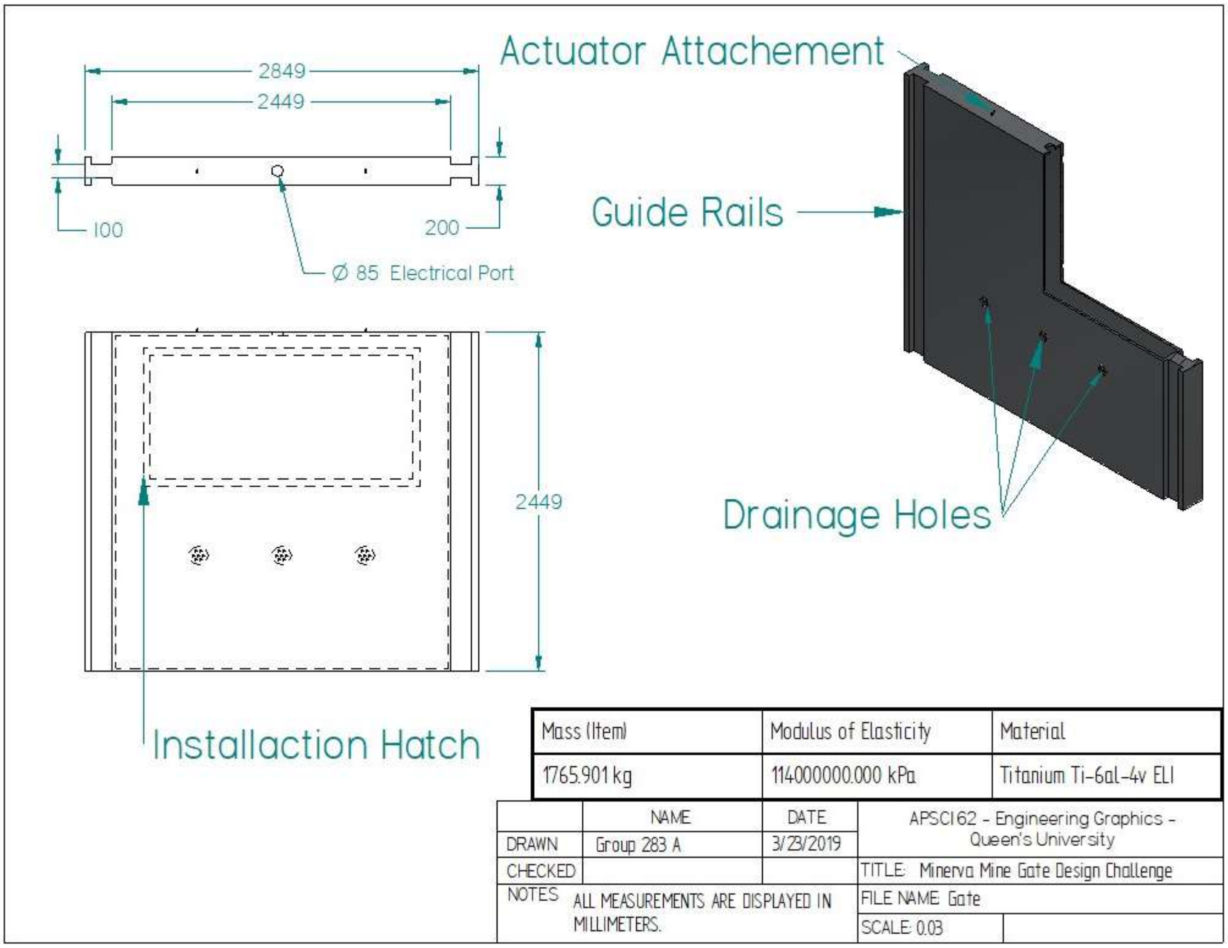


Figure 1 - Mine Control Gate Draft.

Figure 2 - Keyshot Rendering of Mine Gate.

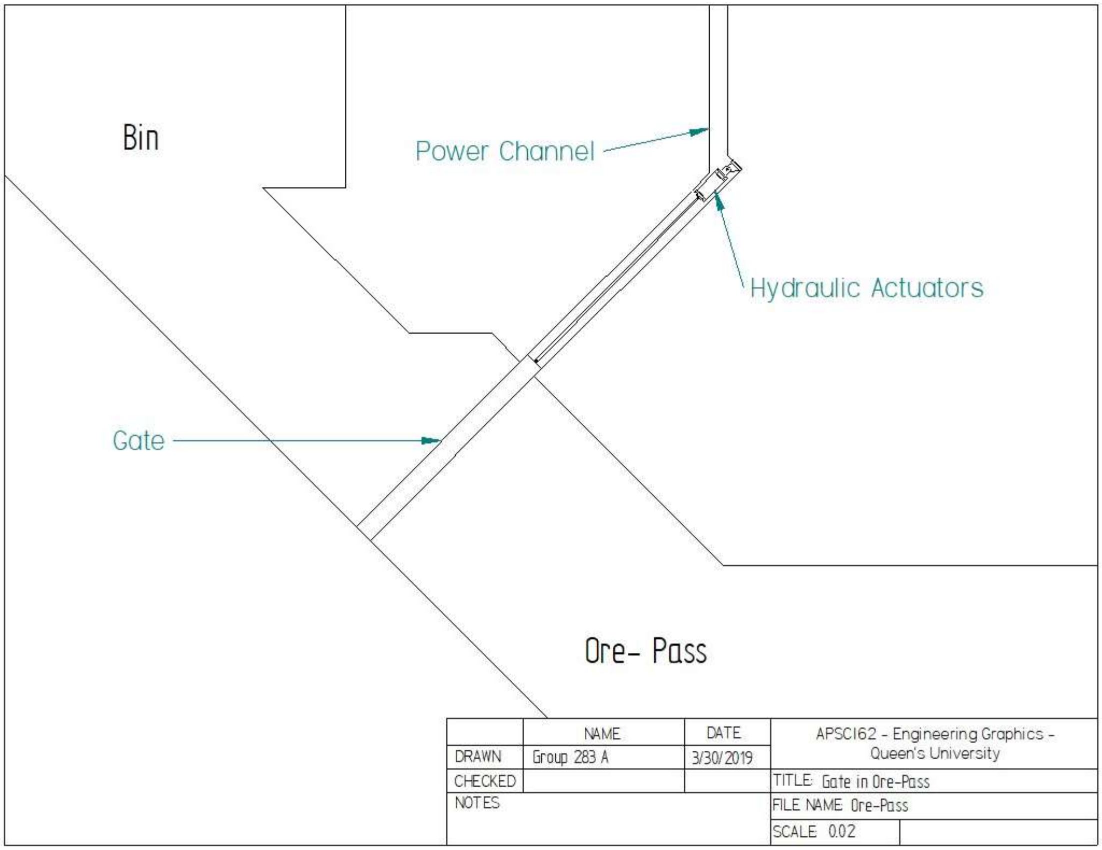


Figure 3 - Draft of Gate System in Ore-Pass.

To quantitatively analyze the new design, Solid Edge loading simulation was utilized to see how it would respond under 20 tons (US ton) of uniform loading, which was the same amount of pressure experienced at the Levack. The actual loading on the gate would be non-uniform as the rocks fall at different times and in different quantities. However, due to a lack of experience with the software, a uniform loading was assumed in the following data. Under these conditions, the data in Table 1 shows areas of maximum (3), minimum (2), and average (1) stress corresponding to Figure 4 in Maximum Principal Stress. Table 2 shows the physical properties of the material used for the gate which corresponds to two technical reports on the material [6] [7].

Table 1 - Critical Points of Stress on Gate.

		Deformation (mm):		
SNo.	Stress (MPa)	X (along top edge)	Y (into gate)	Z (along side edge)
1	58.1	1.22E+03	-1.00E+02	-1.22E+03
2	0.673	1.29E+03	-1.00E+02	-487
3	82.4	1.22E+03	-1.00E+02	323

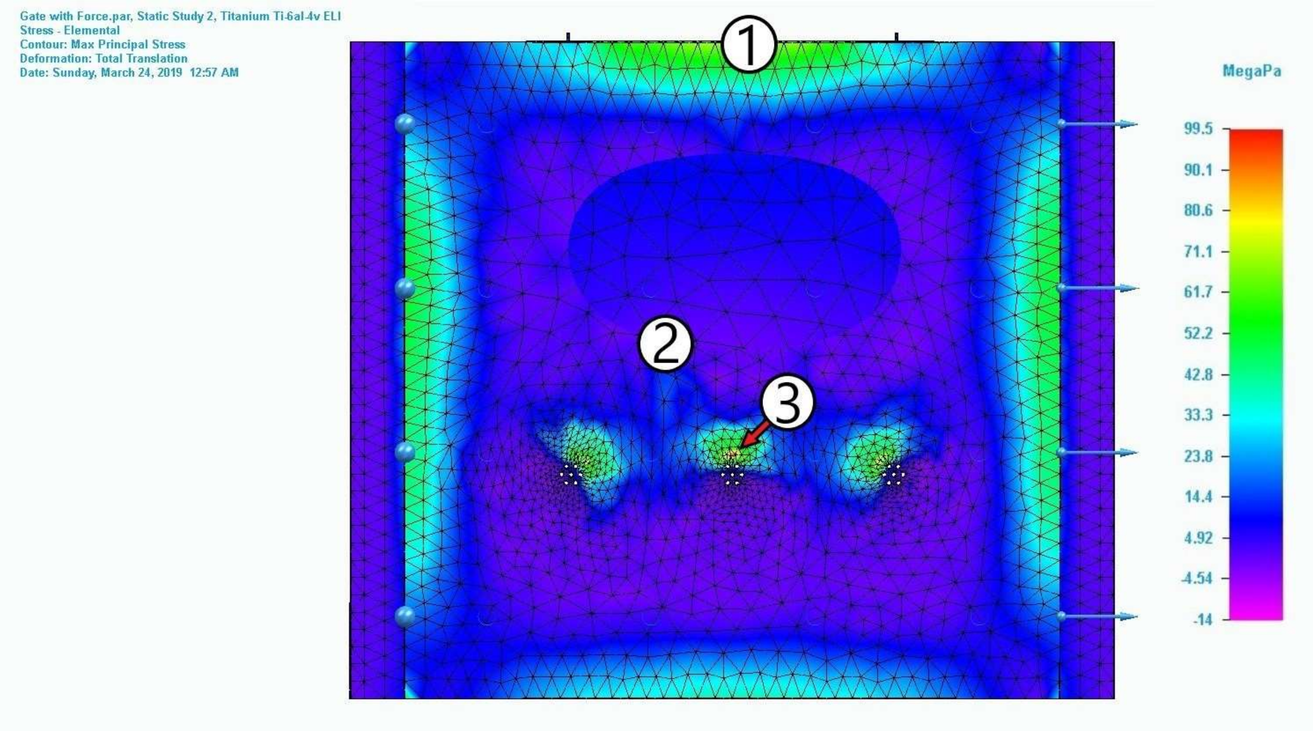


Figure 4 - Solid Edge Simulation for Maximum Principal Stress under 30KPa.

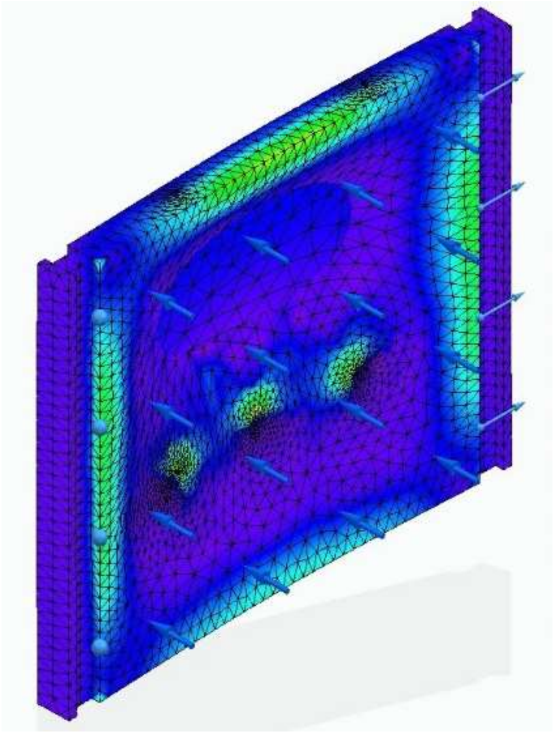


Figure 5 - Figure 3 Alternate View.

Table 2 - Material Properties of Ti6A4V ELI.

Density	4420.000 kg/m^3
Coef. of Thermal Exp.	0.0000 /C
Thermal Conductivity	0.007 kW/m-C
Specific Heat	580.000 J/kg-C
Modulus of Elasticity	114000.000 MegaPa
Poisson's Ratio	3.10E-01
Yield Stress	795.000 MegaPa
Ultimate Stress	860.000 MegaPa
Elongation %	1.00E+01

Deliverable for the client will include all Solid Edge and Excel files used to record and analyze the final design solution, as well as any calculations and the final phase report. The report includes the design procedure, quantitative and qualitative analysis of the design, financial analysis and analysis on the mining safety and management systems. The next steps for the client should be to consider and analyze the design and the material presented to them in this report and consult other professionals on its feasibility and value to an actual mining system. If material from this project is implement or utilized, notification of its use to the authors of this report would be greatly appreciated.

Section 1.4: Conclusions

The final design has been remodeled from previous reports. The final design consists of a hollow rectangle with guide rails that are powered by hydraulic actuators on top of the gate to allow it to open and close. The gate's hollow space allows for reduction in bending moments, material costs, and space for strain-gage load cells. The maximum stress the gate would under-go would be 94.5 MPa located at the center of the gate and an average stress 58 MPa. The new gate is much simpler and thus has a higher ease of repair and a lower cost for parts and overall construction. The new gate is also more fail-safe as in the case of failure, the gate will remain closed and the ore will not be able to fall through the pass.

Some recommended improvements or areas where the design process could be continued include designing a way that rocks will not prevent the gate from closing, possible reinforcement where the gate undergoes the most pressure, and the location of the drainage holes. The first recommendation is due to the gate coming down from above and thus while closing, it is very likely that rocks and boulders could be hung up under the gate and would prevent it to completely and securely close off the ore pass. The second recommendation is due to the three locations where the gate undergoes the significantly higher pressure. Reinforcing these areas within the gate would simply ensure that a failure in the gate does not occur over time in these specific areas that will succumb to wear due to high stress. Finally, on this design, the drainage holes are in and around the center of the gate. Therefore, the water would not be able to be drained until it has accumulated high enough to reach the drainage holes. There are two possible solutions to this problem. Firstly, as stated above, the location of these holes could be moved in correlation with the specific water capacity of the ore pass. Secondly, the holes could remain in the same location as the design, but additional holes could be added to the design at the level of the water capacity of the ore. The disadvantage to this solution is that it reduces the strength of the gate. However, it would allow faster drainage if the volume of water increased significantly.

Part 2: Technical Information

Section 2.1: Conceptual Design Solutions

The three preliminary designs for mine gates include the Undercut-Arcing gate (Figure 6), pinching gate (Figure 7) and drill gate (Figure 8 and Figure 9). These designs must meet certain quantitative and qualitative criteria as set by the client. Each gate system must be able to withstand 20 tons of rock, have failsafe mechanisms to prevent failure, refrain from using pneumatic-actuators, effectively drain water and remain within a $1M budget. Each design includes a preceding dogleg and protective chain guards to reduce dynamic loading.

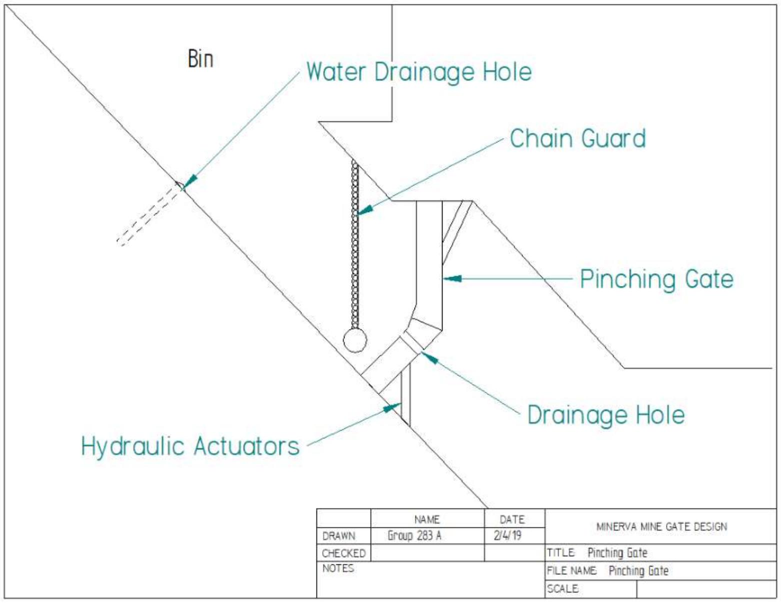


Figure 6 - Pinching Gate.

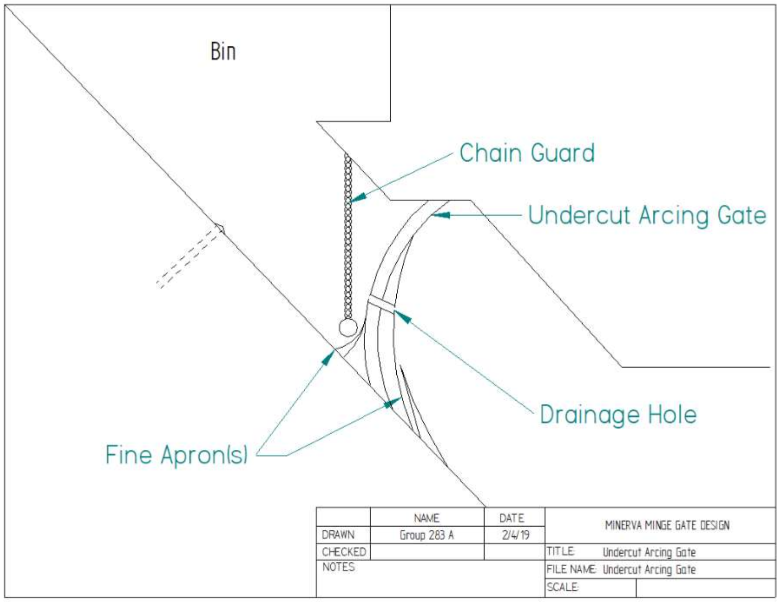


Figure 7 - Undercut-Arcing Gate.

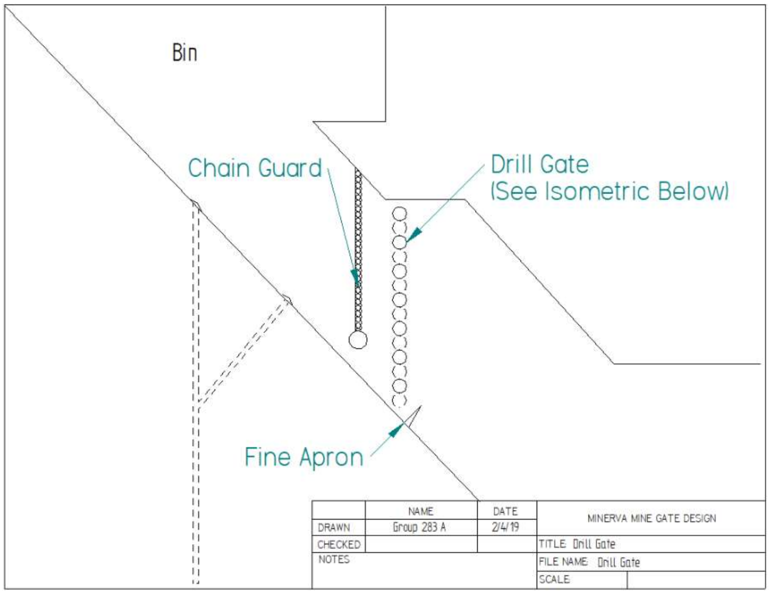


Figure 8 - Drill Gate.

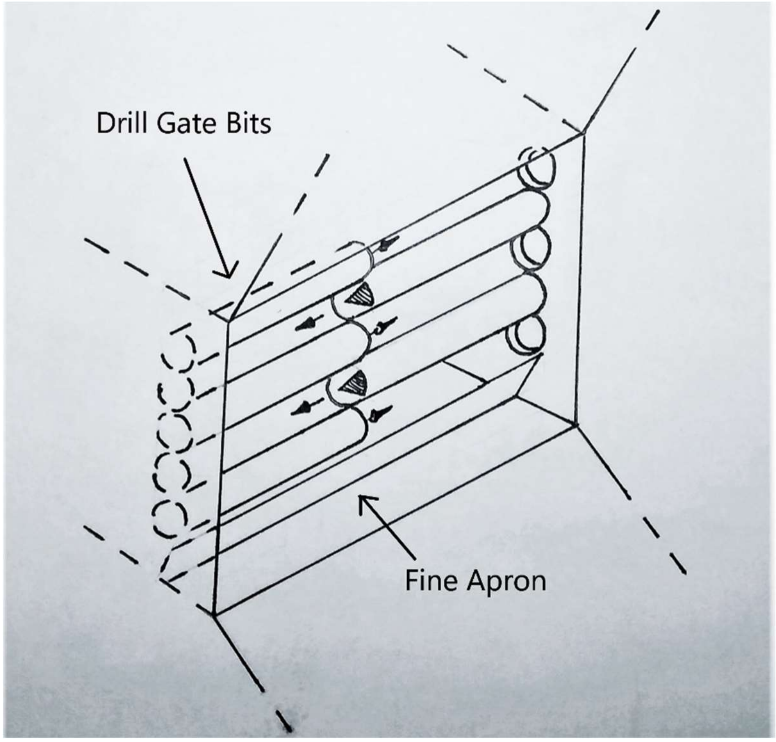


Figure 9 - Simplified isometric view of drill gate.

Table 3 summarizes some obvious advantages and disadvantages of each design which were used in considering the final design.

Table 3 - Design Summary Chart.

Designs	**Main Feature**	**Advantages**	**Disadvantages and Failure Modes**
Undercut	Arced gate that distributes load like an arched bridge or door.	• Simple, • Fine aprons to mitigate seizing.	• Rocks could block the gate from closing which allowing rock flow, • Path of motion requires extra room that would interfere with surrounding systems (failsafe), • Cannot be practically powered with hydraulic actuators due to path.
Pinching	Two doors that act as a gate when pinching together.	• Simple, • Crushes rock wedged between doors.	• Excess rock could block gate, • Requires two doors which would require more actuators and power creating a higher risk of failure due to number of components. • The ability to crush rock is
Drill	Multiple inter-locking drill bits that clear rock when closing.	• Removes rock when closing, • Effective water drainage, • Original.	• Complex, • Potentially fragile to loading since the door is made of many smaller components, • Would be expensive to implement and would require additional space to power the drill bits.

Three failsafe designs which can be incorporated with any of the designs include a sub-bin (Figure 10), slide-extension (Figure 11), or an external guillotine-stopper gate (Figure 12). The sub-bin design works to redirect rock to a new bin, and thus a gate, which would lessen the load on the failing gate. This design would require three gates – main gate, drop hatch, and sub gate – which would be costly. Due to the sub-bin opening being located before the control gate, the drop-hatch would need to have a monitoring system capable of detecting when loads are excessive and activate prior to failure. The slide-extension works in a way that rock flow is redirected over the mine shaft once the gate has failed. For this design, an alternate exit would be in place for workers at the bottom of the shaft to escape. The guillotine-stopper gate activates upon control gate failure, sliding down and acting as a second barrier. Failure could occur in the chance of a slow response time, which would allow for rock to block or pass the door. For all failsafe designs, the direction of water drainage pipes would need to be altered to ensure synchrony between the two sub-systems.

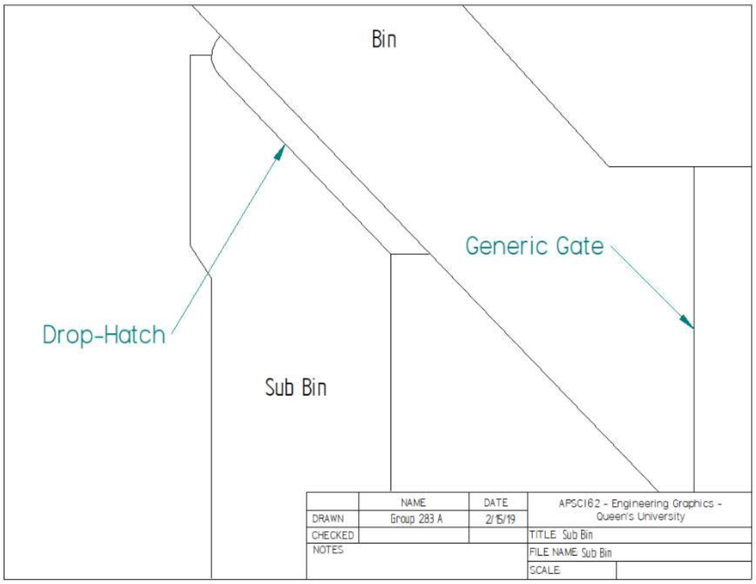


Figure 10 - Sub-Bin Failsafe Design.

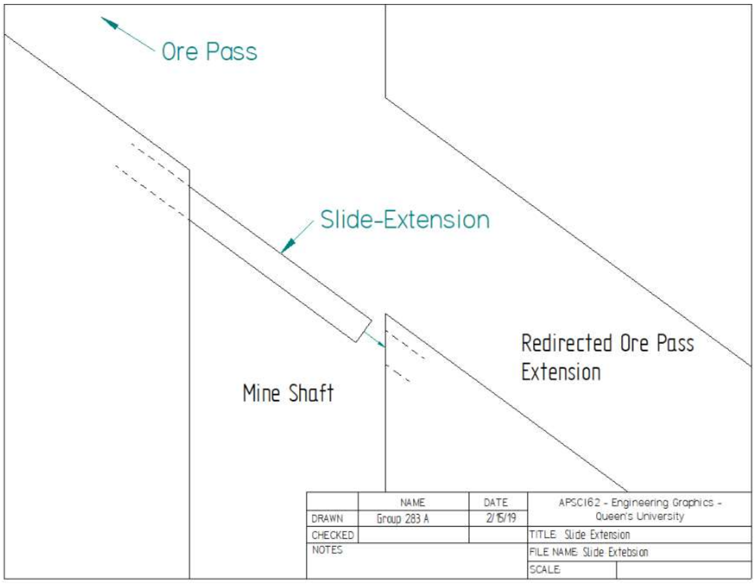


Figure 11 - Slide-Extension failsafe design.

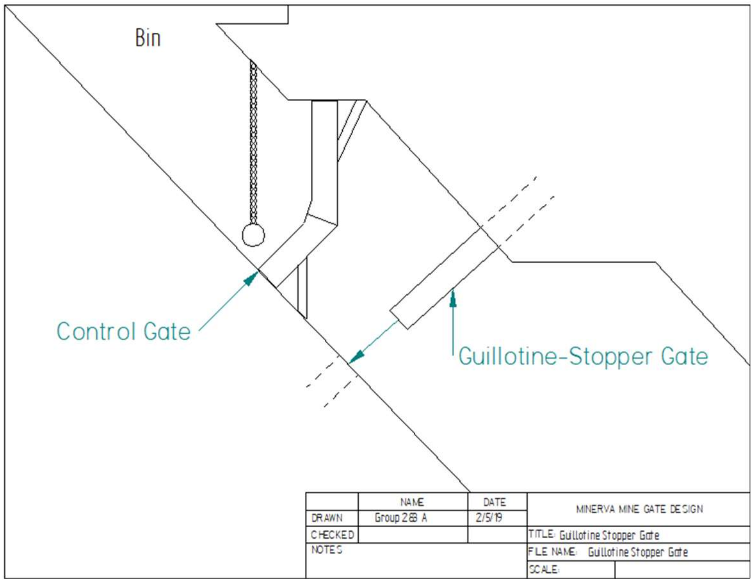


Figure 12 - Generic Control Gate with Guillotine-Stopper Failsafe Gate.

Section 2.2: Decision Making

The evaluation matrix included below assesses the three designs based on the client's needs and other functional criteria. The matrix uses a weighting factor with a maximum being 5/5.

Table 4 - Evaluation Matrix for Gate Designs.

Criteria	Weighting Factor	Undercut	Pinching	Drill	Design Solution
Functional Practicality	4	4	4	2	4
Ease of Repair	5	3	4	2	4
Ease of Operation	3	5	5	5	5
Resistivity Dynamic Load	3	5	5	5	5
Resistivity Static Load	5	5	4	4	5
Water Drainage	5	4	4	5	4
Expected Cost	4	4	4	1	5
Total:		146	138	129	151

Ease of repair was weighted to be a 5 as a gate that is not functioning properly may jeopardize the safety of workers. The gate must be capable of being repaired quickly and safely. Resistivity to static load was also weighted as a 5 since its safety is the main function of the design. Similarly, water drainage was weighted as a 5 as water is one of the key factors in many failures and deaths caused in mines, such as the Levack incident. The functional practicality and expected cost of the design were weighted as a 4. Although they are important, they are a secondary function of the project design. Ease of operation as well as resistivity to dynamic loading were weighted 3 since they are beneficial to the overall design but are not a primary concern linked to the safety of the workers with respect to the other criteria.

The undercut, pinching and design solution gates are both simple and practical designs. The designs were adopted from mine cut designs. This means these designs have had enough research and applications to prove their effectiveness. In contrast, the drill gate is a new, very complex system with minimal research completed on it. There could be hidden problems with the gate that could be difficult to predict and costly to fix.

All gates scored perfect for their resistivity to dynamic load since they all include preceding doglegs and chain guards. While all gates can withstand the specified 20 tons of static load due to their sturdy structure. The design solution gate is favored as it has less components compared to the Pinching Gate, which would be subject to stress at the seam of the doors. The Undercut-Arcing gate is also favored due to its ability to distribute force evenly in the same way the arched bridge or doorway works.

Even though all gates feature a similar pipe-based water drainage system around the gate, the drill gate scored higher as extra water can be drained through the gaps in the drill pieces. Cost analyses on gates like the undercut and pinching gates show that these designs should be able to meet the $1M budget. Conversely, the complexity and the uncertainty of the drill gate design give an error of uncertainty that requires analysis beyond the scope of this project.

Section 2.3: Implementation

Quantitative Analysis

The first step the group took after Phase 3 was to find determine the angle of inclination of the chute. This information was not given, however, from research it was determined that a 45° angle is enough to allow smooth rock flow and to not cause regular hang-ups. This was also the smallest angle in the 45-90° range and it was chosen because a smaller angle would result in a smaller component force of gravity.

The load distribution then needed to be determined. After consulting with a professor, it was determined that it is reasonable to model the static material as if it were water. Water always remains level. Thus, the angle between the water line and the incline will be the same as the angle of incline - 45°. Since the load is proportional to the amount of material, the largest load is along the bottom of the incline and the smallest is along the top. This load, being proportional to the amount of material, also takes the shape of a trapezoid.

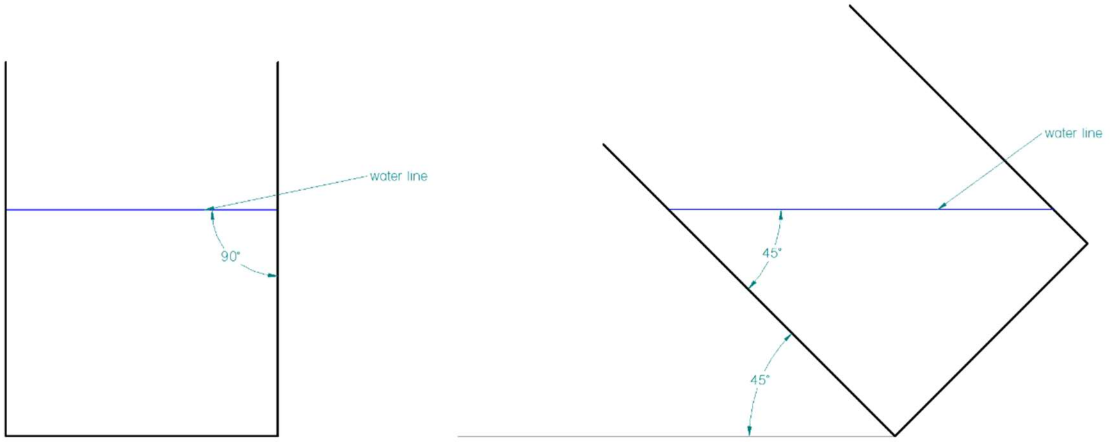


Figure 13 - Diagram Showing how Water Remains Level.

Originally, our solution was an arched gate. To find the shape of this gate, the load was placed on a cable. A cable under load takes the ideal shape to withstand the applied force. Under the trapezoidal load, the cable looks like Figure 14. Thus, the optimal shape of the gate would be the shape of the cable under the trapezoidal load. However, this shape contradicted our gate-lifting mechanism. After proposing different mechanisms to allow material flow from the gate, it became clear that the better solution would be to change the shape of our gate.

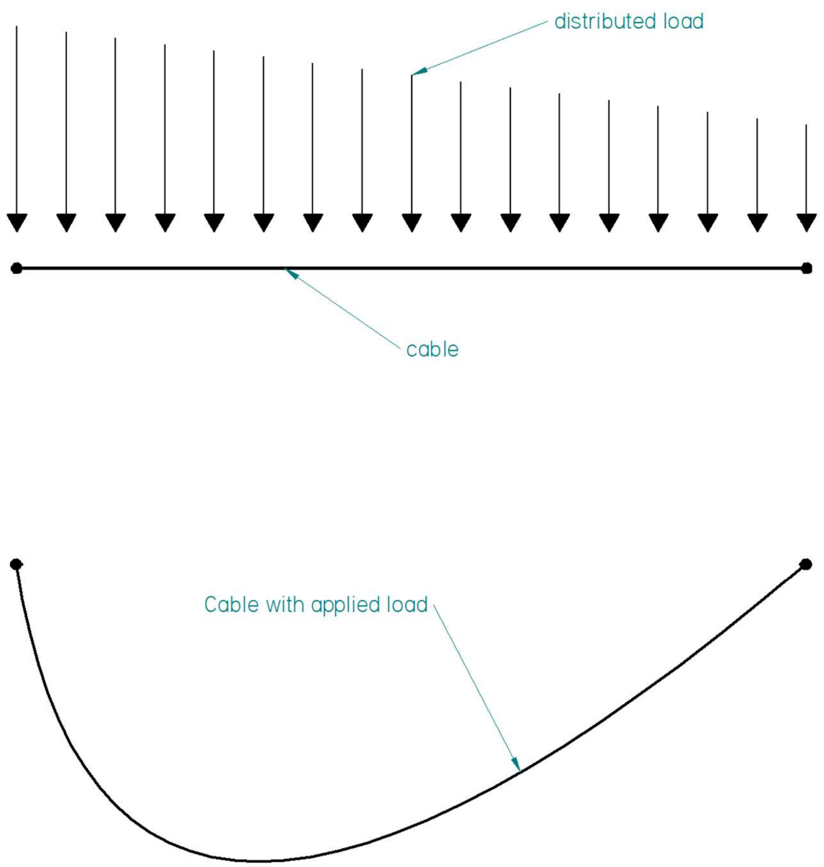


Figure 14 - Diagram which Demonstrates the Ideal Shape of the Gate by the Effects of a Distributed Load on a Cable.

When considering how pressure calculations were going to be made for the gate, the original arched gate lead to simple calculations as the gate would be only under compression. Since we could not use this design, other arched gates were considered. However, any arched gate other than the ideal case in Figure 14, led to calculations that our current course materials and the project scope do not cover. Thus, a straight gate was chosen. Although this is not the optimal solution to reduce stress, it does allow for more realistic quantitative analysis.

To find an equation for the pressure on the gate, the static load was treated as water. This allows for a reasonably conservative calculation using methods which are in within our limits. Water is less dense then the static load which accounts for the cohesion factor of the rock which would have been included in the equations if no approximation was made. 25 tons of water was used to make the calculation since it was indicated that approximately 20 tons of material caused the Levack failure. A perfectly linear distributed load was assumed. It was also assumed that the material completely fills the ore pass. In a real situation, due to the different shapes of material there would be gaps between rocks which would change our calculations. Assuming the that all the space in the ore pass is filled will counter the effect of the additional height gained due to the gaps. Due to the addition of dog legs and control chains in the design, the forces due to dynamic loads were not considered as it was assumed that they would be much less than a large static load.

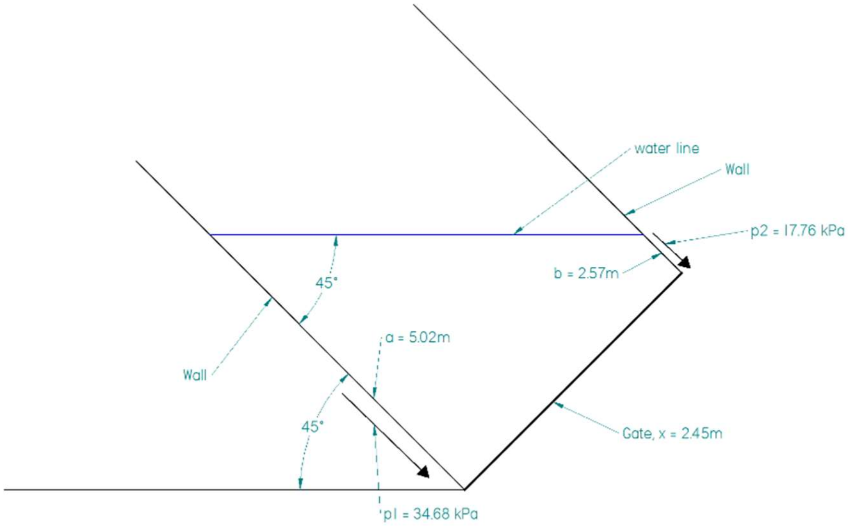


Figure 15 - Diagram Demonstrating the Pressures at the Top and Bottom of the Gate.

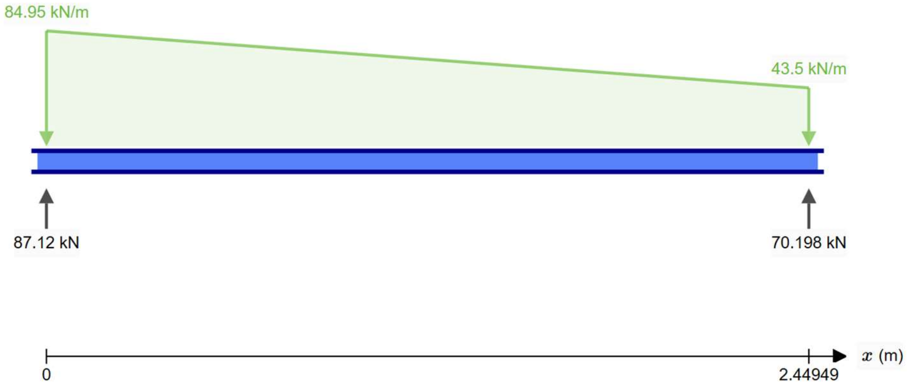


Figure 16 - Force Diagram which Shows the Required Reaction Forces at the Top and Bottom of the Gate.

The pressures at each end of the gate were converted to distributed loads as shown in Figure 16 - Force Diagram which Shows the Required Reaction Forces at the Top and Bottom of the Gate.Figure 16. From these distributed loads a shear force diagram and a bending moment diagram can be made as seen in Figure 17. From the bending moment diagram the maximum bending moment can be used to calculate the tensile and compressive stresses on the gate.

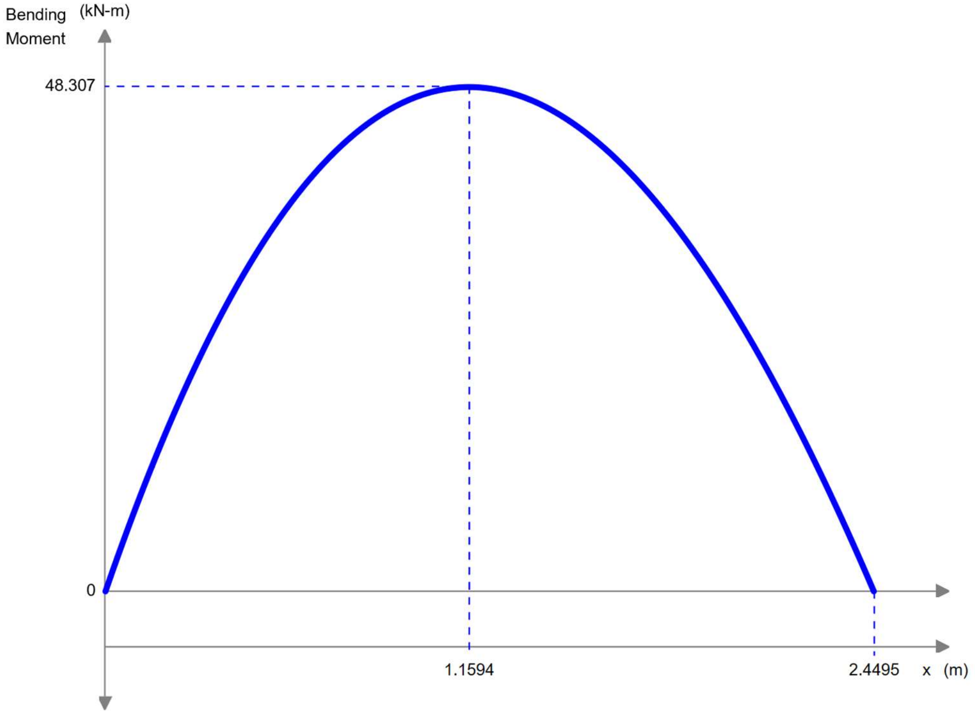


Figure 17 - Bending Moment Diagram with the Maximum Bending Moment of 48.307 kNm at a Height of 1.1594m.

To find an appropriate thickness for the gate, a thickness was chosen, and the tensile stress was calculated at that thickness and compared to the yield tensile strength of titanium, which is 430MPa. This calculation is shown in Equation 7, a gate thickness of 0.2m was chosen and a hollow cross-section of 0.16m was selected. The cross section of the gate was made hollow to save costs. With a large inner hollow rectangle, the stress on the gate is significantly smaller than the yield strength at 5.96MPa. After consulting professors, the dimensions for the gate in Equation 10 were determined to be reasonable. With a stress this low, it would be advisable to use a different material as the strength of titanium is too high for the situation.

To solve for maximum load on the beam we will work backwards from the bending moment. The maximum tensile strength of titanium is 430MPa. From Equation 10 the maximum bending moment is 3486kNm. To find the maximum force we need to find a relationship for the force diagram which was determined to be Equation 11. Using Equation 11, Equation 13 and Equation 14 can be created since they are respectively, the negative integral and negative double integral of Equation 11.

Qualitative Analysis

A survey was sent out to Mining and Mechanical Faculty members at Queen’s University in order to receive professional feedback on the undercut arcing gate. However, the team did not receive any responses in time. With this experienced and professional feedback, the team would have been able to further evaluate and implement the design. The following were the questions that the Faculty members were provided with as well as a picture depicting the undercut arcing gate.

- From your experience, is the method of operation of this control gate clear from the design? Why or why not?

- What features would you add to this design?
- Does the design look original?
- Is the design feasible in its operation and maintenance?
- Briefly describe any potential failures that could result from this specific design.
- Is the material chosen reasonable for the operation of the gate?

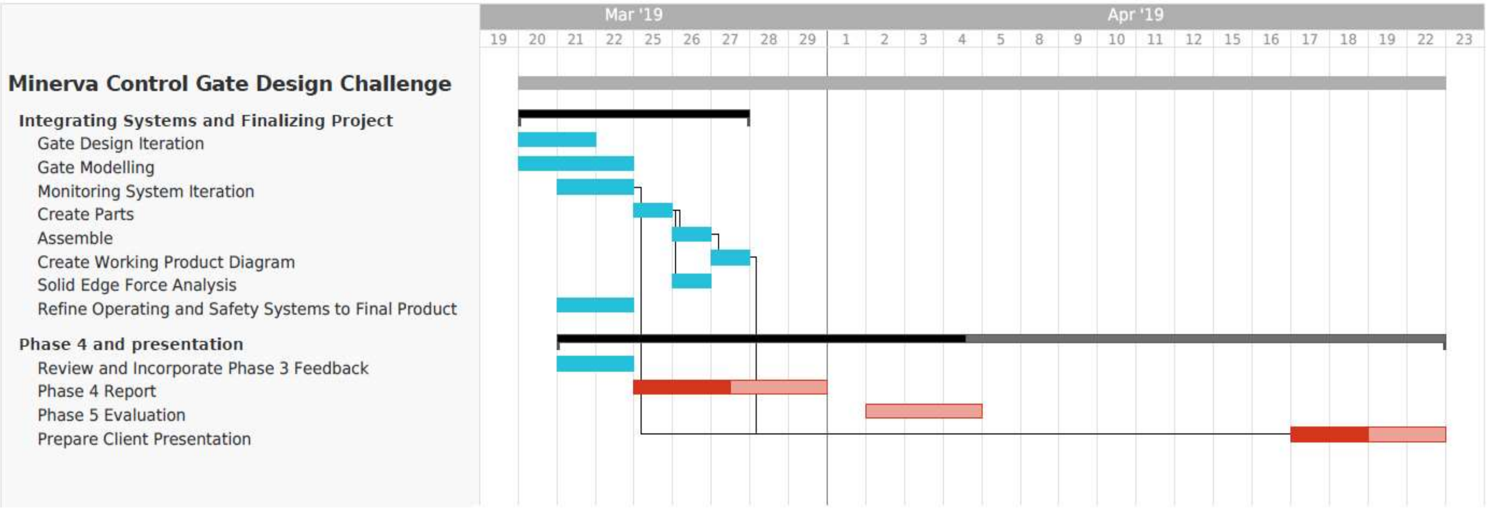
Section 2.4: Project Plan

Key changes of this project timeline include the addition of iteration phases and the amount of time needed to complete each task. This includes revisiting the design, consulting professionals about our design and then redesigning the gate to meet functional requirements. This can be seen in Table 5, where the darkened rows and cells are additional task or time changes. All changes in time have decreased. In order meet project deadline, tasks were previously given more time than anticipated to compensate for uncertainties, such as the amount of time needed to model forces in Solid Edge.

Table 5 - WBS for weeks 7-12.

Task Identifier	Task Description	Expected Duration (Work Days)	Active Leader
1	Gate Design Iteration	2	Pierce, Matt
2	Modelling of Gate	3	Pierce
3	Monitoring System Iteration	2	Cristiano
4.2	Create Parts	1	Matt, Luke, Pierce, Cristiano
4.3	Assemble	3	Matt, Luke, Pierce, Cristiano
4.1	Solid Edge Force Analysis	1	Pierce
4.4	Create Working Product Diagram	1	Matt
5	Refine Operating and Safety System to Final Product	2	Max
6	Review and Incorporate Feedback into Phase 4	2	All
7	Phase 4 Report	5	All
8	Phase 5 Report	3	Individual
9	Prepare Client Presentation	4	All

Table 6 - Gannt chart for Weeks 7-12 of Project.



Reflecting on the original planning, this project could have been planned better through the revision of task deadlines. Prompt deadlines allow for steady progression of a project time line. Even if deadlines are not met, their faults can be analyzed to help future iterative processes. For analysis and iteration, the project timeline could have been reduced if mistakes in our preliminary designs were identified sooner. For example, many of the preliminary design were completely original, but not very feasible. Going to a professional early on, such as a Civil Engineering Professor, to analysis and make suggestions on each design would have quickened the project timeline. With the extra time, more thought could have been put into the selection and optimization of material. Titanium was chosen due to its strength, which at the time seemed applicable to the loading it would receive in an ore-pass. Nonetheless, further optimization would have allowed for a more justifiable choice which would carefully consider cost and practicality.

Section 2.5: Financial Analysis

The chosen material for the gate is titanium which has a high density and strength making it suitable for loads expected in an ore pass. Although there are different grades of titanium, it has a typical density of 4.506 g/cm^3. An example is Ti-6Al-4V ELI, which is a popular choice of titanium in industries like aerospace for its strength and durability [6]. This design would need following components:

Table 7 - Cost Analysis Spreadsheet.

Component:	**Amount:**	**Material Mass (if applicable) [Kg]:**	**Total Cost (CA$):**
Titanium Gate	1	1765.901	131,575.00
Chain Guard (1")	20 (ft)	208	30,320.00
8' Hydraulic Actuators	2	N/A	1,632.00

Fine Aprons	2	N/A	2,306.40
Strain-Gage Load Cell	2	N/A	3,070.00
Pressure Sensors	3	N/A	90.00
Total Cost (Not including installation)			**168,993.40**

2.8m^2 chain guards for dynamic loading, 0.5m thick titanium gate, two 8’ hydraulic actuators, two fine aprons spanning 2.8m by 1m, two strain-gage load cells, and three pressure sensors will be needed. The total cost of this is expected to be $168,993.40 (CAD). After finding minimal information on the installation cost, based off the fact that the gate and all the electricals must be installed, it is roughly estimated that it will cost between $100,000.00-$200,000.00 (CAD) [7].

Section 2.6: Safety, Inspection and Training

Surrounding the Levack incident, there were legal issues involved with the death of the four inspection workers which included who to blame. Ultimately, the service man was charged. However, the cause of the incident was ultimately the fault of management due to their complacency with regards to following the standards of a system that was known to be faulty by the employees. To prevent future incidents such as the one at Levack, changes to inspection, procedures, and work permit control system enhancements must be made.

Procedural Changes

The Levack mine's five-star system for evaluating safety was unreliable, and a lack of communication between mine operators and mine inspectors was a contributor to the fatal incident. The Levack mine should implement improved safety procedures to keep employees safe. A recommended strategy to reduce worker fatigue would be system-imposed routines that allow for consistent shift working hours and for 8 hours of sleep every 24 hours. Compared to when the Levack mine was running, technologies are now available that allow for all employees to be contactable and capable of communicating to anyone throughout the mine. These systems are highly recommended by the Management Resource Solutions company and allow access to high quality communication. The IRS (Internal Responsibility System) is a system that commands every employee to have a responsibility for their own health and safety and that of their job. They must follow a code that keeps a mindset of preventing accidents and illnesses. To maintain a safe workspace, the Mining Association of Canada’s AAA Level Rating, an internal or external audit (including communication and managerial systems) must be completed every 3 years.

Work Permit Control System Enhancements and Inspection

Along with an effective Safety Management System (SMS), technologies and tools can be implemented to improve inspection through permits that regulate service work and inspection. To implement working permits, the electronics mentioned in Section 1.2: Background Information could be paired with employees to ensure the employees are only operating in permitted areas at permitted times and thus acting like a failsafe for employees. For this to work, check points or stations would need to be installed at different entrances in the mine. For example, if a serviceman wanted to lubricate the control system, he would need to tap an electronic key fob or card that permits him to operate in that area. He would also be given a procedural safety sheet that would also be verified by the same system using a different fob, and if there were not any inconsistencies (e.g. an inspection crew is currently operating in a surrounding area and could be at risk), he would then be allowed to continue. If any of these requirements failed, the employee would be denied access to said area or would need to wait until the inspection crew tapped out of the area. To ensure permits are being upheld, a control system and database containing all operations performed and permits given out should be in place for record keeping. In the case of a permit update, management could update the system quickly, and confirm that employees are complying to the update with the help of the electronic failsafe system.

Section 2.7: Evaluation

Overall, the team reached the client's needs while remaining within the quantifiable restrictions outlined. The final gate design is capable of withstanding 20 tons of rock based on the Solid Edge force distribution simulation that proved that the design could withstand the pressure on the gate due to the maximum weight. Based on the financial analysis, the gate will cost approximately $170,000.00 without the cost of installation. The cost of the gate is significantly less than the $1M budget the client gave. Furthermore, the gate is completely automated and includes a water drainage system to reduce the added weight water would create on the gate. This drainage system meets the client's needs as it is present. However, it will only drain water once it has accumulated enough to reach the height of the system – either the drainage holes in the door or drainage pipes throughout the ore-pass. Finally, the last client need was that there would be enough failsafe mechanisms to prevent incidents and fatalities due to gate failure. The designed gate will use the force of gravity as its first failsafe tactic. Being actuated from the top, this feature would allow the gate to close under the force of gravity if there was mechanism or power failure. The final way the design was evaluated was by using a survey that was sent to Queen's University Mining Faculty. The survey included a depiction of the design followed by 6 questions that would provide professional feedback and suggestions for improvement that would help guide the team to expert implementation to provide a better design for the client. In conclusion, the new design of the gate saves the client money, is capable of withstanding more than 20 tons of rock and meets the client's needs. The gate is an effective, safe, and reasonably priced design that can complete all its required functions.

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Appendix I: Equations and Calculations

Loading calculations for Figure 16:

Equation 1 - Bending Stress. Equation 2 - Density.

$$\rho = \frac{m}{v}$$

$$V = \frac{22679.6kg}{\frac{997kg}{m^3}}$$

$$V = 22.75m^3$$

$$V = AL$$

$$A = \frac{22.75m^3}{\sqrt{6}m}$$

$$A = 9.29m^2$$

Equation 3 - Area of Trapezoid.

$$A = \frac{(a+b)(x)}{2}$$

$$9.29m^2 * \frac{2}{\sqrt{6}m} = 2b + \sqrt{6}\,m$$

$$b = 2.57m$$

$$a = 5.02m$$

Equation 4 - Equation for Pressure.

$$p = \frac{\sigma}{A}$$

$$p1 = \frac{997kg}{m^3} * \frac{5.02m}{\sqrt{2}} * \frac{9.8m}{s^2}$$

$$p1 = 34.68kpa$$

$$\frac{F1}{m} = \frac{84.95kN}{m}$$

$$p2 = \frac{997kg}{m^3} * \frac{2.57m}{\sqrt{2}} * \frac{9.8m}{s^2}$$

$$p2 = 17.76kpa$$

$$\frac{F2}{m} = \frac{43.5kN}{m}$$

Where ρ is density, V is volume, A is cross sectional area, b is the length of the top side length and a is the length of the top side, b is the bottom side length, p1 is bottom pressure, p2 is top pressure, F1 is the loading along the bottom edge, and F2 is the loading along the top edge – all units expressed as per calculations (et. Al).

Tensile Stress Calculations:

Equation 5 - Bending Stress.

$$\sigma = \frac{My}{I}$$

$$I\ for\ hollow\ cross\ section = Iouter - Iinner$$

Equation 6 - Moment of Inertia of Beams.

$$I = \frac{bh^3}{12} - \frac{bh^3}{12}$$

Equation 7 - Calculation for the tensile and compressive stresses on the top and bottom of the beam.

$$\sigma = \frac{48.307kNm * 10^6 * 0.1m * 10^3}{\frac{\sqrt{6}m * 10^3 * (0.2m * 10^3)^3}{12} - \frac{2.409m * 10^3 * (0.16m * 10^3)^3}{12}}$$

$$= 5.96MPa$$

Where σ is bending stress, I is moment of inertia, M is bending moment at location of interest, and y is distance from neutral axis.

Equation 8 - Bending Stress.

$$\sigma = \frac{My}{I}$$

$$I\ for\ hollow\ cross\ section = Iouter - Iinner$$

Equation 9 - Moment of Inertia of Beams.

$$I = \frac{bh^3}{12} - \frac{bh^3}{12}$$

$$= \frac{48.307kNm * 10^6 * 0.1m * 10^3}{\frac{\sqrt{6}m * 10^3 * (0.2m * 10^3)^3}{12} - \frac{2.409m * 10^3 * (0.16m * 10^3)^3}{12}}$$

$$= 5.96MPa$$

Where σ is bending stress, I is moment of inertia, M is bending moment at location of interest, and y is distance from neutral axis.

Maximum Loading Calculations:

$$M = 430MPa * \frac{I}{y}$$

$$M = 3486kNm$$

Where M is bending moment at location of interest, I is moment of inertia and y is distance from neutral axis.

Non-Uniformly Distributed Loading Calculations:

Equation 10 - Maximum bending moment calculation.

$$M = 430MPa * \frac{I}{y}$$

$$M = 3486kNm$$

Where M is bending moment at location of interest, I is moment of inertia and y is distance from

The difference between the heights of the side lengths of the trapezoid is (2.45)sin(45°). Thus,

$$\frac{f1}{m} - \frac{f2}{m} = 997 * 2.45sin45 * 9.8 * (6^{\frac{1}{2}})$$

An equation for this relationship is needed. Thus, the slope can be considered(m) as,

$$slope = 997 * 2.45sin45 * 9.8 * \frac{6^{\frac{1}{2}}}{6^{\frac{1}{2}}}$$

$$slope = \frac{16.9kN}{m}$$

This allows for the use of a linear equation,

$$y = mx + b$$

Equation 11 - Relationship Between the Magnitude of the Distributed Load and the Position Along the Gate.

$$y = -16.9x + b$$

Where y is distributed load of the smaller side of the trapezoid, b is the distributed load of the larger side and x is the distance along the length of the gate.

Taking the negative integral of this function, a function for shear force is determined,

$$f(x) = -\int (-16.9x + b)\, dx$$

$$= 8.46x^2 - bx + c$$

Where c is a constant and f(x) is the shear force at a distance along the gate. This constant c will be the leftmost reaction force.

To find this force, there must be consider for a general situation, where b is the left most distributed load. From the relationship between the heights of the top and bottom of the gate, it is concluded that:

Equation 12 - Relationship Between Top and Bottom Distributed Loads.

$$y = b - 41.4$$

Taking the moments about y:

$$0 = -c\left(6^{\frac{1}{2}}\right) + (b\left(\frac{2}{3}\right) * 6(^{\frac{1}{2}})) + (\frac{(b-41.4)}{2} * (6^{\frac{1}{2}}))$$

$$c = 1.22b - 16.9$$

$$f(x) = 8.46x^2 - bx + 1.22b - 16.9$$

The maximum bending moment occurs at f(x)= 0. Thus, the first equation is,

Equation 13 - Equation Using the Location of the Maximum Bending Moment on the Shear Force Diagram.

$$0 = 8.46x^2 - bx + 1.22b - 16.9$$

The bending moment is the integral of shear force. Thus,

$$M(x) = \int 8.46x^2 - bx + 1.22b - 16.9$$

$$= 2.82x^3 - \frac{b}{2}x^2 + 1.22bx - 16.9x + c$$

This determines that M(0)=0, implying that c=0.

Using the previously calculated maximum bending moment, the second equation is,

Equation 14 - Equation for the Maximum Bending Moment.

$$3486 = 2.82x^3 - \frac{b}{2}x^2 + 1.22bx - 16.9x$$

Using MATLAB to solve these equations,

$$b = \frac{4705kN}{m}$$

Thus, y can be determined using Equation 12,

$$y = \frac{4663.6kN}{m}$$

Determining maximum amount of material:

From Equation 4,

$$\frac{\frac{1921000N}{m^2}}{\frac{997kg}{m^3}*\frac{9.8m}{s^2}}*\left(2^{\frac{1}{2}}\right)=a$$

$$278\text{m}=a$$

$$\frac{\frac{1904000N}{m^2}}{\frac{997kg}{m^3}*\frac{9.8m}{s^2}}*\left(2^{\frac{1}{2}}\right)=b$$

$$b=276m$$

$$V=\frac{(a+b)x^2}{2}$$

$$V=1662m^3$$

$$m=\ \rho V$$

$$m=1657014kg$$

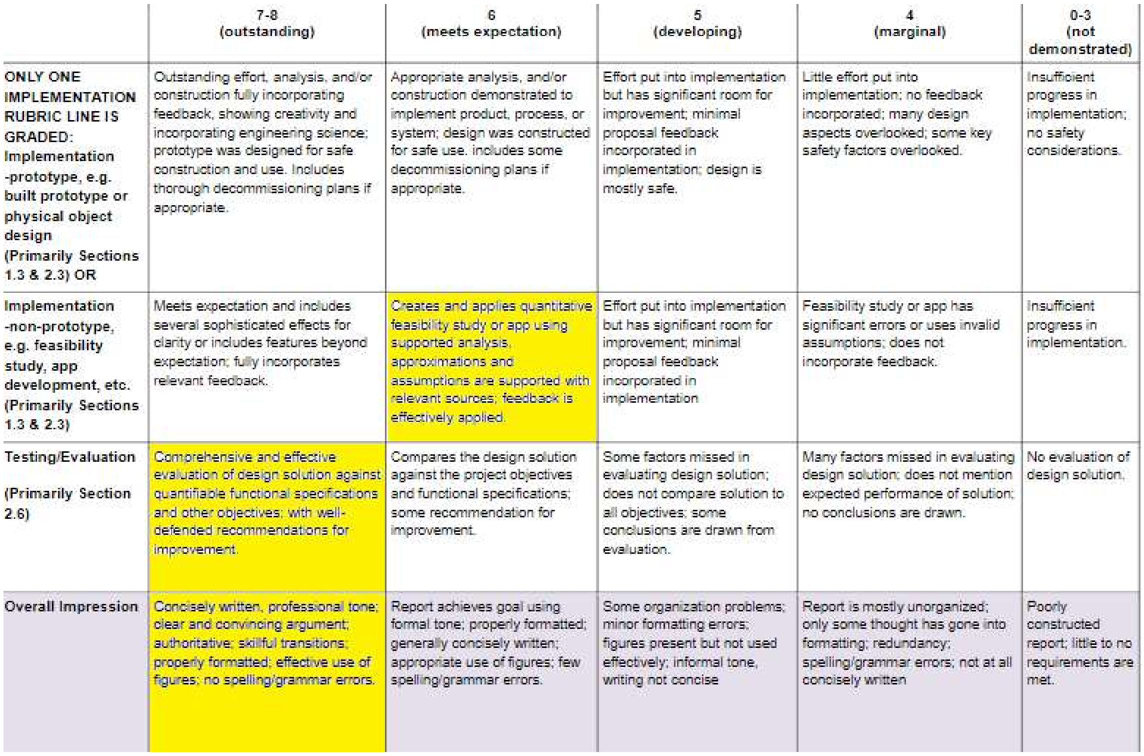
Thus, the gate most likely not fail due to the amount of material. This amount of material is also not realistic as the dimensions of the chute would not be big enough. This calculation is only to show the amount of load that the gate can support.

Appendix II: Individual Contributions

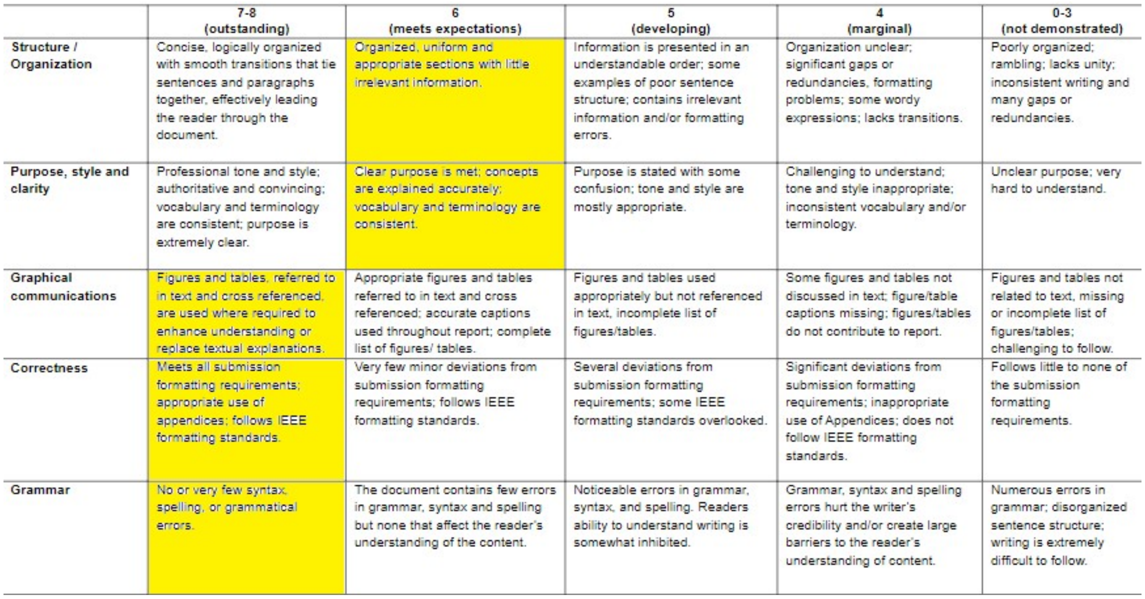
Task	Description of Activity	Activity Duration (hours)	Individual Responsible for Activity
Survey for Faculty Members	To receive feedback on gate designs by professionals	1	Max
Conclusion	To summarize and evaluate the content in the report. Providing suggestions for improvement for the client.	2	Max
Evaluation	To evaluate the success of the design and how much it meets the objectives	1	Max
Editing	To review formatting, grammar, spelling, concision, and quality	3	All
Problem Statement and Scope Definition	To define the task that has been given and to define the overall scope of the report	1/2	Max
Implementation	Described what changes were made to the design from Phase 3.	2	Pierce
Decision Making	Compared designs using an evaluation matrix to determine the best design.	1	Cristiano
Financial Analysis	Analyzed and outlined all the costs of the project.	2	Cristiano
Equations	Created mathematical models to solve for pressures and maximum loadings on the gate. Consulted professors for aid.	4	Pierce
Design Solution	Presenting information about the gate to client.	6	Matthew
Project Plan	Organizing Project Timeline, WBS, and Gannt.	3	Matthew

Conceptual Design Solutions	Generating possible designs and technical information on how they look and function.	4	Matthew
Executive Summary Safety, Inspection and Training	Provide background information and summarize the report Intro for safety inspection and training section.	½ ½	Luke Matthew
Work Permit Control System Enhancements and Inspection Background Information	Provide any background information the reader may need Describing the revised work permit and control systems.	2 1	Luke Matthew

Appendix III: Self-Evaluation



	7-8 (outstanding)	6 (meets expectation)	5 (developing)	4 (marginal)	0-3 (not demonstrated)
ONLY ONE IMPLEMENTATION RUBRIC LINE IS GRADED: Implementation -prototype, e.g. built prototype or physical object design (Primarily Sections 1.3 & 2.3) OR	Outstanding effort, analysis, and/or construction fully incorporating feedback, showing creativity and incorporating engineering science; prototype was designed for safe construction and use. Includes thorough decommissioning plans if appropriate.	Appropriate analysis, and/or construction demonstrated to implement product, process, or system; design was constructed for safe use. includes some decommissioning plans if appropriate.	Effort put into implementation but has significant room for improvement; minimal proposal feedback incorporated in implementation; design is mostly safe.	Little effort put into implementation; no feedback incorporated; many design aspects overlooked; some key safety factors overlooked.	Insufficient progress in implementation; no safety considerations.
Implementation -non-prototype, e.g. feasibility study, app development, etc. (Primarily Sections 1.3 & 2.3)	Meets expectation and includes several sophisticated effects for clarity or includes features beyond expectation; fully incorporates relevant feedback.	Creates and applies quantitative feasibility study or app using supported analysis, approximations and assumptions are supported with relevant sources; feedback is effectively applied.	Effort put into implementation but has significant room for improvement; minimal proposal feedback incorporated in implementation	Feasibility study or app has significant errors or uses invalid assumptions; does not incorporate feedback.	Insufficient progress in implementation.
Testing/Evaluation **(Primarily Section 2.6)**	Comprehensive and effective evaluation of design solution against quantifiable functional specifications and other objectives; with well-defended recommendations for improvement.	Compares the design solution against the project objectives and functional specifications; some recommendation for improvement.	Some factors missed in evaluating design solution; does not compare solution to all objectives; some conclusions are drawn from evaluation.	Many factors missed in evaluating design solution; does not mention expected performance of solution; no conclusions are drawn.	No evaluation of design solution.
Overall Impression	Concisely written, professional tone; clear and convincing argument; authoritative; skillful transitions; properly formatted; effective use of figures; no spelling/grammar errors.	Report achieves goal using formal tone; properly formatted; generally concisely written; appropriate use of figures; few spelling/grammar errors.	Some organization problems; minor formatting errors; figures present but not used effectively; informal tone, writing not concise	Report is mostly unorganized; only some thought has gone into formatting; redundancy; spelling/grammar errors; not at all concisely written	Poorly constructed report; little to no requirements are met.



	7-8 (outstanding)	6 (meets expectations)	5 (developing)	4 (marginal)	0-3 (not demonstrated)
Structure / Organization	Concise, logically organized with smooth transitions that tie sentences and paragraphs together, effectively leading the reader through the document.	Organized, uniform and appropriate sections with little irrelevant information.	Information is presented in an understandable order; some examples of poor sentence structure; contains irrelevant information and/or formatting errors.	Organization unclear; significant gaps or redundancies, formatting problems; some wordy expressions; lacks transitions.	Poorly organized; rambling; lacks unity; inconsistent writing and many gaps or redundancies.
Purpose, style and clarity	Professional tone and style; authoritative and convincing; vocabulary and terminology are consistent; purpose is extremely clear.	Clear purpose is met; concepts are explained accurately; vocabulary and terminology are consistent.	Purpose is stated with some confusion; tone and style are mostly appropriate.	Challenging to understand; tone and style inappropriate; inconsistent vocabulary and/or terminology.	Unclear purpose; very hard to understand.
Graphical communications	Figures and tables, referred to in text and cross referenced, are used where required to enhance understanding or replace textual explanations.	Appropriate figures and tables referred to in text and cross referenced; accurate captions used throughout report; complete list of figures/ tables.	Figures and tables used appropriately but not referenced in text, incomplete list of figures/tables.	Some figures and tables not discussed in text; figure/table captions missing; figures/tables do not contribute to report.	Figures and tables not related to text, missing or incomplete list of figures/tables; challenging to follow.
Correctness	Meets all submission formatting requirements; appropriate use of appendices; follows IEEE formatting standards.	Very few minor deviations from submission formatting requirements; follows IEEE formatting standards.	Several deviations from submission formatting requirements; some IEEE formatting standards overlooked.	Significant deviations from submission formatting requirements; inappropriate use of Appendices; does not follow IEEE formatting standards.	Follows little to none of the submission formatting requirements.
Grammar	No or very few syntax, spelling, or grammatical errors.	The document contains few errors in grammar, syntax and spelling but none that affect the reader's understanding of the content.	Noticeable errors in grammar, syntax, and spelling. Readers ability to understand writing is somewhat inhibited.	Grammar, syntax and spelling errors hurt the writer's credibility and/or create large barriers to the reader's understanding of content.	Numerous errors in grammar; disorganized sentence structure; writing is extremely difficult to follow.