

Spring 2018

Building Entry Flood Barrier

Richard Esker
rse8@zips.uakron.edu

Shannon McCall
sem133@zips.uakron.edu

Andrew Udovich
aeu4@zips.uakron.edu

Brian Foust
bjf54@zips.uakron.edu

Please take a moment to share how this work helps you [through this survey](#). Your feedback will be important as we plan further development of our repository.

Follow this and additional works at: http://ideaexchange.uakron.edu/honors_research_projects



Part of the [Other Mechanical Engineering Commons](#), and the [Structural Engineering Commons](#)

Recommended Citation

Esker, Richard; McCall, Shannon; Udovich, Andrew; and Foust, Brian, "Building Entry Flood Barrier" (2018). *Honors Research Projects*. 671.
http://ideaexchange.uakron.edu/honors_research_projects/671

This Honors Research Project is brought to you for free and open access by The Dr. Gary B. and Pamela S. Williams Honors College at IdeaExchange@UAkron, the institutional repository of The University of Akron in Akron, Ohio, USA. It has been accepted for inclusion in Honors Research Projects by an authorized administrator of IdeaExchange@UAkron. For more information, please contact mjon@uakron.edu, uapress@uakron.edu.

Building Entry Flood Barrier

Ricky Esker, Brian Foust, Shannon McCall, Andrew Udovich

Department of Mechanical Engineering

Honors Research Project

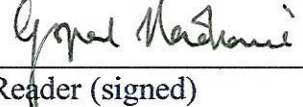
Submitted to

The Honors College

Approved:

 Date 04/24/18
Honors Project Sponsor (signed)

Dr. Stephen Duirk
Honors Project Sponsor (printed)


 Date April 26,
Reader (signed) 2018.

Dr. Gopal Nadkarni
Reader (printed)

 Date 4/24/18
Reader (signed)

Dr. Scott Sawyer
Reader (printed)

Accepted:

 Date 4/26/18
Department Head (signed)

S. Felicelli
Department Head (printed)

 Date 4/26/18
Honors Faculty Advisor (signed)

Scott Sawyer
Honors Faculty Advisor (printed)

Date _____
Dean, Honors College

Building Entry Flood Barrier

Mechanical Engineering/Honors Senior Design Project

April 27, 2018

Team Members:

Ricky Esker

Brian Foust

Shannon McCall

Andrew Udovich

Advisors:

Dr. Stephen Duirk

Dr. Gopal Nadkarni

Dr. Scott Sawyer

Table of Contents

Acknowledgments.....	4
Abstract.....	5
Chapter 1: Background	6
Initial Vision.....	6
Further Exploration	6
Focused Goal.....	7
Design Brief	7
Chapter 2: Conceptual Design	9
Expanded Brief	9
Morphological Chart	9
Concept Sketches.....	10
Rough-Screening	14
Weighted Decision Matrix	15
Objective Tree.....	15
Chapter 3: Embodiment Design.....	17
User Friendly	17
Simplicity.....	17
Force Transmission and Robustness.....	17
Reliability.....	18
3D Model.....	18
Chapter 4: Detail Design	20
Calculations:.....	20
FBD	20
Material Selection:.....	25
Prototype:	25
Frame:	25
Panels:.....	25
Seals:	25
Load bar:	25
Other:	26
Bills of materials (Prototype):.....	26
Drawings:	26

Part Drawings:.....	26
Assembly Drawings:	26
Exploded View Drawings:	26
Discussion.....	27
Prototype testing	27
Force Test:.....	27
Leakage Test:.....	27
Future Changes.....	29
Conclusion.....	30
Works Cited.....	31
Appendix	32
Final Design Iterations:	32
Panel:	32
Telescoping C-Chanel:.....	33
Telescoping L-Chanel (Chosen Design):	34
Part Drawings:.....	37
Assembly Drawing:.....	42
Exploded View Drawing:	43

Acknowledgments

We are very proud of the outcome of this project. Its success is attributed in part to the many people who offered advice and guidance throughout the process. In particular, we thank:

Dr. Stephen Duirk, who graciously and enthusiastically met frequently with us. He offered technical and practical advice and was an integral part of the success of the project. The only person who was more excited than him to see us walk into his office was his lovable dog, Coopers.

Dr. Gopal Nadkarni, who challenged us to think about and approach the project from different views. He wanted to see the project succeed and refused to let us wander down narrow-minded paths. We gained new skills and insights into the process of designing a product, and for that we are grateful.

Dr. Scott Sawyer, who has guided us in this project and in our journey through our undergraduate career at the University of Akron.

All of the generous people who were interviewed by us. They probably will never read this acknowledgement, but their knowledge significantly guided us in the success of this project.

Nate Otermat, who kindly and skillfully welded the prototype frame. His willingness to help is much appreciated, and his work is superb. Thanks to his help, the prototype was a success.

Abstract

The purpose of this project is to develop a flood barrier that would resist flood water from entering through the doorways of a building. The goal is to mitigate extensive flooding within a structure. After the disastrous weather events that impacted American citizens late in the year of 2017, the team was inspired to develop a project to help disaster victims. Through extensive preliminary and market research, it was discovered that flooding is a serious issue that affects people all over the world. A product to stop flooding could benefit people in developed countries, but it could also help citizens of developing countries. After this research, the group was able to strategize and develop a plan to help fight against flooding and lessen the struggle victims endure. After brainstorming multiple solutions to this important problem, the group refined their ideas and settled on a point source flood barrier. This product would fit in doorways and be relatively easy and quick to employ. The team then developed a design, created a 3D model, and built a proof-of-concept prototype. Then testing was done on the prototype to reveal changes that could be made to improve the design. Overall, the team partook in many stages in the design process of a product that could meet the goal of aiding disaster victims.

Chapter 1: Background

Initial Vision

This project was born out of a goal rather than a predetermined design. The year of 2017 was a particularly difficult one for many American citizens in terms of natural disasters. Hurricane Harvey inundated Texas in August. In September, Hurricane Irma struck Florida, and Hurricane Maria devastated Puerto Rico. The hearts and wallets of America opened up for its despairing citizens. It was in this climate that the goal of this project took root.

A team of undergraduate engineers united with two faculty advisors under this goal, hoping to each use their expertise and skills to make headway on a project aimed at disaster relief. The initial potential projects were improved flood barriers and rapidly-deployable emergency housing. Is there a way to stop floods more effectively than by stacking piles of sand bags? Can more humane living conditions be provided for those people who have lost everything? These questions were considered along with many others. In fact, this initial stage of the project seemed to include many more questions than answers. Initial research showed that there were quite a few solutions on the market already. Nevertheless, a novel or improved solution was still sought. Thanks to the media's reporting, it was seen that the current solutions obviously did not solve all of the problems that disaster victims face.

From the beginning, this project had an entrepreneurial attitude. The final goal was a product that could be introduced into the market. With this in mind, many early design questions began to formulate. Who will be using the product? Where will the product be used? How does a product get into the hands of people who need it? Can something be made that would have the potential to be distributed and used by disaster victims? These questions led the team to ponder important design considerations from the beginning of the project.

Further Exploration

However, it was eventually realized that this focused goal was not so narrow. While the end goal was set, the path seemed to be flooded by an unknown depth of water. While the team continued to ask those important questions, they realized that they needed to do more research. They had to get their hands dirty by undertaking two tasks: market research and idea filtering. Together, these tasks would lead them to a more focused goal that could turn into a successful project.

Market research was based upon the humble attitude that the team did not know everything. In fact, they knew quite little about what it means to go through meteorological disasters. So, one of their advisors pushed them to reach out to people who did. They contacted relatives, friends, and strangers who had more experience with disasters, such as people who live in Southern states and people who have done mission work in disaster prone areas. There were people who worked in emergency management offices, people who have lived on the Caribbean island of Hispaniola, and even people who work in hardware stores. Along with interviews, more extensive research was done on how flooding disasters occur and the extent of damage that they cause.

This newly acquired knowledge prepared the team to better be able to approach the project that came out of their initial vision. However, it made little headway in clearing the water from that hidden path of where the project actually will go. They could create a flood barrier or an emergency shelter, but there are also needs for water purification and electric power. They could focus on impoverished nations with a decentralized infrastructure, or they could pitch a preventative product to an average American homeowner. What was needed was a process of filtering ideas so that the focus could be set on a specific project. So, the team created Mind Maps, they considered the needs professed by the people they interviewed, and they spent many hours in team meetings discussing and sometimes painfully debating concepts such as the difference between “diverting” or “blocking” flood water.

Focused Goal

After all the newfound knowledge and ideas, the team somewhat ironically decided on a flood barrier. This is where the vision started, and this, they thought, was where they were able to best use their engineering skills to pursue a successful project. Further, they pursued specific criteria that this product must fulfill. It must be rapidly deployable by requiring minimal time and manpower to install. It must be reusable and easy to store and transport. And obviously, it must stop water from entering a building. Although the team was now focused on a product, more idea narrowing needed to be done. They kept asking themselves why there is not a better solution than the famous sand bag. They asked again, “What products are on the market? Why are they not more effective or widely used?” After more research and consideration, a focused project finally developed. It was termed a “point source entry” flood barrier. The idea is this: stop the water from coming in the “point sources” of a structure, such as doors and window, and homeowners can be saved from significant devastation. Thus, the project was named Building Entry Flood Barrier, and the team moved on to design a product that could accomplish this goal.

Design Brief

In order to mitigate the devastation caused by flooding, a flood barrier is to be developed to resist flood waters from entering a building through single exterior doors. The product must satisfy the following criteria:

- Stop or greatly mitigate flood water entry through a single exterior doorway
- Be adjustable for standard door sizes and resist flood water up to three feet high
- Require minimal time and manpower to install
- Be reusable, easy to store, and easy to transport
- Require no permanent alterations and cause no damage to the building
- Be low priced and marketable to an average American homeowner

These criteria were developed by the team after much team deliberation and research into customer needs for a new product. The goal market would be an average American homeowner, but the product could potentially also be used commercially or in impoverished nations.

Chapter 2: Conceptual Design

Expanded Brief

According to the Federal Emergency Management Agency, 98% of counties in the United States are impacted by different flooding events [3]. Preparing for every case of flooding is impossible as elevations vary drastically even in common flooding areas. William Nettles who was a resident of Florida for 20 years, explained in an interview that Tropical Storm Fay came in and dropped 24 inches of rain in 2 days [7]. Nettles' house was not damaged at all, but his next-door neighbor was under 4 feet of water due to elevation change [7]. Researching into different building entry barriers currently in the market; floodgates by Floodgate Ireland, Absorbent Specialty Products, and Quick Dam all showed to block water up to a standard 26 inches in height. Therefore, it was determined to do a 3 feet tall barrier to hold back more than the typical standard of current products. By measuring door frames on different houses as well as looking up standard exterior door dimensions, we determined to make the frame adjustable from 32" to 36" wide [4]. After standard design criteria was determined, a Morphological Chart was utilized to look at different possible design options.

Morphological Chart

A Morphological Chart shown in Figure 1 considered connection methods, compactibility, bottom seal, anchoring/support, material, and shape. Connection methods are important to how two pieces went together as adjustability is important, so it was known there would not be a single barrier piece concept. Since customer needs are important for use, a compactible barrier is important. Being able to store or ship something awkwardly shaped is not a positive for seller or consumer. The bottom seal between the ground and barrier paneling was considered a very important design criterion, although there were not too many different options listed, it is the first defense in flooding. Anchoring and support of the barrier was initially considered for a free-standing setup in front of the door and was altered later in different concept sketches. Material was considered to determine what to use or if everything would be manufactured from only one type of material. Lastly, shape was a criterion and in concept sketches more creative shapes were thought up as possibilities.

Connection methods	male/female	overlap	hinge	hooks	puzzle pieces	existing structure support
Compactibility	simple wallet	pizza box	scroll	complex wallet		
Bottom seal	water absorbing material	weight of water/smartstructure	structure			
Anchoring/support	weight of water	stake	bottom profile	back supports		
Material	plastic	tarp	rubber	metal	hybrid	
Shape	L-shape	Box	sheet			

Figure 1: Morphological Chart

Concept Sketches

Concept sketches were drawn to come up with different ideas on how to solve the problem at hand. As this is a creative process, some ideas were based to further improve products seen on the market and invent new solutions. Seen in the figures below are the top concept sketches for this project.

Inflatable Sleeve in Figure 2 is a completely new concept to the industry's product line. To keep the water out, a plastic sleeve is put around the frame of the door, the door is shut, and then air would be pumped into the sleeve to create a water-tight seal all around. Material for this would have to be very sturdy but also flexible as it needs to bend around the corners of the door but also not pop easily.

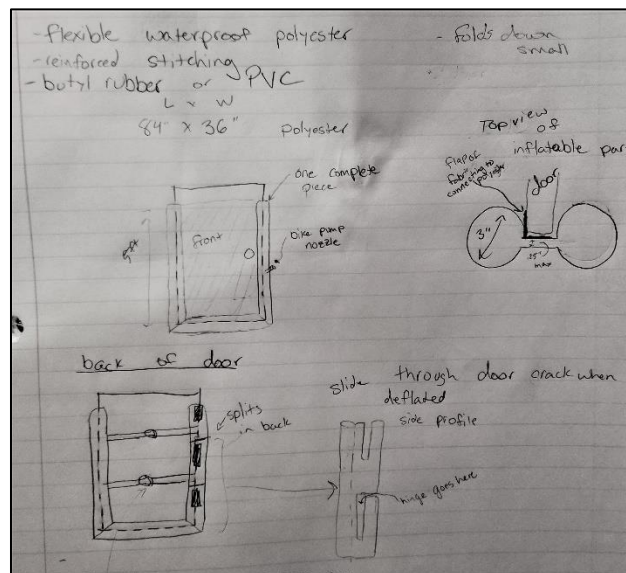


Figure 2: Inflatable Sleeve Concept Sketch

The Sand-Bag Holder in Figure 3 took a very common flooding solution and re-invented the setup process. Instead of simply throwing sandbags in front of an exterior entry point, you would be able to perfectly place them into slots to make the most compact and waterproof barrier as possible with sandbags. This is a prime example of re-inventing and improving old methods of flood protection.

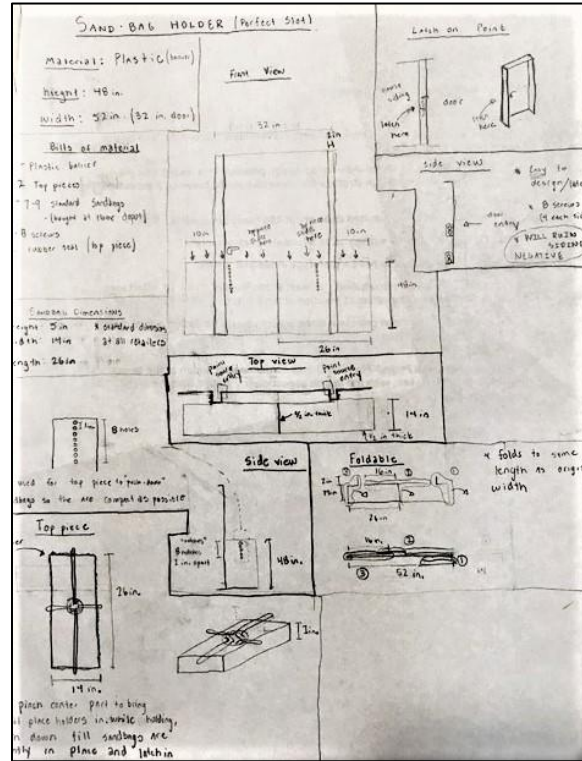


Figure 3: Sand-Bag Holder Concept Sketch

Triangle Block in Figure 4 is a simplistic solution for easy setup and use. The triangle form would fold flat and open easily for deployment, which makes setup and storage no issue. Edges of the barrier would lodge into the door frame to seal and support and a bottom seal would flip down and lodge under the door for added protection.

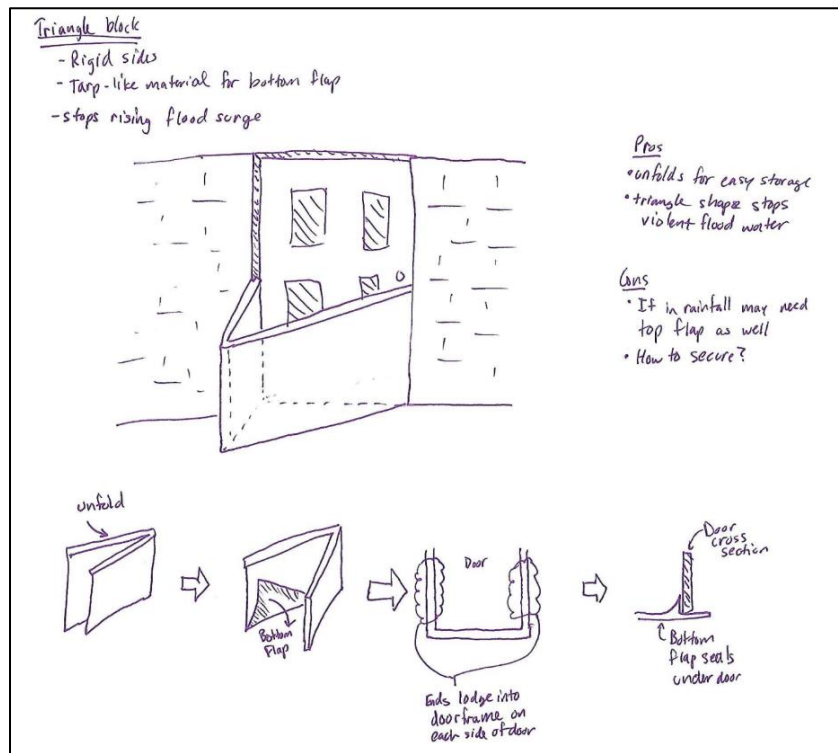


Figure 4: Triangle Block Concept Sketch

Door Blockade Concept in Figure 5 is an innovative design that is based off an unknown material that is both absorbent and adhesive to exterior building surfaces. Concept ideas are meant to be creative and not withheld by realistic constraints until further in the design process. There is a bar that hooks around the border of the door and locks behind, but the exterior foam would still need to help secure it.

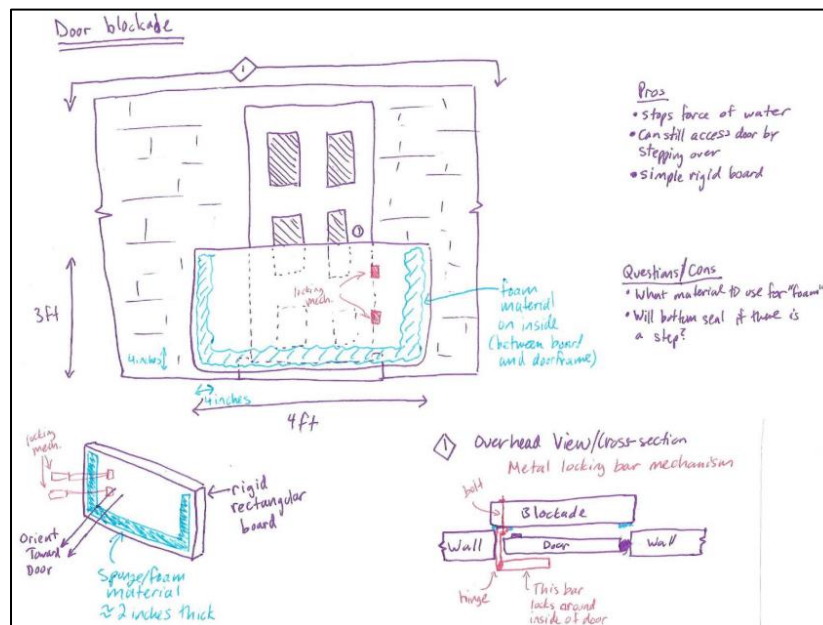


Figure 5: Door Blockade Concept Sketch

Hook Around concept in Figure 6 is based on more of an adaptable design for varying door widths. Base slots are hooked around the door for connected panels to be set into place, depending on the door width changes how many panels you need to have. Material for this concept would need to be strong and flexible to fit around the border of the door and hook on the interior wall.

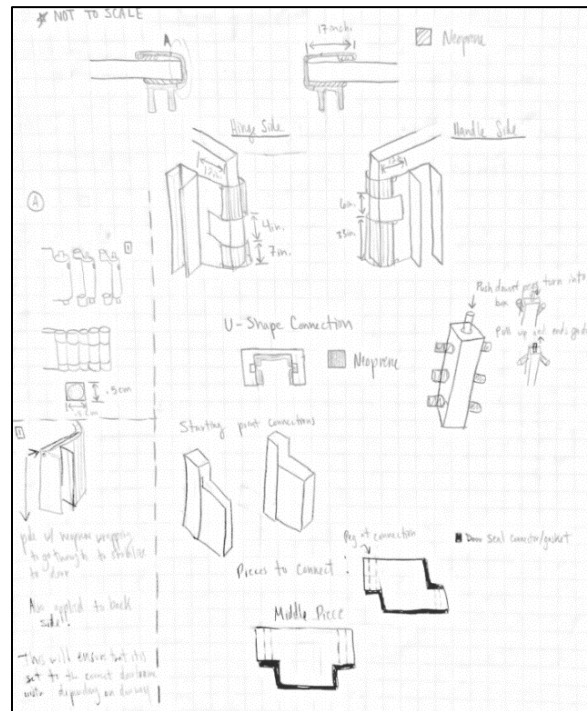


Figure 6: Hook Around Concept Sketch

Baby-Gate Concept in Figure 7 is what the team decided to pursue and prototype. Inspired by a simple household item, this is an easier system for the consumer to deploy and for the manufacturer to make. Design changes were made later in the process and then prototyped.

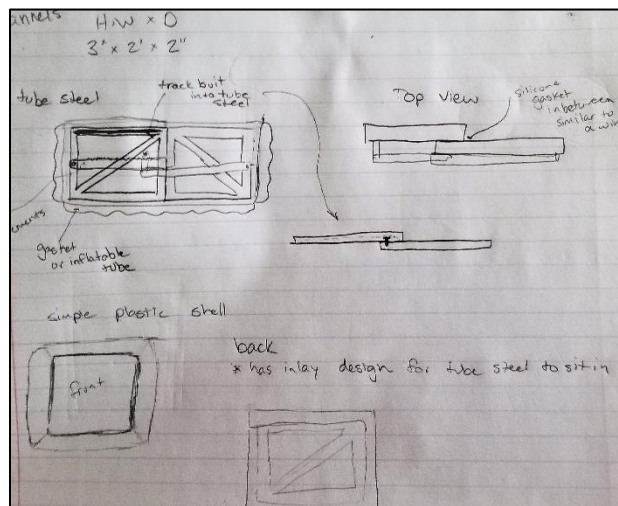


Figure 7: Baby-Gate Concept Sketch

Rough-Screening

Concepts were sifted through different considerations before a final design was chosen to prototype. Manufacturing processes and materials available for common consumers were a main constraint for barrier construction. The only possible concept to pursue with the time frame and constraints was the Baby-Gate in Figure 7. Next steps were taken by completing a House of Quality analysis as seen in Figure 8. The main concept was determined, but next was to completely design the water barrier system. Key components of the barrier determined by the team include locking mechanism design, outer seal, profile material, profile design, and inner seal. Main design considerations involving the customer are listed on the left side of the matrix, if they applied to different key components, a rating was given as it corresponds in the Key. The outcome of the House of Quality displayed the most important component of the system to be the locking mechanism. Different locking mechanisms were evaluated using a Weighted Decision Matrix to be discussed next.

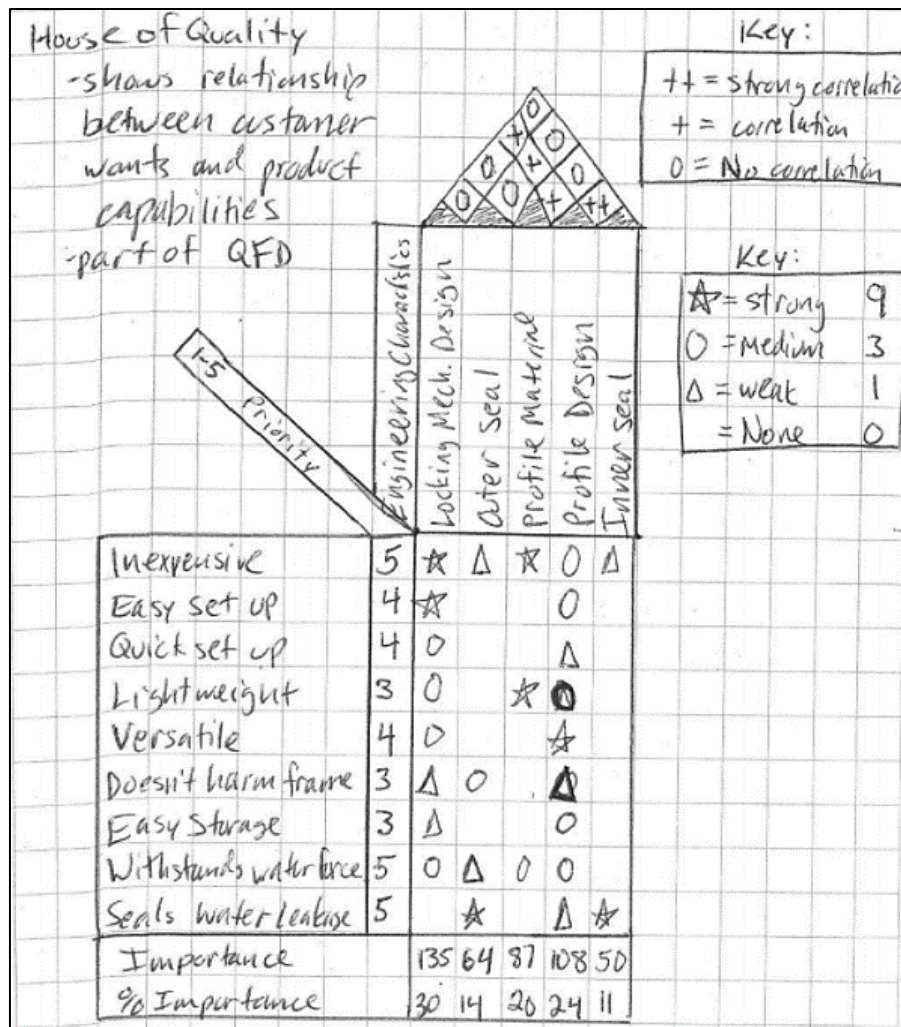


Figure 8: House of Quality

Weighted Decision Matrix

The Weighted Decision Matrix in Figure 9 for this project was applied to the most important component of the barrier design – locking mechanisms. The locking device is not only important because of its ranking in the House of Quality Figure 8, but also since this mechanical device holds the barrier in place against flood water force loading. Devices considered included a power screw bar in which the consumer would use an electric screwdriver to tighten into place, a load bar that is ratcheted into place, and a pressure lock that would be hand pumped using a bicycle tire pump or electric air pump. Top three weighted criteria include: materials, ease of set-up/take-down, and initial tight fit. Load bar ranked highest in ease of set-up/take-down and second in both materials and initial tight fit. Overall, the load bar was rated highest in the end and was decided upon for the mechanical tightening device.

Weighted Decision Matrix		Power Screw		Load Bar		Pressure Lock	
Design Criteria	Weight Factor	Score	Rating	Score	Rating	Score	Rating
Initial Tight Fit	0.5	10	5	8	4	7	3.5
Durable	0.1	8	0.8	8	0.8	6	0.6
Doesn't loosen over time	0.4	8	3.2	10	4	10	4
Ease of set-up/take down	0.6	5	3	9	5.4	7	4.2
Ease of Manufacturing	0.4	5	2	6	2.4	7	2.8
Materials	0.6	5	3	6	3.6	8	4.8
Complexity	0.4	5	2	6	2.4	6	2.4
Total			19		22.6		22.3

Figure 9: Weighted Matrix for Locking Mechanisms

Objective Tree

Two objective trees were made; one for the general product and another for the locking mechanism since it is the most user oriented and important design detail for the barrier. Figure 10 for the Building Entry Flood Barrier has 3 main focuses on the barrier being water resistant, deployment of the barrier, and how durable it will be. Branches off each show what can make up the fundamental section and what to focus on for improvements. Most of the end branches are either design possibilities or choices that can solve the previous customer desire.

Considering the locking mechanism objective tree in Figure 11; strength, ease, and cost are important. A strong mechanism leads to a more robust and solid barrier to withstand and hold back water more efficiently. Ease of the locking mechanism is important as this is what the user will interact with to make the barrier watertight, the easier it is to setup, the more likely it will be used and earn a wider range of consumers. The cost for it is a separate cost from the materials of the barrier as it is a stand-alone function that attaches or is installed into the frame. Deciding how expensive this should be could increase or decrease the total cost of the barrier. Different materials and how complex the mechanism is will alter the price. Drawing up the objective trees helps show where everything connects and how it can affect the overall product.

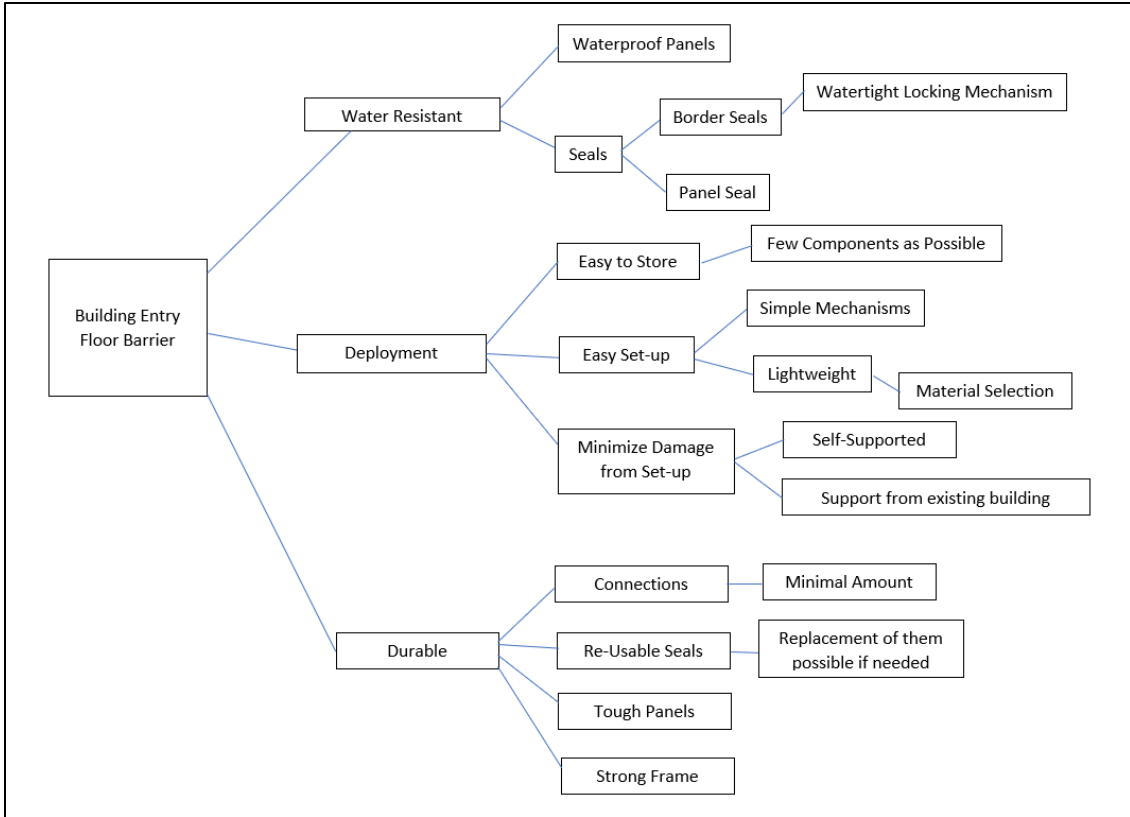


Figure 10: Building Entry Flood Barrier Objective Tree

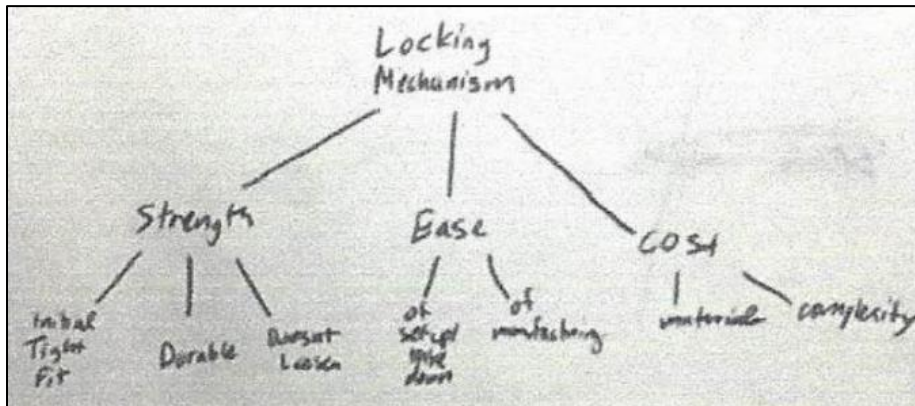


Figure 11: Locking Mechanism Objective Tree

Chapter 3: Embodiment Design

Since this project was very open-ended, there were quite a few designs and ideas that the group went through. Embodiment design was an important part of the design process. As the group was trying to figure out which principles to really focus on, there were five main categories: user-friendly design, simplicity, force transmission, reliability, and robustness.

User Friendly

One of the most important things that the design needs to be, is user-friendly. After doing a significant amount of market research, it was determined that most of the designs on the market were extremely cumbersome. This made it difficult for the barrier to be easily transported and deployed. A customer might have this huge leak-proof barrier, but if they are not able to actually get this barrier in front of the door quickly or easily, and then on top of that, if they are not able to easily lock it into place, the design is useless. The idea was to have a barrier that would be able to be used easily by most age groups, and even those with more physical limitations. The goal also was to be able to place the barrier in a doorway, then quickly and easily extend out the panels to lock it into place.

Simplicity

Another important part of this design is simplicity. When trying to come up with a simple design, the group found inspiration from a baby gate, because baby gates are very intuitive to use. They are also relatively strong for their size. The group discussed that if it was as simple and effective as a baby gate, it might be possible to build a more robust and watertight “gate” or barrier. After looking at what was currently on the market, it was discovered that most other viable options required special tools or a time consuming set-up. This is drastically different than the design the group came up with, which is simple and quickly deployable. This barrier should be able to be placed and tightened in place without the need for tools, and that was exactly why this was the design that was chosen. There should be little to no instructions needed when setting up this barrier. And that goal was achieved. The prototype is still a bit rough around the edges, but as the design is further refined and optimized for production, it will be extremely simple. This current design would be considered a proof-of-concept design. It is just two panels that slide within each other and are locked into place with a ratcheting load bar.

Force Transmission and Robustness

Force transmission is an important part of any design. Flood waters can slowly rise, or they can come in a storm surge and be incredibly violent. It is important that the forces the water exerts on the barrier are able to be transmitted to the entire barrier, and not just pushed on the plastic panels. This idea of force transmission also plays into the idea of robustness. They both go hand-in-hand. The design of the barrier must be robust, and while it is robust, it must also transmit the force of water so it can withstand the intense force of flood water. To make this design more robust, the group decided to reinforce the barrier with a metal frame. High Density Polyethylene (HDPE) plastic is a flexible and strong material that is very robust and

resilient. A robust and resilient material is necessary in order to hold back rising water. The other beneficial thing about HDPE is that it is not a brittle material. If debris or a strong surge of water were to hit the plastic panels, they would momentarily bow, but they would not snap or have brittle failure. The material behaves in a way that it does not plastically deform. It is able to return to its shape. The metal frame also helps keep the barrier in its original shape. The cargo bar also adds support through the middle of the barrier. The parts also use the principle of self-help, because instead of adding extra reinforcement, the design uses itself and the different parts to reinforce itself. All parts were designed and created to be simple yet extremely robust.

Reliability

Reliability is exceptionally important when it comes to any sort of prevention. So when it comes to water prevention, reliability is important because if a seal were to fail, it would be a huge issue in the protection of a house or structure. If this water barrier was not reliable in disaster situations, then this project is a failure. All of the materials chosen need to be able to have a long life cycle, which is one reason we chose HDPE for the panels, aluminum for the frame, and rubber for the seals. The group believes that these materials would create the best barrier possible.

3D Model

After refining the different ideas, a final design was chosen, and it was necessary for 3D modeling to begin. Before the group arrived at the current design, there were quite a few revisions of this design. The group first had to decide if it would be better to have two panels slide on top of each other, similar to how a window works, or if it would be better to use a telescoping design. Both types of design had their challenges. Ultimately, the group decided to go with the telescoping idea. After that decision was agreed upon, there were other smaller decisions that had to be made. Most of those decisions revolved around the profile of the metal channels. The group kept bouncing between a C-Channel and a L-Channel for the smaller panel to slide into. These other design iterations can be found in the Appendix. The L-Channel profile is what was chosen. After multiple revisions and changing the positions of the HDPE panels, the final 3D model was created in Autodesk Inventor. The seals were created as a placeholder for what the group ultimately chose as a satisfactory seal, since in the actual production model of this barrier, the seals would hopefully be sourced and not necessarily custom. Also, the cargo bar, will ultimately be a slightly modified design from a vendor that already creates a bar to fit those specifications. The 3D model for that was pulled from the McMaster-Carr website. The goal was to use components that were standardized, as opposed to creating everything custom. By using standard sized aluminum pieces, it allows the group to use a less costly extruded metal. The group was not trying to create everything custom, because most of the current designs that were found during market research were custom. Having these custom designs caused the prices to be \$600-\$1000, for the barriers. That pricing is just not realistic for the everyday consumer. By using standardized components, the cost will be significantly decreased.

The group was very pleased with the proof-of-concept 3D model that was created for the barrier.

The heart behind this design was to create something that conformed to the following embodiment design principles: user-friendly design, simplicity, force transmission, reliability, and robustness. The group was able to achieve those design principles with this proof-of-concept design for a flood barrier. The group was able to make a design that would be obtainable for the everyday consumer. Unlike most designs currently on the market, this design could also be transported and implemented in disaster zones around the world. This project originally started out as a project to help those in third world countries, or disaster prone regions. By creating a simple, reliable, and user-friendly design that is not over-engineered, this design could be taken worldwide, and could protect many homes and buildings. Following the ideas and principles behind embodiment design was an important part of creating a design that achieved all of those goals providing a solution, meeting a desperate need.

Chapter 4: Detail Design

Calculations:

The barrier is to be designed to seal off 3 feet of water from entering at the point source entry positions of a doorway. This is to concern the outside portions of the doorways where the seals will be placed on the barrier. The seals will act as the prevention to water entering through the point source area of the doorway (up to 3 feet in height). To ensure that the seals on the barriers will prevent the water from entering through, the force required at seal must overcome the force of the hydrostatic pressure from the water.

First, a free body diagram of the wall, seal, and static water pressure will be made

FBD

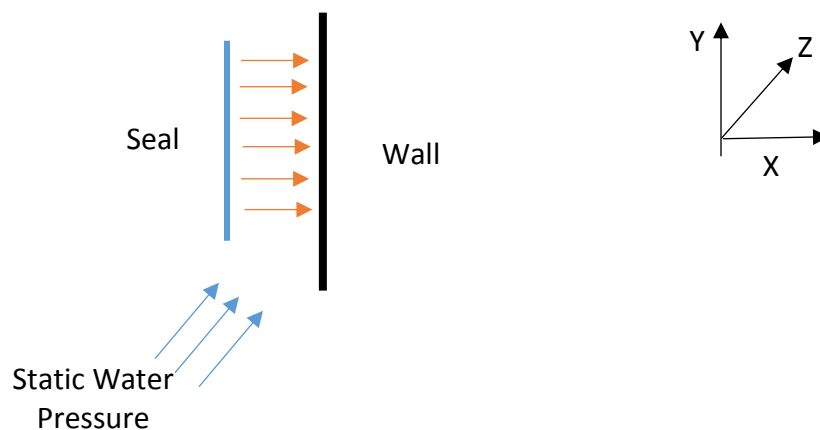


Figure 12: FBD of forces

In a XYZ coordinate plane, the seal will be placed along the x-axis and the static water pressure will be along the z-axis.

For finding the sealing force, the friction force of the runner on the wall must overcome that of the static water pressure. First, the static water pressure must be calculated. To do this, two assumptions must first be made:

1. The fluid is incompressible
2. The pressure is static

These are two fair assumptions to make in the case of the barrier. Water will be the fluid that is being suppressed and the water will be slowly rising, so it is assumed as static.

These two assumptions allow for Pascal's law to be applied. Pascal's law states that the pressure at any point on a fluid at rest is independent of direction. This can mathematically be denoted as:

$$\Delta P = \rho g(\Delta h) \quad (1)$$

ΔP : Hydrostatic Pressure

ρ : Density of the Fluid

g : Gravity

Δh = the difference in elevation from the reference point

ΔP is directly related to Δh in this equation as the gravity and density of the fluid remain the same. This means that as the difference in elevation from the reference point increases, the hydrostatic pressure will as well. The reference point for this calculation will be the top of barrier, a free surface.

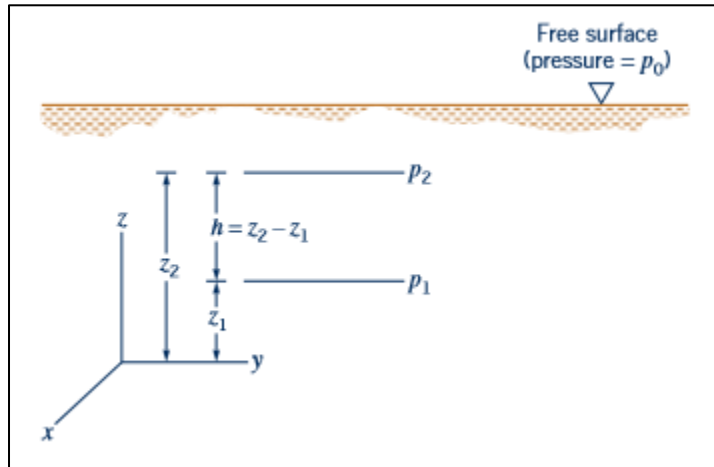


Figure 13: Hydrostatic Distribution [2]

Figure 13 represents the concept of hydrostatic distribution. The figure shows a free surface and two pressures p_1 and p_2 within a fluid. Both p_1 and p_2 are distinctly defined by two different heights, z_2 and h , but each have the same density and gravity (same fluid). Because of this, p_1 would be a higher pressure than p_2 because z_2 would be larger than h . This type of pressure distribution is known as hydrostatic distribution.

Based off Pascal's law and hydrostatic distribution, a function for pressure of the water on the barrier at any given Δh can be developed. To do this, $\Delta h(x)$ will be used as a variable of water depth.

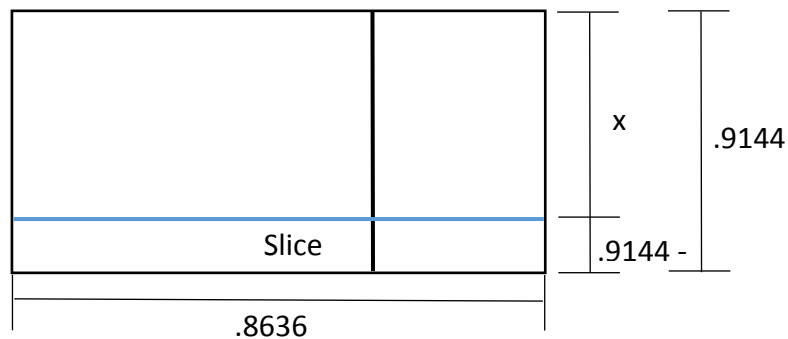


Figure 14: Dimensional figure of the Barrier

Figure 14 represents the barrier (includes dimensions of max width of 34 inches and max height of 36 inches). The pressure against the barrier is directly related to the height of the water, x . By using Pascal's law and applying the barrier's dimensions the equation as a function of height, the force of the water on the barrier can be developed at any given height.

A slice of the barrier will be taken at x depth. This will act as the area of the barrier that the force is being exerted across. Taking this area and adding it to Pascal's equation yields:

$$F_{water} = \rho g(x) * A_{slice} \quad (2)$$

$$A_{slice} = (.8128m) * (.9144m - x) \quad (3)$$

Plugging equation 3 in equation 2 yields:

$$F_{water} = \rho g(x) * (.8636m) * (.9144m - x) \quad (4)$$

x : Depth of the water

Notice that the pressure calculation now turns into a force calculation with the addition of the area to the equation.

Now, defining density and gravity gives the final equation that will give the force of the water on the barrier at any given water height.

$$\rho = 1000 \frac{kg}{m^3}$$

$$g = 9.81 \frac{m}{s^2}$$

$$F_{water} = (1000) \frac{kg}{m^3} (9.81) \frac{m}{s^2} (x)m * [(.8128)m * (.9144 - x)m]$$

$$\lim_{x \rightarrow \infty} \sum_{i=1}^x (9810) \frac{N}{m^3} * (x)m * [(.8636) * (.9144 - x)m^2] \quad (5)$$

Note: .8638 is based off a 34" doorway. This number must be adjusted if the doorway is not 34"

To calculate the force needed from the load bar to seal, the resultant force of the water on the barrier must be found. As the water depth increases, so will the force on the barrier. This is a linear relationship due to Pascal's law (Equation 1, ΔP is an equation of Δh).

Δh	ΔP
0	0
0.5	4905
1	9810
1.5	14715
2	19620
2.5	24525
3	29430

Table 1

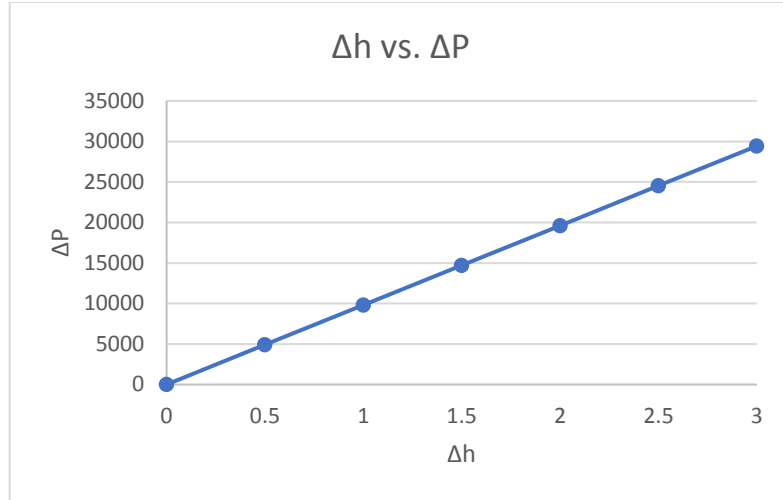


Table 2

Note: This is the relationship of $\Delta P = \rho g(\Delta h)$ with $\rho = 1000 \frac{kg}{m^3}$ and $g = 9.81 \frac{m}{s^2}$

This relationship allows for a force curve to be drawn on the barrier. Now that the relationship is known to be linear, the resultant force of the force curve needs to be found.

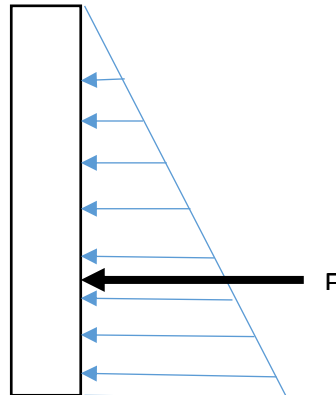


Figure 15: Resultant force on the barrier

The resultant force must pass through the centroid of the pressure prism. For the volume under consideration the centroid is located along the vertical axis of symmetry of the surface and at a distance one third of the height above the base [2]. Simply because the pressure prism is linear, the resultant force will occur based on the pressure at the center of the height of the barrier. The magnitude of the resultant fluid force is equal to the pressure acting at the centroid of the area multiplied by the area.

$$F = \rho g A h_c$$

F: Resultant Force

ρ : Density of the Fluid

g: Gravity

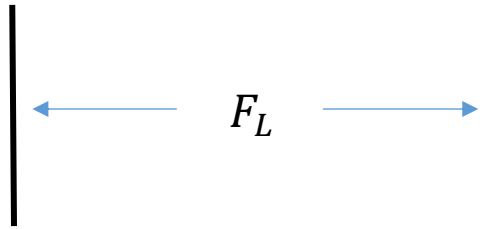
A: Area of the barrier

h_c = Average height of the barrier

$$F = (1000) \frac{\text{kg}}{\text{m}^3} (9.81) \frac{\text{m}}{\text{s}^2} (.8636 * .9144) \text{m}^2 * (.4572) \text{m}$$

$$F_R = 3541.8 \text{ N}$$

Now the resultant force is known, the force of the load bar required to overcome the force of hydrostatic pressure can be calculated. The load bar will be applying force (F_L) to the right and left side of the barrier. This means it will be distributing the load over two surfaces.



Note: F_L is the force of the Load bar

To ensure sealing force is enough to overcome the effect of hydrostatic pressure, the friction force created by the load bar must overcome that of the total hydrostatic pressure.

$$2\mu F_L > F_R \quad (6)$$

μ : Coefficient of Friction (static)

F_L : Force of the Load Bar

F_R : Resultant Force of the Hydrostatic Pressure

The seals for the barrier are rubber seals, so the coefficient of friction for the seals need to be assumed. According the Engineering Toolbox [6], the static coefficient of friction for rubber will be assumed to be .6. This is the average of the coefficient of friction for rubber against dry and wet concrete.

$$2(.6)(F_L) > 3541.8 \text{ N}$$

$$F_L > \frac{3541.8 \text{ N}}{2(.6)}$$

$$F_L = 2951.5 \text{ N or } 663.49 \text{ lbf}$$

The resultant force, force needed from the load bar, and hydrostatic pressure are all calculated. Using these calculations, materials for the design can be chosen.

Material Selection:

Prototype:

The barrier can be broken down into a few different main categories. The frame of the barrier, the panels, the seals, and the load bar. For creation of the prototype, different materials than what would be used in a final product design were used. This is due to ease of assembly, convenience, and price of these materials.

Frame:

The frame of the prototype was made of steel. This frame was made with tube steel and angle iron steel. Steel was chosen for the prototype because of its ease of use in terms of welding. Tube steel and angle iron steel were welded together to make a frame of .8636m by .9144m, the same size as our desired product (note that the .8636m is adjustable). Two pieces were made for the frame. The static frame and the sliding frame. The static frame had one long piece of angle iron steel (.9144m, the height of the barrier) and two pieces of angle iron steel welded to it. The static frame was made ½" taller than the adjustable frame so the adjustable frame could slide in and out of the static frame. The static frame also had a slot cut on the bottom angle iron steel piece for the seal of the adjustable frame to slide into. The adjustable frame was also made of one long piece of tube steel (1/2" smaller than the height of the static frame) and two other tube steel pieces. With the frames built, the adjustable frame guided into the static frame. One last angle iron steel piece was put over the top of the static piece to ensure a "guide" for the adjustable frame.

Panels:

The Panels of the prototype were made out of HDPE (High Density Polyethylene). This is the same material that would be used on the desired product. The difference in the prototype is that the panels are glued to the frame. Two HDPE sheets were each glued on the backside of the steel frame. On the desired consumer model, the HDPE sheets would be molded to fit perfect within the frame.

Seals:

Two different seals were used in the prototype. Rubber seals for the sides of the barrier and sponge seals for the bottom of the barrier. Rubber seals were able to be used on the side of the barrier. This is due to the side seals being a straight seal right down the side. The bottom seal needed to be cut and designed to move with the barrier as it adjusted. Because of this, sponge seals were used because of convenience to cut and shape the foam seal to any desired fashion. The seals on the bottom of the design had to be adjustable and be able to slide with the adjustable panel as the barrier was adjusted. Ideally, the desired product would have a rubber seal that was custom made to fit the bottom of the barrier to accommodate the sliding adjustment.

Load bar:

Ideally, the load bar for the desired product should be able to exert 663 lbf. For the prototype, the load bar was chosen based off its low price, but also size as well. There is no load bar

currently sold on the market that would fit the width of the desired consumer product (same for the prototype). So, the load bar chosen for the prototype had to be cut down to fit the prototype. Ideally, the desired product would have a custom load bar.

Other:

Three HDPE strips were used on the outer part of the sliding frame to make sure the steel frame was not exposed. This was done for cosmetic reasoning and for ensuring better tolerances.

Bills of materials (Prototype):

The following bill of materials for the prototype shows the items for the prototype, location of purchase, and cost of each item.

Item	Location	Amount
Seals	Home Depot	\$13.85
Load Bar, Epoxy	Harbor Freight	\$23.46
Steel	Standard Welding	\$51.77
Super Glue	Home Depot	\$6.71
HDPE	McMaster	\$93.18
Total:		\$188.97

Table 3: Bill of Materials

The steel was purchased and cut by Standard Welding (Medina, Ohio). Welding was done through labor and not paid for.

Drawings:

Part Drawings:

L Frame: Appendix page 36

L Slot (bottom): Appendix page 37

HDPE Panel: Appendix page 38

Tube Frame: Appendix page 39

Tube HDPE panel: Appendix page 40

Assembly Drawings:

L Design: Appendix page 41

Exploded View Drawings:

Exploded View: Appendix page 42

Discussion

Prototype testing

After the team built a proof-of-concept prototype, they sought to subject it to tests. Two tests were proposed. One test was a force test. This type of test was not done on the prototype because the prototype was a proof-of-concept prototype, meaning that it was not made with the same materials and precision that a final product would be made with. Rather, an Alpha prototype made from the design materials and manufactured to fit together with more precision would be needed. The results of this test on a proof-of-concept prototype would not be very significant. Nevertheless, the proposed force test is outlined below. The second proposed test was a leakage test. This test was done on the proof-of-concept prototype and is outlined along with the results below.

Force Test:

A force test would see how the product performed under a “worst-case scenario” in which the barrier would have to hold back flood water that was three feet in depth. Fluid calculations give the hydrostatic pressure due to the flood water that the barrier would need to withhold. Thus, this test would involve that known pressure being applied to the exterior side of the installed prototype barrier. A test would be considered a success if the barrier remained firmly fixed in the doorway while the pressure was applied. This pressure could be applied by applying a resultant force at the center of pressure of the barrier. Additionally, analysis could be done into the material properties and failure characteristics of the plastic used in an Alpha prototype.

A second part to the force test would be to test the force exerted by the load bar. The load bar applies a normal force to the sides of the barrier which increases the friction between the side seals and the door frame. This friction (along with some friction from the bottom seal, although the contribution there may be negligible) is what ultimately keeps the barrier in place to hold back the hydrostatic pressure of the flood water. The required normal force needed from the load bar was calculated, and this force should be met by an Alpha prototype load bar.

Refer to calculations earlier in the report for the calculated values of these forces.

Leakage Test:

A leakage test exhibits how well the seals on the sides and bottom of the barrier would stop water from coming into the building. For this test, the barrier is first installed in a doorway. Then it is sprayed with a garden hose at the seal locations. The test setup is shown in the following Figures.



The test resulted in water leaking from the bottom seal, but not from the side seals. These results led the team to consider some propositions for a subsequent prototype. First, the seal type was evaluated. On the proof-of-concept prototype, a Sponge Window Seal was used for the bottom seal and an Auto and Marine Rubber Weather seal was used for the side seals. During the test, the sponge seal on the bottom got saturated with water, which is one hypothesis on why the bottom seal leaked. Overall, it seems that the rubber seal did a better job keeping water out and should be used on the bottom of the barrier as well.

The sponge seal was used on the proof-of-concept prototype because the bottom seal needed to be cut to a specific shape. In order for the panels to slide into each other, the seal needed to interlock. The sponge seal was easier to cut to these shapes for the prototype. However, this piecing together of sponge seal sections may have led to gaps through which the water leaked through. Additionally, there was a small height difference between the bottom seals on each panel because the purchased window seal had only one thickness. In an Alpha prototype, the bottom seal should be made with the correct shape and dimensions. The bottom seal on the proof-of-concept prototype after the leakage test is shown in the following Figure.



Finally, this leakage test was an initial evaluation of the sealing capacity of the barrier. A more intensive leakage test would need to be done with the barrier holding back three feet of flood water. This would show if the sealing capacity was reduced by the presence of hydrostatic pressure.

Future Changes

After building a proof-of-concept prototype, several propositions were made for changes that would be incorporated into a subsequent Alpha prototype. These included the materials used for the plastic panels and the frame and the addition of an inner seal between the panels.

In an Alpha prototype, the frame would be made out of aluminum. This would reduce the overall weight of the product. Additionally, the plastic panels would be made more precisely. The design was based on plastic panels that would be injection molded to be the correct shape to fit around the frame. However, the proof-of-concept prototype was made by gluing cut pieces of HDPE plastic sheet to the frame. An Alpha prototype panel would be molded so that each panel would be one piece in which the frame would fit inside. This would eliminate all of the seams that were present between plastic pieces on the proof-of-concept prototype. Also, an Alpha prototype panel would hopefully not deform or bow in the middle as the proof-of-concept panels did. Due to this bowing, the proof-of-concept prototype needed extra supporting pieces added into the frame. Perhaps the panels would need to be thicker or have supporting ribs to reduce the bowing.

The bowing effect in the middle of the panels contributed to one of the major changes that would need to be made in an Alpha prototype, which is the design of an inner seal between the panels. This seal was intentionally left out until after the proof-of-concept prototype was made and analyzed. The presence of a seal, along with more precisely manufactured plastic panels, would resist water from leaking between the two sliding panel sections. Several ideas for this inner seal are as follows:

- Absorbent material: An absorbent material, such as a towel, could be attached to the outside of the front panel. After the barrier is installed in the doorway, this material would be “tucked” into the gap between the panels by hand or with a tool. This material would absorb water at the onset of the flood, then hopefully the saturated material would work as a seal to resist more water from coming through the gap in the panels.
- Accordion-folded material: A sheet of thin water-resistant material would be folded over-and-back on top of itself like an accordion. This sheet would be in between the two panels and attached to each panel on the side opposite the side seals. The accordion folding techniques would allow the panels to still slide with each other to adjust to different width doorways.

- Rubber seal: A strip or sheet of a thin rubber seal would be affixed in the gap to one of the panels. This would reduce any nominal gap in between the panels, however, it could add unwanted friction that would make adjusting the panels difficult.

Conclusion

The team is proud of how the project ended up. After deciding upon a goal of helping victims of natural disasters, much work was spent in several stages of the design process of a product. The project ended after a proof-of-concept prototype was built and evaluated. Overall, the team learned knowledge and skills that will help them in their engineering futures to come.

Works Cited

- [1] "2-In-1 Support/Cargo Bar." *Harbor Freight Tools*, www.harborfreight.com/2-in-1-support-cargo-bar-66172.html.hg
- [2] B. Munson, T. Okiishi, W. Huebsch, A. Rotj Mayer, *Fundamentals of Fluid Mechanics*, New Jersey, John Wiley & Sons, Inc., 2013, Page 60, Print
- [3] "Data Visualization: Historical Flood Risk and Costs." *Data Visualization: Historical Flood Risk and Costs | FEMA.gov*, Department of Homeland Security, 24 Jan. 2018, www.fema.gov/data-visualization-floods-data-visualization.
- [4] Deziel, Chris. "Standard Entrance Door Dimensions." *Home Guides | SF Gate*, San Francisco Chronicle, 7 Oct. 2016, homeguides.sfgate.com/standard-entrance-door-dimensions-89777.html.
- [5] Dieter, George Ellwood., and Linda C. Schmidt. *Engineering Design*. 5th ed., McGraw-Hill, 2013.
- [6] *Friction and Friction Coefficients*, www.engineeringtoolbox.com/friction-coefficients-d_778.html
- [7] Nettles, William, and Shannon McCall. "Flooding Experience." 22 Nov. 2017.
- [8] "Light Duty Cargo Bar for Vans and Small Trucks." McMaster-Carr, www.mcmaster.com/#3182t72/=1ckz2sl.

Appendix

Final Design Iterations:

Panel:

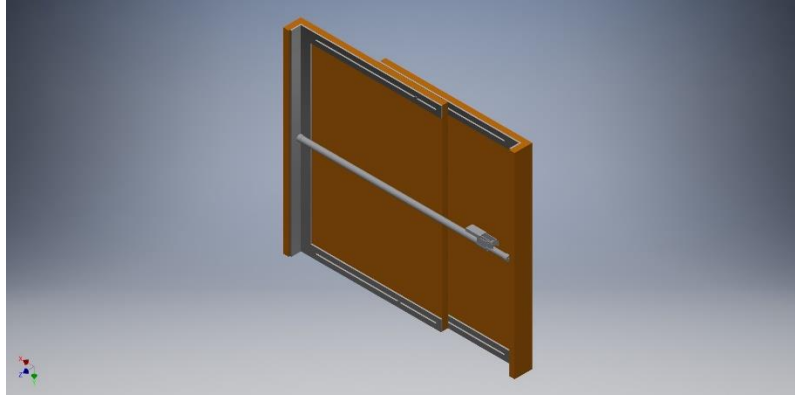


Figure 16

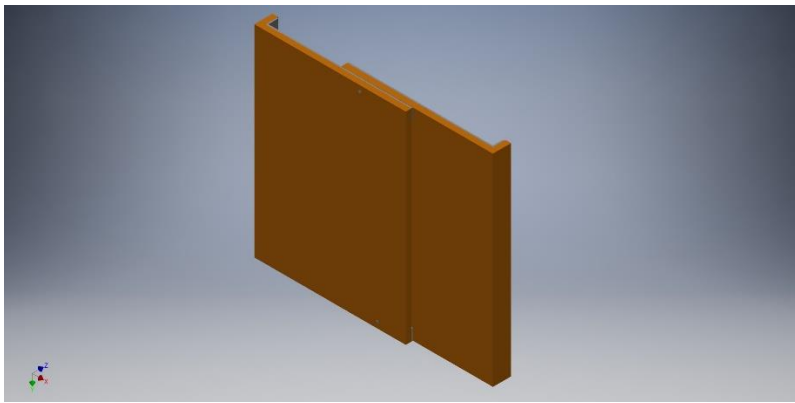


Figure 17

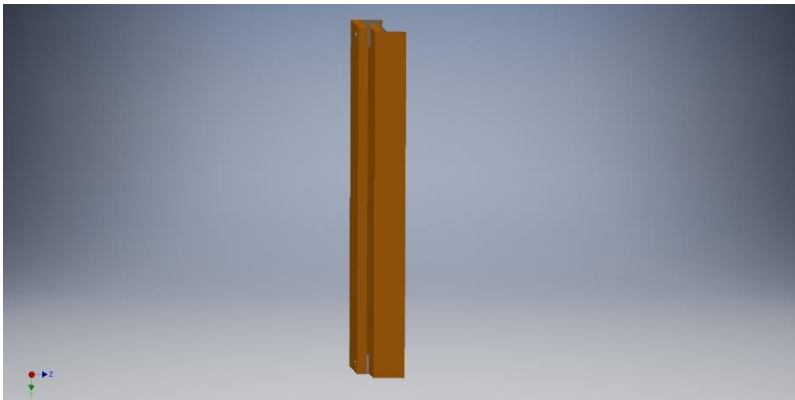


Figure 18

Telescoping C-Chanel:

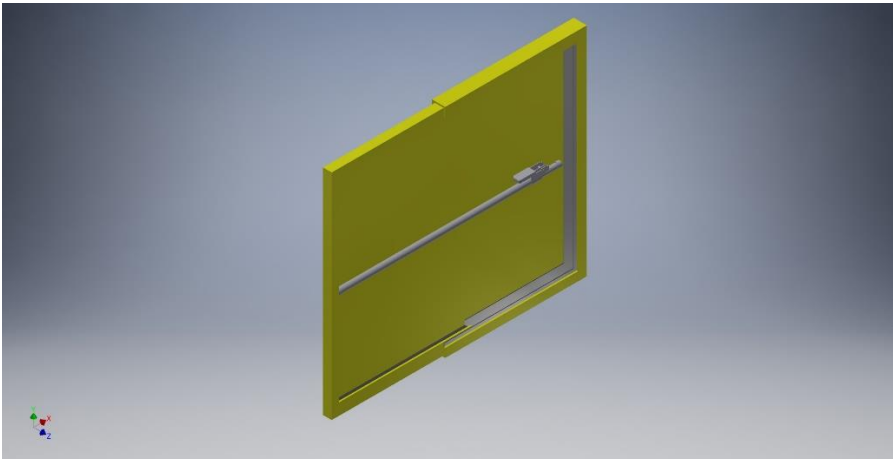


Figure 19

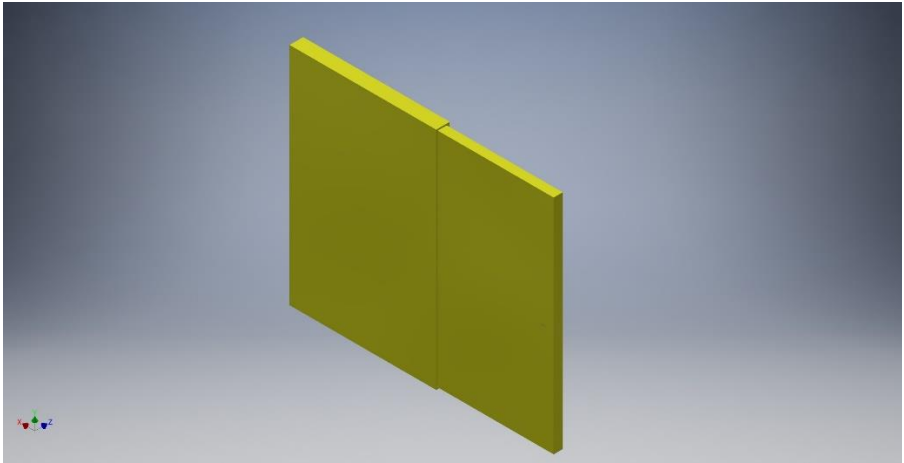


Figure 20

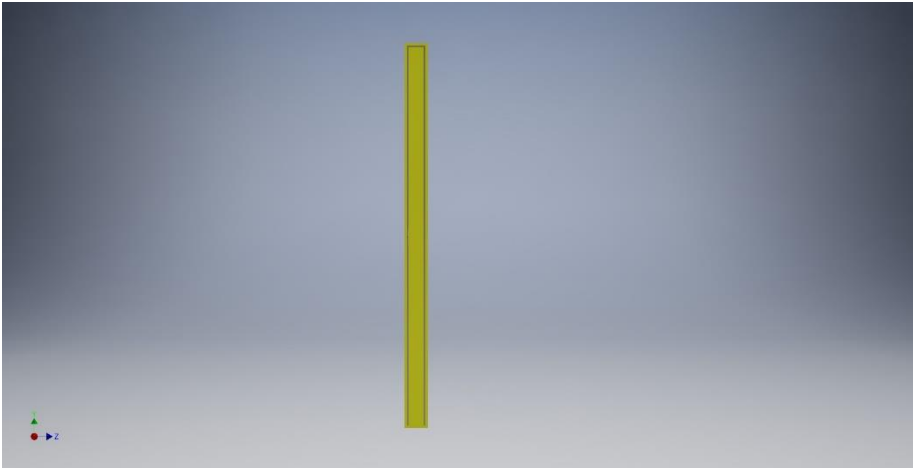


Figure 21

Telescoping L-Chanel (Chosen Design):

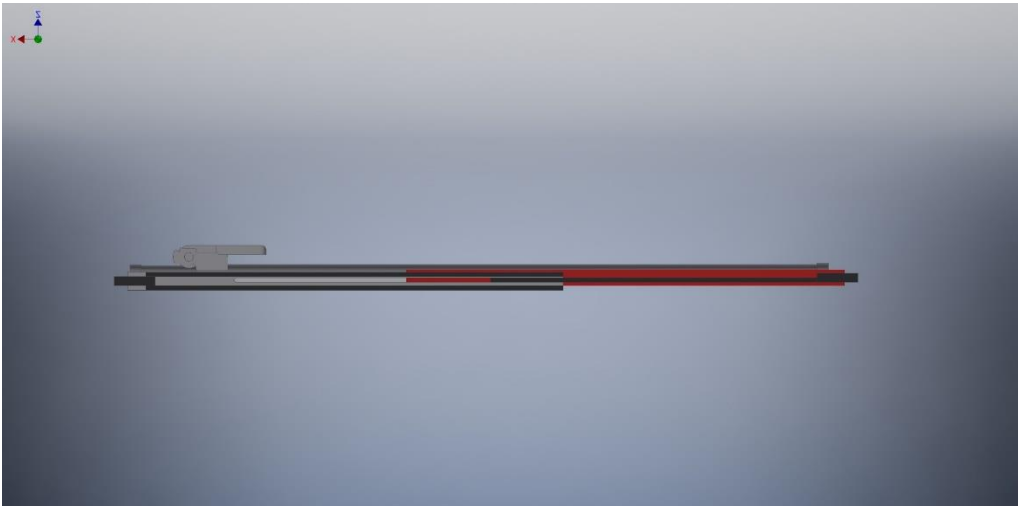


Figure 22

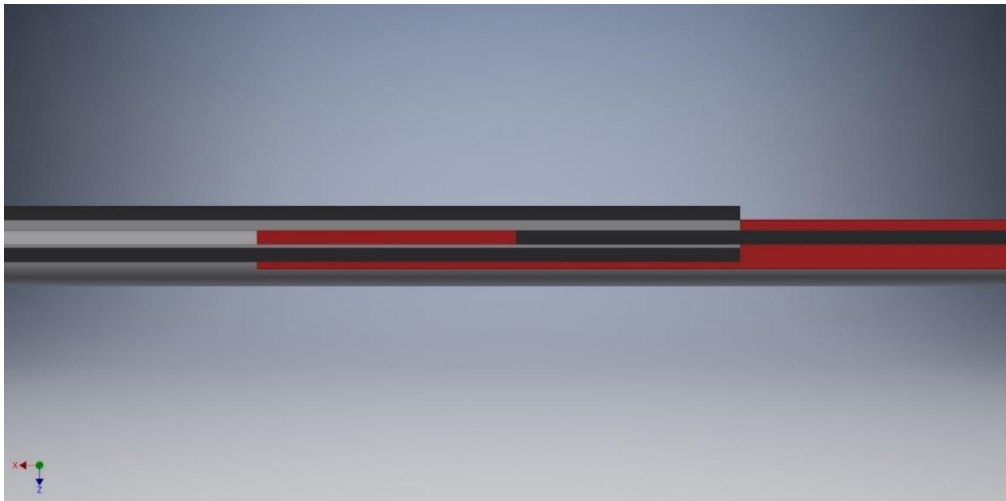


Figure 23

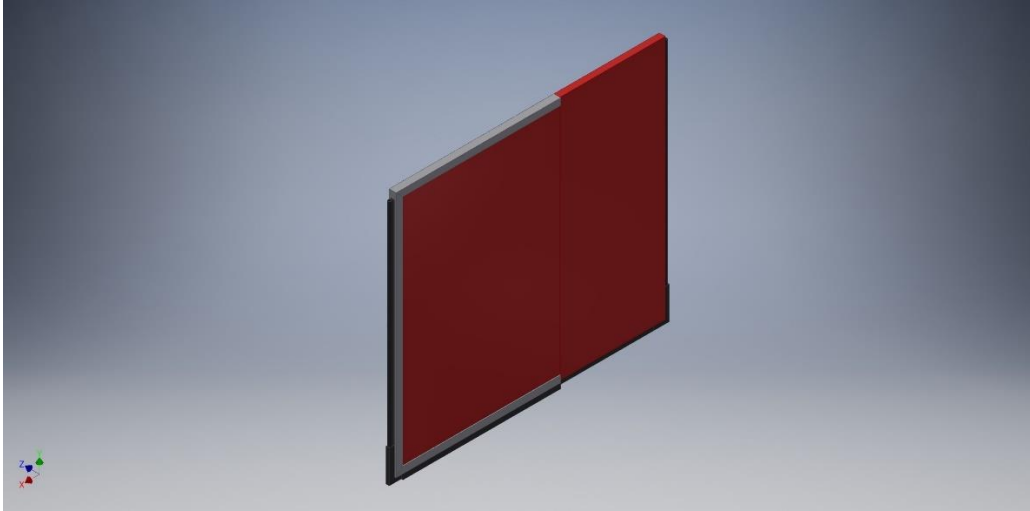


Figure 24

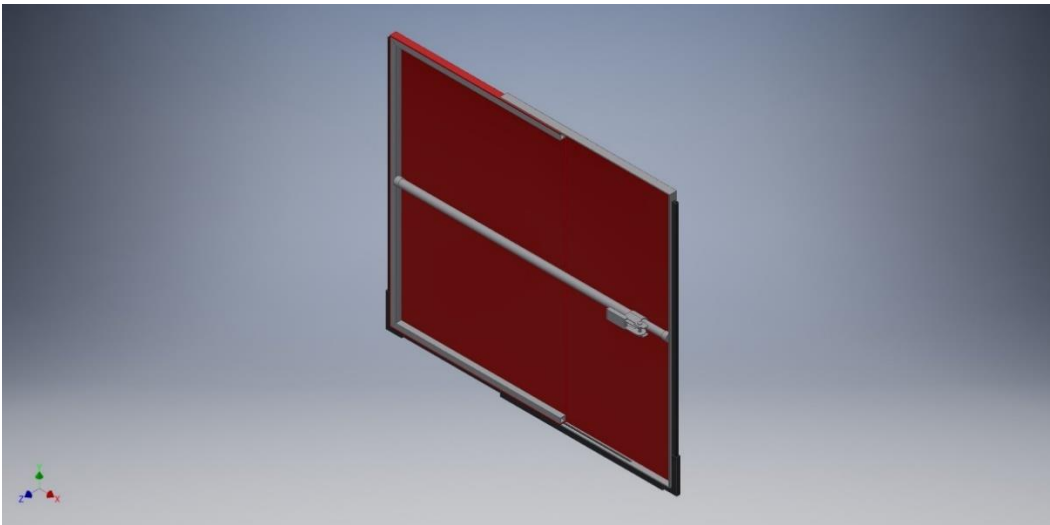
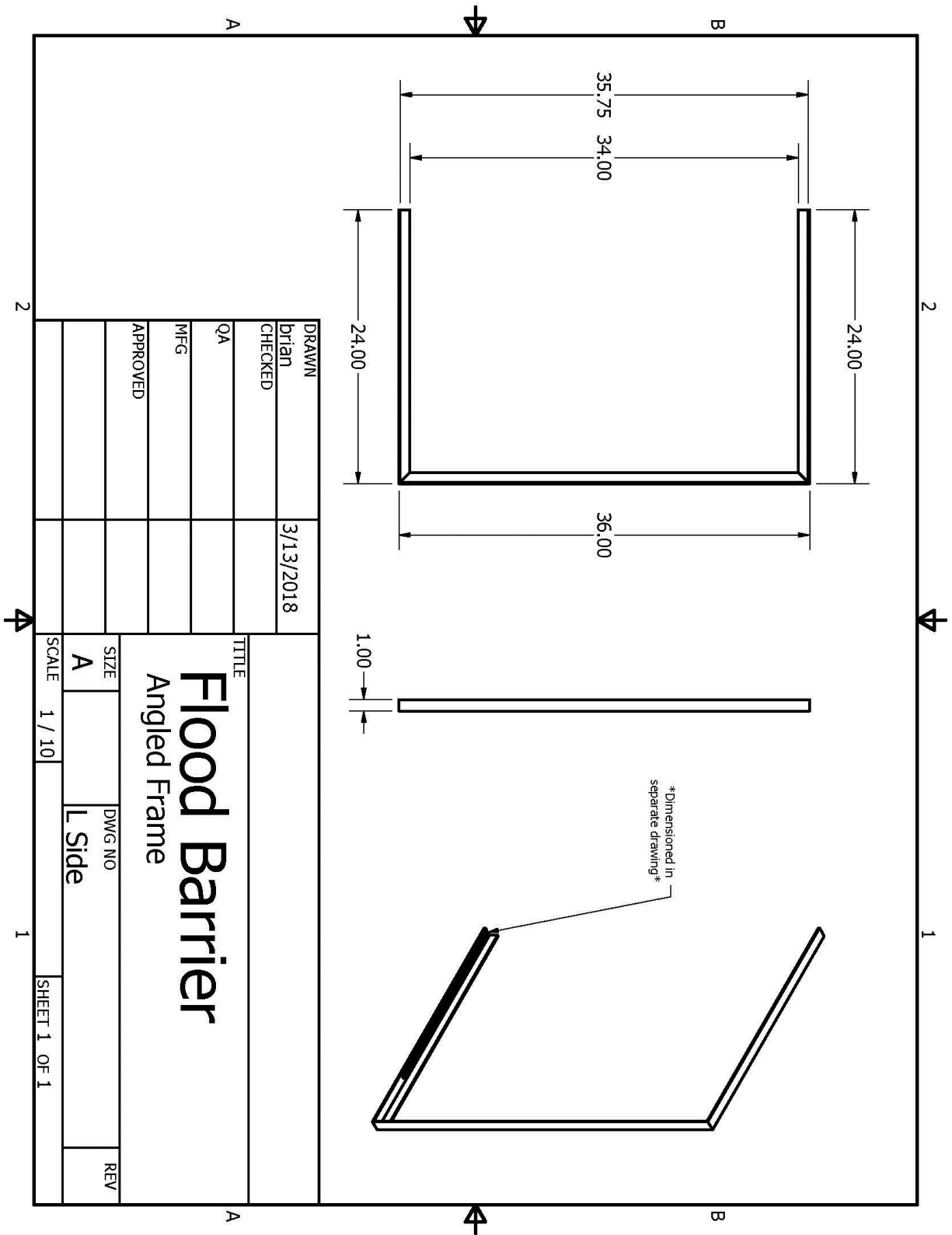


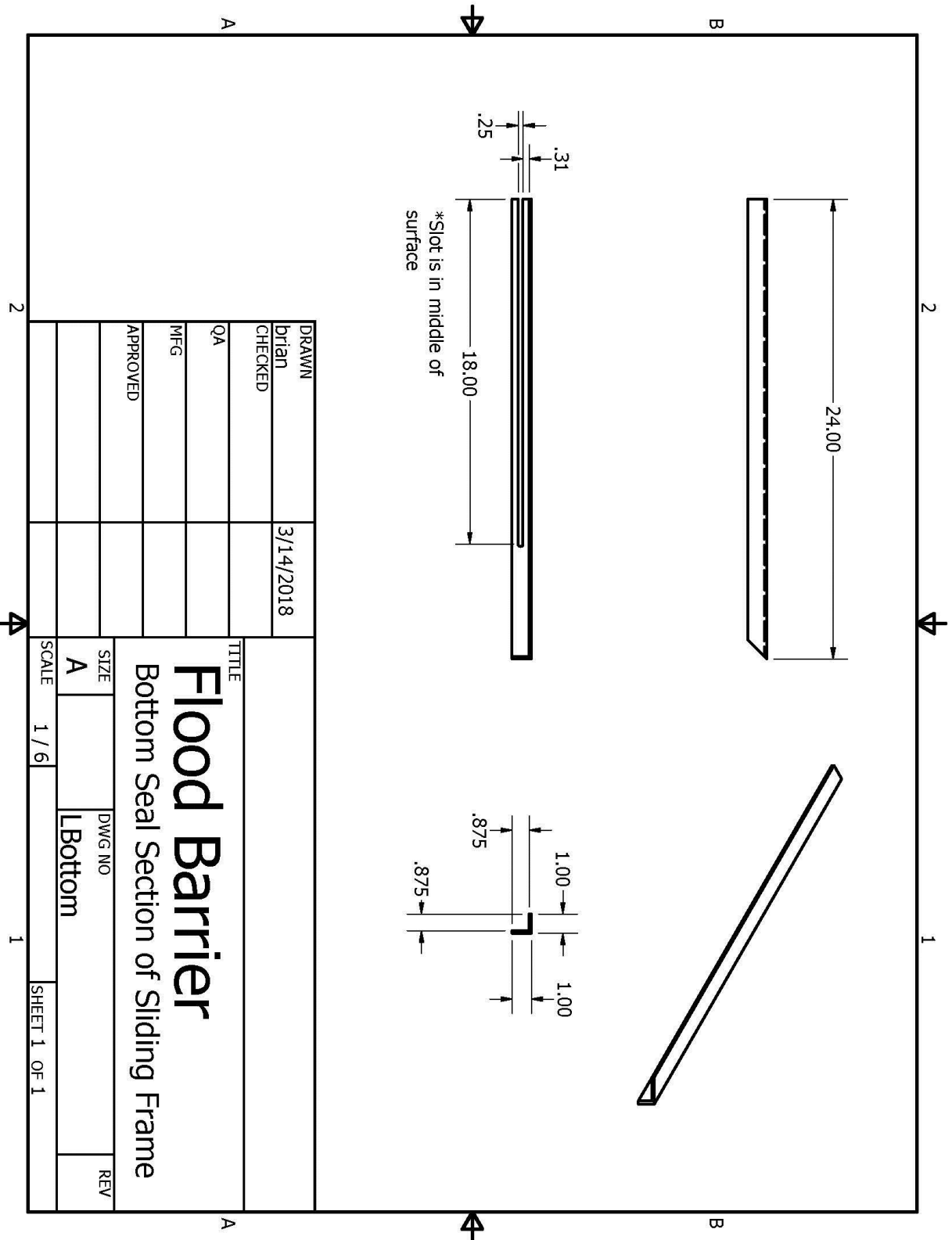
Figure 25



Figure 26

Part Drawings:

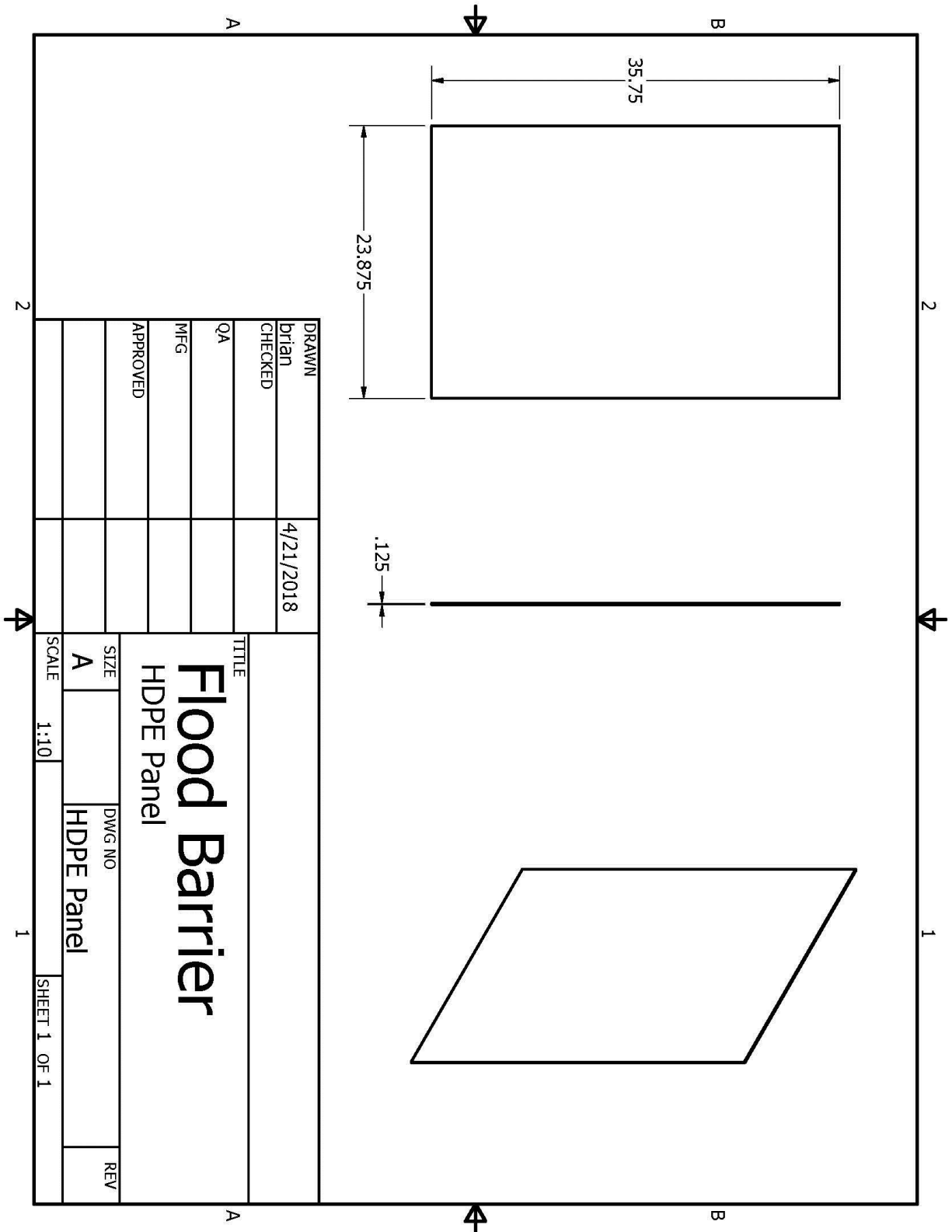




*Slot is in middle of surface

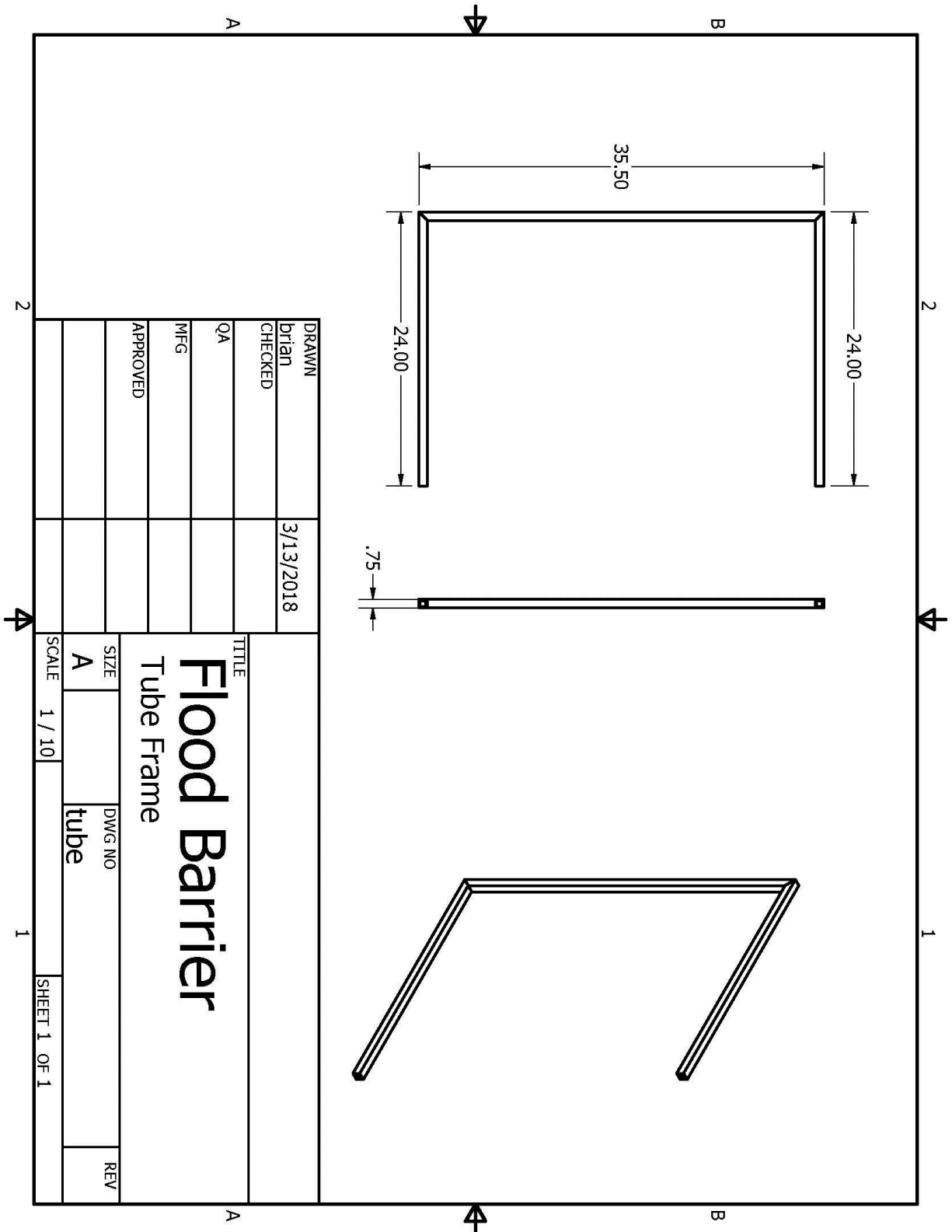
DRAWN	3/14/2018
Checked	
QA	
MFG	
APPROVED	

TITLE		Bottom Seal Section of Sliding Frame	
SIZE		A	
SCALE		1 / 6	
DWG NO		LBottom	
REV			
SHEET 1 OF 1			



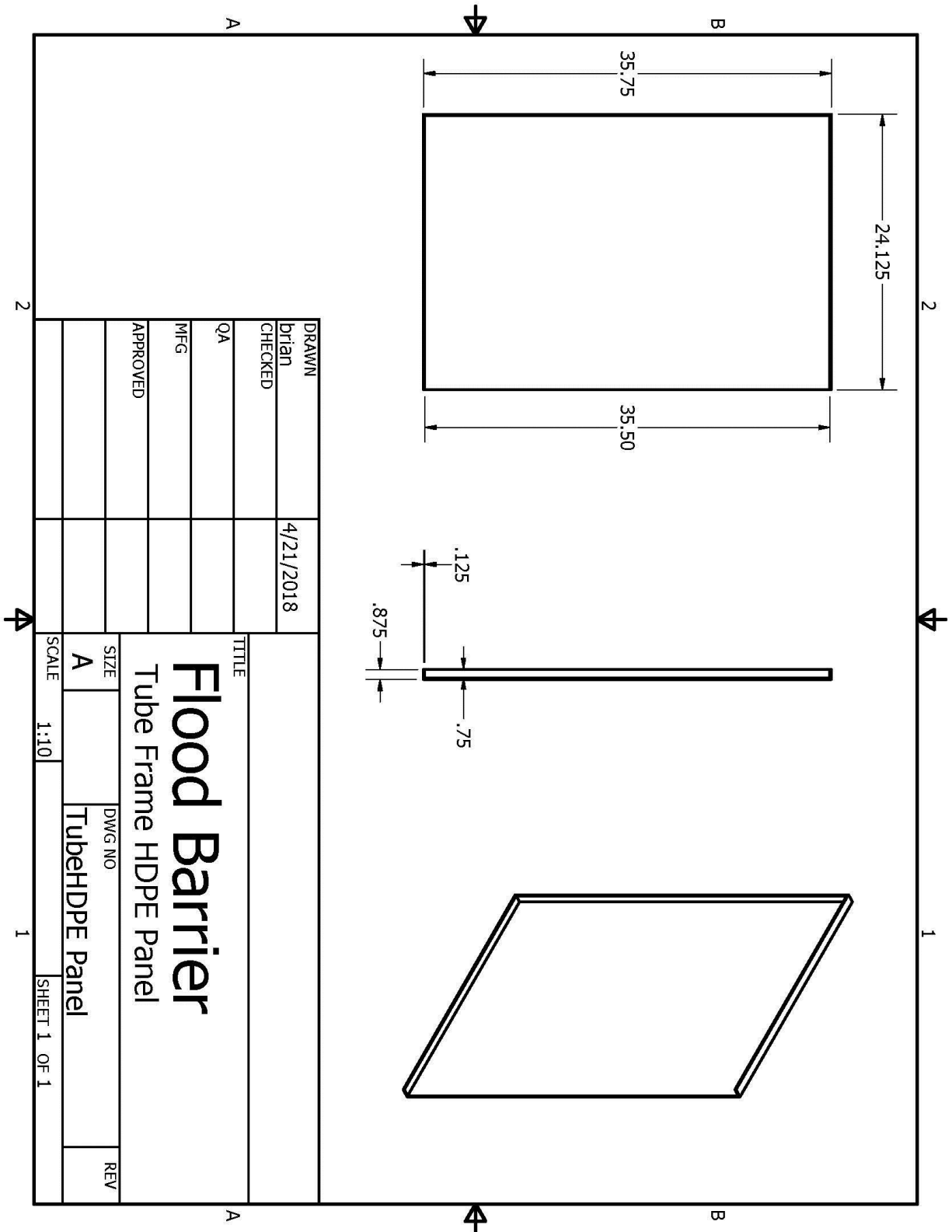
DRAWN	4/21/2018
Checked	
QA	
MFG	
APPROVED	

TITLE		HDPE Panel	
SIZE		A	
SCALE		1:10	
DWG NO		HDPE Panel	
REV			



DRAWN		3/13/2018
CHECKED	brian	
QA		
MFG		
APPROVED		

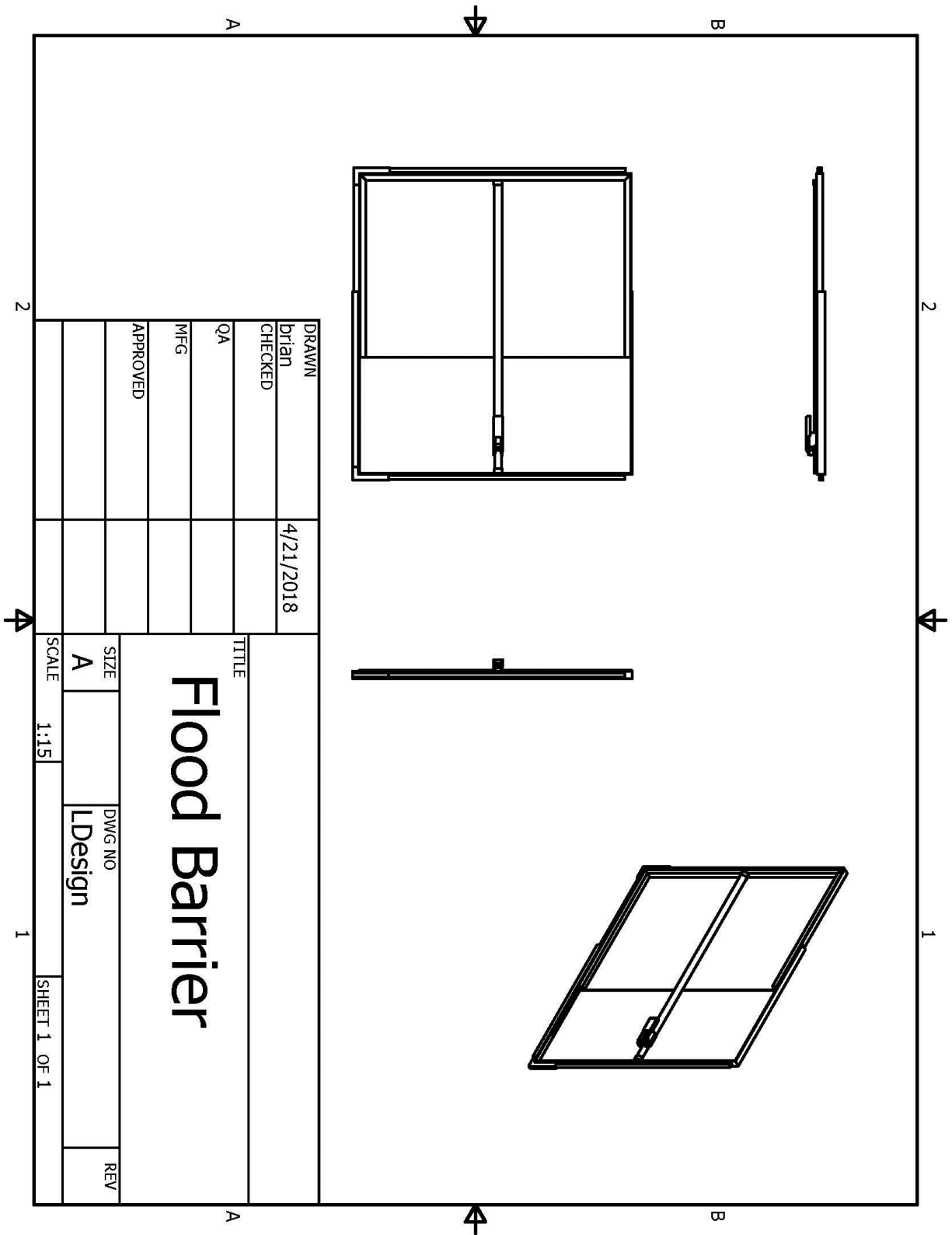
TITLE		Flood Barrier	
Tube Frame			
SIZE	A	DWG NO	tube
SCALE	1 / 10		
SHEET 1 OF 1			
REV			



DRAWN	4/21/2018
Checked	
QA	
MFG	
APPROVED	

TITLE		Flood Barrier	
Tube Frame HDPE Panel		TubeHDPE Panel	
SIZE	A	DWG NO	
SCALE	1:10	SHEET 1 OF 1	

Assembly Drawing:



Exploded View Drawing:

PARTS LIST		PART NUMBER
ITEM	QTY	
1	1	L Side
1-1	1	L Side
1-2	1	L TopBottom
1-3	1	L Bottom
1-4	1	HDPE Panel
1-5	1	sideseals
1-6	1	corner seal
1-7	2	BottomSeal
2	1	tube
2-1	1	square side
2-2	2	square side topbottom
2-3	1	TubeHDPE Panel
2-4	1	sideseals
2-5	1	corner seal
2-6	1	BottomSealSlot
3	1	modified CARGO BAR

DRAWN brian	4/21/2018		
CHECKED			
QA			
MFG			
APPROVED			

Flood Barrier		TITLE
Exploded View		Exploded View
SIZE A	DWG NO Exploded View	REV
SCALE 1:17	SHEET 1 OF 1	