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Slope Stability Flume

Senior Design Report

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- Justin Amos – Applied Engineering Center Lab Manager
- Dr. Todd Nelson – Assistant Professor of Engineering
- Mr. Kevin Nelson – Assistant Professor of Engineering
- Ms. Jamie Curry – Senior Administrative Assistant

Abstract

The scope of this project is to continue building and designing a slope stability flume for the USI's civil engineering department. A slope stability flume is a device used to simulate landslides, water erosion, evaporation, etc. The flume will be made by using steel bar stock, Lexan siding, and other materials. A floor jack will be provided to be able to tilt one side of the flume when used for testing, as well as casters for easy movement. The flume will also be able to support the weight of moist sand, along with easy cleaning solutions. The flume will also double as a storage bin and desk for students when it is not being used.

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Introduction

Objective

The goal of this project is to:

Update, design, fabricate, and finish a slope stability flume for the USI Civil Engineering department.

The USI Civil Engineering Department reached out to the previous seniors Ethan Hahn and Calvin Brinton, to create a slope stability testing flume. The flume is used to simulate a landslide using moist sand. Our goal is to continue what they had started, while also adjusting their designs to improve this flume.

Deliverables

The deliverables of this project are as follows:

- Improvements and updates to the previous design
- Create a functional Slope Stability Flume

The Slope Stability Flume should be complete and have a multifunctional purpose to serve as a storage bin, or table when not in use. It should roll freely for easy mobility.

What is a Slope Stability Flume?

A slope stability flume is an apparatus to test and analyze the response of loose solids and debris. A flume can vary in size and is used to contain different ground materials. Small scale testing can include controlling the slope angle and material content. Large scale testing involves more in-depth testing devices such as scales, sensors, and filtration. Figure 1 is an example of what happens during the stages of a slope failing [1]. The picture shows the flume bed in blue, the orange dotted line shows the original shape of the flume, and the black outline shows the failure occurring in the slope. The first stage is wetting (a) which shows the beginning of the process. (b) Shows the first few small failures. Similar to an avalanche, (c) is the slope in major failure. (d) is the successive motion of the slope when is has failed completely. The orange dashed line shows where the slope had been originally.

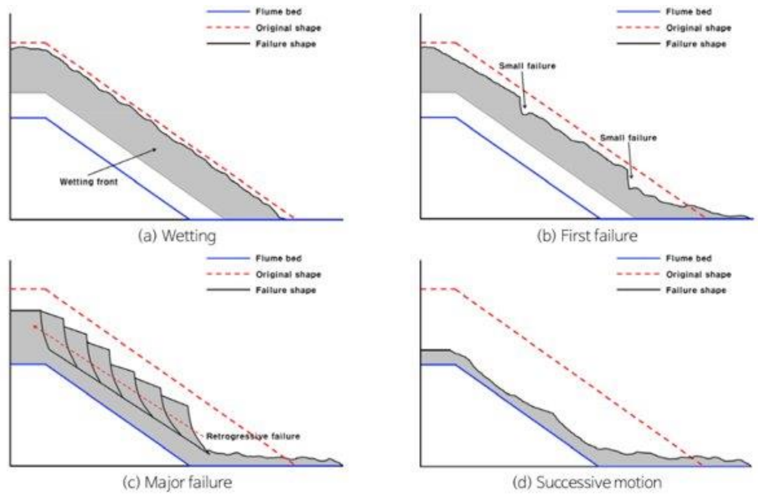

Figure 1: Slope Stability Analysis [1]

Testing involves real-time data to consider where a landslide will take place. An example of this would being testing whether an embankment will divert water correctly without damaging the surrounding area. Another use for a slope stability flume is to predict/prevent risks and hazards of natural disasters. Dave Petley, an earth scientist at the University of Sheffield, calculated that landslides have caused 32,322 fatalities between 2004-2010 [2]. By implementing the use of a slope stability flume, that number can be reduced in the future to come.

Previous work

In the fall semester of 2021, two students, Calvin Brinton and Ethan Hahn had started a project for the civil engineering department. Their goals were to design and create a slope stability flume as a testing device that will be used to simulate landslides.

The two seniors had started by looking into the background of the stability flumes. Then after going through calculations, design, and preparation, they started welding the structure together. As the semester ended, they were not able to finish the flume. Figures 2 and 3 show their design and the completion of the project.

The project was then handed over to this senior project team. The design was reviewed. New calculations showed that there could be better alternatives to the design. With this, the previous SolidWorks file was used to redesign the flume to improve the structure.

Figure 2:Previous Work *Figure 3: Previous Design*

Teamwork

Plans

After reviewing the previous work, the main goal of this project was to get it completed. We learned more about the slope stability flume and how it works. With this information, a plan was made to take last semester's design and improve it. After talking with professors and the team who had originally started the project, the decision was to first run a simulation of the SolidWorks design. Listed below is the list of tasks to have completed.

- Define the project
    - Go over previous work
    - Understand the use for a slope stability flume
- Get required AEC safety and welding training
- Learn SolidWorks finite element analysis from Dr. Nelson
- Designs/simulation
    - Improve designs
    - Create simulations of each design
- Create Bill of Material
    - Add new material/steel

    - New casters
- Order Material
- Fabrication
    - Finish welding
    - Create plates for casters
    - Cut/size polycarbonate (Lexan) sides and base
    - Seal and fasten
    - Incorporate plate for jacks

Materials

Previous Materials

Table 1: Previous Bill of Material shows the list of materials and pricing from the previous team. Items in the list include various steel cuts of different sizes, silicone caulking, and caster wheels. With the items in the list there was little left over. As shown, their total was at $400 which was under their budget of $500.

BILL OF MATERIAL (Previous Semester)			
Material	Quantity	Price	Total
2inx2inx4ft Rolled Steel Angle	3	$ 21.40	$ 64.20
2inx2inx3ft Rolled Steel Angle	7	$ 15.19	$ 106.33
2inx3ft Flat Rolled Steel	10	$ 8.65	$ 86.50
2x3 Flat Rolled Steel Angle	6	$ 11.93	$ 71.58
Waterproof Caulk	2	$ 5.98	$ 11.96
5in Casting Wheels (2 Pack)	2	$ 29.76	$ 59.52
TOTAL			**$ 400.09**

Table 1: Previous Bill of Material

Updated Bill of Material

Using the material that was left over from last semester, remaining pieces had to be ordered due to assorted reasons. One of these reasons being that the casters used last semester were only rated at 300 lb. per piece. The calculations verified the casters needed to be rated for at least 400 lb. This was resolved by returning the old casters and ordering the new ones shown in Table 2: Updated Bill of Material. A plan was made to order more 2-in x 2-in x 1/8-in angles to complete the side pieces of the flume. Lastly, ordering nuts, bolts, washers, and caulk, to be able to fasten and seal the Lexan siding to the flume bolt the casters on the bottom.

BILL OF MATERIAL (Updated)			
Material	Quantity	Price	Total
Grainger: 782LG7 - 24 in x 4 in x 3/8 in	1	$ 68.01	$ 68.01
Grainger: 435X89 - Casters	4	$ 44.86	$ 179.44
Grainger: 26LH69 - Nuts - 50 Pack	1	$ 6.60	$ 6.60
Grainger: 1JY33 - Washer - 100 pack	1	$ 8.37	$ 8.37
Grainger: 22RX12 - Bolts - 50 pack	1	$ 15.68	$ 15.68
Home Depot - 2 in. x 1/8 in. x 48 in. Plain Steel Angle	2	$ 15.87	$ 31.74
Home Depot - Alex Plus 10.1 oz. Clear Acrylic Latex Caulk Plus Silicone	3	$ 3.18	$ 9.54
TOTAL			**$ 319.38**

Table 2: Updated Bill of Material

Cost Analysis

In Table 2: Updated Bill of Material, the total amount spent was $319.38, which was under the $400 dollar limit.

Design/Improvements

Process

The design process started off by looking at what the team in the previous semester had completed. A plan was made to analyze their results and see what adjustments needed to be done. A few minor adjustments were made that helped increase the strength of the flume. Such improvements were adding a middle and top horizontal 2-ft x 2-in x 2-in steel angles on each short end along with a 3-ft x 2-in x 1/8-in steel flat bar to tie them together.

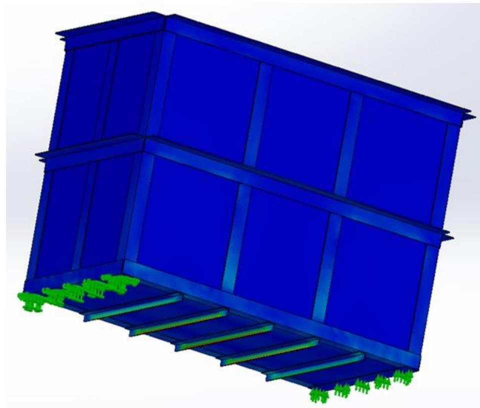

Figure 4: Added Angle

Another improvement made was moving the 3 -ft x 1-in x 1-in steel angle bottom Lexan support from inside the structure to under the structure. This was because the steel angle would have created an isolated point of stress on the Lexan. With the completed drawings, a meeting with Dr. Todd Nelson was made to be taught how to run the finite element analysis through SolidWorks.

Finite Element Analysis (FEA)

Dr. Todd Nelson provided more information about SolidWorks' finite element to get a better understanding of the software. Formatting, meshing, and calculating are all important parts of the analysis. Dr. Nelson gave a step-by-step tutorial on how this information would need to be inputted into the software. Involving the finite element analysis software would give more information on what would need to be done to the flume.

A finite element analysis is a computerized method for predicting how a product reacts to real-world forces. Finite element analysis shows whether a product will break, wear out, or work the way it was designed. It can be also used to predict what is going to happen when the product is used. The way the FEA works is by breaking down a real object into thousands of finite elements, such as little cubes. Mathematical equations help predict the behavior of each element. A computer then adds up all the individual behaviors to predict the behavior of the actual product [3].

To determine whether the structure will yield or fracture under load, the von Mises stress scale was provided in the analysis. von Mises stress is a value used to determine if a given material will yield or fracture. It is used mainly for ductile materials, such as metals. The von Mises yield criterion states that if the von Mises stress of a material under load is equal or greater than the yield limit of the same material under simple tension then the material will yield [4]. See figure 5.

Figure 5 is the von Mises stress scale associated with the FEA's shown below. The scale is in units of N/m^2, this is how von Mises stress is calculated. The yield limit of steel is normally around 3.5e+08 N/m^2. If the steel would surpass the yield limit, it would cause permanent plastic behavior for the flume. This would give a good direction of where the flume's stress needed to be.

Figure 5: von Mises Stress Scale

FEA 1

In the first finite element analysis of the initial design, the steel material of our structure to be cold rolled steel was defined. 1600 lb was applied throughout the bottom of the flume, this is shown in the figure being orange downward pointing arrows. The 1600 lb was used due to the calculations of the total weight being under 1500 lb when everything is added. The upward pointing arrows colored green are a representation of the casters applying a resistance to the force. The first run did not include the Lexan glass. This would test the tensile strength of the steel base. The bottom Lexan would be supported by three 1-in x 1-in steel angles. Once the analysis was finished, the results concluded that the structure was sound based on the von Mises stress scale.

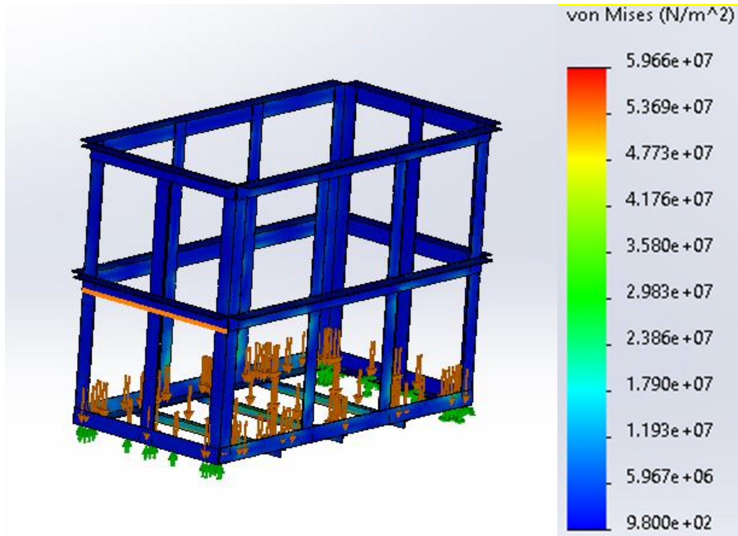

Figure 6: Simulation 1 (Three (3) 1-in x 1-in angle)

FEA 2

For the second analysis pieces of Lexan were added to the model. Another simulation was run with the same settings and found that the middle steel 1-in by 1-in angle was reaching failure. The three 1-inch angle was too small/weak to support the 1600 lb of force.

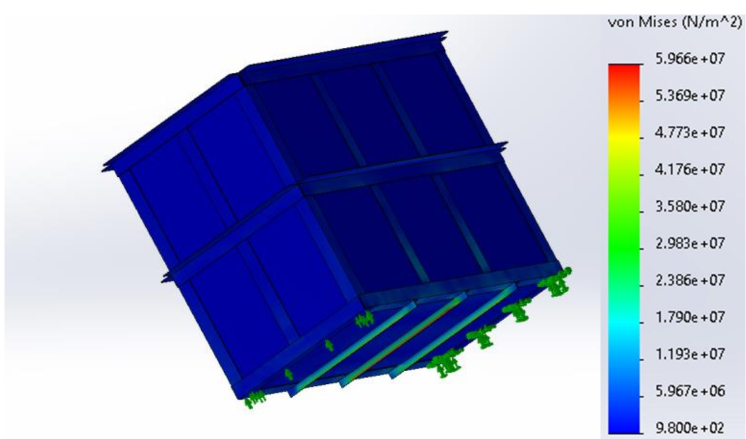

Figure 7: Simulation 2 (Added Lexan)

FEA 3

For the third analysis, the 1-inch angle was replaced with a 2-inch angle and kept everything else the same. It was expected to pass the test due to it being stronger and having more surface area for the Lexan to rest on. Unfortunately, the simulation had shown the same problems as the previous test. The middle piece of angle iron had too much stress on the bottom.

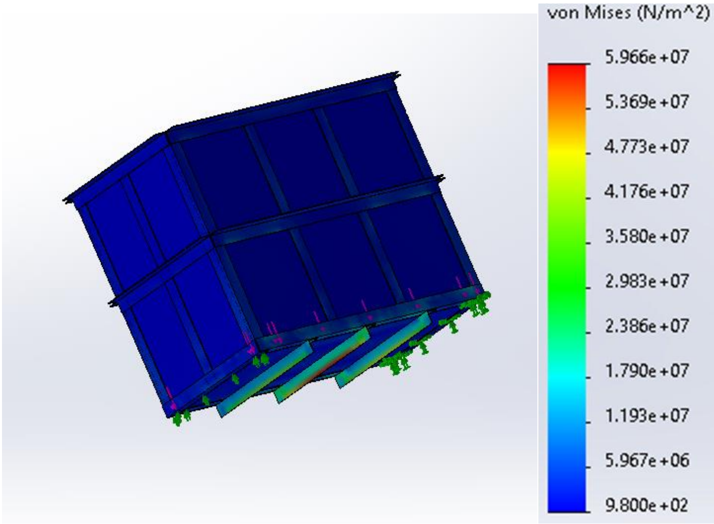

Figure 8: Simulation 3 (2x2x1/8 angle)

FEA 4

For the fourth analysis, five 1-in steel angles for the Lexan support. The structure is sound based on the von Mises stress scale.

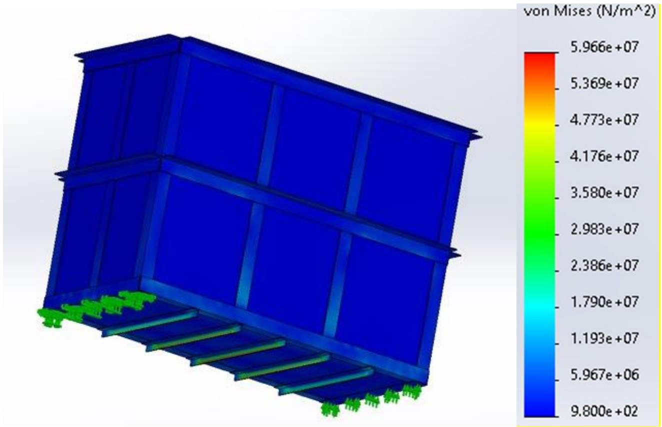

Figure 9: Simulation 4 (with 5-1x1x1/8 angle)

Fabrication

Before the continuation of the construction, it was determined that the shorter sides of the flume were not stable. This was due to the lack of support from steel angle in that area. Because of this, it was decided to add a 3-ft x 2-in x 1/8-in piece of vertical flat stock and a two 2-ft 2-in x 2-in x 1/8-in pieces of steel angle horizontally. See figure 10. This helped with the increase in strength and decrease in the flexibility of the structure. This would also help when attaching and fastening the Lexan sheets later.

Figure 10: Top View of Edge

Figure 11 shows the process of welding on the side pieces of the flume. Proper cuts and measurements allowed us to mount and weld the pieces to create additional strength. Horizontal 2-inch x 2-inch angle will help decrease the flexibility in the structure of the flume. Adding the vertical piece of 3ft x 2-in flat sock will not only help with tying the steel together but will also keep the Lexan at the same level throughout the entire side. This is because the 1/8-in thick piece is on the same plane as the 2-in x 2-in angle on the corners.

Figure 11: Welding the Sides

Next, the designs were necessary to verify what needed to be done. After noticing some minor welding flaws from the previous semester and decided to grind down the welds. Doing this allows smoother working areas and a better surface when attaching the Lexan. Additional welds to the corners with gaps were intended to increase the strength of the flume.

The bottom side was evenly measured to fit the five 2-ft x 1-in x 1-in angle and secure them using clamps as shown in Figure 12. All five pieces were attached about 7 and ¾ inches apart to give the best distribution of the forces acting down on it.

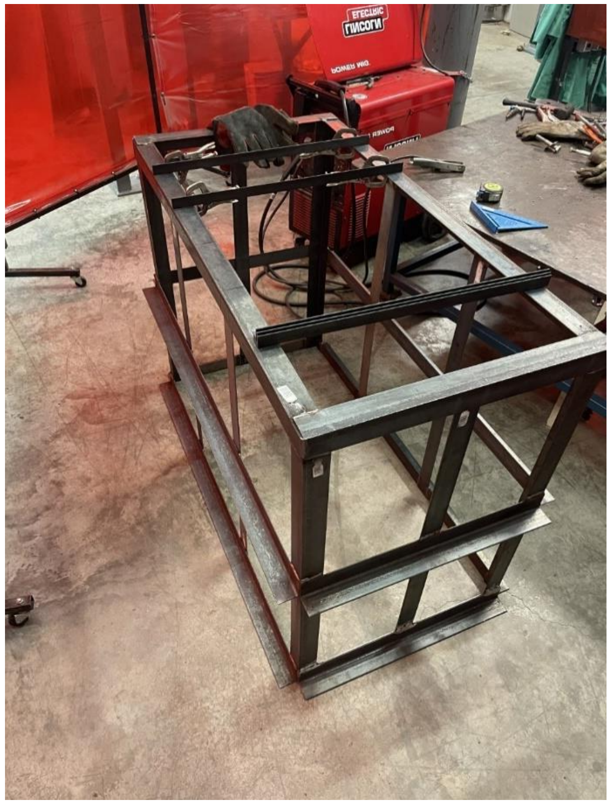

Figure 12: Attaching the Angle

After attaching the bottom supports, the plan was to move on to cutting and drilling the holes for the steel plates needed for the casters. The first step was to use the horizontal band saw to cut the 24-in x 4-in thick steel plate into 4-in x 4 ½ -in plates to match the mounting plate of the casters. After marking the locations of the holes on each individual plate, the vertical mill to drill them in. In Figure 13*,* it shows how the plate is secured to the mill to drill the holes for the plates.

Figure 13: Drilling Holes

Following this, we were able match up the plates to the corners of our flume. At first, that the plates would not sit flush on the bottom due to the overlapping of the corners. The problem was fixed by adding 2-in cuts of 1/8-in flat stock to even out the corners. Next, the welds were grinded down to level the area obtaining a flush surface. Figure 14 shows us grinding down the corners to smooth the surface. After smoothing the surface, the holes were drilled to attach the plates and casters.

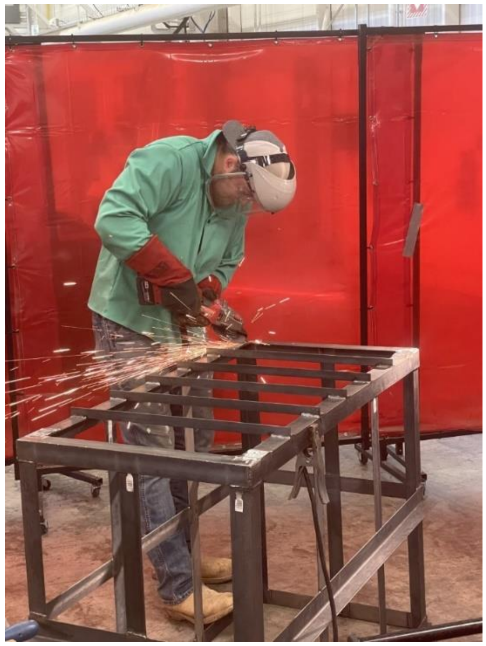

Figure 14: Grinding Edges

After positioning the plate, marks were made on the base of the frame to drill the holes. This time, a cordless drill to complete this task. After the first holes were made, a noticeable mistake occurred. The holes line up with the caster plates and the bolts fit through, but the washers would not fit on this inside of the frame due to the little amount of room. Shown in Figure 15, we did not look forward enough to see if this was able fit the way we needed.

Figure 15: Flaws in Drilling

To fix this issue, it was decided to relocate the plate to hang off the outside edge of the frame. The plate would be attached by welding it to the steel angle. This allows up to be able to secure one bolt into the Lexan and three of the bolts on the outside of the frame. Doing this also gives it enough room to add the washers to the frame. Figure 16 shows the new position for our plates and how we overcame this issue.

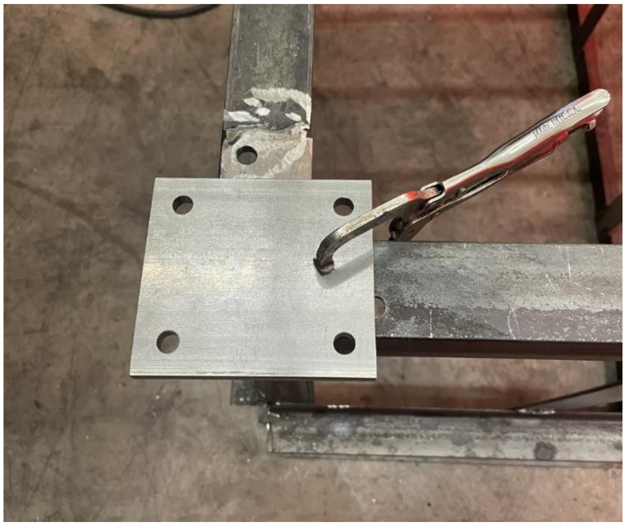

Figure 16:Relocating the Plates

Now that the base of the frame is completed, it was time to measure and sketch the drawing for the Lexan siding. There are 2 Lexan sheets that are 5-ft x 8-ft x ½-in thick to cut from. Because the water jet is being used to cut the Lexan into correct sizing, it needed to have an AutoCAD drawing to use the programming for the machine. Figure 17 is the AutoCAD file which was used to format the measurements of the sheets. Mr. Amos was able to show us how to articulate the file and use the CNC water jet properly. Shown below in figure 18, is the waterjet in action.

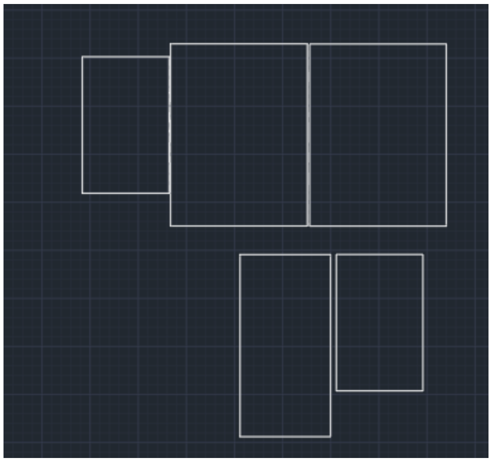

Figure 17: AutoCAD Drawing for Lexan

Figure 18: Water Jet Cutting Lexan

The next step was to attach the casters to the flume. After double checking the sizing of the holes and location of the plates, the next step is to weld on the plates. When attaching the plates, the bolts, nuts, and washers were needed. Running into a problem that the small gap between the Lexan and the plate had not given enough room for the bolt to fit. See figure 19. The only solution to this problem was to buy longer bolts.

Figure 19: Bottom Lexan Bolt Hole

When installing the casters, the main problem was the turning of the wheels. The caster was catching the edge of the washer and causing minor problems when moving the flume. To fix this, the washers on the bottom side of the casters had to be machined to create a flat edge. Seen in figure 20, the best way to do this was by grinding a very small amount off. This allows the caster to miss the edge of the washer allowing it to move freely.

Figure 20: Grinding the Washers

There was a series of holes that needed to be drilled out for the siding pieces of Lexan since the bottom Lexan holes had already been drilled. Figure 21 shows the drill we used to complete this task. Spacing out the holes strategically was the hard part. In this process, the holes were drilled out in diagonal patterns to get a good spread of tension on the Lexan.

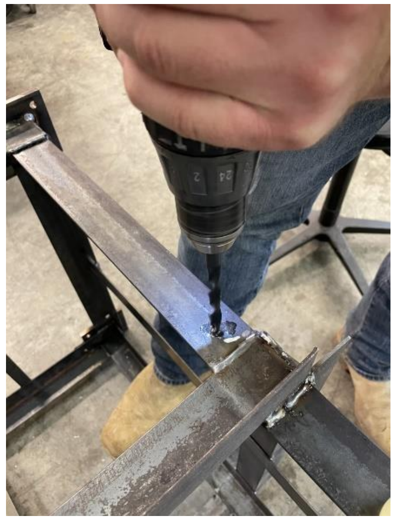

Figure 21: Drilling

Having our cut pieces of Lexan, as well as having the holes predrilled, the Lexan can be added. The Lexan was clamped down to the frame. This allowed for the hole in the frame to be used as a pilot hole for the Lexan. Following the drilled holes, the bolts and washers were to fasten the Lexan and have our flume ready for Caulking.

In Figure 22, the procedure of caulking the flume is shown as well as the pieces of Lexan fastened to the flume. Shown below is the bead of caulking coming out white. When it dries it will become clear to make a cleaner look to the flume. The need for caulking was important because it allows the flume to become watertight in areas that are not tight enough to restrain the water and sand from passing through.

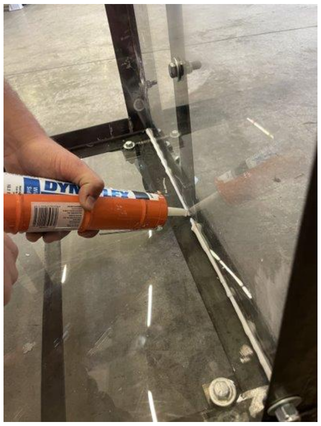

Figure 22: Caulking the Flume

Mentioned previously, for the testing to be done it would need a lifting point for the jack. After contemplating a few ideas, the flume would be raised by a small car jack with a piece of 2-inch by 4-inch wood block to disperse the force. See figure 23.

Figure 23: Raising the Flume

Conclusion

The finished slope stability flume is shown below in figure 24. Along with finishing the flume, knowledge of welding, machinery, safety, and SolidWorks had been gained. The flume consisted of many hours of learning and experience. The accomplished tasks were improving the weight calculations, increasing the strength of the structure, drilling holes throughout the steel, adding the 400-pound rated casters, and attaching the Lexan.

Figure 24: Finished Flume

After completing the project, a major recommendation for its longevity of use would be to use a wet/dry vacuum to cleanly remove the sand and water. This will keep the flume from molding. Another recommendation would be to replace and redo the caulking every few semesters to keep a good seal to in the flume.

Future work

Along with our recommendations, more work could be done to improve the flume itself. One of these being to paint the steel to prevent it from rusting. Another addition to the flume would be the wooden tabletop. This is to add a secondary use to the classroom as an extra table for students to use in the classroom.

References

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Appendix

$$Steel = 106lb$$

$$Lexan = 137lb$$

$$Sand = 1140lb$$

$$Water = 83lb$$

$$Hardware = 10lb$$

$$Total = 1476lb$$