# Avalon Submersible Support Structure

# Final Design Report

*Sponsor: Bob McCay, MBMM*

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## *Statement of Disclaimer*

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# List of Nomenclature

All design components that will be referred to by a specific name are defined in order of appearance in the report, using labeled images of CAD models. What follows is a list of all component names used in the report, for reference by the reader.

*A. The Final Design*

1. *Connection Box:* The component of our design that directly interfaces with the trailer.
2. *Sawhorse:* The component of our design consisting of an H-beam, two 6x6" square tubes, and three 4x4" square tubes per 6x6" square tube. The part of the design that interfaces directly with the asphalt.
3. *Shim Pack:* The collection of shims and their connecting hardware that resides between the connection box and the sawhorse.
4. *Stability Rod:* A ⅝" diameter rod that links the connection boxes on either side of the trailer. The stability rod runs through a portion of the existing trailer.
5. *Trailer Bolt:* The bolt that attaches the connection box directly to the trailer.
6. *Trailer Interface Nut:* The nut that accompanies the trailer bolt.
7. *Trailer Back Plate:* A small plate that lies at the interface between the trailer interface nut and the back of the connection box.
8. *Trailer Bushing:* A bushing that is placed in the hole that connects the connection box to the trailer. It accounts for the fact that the hole on the trailer is larger than the hole on the connection box.
9. *Long Interface Bolt:* One of four bolts that runs through the shim pack to connect the sawhorse to the connection box.
10. *Nut:* The nut that accompanies each long interface bolt.
11. *Clamping Nut:* The nut that accompanies the stability rod connection.
12. *Puck:* The somewhat semicircular piece of the connection box that sits inside the semicircular holes on the trailer. The puck carries most of the load.
13. *Box Plate:* The bottommost plate of the connection box that interfaces with the interface plate.
14. *Puck Gusset:* A gusset on the connection box located underneath the puck.
15. *Interface Plate:* Basically, the top and bottom shims, one of which is welded to the connection box, and the other of which is welded to the sawhorse.
16. *Back Plate:* The plate of the connection box that directly interfaces with the trailer, by sitting flush with the trailer.
17. *Box Gusset:* One of two triangular plates that joins the back plate and the box plate.
18. *Main Beam:* The H-beam of the sawhorse that runs parallel to the trailer.
19. *Vertical Column:* One of two 6x6" square tubes per sawhorse that runs vertically from the sawhorse towards the asphalt.

20. *Long Foot:* The longer of two plates of the sawhorse that interfaces with the asphalt.
21. *Short Foot:* The shorter of two plates of the sawhorse that interfaces with the asphalt.
22. *Stability Strut:* One of three 4x4" square tubes that brace each vertical column by intersecting it at 45 degrees.
23. *Beam Cap:* One of two square plates that attach, or "cap," the ends of the main beam.
24. *Beam Gusset:* One of two gussets that braces the flanges of the main beam on the side of the beam visible to the public.
25. *Torsion Gusset:* One of two gussets that braces the flanges of the main beam on the side of the beam not visible to the public.

*B. The Steel Scaled Prototype*

1. *Sawhorse:* A scaled version of the sawhorse defined above for the final design.
2. *Moment Fixture:* The assembly that contains the parts that replaced the connection box in the steel scaled prototype.
3. *High Strength Bolt:* One of four bolts connecting the moment fixture to the sawhorse.
4. *High Strength Nut:* The nut that accompanies each high strength bolt.
5. *I-beam:* The scaled version of the main beam defined above for the final design.
6. *Column:* The scaled version of the vertical column defined above for the final design.
7. *Strut:* The scaled version of the stability strut defined above for the final design.
8. *Long Base Plate:* The scaled version of the long foot defined above for the final design.
9. *Short Base Plate:* The scaled version of the short foot defined above for the final design.
10. *End Plate:* The scaled version of the beam cap defined above for the final design.
11. *Gusset:* A scaled version of the beam gusset defined above for the final design.
12. *Fixture Base Plate:* The bottommost plate of the moment fixture that interfaces with the sawhorse.
13. *Moment Column:* The 4x4" square tube of the moment fixture.
14. *Ram Connection Plate:* One of two plates attached to the top of the moment column that serves as the connection point for the ram.
15. *Reaction Fixture:* The overall fixture built to hold the hydraulic ram.
16. *Engine Stand:* An engine stand that was purchased and incorporated into the reaction fixture design.
17. *Strong Floor Plate:* One of four plates welded to the engine stand that was used to bolt the reaction fixture to the strong floor of the Composites Lab.
18. *Engine Stand Attachment:* The assembly of all components, with the exception of the strong floor plates, that attach to the engine stand.

19. *Engine Stand Insert:* A cylindrical piece that was purchased with the engine stand that was used to attach the engine stand to the remainder of the reaction fixture.
20. *Pre-Welded Structure:* A piece of steel found in the scrap yard of the Cal Poly Machine shops that consists of plate and I-beam welded together.
21. *Attachment Plate:* A plate welded to the top of the pre-welded structure that serves as the connection point for the hydraulic ram.
22. *⅜" Hex Bolt:* One of six bolts that connects the pre-welded structure to the engine stand insert.
23. *⅜" Hex Nut:* The nut that accompanies each ⅜" Hex Bolt.

*C. The Wooden Full-Scale Prototype*

1. *Connection Box:* The wooden version of the connection box as defined above for the final design.
2. *Sawhorse:* The wooden version of the sawhorse as defined above for the final design. The wooden sawhorse contains more components than the steel sawhorse, since the wooden sawhorse was assembled using individual pieces of plywood.
3. *Puck:* The wooden version of the puck as defined above for the final design.
4. *Back Plate:* The wooden version of the back plate as defined above for the final design.
5. *Box Gusset:* The wooden version of the box gusset as defined above for the final design.
6. *Box Plate:* The wooden version of the box plate as defined above for the final design.
7. *Puck Gusset:* The wooden version of the puck gusset as defined above for the final design.
8. *Interface Plate:* The wooden version of the interface plate as defined above for the final design.
9. *Beam Assembly:* The wooden version of the main beam, only containing more components than the original beam since the beam was constructed out of individual pieces of plywood.
10. *Column Assembly:* The wooden version of the vertical columns, only containing more components than the original vertical columns since the columns were constructed out of individual pieces of plywood.
11. *Strut:* The wooden version of the stability strut as defined above for the final design.
12. *Long Foot:* The wooden version of the long foot as defined above for the final design.
13. *Short Foot:* The wooden version of the short foot as defined above for the final design.
14. *4x4" Block:* A block used to aid in the assembly of the column assembly. The 4x4" block is not visible upon assembly of the columns.

15. *2x4" Block:* One of two blocks used to aid in the assembly of the column assembly. The 2x4" blocks are not visible upon assembly of the columns.
16. *5 inch Plank:* One of two pieces of plywood per column used to construct the wooden version of the vertical column.
17. *6 inch Plank:* One of two pieces of plywood per column used to construct the wooden version of the vertical column.
18. *Top Attachment Plate:* The piece of plywood that caps the top of each column assembly, to aid in attaching the column assembly to the beam assembly.
19. *8 ft Flange:* An 8 ft long section of plywood used in the construction of the flange of the wooden I-beam.
20. *End Cap:* One of two pieces of plywood that represents the wooden version of the beam cap as defined above for the final design.
21. *7 ft Web:* A 7 ft long section of plywood used in the construction of the web of the wooden I-beam.
22. *Attachment Block:* One of several blocks used in the assembly of the wooden I-beam to stabilize the connection between the flange and the web.
23. *7 ft Flange:* A 7 ft long section of plywood used in the construction of the flange of the wooden I-beam.
24. *Torsion Gusset:* The wooden version of the torsion gusset as defined above for the final design.
25. *2.5 ft Flange:* A 2.5 ft long section of plywood used in the construction the flange of the wooden I-beam.
26. *2.5 ft Web:* A 2.5 ft long section of plywood used in the construction the web of the wooden I-beam.
27. *1.5 ft Flange:* A 1.5 ft long section of plywood used in the construction the flange of the wooden I-beam.
28. *Interface Plate:* The wooden version of the interface plate as defined above for the final design.

# Executive Summary

The MBMM, represented by our sponsor Bob McCay, is currently looking for a new way to support the Deep Submergence Rescue Vehicle (DSRV), Avalon, that they have on display. The DSRV is currently sitting on a Short Haul Vehicle (SHV) trailer and the total weight (32 tons) is currently being supported by the SHV's tires. This is a source of concern for the MBMM due to the weathering the tires have undergone combined with the amount of time that they have been supporting the weight. The MBMM is looking for a support structure that will take the weight off of the tires so that they can be removed at their convenience. Our goal for this senior project, under the direction of our advisor Eileen Rossman, was to design a structure that will allow the museum to support the submersible, keep as much of it visible for viewing as possible, and allow the museum to transport it to its final location at their proposed Interpretive Center in the future. First, background research was conducted regarding both submersible support structures, and other types of structures that support large, heavy objects. Next, idea generation sessions were held, and potential solutions were selected using a combination of go/no-go evaluation, pugh matrices, and a weighted decision matrix. The decision regarding the final design was left to the MBMM, as our weighted decision matrix indicated that aesthetics was the final deciding factor. After the final design was selected, extensive analysis was conducted to determine whether it was feasible. To validate the design, we built a steel scaled model of the most critical portion of our design and tested it under the anticipated load case. We also built a wooden, full-scale model of our design for geometric testing. Our testing on the steel scaled model indicated that the design did not meet the strict seismic requirement in our engineering specifications. After discussing this with the MBMM, they agreed to loosen the seismic requirement. However, before manufacturing begins, we recommend that the MBMM have a structural engineer look over our design and calculations, and verify that our structures will not fail in the event of an earthquake.

# Chapter 1 - Introduction

The MBMM (MBMM) is a non-profit organization committed to providing the public "an easily accessible educational venue for maritime history, science, and technology" [1]. The museum, represented by our sponsor Bob McCay, is currently looking for a new way to support the Deep Submergence Rescue Vehicle (DSRV), Avalon, that they have on display. The DSRV is currently sitting on a Short Haul Vehicle (SHV) trailer and the total weight (32 tons) is currently being supported by the SHV's tires. This is a source of concern for the MBMM due to the weathering the tires have undergone combined with the amount of time that they have been supporting the weight. The MBMM is looking for a support structure that will take the weight off of the tires so that they can be removed at their convenience. Our goal for this senior project, under the direction of our advisor Eileen Rossman, was to design a structure that will allow the museum to support the submersible, keep as much of it visible for viewing as possible, and allow the museum to transport it to its final location at their proposed Interpretive Center in the future. To validate our design, we built a steel scaled model of the most critical portion of our design and tested it under the anticipated load case. We also built a wooden, full-scale model of our design for geometric testing.

### *A. Overall Goals*

Our goal was to provide a cost effective design of a support structure that met the project criteria provided by the MBMM. The design package includes a detailed CAD model, the accompanying drawings, a scaled steel prototype of a structure, and a wooden full-scale prototype.

### *B. Problem Definition*

The MBMM needs a new support system for the 32 ton Avalon Deep Submergence Rescue Vehicle because the current structure puts all the weight on tires, which are showing signs of wear. The new structure needs to safely and reliably carry the load, maintain maximum visibility of the DSRV to the public, allow for variable height due to uneven ground, be simple to manufacture, and allow for future transport of the submarine.

### *C. Boundary Sketch*

In the preliminary stages of understanding the problem, we developed a rough boundary sketch. The purpose of this sketch was to illustrate the current situation our sponsor is in, and highlight the area our design will focus on by surrounding the area with a dashed line. Our boundary sketch can be found in Figure 1.

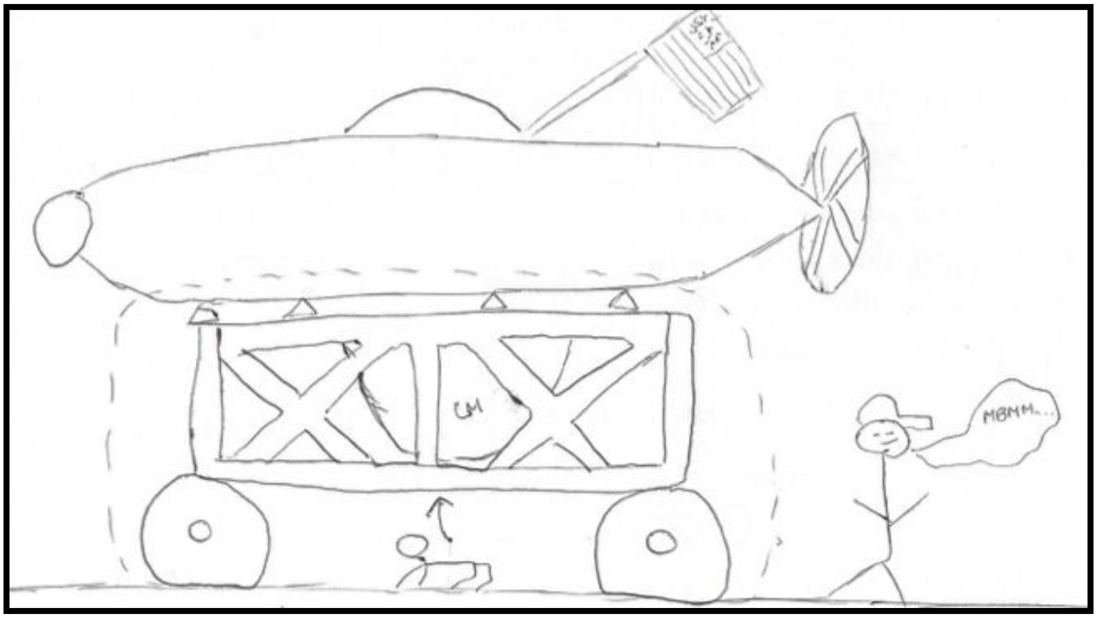


**Figure 1.** Our boundary sketch of the sponsor's current situation.

The sketch depicts two of the major problems with the DSRV's current support structure -- all of the weight is supported by the tires, and the people that take tours of the DSRV are forced to crawl underneath the structure to enter the DSRV.

*D. Requirements*

Based on our conversations with Mr. McCay and other members of the Maritime Museum, we have developed a list of customer requirements for the new support structure. These are summarized below:

1. Strength
    a. The structure should be capable of holding the 43,000 lb vessel and 17,000 lb trailer that the DSRV currently sits on.
    b. The weight of the structure will not be carried by the tires the way it currently is.

2. Sturdiness and Stability
    a. The structure will be earthquake resistant, and prevent the DSRV from tipping over in the event of an earthquake.

3. Safety
    a. The structure will not present a tripping hazard to the public touring the DSRV.

4. Manufacturability
    a. The design will be be able to be built by the welder that the MBMM has on hand.
    b. The structure will be assembled in the area near the submersible.

5. Supplies and Materials
    a. Utilizing the MBMM's preferred supplier will be a priority.
    b. We will use commercial, off the shelf material.
    c. All material will be locally sourced.

6. Mobility and Variability
    a. The structure will be able to be transported by either a pallet jack or forklift.
    b. The structure will be height adjustable to account for the uneven ground that the DSRV currently sits on.
    c. The DSRV will remain portable, meaning that the tires can be put back on the structure allowing the MBMM to transport the DSRV to its new location in the future.

7. Aesthetics
    a. The design will be pleasant to the eye and have a look fitting to the submarine.
    b. The design will not impede or hinder the overall view and look of the submarine.

8. Corrosion Resistance
    a. The design will prevent rusting due to either dissimilar metal contact or oxidation due to the salty air.
    b. Corrosion resistance measures will be taken to prevent rusting.
    c. Methods of maintenance should be able to be carried out by MBMM volunteers.

9. Cost
    a. The final fabrication and installation cost will be under $10,000.
    b. The design will best utilize volunteer assembly and installation time.

### *E. Specifications*

After developing a list of our sponsor's requirements, we then generated a list of engineering specifications. In order to verify that our engineering specifications addressed each of our sponsor's requirements, we used a process called Quality Function Deployment (QFD). This allowed us to make sure that each requirement was addressed with a quantifiable engineering specification, and allowed us to specify the way that we will prove that we have met each specification. QFD also allowed us to weigh our sponsor's requirements to determine which requirements were most important. This method also enabled us to compare our specifications to each other to eliminate any redundancies. Finally, the QFD allowed us to analyze how well existing products satisfy the sponsor's requirements. A copy of our QFD matrix, produced in Microsoft Excel, has been provided in Appendix A.

Our engineering specifications are summarized in Table 1. The “Target” column contains our targeted values for each specification. The “Tolerance” column indicates whether that target is an absolute maximum or minimum value, or whether it has a tolerance associated with it. Risk refers to how difficult each specification is going to be to achieve, where “L” (low) corresponds to easy to achieve, “M” (medium) refers to somewhat difficult to achieve, and “H” (high) refers to difficult to achieve. Compliance refers to how we will prove that we have met each specification. “A” refers to analysis, “T” refers to testing, “S” refers to similitude, and “I” refers to inspection. “T” has not been included in our compliance column because we will not actually be building the final support structure. The majority of our compliance verification will be done in the form of analysis and similitude. This refers to performing a test on either the steel scaled model, or the wooden full-scale model and then analyzing the test results to ensure that they meet the specification for the final product.

**Table 1.** A summary of our engineering specifications

| Spec # | Specification Description | Target | Tolerance | Risk | Compliance |
|---|---|---|---|---|---|
| 1 | Load on Tires | 0 lb | Max | L | I |
| 2 | Weight of Structure | 5,000 lb | Max | M | A |
| 3 | Fabrication Location | Within 200 ft of DSRV's current location | Max | L | I |
| 4 | Budget | $10,000 | Max | M | A |
| 5 | Maintenance Period | 1 Year | ± 2 years | L | A |
| 6 | Materials from Local Supplier | Within 30 mi | Max | L | I |
| 7 | Visibility Impedance Height | 90% of structure below 69" from ground | Min | L | A, S |
| 8 | Adjustment Resolution | 3" | ± 1 in | M | A |
| 9 | Jacking Height Capability | Lift tires 4" off ground | +8in, -3in | L | A |
| 10 | Structure Extrusion | 3.5' from existing tires | Max | M | A, S |
| 11 | Lateral Acceleration Tolerance | 0.52g | ± 0.5 g | M | A, S |
| 12 | Entry Clearance | Increase by 1' | Min | M | A, S |
| 13 | Weight Load | 32 tons | Min | M | A, S |

The MBMM's primary goal for the new structure is that it take the weight off of the tires of the trailer that the DSRV currently sits on. For this reason, we have included the load on tires as an engineering specification with a target of zero pounds. The new structure may or may not need to be removed from the trailer in order to transport the DSRV to its new location. Therefore, we plan on limiting the weight of the structure to 5,000 pounds so that it will be easily removable with a forklift. The MBMM would like the new structure to be manufactured on site. Therefore, we have specified the fabrication location to be within 200 ft of the DSRV's current location. The Museum has allocated $10,000 for the fabrication and installation of the structure. In our design of the structure, we will ensure that the projected cost does not exceed $10,000 and, if possible, keep the cost to under this amount.

Maintenance period refers to the interval of time that can pass before the MBMM will need to perform maintenance on the structure, such as applying a fresh coat of paint. Based on corrosion research and the Museum's current maintenance schedule on the DSRV and the trailer, we have specified this period to be one year. The Museum has access to a steel yard in Atascadero where they can obtain steel at a reduced price. Using this supplier will be a priority in order to keep the cost of the structure as low as possible.

Visibility impedance height refers to the maximum height that the structure can be before the visibility of the DSRV is compromised. Our specification is based on the new structure not extending any higher than the current structure. Adjustment resolution refers to the intervals in which the structure can be adjusted to account for uneven ground. We have specified this to be 3 inches as a preliminary estimate.

Jacking height capability refers to the amount that we plan on lifting the existing structure off of the ground. We estimate that being able to lift the structure such that the tires are 4 inches off of the ground would provide enough ground clearance for our new structure to be installed. Structure extrusion refers to how far the structure will extend beyond the tires of the trailer that the DSRV currently sits on. This will be limited in our design in order to not present a tripping hazard for the public.

Lateral acceleration tolerance is directly proportional to the maximum lateral force that the structure can withstand. The effects of an earthquake on the structure will be modeled as a lateral force applied to the structure. We have specified the lateral acceleration that the structure will be able to withstand as 0.52g based on research and analysis.

Entry clearance refers to the distance between the ground and the point at which the public accesses the DSRV for tours. The height of the new structure will be based on maximizing this entry clearance so that the public does not have to bend down as much to access the DSRV. Weight load refers to the amount of weight that the structure will have to be able to support. This includes the combined weight of the DSRV, the weight of the trailer that it currently sits on, and the weight of people inside the DSRV taking the tour.

### F. Project Management

Each team member has been tasked with certain responsibilities throughout the design process. These responsibilities are summarized below:

Alexandra Zaragoza

- Serves as main point of contact with sponsor and will facilitate meetings with sponsor
- Documents project progress
- Serves as primary drafter and editor of project milestone documents
- Documents and prepares all requirements for the Baker/Koob Grant Final Report
- Updates and maintains team Gantt chart

Austin Eslinger

- Maintains team's travel and materials budget
- Makes purchases and is in charge of invoices and tracking numbers of packages
- Oversees all solid modeling and serves as primary solid modeler
- Manages solid modeling versions
- Assists with manufacturing as needed

Octavio Mendoza

- Serves as primary researcher for team
- Manages manufacturing aspects of project including designing for manufacturability as well as managing our team's manufacturing of a prototype
- Serves as primary manufacturer of prototypes
- Oversees all welding procedures and serves as primary welder

# Chapter 2 - Background

### A. Avalon Background

The DSRV-2 Avalon is the second of two Deep Submergence Rescue Vehicles built for the Navy. The Navy commissioned the development of the DSRV in the mid 1960's as a "result of the USS Thresher submarine accident in 1963, when all hands were lost" [2]. The cause of the Thresher's implosion is still unknown; however, the most likely explanation is a piping joint in the engine room that gave way, resulting in a spray that shorted out electronics, which forced an automatic shutdown of the nuclear reactor [3]. At the time, submarine operating depths greatly exceeded the capabilities of the existing rescue vessels. After this tragic event, the Navy took the necessary measures to ensure that another tragedy like this did not happen again. Therefore, following the "recommendations of a special Presidential Deep Submergence Review Group, the Deep Submergence Rescue System was developed" [2]. The DSRV was contracted and designed by Lockheed Missiles and Space Company with the sole purpose to "perform rescue operations on submerged, disabled submarines of the U.S. Navy or foreign navies" [4]. The DSRV-1 Mystic was launched in 1970 and the DSRV-2 Avalon in 1971, and thus these two submersibles became the genesis of the Deep Submergence Unit program. They were the only two DSRV's to be built for over 30 years.

With a descent rate of 100 ft/min, the DSRV was capable of diving to depths of up to 5,000 feet in order to reach disabled submarines. The DSRV has an overall length of 49 feet and an 8-foot beam. In rescue missions, the DSRV was capable of transporting up to 24 mariners along with its two-man rescue personnel and two pilots. The DSRV was designed to deploy quickly and work together with either a "mothership" or submarine during rescue missions. Upon deployment, it would conduct a sonar search for the sunken vessel. These highly specialized rescue vessels were equipped with Deep Submergence Obstacle Avoidance Sonar (DSOAS), Downward Looking Sonar (DLS), Side Looking Sonar (SLS), and a Directional Listening Hydrophone. Once having located the sunken vessel, the DSRV attached itself to the disabled submarine's hatch and began boarding its crew.

The DSRV's capability to perform at such deep sea levels is, in part, due to its pressure hull design. The DSRV is composed of three interconnected steel spheres, and hatches allow for passage between them. Each sphere is 7.5 feet in diameter and made of high tensile strength steel. The two pilots navigated the DSRV from the forward sphere which contained the "vehicle's sophisticated control and navigation equipment" while the center and after sphere accommodated the two-man crew and 24 mariners [2]. The three spheres are encased by an outer hull made from 13 layers of formed fiberglass. The fully equipped DRSV weighed 36 metric tons, or approximately 79,366 pounds. Navigation of the DSRV was supplied by electric motors that were powered by silver-zinc batteries. The DSRV power system allowed for 36 hours of life support during any given rescue mission. During its use by the Navy, the DSRV was capable of being transported by land, air, and sea to locations throughout the world. DSRVs were, in fact, the first submersibles that had such great capability of transportation.

*B. Avalon arriving in Morro Bay/Museum Display*

In 2006 the Navy began the first of three phases of implementing a new generation of submarine rescue vehicles. With the completion of phase three in 2012, the new Submarine Rescue Diving and Recompression System (SRDRS) would pick up where its two predecessors left off. The new "SRDRS is a rapidly deployable rescue asset that can be delivered by air or ground, installed on pre-screened military or commercial vessels of opportunity (VOO) via a ship interface template, and mated to a distressed submarine within a 72-hour time to first rescue period" [5]. A disadvantage of the DSRV's is that they could only be attached to modified U.S. Navy submarines, whereas the "SRDRS is a "fly-away" system that can quickly and easily be mobilized via large military or civilian transport aircraft and installed aboard a variety of VOOs within hours of notification of a submarine in distress" [5]. The Navy deactivated the Avalon in the year 2000 and the Mystic in 2008 [5]. Upon deactivation, the DSRV Avalon sat at a Naval storage yard for a number of years. The MBMM and the City of Morro Bay worked together to obtain a long term loan of the Avalon from the Naval Historical Center in Washington D.C. and thus in

June of 2012 the Avalon arrived in Morro Bay. The Avalon is now on display at the waterfront of Morro Bay for the public to enjoy and admire.

*C. Museum need for a support structure*

With the acquisition of such a unique part of U.S. Navy history by the MBMM, there is now the need to safely display the Avalon in a manner that is befitting of this unique piece of history. The DSRV is currently sitting on Short Haul Vehicle (SHV) that was used to transport it when traveling by land. The 17,000-pound trailer is the DSRV's sole support structure, and the combined weight of the DSRV and trailer is upwards of 30 tons (some systems from the original DSRV have since been removed, such as batteries). The total weight is currently being supported by the SHV's tires - a source of concern for the MBMM. Due to its waterfront location, the SHV tires are exposed to rain, fog, sea winds, and UV radiation from the sun. There is a concern that the weathering of the tires combined with the amount of time that they have been supporting the weight, could cause the tires to fail. The MBMM is looking for a support structure that will take the weight off of the tires so that they can be removed and provide the mobility necessary to relocate the DSRV to its future home in an indoor display at the MBMM.

*D. Existing Support Structures*

There are numerous submarines that are on display in museums around the world. The vast majority of the submarines on display are placed on top of concrete bases. The use of a concrete support system requires that the submarine be placed permanently in one location. This is not an option for the DSRV support structure since the submersible is not currently in its permanent location. Upon the completion of the MBMM, the DSRV will need to be able to move to its new indoor location. Another disadvantage of many concrete support structures is that they display the vessel close to the ground. The DSRV needs a support system that will allow enough clearance for the general public to be able to access its hatch located on the underside of the vessel. Access to the interior of the DSRV is of utmost importance and thus there needs to be a suitable distance between the ground and the DSRV entry point. This will allow the majority of the public to enter the DSRV easily. There are a few examples of submarines displayed well above ground level. The Gangneung, a North Korean Sang-O class submarine is an example of a submarine on display that places the vessel well above ground, as seen in Figure 2. The distance between the ground and the underside of the submarine easily allows most children and adults to walk underneath it. There is also a staircase and platform to allow access to the Gangneung's entry hatch. The support structure of this North Korean submarine is the one that appears to give the greatest ground clearance from all the submarines on display that research has produced thus far. The major drawback is that the structure is permanent and does not allow for any movement.

**Figure 2.** A captured North Korean submarine on display in South Korea [7].

Another readily used method to display submarines, is the use of steel support columns attached to a steel platform. These support structures tend to be bulky looking and take the viewer's sight away from the focal point, which is supposed to be the submarine. While they do provide the possibility for future relocation, they lack the vertical height necessary to allow access to the DSRV’s entry point.

Since there are no readily available products specifically designed to support a submarine, additional research in support systems for other large objects was also conducted. In order to prop a vehicle up in a secure and safer manner, a modified car stand that attaches to the wheel hub can be used as seen in Figure 3.

**Figure 3.** Car stand attached to a vehicle [21].

These types of car stands take advantage of the vehicle's pre-designed loading points by attaching them to the points of the vehicle that are known to be safe and secure. Unlike conventional car stands that are placed at locations determined by the operator, which may not be at secure locations, this stand takes all of the guesswork out of jack placement. By eliminating the guesswork in car jack placement and by using the wheel's own lug nuts, this stand provides an easy and effective way to keep the vehicle off its tires.

A limitation to using this type of stand is the lack of height variability and the limited clearance from the ground. People have worked around this problem by placing the stands on top of another support structures like the one in Figure 4. Although a secure platform could be designed, there would still be the need to lift the entire vehicle and stands up onto the platform.

**Figure 4.** Vehicle with hub stands being supported on a platform [22].

A similar stand could be designed for the SHV in order to remove the tires, thus allowing the entire structure to be supported at known secure locations. At a future date, the stands could be removed and replaced with the tires in order to allow for mobility. However, allowing for an increase in the height of the structure would be an additional challenge.

*E. Patent Search*

After conducting an in depth patent search, we found that there are no patented solutions directly applicable to our problem. There are many patents on specific designs of variable height jack stands; however, most are intended for general automotive use and will not directly apply to our problem.

*F. Corrosion Resistance*

The Avalon DSRV is on display outdoors at the MBMM's facility, which is just a few hundred feet away from the ocean. In order for corrosion to take place on materials like iron and steel, both water and oxygen must simultaneously be present [8]. This makes corrosion a serious problem in marine environments because of the large amount of moisture and chlorides in the air [8]. Therefore, corrosion is an important consideration in the design of the DSRV's support system.

There are many preliminary measures that can be taken to reduce the likelihood of corrosion on a structure. One such example is designing to reduce the entrapment of moisture and dirt [8]. Examples of this would include using welded joints over bolted joints and avoiding open crevices [8]. Another example is avoiding the use of dissimilar materials [8]. Additionally, designing a structure with larger flat surfaces as opposed to complicated shapes allows for easier initial coating and future maintenance [8]. Additional examples can be found in Figure 1B of Appendix B.

While physical design decisions are important, painting of the structural steel is likely the primary means of protection against corrosion for this application. Metals exposed to marine environments must be pre-treated before they can be painted. The purpose of this is to remove the following contaminants: salts, oils, grease, dust, mill scale, rust, and old coating [9]. This prevents osmotic blistering, flaking, and creates a uniform surface profile [9]. Pre-treatment methods range from manual methods like grinding, to mechanical methods such as dry abrasive blasting, wet sandblasting, and high pressure cleaning.

After the material is pre-treated, the material should be painted because, according to Corus Construction, "Painting is the principle method of protecting structural steelwork from corrosion" [8]. The various paint coats that are applied serve specific purposes and are applied one coat on top of the other [8]. The primer's purpose is "to wet the surface...to provide good adhesion for subsequently applied coats... [and] to provide corrosion inhibition" [8]. The intermediate coats that are applied serve to increase the thickness of the overall coating [8]. A thicker coating corresponds to a longer life, generally [8]. The final coat is the first line of defense against the marine environment [8].

There are many different types of paint available for our application. The main categories of paint include air drying paints, one pack chemical resistant paints, and two pack chemical resistant paints [8]. An example of air drying paints are alkyds [8]. One pack chemical resistant paints include acrylated rubbers and vinyls [8]. Two pack chemical resistant paints include epoxy and urethane [8]. Table 1C in Appendix C includes a summary of various types of paints and their properties. We are interested in a paint that is both water resistant, and responds well to additional coating.

According to Force Technology, depending on the "aggressiveness of the environment, the inspection interval may be 1-5 years [9]. Table 2 outlines standard condition assessment methods and techniques [9].

**Table 2.** Condition assessment methods, the corresponding techniques, and the purpose of each assessment [8].

| Method | Technique | Purpose |
|---|---|---|
| Visual inspection | - Degree of blistering, rusting, cracking, flaking, chalking | Identify coating breakdown |
| Non destructive tests | - Dry Film Thickness (DFT) | Identify coating thickness |
| Destructive tests | - Adhesion test (x-cut, pull off) | Identify potential reduction in adhesion/cohesion |
| Laboratory analyses | - FTIR or solvent dissolution test | Identify coating type if unknown |

*G. Earthquake Codes, Requirements, and Analysis Methods*

One major hurdle we needed to overcome during the analysis phase of the design process was understanding the specificities and nuances of structural loading during seismic activity. In order to get a general understanding of the legally required and professionally applied methods for quantifying earthquake loadings, we turned to many resources on load quantifying guidelines and analysis methods. Federal Emergency Management Agency (FEMA) provides a detailed list of requirements and overview of analysis methods applying to seismic activity [10]. We compiled a brief overview and summary of the process used to ensure structural safety described in Reference 10.

The first step in the process is quantifying the requirements of the structure and the earthquakes it should withstand. This process involves looking at structure details like height, material, whether or not it holds people, and general eccentricity of the structure. These details are then translated into coefficients that will later be applied to an engineering equation developed by the American Society of Civil Engineers (ASCE). From there, we then look at the earthquake requirements. The same process described above is applied to factors that designers cannot change like geographical location, ground material, and maximum expected earthquake magnitude. With the coefficients we arrive at from the earthquake and structural properties, we can choose accepted analysis methods and redundant loading factors to apply to our design. The three main analysis methods to choose from are briefly described below.

*1. Modal Analysis*

Modal analysis looks at how a structure reacts due to the frequency of the earthquake. Similar to a guitar string, all structures have a frequency they naturally vibrate at when they are disturbed. Plucking a guitar string causes it to naturally vibrate at an audible frequency. The same phenomenon happens to structures during earthquakes. However, instead of just a single pluck like a guitar, earthquakes effectively ‘pluck’ the structure multiple times at a particular frequency. If the earthquake frequency is close to the natural frequency of the structure, it could potentially cause the structure to tear itself apart. Modal analysis applies the principles of engineering vibrations to ensure the structure’s natural frequency is not near the effective frequency of an earthquake.

*2. P-Delta Analysis*

P-Delta analysis involves modeling the structure as an eccentrically loaded slender column to analyze buckling characteristics. Buckling is a phenomenon caused by structural instability rather than material failure. Crushing an aluminum soda can is an example of buckling. Even though aluminum is a strong and rigid material, the can collapses because the shape and thickness of the can will only support so much load. Once a loading threshold is surpassed, the center of the can will collapse in, or buckle. This same problem occurs with large structures at much higher loading conditions. One important consideration in buckling is eccentric loading, or a compressive force that is off the centerline of the column, causing a bending effect. This bending induced by eccentric loading is illustrated with a soda can if you bend it sideways rather than simply trying to crush it. Bending a can to make it collapse is much easier than just crushing it, which is a phenomenon seen in large structures as well. P-Delta analysis makes sure that any eccentric compression induced bending caused by the earthquake will not cause our structure to buckle.

*3. Equivalent Lateral Force Analysis*

Lateral force analysis models the structure as if the earthquake generates a force that pushes on the side of the structure. After quantifying this lateral load, we can determine whether or not the load seen by the structure will cause failure.

*4. Seismic Load Case Development*

After receiving guidance from seismic expert Dr. Robb Moss of the Cal Poly Civil Engineering Department and conducting more research, we generated a conservative load case to which we will design our structure. We will be modeling the earthquake as an equivalent load of 37,612 $lb_f$ applied at an equivalent height of 9.2 feet, measured from the ground. This corresponds to an equivalent lateral acceleration of 0.52g applied at the center of mass of the submarine. Appendix D contains further details regarding the analysis that led to these conclusions.

*H. Commercially Available Heavy Duty Jacks*

In order to lift the sub off of its tires initially, we need some sort of jacking system capable of lifting the expected loads. After extensive research, we found a few industry standard methods and solutions for jacking heavy vehicles. Below are the three jacking systems we found that are most applicable to the problem of lifting the heavy submersible.

*1. Bottle Jack*

A bottle jack is a manually operated hydraulic or mechanical jack that is capable of lifting a large range of loads. We found a cost effective bottle jack that could potentially jack the submersible. The jack is rated to 50 tons and is available through Northern Tools [11]. Figure 5 contains a picture from their website:


**Figure 5.** 50-Ton Bottle Jack [11].

The specifications for this jack, as well as other similar ones we found, are as follows:

| | |
|---|---|
| Lift Capacity: | 100,000 lbs |
| Minimum Lift Height: | 9.25 in |
| Maximum Lift Height: | 14.00 in |
| Ram Travel: | 4.75 in |
| Cost: | $ 120 |

*2. Trailer Stabilizing Jack*

Another type of jack we found was a heavy duty jack used to keep big rig trailers standing when they are not connected to the semi-tractor. Figure 6 depicts an example of a semi-trailer stabilizing jack.

**Figure 6.** Semi-Trailer Stabilizing Jack [12].

Since this jack was designed specifically for semi-trailers, the load capabilities are much higher than the bottle jack. Below is a compilation of the specifications for this particular design made by Vestil Manufacturing [12].

| | |
|---|---|
| Lift Capacity: | 50,000 lbs |
| Uniform Static Capacity: | 100,000 lbs |
| Minimum Lift Height: | 41.00 in |
| Maximum Lift Height: | 55.00 in |
| Ram Travel: | 14 in |
| Operation: | Hand Crank |
| Cost: | $ 630 |

*3. Bridge Jack*

Another hand operated jacking solution we found was a Bridge Jack sold by Ellis Manufacturing [13]. This option is specifically designed for large static loads and comes in many different sizes that allow for the same style of jack to be applied to different height applications. Figure 7 contains a photo of this jack:


**Figure 7.** Ellis Bridge Jack [13].

The following specifications show all available Bridge Jack sizes and the price range between them. All jacks are also rated to carry the same load.

| | |
|---|---|
| Lift Capacity: | 80,000 lbs |
| Tested Failure Load: | 200,000 lbs |
| Available Lifting Ranges: | 10 in - 13 in |
| | 13 in - 19 in |
| | 16 in - 25 in |
| | 19 in - 32 in |
| | 29.5 in - 50.5 in |
| Operation: | Hand Crank |
| Cost: | $ 210 - $370 |

# Chapter 3 - Design Development

*A. Idea Generation*

After receiving feedback from our sponsor that our engineering specifications accurately depicted the requirements of the MBMM, we began generating possible solutions. We did this through three structured ideation sessions, where we used different techniques to help us generate ideas. The first technique we used is called brainwriting. During brainwriting, we each sketched a few ideas in our logbooks and then after a set amount of time, passed the logbook to the next team member. It was then the team member's job to build on the ideas of the previous team member, or generate new ideas based on inspiration acquired from the sketches of the previous team member. The second technique we used is called SCAMPER -- Substitute, Combine, Adapt, Modify, Put to another use, Eliminate, and Reverse. Substituting meant replacing something on the existing structure with something new. Combining referred to combining new ideas with the existing structure. Adapting or modifying referred to adapting or modifying the existing trailer. Put to another use would mean to use portions of the existing design in a new way. This facet of SCAMPER was not utilized because we are planning on keeping the existing structure intact. Eliminate referred to eliminating a portion of the structure which in our case, primarily meant eliminating the tires. Finally, reverse meant looking at the problem and structure in a completely opposite way than we had previously. The final technique, and most effective technique for us, was traditional brainstorming. This included all three team members using dry erase markers and writing as many ideas as possible on a white board. While our idea generation sessions helped us generate a large quantity of ideas, the next step of the design phase required us to evaluate these ideas and focus on quality instead of quantity.

*B. Go/No-Go Idea Evaluation*

Our ideation sessions helped us generate numerous solutions to our problem. However, since we were focusing on quantity of ideas and not quality of ideas initially, not all of these solutions were actually possible. Therefore, the first iteration of our idea evaluation consisted of a go/no-go test, where we used our engineering judgment to determine whether each solution was actually achievable. This led us to eliminate all ideas save four, which are summarized in the next section.

*C. Potential Solutions*

There are many nuances to this problem that will be addressed during detailed design; however, these design solutions are meant to show general methods and conceptual approaches that could be used to solve the problem. Below are the initial concepts we developed:

*1. Potential Solution #1*

This idea involves an independent jacking and support system. By that, we mean that we will first lift the submarine using a commercially available jack similar to one described in our Background section, and then install an independent support structure. Figure 8 contains a rough sketch of a potential concept.

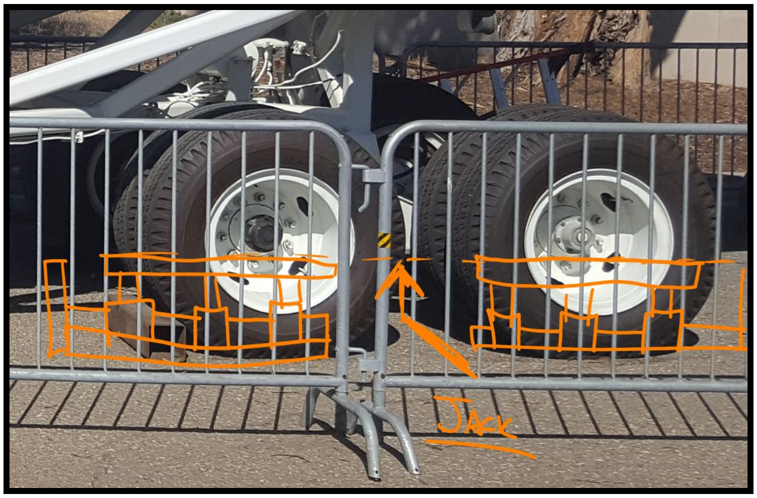


**Figure 8.** Rough sketch showing where the Potential Solution #1 would be located behind the tires.

Here we attempt to depict the general configuration of the system that involves using a jack between the tires and installing two small, adjustable pieces of structure behind either side of the tires. This design is meant to bear the load of the trailer and submarine at the axle, where we know for a fact the load can be supported. Figure 9 contains a conceptual prototype of the adjustable structure that is roughly sketched in Figure 8.

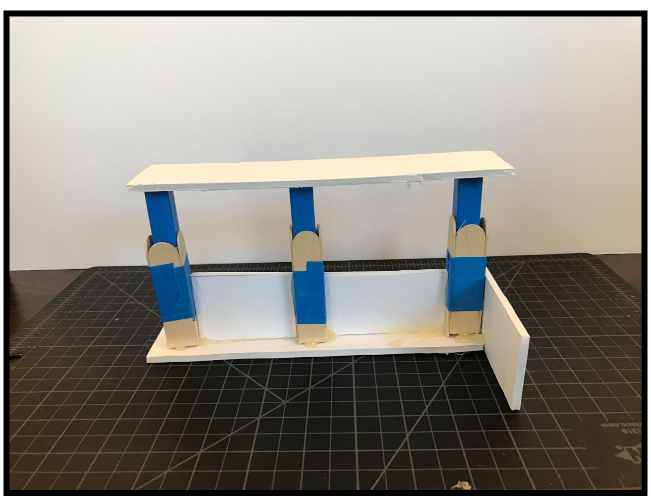

**Figure 9.** Prototype of Concept #1 which was built during an in-class ideation session.

Figure 10 shows a more detailed model of this design, produced in SolidWorks.

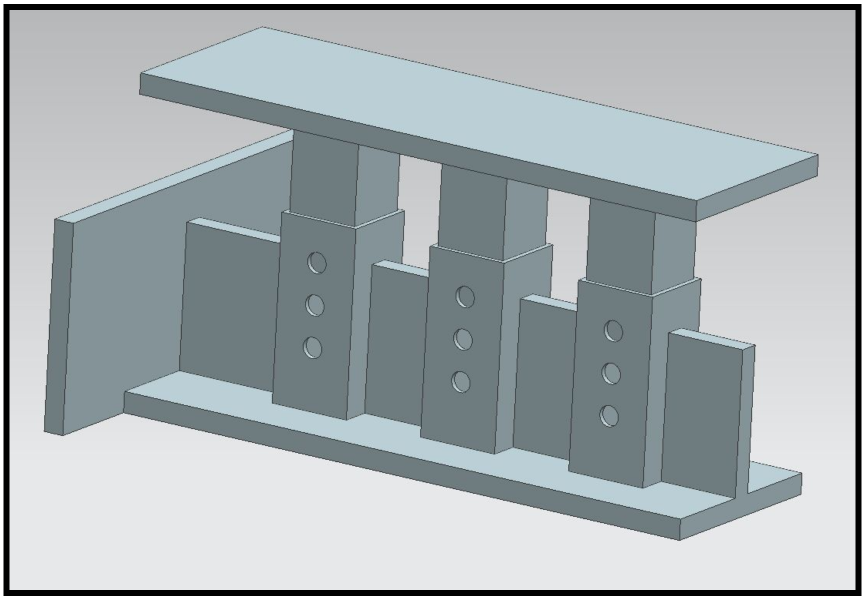

**Figure 10.** Conceptual solid model that will mount to the axle behind the tires

This solution involves using eight independent structures that support the trailer after installation. The high number of parts will keep the weight of each structure down and keep the structure easy to install and remove. This design will also distribute the load over many supports to keep concentrated loading at a minimum on either the trailer or the support structure.

*2. Potential Solution #2*

The next general design concept is similar to the first design in that the lifting and support functions are independent. A preliminary 3D model of this solution, generated in SolidWorks, can be found in Figure 11.

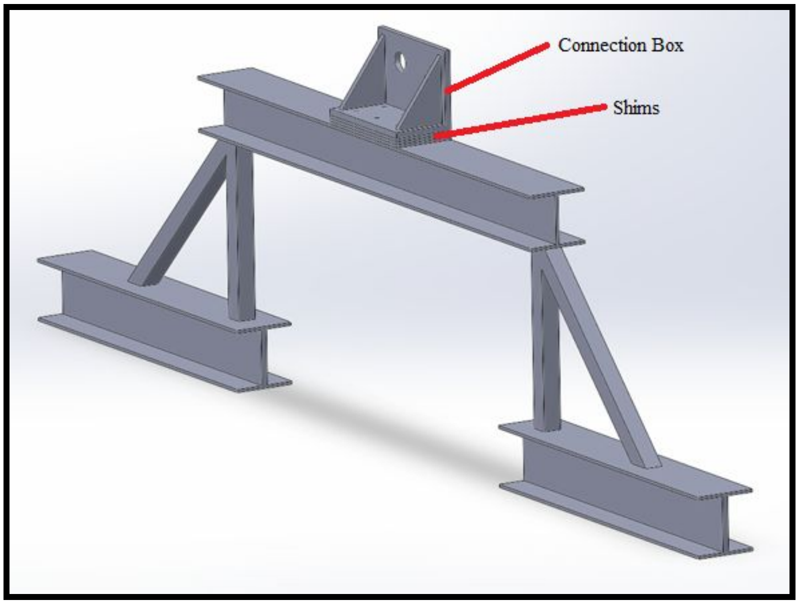


**Figure 11.** Preliminary solid model of assembly for Potential Solution #2

The concept behind this design is the use of a more modular system where there is a connection box that directly interfaces with the trailer. This connection box is the initial location of the load transfer. As shown here, the connection box would bear the load through the large pins in the steel plate. This box would then interface with a large support that is on the ground through shims that will be used to vary the height of the submarine. A sketch depicting how this design interfaces with the existing trailer can be found in Figure 12.

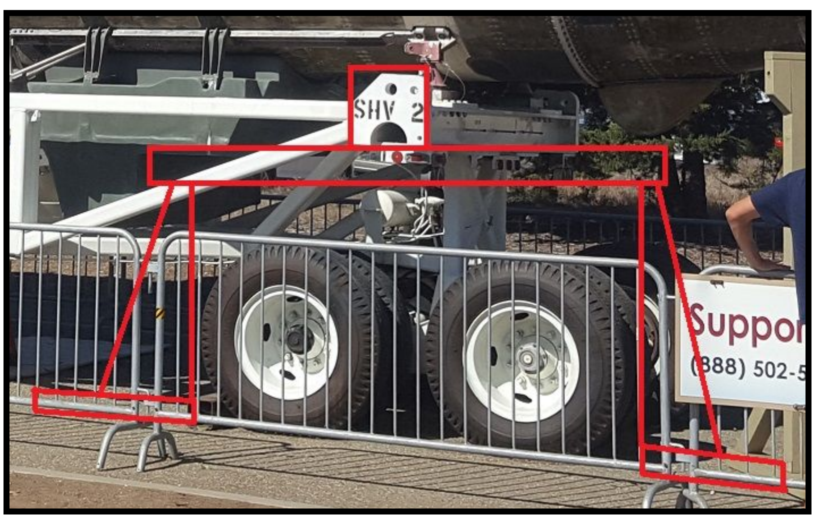


**Figure 12.** A sketch depicting how Potential Solution #2 would interface with the trailer.

Other iterations of this design that include additional cross-bracing can be found in Appendix F.

*3. Potential Solution #3*

The concept behind this idea is simply replacing the tires with another structure that bolts onto the trailer like a tire would. A CAD model of this design, generated in SolidWorks, can be seen in Figure 13.

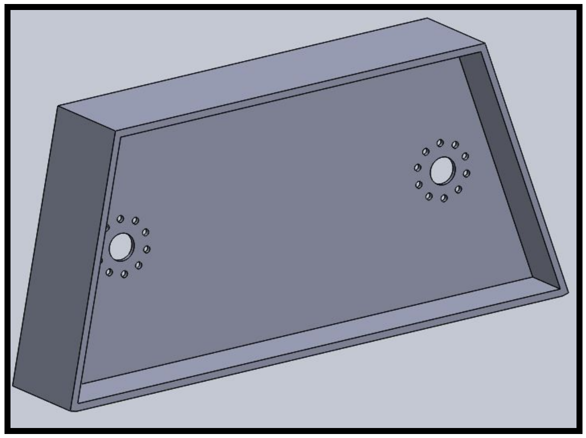

**Figure 13.** A CAD model of Potential Solution #3.

The design consists of a trapezoid constructed out of wide flange steel I-beams. Steel plates are shown as being welded to the angled sides to account for the material removed while making the angled cut, as well as to increase stability. The 10 bolts connecting the structure to the trailer would be attached at the center of the web of the beam.

The trapezoidal I-beam would span the width of two tire diameters, meaning that there would be a total of four of these supports. The height of the structure would be approximately that of the diameter of the tires. Here, the structure is shown as being constructed out of 40 inch I-beam with ¾ inch steel plates that span the width of the flange. A concept model, generated in an in-class ideation session, of how this structure would be installed onto the existing structure can be seen in Figure 14.

**Figure 14.** A concept model of the DSRV, the trailer it currently sits on, and Potential Solution #3. Note that the bolting mechanisms have been left off for the sake of simplicity in the model.

In Figure 14, it can be observed that the tires have been removed, and replaced with the trapezoidal structure of Potential Solution #3. A sketch of this design overlaid on an image of the existing trailer can be found in Figure 15.


**Figure 15.** A sketch depicting how Potential Solution #3 would interface with the existing trailer.

Here, the size of this design relative to the existing trailer can be observed. One advantage of this design is that it requires that the tire axles carry the load. Because the axles are currently responsible for carrying the load, this gives us confidence that this design will be able to support the weight of the DSRV. One disadvantage of this design is that height adjustments cannot be made easily. Adjusting the height of this design would require welding steel plates to the bottom of each support.

*4. Potential Solution #4*

Similar to the previous design concept, Potential Solution #4 involves the use of a modified stand that can be used to replace the wheels. The modified stand in Figure 16 would replace the rims on the support structure and be attached to the wheel hub.

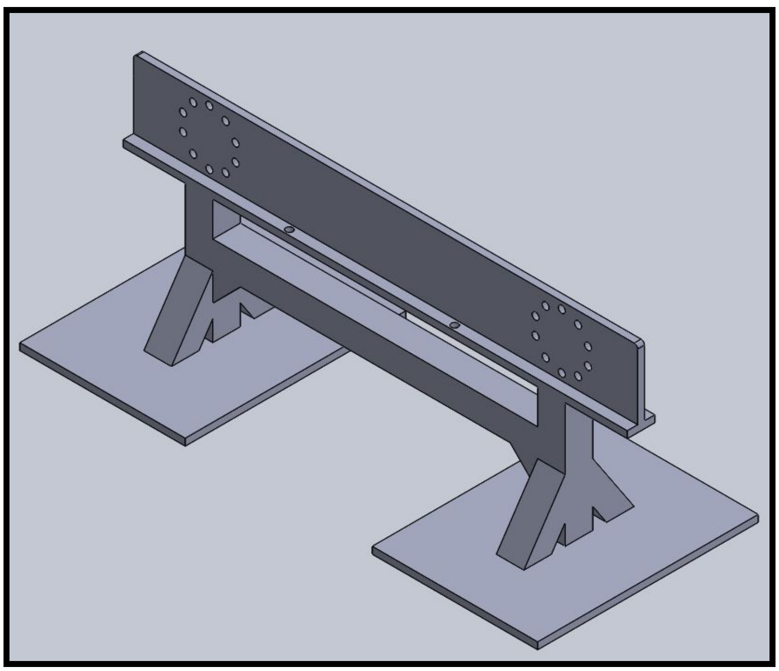

**Figure 16.** A SolidWorks model of Potential Solution #4

Once the SHV has been lifted off the ground, the tires can be removed and the stand can then be fitted over the existing bolts located on the wheel hubs. The support stand would then be secured to the wheel hub using the same lug nuts that were used to secure the rims.

All 10 lug nuts from each rim would be used in securing the support stand to the wheel hubs. Since each support stand is designed to fit over each set of wheel hubs, a total of four support structures would be required to replace all 16 tires. The support stand would be constructed by welding together pieces of heavy duty steel square tubing. Since the axles are already designed to carry the load of the SHV and DSRV, we know that this is a secure loading point. The stand itself would transfer the load over a greater area than the tires are currently doing. By distributing the load over a greater area there is less stress applied to the asphalt or concrete located beneath the structure. The pressure exerted on the foundation would decrease and one would also have the added benefit of greater stability. A sketch depicting how this design would interface with the existing trailer can be found in Figure 17


**Figure 17.** A sketch depicting how Potential Solution #4 would interface with the existing trailer.

The support stand is composed of two independent pieces - one that attaches itself to the wheel hub and the other that is the main support stand. In order to allow for minor adjustments in height, 1” or ½”  metal plates can be added to the support stand and secured in place using bolts or heavy duty hitch pins. This feature would allow the structure to compensate for the uneven terrain. These additional plates used for the height adjustments are placed in between the two components of the structure and secured into place as seen in the side view of the design presented in Figure 18.

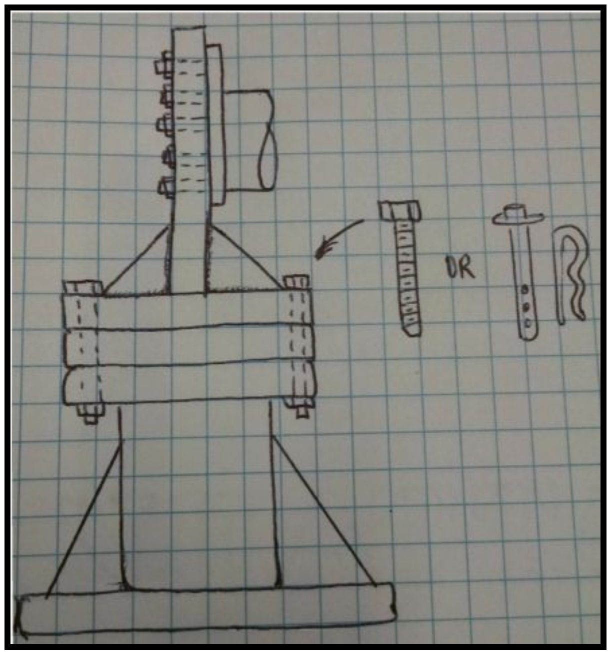


**Figure 18.** Side view of stand with additional plate included.

An iteration of Potential Solution #4, designed to reduce welding time, can be found in Appendix G.

*D. Solution Selection Process*

*1. Pugh Matrices*

The first iteration of our selection process involved the use of Pugh Matrices. The Pugh Matrices allowed us to compare the subsystems of each overall design concept based on how well they performed the critical functions that our design must be able to carry out. These functions included height adjustment, mobility, and ability to support the load of both the DSRV and the trailer. In each matrix, a design was selected as the datum, and the other designs were compared to this datum based on a series of criteria. If the design did something better than the datum, it was scored with a “+”. If a design did something worse than the datum, it was scored with a “-”. Finally, if a design did something as well as the datum, it was scored with an “S” where “S” stands for “same.”

In the Pugh Matrix for height adjustment, the way that our four potential solutions adjust the height were compared to a jack stand. The datum, or the concept labeled “1”, represents a jack stand. The concepts labeled as “2-5” correspond to Potential Solutions 1-4 as presented in Chapter 3 Section C.1-4, where Concept 2 corresponds to Potential Solution #1 and Concept 3 Corresponds to Potential Solution #2, etc. The comparison criteria was based on each structure’s ability to account for structure height variance, the adjustment resolution, the ease of adjustment, the stability after adjustment, and whether or not each was aesthetically pleasing. The Pugh Matrix for height adjustment can be found in Appendix H. The results of this Pugh Matrix made it clear that Solutions 2-4 performed the same in reference to the datum.

In the Pugh Matrix for mobility, the mobility of each structure, meaning the installation and removal of each structure, was compared to the mobility of the trailer. The datum, or the concept labeled “1”, represents the current trailer that the DSRV rests on. The concepts labeled “2-5” correspond to Potential Solutions 1-4 as presented in Chapter 3 Section C.1-4, where Concept 2 corresponds to Potential Solution #1 and Concept 3 Corresponds to Potential Solution #2, etc. The comparison criteria was based on aesthetics, how well each design complemented the existing trailer, the weight of each structure, how mobile the structure was, and how easy the structure was to install. The Pugh Matrix for mobility can be found in Appendix I. The results of this Pugh Matrix highlighted the importance of aesthetics in the selection of our final design.

In the Pugh Matrix for load capability, each design was compared to the current tire rims in terms of its ability to support the load. The datum, or the concept labeled “1”, represents the tires of the existing trailer. The concepts labeled “2-5” correspond to Potential Solutions 1-4 as presented in Chapter 3 Section C.1-4. The concept labeled “6” corresponds to the iteration of Potential Solution #4 as presented in Appendix G. The comparison criteria was based on the following: ease of achieving, complexity, ease of maintenance, weight of structure, size, number of parts, manufacturing cost, ease of installation, lifespan, and aesthetics. The Pugh Matrix for load capability can be found in Appendix J. The results of this Pugh Matrix made it clear that Solutions 2-4 performed the same in reference to the datum.

Our individual Pugh Matrices highlighted the fact that our top three concepts (Potential Solutions 2-4) perform each of the three selected functions relatively the same. Therefore, we decided to develop a system level Pugh Matrix to compare Potential Solutions 2-4 against Potential Solution #1, where all functions and attributes were included as comparison criteria in the matrix. This matrix is provided in Appendix K. The system level Pugh Matrix, again, highlighted the fact that Potential Solutions 2-4 perform each function relatively equally and that the driving factor in the final decision was aesthetics.

*2. Decision Matrix*

After developing the Pugh matrices, we generated a weighted decision matrix that compared every potential solution to the engineering specifications. This matrix generated an arbitrary score based on how well each solution met the specifications and what the specification's relative importance was. Each score for every specification was then added and used to objectively compare each solution. This decision matrix is provided in Appendix L; however, the final scores are summarized in Table 3:

**Table 3.** Weighted decision matrix results

| *Potential Solution Number* | *Weighted Total* |
|---|---|
| *1* | *7.72* |
| *2* | *7.80* |
| *3* | *8.15* |
| *4* | *8.06* |

It should be noted that while the decision matrix did appear to give us a ranking among our chosen concepts, our matrix did not include aesthetics as a criterion. This is because we felt that aesthetics is extremely subjective, and the ultimate decision regarding the appearance of the structure should be left up to the MBMM. Therefore, we elected to pursue our top three concepts as ranked by our decision matrix. Potential Solution #1 ranked lowest in the matrix due to its relative instability in the event of an earthquake. Potential Solutions 2-4 bolt onto the structure itself, and Potential Solution #1 involves the trailer simply resting on the support structures.

*3. Current Solution Decision*

We decided that the jacking and support functions will be independent. By that, we mean that the jacking system will not be incorporated into the structure. We decided this relatively early on due to the fact that jacking solutions are relatively expensive and can potentially get either stolen or weathered if left out for a long period of time. Another factor we considered is that someone might try to raise or lower the submarine by themselves. Instead of trying to prevent someone from using the jacks, we decided to remove them from the support structure entirely.

We honed our design down to two potential configurations, and three designs. The first design we seriously considered was the method described in Potential Solution #2 with the large structure extending over the tires. The second design was that described by Potential Solutions 3 and 4 -- a structure that attaches to the trailer exactly like the tires currently do. The results of our weighted decision matrix indicated that the primary factors driving our selection were aesthetics and method of installation. Our preliminary engineering analysis gave us confidence that all three potential solutions would be able to support the load, withstand an earthquake, and remain within the MBMM's budget for cost. Therefore, we left the final decision for which design to select up to the sponsor, considering the final choice would essentially be a matter of preference.

*E. Feasibility Analysis*

*1. Solution #1*

Originally Potential Solution #2, the design seen in Figure 19 will now be referred to as Solution #1, as it is one of our final design concepts.

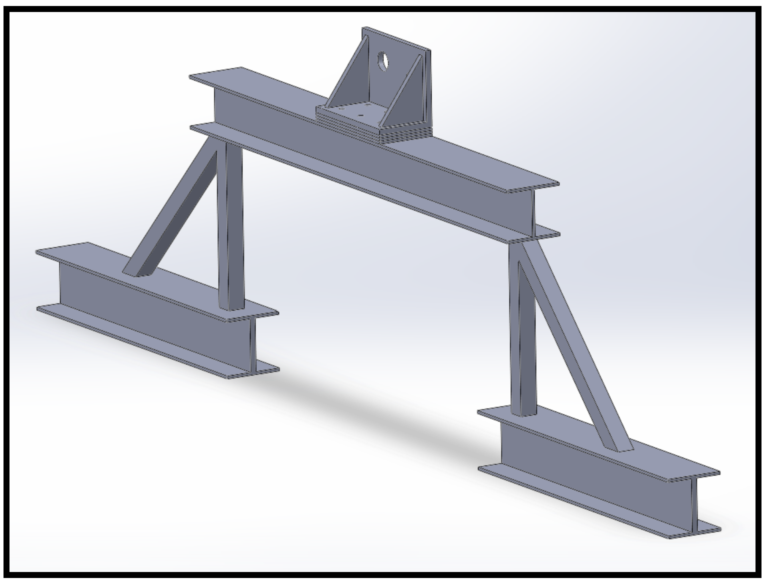

**Figure 19.** Solution #1

In order to ensure that the long, tall structural member that interfaces with the shims can handle the transferred static loads, we generated a preliminary Finite Element Analysis (FEA) model with very conservative assumptions and boundary conditions to validate the approach. We assumed that the connections located on the bottom of the I-beam were fixed and did not deflect under load. Since deflections can decrease the stress in loaded members, we know that this model is more conservative than any real structure. Figures 20 and 21 contain two screenshots from the SolidWorks finite element static load simulation. We used a conservative load of 20,000 pounds, where we would anticipate an actual static load of 16,000 lbs.

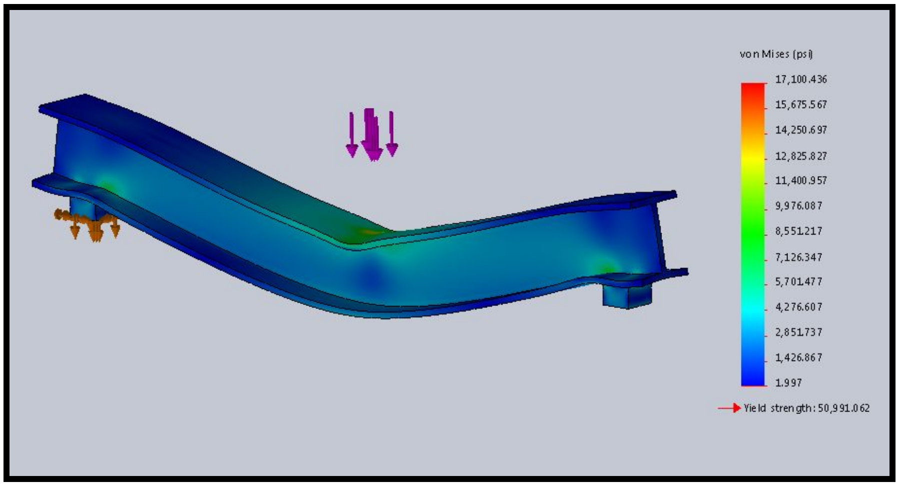


**Figure 20.** Above we show that for a 20,000 lb load in the center of the beam (The purple arrows), we see a maximum stress of 17,100 psi. The yield strength of steel is 60,000 psi, thus giving us a factor of safety of 3.5.

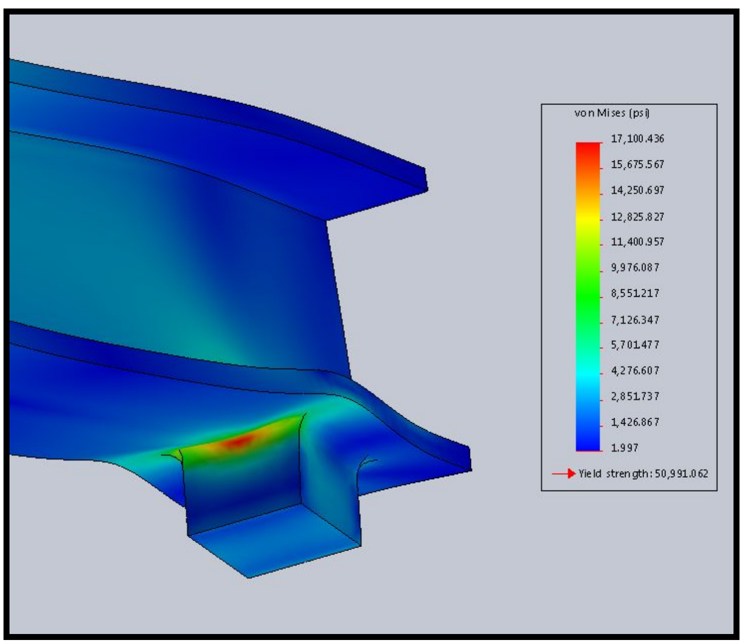


**Figure 21.** We see the maximum stress is at the location between the connection and the I beam. This stress concentration is expected and overly conservative due to the boundary conditions. This means we can assume that factor of safety will be higher than 3.5 for a 20,000 lb load.

In order to validate the two load transfer locations for the connection box, we ran a few preliminary calculations. We first calculated the force needed to shear a 2 inch diameter steel rod. This size is similar to that of the large hole on the steel plate. The results from the calculation in Appendix M show that a 2 inch steel rod will fail at a shear load of around 94,000 pounds. This means that four pins will have a load capacity around 377,000 pounds in shear. That gives us a factor of safety of 6.1, which validates this method of load transfer.

*a. Preliminary Cost Estimate*

In order to try to estimate the cost of the design, we began looking at the weight of each structure using the rough estimate of $0.50 per pound of steel to arrive at a total cost of material. Looking at our solid model and giving it a conservative weight estimate, we imagine the weight of each structure will be around 2,500 lbs. That brings the total weight for all four structures up to 10,000 lbs. Using the price per pound, we estimate the material cost to be around $5,000 dollars. However, one benefit of this design is the utilization of I-beams, which the museum already owns. If we were able to use currently available I-beams, whose total weight is almost 7,000 pounds, the material cost could be as low as $1,500.

Another consideration is the welding cost. This preliminary design has an estimated 200 inches of weld per structure. While this is a lot of welding, this is only a preliminary estimate that will be reduced with further design iteration. As of now, we don't know the welder's hourly rate or how quickly he could potentially complete the fabrication so we cannot give a cost estimate for labor.

*b. Installation Process*

One benefit of this design is the potential simplicity and safety of the installation. To illustrate this, we have included a brief description of the installation process:

1. The nuts on all tires would be broken and loosened while the trailer is on the ground.
2. Using the forklift, the connection box would be lifted to the appropriate height then inserted and bolted onto the SHV plates on every corner of the trailer.
3. The large support structures would be brought in by a forklift over the tires and aligned with the connection box interface (i.e. align the slots on the structure with the slots on the connection box).
4. 2 bottle jacks would be placed on each axle, either on the U bolts or the axle, whichever is deemed best by Santa Maria Tire.
5. The jacks would lift the trailer to the desired height.

6. The proper quantity of shims would be placed between the connection box and structure.
7. Bolts through the connection box, shims, and structure would be inserted.
8. The jacks would be lowered and removed.
9. The bolts would be tightened.
10. The process will be repeated on the opposite side of the submarine
11. The tires can then be removed and stored.

*c. Discussion of Major Benefits and Shortcomings*

In order to understand the benefits and shortcomings of this design, we have compiled a list of Pros and Cons:

<u>Pros:</u>

1. Assuming the MBMM has access to the city's forklift, this design is very mobile. The large structure that goes over the tires can be easily moved into place by placing the forks underneath the large longitudinal member. The connection box can also be lifted into place very easily with the forklift. The benefit of the connection box is that it only needs to be installed once. When the submarine is moved to its new location, the connection box does not need to be removed, thus improving the mobility.

2. The installation process will be very safe. This design minimizes the time that the trailer will be jacked up. Since all of the structure will be in place beforehand, when the trailer gets jacked, the only parts that need to be installed will be shims and bolts that are the interface between the connection box and the large structure. At no point will an installer be moving heavy structures or be underneath the trailer while it is jacked and in a relatively unstable state.

3. The structure will be aesthetically integral to the display. The size of the display will allow us to make the structure appear complementary to the trailer by using large, long structural members similar to those on the trailer. By making the structure large and prominent, it avoids making it appear as though it was an afterthought to the display.

4. This design will maximize the use of materials the museum already owns.

Cons:

1. The cost will be higher for this design. With a much larger size, it is inevitable that the cost for materials and manufacturing will be higher since it will most likely require more welding.

2. This design could potentially create a tripping hazard. Since this design protrudes out from the trailer, it inherently creates more of a hazard. However, even though it protrudes out, the tripping hazard is relatively mitigated since it protrudes not only around the ground, but also up at eye level.

*2. Solution #2*

Originally Potential Solution #3, the design seen in Figure 22 will now be referred to as Solution #2, as it is one of our final design concepts.

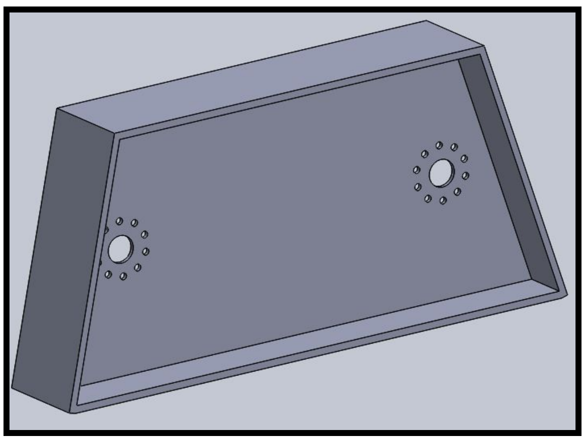

**Figure 22.** Solution #2

To assess the feasibility of Solution #2, the induced force on each support due to an earthquake was calculated based on assuming the earthquake supplied an equivalent lateral force of 37,612 $lb_f$ at an equivalent height of 9.2ft (see Appendix C for more information). This force was calculated to be approximately 59,000 $lb_f$. The stress that this force would induce on the asphalt that the trailer currently rests on was calculated to be approximately 29 psi. This value was based on the surface area of the I-beam in contact with the asphalt. Considering the extremely small magnitude of this number, exceeding the compressive strength of the asphalt is not an issue. Finally, a calculation was performed to ensure that buckling would not be an issue. Using Euler's equation for buckling, the maximum force that the I-beam could withstand before it buckles was calculated to be about 54 million $lb_f$. This value was calculated assuming the load was applied at the top of the I-beam and that the end conditions were fixed-free. Because the actual load would be applied at the center of the I-beam, where the structure bolts to the axles, this represents the worst case scenario. Considering 54 million $lb_f$ is well above the estimated load of 59,000 $lb_f$, buckling was determined to not be a concern. Further detail regarding these calculations can be found in Appendix N.

Next a preliminary cost assessment was performed to further assess the feasibility of this design. With an assumed price of steel of $0.50 per pound based on an estimate of the price at the MBMM's supplier, the cost of materials was calculated to be $6,885. The amount of weld inches required for the design was calculated to be 86.4 inches. This was based on an estimate that 4 out of every 10 inches along the angled sides of the structure would need to be welded (i.e. the welder could weld 4 inches, skip 6 inches, and then weld 4 more inches). The cost associated with welding has been left out of the preliminary cost estimate because, as previously mentioned, the MBMM welder's hourly rate is unknown to us at this time. It should also be noted that the cost of renting jack stands has not been included in the cost estimate.

*3. Solution #3*

Originally Potential Solution #4, the design seen in Figure 23 will now be referred to as Solution #3, as it is one of our final design concepts.

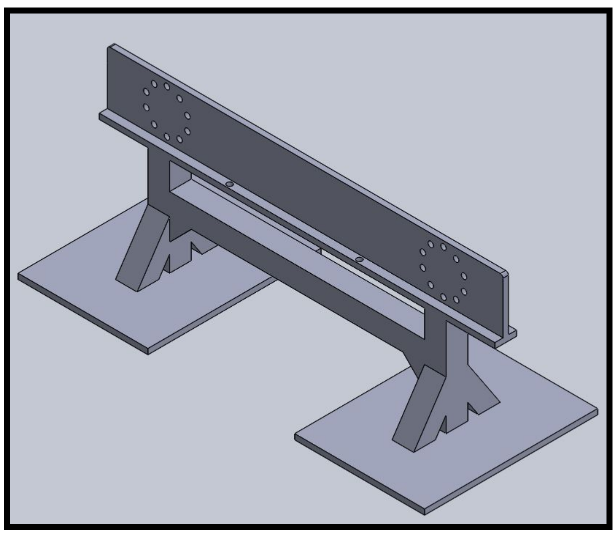

**Figure 23.** Solution #3

The installation process required to install the support stand largely depends on who is going to be removing the tires. Regardless of which design is pursued, the actual removal of all the tires is a critical step of the process. It would be beneficial to consider hiring a local tire shop to do the actual jacking of the structure and removal of the tires for a number of reasons. Because we are located in a predominantly agricultural based area, there are many tire shops that routinely do on-site tire changes and repairs for large farming and trucking equipment. They are equipped with the appropriately sized jacks and equipment to change tires on heavy equipment. The 1" impact wrench required to simply remove the lug nuts typically costs between $800 to $1,000. Having a third party remove the tires would also save a lot of time since they are professionals and routinely do similar jobs. Installing the support stand would require that two sets of tires be removed at a time, in order to attach the support structure to the wheel hubs. The four support structures required to support the entire load would also require the installation of any additional steel plates at this time. The number and size of steel plates required to keep the SHV level would have to be determined prior to the stand installation in order to avoid having to jack the SHV up again.

The cost of 2 x 2' A36 steel plate is approximately $108.00 for ½" thickness, and $255 for 1" thick plates. This price can be greatly reduced if the MBMM supplier has similar sized steel on hand. The support structure is designed using readily available 4 x 4 x 1/2" A500 steel square tubing, although it can easily be modified to suit whichever materials are actually available by the MBMM material supplier. Square and rectangular tubing are commonly used for structural support due to their ability to withstand shearing and bending in both directions. A single 18" length of the square tubing will deflect only 0.0144 inches when a 60,000 lb force is applied. The typical cost of the 4 x 4 x 1/2" A500 steel square tubing can range between $116 and $173 for 6' lengths. Each individual structure can be manufactured with 20' of tubing at a cost of $404, for a total of $1,616 for the four support structures required. The prices for the materials are wholesale prices available to the public, and it does not take into account the reduced rates offered by the MBMM material supplier.

The cost does not include the time required to weld the approximately 696 inches of welds for the four structures. By using the three column support design, presented in Appendix G, 152 inches of welding can be eliminated. Less welding is an important cost consideration and this will most likely not compromise safety. The three 18" support columns used in the modified design will endure an axial stress of 714 psi, well below the material ultimate tensile strength and yield strength of 58,000 psi and 45,700 psi respectively. The supporting calculations can be found in Appendix O.

*F. Summary of Total Costs for Solutions 1-3*

Table 4 summarizes the estimated total cost of Solutions 1-3, where Solutions 1-3 have been presented in Chapter 3 Section E.1-3, respectively.

**Table 4.** A summary of the estimated total cost of Solutions 1-3

| Solution Number | Estimated Total Cost |
|---|---|
| 1 | $5,000 |
| 2 | $6,885 |
| 3 | $2,480 |

It should be noted that these cost estimates were based off of the reduced price estimate of $0.50 per pound of steel provided by the MBMM. It should also be noted that these estimates do not include the costs associated with welding and renting of jack stands. In order to provide an idea of the amount of welding time associated with each solution, the total number of weld inches for all four supports of each solution has been summarized in Table 5.

**Table 5.** A summary of the total number of weld inches required for each solution.

| Solution Number | Total Weld Inches |
|---|---|
| 1 | 800 |
| 2 | 86.4 |
| 3 | 696 |

It should be noted that the larger quantity of weld inches for Solutions 1 and 3 would drive the total cost of these designs up significantly, thereby bringing the total cost much closer to if not greater than the estimated cost for Solution 2.

# Chapter 4 - Description of the Final Design

### *A. Introduction*

After presenting our three final design concepts to our Sponsor and the board members of the MBMM, we chose to move forward with the concept presented in Solution #1. As described previously, we anticipated that the details of the design would be altered based on the materials readily available from the MBMM's preferred supplier. A few iterations of the design were presented in Appendix F. However, upon further investigation, we discovered that these designs would have a clearance issue with the trailer. Based on the materials available from the MBMM's preferred supplier, our structural analysis, and input from our sponsor and the president of the MBMM, we have refined the concept of Solution #1 into a final design, which will be described in depth in the following section.

### *B. Overall Description of Final Design*

Our design is composed of four independent structures that attach to the trailer that the DSRV currently sits on. Each structure attaches to the trailer at the location depicted in Figure 24.


**Figure 24.** The attachment point for each of the four structures.

Figure 25 depicts a CAD model of the trailer with our four structures attached. This is how the final design would appear when installed on the trailer the DSRV currently sits on. It can be observed that the design will allow all weight to be removed from the tires, thereby meeting Specification #1, as outlined in Table 1.

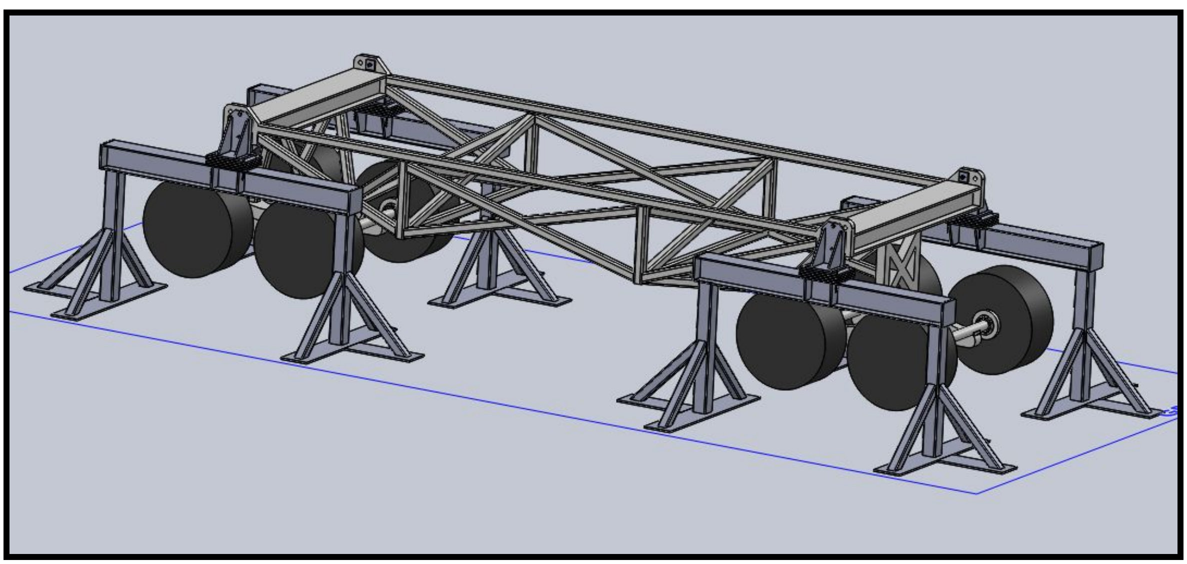

**Figure 25.** A CAD model depicting our final design as it would interface with the trailer that the DSRV currently sits on.

A close-up of one of the structures can be found in Figure 26. A final assembly drawing can be found in Appendix R.

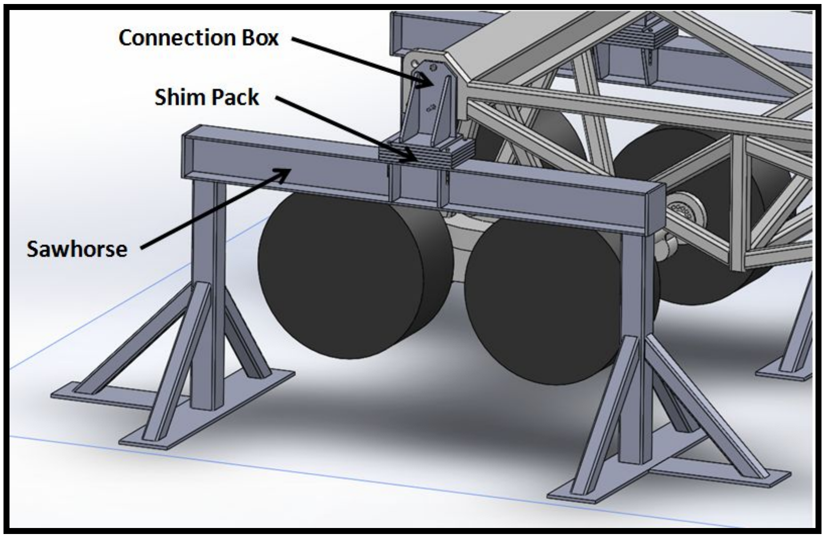


**Figure 26.** A close-up on one of the four structures that will be installed on the trailer.

Each structure weighs under 5,000 lb, thereby meeting Specification #2, as outlined in Table 1. Our design is composed of two main components -- "the connection box" and "the sawhorse." These two components interface via ¾ x 14 ½ x 18" shims, the "shim pack," that can be added to increase the overall height of the trailer and DSRV. These three facets of our design have been labeled in Figure 26 for reference so that the terms "connection box", "sawhorse", and "shim pack" can be used in the remainder of this report. It is worth noting that all components of our design will be composed of structural steel.

Each connection box has a hole in the center of it that serves as the attachment point for a rod that will be run through the trailer to connect the connection boxes on each side together. This rod will be referred to as the "stability rod" throughout the remainder of this report. An image of what this rod connection will look like can be found in Figure 27.

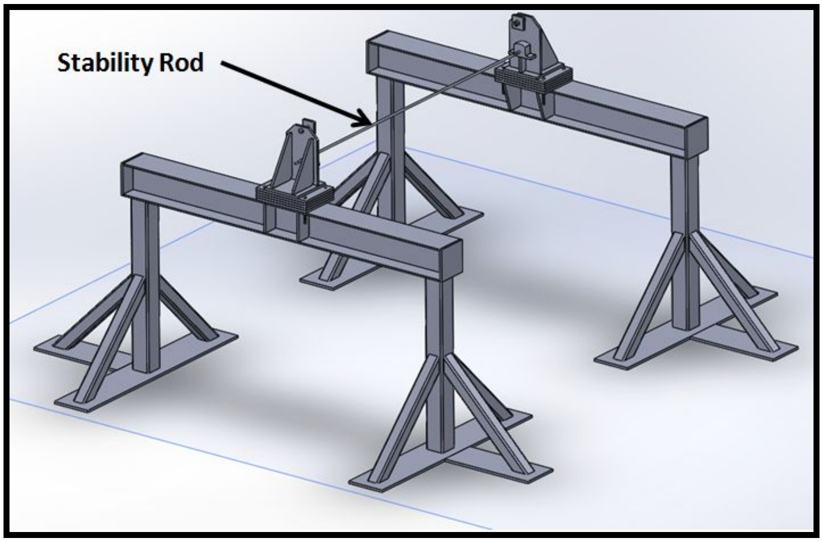


**Figure 27.** An image of two structures connected by the ⅝" diameter rod that will run through a beam on the trailer.

It should be noted that Santa Maria Tire has agreed to jack the trailer and DSRV up 1' during the installation. Therefore, Specification #9, as outlined in Table 1, will be met.

*C. Detailed Description of Final Design*

As can be seen in Figure 26, each connection box attaches to a 2 ½ " thick plate located on the corners of the trailer. Figure 28 contains a closer view of the connection box. Detail drawings for all components of the connection box can be found in Appendix R.

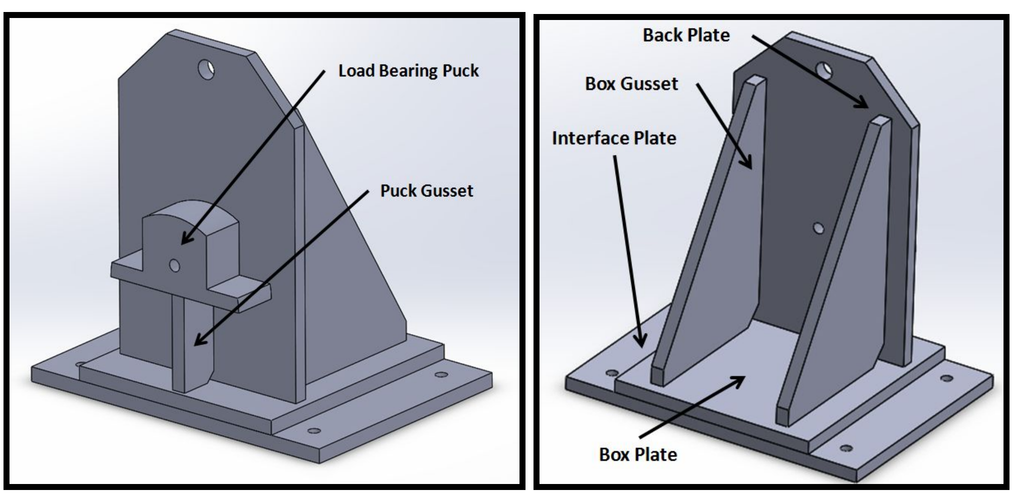


**Figure 28.** A closer look at the connection box that interfaces with the trailer.

The bottom piece of the connection box, which will be referred to as the upper “interface plate,” is a ¾ x 13 ¼ x 18” plate. This will serve as the uppermost shim, and will have four ⅝” diameter holes drilled into it. These holes are what will allow a 8” long Grade 8 bolt to connect the connection box, shims, and sawhorse together.

The next plate of the connection box, which will be referred to as “the box plate”, is a ¾ x 13 ¼ x 12” plate. Welded to this plate is a ¾ x 11 x 17” thick plate with 45 degree notches cut out of the corners at a height of 14”. This plate will be referred to in our drawings as “the back plate.” The back plate has a ⅝” diameter hole drilled in it so that the stability rod can be run through the trailer to connect the connection boxes on either end together. The stability rod is ⅝” in diameter, 110” long, and threaded on both ends. The back plate also has a 1” diameter hole drilled into it which serves to allow the connection box to bolt onto the trailer using a 5” grade 8 bolt and a 2 ½” outer diameter, 0.88” inner diameter bushing. A close-up of what the rod connection will look like can be found in Figure 29.

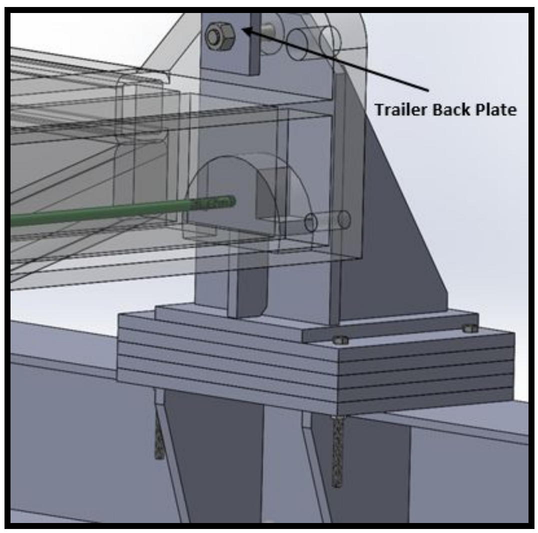


**Figure 29.** A close-up showing the stability rod (highlighted in green for reference) as it would run through the I-beams beams on the trailer, which has been made transparent in this image. The trailer back plate can be seen at the top of the image, at the connection between the connection box and the trailer.

Also welded to the box plate is a 5 x 2 ¼ x 3/4” plate that has two 45 degree notches cut out of the corners that will interface with the back plate. This piece will be referred to as “the puck gusset” because its primary purpose is to support another piece called “the puck.” The puck is the primary means of supporting the static load of the trailer and DSRV. It is 2 ¼” thick, and will have a ⅝ ” diameter hole drilled into it so that the stability rod can connect the connection boxes on either end together. Further dimensions for the puck can be found in Appendix R. An image of the puck can be found in Figure 30.

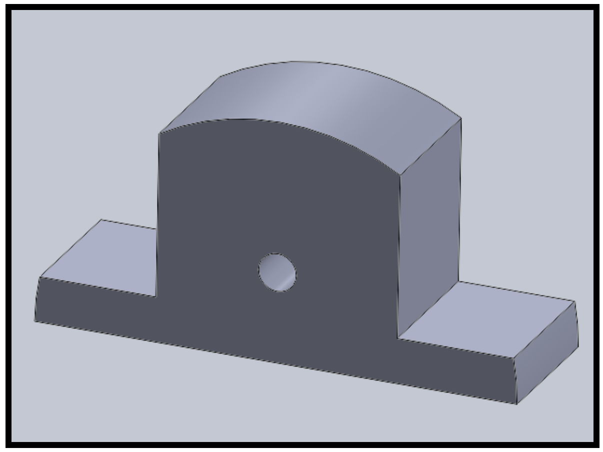

**Figure 30.** An image of the puck, which is the primary means of supporting the static load of the trailer and DSRV.

The shape of the puck was selected based on the semi-circular hole on each of the plates on the trailer that the connection box will be attaching to. Refer to Figure 24 for an image of the attachment point.

Also welded to the box plate will be a two 9 ¼ x 14 ¼ x ¾" thick triangular gussets, which will be referred to as "the box gussets." The corner of each gusset that interfaces with the back plate will have a 45 degree notch cut out of it, to provide additional welding surface area.

Again, the connection box interfaces with the rest of the structure, which will be referred to as the "sawhorse," via ¾ x 13 ¼ x 18" shims that are held in place by four ⅝ " diameter, 8" long Grade 8 bolts that run through all of the shims. The bottom-most shim, or the lower "interface plate," will be welded to the H-beam such that one end of the shims will sit flush with the edge of the flange, and the other end will overhang in the direction going towards the trailer by 3 ¼ ". The overhanging portion will be welded to the top of two gussets placed between the flanges of the H-beam, which will be referred to as "the torsion gussets." These pieces have been termed the torsion gussets because their primary purpose is to reduce torsion in the sawhorse caused by the offset load placed on the puck. A closer look at this connection can be found in Figure 31.

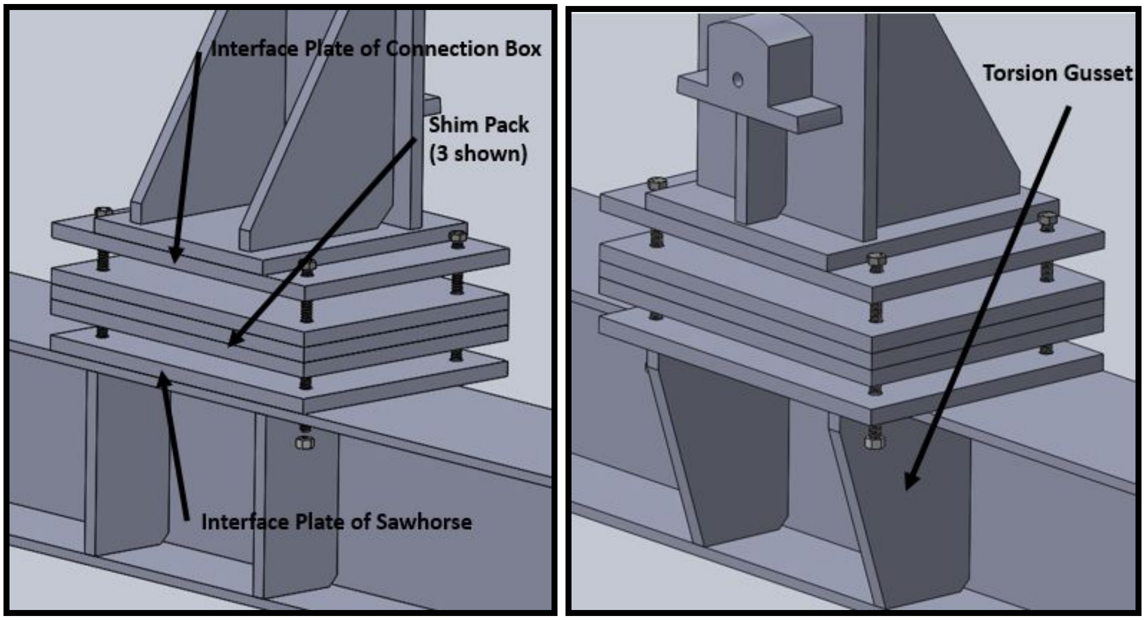


**Figure 31.** An up-close look at the shim connection between the sawhorse and the connection box. In the picture on the right, it can be observed that the load placed on the connection box will be offset from the centerline of the main beam. The purpose of the torsion gussets is to minimize the effect of the torsion induced on the beam by this offset load.

The upper piece of the sawhorse is constructed out of a 9 ½' long 10" H-beam, which will be referred to as "the main beam." Two additional ¾" thick gussets, referred to as "the beam gussets," will be welded between the flanges of the main beam under the location of the connection box, on the side facing away from the trailer. These serve to provide more structural support and to not overstress or deflect the flanges of the main beam. The main beam is also capped on both ends by ¾" thick steel plate that serves to increase the structural stability of the beam. An image of the sawhorse has been provided in Figure 32. All detail drawings for the sawhorse can be found in Appendix R.

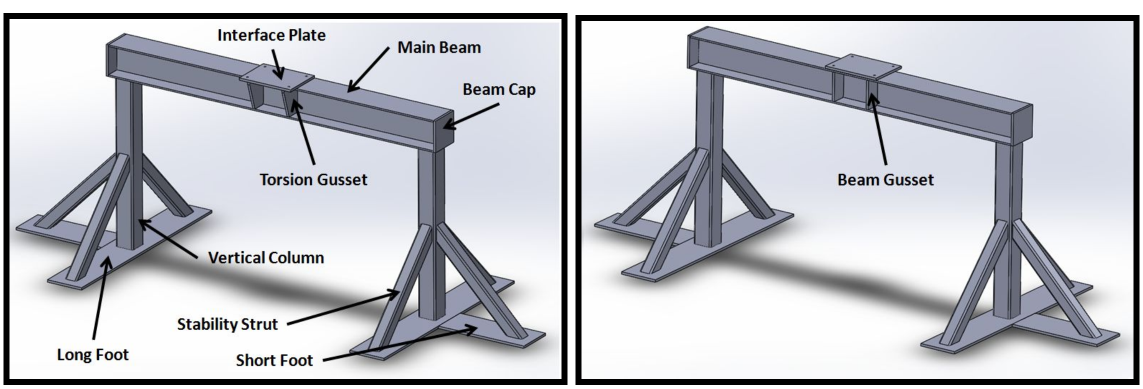


**Figure 32.** Two images of the sawhorse.

On either side of the H-beam, 6 x 6 x ½", 4 ½' long steel square tubing drops down vertically. These two pieces will be referred to as "the vertical columns" in the report and referred by its technical name "chord" in the analysis. Welded to each these vertical columns are three 4 x 4 x 3/16" square tubes that intersect each vertical column at 32" above the ground. These square tubes, or "the stability struts," are cut at a 45 degree angle, and extend from the front, back, and outer side of each vertical column. All three stability struts of each side of the sawhorse are welded to ¾" thick plate that will consist of two plates welded together to form the T-joint. The dimensions of these two plates are as follows: 12 x 72" and 12 x 30". The longer of the two plates will be referred to as the "long foot" and the shorter of the two plates will be referred to as the "short foot."

*1. A Note on Functions*

Our design has three basic functions that it must carry out: it must lift the trailer and DSRV such that the weight is removed from the tires and placed on our structure, it must increase the clearance between the entry point of the DSRV and the ground, and it must allow the MBMM to adjust the height of the trailer and DSRV to account for uneven ground. While each of our structures will serve the function of lifting the trailer and DSRV, the piece of the structure that will carry most of the load is the puck. As a result, the puck is how our structure will carry out the first function of lifting the trailer and transferring the load from the tires to our structure. This is also how Specification #13 will be met, as outlined in Table 1.

The entry point clearance will be increased by two portions of each structure -- the vertical columns of the sawhorse, and the shims. 6" of the extra clearance will be achieved through the length of the vertical columns. The additional clearance will be achieved through the use of ¾" thick shims placed between the connection box and the sawhorse. Overall, we estimate that the entry clearance will be increased by 1', thereby meeting Specification #12, as outlined in Table 1.

Finally, the height adjustments due to uneven ground will be achieved through the use of the ¾" thick shims described above. With the use of a level, the MBMM will be able to add or remove shims from each of the four structures until the trailer and DSRV are level. This allows Specification #8 to be met, and exceeded, as outlined in Table 1.

### *2. Surface Treatment and Expected Maintenance*

As discussed in Chapter 2, Section F., an important facet of our design is that it be able to withstand the harsh marine environment that is characteristic of Morro Bay. To prevent corrosion, we will perform the following procedure:

1. Any existing rust or surface contaminants will be removed, preferably by sand blasting.
2. All material will be coated in OSPHO, a rust-inhibiting coating. This chemical was selected because it is currently used by the MBMM to coat their other vessels.
3. All material will be coated in a Sherwin-Williams Industrial Coating, a macropoxy primer. This primer was selected based on the procedures already in-use by the MBMM.
4. Finally, an oil-based, white top coat of paint will be applied to all materials. This was selected, once again, based on the procedures already in-use by the MBMM on the trailer that the DSRV sits on.
5. After the structure is assembled, we recommend any necessary touch-up painting be performed immediately.

Our prior research indicated that the maintenance period for paints could range anywhere from 1-5 years depending upon the specific type of paint and primer used. Our selected painting procedure should allow the MBMM to continue their annual procedure of performing paint touch up on all vessels. In fact, our goal is for the MBMM to be able to repaint our structure using the same procedure and materials that they use on the trailer.

## *D. Analysis Results*

To analyze our design, we decided it would be best to separate the structure into its main components. After that, we conducted a Failure Modes and Effects Analysis on our design based on our structure. This can be found in Appendix S. Based on this, coupled with the original analysis we had planned to do, as outlined in Table 1, we developed an Analysis Plan, which can be found in Appendix T. We then analyzed each component separately for stresses and deflections. The following sections detail our analysis procedures used for each component of the structure. The results of our analysis are summarized in the Analysis Plan in Appendix T.

### *1. Welding Analysis*

Proper welding procedure and design is a critical component to the integrity of the structure design. One of the most important aspects of proper weld design is choosing the correct type and size of weld. In particular, it is the throat of the weld that is especially important in determining the strength of the welded joints. The throat of a fillet weld is responsible for carrying the load and determines the strength of the fillet weld. In order to assure that the weld would not fail, we followed the standard procedure of selecting a fillet weld size based on the thickness of the material that is being used [17]. For the majority of the sawhorse, a ⅜” fillet weld size was specified as the minimum fillet weld size. The specified fillet weld size assures us that failure of the structure would occur in the material itself and not at the welds. In the cases where the thicknesses of the materials is dissimilar, the thickness of the thinner plate was used.

A spreadsheet in Microsoft Excel was created in order to calculate some of the values required in the welding analysis. Some of the weld properties such as the throat area, locations for the centroid, and the polar moments of area could be quickly determined by simply inputting the material thickness, desired weld lengths, and the geometry of the welds. The use of the spreadsheet allowed us to quickly determine the properties for a specific weld without all the tedious hand calculations that would usually be required. This gave us the freedom to specify different fillet weld thicknesses and lengths to determine how the changes would affect the strength of the structure. The spreadsheet and sample calculations have been provided in Appendix U.

The use of the American Welding Society D1.1 Structural Welding Code for steel was also implemented. This allowed us to specify and check the welding parameters of our design with those specified by AWS. By using and comparing to their prequalified welds, we were able to meet and exceed the requirements set forth by the AWS D1.1 throughout the design of the structure. By using the AWS D1.1 as a guide throughout the design process, we were able to determine the strength for the welds used in our design.

Shielded Metal Arc Welding (SMAW) process was used in the initial analysis of the welds and in determining the cost for the welding in our design. A E70XX filler metal with a minimum tensile strength of 70 ksi was also recommended to be used in conjunction with the SMAW welding procedure. After our analysis had been presented to and reviewed by our sponsor, we were informed that the welder will actually be using a different welding method to manufacture the support structure. The welder will be using a Flux Cored Arc (FCAW) welder running at 325 amps and using ⌀0.068 Innershield NR-212 flux core wire. The mechanical properties of the NR-212 wire are very similar to those of the E70XX electrode. It has a typical yield strength of 64-74 ksi and tensile strength of 84-88 ksi. A great advantage in using FCAW is the higher efficiency that can be achieved over SMAW. The typical welding efficiency can increase by 20-25% when using FCAW. By utilizing a flux core wire with an average tensile strength that exceeds 70 ksi, the weld line load capacity of 11,135 lbs/in. can be achieved for a ⅜” fillet weld [17]. That means that one 6 x 6 x ½ ” square tube welded on all four sides to the H-beam, has a weld strength equal to 267,250 psi. A summary of some of the welding analysis using FCAW can be seen in Table 6. Please note that where N/A is used in the “Allowable” column, it indicates that the data was not available.

**Table 6.** Summary of the welding analysis.

| Feature | Property | Actual | Allowable | Safety Factor |
|---|---|---|---|---|
| Vertical Column (top) | Weld metal strength: | 267,246 psi | N/A | N/A |
| | Weld line load capacity (per 6 in. of weld): | 66,812 $lb_f$ | N/A | N/A |
| | Shear stress on base metal adjacent to weld: | 1,778 psi | 18,400 psi | 10.3 |
| | Moment | 49,941 lb-in | 50,400 lb-in | 1.0 |
| | Primary shear, $\tau'$ | 1,257.3 psi | N/A | N/A |
| | Secondary Shear, $\tau''$ | 2,774.9 psi | N/A | N/A |
| | Shear, $\tau_{total}$ | 2,085 psi | 13,800 | 6.6 |
| Vertical Column (bottom) | Weld metal strength: | 267,246 psi | N/A | N/A |
| | Weld line load capacity (per 6 in. of weld): | 66,812 $lb_f$ | N/A | N/A |
| | Shear stress on base metal adjacent to weld: | 1,778 psi | 18,400 psi | 10.3 |
| | Primary shear, $\tau'$ | 1257.3 psi | N/A | N/A |
| | Secondary Shear, $\tau''$ | 28,557 psi | N/A | N/A |
| | Shear, $\tau_{total}$ | 27,682 psi | 33,420 | 1.2 |
| Stability Strut | Weld metal strength: | 133,680 psi | N/A | N/A |
| Strut-Column Connection | Punching Shear Stress, $V_p$: | 741.7 psi | 14,362 psi | 19.4 |
| | Weld line load capacity (per 4 in. of weld): | 37,118 $lb_f$ | N/A | N/A |
| Puck | Weld metal strength: | 25,149 psi | N/A | N/A |
| | Shear loading of fillet weld: | 3,143.6 psi | 18,400 psi | 5.6 |
| | Shear stress on base metal adjacent to weld: | 2,362 psi | 18,400 psi | 7.8 |
| | Allowable stress for tension: | 656 psi | 27,600 psi | 42 |
| | Allowable stress for simple compression: | 656 psi | 27,600 psi | 42 |

*2. Analysis of Steel Plate Interfacing with Ground*

We needed to make sure that the surface area of our structure would suffice to not overstress the asphalt that the trailer is currently sitting on. To do this, we calculated the vertical reaction force that would be induced on each leg of the sawhorse in the event of an earthquake. We converted this force into a stress using the T-shaped surface area of each side of the sawhorse. We found this value to be 24 psi, which is extremely low, giving us confidence that the asphalt will not be damaged in the event of an earthquake. Hand calculations for the T-shaped steel plate analysis can be found in Appendix V.

*3. Analysis of Connection Box*

To verify that the connection box is structurally sound, we calculated the direct shear and bending stress induced by the DSRV and the trailer during the worst case earthquake. After applying maximum shear stress failure theory and Mohr's circle, we found that the box has a static factor of safety of 55.4 and a seismic factor of safety of 3.06. The detailed process is shown in Appendix W.

*4. Analysis of H-beam*

To verify that the H-Beam of the sawhorse is structurally sound, we calculated the direct shear, torsional, and bending stresses induced by the DSRV and the worst case earthquake. After applying maximum shear stress failure theory and Mohr's circle, we found that the H-beam has a static factor of safety of 7.0 and a seismic factor of safety of 1.45. The detailed process is shown in Appendix X. To simplify this analysis, we assumed that the beam was fixed on its far ends, which increases the bending stress and torsional shear in the beam. To keep our analysis conservative, we also assumed that no matter the location of maximum stresses within the cross section, the stresses were additive and always increased the stress in the beam.

Also shown in Appendix X is a calculation to ensure that the gussets supporting the H-beam would not buckle under seismic conditions. We calculated the force required to buckle a gusset, modeling it as a slender column, and found this value to be substantially higher than any load our structure would see during an earthquake.

*5. Analysis of Square Tube Column*

To verify that our square tube columns would be both statically and seismically stable, we looked at the direct shear, torsional, compression, and bending stresses caused by both the weight of the DSRV and the worst case seismic load. In the seismic analysis, we assumed that only two of the four structures would carry the seismic load, thus making our analysis very conservative. We also assumed that the moment would be transferred to the struts that extend diagonally. As a result, we looked at the bending stress directly above the struts. The detailed process is shown in Appendix Y. After applying maximum shear stress failure theory and Mohr's circle, we found that this area has a static factor of safety of 8.6 and a seismic factor of safety of 1.50.

We also calculated the amount of force that it would take for one of the 6 x 6 x ½" vertical columns to buckle. This value was found to be significantly larger than the value that these columns would see in an earthquake. The hand calculations for this can also be found in Appendix Y.

### *6. A Summary of Safety Factors*

A summary of the safety factors on the major components of our design are summarized in Table 7.

**Table 7.** Summary of Analyzed Safety Factors

| Safety Factors | | |
|---|---|---|
| *Location* | *Static* | *Seismic* |
| Connection Box | 55.4 | 6.5 |
| Beam | 7.0 | **1.37** |
| Column | 8.6 | 1.50 |
| Stability Strut | - | 4.49 |
| Interface Bolt | - | 1.35 |

## *E. Cost Breakdown*

### *1. Cost of Final Product*

The majority of the material used in our design was selected based on what was readily available at the MBMM's preferred supplier, Dwight Peterson. For this reason, our structure utilizes a lot of ¾" steel plate, and large sections of 10" H-beam. We based our cost estimate of these components on a reduced price of $0.50 per pound of steel, as specified by Mr. Peterson. We have yet to confirm whether Mr. Peterson has the following materials: 6 x 6 x ½" square tubing, 4 x 4 x ½" square tubing, 2 ¼ " plate, ⅝" round stock, or 2 ¼ " round stock. If he does not, these materials will most likely be purchased from B&B Steel in Santa Maria, who will deliver to the museum for $100, provided we purchase over $1,000 in material. The MBMM is currently trying to work out a reduced rate on materials from this supplier. Because B&B Steel does not list its prices online, we based our cost estimates on these materials off of prices from McMaster-Carr and Speedy Metals. To compensate for the reduced pricing and shipping we anticipate receiving from B&B Steel, we neglected shipping costs in our estimate. Our Bill of Materials for the final product can be found in Appendix Z. It should be noted that the cost of water jet cutting any material has been left off of the Bill of Materials, as the MBMM hopes to have this labor donated.

Standard industry procedures and guidelines were used in determining the total number of man hours required to complete the entire design. The weight of deposited metal (WM) was calculated based on the cross-sectional area of each fillet weld, the length of each weld, and the density of the material that is being used. The deposition rate is the rate of a welding procedure that determines the pounds of weld metal deposited per hour during welding. Using FCAW, a ∅0.068 wire running at 325 amps has a deposition rate of approximately 8.4 lbs/hr. For FCAW, the welder's efficiency, or operator factor, is generally accepted to be between 45%-55%, compared to SMAW efficiency of 5%-30%. An operator factor of 40% was used in determining the total number of man hours. A total of 60 man hours of welding was determined to be required in order to complete the entire design. A summary of the welding man hours required per structure and connection box can be seen in the following tables, Table 8 and Table 9.

**Table 8.** Total Man Hours of Welding Per Structure.

| **Feature** | **Weld length [in.]** | **Man Hrs [hr]** | **Man Hrs [min]** | **# of Times Process is Repeated** | **Total Man Hrs [hr]** | **Total Man Hrs [min]** |
|---|---|---|---|---|---|---|
| Vertical Column to H-beam | 24 | 0.77 | 57.5 | 2 | 1.54 | 92.4 |
| Vertical Column to Long Foot | 24 | 0.77 | 57.5 | 2 | 1.54 | 92.4 |
| Stability Strut to Vertical Column | 16 | 0.51 | 38.3 | 6 | 3.07 | 184.2 |
| Stability Strut to Long Foot | 16 | 0.51 | 38.3 | 6 | 3.07 | 184.2 |
| Beam Cap to Main Beam | 31 | 0.44 | 33 | 2 | 0.88 | 52.8 |
| Torsion Gusset to Main Beam | 38 | 0.84 | 63.2 | 2 | 1.68 | 100.8 |
| | | | | **Total :** | **11.78** | **706.8** |

**Table 9.** Total Man Hours of Welding Per Connection Box

| Feature | Weld length [in] | Man Hrs [hr] | Man Hrs [min] | # of Times Process is Repeated | Total Man Hrs [hr] | Total Man Hrs [min] |
|---|---|---|---|---|---|---|
| Box Gusset to Box Plate | 17.25 | 0.38 | 23.0 | 2 | 0.78 | 46.1 |
| Box Gusset to Back Plate | 27.25 | 0.61 | 36.9 | 2 | 1.22 | 73.0 |
| Puck Gusset to Back Plate | 10 | 0.22 | 13.4 | 1 | 0.22 | 13.4 |
| Puck Gusset to Box Plate | 2.5 | 0.06 | 3.4 | 2 | 0.12 | 6.8 |
| Puck Gusset to Puck | 5 | 0.11 | 6.7 | 1 | 0.11 | 6.7 |
| Puck to Back Plate | 10.79 | 0.24 | 14.4 | 1 | 0.24 | 14.4 |
| Back Plate to Box Plate | 19.76 | 0.44 | 26.4 | 1 | 0.44 | 26.4 |
| | | | | **Total :** | **3.1** | **186.8** |

It can be seen in the BOM in Appendix Z that including the cost of materials and labor, our design will cost the MBMM less than their budgeted amount of $10,000, thereby meeting Specification #4 as outlined in Table 1.

*2. Cost of Prototypes*

To communicate our final design concept to the MBMM, we produced two prototype models. The first was a steel scaled model of the design. This scaled model allowed us to confirm our analysis, some of which was difficult to accurately analyze by hand. The second was a full-size wooden model of one of our support structures. The purpose of this model was to provide the welder and the members of the MBMM with an idea of how easily accessible different portions of the structure will be for welding, coating, and painting purposes. The following two sections summarize the costs associated with the steel scaled prototype and the wooden full-scale prototype. The cost of our models was covered by the generous funding allocated to our team by the Baker/Koob Grant for $500 that we received.

*a. Steel Scaled Prototype*

The cost of building the steel scaled prototype was $306.63. The materials and quantities required can be found in Appendix AA, the Bill of Materials for both prototypes. More detailed information regarding the vendors can be found in Appendix AA, and vendor supplied component specifications for the materials can be found in Appendix BB.

*b. Wooden Full-Scale Prototype*

The cost of building the wooden full-scale prototype was $127.74. The materials and quantities required can be found in Appendix AA, the Bill of Materials for both prototypes. More detailed information regarding the vendor can be found in Appendix AA, and vendor supplied component specifications for the materials can be found in Appendix BB.

*F. Materials Selection*

As mentioned in Chapter 2, Section F, it is best to not bring dissimilar metals into contact in a corrosive environment. For this reason, we have decided to use carbon steel, because that is what the trailer is made out of, and our structure will be directly interfacing with the trailer. We will be using A500 steel for the square tubing on the sawhorses, A36 steel for the plates, and A500 steel for the 10” H-beams. These materials were selected based on what was readily available from B&B Steel and Dwight Peterson’s steel yard, as these were preferred suppliers for the MBMM. This also ensures that Specification #6, as outlined in Table 1, is met. Additionally, carbon steel is an ideal choice because it is a more common material used when welding will be performed.

*G. Fabrication*

The following sections detail the anticipated fabrication of all components of the two main pieces of our design -- the connection box, and the sawhorse. It should be noted that all edges will be deburred after manufacturing, to ensure that no sharp edges remain. It should also be noted that all manufacturing was originally specified such that it could be performed within 200 ft of the DSRV’s current location, thereby meeting Specification #3, as outlined in Table 1. The water jet cutting of the connection box was a decision made by the MBMM after discovering that they had access to a shop in Los Angeles.

*1. Connection Box*

The puck of the connection box will be water jet from 2 ¼" thick steel plate. Further dimensions on the puck can be found in Appendix R. An image of the puck can be found in Figure 33.

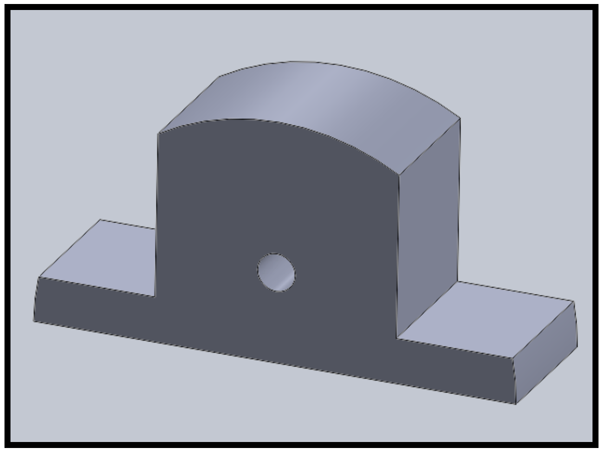

**Figure 33.** An image of the puck.

The puck gusset will be be water jet from ¾" thick steel plate into a 2 ¼ x 5" rectangle, with the corners that interface with the back plate removed at 45 degree angles. The purpose of this is to increase the weld surface area.

The upper interface plate will be made out of ¾" steel plate and cut into 13 ¼ x 18" rectangles using a plasma torch. This plate will have four ⅝" diameter holes drilled into its four corners, 1 ¾ " away from each side, by a drill press.

The box plate will be water jet from ¾" thick steel plate cut into a 13 ¼ x 12" rectangle. The back plate will also be made out of ¾" steel plate, and will be water jet into a 11 x 17" rectangle. The upper corners of the rectangle will be notched off at 45 degree angles, beginning at a height of 14" This plate will also have a 1" diameter hole at a height of 15 ¾ " as well as a ⅝" diameter hole at a height of 6 ½ " drilled into the plate using a drill press.

The box gussets will be water jet from ¾" steel plate into 9 ¼ x 14 ¼ " triangles. The corners of these gussets will be removed at 45 degree angles to increase weld surface area. An image of this gusset can be found in Figure 34.

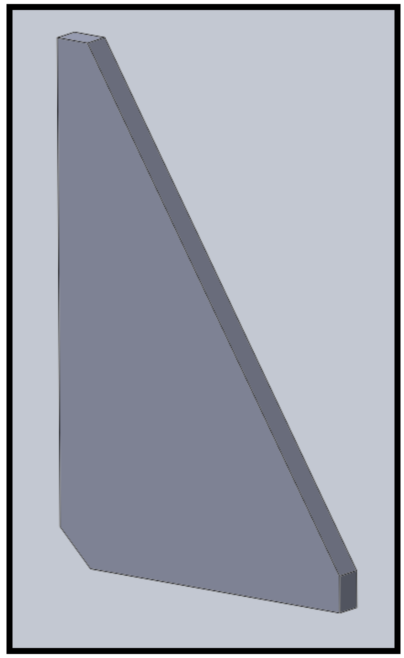

**Figure 34.** An image of the box gusset.

*2. Sawhorse*

Each main beam will be cut into 9 ½' lengths using an acetylene torch. Two of these pieces will be cut from the H-beams that the MBMM has on hand behind their museum. The other two will be cut from material in Dwight Peterson's steel yard. The end caps of the beams will be cut from ¾" steel into 10 x 10" pieces using a plasma torch.

The top of the main beam will have the lower interface plate welded on top of it. The lower interface plate, as well as all of the shims, will be made out of ¾" steel plate, into 13 ¼ x 18" rectangles using a plasma torch. This plate will have four ⅝" diameter holes drilled into its four corners, 1 ¾" away from each side, by a drill press. Two ⅝" holes will need to be drilled through the flange of the main beam as well, using a drill. This is because the connection box and shims will align such that they are flush with the front of the main beam, and overhang by 3 ¼ " from the back of the main beam (the side nearest the trailer). The holes will need to be drilled into the flange on the side farthest from the trailer.

The beam gussets will be placed on the main beam on the side farthest from the trailer in line with the bolts running through the shims. They will be cut from ¾” steel plate into 9 x 4 ¾” rectangles using a plasma torch. The corners of these gussets that interface with the web of the main beam will be notched off at 45 degree angles. This is due to the fact that that the intersection of the web and the flange of an H-beam is not 90 degrees, so the gussets will not fit if they are perfect rectangles. The other gussets, the torsion gussets, will be welded to the side nearest the trailer, will sit flush with the upper interface plate and then proceed at an angle until they meet the lower flange of the H-beam. Further detail regarding these gussets can be found in Appendix R. An image of one of these gussets has been provided in Figure 35, for reference.

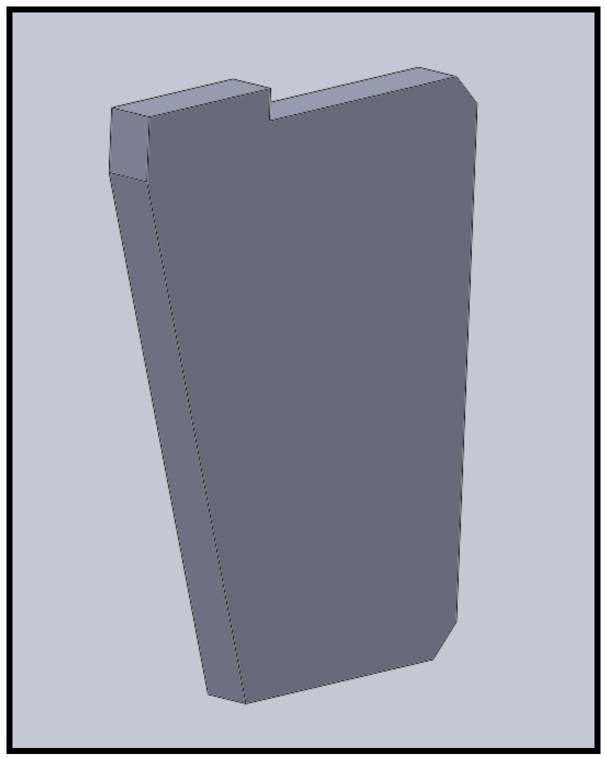

**Figure 35.** An image of the torsion gusset.

An image of the main beam, complete with gussets, end caps, and the lower interface plate can be found in Figure 36.

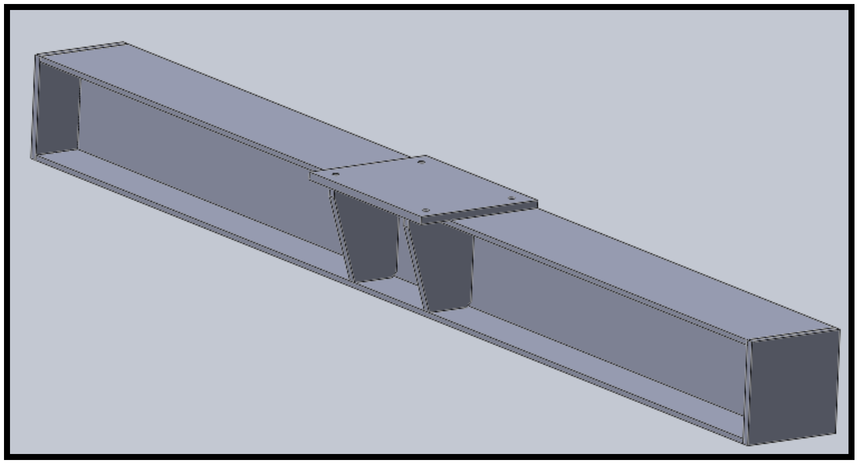

**Figure 36.** An image of the main beam with the gussets, end caps, and lower interface plate installed.

The two vertical columns will be cut from 6 x 6" wide ½" thick square tubing into 4 ½' lengths using a bandsaw. The three stability struts per each vertical column will be made out of 4 x 4" wide 3/16" thick square tubing and will also be cut using a bandsaw. These will intersect the vertical columns at a height from the ground of 32", meaning that each piece will be 42" long. The four tubes per side of the sawhorse will be connected via a T-shaped plate that will be made of ¾" steel, cut with a plasma torch. The T will be constructed by welding the long foot and the short foot together.

*3. Additional Components*

The trailer backplate will be made from ¾" thick steel plate cut into a 4 x 4" rectangle using a plasma torch. This plate will have a 1" diameter hole drilled into it, using a drill press, for the trailer bolt. The trailer bushing will be cut from 2.5" diameter round stock to a length of 2.5". A ⅝" diameter hole will then be drilled through it such that it is concentric with the rest of the piece.

The stability rod will be made from ⅝" diameter round stock. The ends will be threaded using a die. The trailer bolt, trailer interface nut, long interface bolt, and the nut for the long interface bolt will all be purchased parts.

*H. Safety, Maintenance, and Repair Considerations*

*1. Safety Considerations*

In analyzing our final design, we revisited the Design Hazard Checklist and identified additional hazards that we were unaware of previously. The Design Hazard Checklist in Appendix P has been updated to reflect these changes. All hazards and planned corrective actions on the checklist will be described in greater detail in this section, although a summary of each is provided in the checklist in the Appendix.

The first identifiable hazard noted is that the DSRV and the trailer could fall under gravity, creating injury. In analyzing our design, we have determined our structure will prevent this from happening and that the static factor of safety on all components of our design is greater than 7.0.

The second identifiable hazard is that the system could potentially have sharp edges. To mitigate this, we will specify that all edges are beveled or ground to remove potentially sharp edges.

The third identifiable hazard is that the user may be required to exert abnormal physical effort during the installation of the design. While each of the sawhorses will be brought as close in place as possible by the forklift driver, the final adjustments will have to be made manually. We will recommend that four people carry the sawhorses using the following procedure: lifting one side, moving it a little, setting it down, moving the other side so that the structure is again parallel with the trailer, and setting it down. We will recommend that this be performed in small increments. Further detail regarding this installation procedure can be found in the Operator's Manual in Appendix GG.

The fourth identifiable hazard is that the system will be exposed to extreme environmental conditions, specifically the moisture and salt associated with a marine environment. To protect our structure from corrosion, we will perform the following procedures: grind off existing rust, coat the structure in a rust-inhibiting coating, apply a two-part polyurethane primer, and paint the structure with an oil-based top coat.

The final identifiable hazard is that it is possible for the system to be used in an unsafe manner. As with the existing trailer, our structure would be fairly easy to climb on, which could result in someone falling and becoming injured. To mitigate this, we will recommend that warning labels be placed on all four structures, warning museum visitors to not climb on the structures. We will also recommend that a caution label be placed on the feet of the sawhorse. While these feet introduce a tripping hazard that ideally would have been avoided, we have elected to add them in order to improve the seismic stability of our design. In our opinion, it is more critical that the trailer and DSRV not fall and crush someone than it is to not present a tripping hazard.

*2. Maintenance*

Our selected painting and coating procedures should allow the MBMM to simply touch-up the painting job on the four structures annually, thereby meeting Specification #5, as outlined in Table 1. Any rust or surface contaminants should be removed prior to touch-up. Next, the material should be coated in OSPHO, followed by the macro epoxy primer. Finally, an oil-based white top coat of paint should be applied to all touch-up locations.

*3. Repair*

Under the typical static load that our structures will see, repair will not be necessary. However, should an earthquake occur, it is possible that components of our structures will need to be repaired. The primary locations to inspect for damage include the welds, and the bolted connections.

In the event that the MBMM needs to either repair a structure, or move the trailer and DSRV, perhaps to its final location in the interpretive center, the four structures will need to be removed, and the tires will need to be reinstalled. The Operator's Manual, provided in Appendix GG outlines the necessary steps.

# Chapter 5 - Product Realization

*A. Overview of Models*

Since our team will not be building the final structure that will support the DSRV and the trailer, we built a steel scaled prototype of our design, as well as a full-scale wooden prototype of the design. For the steel scaled model, we primarily tested the strength of the sawhorse under both a static and seismic load. An image of the CAD model and the completed model of the steel scaled prototype can be found in Figure 37.

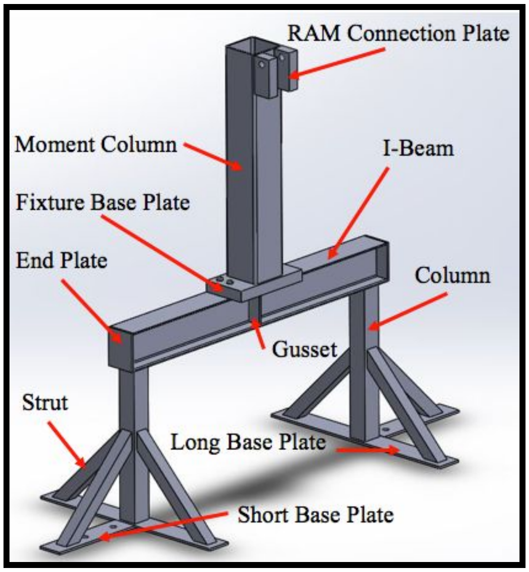


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**Figure 37.** On the left, an image of the CAD model of the steel scaled prototype. On the right, an image of the steel scaled prototype we built.

Our model is a 1:4.28 scaled version of the final design. We selected this scale by first determining the stresses at the most critical locations. We then determined the smallest sized I-beam we could readily purchase. Finally, we selected a load based on how much force it would take to generate the critical stresses in the scaled material.

We have replaced the connection box with a moment column, which allowed us to load the sawhorse with 1,500 pounds at an angle of 45 degrees. This load was selected based on both the capabilities of the hydraulic ram we used to produce the load, and the stresses that it would induce on the critical locations of the sawhorse. To support the hydraulic ram, we constructed a testing fixture, which can be found in Figure 38.

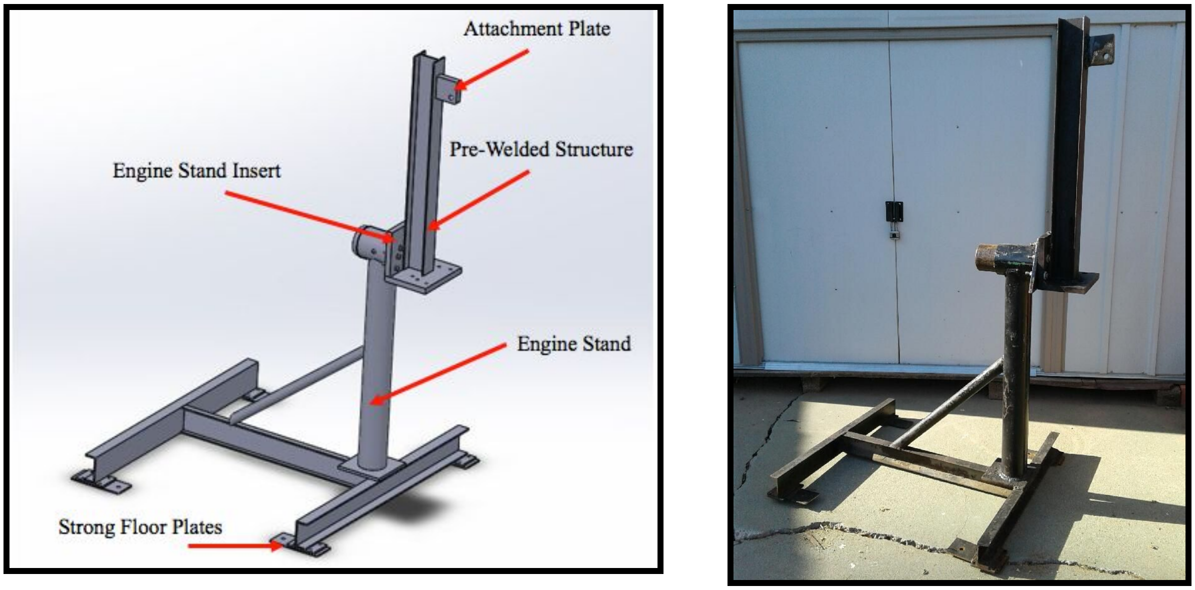



**Figure 38.** On the left, an image of the testing fixture, constructed with CAD. On the right, an image of the testing fixture, manufactured out of scrap materials.

Loading the sawhorse at 45 degrees allowed us to simulate both the vertical static load that the sawhorse will see during a typical day, as well as the horizontal load that an earthquake would induce on the structure. We decided not to build a scaled model of the connection box due to the difficulties that would be encountered in welding such a small object. Additionally, we anticipate that, should failure occur in our structure, it will not fail at the connection box. Detailed drawings for the steel scaled model can be found in Appendix CC.

For the wooden full-scale model, we primarily tested the geometry of the structure, and how it interfaces with the actual trailer. Images of the CAD model and completed model of the wooden full-scale prototype can be found in Figure 39.

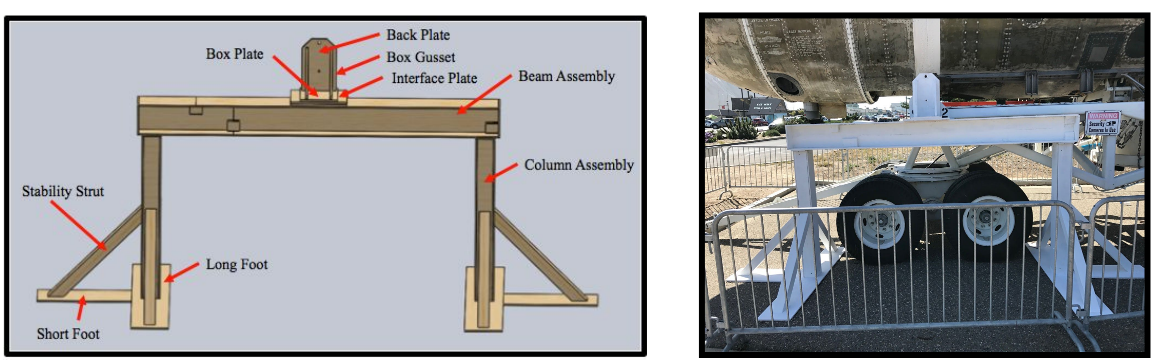



**Figure 39.** On the left, an image of the CAD model of the wooden full-scale prototype. On the right, an image of the wooden full-scale prototype we built.

We built the model at Cal Poly and completed the final assembly steps in Morro Bay alongside the DSRV. We placed the model up against the trailer to measure how far the structure will extend out from the trailer. It should be noted that the actual gussets on the H-beam have not been included in this model. Leaving these pieces separate from the model allowed us to check that we had sized the gussets correctly for the actual steel H-beam. Detailed drawings for the wooden full-scale prototype can be found in Appendix DD.

*B. Description of Manufacturing Processes: The Steel Scaled Prototype*

What follows is a summary of all manufacturing and assembly processes performed on the steel scaled model, broken down by component. It should be noted that all components will be referred to by their names as defined in Figure 37 above.

*Column*

The oil coating on the material used for the column was removed using an angle grinder. An image of the angle grinder has been provided in Figure 40.

**Figure 40.** The angle grinder used to remove the oil coating on the material for the column.

The material was then cut to size using a chop saw. An image of this has been provided in Figure 41.

**Figure 41.** An image of Austin cutting the material for the column to size, using a chop saw.

All edges were deburred using a file, a deburring tool, and an angle grinder. These procedures were then repeated for the second column of the sawhorse.

*Long Base Plate*

The material for the long base plate was cut to size using a combination of the horizontal bandsaw and an angle grinder with a cutoff wheel. An image of the angle grinder with the cutoff wheel has been provided in Figure 42.


**Figure 42.** An image of the angle grinder with the cutoff wheel attached.

All edges were deburred using an angle grinder. This process was then repeated for the second long base plate.

*Short Base Plate*

The material for the short base plate was cut to size using a plasma cutter. All edges were straightened out and deburred using a bench grinder.

*Strut*

The oil coating on the material used for the strut was removed using an angle grinder. The material was then cut to size using a chop saw, and the miter cuts were also performed using a chop saw. An image of the setup used for the miter cuts has been provided in Figure 43.

**Figure 43.** An image of Austin setting up the chop saw in preparation for making the miter cuts on the struts.

All edges were deburred using an angle grinder. These procedures were then repeated for the other five struts of the sawhorse. Each column and its corresponding three struts were welded together using a Miller MIG welder. An image of this welder has been provided in Figure 44.


**Figure 44.** An image of the Miller MIG welder used for all welding operations.

An image of the joined column and struts after welding has been provided in Figure 45.

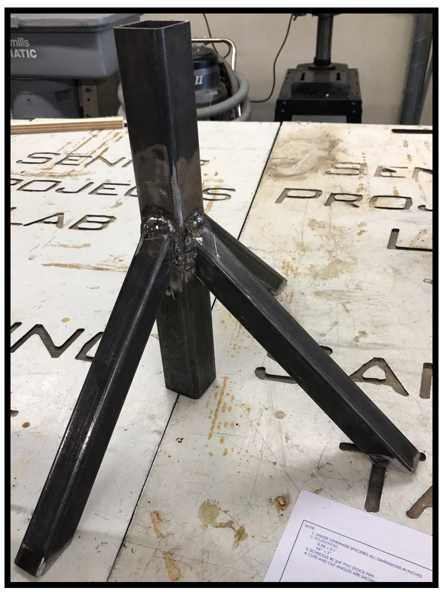


**Figure 45.** An image of the joined struts and column.

Each strut was then welded to the short and long base plates using a Miller MIG welder. An image of the joined struts and base plates has been provided in Figure 46.

**Figure 46.** An image of the joined base plates and struts.

*I-Beam*

The I-beam for the sawhorse was cut to size using both a chop saw and a horizontal bandsaw. An image of cutting the I-beam with the chop saw has been provided in Figure 47.

**Figure 47.** An image of Octavio attempting to cut the I-beam using a chop saw.

After flipping the I-beam over several times in an attempt to complete the cut, the final cut on the I-beam was made using a horizontal bandsaw per the recommendation of a shop technician. All edges were deburred using an angle grinder. The holes in the I-beam were drilled using a drill press. Finally, the I-beam was welded to the columns using a Miller MIG welder. At this point, the manufacturing of the sawhorse was complete. Next, the sawhorse was brought to the Composites Lab, 192-135, to determine the precise locations where the holes needed to be drilled so that the fixture correctly aligned with the strong floor slots.

*Fixture Base Plate*

The material for the fixture base plate was cut to size using a horizontal bandsaw. All edges were deburred using an angle grinder. The holes were drilled using a drill press.

*Moment Column*

The material for the moment column was cut to size using a chop saw. All edges were deburred using an angle grinder. The moment column was welded to the top of the fixture base plate using a Miller MIG welder. An image of the moment column before it was welded to the fixture base plate has been provided in Figure 48.

**Figure 48.** An image of the moment column before it was welded to the fixture base plate.

*Ram Connection Plates*

The ram connection plates were cut to size using a horizontal bandsaw. All edges were deburred using an angle grinder. The holes were drilled using a drill press. An image of this has been provided in Figure 49.

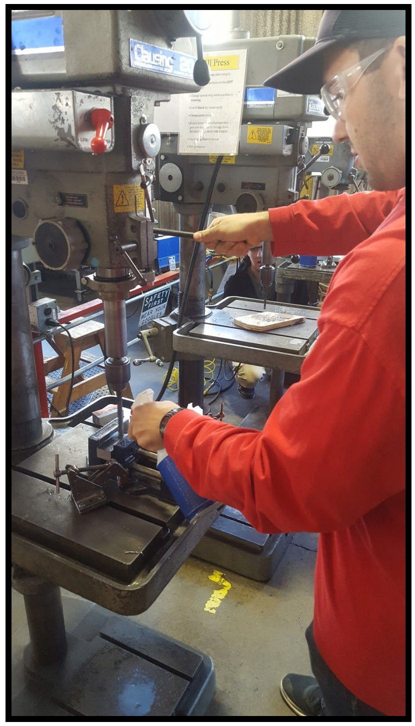


**Figure 49.** An image of Austin drilling the holes in the ram connection plates.

The two ram connection plates were welded to the moment column using a Miller MIG welder. The ram connection plates can be observed in Figure 48, welded to the moment column.

*Gussets and End Plates*

The gussets and end plates were cut to size using a plasma cutter. The final size adjustments were made using an angle grinder. The end plates were welded to the ends of the I-beam using a Miller MIG welder. The gussets were welded between the flanges of the I-beam using a Miller MIG welder. An image of the I-beam after the gussets and end plates were welded on has been provided in Figure 50.

**Figure 50.** An image of the I-beam after the end plates and gussets were welded on.

*C. Description of Manufacturing Processes: The Testing Fixture*

What follows is a summary of all manufacturing and assembly processes performed on the testing fixture, broken down by component. It should be noted that all components will be referred to by their names as defined in Figure 38. The detailed drawings for the fixture have been provided in Appendix CC.

*Pre-Welded Structure*

First, a portion of the pre-welded structure was removed using the horizontal bandsaw. An image of this has been provided in Figure 51.

**Figure 51.** An image of the pre-welded structure after a portion of it was removed on the horizontal bandsaw.

All edges were deburred using an angle grinder. Next, holes were drilled into the plate portion of the piece using a drill press. These holes were positioned such that they would align with the holes located on the engine stand insert.

*Attachment Plate*

The material for the attachment plate was cut to size using a horizontal bandsaw. The holes were drilled into it using a drill press. The attachment plate was welded to the pre-welded structure using a Miller MIG welder. An image of the attachment plate after it was welded to the pre-welded structure has been provided in Figure 52.

**Figure 52.** An image of the attachment plate after it was welded to the pre-welded structure.

*Strong Floor Plates*

The material for the strong floor plates was cut into four rectangles using an angle grinder with a cutoff wheel. All edges were deburred using a bench grinder. Each plate was welded to the bottom of the engine stand using a Miller MIG welder. An image of this has been provided in Figure 53.

**Figure 53.** An image of Octavio welding the strong floor plates to the bottom of the engine stand.

The paint on the engine stand at each welding location was removed using an angle grinder prior to welding. An image of these four plates welded to bottom of the engine stand can be found in Figure 54.

**Figure 54**. An image of the four strong floor plates after they were welded to the base of the engine stand.

Next, the engine stand was brought into the Composites Lab, 192-135, to determine the precise locations where the holes needed to be drilled so that the fixture correctly aligned with the strong floor slots. After marking these locations, the holes were drilled using a drill press.

*Load Cell Coupler*

The load cell coupler that connects the load cell to the hydraulic ram was manufactured out of rectangular steel stock that was purchased from McMaster-Carr. First, the rectangular stock was cut to size using a horizontal bandsaw. Next, the hole was counterbored into the piece using a drill press. This hole allowed the bolt to connect to the load cell on one side, and allowed the hydraulic ram to rest inside the bore on the other side. An image of the manufactured load cell coupler has been provided in Figure 55.

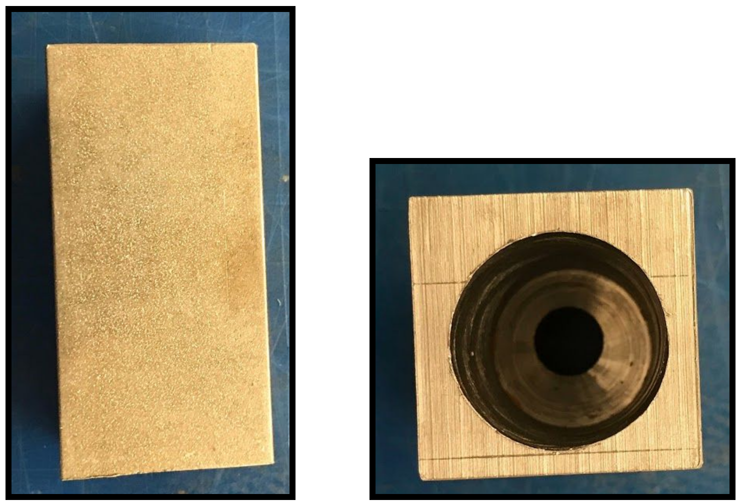


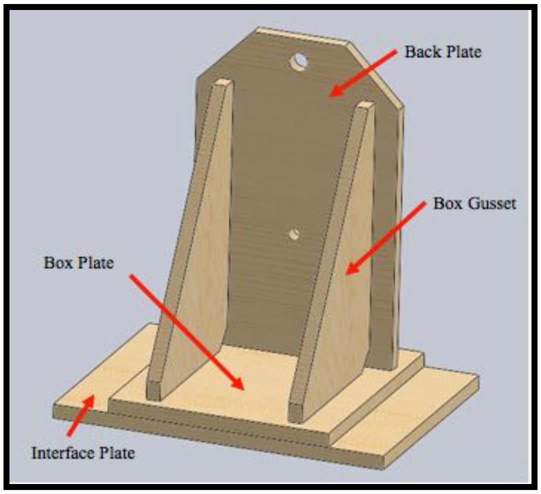
**Figure 55.** An image of the manufactured load cell coupler.

*D. Description of Manufacturing Processes: The Wooden Full-Scale Prototype*

What follows is a summary of all manufacturing and assembly processes performed on the wooden full-scale model. In the first two sections, the manufacturing processes are outlined, broken down by component. It should be noted that all components will be referred to by their names as defined in Figure 39 above. In the third section, the assembly process is outlined. Lastly, in the fourth section, the painting process is described.

*1. Manufacturing: The Connection Box*

A front and back view of the connection box have been provided in Figure 56. All components of the connection box will be referred to by their names as defined in these images.



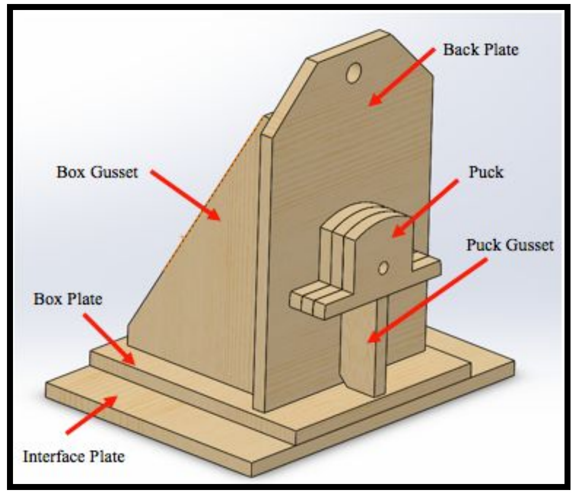




**Figure 56.** On the left, an image of the front of the connection box. On the right, an image of the back of the connection box.

*Puck*

All cuts on the puck were performed on a bandsaw. An image of this has been provided in Figure 57.

**Figure 57.** An image of the puck being cut on the bandsaw.

The hole in the puck was drilled using a drill press.

*Back Plate*

All square cuts on the back plate were performed using a table saw. An image of this has been provided in Figure 58.

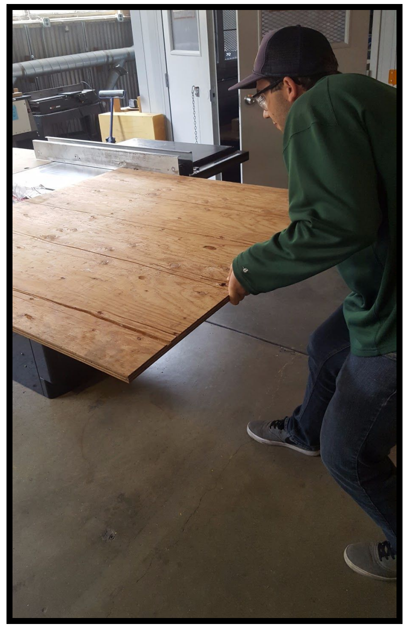


**Figure 58.** An image of the back plate being cut on the table saw.

The two mitered cuts were performed using a compound miter saw. The two holes on the back plate were drilled using a drill press.

*Box Gussets*

The square cuts on the box gussets were performed using a table saw. The angled cuts on the gussets were performed on a bandsaw.

*Box Plate*

All cuts on the box plate were performed using a table saw.

*Puck Gusset*

All square cuts on the puck gusset were performed using a table saw. The curved cuts on the puck gusset were performed using a vertical belt sander.

*Interface Plate*

All cuts performed on the interface plate were performed using a table saw.

*2. Manufacturing: The Sawhorse*

*Beam Assembly*

All components of the beam assembly will be referred to by their names as outlined in Figure 59.

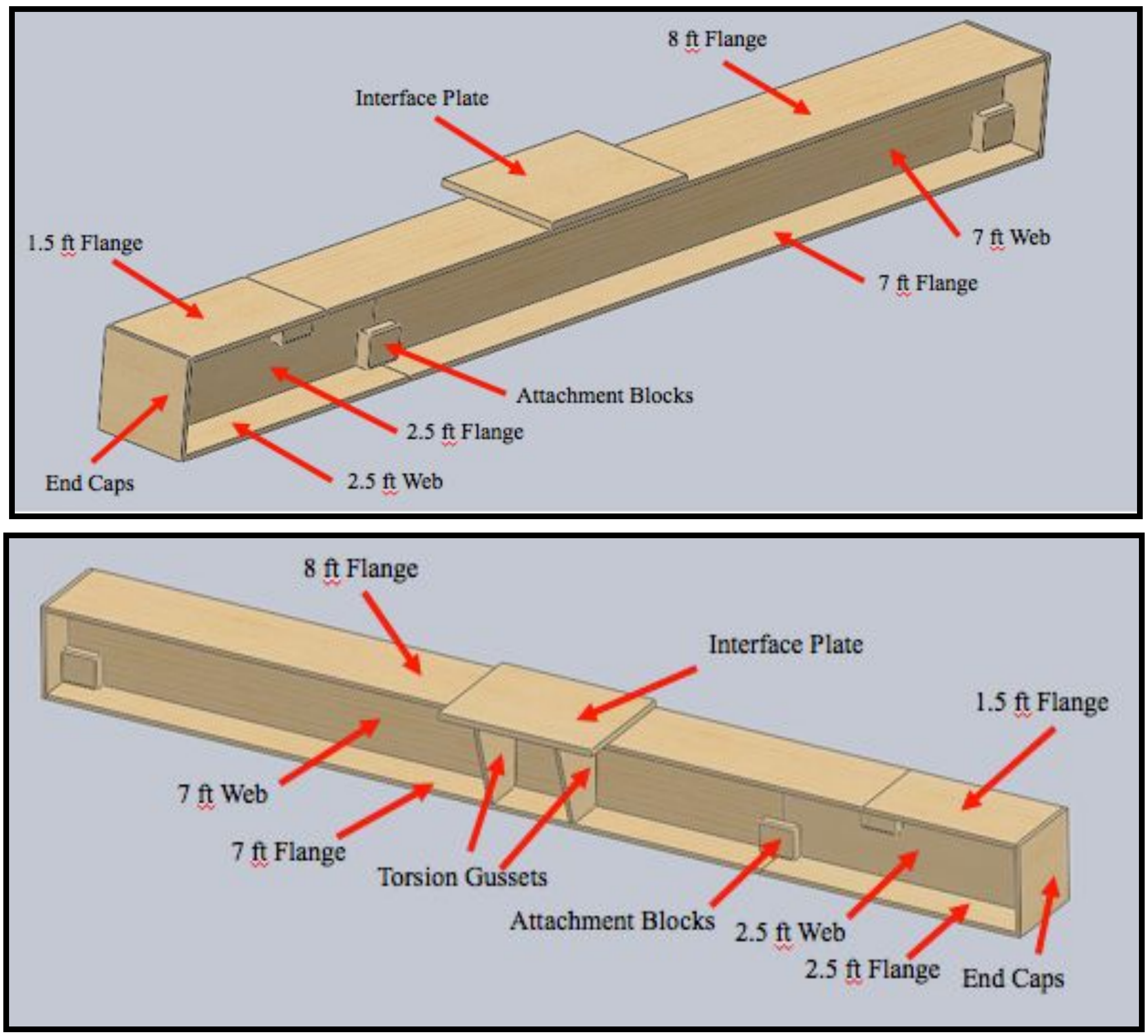



**Figure 59.** On the top, an image of the front view of the beam assembly. On the bottom, an image of the back view of the beam assembly, with the torsion gussets included.

*i.* *8ft Flange*

The 8ft flange was cut using a table saw.

*ii.* *7ft Flange*

The 7ft flange was cut using a table saw.

*iii.* *2.5ft Flange*

The 2.5ft flange was cut using a table saw.

*iv.* *1.5ft Flange*

The 1.5ft flange was cut using a table saw.

*v.* *7ft Web*

The 7ft web was cut using a table saw.

*vi.* *2.5ft Web*

The 2.5ft web was cut using a table saw.

*vii.* *End Caps*

The end caps were cut using a table saw.

*viii.* *Interface Plate*

The 7ft web was cut using a table saw.

*ix.* *Torsion Gussets*

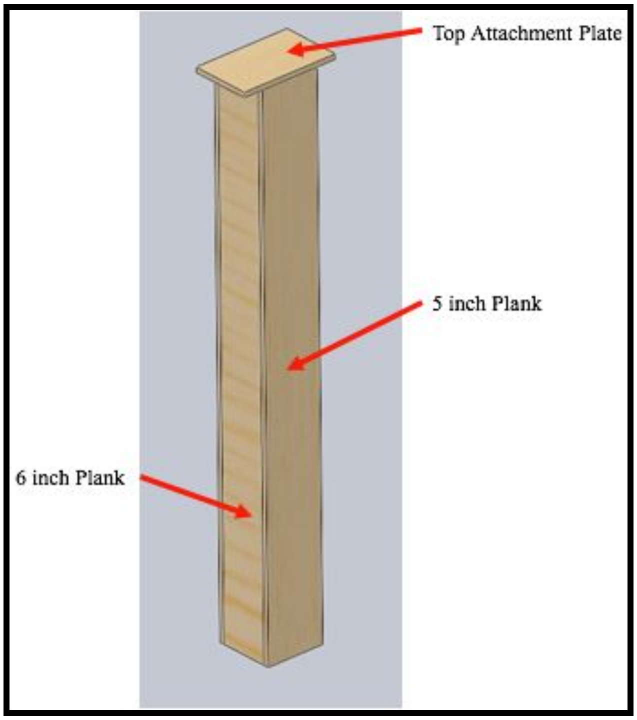
The torsion gussets were cut into a square using a table saw, and the remaining cuts, including the miter cuts, were performed on a compound miter saw.

*x.* *Attachment Blocks*

The attachment blocks were cut using a compound miter saw.

*Column Assembly*

All components of the column assembly will be referred to by their names as outlined in Figure 60.



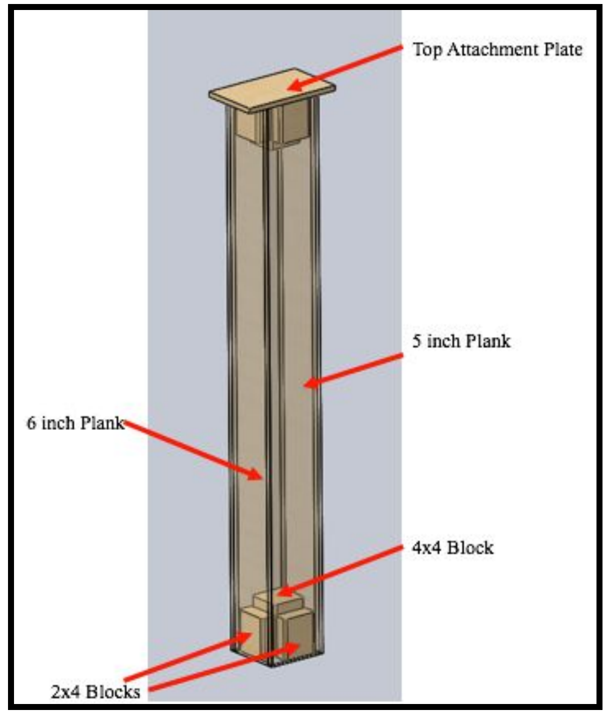



**Figure 60.** On the left, an image of how the column assembly would actually look. On the right, an image where the planks have been made transparent to show how the 2x4" and 4x4" blocks interface with the planks to form the square tubes.

i. *5" Plank*
The 5" plank was cut using a table saw.

ii. *6" Plank*
The 6" plank was cut using a table saw.

iii. *Top Attachment Plate*
The top attachment plate was cut using a table saw.

iv. *4x4" Blocks*
The 4x4" blocks were cut using a compound miter saw.

v. *2x4" Blocks*
The 2x4" blocks were cut using a compound miter saw.

*Struts*

The struts were cut to size using a compound miter saw. The miter cuts on the struts were performed using a compound miter saw. An image of this has been provided in Figure 61.

**Figure 61.** An image of the miter cuts being performed on the compound miter saw.

*Long Feet*

The long feet were cut to size on a table saw.

*Short Feet*

The short feet were cut to size on a table saw.

*3. Assembly*

This section outlines the assembly process of the wooden full-scale prototype.

*a. Connection Box*

The connection box was assembled using a cordless drill and a Phillips screwdriver bit. Pilot holes were drilled using a drill bit, and then the screws were driven into place using a Phillips head drill bit.

*b. Beam Assembly*

First, pilot holes were drilled using a cordless drill with a drill bit. Second, the holes were countersunk using a cordless drill with a countersink bit. This was done to prevent the wood from splitting upon insertion of the screws. Finally, the screws were driven into place using a cordless drill with a Phillips screwdriver bit. An image of assembling the beam assembly has been provided in Figure 62.

**Figure 62.** An image of Austin and Octavio assembling the beam assembly.

*c. Column Assembly*

First, the 4x4" and 2x4" blocks were attached to each other. This was done using the same pilot hole, countersink, and screw driving procedure outlined previously. Second, the 5" and 6" planks were attached to each other and the blocks. This was also done using the same pilot hole, countersink, and screw driving procedure outlined previously. Finally, the top attachment plate was attached, using the same procedure outlined previously. An image of assembling the column assembly has been provided in Figure 63.

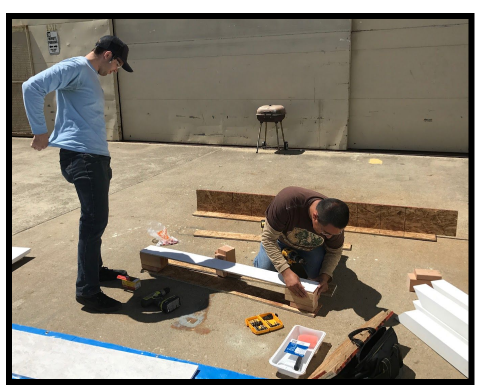


**Figure 63.** An image of Austin and Octavio assembling the column assembly.

*d. Column to Long Foot*

Next, the column was attached to the long foot using the same pilot hole, countersink, and screw driving procedure outlined previously.

*e. Two Struts to Column and Long Foot*

Then, two of the struts were attached to the column using the same pilot hole, countersink, and screw driving procedure outlined previously. The two struts were then attached to the long foot using the same pilot hole, countersink, and screw driving procedure outlined previously.

*f. Short Foot to Strut*

The remaining strut was attached to the short foot using the same pilot hole, countersink, and screw driving procedure outlined previously.

*g. Short Foot and Strut to Long Foot/Column/Two Struts*

The short foot and strut were attached the long foot/column/two strut piece assembled in step e, using the same pilot hole, countersink, and screw driving procedure outlined previously. An image of this step has been provided in Figure 64.

**Figure 64.** An image of Octavio connecting the short foot and strut to the column.

*h. Column to Beam*

Finally, the column, with all struts and feet now attached, was attached to the beam using the same pilot hole, countersink, and screw driving procedure outlined previously.

*4. Painting*

All pieces were painted with white, Glidden interior paint using a roller and paintbrush. The painting of a few components has been provided in Figures 65-67.

**Figure 65.** An image of the struts being painted.

**Figure 66.** An image of the connection box being painted.

**Figure 67.** An image of Alexandra painting the long feet.

# Chapter 6 - Design Verification

The following sections detail all tests performed on the steel scaled prototype as well as the wooden full-scale prototype. The DVP and anticipated test plan for the steel scaled prototype can be found in Appendix EE. It should be noted that the actual tests performed on the steel scaled prototype differ slightly from the anticipated test plan. The first reason for this is that the DAQ software would not install properly on our laptops, which prevented us from recording the data on the DAQ. Instead, we simply took a video of the load cell indicator during the test. Additionally, when setting up the test, we discovered that hydraulic rams do not work upside down. This caused us to flip our setup between the prototype and the fixture 180 degrees, resulting in a slight eccentricity in the load case our model was subjected to. This eccentricity has been shown in Figure 68 and was neglected since the additional stress it introduced to the test was negligible compared to the stress from the weak side bending and torsion on the beam.

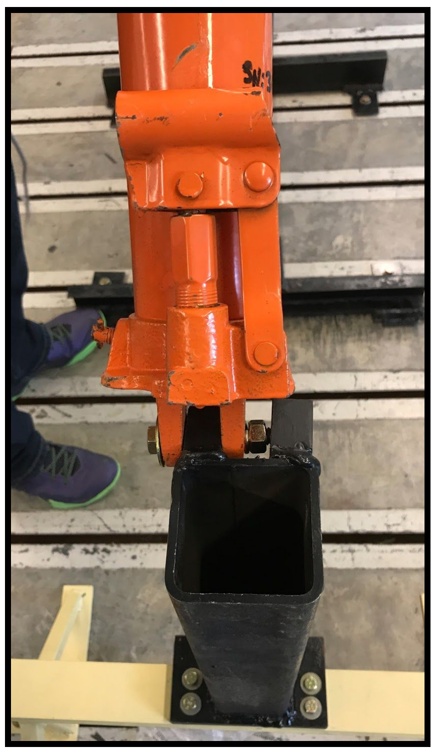


**Figure 68.** An image highlighting the induced eccentricity in the load case due to the hydraulic ram not working upside down.

*A. Testing on the Steel Scaled Prototype*

1. First, all team members donned their safety glasses.
2. Second, we bolted the steel scaled model as well as the testing fixture to the strong floor, using T-nuts provided by the Composites Lab. An image of this has been provided in Figure 69.

**Figure 69.** On the left, an image of the testing fixture bolted to the strong floor. On the right, an image of the steel scaled prototype bolted to the strong floor.

3. Next, the load cell was connected to the load cell indicator. This has been shown in Figure 70.

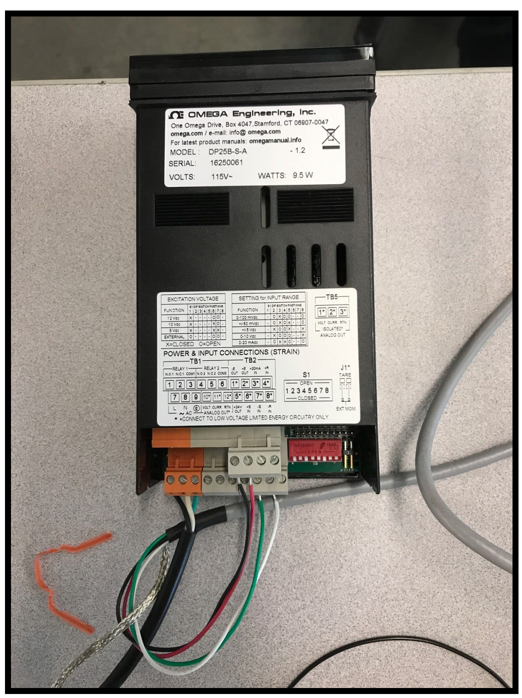



**Figure 70.** An image of the load cell connected to the load cell indicator.

4. The load cell was then connected to the rod end. This step has been shown in Figure 71.

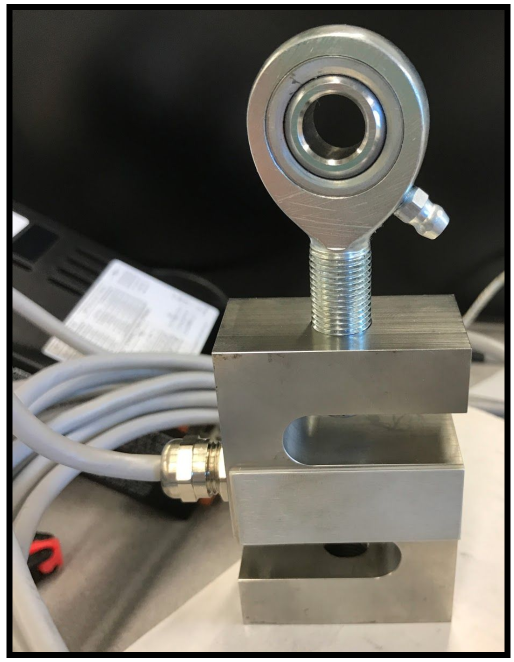


**Figure 71.** An image of the load cell connected to the rod end.

5. Next, the load cell was connected to the load cell coupler. This has been shown in Figure 72.

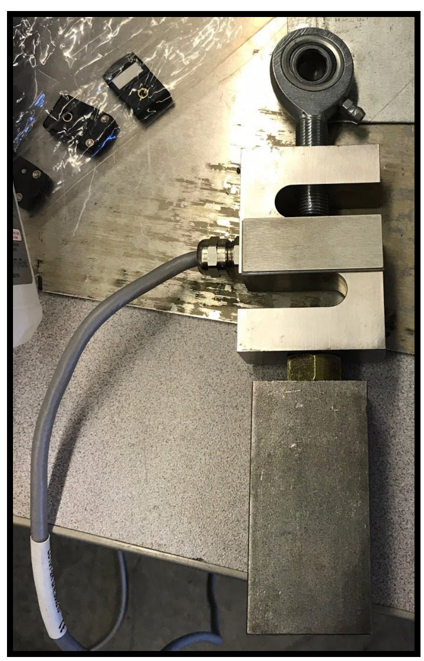


**Figure 72.** An image of the load cell and rod end connected to the load cell coupler.

6. The load cell, rod end, and load cell coupler were then attached to the ram connection plate. This step has been shown in Figure 73.

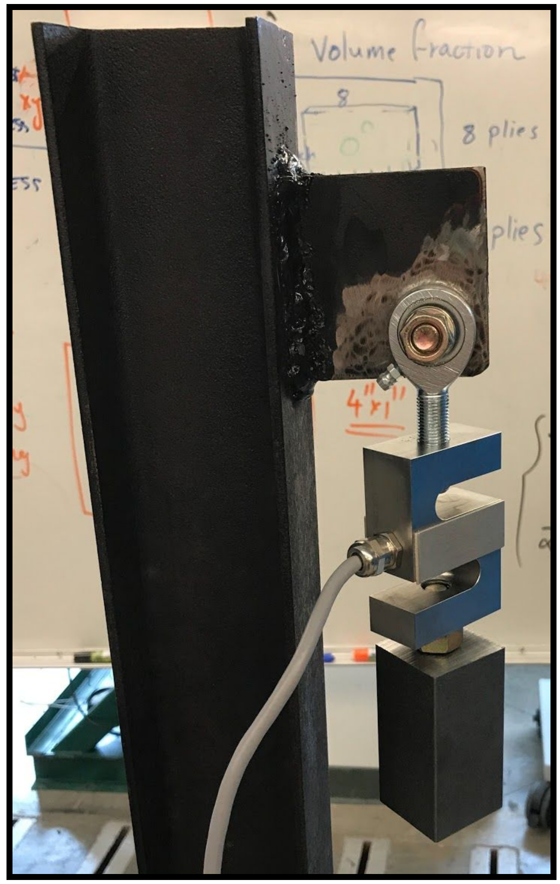



**Figure 73.** An image of the rod end, load cell, and load cell coupler attached to the ram connection plate.

7. Next, the hydraulic ram was connected to the attachment plate. This step has been shown in Figure 74.

**Figure 74.** An image of the ram being connected to the attachment plate.

8. Next, adjustments were made until the angle between the model and the fixture, formed by the ram, was approximately 45 degrees. This step has been shown in Figure 75.

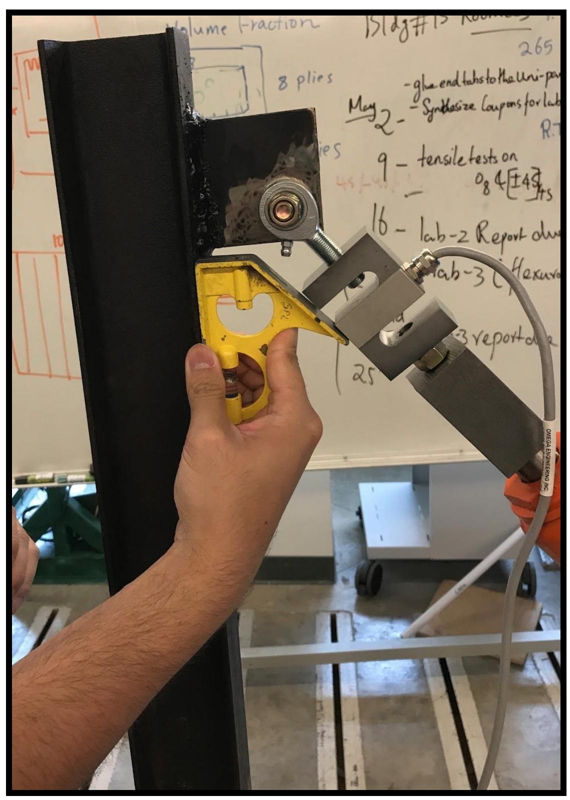



**Figure 75.** An image of the connections being adjusted until the angle between the model and the fixture, formed by the ram, was approximately 45 degrees.

9. Next the hydraulic ram was pumped, and the readout on the load cell indicator was observed. Both of these steps were recorded via video. An image of the completed test setup, has been provided in Figure 76.

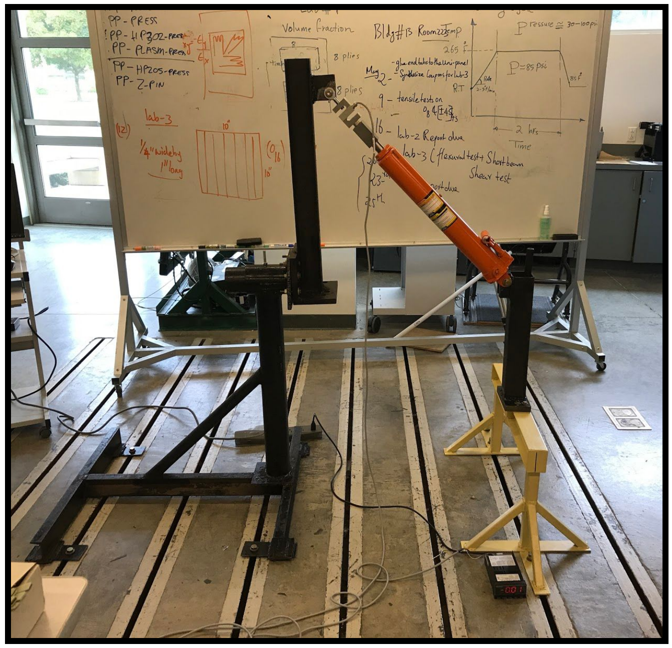



**Figure 76.** An image of the test setup, just prior to testing.

*Results*

The structure yielded at a load of 989 $lb_f$, thereby not meeting specification #11 as defined in Table 1 (a lateral acceleration tolerance of 0.52g). The structure failed due to weld shear between the gusset and the I-beam, which can be observed in Figure 77.

**Figure 77.** An image of the sawhorse after testing was completed. It is obvious from this picture that the structure yielded at the gusset.

The resulting deflection in the beam can be observed in Figure 78.

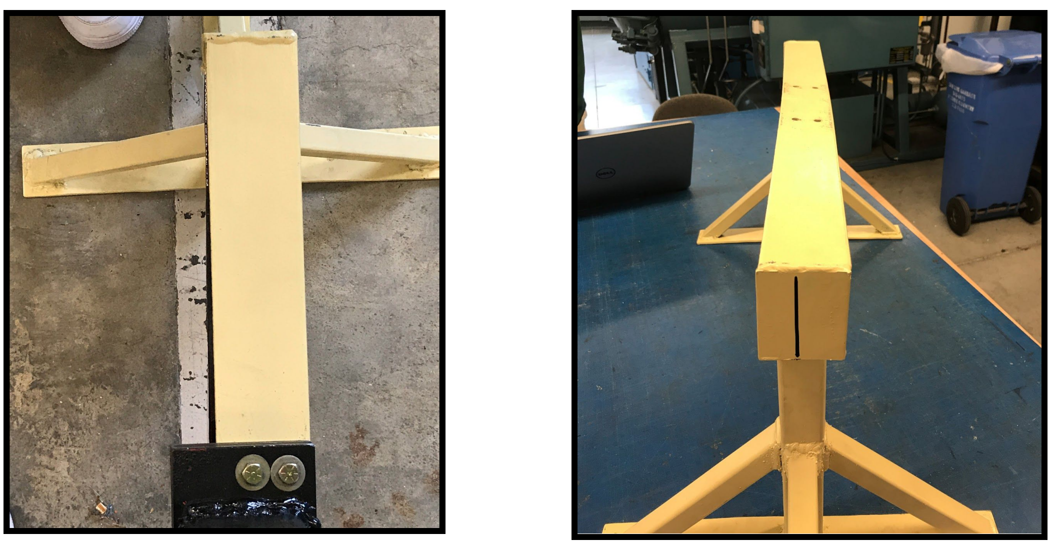


**Figure 78.** Two images showing the deflection of the material after testing.

On the left, the black line was colored in on the bottom flange to demonstrate how the beam deflected. On the right, the curvature in the beam after testing is apparent.

The overall deflection can be observed in Figure 79.


**Figure 79.** An image of the steel scaled prototype after testing.

The original seismic requirement we specified came from the USGS Maximum Expected Peak Lateral Acceleration. This value was specified to ensure structural integrity was strongly considered throughout the design process. However, in most modern structural designs, this acceleration is excessive, so the USGS has specified Maximum Design Peak Lateral Acceleration. This number is used for most structural designs and is lower than the Maximum Expected Peak Lateral Acceleration. After loosening the seismic requirement to this commonly used value, our test results actually show that we have a factor of safety of 1.43. This calculation can be found in Appendix FF.

Another reason for premature failure is due to the stress concentrations between the gusset and I-beam. In reality, we will have two gussets on either side of the I-beam, which will alleviate some of the stress by creating another load path. Between relaxing the lateral acceleration requirement to a more common value and adding more gussets to the beam for the real construction, we are convinced that the design is seismically stable.

*B. Testing on the Wooden Full-Scale Prototype*

For ease of transportation, the wooden model was brought to Morro Bay in multiple pieces. These consisted of the following: the main beam, the column connected to the long foot with two struts attached, the other strut attached to the short foot, the connection box, the interface plate, and the torsion gussets. Upon arrival in Morro Bay, the short foot and strut pieces were attached to the column and the main beam was attached to both columns, thereby completing the sawhorse. We then proceeded with conducting our testing. The connection box, interface plate, and torsion gussets were not connected to the sawhorse during testing because the sawhorse, connection box, and torsion gussets were tested separately.

*Structure Extrusion and Tire Clearance*

The first test consisted of checking to make sure sufficient clearance existed between the tires and the sawhorse in order for the tires to be removed easily. To do this, the sawhorse was placed in front of the trailer at the actual location where the final design will be installed. This has been shown in Figure 80.


**Figure 80.** An image of the sawhorse placed up against the trailer. This is where the sawhorse will actually sit upon installation.

The clearance between the tires and each vertical column was determined to be sufficient, and was measured to be 6 inches. Next, the structure extrusion, or how far the structure extends out from the trailer, was measured to be 3.5 ft, thereby meeting Specification #10, as defined in Table 1. This is what we expected the extrusion to be based on our CAD models of the trailer and our design.

*Connection Box*

Next, the connection box was held in place against the trailer. This has been shown in Figure 81.

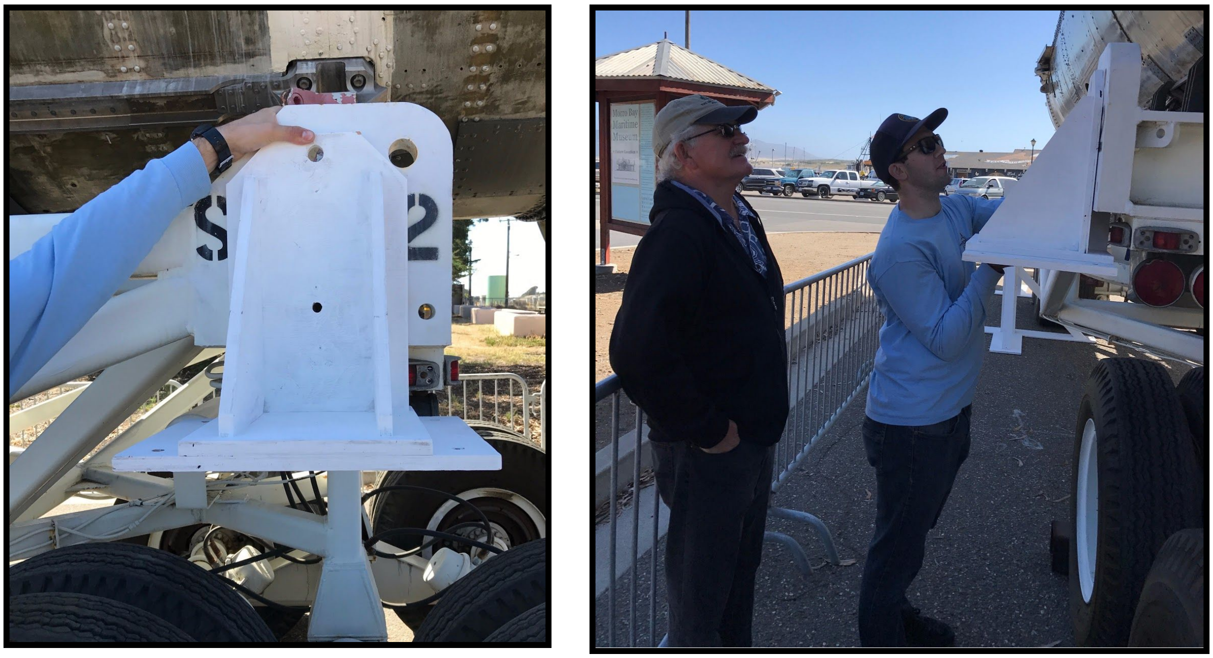


**Figure 81.** On the left, an image showing the connection box from the front, as it would look when attached to the trailer. On the right, an image showing this same connection from the side.

First, the sizing of the puck was tested, and the puck was found to be slightly oversized. As this is a minor change, we incorporated this into our final design and changed the puck diameter from 8” to 7.75”. Next, the hole placement on the back plate was verified.

*Torsion Gussets*

For the purposes of our geometric testing, the torsion gussets were not attached to the beam. Instead, the torsion gussets were placed between the flanges of the actual steel H-beam material that the MBMM has on hand to verify their sizing. The gussets almost fit inside the beam, but were slightly oversized because the flanges of an H-beam are not horizontal -- they slope inward as the web is approached. From our test, we concluded that the best way to ensure the torsion gussets fit snugly will be to manufacture them to our recommended size, and then grind and check the gussets repeatedly with the H-beam until they fit. This will need to be performed for each pair of torsion gussets, since not all of the H-beams will be 100% identical.

After the geometrical testing was complete, the connection box was placed on top of the sawhorse to give the MBMM an idea of what the complete structure will look like when assembled. An image of this has been provided in Figure 82.


**Figure 82.** An image of the completed structure, as it will look when installed on the trailer.

It should be noted that in Figure 81, the structure slightly covers the bottom of the DSRV. This will be eliminated when the trailer has been jacked up, and the structure has actually been installed. The additional height in the vertical columns that will temporarily cause this visual impedance is necessary in order for the entry clearance of the DSRV to be increased by 1 foot. As a result, we feel confident that our design meets specification #7, as outlined in Table 1.

# Chapter 7 - Conclusions and Recommendations

This section lists our final conclusions based on our analysis, manufacturing, and testing, and includes recommendations for the MBMM as they move forward with implementing our design.

- In our analysis, we made many simplifying assumptions. While we did our best to make our calculations conservative, we recommend that the MBMM have a structural engineer look over our design and calculations, and verify that our structures will not fail in the event of an earthquake. None of our classes at Cal Poly have outlined the analysis of structures in the event of seismic events. While we conducted extensive research to determine the best way to model an earthquake, it is possible that something was overlooked and this is why the structure yielded at a lower than anticipated load.
- Since our structure yielded under the strict requirement of 0.52g, we recommend that the MBMM relax the seismic requirement to 0.36g. Between the additional gussets added to the beam and the conservative nature of the 0.52g requirement, we still feel confident in the structural integrity of the design even with the loosening of the seismic requirement.
- Our testing on the steel scaled prototype was performed with the structure bolted to the floor in the Composites Lab, in accordance with the safety requirements of the lab. It should be noted that

this is the only scenario for which our testing is valid, and we highly recommend the MBMM bolt the final structures to the asphalt, if possible.

- We recommend that the MBMM place "Caution: Do Not Climb" labels on each of the four sawhorses. This will, hopefully, prevent people from climbing on the sawhorses both when they are and are not attached to the trailer. We also recommend that caution tape be placed on the stability strut that sticks out the most from the trailer, to attempt to mitigate the tripping hazard.
- Each plate on the trailer where the connection boxes will be placed is slightly different in terms of both the size and location of the holes. After determining the shop that will be fabricating the connection boxes, we recommend that the MBMM make sure that the differences in hole placement and size are less than the tolerance of the machine shop. Otherwise, dimensions will need to be specified for each connection box, rather than being able to use one set of drawings for all four connection boxes. We have measured each location on the trailer and can provide the MBMM with these differences.

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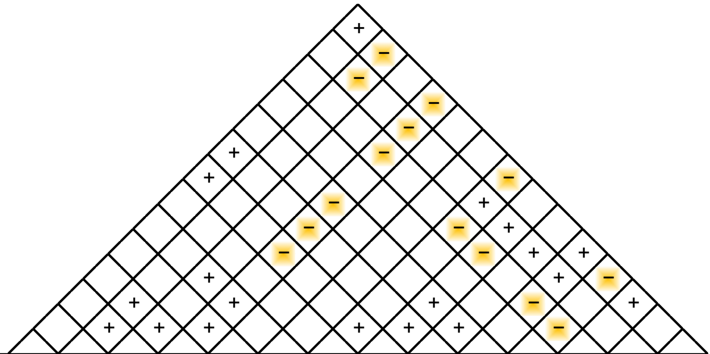
# Appendices

# Appendix A: Quality Function Deployment Matrix

| Correlations | |
|---|---|
| Positive | + |
| Negative | − |
| No Correlation | |

| Relationships | |
|---|---|
| Strong | ● |
| Moderate | ○ |
| Weak | ▽ |

| Direction of Improvement | |
|---|---|
| Maximize | ▲ |
| Target | ◇ |
| Minimize | ▼ |

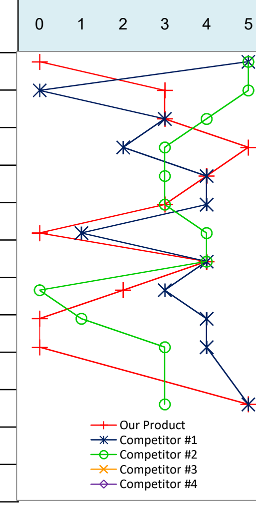


WHO: Customers

HOW: Engineering Specifications

NOW: Current Product Assesment - Customer Requirements

| Row # | Weight Chart | Relative Weight | Morro Bay Maritime Museum | Visitors of Museum | Manufacturer | Maximum Relationship | WHAT: Customer Requirements (explicit & implicit) | Load on tires | Weight of structure | Manufacturing location | Budget constraints | Maintenance period | Materials from local supplier | Visibility impedence height | Structure height variance | Adjustment resolution | Jacking Height Capability | Structure extrusion | Lateral acceleration tolerance | Entry clearance | Weight load | Short Haul Trailer | Permanent Sub Structure | Big Rig Stand | Row # |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Column # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | | | | |
| | | | | | | | Direction of Improvement | ◇ | ▼ | ▼ | ▼ | ◇ | ◇ | ▼ | ▲ | ▼ | ▲ | ▼ | ◇ | ▲ | ◇ | | | | |
| 1 | \|\| | 5% | 10 | 1 | 1 | 9 | Take weight off the tires | ● | ○ | | | | ▽ | | ▽ | ▽ | ▽ | | | ▽ | ▽ | 0 | 5 | 5 | 1 |
| 2 | \|\| | 6% | 9 | 2 | 2 | 9 | Portable and removable structure | | ● | ○ | | | | | | | | ▽ | | | ○ | 3 | 0 | 5 | 2 |
| 3 | \|\|\|\| | 9% | 7 | 1 | 9 | 9 | Manufactured on site | | | ● | ▽ | | ▽ | | | | | | | | | 3 | 3 | 4 | 3 |
| 4 | \|\|\| | 7% | 10 | 1 | 5 | 9 | Low cost | | ○ | ○ | ● | | ○ | | ▽ | ▽ | ▽ | | | | | 5 | 2 | 3 | 4 |
| 5 | \|\| | 6% | 8 | 1 | 4 | 9 | Easy to maintain with industry standard practices | | | | ▽ | ● | ▽ | | | | | | | | | 4 | 4 | 3 | 5 |
| 6 | \|\|\|\| | 9% | 8 | 8 | 1 | 9 | Maintain maximum visibility of the DSRV | | ▽ | | | | | ● | ▽ | | ▽ | | ▽ | ▽ | | 3 | 4 | 3 | 6 |
| 7 | \|\|\| | 7% | 7 | 1 | 6 | 9 | Adjustable for uneven ground | | ▽ | | ▽ | | | | ● | ● | ● | | | ○ | | 0 | 1 | 4 | 7 |
| 8 | \|\|\|\| | 10% | 7 | 9 | 2 | 9 | Does not present a tripping hazard | | ▽ | | | | | | | | | ● | ○ | | | 4 | 4 | 4 | 8 |
| 9 | \|\|\|\|\|\| | 13% | 8 | 8 | 8 | 9 | Earthquake safe | ▽ | ▽ | | ▽ | | | ▽ | ○ | ▽ | ○ | ○ | ● | ▽ | ○ | 2 | 3 | 0 | 9 |
| 10 | \|\| | 5% | 7 | 1 | 3 | 9 | Make use of  locally sourced materials | | | | ● | | ● | | | | | | | | | 0 | 4 | 1 | 11 |
| 11 | \|\|\|\| | 10% | 7 | 9 | 2 | 9 | Increase ground clearance of entry point | | ▽ | | ▽ | | | | ○ | ▽ | ○ | ▽ | ○ | ● | ▽ | 0 | 4 | 3 | 12 |
| 13 | \|\|\|\|\|\|\| | 15% | 9 | 9 | 9 | 9 | Must withstand weight of DSRV, trailer, and 10 people | ▽ | ○ | | ▽ | | ▽ | ▽ | ▽ | ▽ | ▽ | ▽ | ○ | ▽ | ● | 5 | 5 | 3 | 15 |




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HOW MUCH: Target | $0\ lb_f$ | Under 5,000 | Within 200ft of the sub | $10,000 | 5 years | 30 mile radius of Morro Bay | 90% of structure below 69" from ground | 9" | 3" | Lift Tires 4" off ground | Does not extend 1' ft further than tires currently do | 1g | Increase by 1ft | 32 tons |
| Max Relationship | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| Technical Importance Rating | 70.43 | 179.22 | 118.39 | 169.62 | 53.702 | 101 | 105.42 | 165.56 | 111.59 | 165.56 | 155.44 | 228.23 | 148.05 | 203.36 |
| Relative Weight | 4% | 9% | 6% | 9% | 3% | 5% | 5% | 8% | 6% | 8% | 8% | 12% | 7% | 10% |
| Weight Chart | | | | | | | | | | | | | | |

**Appendix B: Designing for Corrosion Prevention**

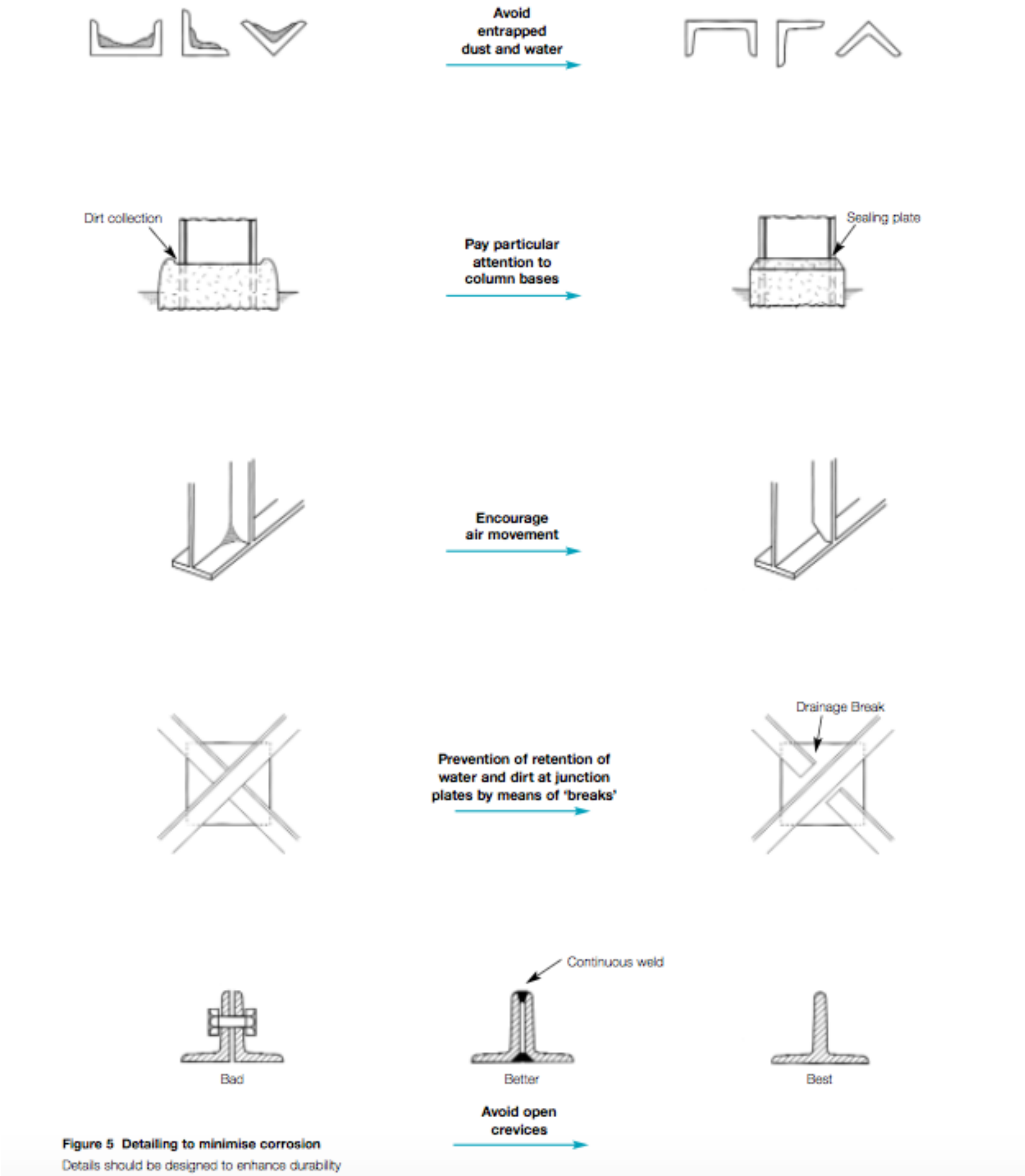



**Figure 1B.** Design Techniques for Avoiding Corrosion [8].

**Appendix C: Paints and Their Properties**

**Table 1C.** A summary of various types of paint and their properties [8]. The binder is the "film forming component in the paint [8]. We are interested in a paint that is both water resistant, and responds well to additional coating.

| Binder | | System Cost | Tolerance of Poor Surface | Chemical Resistance | Solvent Resistance | Water Resistance | Overcoating After Aging | Comments |
|---|---|---|---|---|---|---|---|---|
| Black Coatings (based on Tar products) | | Low | Good | Moderate | Poor | Good | Very good with coatings of same type | Limited to black or dark colours. May soften in hot conditions. |
| Alkyds | | Low – Medium | Moderate | Poor | Poor – Moderate | Moderate | Good | Good decorative properties. High solvent levels. |
| Acrylated Rubbers | | Medium – High | Poor | Good | Poor | Good | Good | High build films that remain soft & are susceptible to sticking. |
| Epoxy | Surface Tolerant | Medium – High | Good | Good | Good | Good | Good | Can be applied to a range of surfaces and coatings*. |
| | High Performance | Medium – High | Very Poor | Very Good | Good | Very Good | Poor | Susceptible to 'chalking' in U.V. light. |
| Urethane & Polyurethane | | High | Very Poor | Very Good | Good | Very Good | Poor | Can be more decorative than epoxies. |
| Organic Silicate & Inorganic Silicate | | High | Very Poor | Moderate | Good | Good | Moderate | May require special surface preparation. |

**Appendix D: Seismic Load Case Development**

After receiving guidance from seismic expert Dr. Robb Moss of the Cal Poly Civil Engineering Department and conducting more research, we generated a conservative load case that we will design our structure to.

We first looked at the seismic codes enforced by Morro Bay from their city website [14]:

Site Class: Class D (Stiff Soil)
Building Code: 2012 IBC (we also applied ASCE-7)
Seismic Design Category: D or D2

With this information, we used the Seismic Design Map application available through the United States Geographical Survey (USGS) website to develop design criteria we can apply to our analysis methods [15]. The design report, given in Appendix E, generated the plot shown below in Figure 1D.

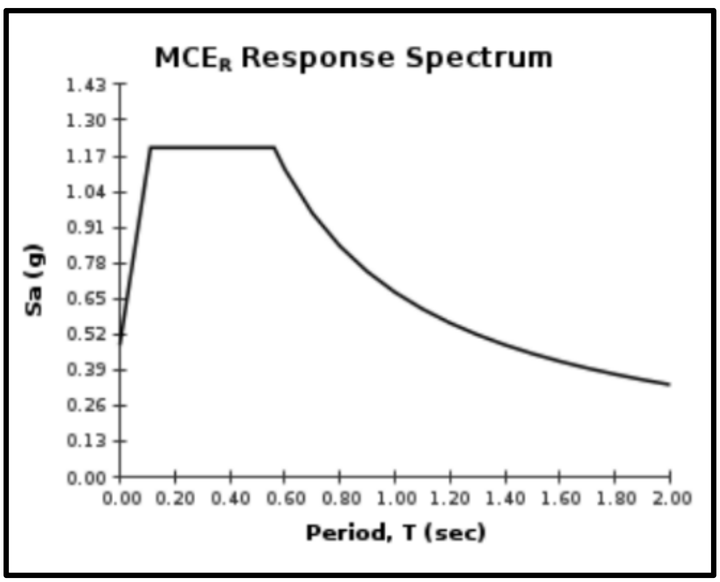



**Figure 1D.** Maximum Considered Earthquake Response Spectrum Plot, where $S_a$ represents the spectral acceleration.

With guidance from Dr. Moss, we can neglect any loading induced by a modal response. Since our structure is relatively small compared to multi-story structures, the natural frequency of our structure will be very high, causing a negligible modal response. Since the period of a wave is proportional to the inverse of its frequency, we look at the ground acceleration for T = 0. After reading the plot, we chose to design to a lateral ground acceleration of 0.52 g.

This data, along with the total weight of the submarine and trailer, were applied using the equivalent lateral force method. The first step in this method is to calculate the base shear force. This equation is pulled from Basic Earthquake Engineering and simplified to the following:

$$V_b = W \cdot S_A(T) \tag{1}$$

where $W$ is the weight of both the trailer and the submarine and $S_A$ is the spectral acceleration [16]. Assuming the submarine weighs 44,000 pounds and the trailer weighs 18,000 pounds, we calculated the base shear to be 32,240 pounds.

The next step is to equate the base shear to a lateral force. The equation and distributed load described in the textbook and used in building codes is as follows:

$$f_j = (V_b)\frac{w_j H_j}{\sum_{i=1}^{N} w_i H_i} \tag{2}$$

Where the variables are defined graphically below in Figure 2D:

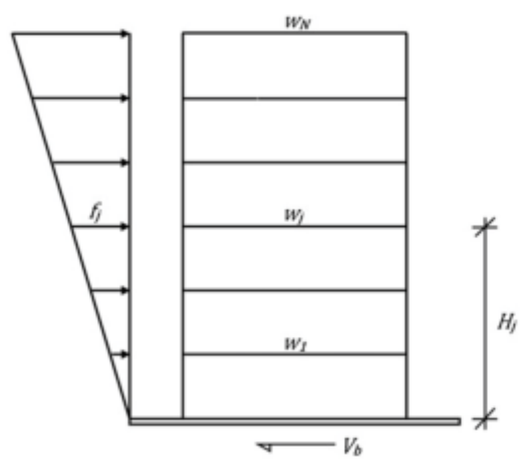



**Figure 2D.** Illustration from Basic Earthquake Engineering [16].

Applying this equation to the submarine and trailer independently, we developed a set of lateral point loads at every foot of height. The resulting lateral force distribution is shown below in Figure 3D.

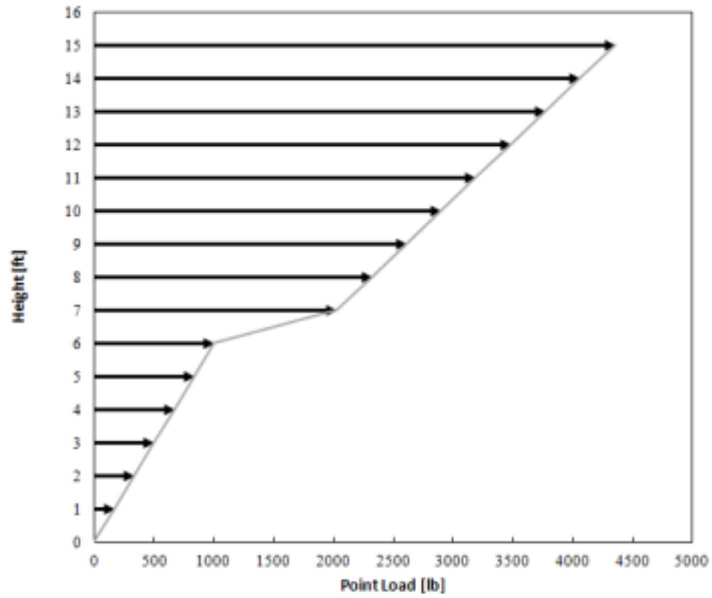



**Figure 3D.** Lateral force distribution for the trailer and submarine

This load distribution then allowed us to generate an equivalent point load at a specific height where the results are tabulated below in Table 1D:

**Table 1D.** Equivalent lateral loading for the maximum expected earthquake magnitude

| Calculated Values | | | |
|---|---|---|---|
| Description | Variable | Value | Units |
| **Equivalent Height** | ***Heq*** | **9.2** | **[ft]** |
| **Equivalent Load** | ***feq*** | **37612** | **[lbf]** |

The equivalent height and load are defined as follows, in Figure 4D.

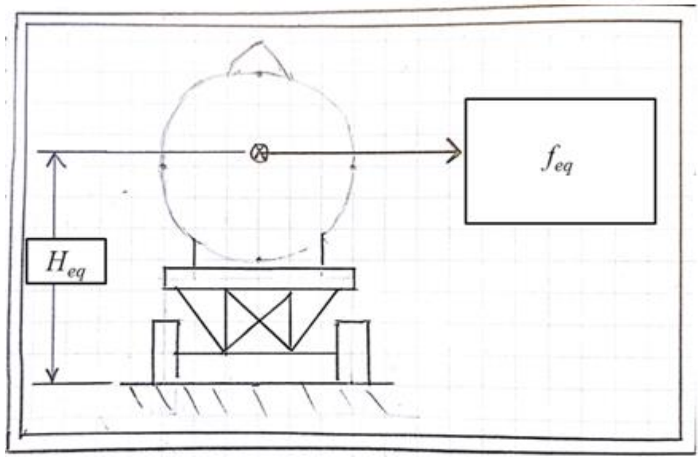



**Figure 4D.** A schematic showing how the equivalent height and force are defined with respect to the DSRV and trailer.

The above load case represents the most extreme expected loading from an earthquake in Morro Bay. The USGS's statistical analysis claims that these loading conditions have a 2.0% chance of being exceeded in the next 50 years [15]. This means that the probability of Morro Bay seeing an earthquake that would produce this load case in the next 50 years is 2.0%.

**Appendix E: Seismic Design Report**

## USGS Design Maps Summary Report

**User–Specified Input**

**Building Code Reference Document** ASCE 7-10 Standard
(which utilizes USGS hazard data available in 2008)

**Site Coordinates** 35.36445°N, 120.84656°W

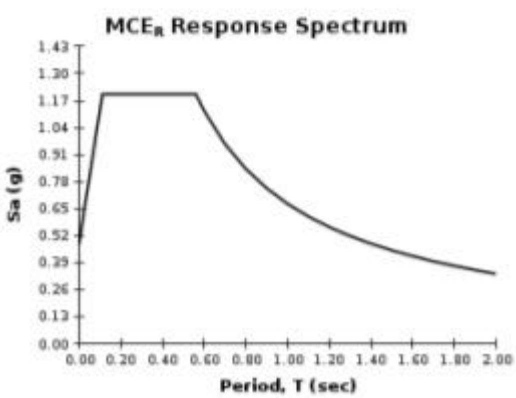
**Site Soil Classification** Site Class D – "Stiff Soil"

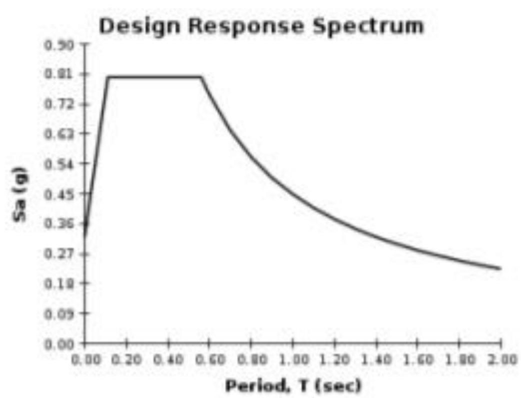
**Risk Category** I/II/III


**USGS–Provided Output**

| | | | | | |
|---|---|---|---|---|---|
| $S_S$ = | 1.157 g | $S_{MS}$ = | 1.200 g | $S_{DS}$ = | 0.800 g |
| $S_1$ = | 0.428 g | $S_{M1}$ = | 0.673 g | $S_{D1}$ = | 0.449 g |

For information on how the SS and S1 values above have been calculated from probabilistic (risk-targeted) and deterministic ground motions in the direction of maximum horizontal response, please return to the application and select the "2009 NEHRP" building code reference document.




For $PGA_M$, $T_L$, $C_{RS}$, and $C_{R1}$ values, please view the detailed report.

**Appendix F: Additional Iterations of Potential Solution #2**

Figures 1F and 2F below depict two iterations of Potential Solution #2 that involve the use of additional cross-bracing.

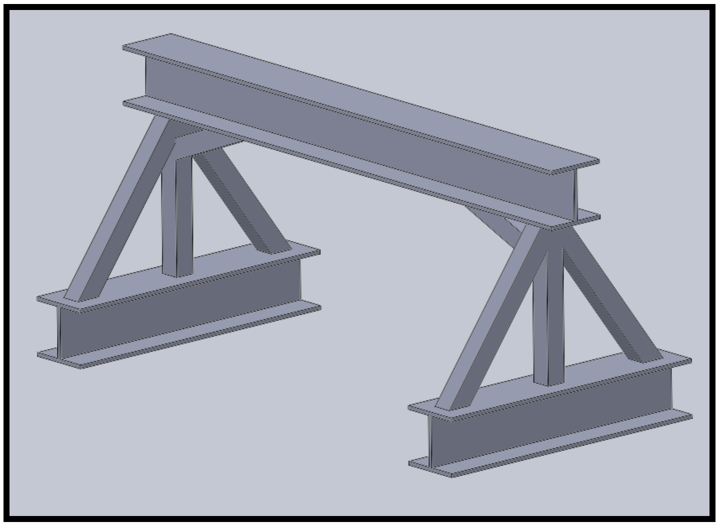


**Figure 1F.** This accounts for increasing the lateral stability of the structure.

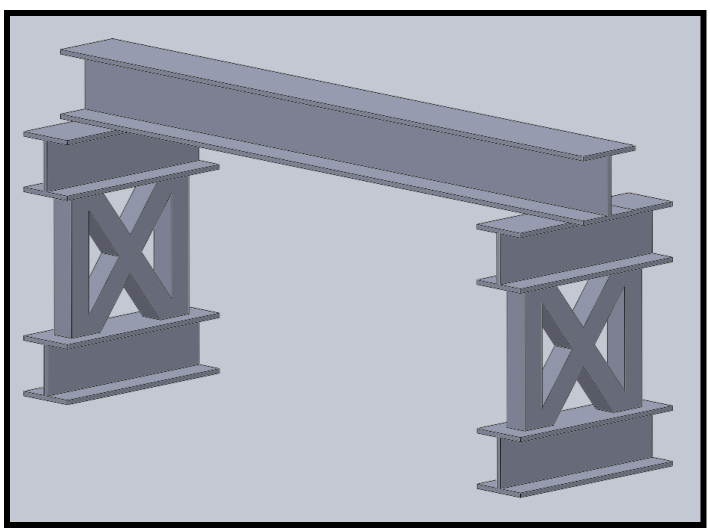


**Figure 2F.** This iteration attempts to maximize the use of I-beams that the MBMM already has on hand.

**Appendix G: An Iteration of Potential Solution #4**

The following modification to Potential Solution #4, shown below in Figure 1G, greatly reduces the amount of welding that will be required in the manufacturing of the stand. The support stand can be constructed using round stock or square tubing -- a choice that is largely based on aesthetics since both are capable of supporting the load. Square tubing was chosen for this design to help it complement the existing trailer structure.

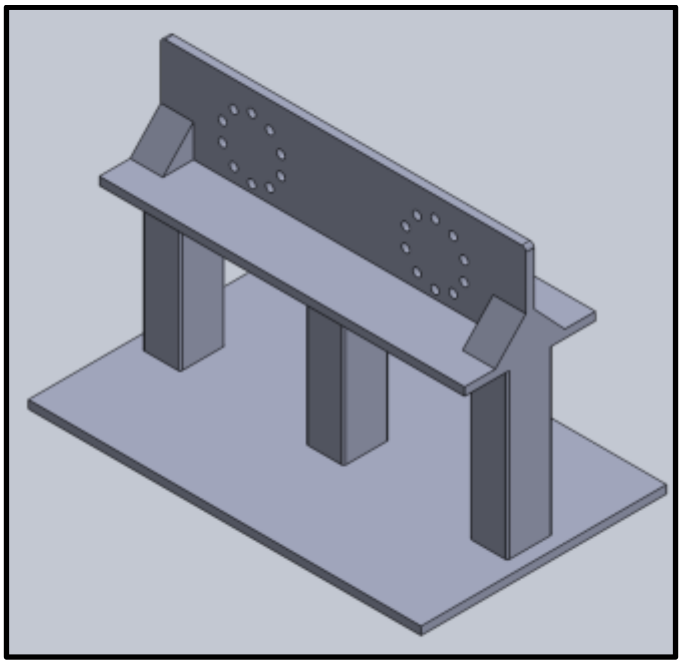
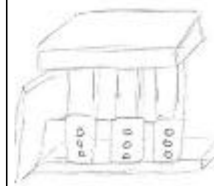
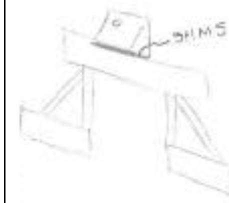
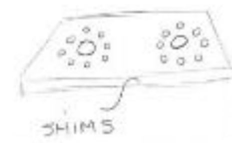
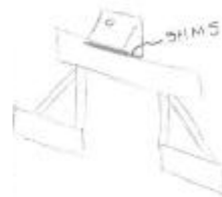
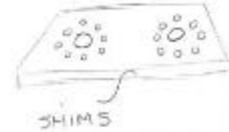


**Figure 1G.** Support stand utilizing square tubing supports.

# Appendix H: Height Adjustment Pugh Matrix

| Concept |  |  |   |   |   |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Criteria | Jack Stand Datum | Potential Solution #1 | Potential Solution #2 | Potential Solution #3 | Potential Solution #4 |
| Structure Height Variance (9”) | D | S | S | S | S |
| Adjustment Resolution (3”) | A | S | S | S | S |
| Ease of Adjustment | T | - | - | - | - |
| Stability After Adjustment | U | S | + | + | + |
| Aesthetically Pleasing | M | + | + | + | + |

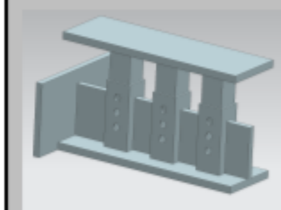
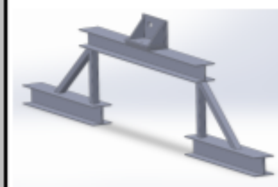
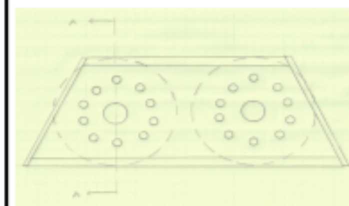
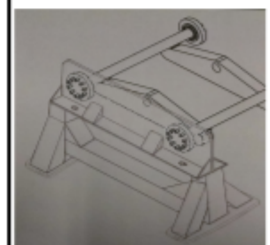
# Appendix I: Structure Mobility Pugh Matrix

| Concept |  |  |  |  |  |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Criteria | Current Trailer | Potential Solution #1 | Potential Solution #2 | Potential Solution #3 | Potential Solution #4 |
| Aesthetically Pleasing | D | S | + | S | + |
| Complementary to Surrounding Structure | A | - | + | S | + |
| Weight | T | + | S | + | + |
| Mobility | U | - | - | - | - |
| Ease of Installation | M | - | - | - | - |

# Appendix J: Load Capability Pugh Matrix

| Concept |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Criteria | Datum | Potential Solution #1 | Potential Solution #2 | Potential Solution #3 | Potential Solution #4a | Potential Solution #4b |
| Ease of Achieving | D | S | S | S | S | S |
| Complexity | | - | - | S | - | - |
| Ease of Maintenance | A | - | - | - | - | - |
| Weight (compared to tire) | | + | - | - | - | - |
| Surface Area | T | + | + | + | + | + |
| Number of Parts | | - | - | S | - | - |
| Manufacturing Cost | U | - | - | - | - | - |
| Lifespan | | + | + | + | + | + |
| Aesthetically Pleasing | M | + | + | + | + | + |

# Appendix K: System Level Pugh Matrix

| System Level Pugh Matrix | | | | |
|---|---|---|---|---|
| ***Concept Selection Legend***<br>Better +<br>Same S<br>Worse -<br><br>**Key Criteria** |  |  |  |  |
| Aesthetically Pleasing | DATUM | + | + | + |
| Ease of Achieving | DATUM | S | S | S |
| Complexity | DATUM | S | + | S |
| Ease of Maintenance | DATUM | S | S | S |
| Extrusion | DATUM | - | S | S |
| Manufacturing Cost | DATUM | S | + | S |
| Ease of Installation | DATUM | + | - | - |
| Lifespan | DATUM | S | S | S |
| Complementary to surrounding structure | DATUM | + | S | + |
| Stability | DATUM | + | + | + |
| Structure Height Variance | DATUM | S | S | S |

# Appendix K: System Level Pugh Matrix (Page 2)

| | | | | |
|---|---|---|---|---|
| Adjustment Resolution | DATUM | S | S | S |
| Ease of Adjustment | DATUM | + | - | + |
| Weight (Considering Pallet Jack/Fork Lift) | DATUM | S | S | S |
| Mobility | DATUM | + | S | S |
| Ease of Installation | DATUM | + | S | S |
| Safety of Installation | DATUM | + | + | + |

# Appendix L: Weighted Decision Matrix

| | Specification | Load on tires | Weight of structure | Manufacturing location | Budget constraints | Maintenance period | Materials from local supplier | Visibility impedance height | Structure height variance | Adjustment resolution | Jacking Height Capability | Structure extrusion | Lateral acceleration tolerance | Entry clearance | Weight load | Weighted Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Weight | 4% | 9% | 6% | 9% | 3% | 5% | 5% | 8% | 6% | 8% | 8% | 12% | 7% | 10% | |
| Concept 1 | Rating | 10 | 8 | 10 | 5 | 8 | 10 | 10 | 8 | 7 | 5 | 8 | 6 | 7 | 10 | 7.72 |
| | Weighted Rating | 0.4 | 0.72 | 0.6 | 0.45 | 0.24 | 0.5 | 0.5 | 0.64 | 0.42 | 0.4 | 0.64 | 0.72 | 0.49 | 1 | |
| Concept 2 | Rating | 10 | 6 | 10 | 7 | 8 | 10 | 10 | 8 | 7 | 5 | 6 | 8 | 7 | 10 | 7.8 |
| | Weighted Rating | 0.4 | 0.54 | 0.6 | 0.63 | 0.24 | 0.5 | 0.5 | 0.64 | 0.42 | 0.4 | 0.48 | 0.96 | 0.49 | 1 | |
| Concept 3 | Rating | 10 | 7 | 10 | 9 | 8 | 10 | 10 | 8 | 7 | 5 | 7 | 8 | 7 | 10 | 8.15 |
| | Weighted Rating | 0.4 | 0.63 | 0.6 | 0.81 | 0.24 | 0.5 | 0.5 | 0.64 | 0.42 | 0.4 | 0.56 | 0.96 | 0.49 | 1 | |
| Concept 4 | Rating | 10 | 7 | 10 | 8 | 8 | 10 | 10 | 8 | 7 | 5 | 7 | 8 | 7 | 10 | 8.06 |
| | Weighted Rating | 0.4 | 0.63 | 0.6 | 0.72 | 0.24 | 0.5 | 0.5 | 0.64 | 0.42 | 0.4 | 0.56 | 0.96 | 0.49 | 1 | |

**Appendix M: Bolt Shearing Calculation**

LOAD TO SHEAR STEEL BOLT...

$$\tau_{UTS} = 0.5\,\sigma_{UTS}$$

$$\sigma_{UTS} \simeq 60{,}000 \text{ psi}$$

$$\tau_{UTS} = 30{,}000 \text{ psi}$$

FOR A 2" ROD...

$$A = \frac{\pi}{4} D^2$$

$$A = \frac{\pi}{4} (2\text{ in})^2$$

$$A = 3.14\text{ in}^2$$

$$V_{shear} = \tau A$$

$$V = (30{,}000 \text{ psi})(3.14 \text{ in}^2)$$

SHEAR FORCE, V

$$\boxed{V = 94{,}200 \text{ lb}_f}$$

DISTRIBUTED AMONG 4 BOLTS...

TOTAL FORCE $V_{tot}$

$$V_{tot} = 376{,}800 \text{ lb}_f$$

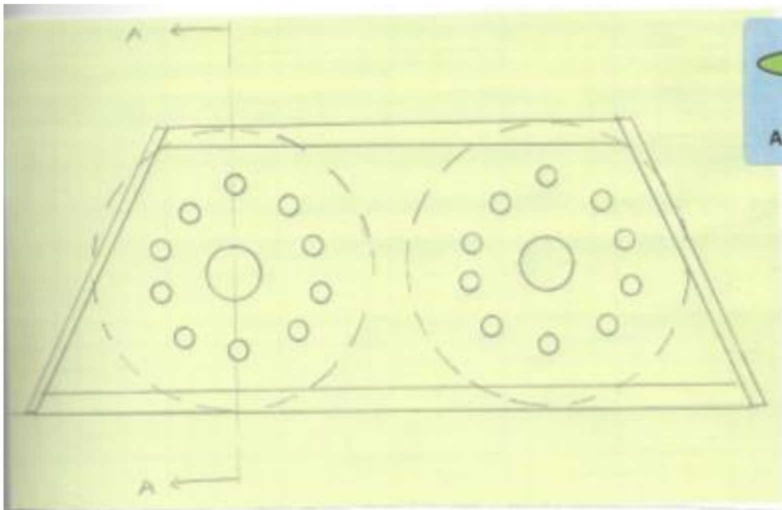
THIS GIVES A FACTOR OF SAFETY OF...

$$F.S. = \frac{376{,}800 \text{ lb}_f}{62000}$$

$$\boxed{\text{FACTOR OF SAFETY} = 6.1}$$

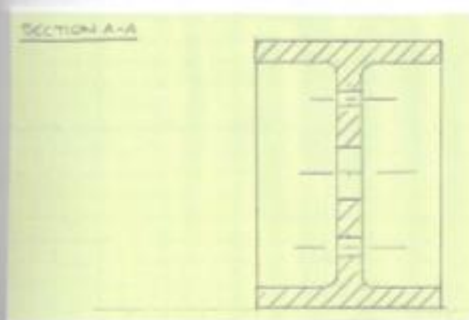
**Therefore, a 2 inch rod will fair at a shear load of around 94,000 lbs, meaning four pins will have a load capacity of around 377,000 lbs in shear. The factor of safety of 6.1, therefore, validates the method of load transfer in Solution #1.**

**Appendix N: Stress and Buckling Calculation for Solution #2**

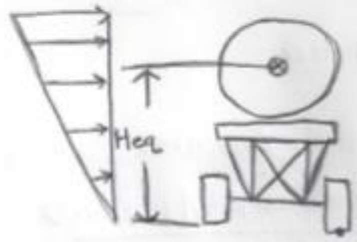



PDR

Idea Evaluation: Will it work?
Analysis, additional modeling, etc.

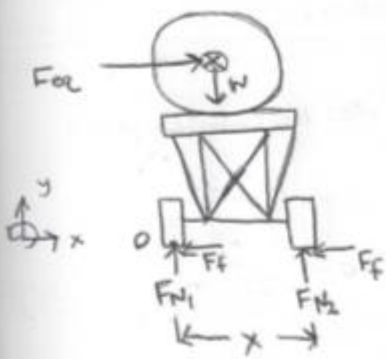



will it withstand an earthquake?




$F_{eq} = 37,612\ lbf$

$H_{eq} = 9.2\ ft$




$\circlearrowleft\ \Sigma M_o = 0$

$-F_{eq}H_{eq} - W\left(\frac{x}{2}\right) + F_{N2}(x) = 0$

$F_{N2} = \dfrac{F_{eq}H_{eq} + W\frac{x}{2}}{x}$

$= \dfrac{(37,612\ lbf)(9.2\ ft) + (49,000\ lbf + 18,000\ lbf)\left(\frac{4\ ft}{2}\right)}{4\ ft}$

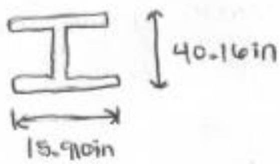
$F_{N2} = 117,507.6\ lbf$

This is carried by the two supports on each side during an earthquake.

$\therefore\ F = 58,753.8\ lbf$ per support

## Appendix N: Stress and Buckling Calculation for Solution #2 (Page 2)

I-beam Specs from SAGINAW PIPE: 11/13/2016




weight per ft: 324 lb/ft
avg. flange thickness: 1.801in
web thickness: 1.000 in

2 tire diameters $\approx 39^{3}/_{4}$" x2 = 79.5in = 6.625 ft

Estimate that the base of the trapezoid is about 4 ft longer than 2 tire diameters.

∴ length of I-beam contacting ground is $\approx$ 10.625 ft

Area = 10.625ft (15.910/12 ft) = 14.09 ft$^2$ or 2028.525 in$^2$

$\sigma = \frac{F}{A} = \frac{58{,}753.8\ lbf}{2028.525 in^2} = 28.964\ psi$ By inspection, this will not damage the asphalt.

Check for Buckling (assume the load is applied at the top of the I-beam for worst case scenario).

$F = \frac{n\pi^2 E I}{L^2}$

n = 0.25 for fixed-free

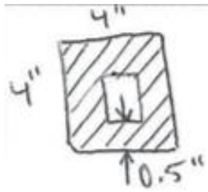
I = 1220 in$^4$

E = 29,000,000 psi for A36 Steel

$F = \frac{(0.25)\pi^2(29{,}000{,}000\ psi)(1220 in^4)}{(40.16in)^2}$

F = 54,126,529 lbf ∴ Buckling is not a problem

## Appendix O: Square Tubing Calculation




ASTM A500 STEEL, GRADE B $\quad 4" \times 4" \times 1/2"$

$\rho = 0.284 \frac{lb}{in^3}$

$A = (4in.)(4in.) - (3in.)(3in.) = 7 in.^2$ (CROSS-SEC. AREA)

$$I = \frac{bd^3 - b_i d_i^3}{12}$$

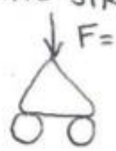
$$I = \frac{4in.(4in.)^3 - 3in.(3in.)^3}{12} = 14.583\ in.^4$$

CHECK FOR BUCKLING:

BOTH ENDS FIXED = $P_{crt} = \frac{4\pi^2 EI}{L^2}$ WHERE $E = 30 \times 10^6\ psi$

$$P_{crt} = \frac{4\pi^2 (30\times10^6 \frac{lb_f}{in^2})(14.583\ in.^4)}{(18in.)^2} = 53.3\times10^6\ lb_f$$

AXIAL STRESS: $\sigma$




$\frac{F}{4}$ = FORCE ON EACH OF THE TIRE SETS

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

A PER COLUMN = $7 in.^2$

FOR 3 COLUMNS : $3A = 21 in^2$

$$\sigma = \frac{15000\ lb_f}{21\ in^2} = 714.3\ psi$$

**The three 18" support columns of the design presented in Appendix G will endure an axial stress of 714 psi, which is well below the material ultimate tensile strength and yield strength, thereby validating the design.**

## Appendix P: Hazard Identification Checklist

DESIGN HAZARD CHECKLIST

Team: **Sublime Squad** Advisor: **Eileen Rossman**

| Y | N | |
|---|---|---|
| ☐ | ☑ | 1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points? |
| ☐ | ☑ | 2. Can any part of the design undergo high accelerations/decelerations? |
| ☐ | ☑ | 3. Will the system have any large moving masses or large forces? |
| ☐ | ☑ | 4. Will the system produce a projectile? |
| ☑ | ☐ | 5. Would it be possible for the system to fall under gravity creating injury? |
| ☐ | ☑ | 6. Will a user be exposed to overhanging weights as part of the design? |
| ☑ | ☐ | 7. Will the system have any sharp edges? |
| ☐ | ☑ | 8. Will any part of the electrical systems not be grounded? |
| ☐ | ☑ | 9. Will there be any large batteries or electrical voltage in the system above 40 V? |
| ☐ | ☑ | 10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids? |
| ☐ | ☑ | 11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system? |
| ☑ | ☐ | 12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design? |
| ☑ | ☐ | 13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design? |
| ☐ | ☑ | 14. Can the system generate high levels of noise? |
| ☑ | ☐ | 15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc? |
| ☑ | ☐ | 16. Is it possible for the system to be used in an unsafe manner? |
| ☑ | ☐ | 17. Will there be any other potential hazards not listed above? If yes, please explain on reverse. |

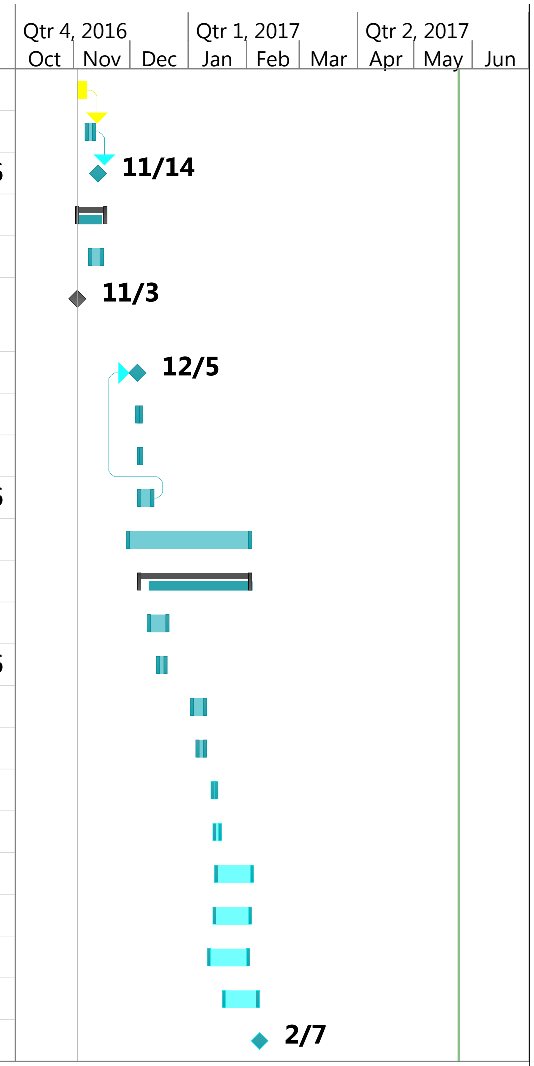
For any "Y" responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.

## Appendix P: Hazard Identification Checklist (Page 2)

| Description of Hazard | Planned Corrective Action | Planned Date | Actual Date |
|---|---|---|---|
| The system could fall under gravity, causing injury | We will apply a large factor of safety on all parts of our design. | 2/7 | 2/3 |
| The design could contain sharp edges | All edges will be beveled, ground, and coated | 6/17 | |
| The user may need to exert abnormal physical effort during the installation of the design | Our installation guide will specify multiple installers for all heavy components | 3/9 | 3/8 |
| Materials known to be hazardous to humans will be used in the installation of the design | Proper Protective Equipment will be required for those coating, priming, and painting. | 6/17 | |
| The design will be exposed to extreme environmental conditions | All material will be sand-blasted, coated in OSPHO, primed, and painted. | 6/17 | |
| It is possible for the design to be used in an unsafe manner | We will recommend warning labels be placed on each structure. | 3/9 | 3/8 |
| The design will present a tripping hazard to members of the public touring the structure | We will recommend caution labels be placed on all feet of each sawhorse. | 3/9 | 3/8 |
| | | | |
| | | | |

# Appendix Q: Gantt Chart (Planned)

| ID | | Task Mode | WBS | Task Name | Duration | Start | Finish |
|---|---|---|---|---|---|---|---|
| 1 | | | 1 | Select Design | 3 days | Thu 11/3/16 | Mon 11/7/16 |
| 2 | | | 2 | Analyze Feasibility | 4 days | Tue 11/8/16 | Fri 11/11/16 |
| 3 | | | 3 | PDR Class Presentation | 0 days | Mon 11/14/16 | Mon 11/14/16 |
| 4 | | | **4** | **PDR Report** | **11 days** | **Thu 11/3/16** | **Thu 11/17/16** |
| 5 | | | 4.1 | SolidWorks Model | 4 days | Thu 11/10/16 | Tue 11/15/16 |
| 6 | | | 4.2 | Preliminary Design Safety Hazard Identification Checklist | 0 days | Thu 11/3/16 | Thu 11/3/16 |
| 7 | | | 5 | PDR Sponsor Presentation | 0 days | Mon 12/5/16 | Mon 12/5/16 |
| 8 | | | 6 | Feedback from Sponor on PDR | 2 days | Mon 12/5/16 | Tue 12/6/16 |
| 9 | | | 7 | FMEA, DVP, & Analysis Plan | 1 day | Tue 12/6/16 | Tue 12/6/16 |
| 10 | | | 8 | Develop Final Design | 5 days | Tue 12/6/16 | Mon 12/12/16 |
| 11 | | | 9 | Design Verification Plan | 47 days | Wed 11/30/16 | Thu 2/2/17 |
| 12 | | | **10** | **Design Analysis** | **43 days** | **Tue 12/6/16** | **Thu 2/2/17** |
| 13 | | | 10.1 | Structural Limitations | 8 days | Sun 12/11/16 | Tue 12/20/16 |
| 14 | | | 10.2 | Material Analysis and Availability | 2 days | Fri 12/16/16 | Mon 12/19/16 |
| 15 | | | 10.3 | Jacking Techniques and Hardware | 5 days | Tue 1/3/17 | Mon 1/9/17 |
| 16 | | | 10.4 | Installation Safety Analysis | 2 days | Fri 1/6/17 | Mon 1/9/17 |
| 17 | | | 10.5 | Welding Limitations | 2 days | Sat 1/14/17 | Sun 1/15/17 |
| 18 | | | 10.6 | Cost Analysis | 3 days | Sun 1/15/17 | Tue 1/17/17 |
| 19 | | | 10.7 | Geometric Analysis | 15 days | Mon 1/16/17 | Fri 2/3/17 |
| 20 | | | 10.8 | Structural Analysis | 15 days | Sun 1/15/17 | Thu 2/2/17 |
| 21 | | | 13 | Detail Design Drawings | 15 days | Thu 1/12/17 | Wed 2/1/17 |
| 22 | | | 12 | BOM | 12 days | Fri 1/20/17 | Mon 2/6/17 |
| 23 | | | 13 | CDR Class Presentation | 0 days | Tue 2/7/17 | Tue 2/7/17 |

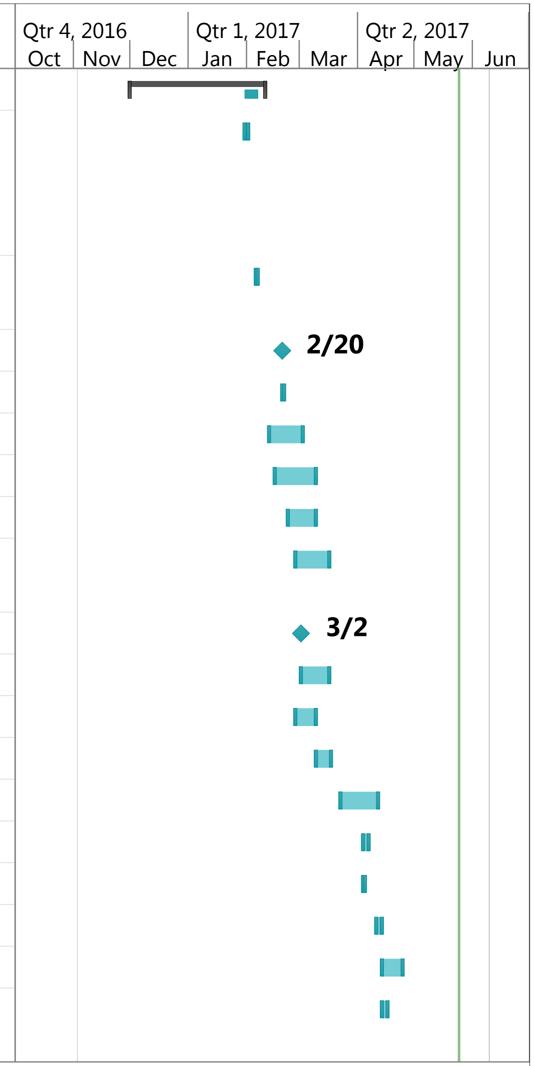



Project: Senior Project

| | | |
|---|---|---|
| Task | Inactive Summary | External Tasks |
| Split | Manual Task | External Milestone |
| Milestone | Duration-only | Deadline |
| Summary | Manual Summary Rollup | Progress |
| Project Summary | Manual Summary | Manual Progress |
| Inactive Task | Start-only | |
| Inactive Milestone | Finish-only | |

## Appendix Q: Gantt Chart (Planned)

| ID | Task Mode | WBS | Task Name | Duration | Start | Finish |
|---|---|---|---|---|---|---|
| 24 | | **14** | **CDR Report** | **52 days** | **Thu 12/1/16** | **Fri 2/10/17** |
| 25 | | 14.1 | Critical Design Safety Hazard Identification Checklist | 2 days | Tue 1/31/17 | Wed 2/1/17 |
| 26 | | 14.2 | Critical Design Safety Review | 1 day | Mon 2/6/17 | Mon 2/6/17 |
| 27 | | 15 | CDR Sponsor Presentation | 0 days | Mon 2/20/17 | Mon 2/20/17 |
| 28 | | 16 | Feedback from Sponsor on CDR | 1 day | Mon 2/20/17 | Mon 2/20/17 |
| 29 | | 17 | Design Testing Fixture | 14 days | Mon 2/13/17 | Thu 3/2/17 |
| 30 | | 18 | Purchase Parts for Steel Model | 16 days | Thu 2/16/17 | Thu 3/9/17 |
| 31 | | 19 | Obtain Parts for Testing Fixture | 11 days | Thu 2/23/17 | Thu 3/9/17 |
| 32 | | 20 | Manufacturing Status and Test Plan Presentation | 14 days | Mon 2/27/17 | Thu 3/16/17 |
| 33 | | 21 | Run Test by Dr. Mello | 0 days | Thu 3/2/17 | Thu 3/2/17 |
| 34 | | 22 | Project Update Report | 11 days | Thu 3/2/17 | Thu 3/16/17 |
| 35 | | 23 | Operators' Manual | 9 days | Mon 2/27/17 | Thu 3/9/17 |
| 36 | | 24 | Assemble Fixture for testing | 6 days | Fri 3/10/17 | Fri 3/17/17 |
| 37 | | 25 | Build Scale Model | 14 days | Thu 3/23/17 | Tue 4/11/17 |
| 38 | | 26 | Reserve Hydraulic Ram | 3 days | Tue 4/4/17 | Thu 4/6/17 |
| 39 | | 27 | Reserve Composites Lab | 1 day | Tue 4/4/17 | Tue 4/4/17 |
| 40 | | 28 | Testing of Model | 3 days | Tue 4/11/17 | Thu 4/13/17 |
| 41 | | 29 | Analyze Results | 7 days | Fri 4/14/17 | Mon 4/24/17 |
| 42 | | 30 | Purchase Parts for Wooden Prototype | 2 days | Fri 4/14/17 | Sun 4/16/17 |

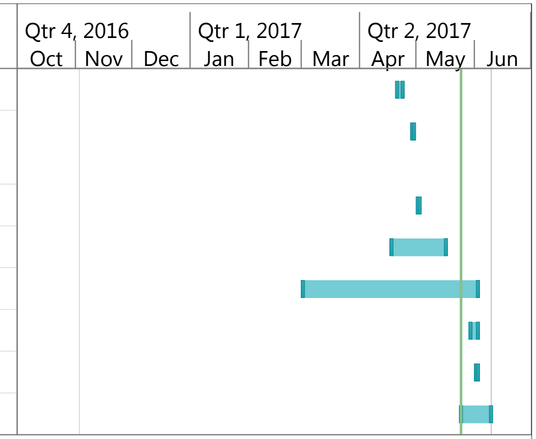



Project: Senior Project

Task
Split
Milestone
Summary
Project Summary
Inactive Task
Inactive Milestone
Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
External Tasks
External Milestone
Deadline
Progress
Manual Progress

## Appendix Q: Gantt Chart (Planned)

| ID | | Task Mode | WBS | Task Name | Duration | Start | Finish |
|---|---|---|---|---|---|---|---|
| 43 | | | 31 | Wooden Prototype Assembly | 2 days | Fri 4/21/17 | Sun 4/23/17 |
| 44 | | | 32 | Check Clearance with Wooden Prototype | 1 day | Sat 4/29/17 | Sat 4/29/17 |
| 45 | | | 33 | Project Hardware/Safety Demo | 1 day | Tue 5/2/17 | Tue 5/2/17 |
| 46 | | | 34 | 3D Print Model | 21 days | Tue 4/18/17 | Tue 5/16/17 |
| 47 | | | 35 | FDR Report | 67 days | Thu 3/2/17 | Fri 6/2/17 |
| 48 | | | 36 | FDR Project Expo | 4 days | Tue 5/30/17 | Fri 6/2/17 |
| 49 | | | 37 | FDR Hardware Handoff | 1 day | Fri 6/2/17 | Fri 6/2/17 |
| 50 | | | 38 | Final Checklist | 12 days | Thu 5/25/17 | Fri 6/9/17 |

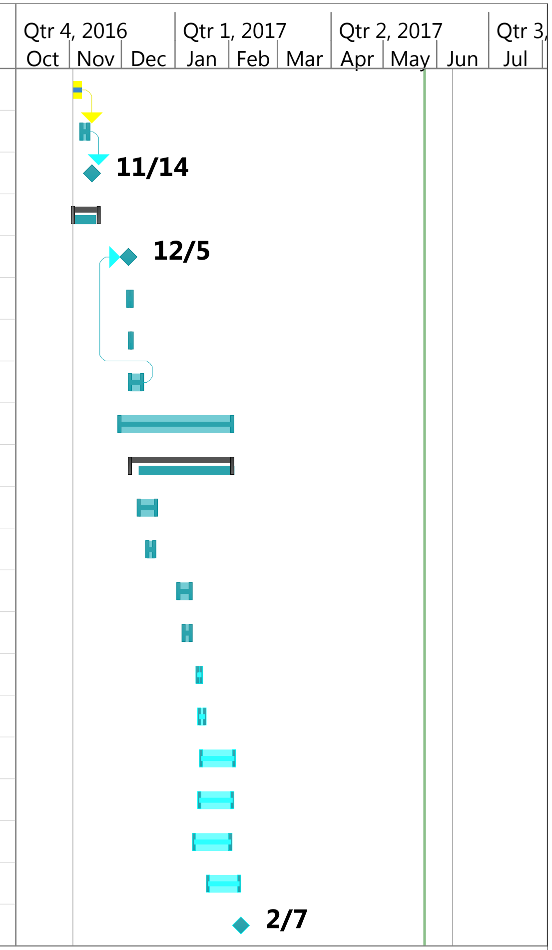



Project: Senior Project

| | | |
|---|---|---|
| Task | Inactive Summary | External Tasks |
| Split | Manual Task | External Milestone |
| Milestone | Duration-only | Deadline |
| Summary | Manual Summary Rollup | Progress |
| Project Summary | Manual Summary | Manual Progress |
| Inactive Task | Start-only | |
| Inactive Milestone | Finish-only | |

# Appendix Q: Gantt Chart (Actual)

| ID | | Task Name | Duration | Start | Finish | Predecessors |
|---|---|---|---|---|---|---|
| 1 | ✓ | Select Design | 3 days | Thu 11/3/16 | Mon 11/7/16 | |
| 2 | ✓ | Analyze Feasibility | 4 days | Tue 11/8/16 | Fri 11/11/16 | 1 |
| 3 | ✓ | PDR Class Presentation | 0 days | Mon 11/14/16 | Mon 11/14/16 | 2 |
| 4 | ✓ | **PDR Report** | **11 days** | **Thu 11/3/16** | **Thu 11/17/16** | |
| 7 | ✓ | PDR Sponsor Presentation | 0 days | Mon 12/5/16 | Mon 12/5/16 | 10 |
| 8 | ✓ | Feedback from Sponor on PDR | 2 days | Mon 12/5/16 | Tue 12/6/16 | |
| 9 | ✓ | FMEA, DVP, & Analysis Plan | 1 day | Tue 12/6/16 | Tue 12/6/16 | |
| 10 | ✓ | Develop Final Design | 5 days | Tue 12/6/16 | Mon 12/12/16 | |
| 11 | ✓ | Design Verification Plan | 47 days | Wed 11/30/16 | Thu 2/2/17 | |
| 12 | ✓ | **Design Analysis** | **43 days** | **Tue 12/6/16** | **Thu 2/2/17** | |
| 13 | ✓ | Structural Limitations | 8 days | Sun 12/11/16 | Tue 12/20/16 | |
| 14 | ✓ | Material Analysis and Availability | 2 days | Fri 12/16/16 | Mon 12/19/16 | |
| 15 | ✓ | Jacking Techniques and Hardware | 5 days | Tue 1/3/17 | Mon 1/9/17 | |
| 16 | ✓ | Installation Safety Analysis | 2 days | Fri 1/6/17 | Mon 1/9/17 | |
| 17 | ✓ | Welding Limitations | 2 days | Sat 1/14/17 | Sun 1/15/17 | |
| 18 | ✓ | Cost Analysis | 3 days | Sun 1/15/17 | Tue 1/17/17 | |
| 19 | ✓ | Geometric Analysis | 15 days | Mon 1/16/17 | Fri 2/3/17 | |
| 20 | ✓ | Structural Analysis | 15 days | Sun 1/15/17 | Thu 2/2/17 | |
| 21 | ✓ | Detail Design Drawings | 15 days | Thu 1/12/17 | Wed 2/1/17 | |
| 22 | ✓ | BOM | 12 days | Fri 1/20/17 | Mon 2/6/17 | |
| 23 | ✓ | CDR Class Presentation | 0 days | Tue 2/7/17 | Tue 2/7/17 | |

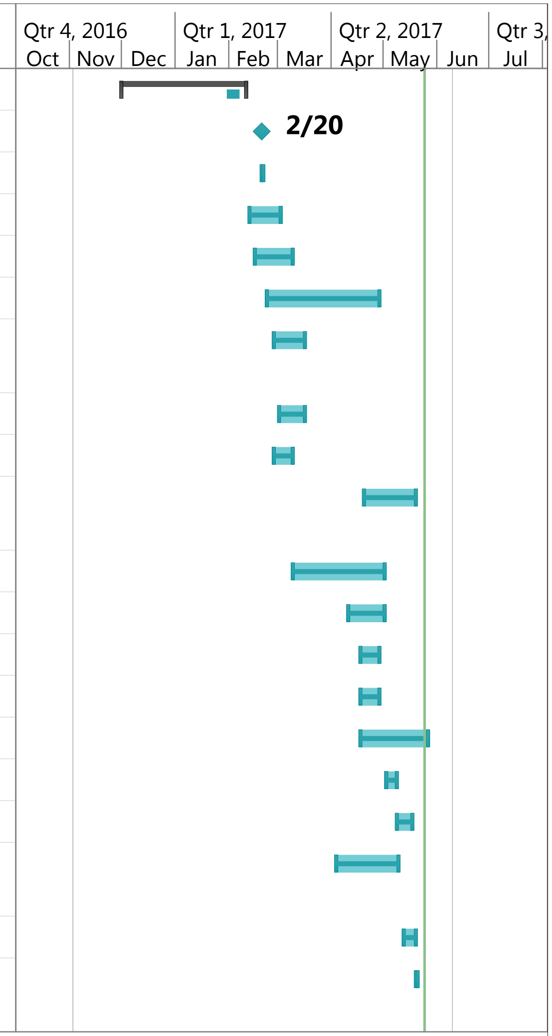



Project: Senior Project

| | | | | | |
|---|---|---|---|---|---|
| Task | | Inactive Summary | | External Tasks | |
| Split | | Manual Task | | External Milestone | |
| Milestone | | Duration-only | | Deadline | |
| Summary | | Manual Summary Rollup | | Progress | |
| Project Summary | | Manual Summary | | Manual Progress | |
| Inactive Task | | Start-only | | | |
| Inactive Milestone | | Finish-only | | | |

# Appendix Q: Gantt Chart (Actual)

| ID | | Task Name | Duration | Start | Finish | Predecessors |
|---|---|---|---|---|---|---|
| 24 | ✓ | **CDR Report** | **52 days** | **Thu 12/1/16** | **Fri 2/10/17** | |
| 27 | ✓ | CDR Sponsor Presentation | 0 days | Mon 2/20/17 | Mon 2/20/17 | |
| 28 | ✓ | Feedback from Sponsor on CDR | 1 day | Mon 2/20/17 | Mon 2/20/17 | |
| 29 | ✓ | Design Testing Fixture | 14 days | Mon 2/13/17 | Thu 3/2/17 | |
| 30 | ✓ | Purchase Parts for Steel Model | 16 days | Thu 2/16/17 | Thu 3/9/17 | |
| 31 | ✓ | Obtain Parts for Testing Fixture | 47 days | Thu 2/23/17 | Fri 4/28/17 | |
| 32 | ✓ | Manufacturing Status and Test Plan Presentation | 14 days | Mon 2/27/17 | Thu 3/16/17 | |
| 33 | ✓ | Project Update Report | 11 days | Thu 3/2/17 | Thu 3/16/17 | |
| 34 | ✓ | Operators' Manual | 9 days | Mon 2/27/17 | Thu 3/9/17 | |
| 35 | ✓ | Receive approval on O.M. from sponsor | 22 days | Thu 4/20/17 | Fri 5/19/17 | |
| 36 | ✓ | Assemble Fixture for testing | 37 days | Fri 3/10/17 | Mon 5/1/17 | |
| 37 | ✓ | Build Scale Model | 15 days | Tue 4/11/17 | Mon 5/1/17 | |
| 38 | ✓ | Run Test by Mel | 9 days | Tue 4/18/17 | Fri 4/28/17 | |
| 39 | ✓ | Reserve Hydraulic Ram | 9 days | Tue 4/18/17 | Fri 4/28/17 | |
| 40 | ✓ | Reserve Composites Lab | 29 days | Tue 4/18/17 | Fri 5/26/17 | |
| 41 | ✓ | Testing of Mødel | 4 days | Wed 5/3/17 | Mon 5/8/17 | |
| 42 | ✓ | Analyze Results | 7 days | Tue 5/9/17 | Wed 5/17/17 | |
| 43 | ✓ | Purchase Parts for Wooden Prototype | 26 days | Tue 4/4/17 | Tue 5/9/17 | |
| 44 | ✓ | Wooden Prototype Assembly | 6 days | Sat 5/13/17 | Fri 5/19/17 | |
| 45 | ✓ | Check Clearance with Wooden Prototype | 1 day | Sat 5/20/17 | Sat 5/20/17 | |

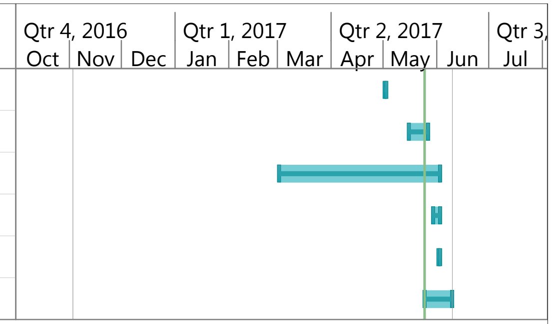



Project: Senior Project

| | | | | | |
|---|---|---|---|---|---|
| Task | | Inactive Summary | | External Tasks | |
| Split | | Manual Task | | External Milestone | |
| Milestone | | Duration-only | | Deadline | |
| Summary | | Manual Summary Rollup | | Progress | |
| Project Summary | | Manual Summary | | Manual Progress | |
| Inactive Task | | Start-only | | | |
| Inactive Milestone | | Finish-only | | | |

# Appendix Q: Gantt Chart (Actual)

| ID | | Task Name | Duration | Start | Finish | Predecessors |
|---|---|---|---|---|---|---|
| 46 | ✓ | Project Hardware/Safety Demo | 1 day | Tue 5/2/17 | Tue 5/2/17 | |
| 47 | ✓ | Expo Poster | 9 days | Tue 5/16/17 | Fri 5/26/17 | |
| 48 | ✓ | FDR Report | 67 days | Thu 3/2/17 | Fri 6/2/17 | |
| 49 | ✓ | FDR Project Expo | 4 days | Tue 5/30/17 | Fri 6/2/17 | |
| 50 | ✓ | FDR Hardware Handoff | 1 day | Fri 6/2/17 | Fri 6/2/17 | |
| 51 | ✓ | Final Checklist | 12 days | Thu 5/25/17 | Fri 6/9/17 | |

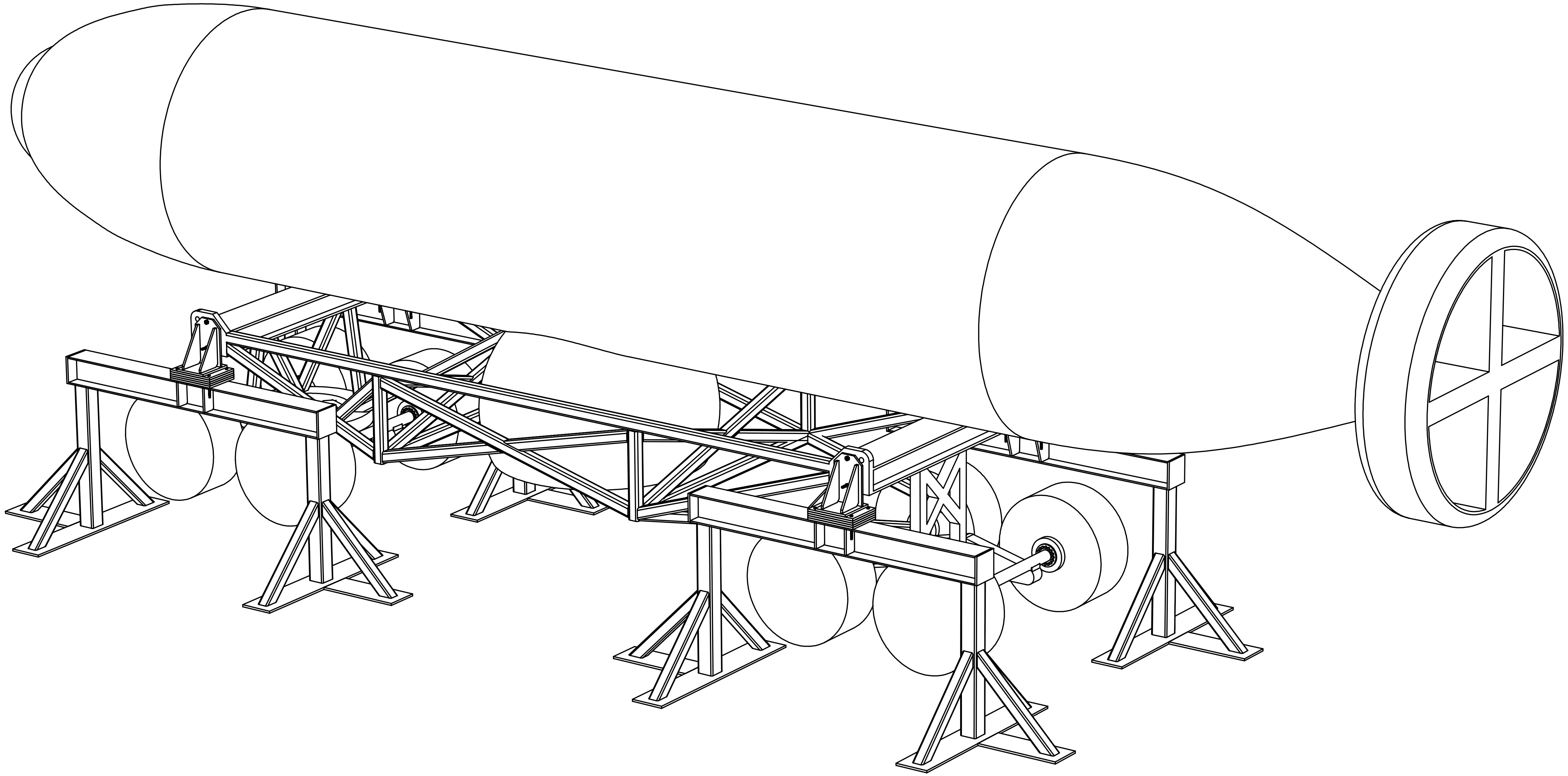



Project: Senior Project

| | | | | | |
|---|---|---|---|---|---|
| Task | | Inactive Summary | | External Tasks | |
| Split | | Manual Task | | External Milestone | |
| Milestone | | Duration-only | | Deadline | |
| Summary | | Manual Summary Rollup | | Progress | |
| Project Summary | | Manual Summary | | Manual Progress | |
| Inactive Task | | Start-only | | | |
| Inactive Milestone | | Finish-only | | | |

NOTE:

FULL INSALLATION SHOWN FOR REFERENCE



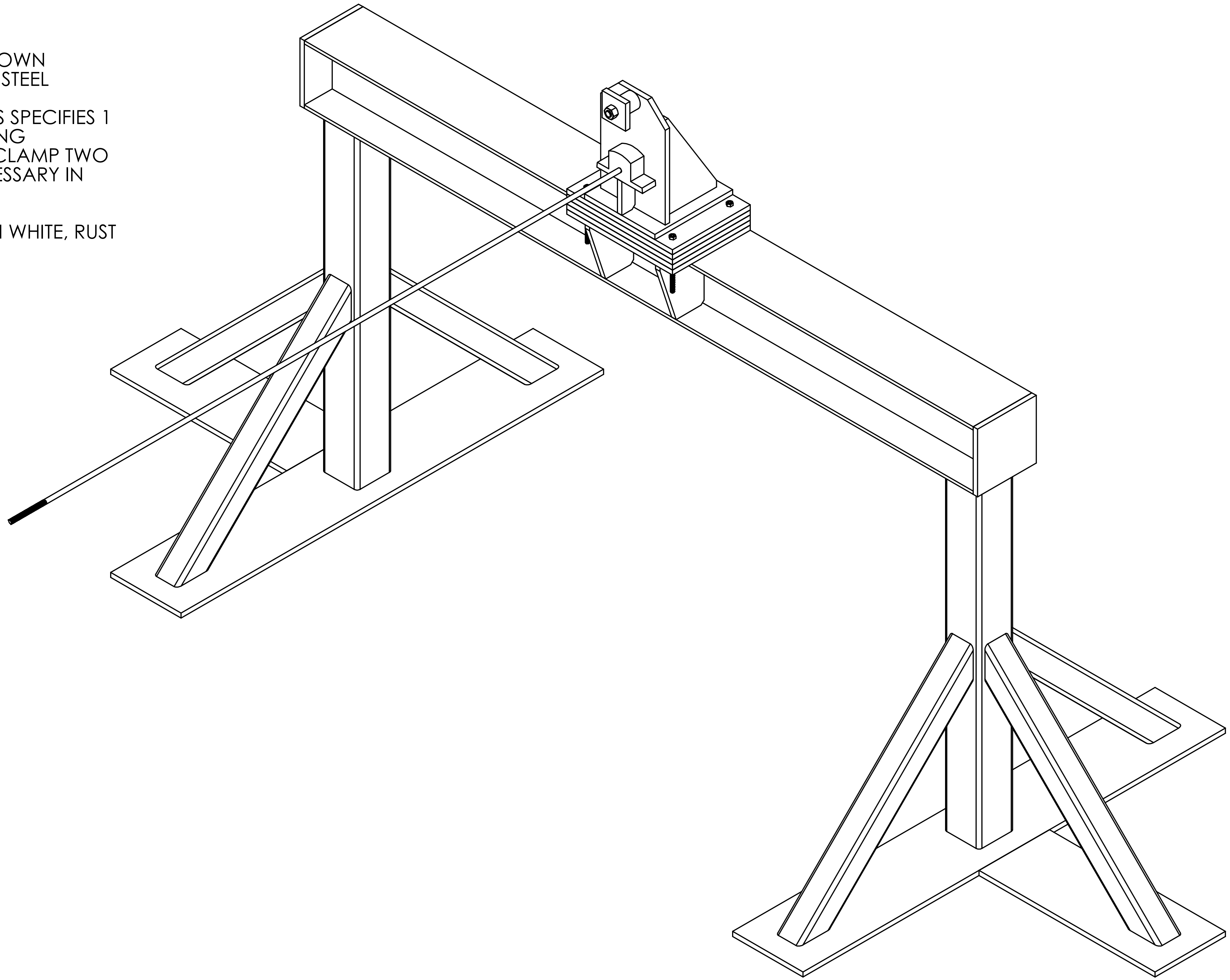
Text



| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: COMPLETE INSTALLATION | | Drwn. By: SUBLIME SQUAD |
|---|---|---|---|---|
| | Dwg. #: A0000 | Date: 5/23/2017 | Scale: 1:35 | Advisor: EILEEN ROSSMAN |

NOTE:

1. FINAL STRUCTURE INSTALLATION SHOWN
2. ALL MATERIAL IS A500 STRUCTURAL STEEL UNLESS OTHERWISE SPECIFIED
3. THE FOLLOWING SET OF DRAWINGS SPECIFIES 1 OF 4 ASSEMBLIES FOR MANUFACTURING
4. CLAMPING ROD, A008, USED TO CLAMP TWO STRUCTURES TOGETHER. ONLY 2 NECESSARY IN TOTAL
5. CLAMPING NUT NOT SHOWN
6. ALL STRUCTURES ARE COATED WITH WHITE, RUST RESISTANT PAINT OR EPOXY

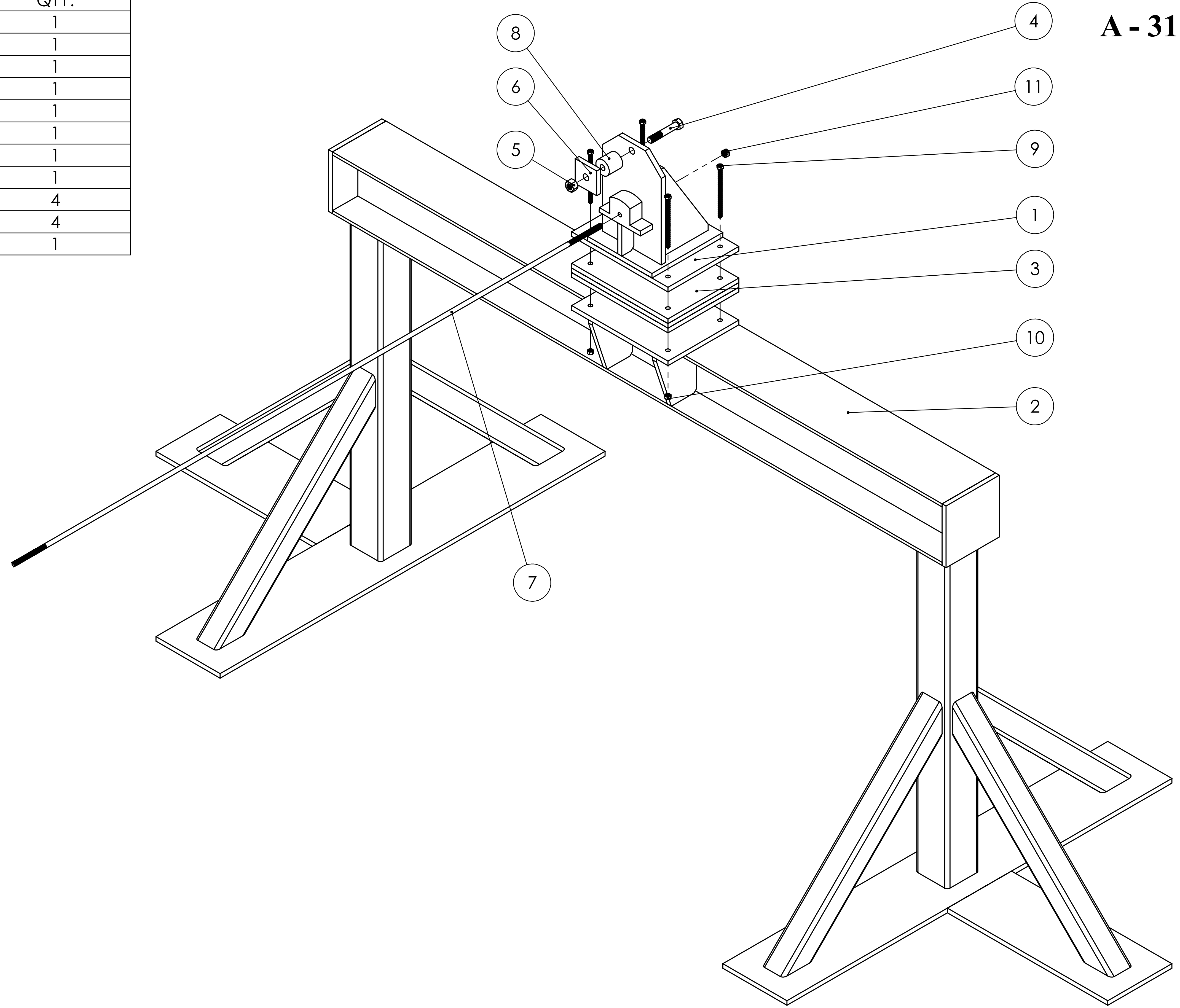




| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: FINAL ASSEMBLY | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: A000 | Date: 5/23/2017 | Scale: 1:14 | Advisor: EILEEN ROSSMAN |

| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | AA00 | CONNECTION BOX | 1 |
| 2 | AB00 | SAWHORSE STRUCTURE | 1 |
| 3 | AC00 | SHIM PACK | 1 |
| 4 | 91257A941 | TRAILER BOLT | 1 |
| 5 | 94811A255 | TRAILER INTERFACE NUT | 1 |
| 6 | A006 | TRAILER BACK PLATE | 1 |
| 7 | A007 | CLAMING ROD | 1 |
| 8 | A008 | TRAILER BUSHING | 1 |
| 9 | 92620A733 | LONG INTERFACE BOLT | 4 |
| 10 | 94895A823 | NUT | 4 |
| 11 | 94895A835 | CLAMPING NUT | 1 |






NOTE:

1. NUT AND BOLT PART NUMBERS ARE FROM MCMASTER CARR
2. ASSEMBLY AC00 IS NOT EXPLICITY DRAWN. SEE AX01 FOR PART DRAWING RELATED TO SUBASSEMBLY OF SHIM PACK

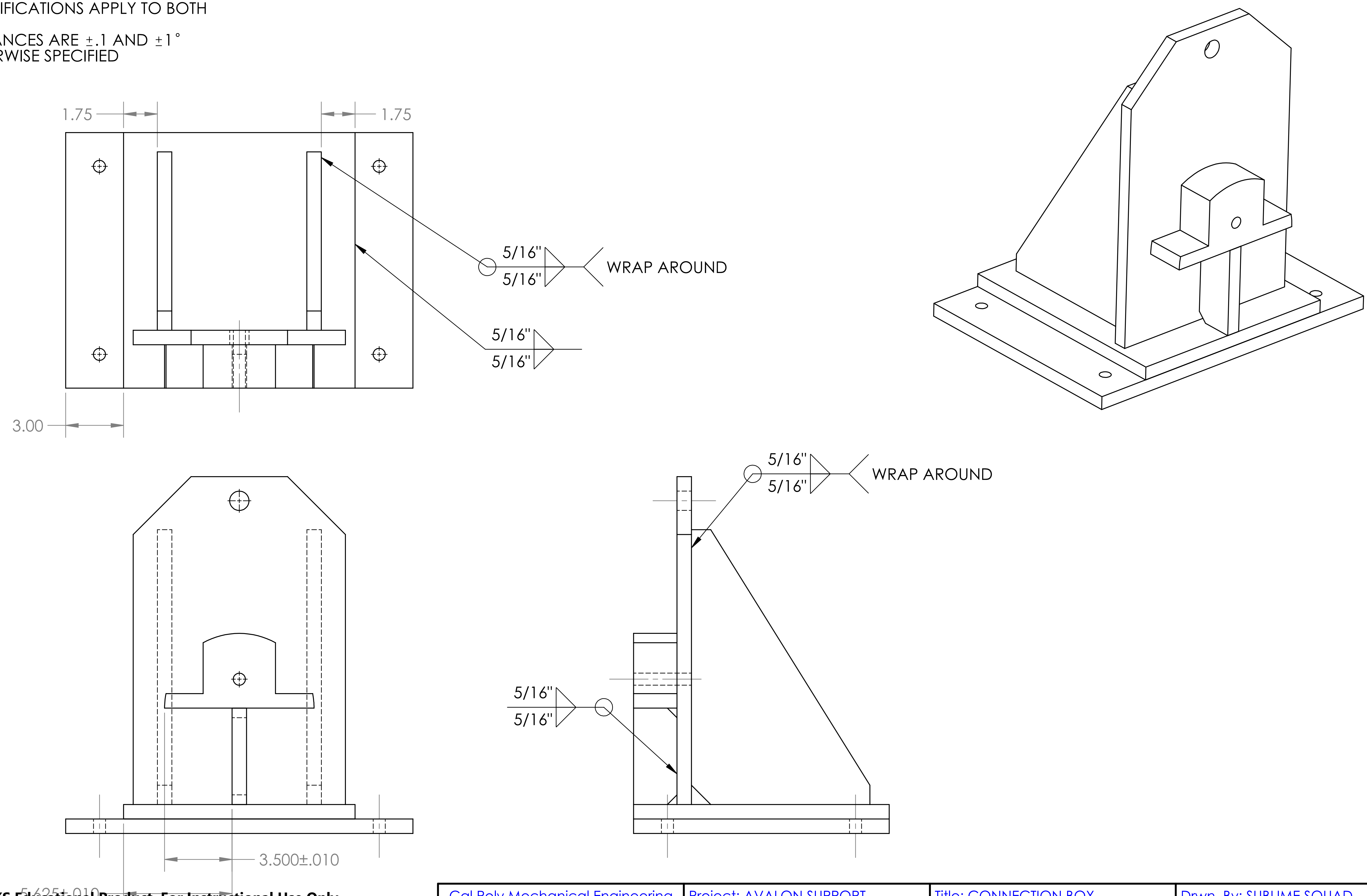


| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: EXPLODED ASSEMBLY | | Drwn. By: SUBLIME SQUAD |
|---|---|---|---|---|
| | Dwg. #: A000-E | Date: 5/23/2017 | Scale: 1:14 | Advisor: EILEEN ROSSMAN |

NOTE:

1. WELD SPECIFICATIONS APPLY TO BOTH GUSSETS
2. ALL TOLERANCES ARE ±.1 AND ±1° UNLESS OTHERWISE SPECIFIED

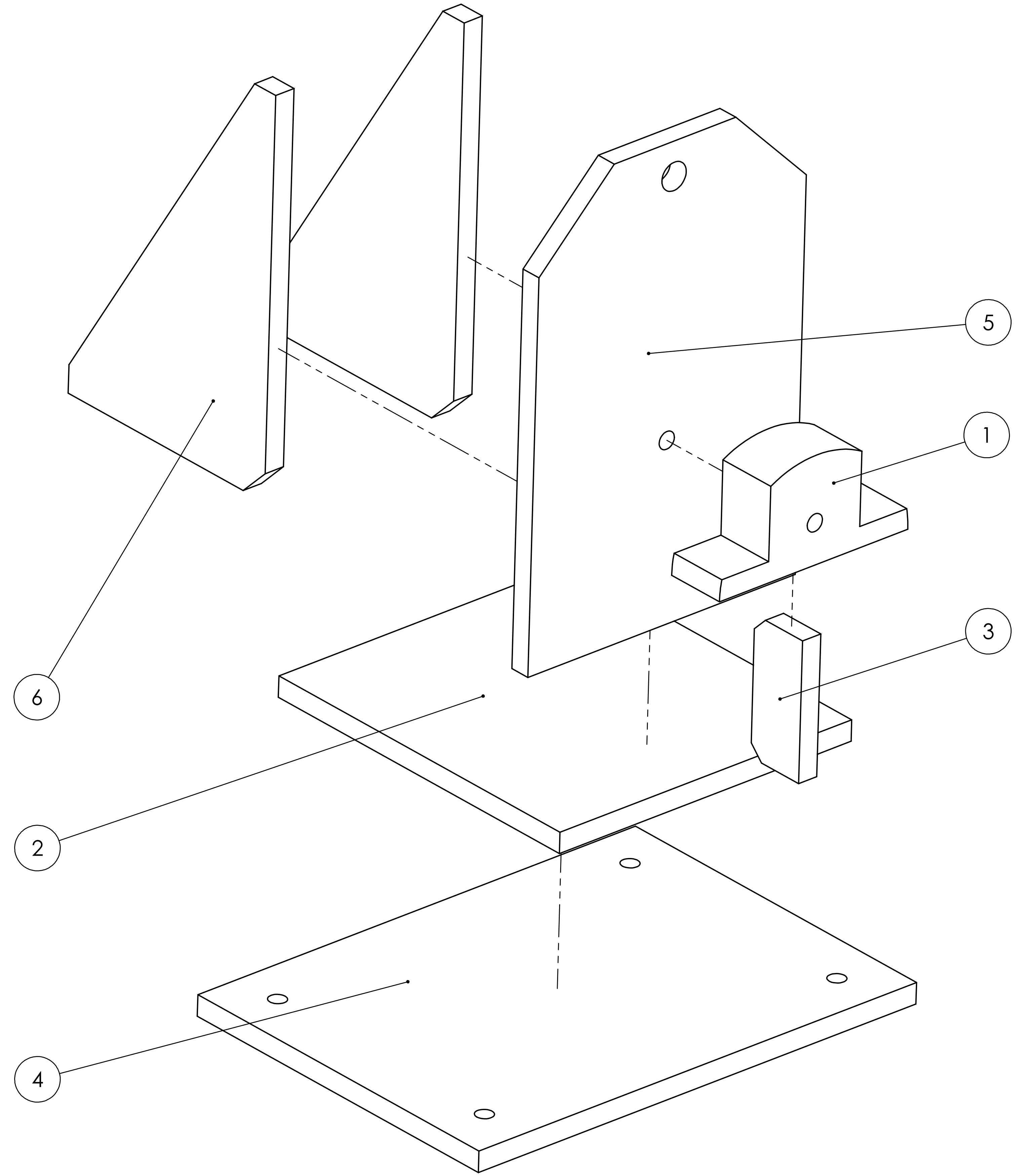
**A - 32**






| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON SUPPORT | Title: CONNECTION BOX | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: AA00 | Date: 5/23/2017 | Scale: 1:5 | Advisor: EILEEN ROSSMAN |

| ITEM NO. | PART NUMBER | DESCRIPTION | MATERIAL | QTY. |
|---|---|---|---|---|
| 1 | AA01 | LOAD BEARING PUCK | A36 STEEL | 1 |
| 2 | AA04 | BOX PLATE | A36 STEEL | 1 |
| 3 | AA05 | PUCK GUSSET | A36 STEEL | 1 |
| 4 | AX01 | INTERFACE PLATE | A36 STEEL | 1 |
| 5 | AA02 | BACK PLATE | A36 STEEL | 1 |
| 6 | AA03 | BOX GUSSET | A36 STEEL | 2 |

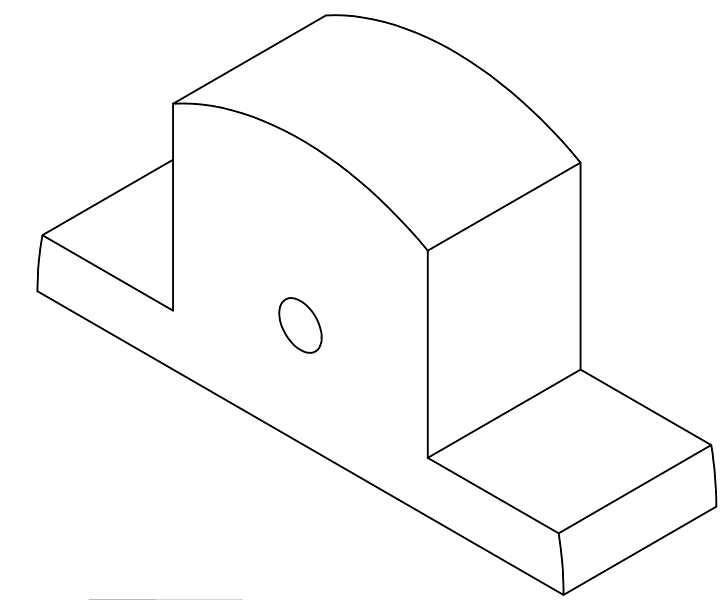


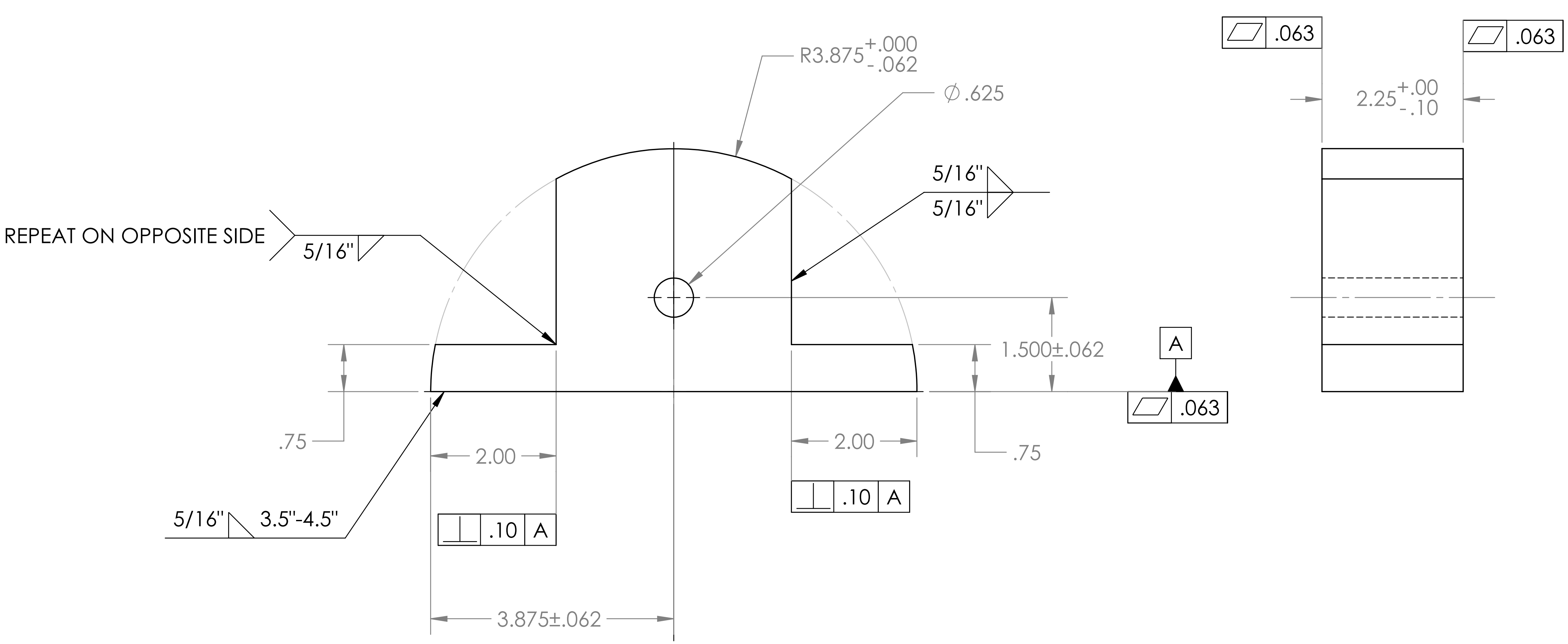



| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: EXPLODED CONNECTION BOX | | Drwn. By: SUBLIME SQUAD |
|---|---|---|---|---|
| | Dwg #: AA00-E | Date: 5/23/2017 | Scale: 1:4 | Advisor: EILEEN ROSSMAN |

NOTE:

1. ALL TOLERANCES ARE ±.10 AND ±1° UNLESS OTHERWISE SPECIFIED
2. SPACE ON THE BOTTOM SIDE OF THE PUCK TO ALLOW INSTALATION OF THE PUCK GUSSET



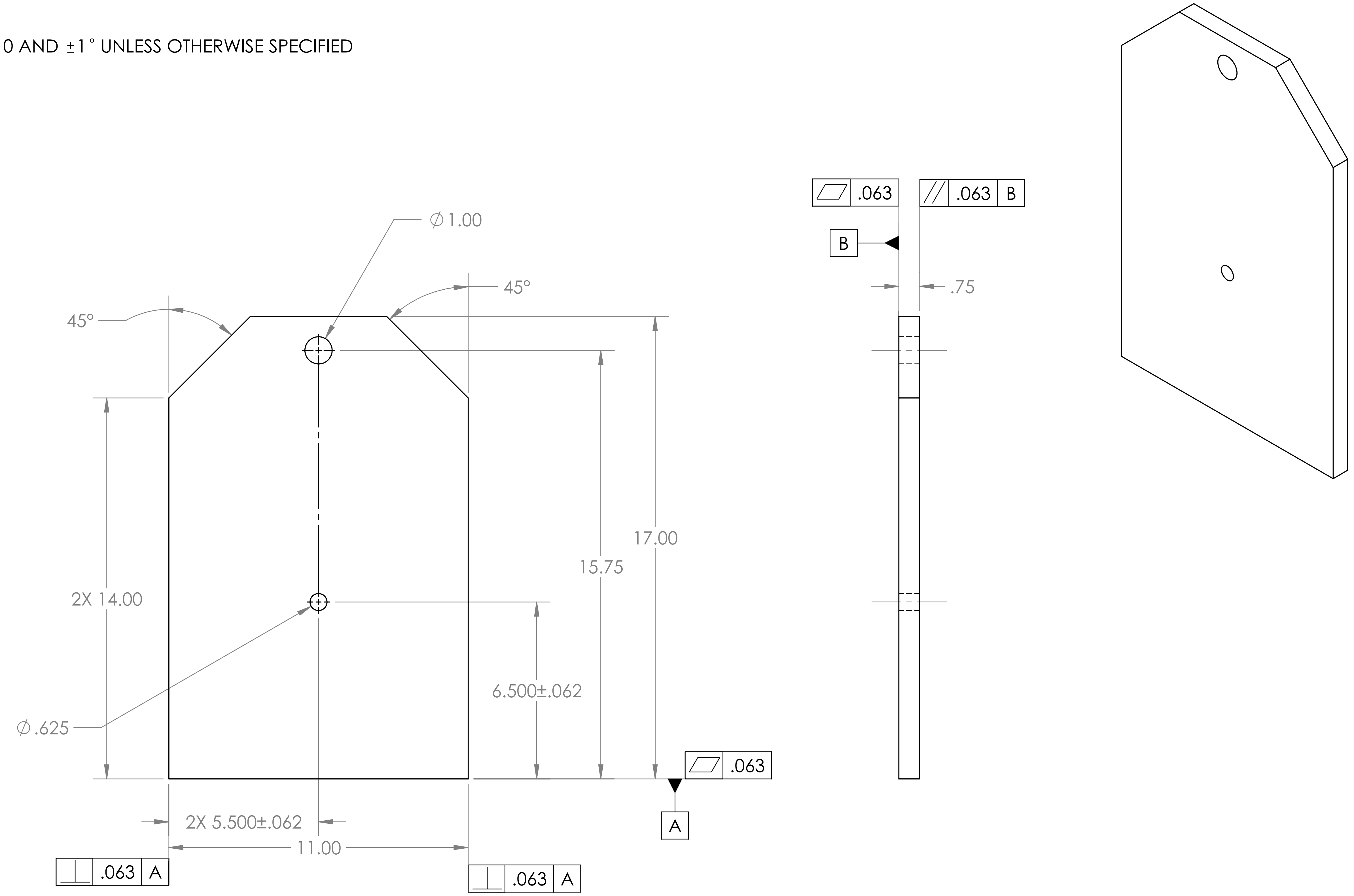



**SOLIDWORKS Educational Product. For Instructional Use Only**

| | | | |
|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: LOAD BEARING PUCK | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: AA01 | Date: 5/23/2017 / Scale: 1:2 | Advisor: EILEEN ROSSMAN |

NOTE:

1. ALL TOLERANCES ARE ±.10 AND ±1° UNLESS OTHERWISE SPECIFIED



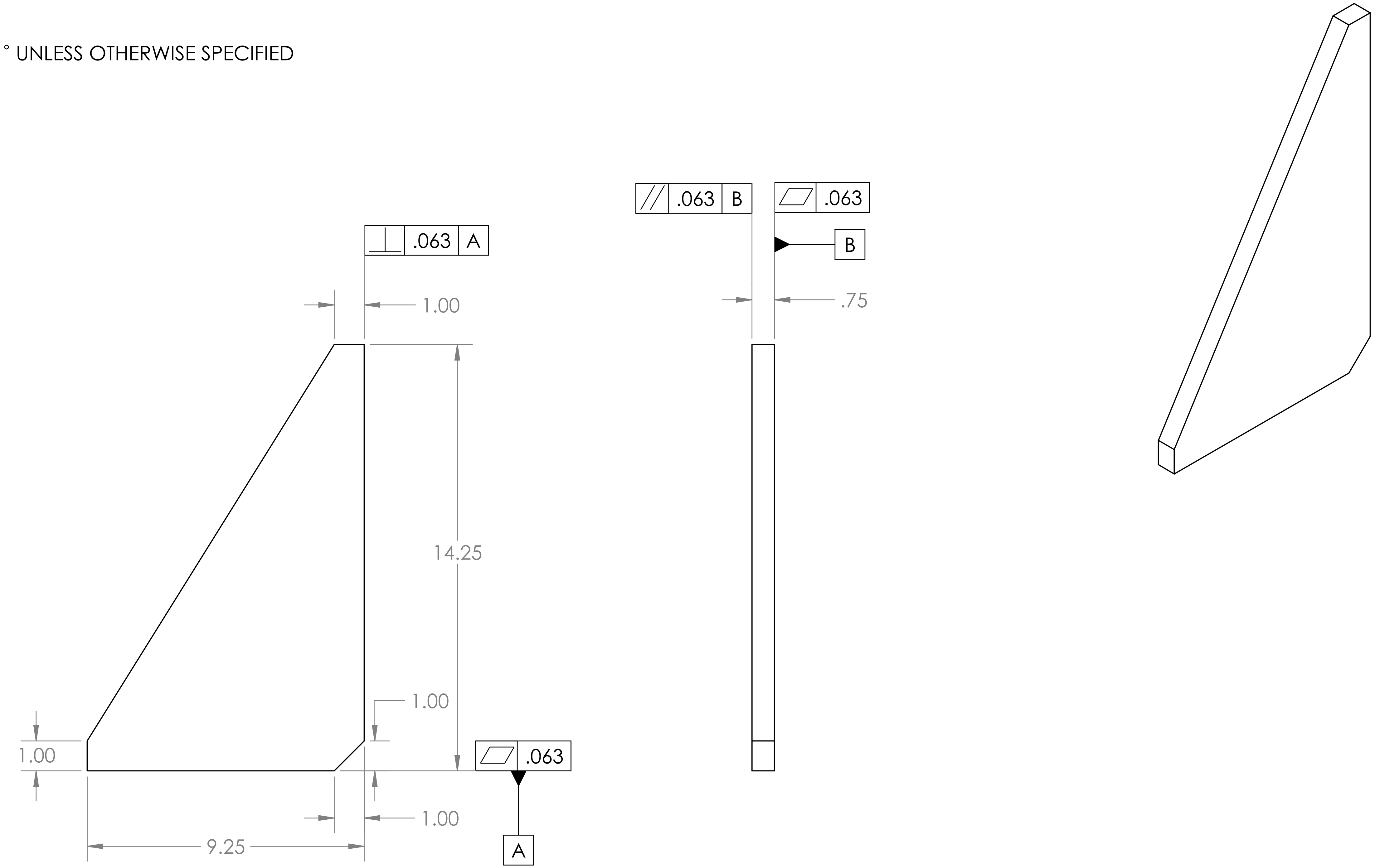



| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: BACK PLATE | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: AA02 | Date: 5/23/2017 | Scale: 1:4 | Advisor: EILEEN ROSSMAN |

**A - 36**

NOTE:

1. ALL TOLERANCES ARE ±.10 AND ±1° UNLESS OTHERWISE SPECIFIED

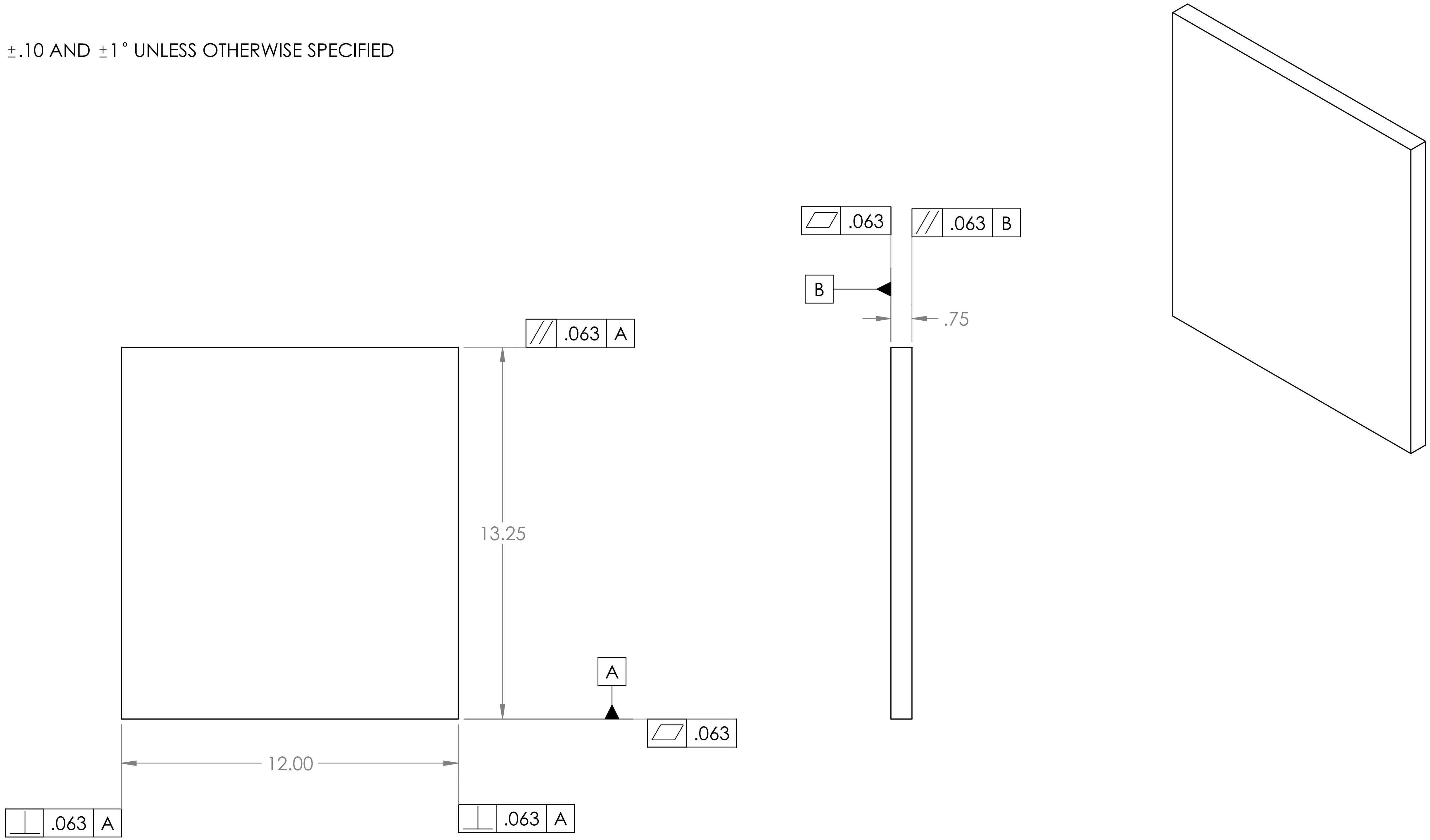





| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering<br>SENIOR PROJECT | Project: AVALON STRUCTURE | Title: BOX GUSSET | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: AA03 | Date: 5/23/2017 | Scale: 1:4 | Advisor: EILEEN ROSSMAN |

NOTE:

1. ALL TOLERANCES ARE ±.10 AND ±1° UNLESS OTHERWISE SPECIFIED

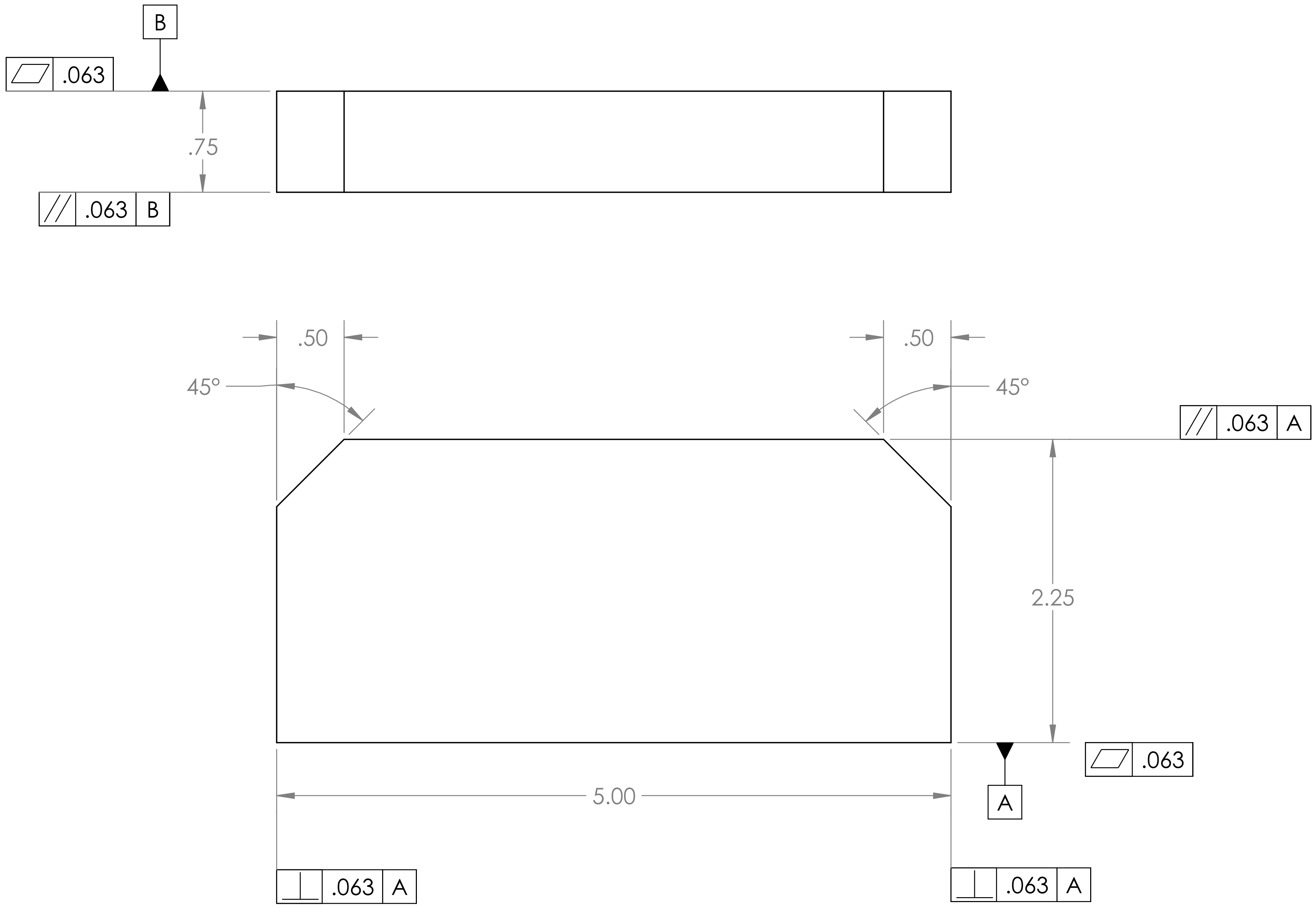


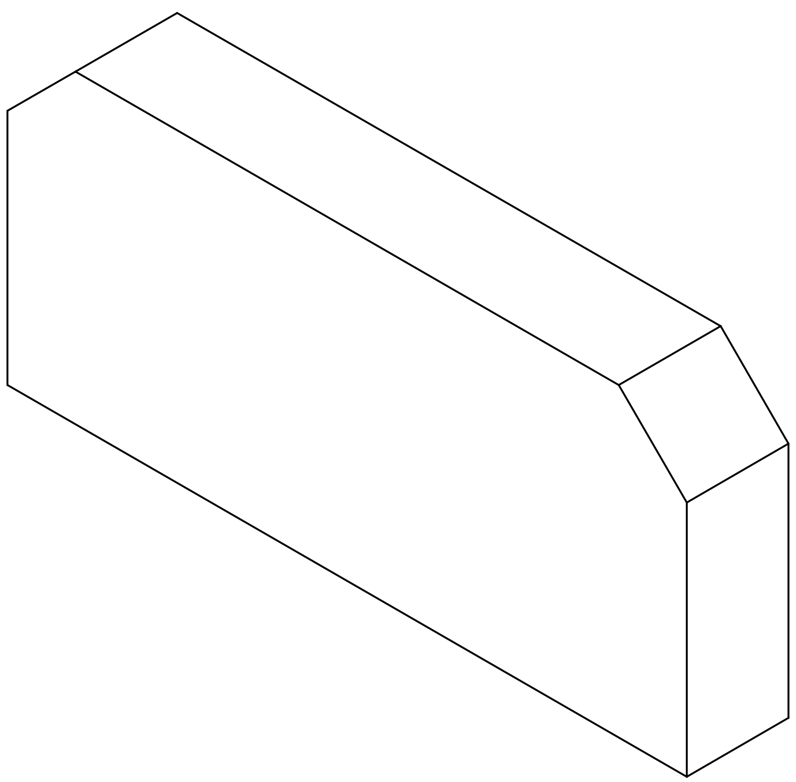

**SOLIDWORKS Educational Product. For Instructional Use Only**

| | | | |
|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: BOX PLATE | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: AA04 | Date: 5/23/2017 Scale: 1:4 | Advisor: EILEEN ROSSMAN |

NOTE:

1. ALL TOLERANCES ARE ±.10 AND ±1° UNLESS OTHERWISE SPECIFIED



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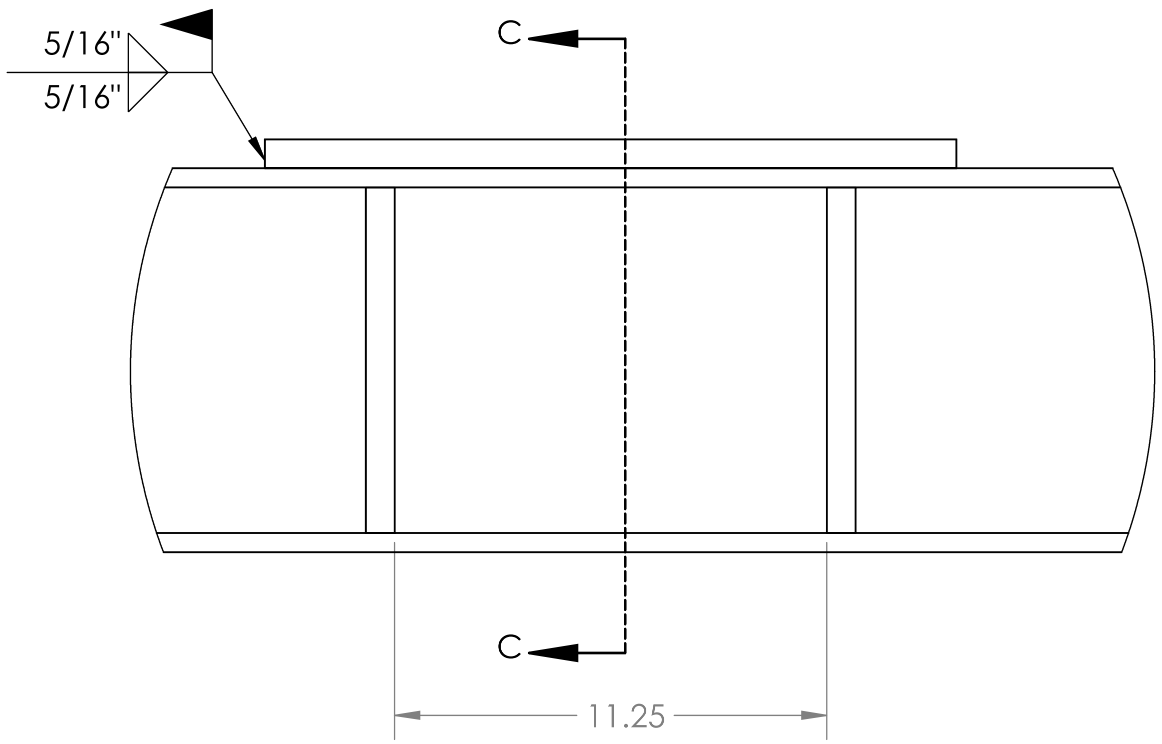
| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: PUCK GUSSET | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: AA05 | Date: 5/23/2017 | Scale: 1:4 | Advisor: EILEEN ROSSMAN |




DETAIL A
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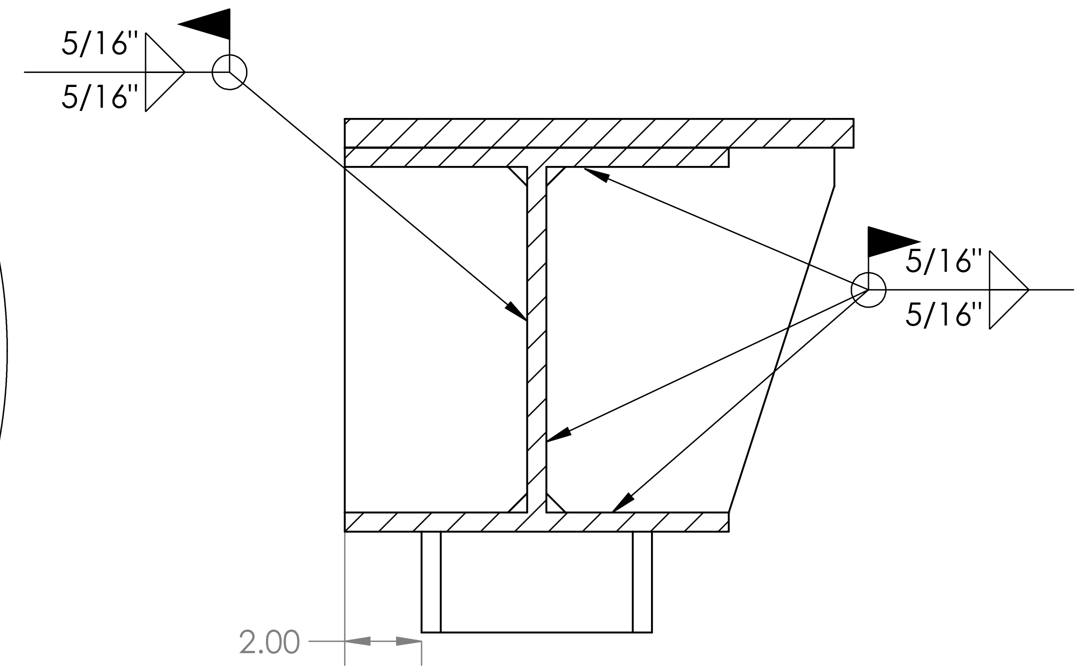
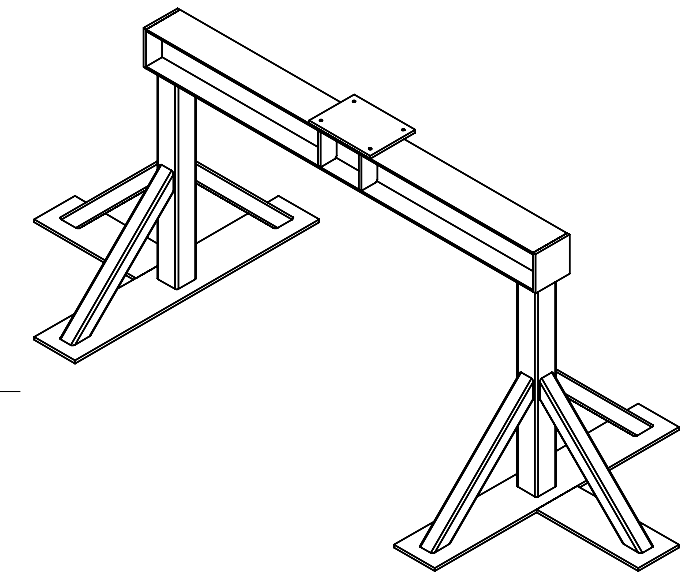



SECTION C-C
SCALE 1 : 5



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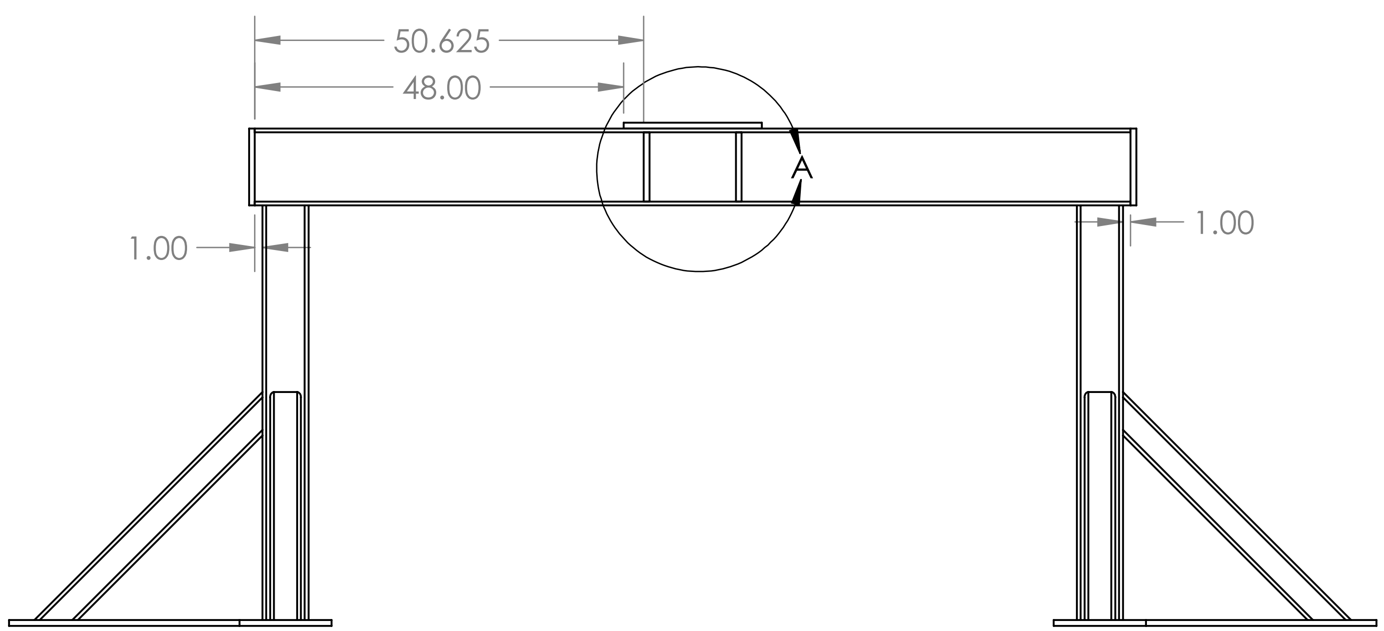
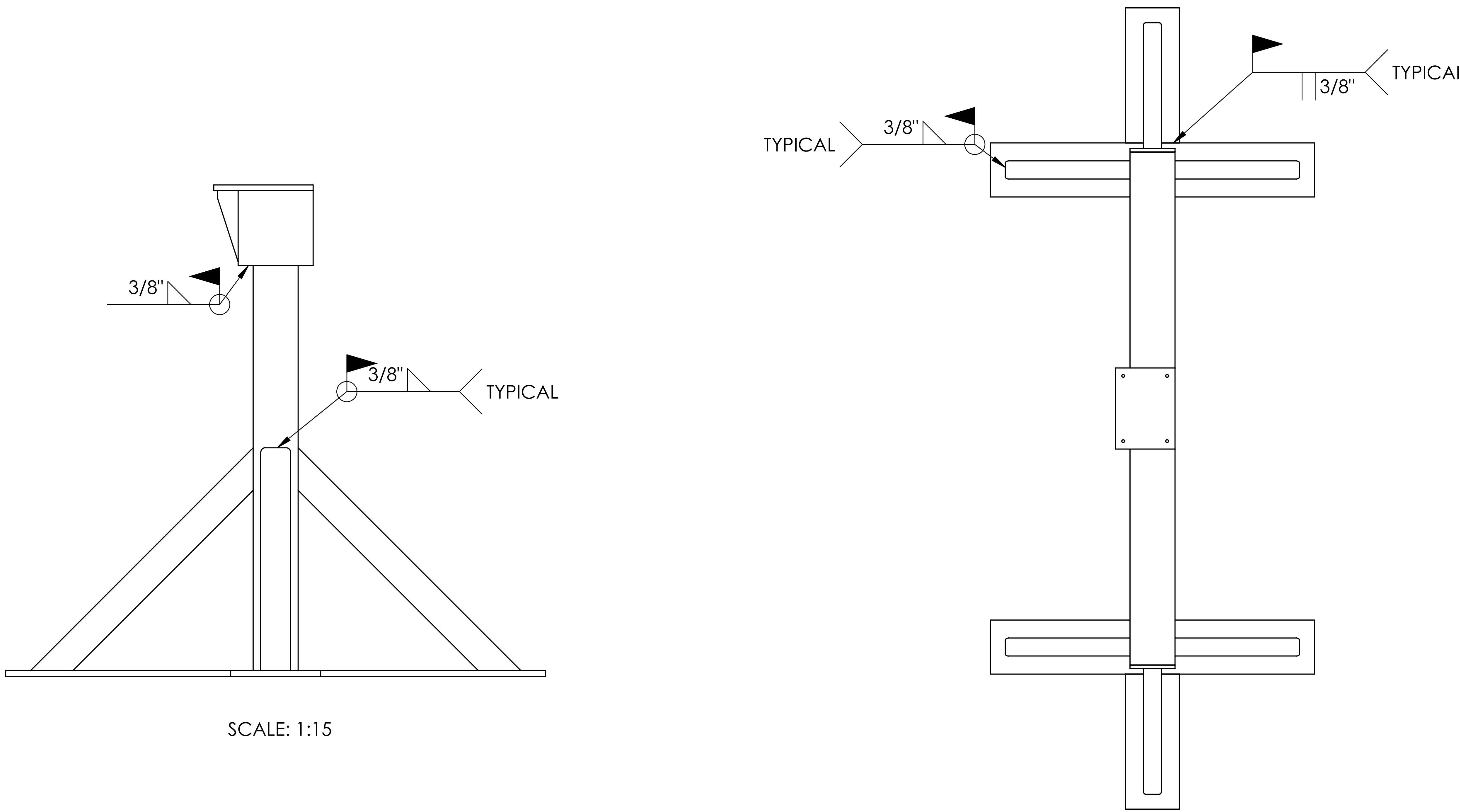





| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON SUPPORT | Title: SAWHORSE | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: AB00-1 | Date: 5/23/2017 | Scale: 1:25 | Advisor: EILEEN ROSSMAN |

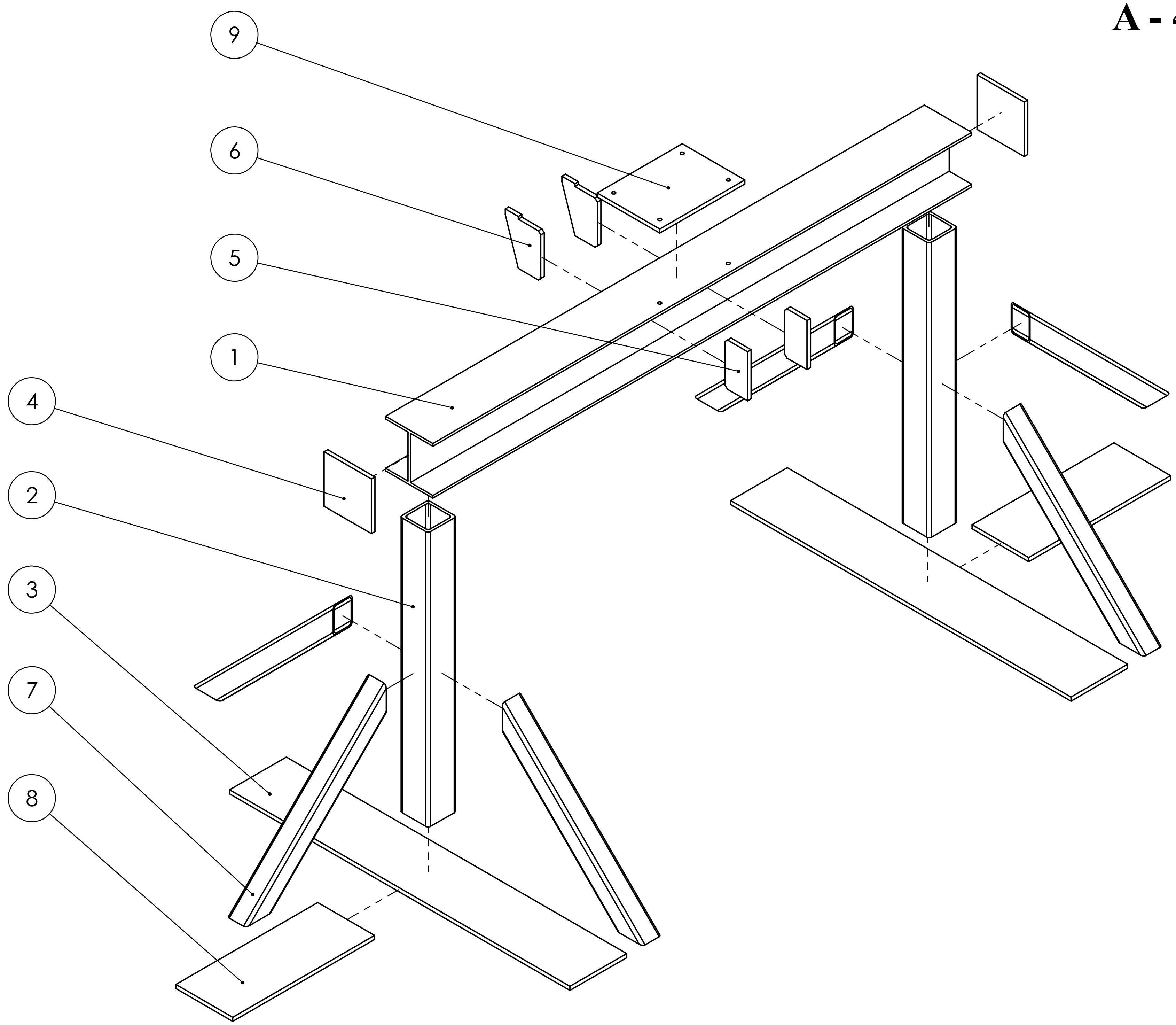





| | | | |
|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON SUPPORT | Title: SAWHORSE | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: AB00-2 | Date: 5/23/2017 / Scale: 1:25 | Advisor: EILEEN ROSSMAN |

| ITEM NO. | PART NUMBER | DESCRIPTION | MATERIAL | QTY. |
|---|---|---|---|---|
| 1 | AB01 | MAIN BEAM | A500 STEEL | 1 |
| 2 | AB02 | VERTICAL COLUMN | A500 STEEL | 2 |
| 3 | AB03 | LONG FOOT | A36 STEEL | 2 |
| 4 | AB04 | BEAM CAP | A36 STEEL | 2 |
| 5 | AB05 | BEAM GUSSET | A36 STEEL | 2 |
| 6 | AB06 | TORSION GUSSET | A36 STEEL | 2 |
| 7 | AB07 | STABILITY STRUT | A500 STEEL | 6 |
| 8 | AB08 | SHORT FOOT | A36 STEEL | 2 |
| 9 | AX01 | INTERFACE PLATE | A36 STEEL | 1 |



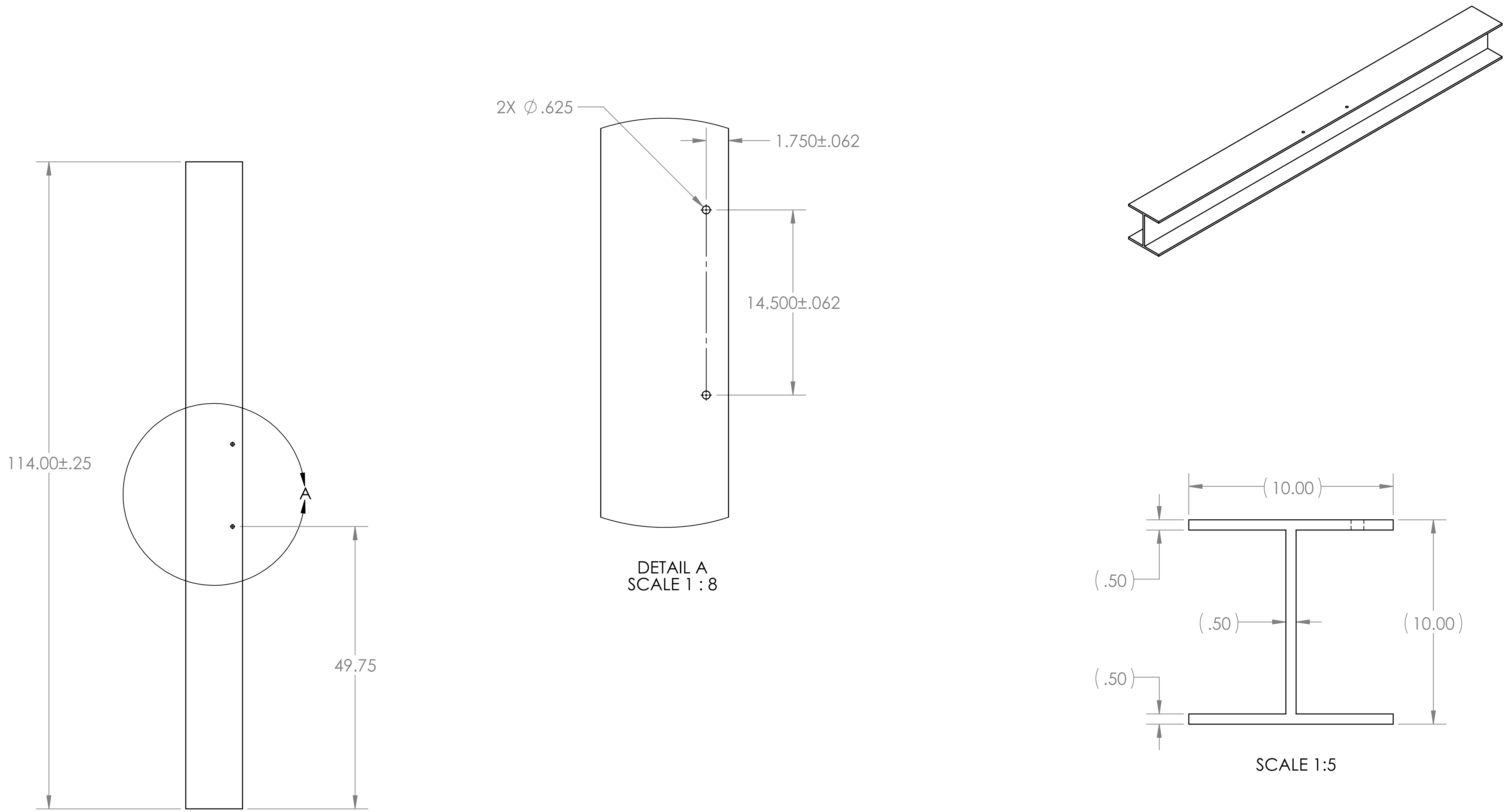





| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: EXPLODED SAWHORSE | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: AB00-E | Date: 5/23/2017 | Scale: 1:20 | Advisor: EILEEN ROSSMAN |

NOTE:

1. ALL TOLERANCES ARE ±.10 AND ±1° UNLESS OTHERWISE SPECIFIED
2. PARENTHESIS INDICATE STOCK DIMENSIONS

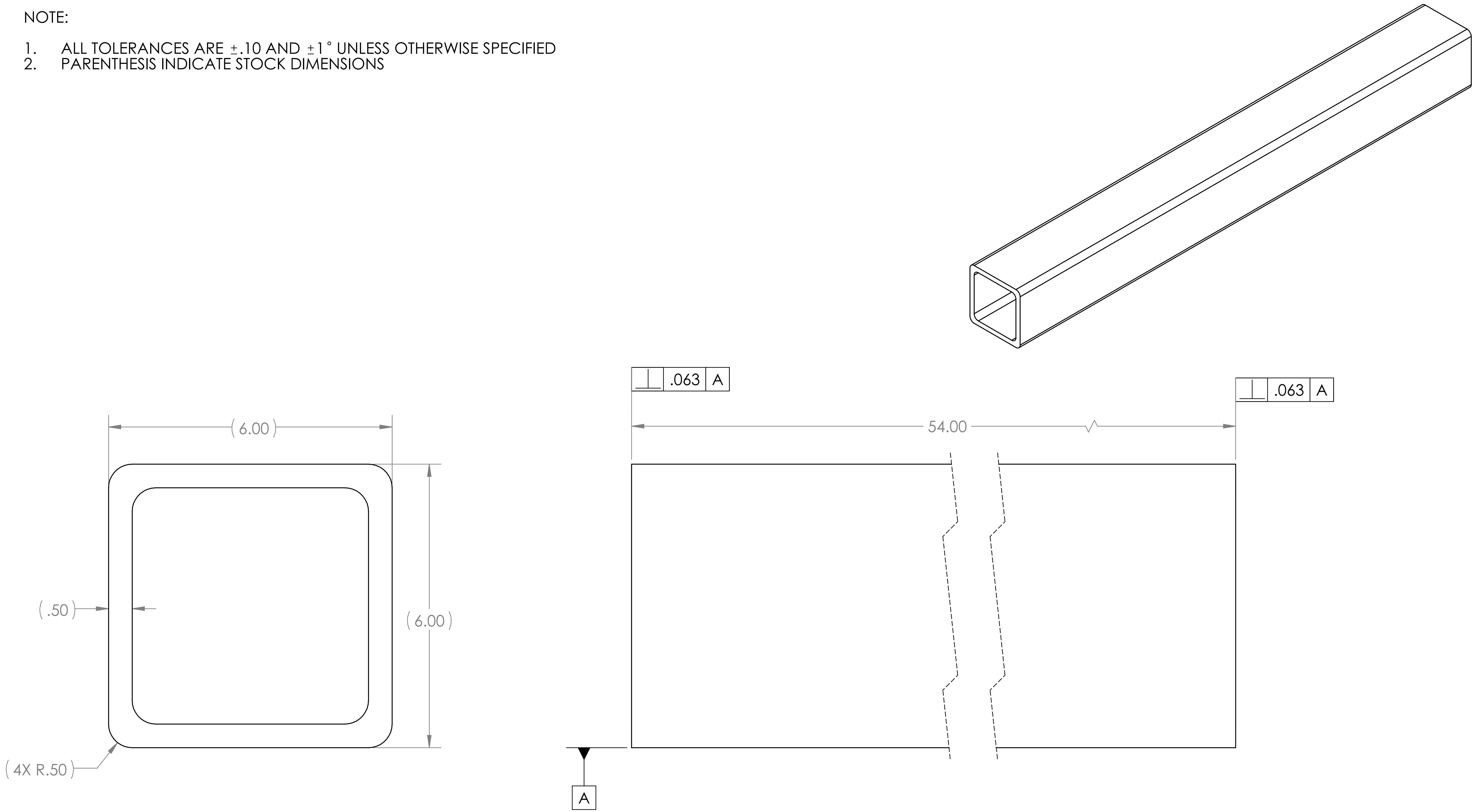





| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON SUBMERSIBLE | Title: MAIN BEAM | | Drwn. By:SUBLIME SQUAD |
| | Dwg. #: AB01 | Date: 5/23/2017 | Scale: 1:18 | Advisor: EILEEN ROSSMAN |

NOTE:

1. ALL TOLERANCES ARE ±.10 AND ±1° UNLESS OTHERWISE SPECIFIED
2. PARENTHESIS INDICATE STOCK DIMENSIONS

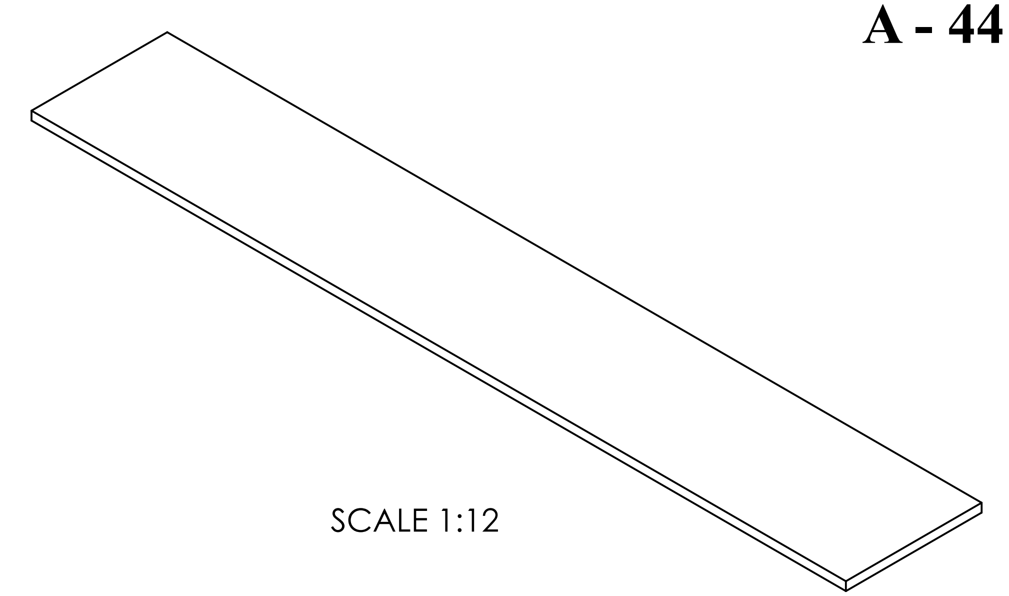





| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: VERTICAL COLUMN | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: AB02 | Date: 5/23/2017 | Scale: 1:2 | Advisor: EILEEN ROSSMAN |

NOTE:

1. ALL TOLERANCES ARE ±.25 AND ±1° UNLESS OTHERWISE SPECIFIED
2. PARENTHESIS INDICATE STOCK DIMENSIONS



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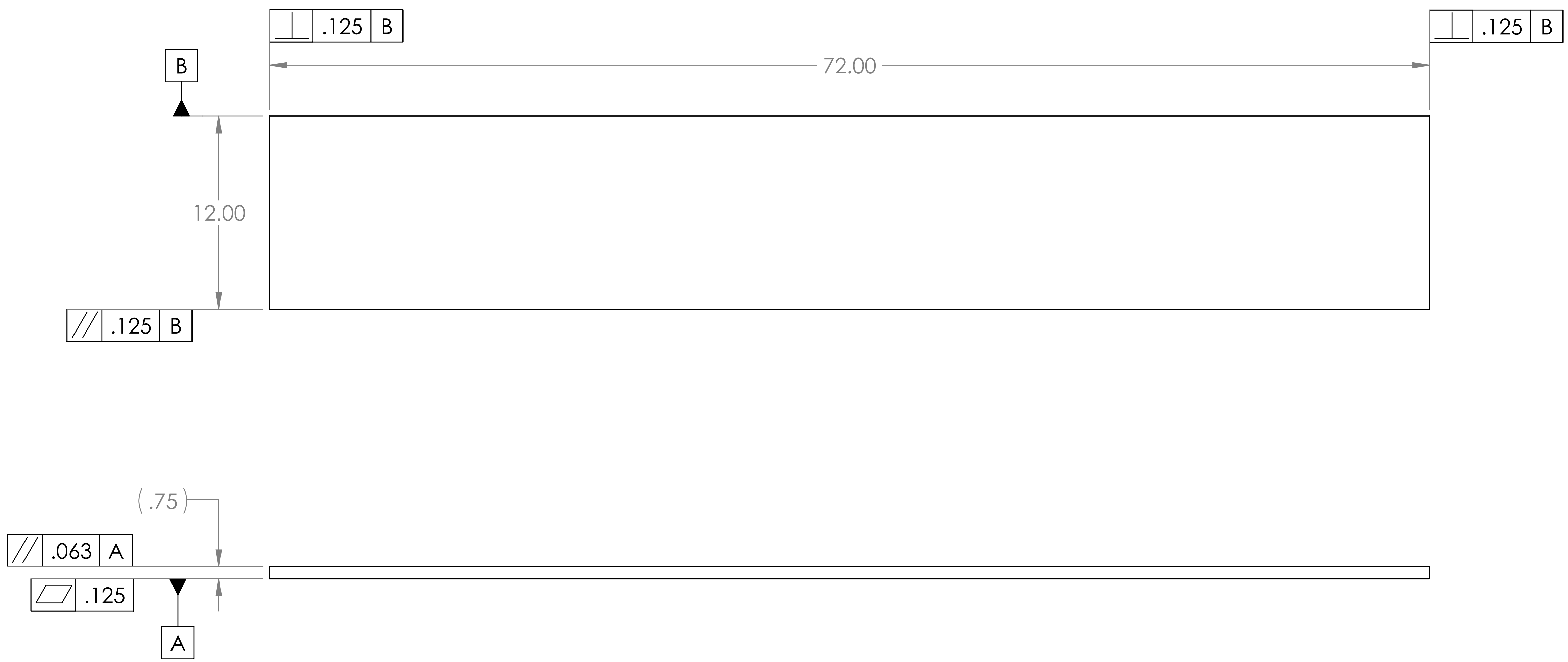
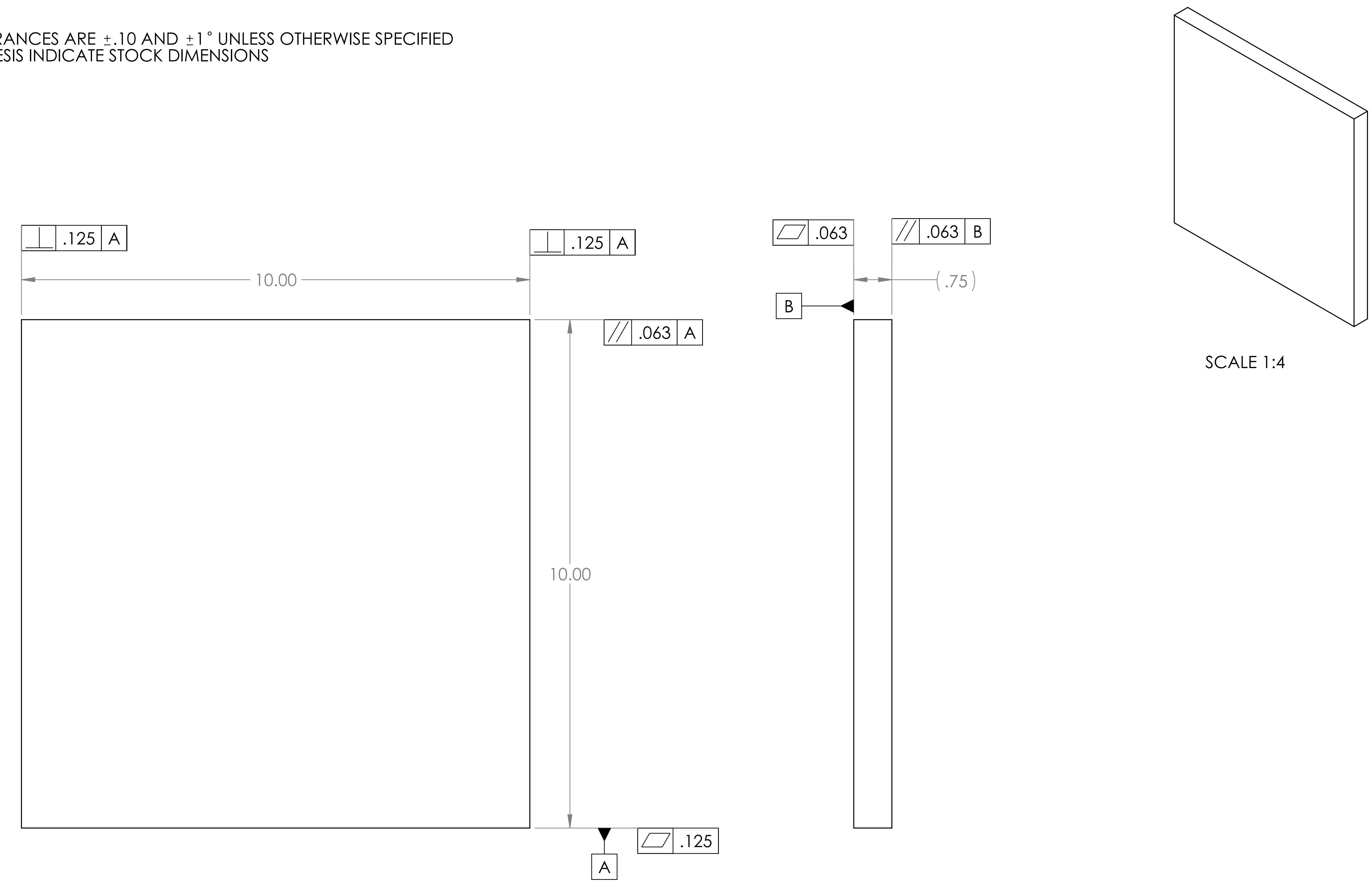





| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON SUPPORT | Title: LONG FOOT | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: AB03 | Date: 5/23/2017 | Scale: 1:8 | Advisor: EILEEN ROSSMAN |

NOTE:

1. ALL TOLERANCES ARE ±.10 AND ±1° UNLESS OTHERWISE SPECIFIED
2. PARENTHESIS INDICATE STOCK DIMENSIONS

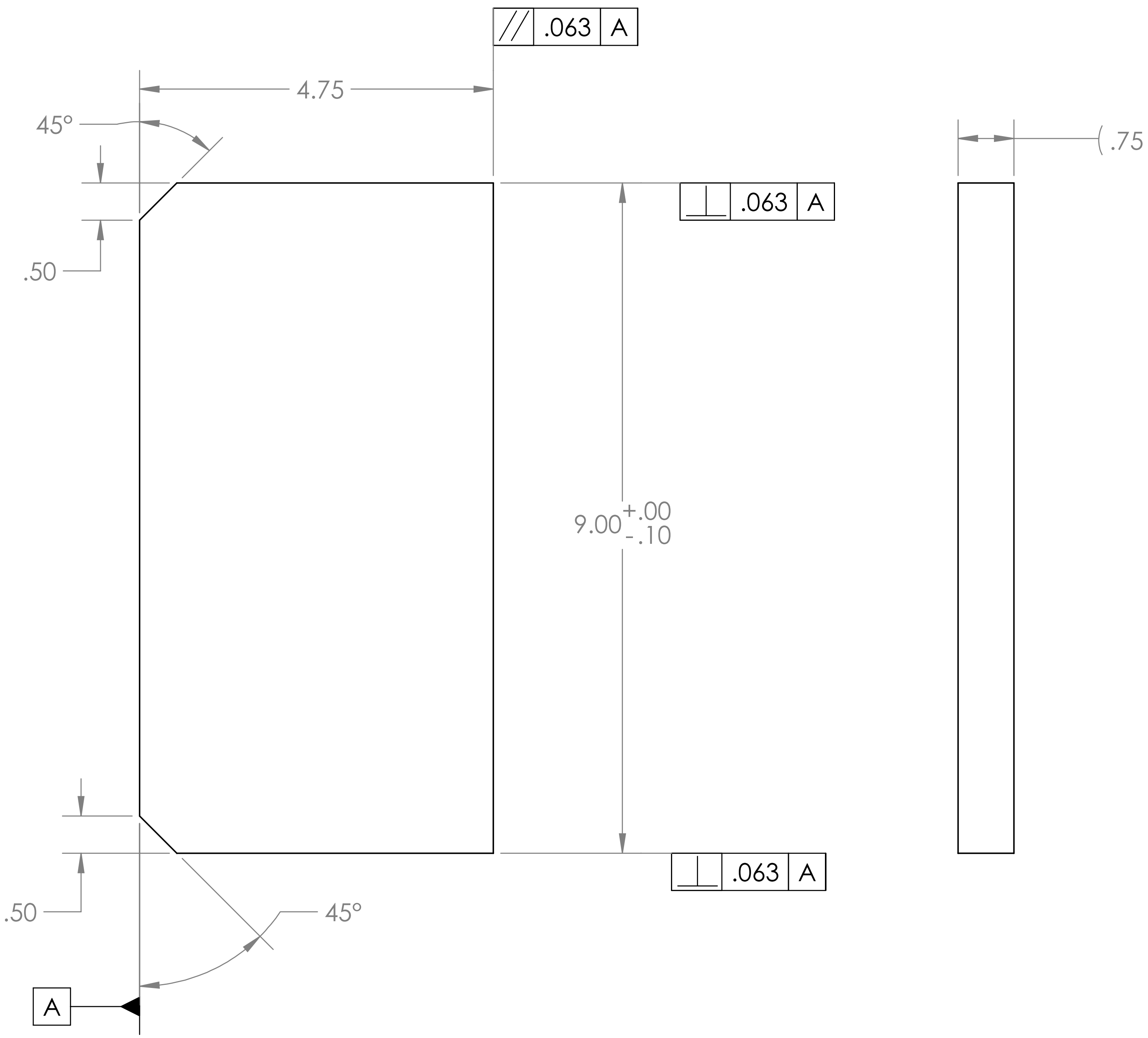


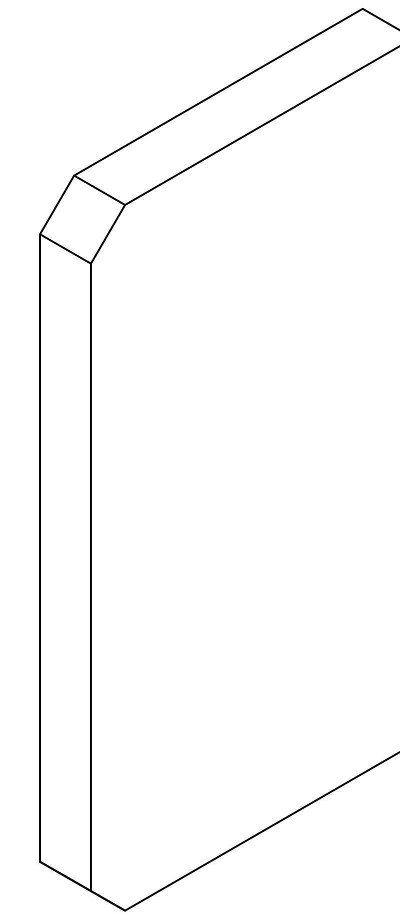



| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: BEAM CAP | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: AB04 | Date: 5/23/2017 | Scale: 1:2 | Advisor: EILEEN ROSSMAN |

NOTE:

1. ALL TOLERANCES ARE ±.10 AND ±1° UNLESS OTHERWISE SPECIFIED
2. PARENTHESIS INDICATE STOCK DIMENSIONS



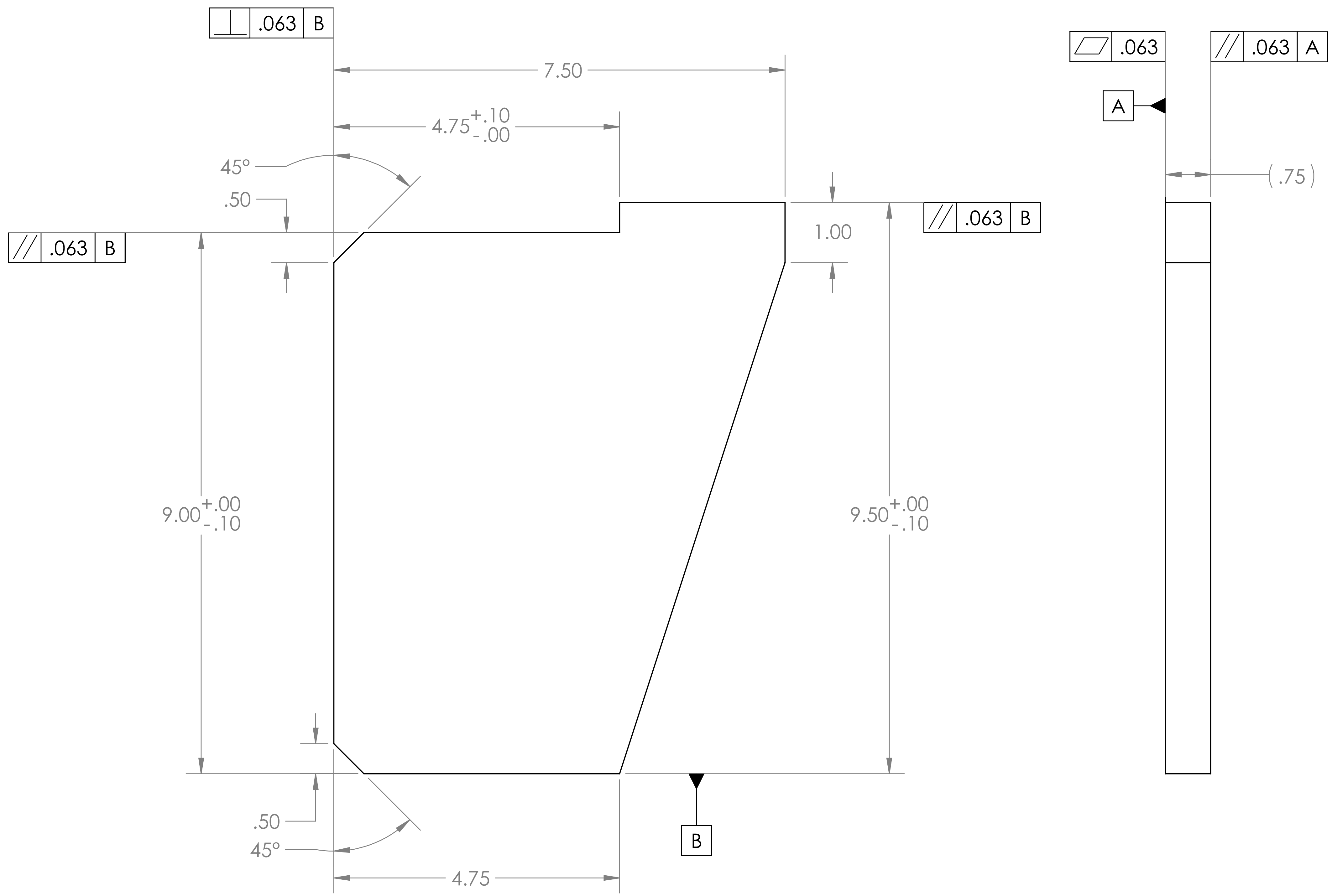



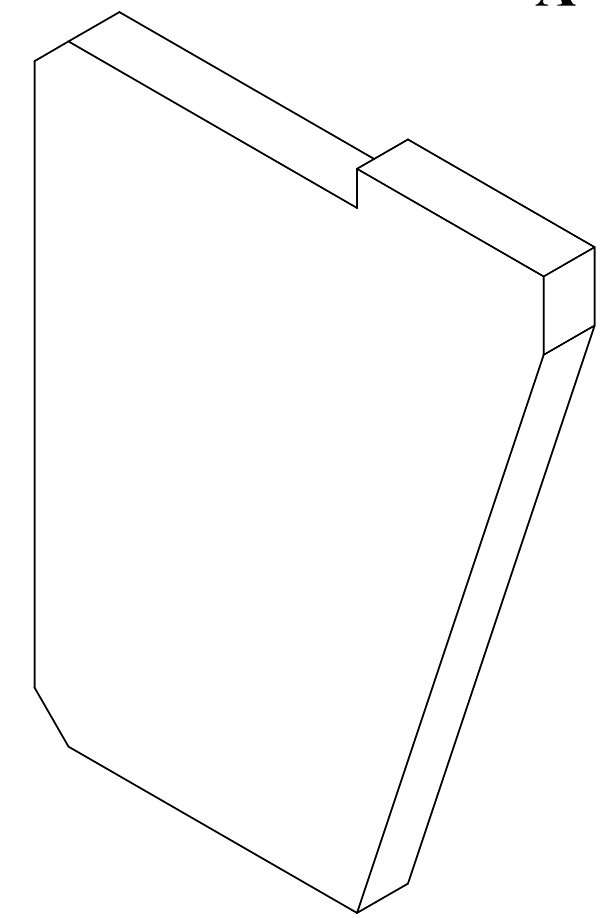


| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: BEAM GUSSET | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: AB05 | Date: 5/23/2017 | Scale: 1:2 | Advisor: EILEEN ROSSMAN |

NOTE:

1. ALL TOLERANCES ARE ±.10 AND ±1° UNLESS OTHERWISE SPECIFIED
2. PARENTHESIS INDICATE STOCK DIMENSIONS
3. GRINDING IS REQUIRED TO FIT GUSSET SNUG INSIDE BEAM



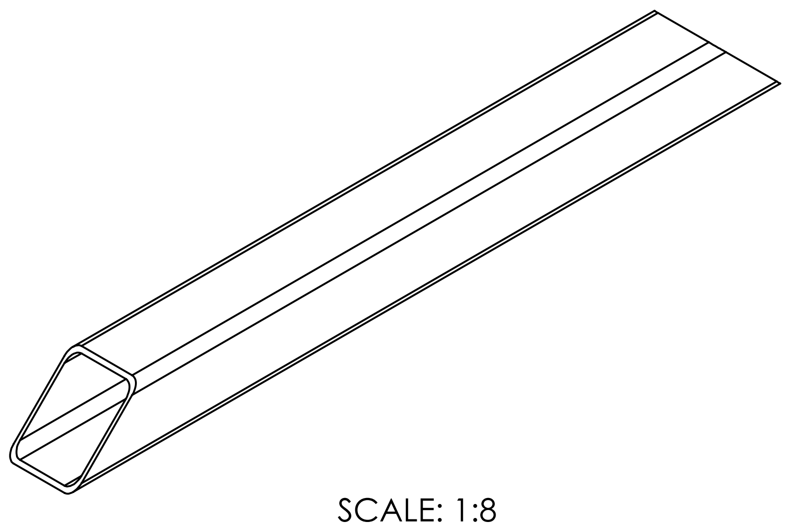





| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: TORSION GUSSET | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: AB06 | Date: 5/23/2017 | Scale: 1:2 | Advisor: EILEEN ROSSMAN |

NOTE:

1. ALL TOLERANCES ARE ±.10 AND ±1° UNLESS OTHERWISE SPECIFIED
2. PARENTHESIS INDICATE STOCK DIMENSIONS



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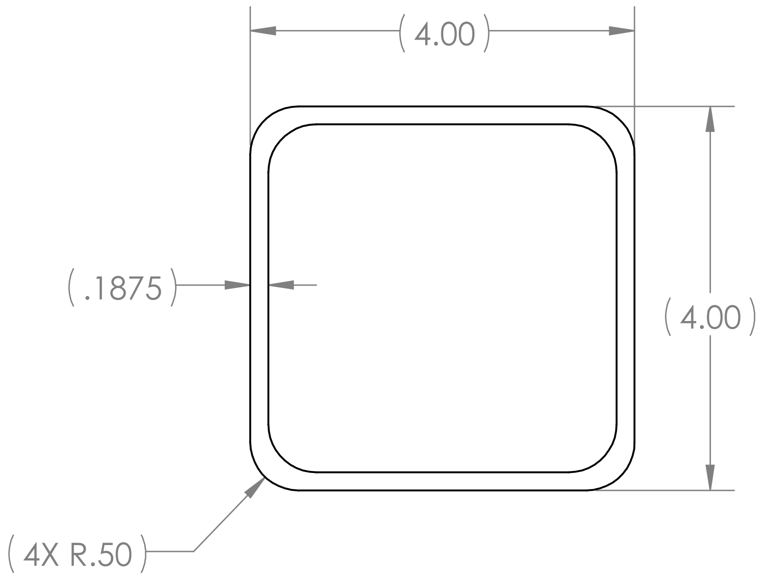
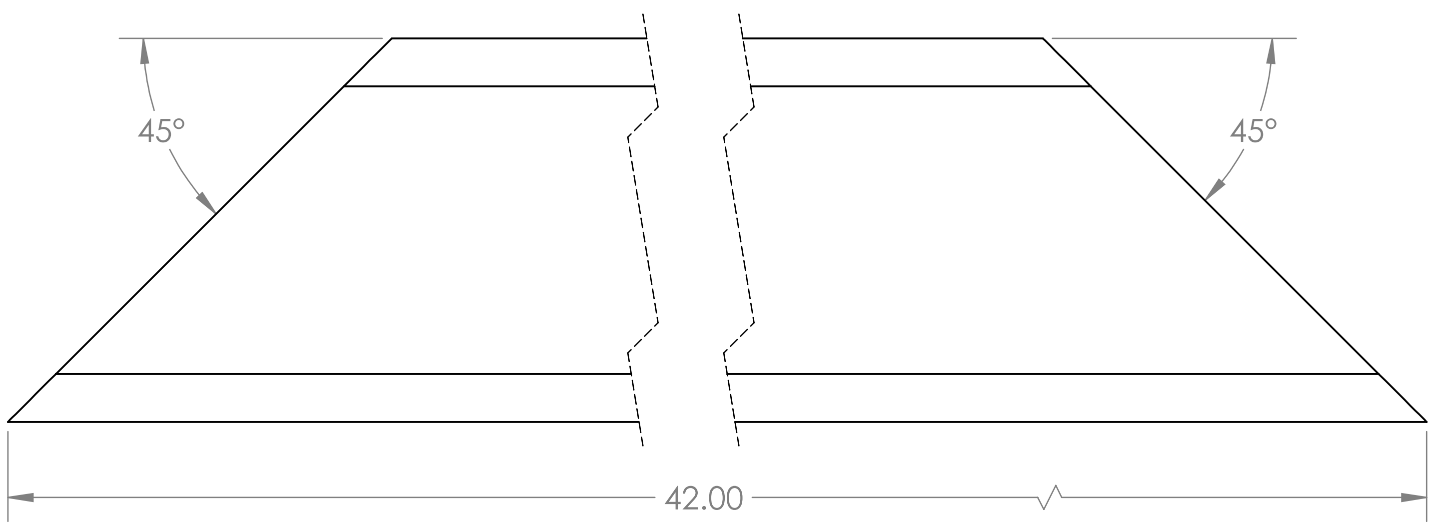


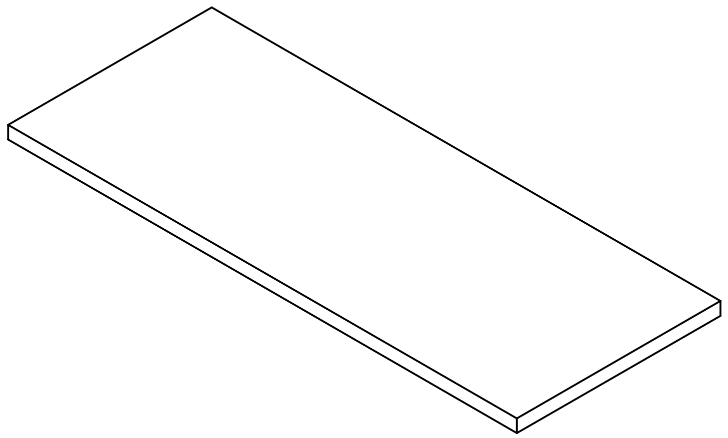






| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: STABILITY STRUT | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: AB07 | Date: 5/23/2017 | Scale: 1:2 | Advisor: EILEEN ROSSMAN |

NOTE:

1. ALL TOLERANCES ARE ±.10 AND ±1° UNLESS OTHERWISE SPECIFIED
2. PARENTHESIS INDICATE STOCK DIMENSIONS



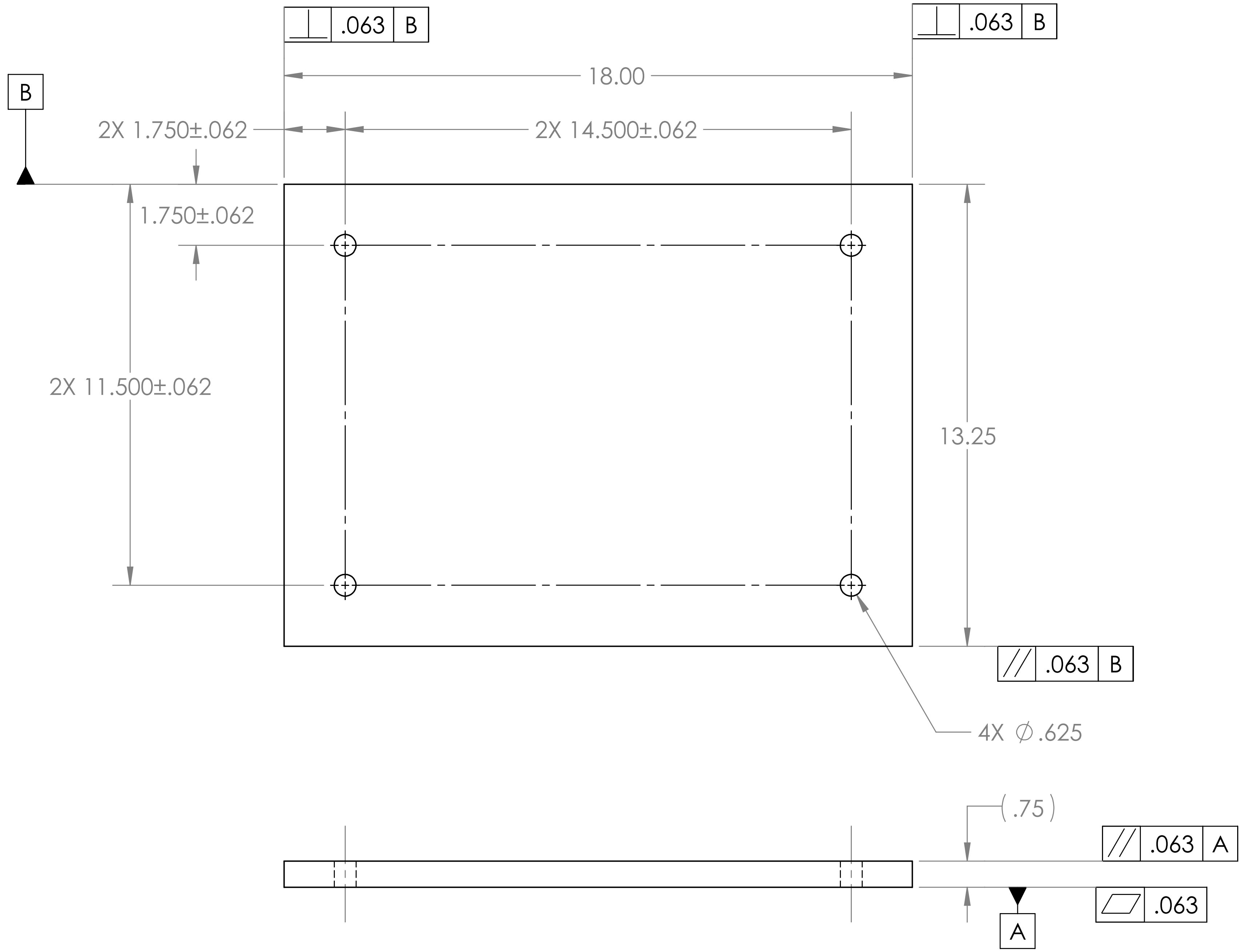
SCALE: 1:8

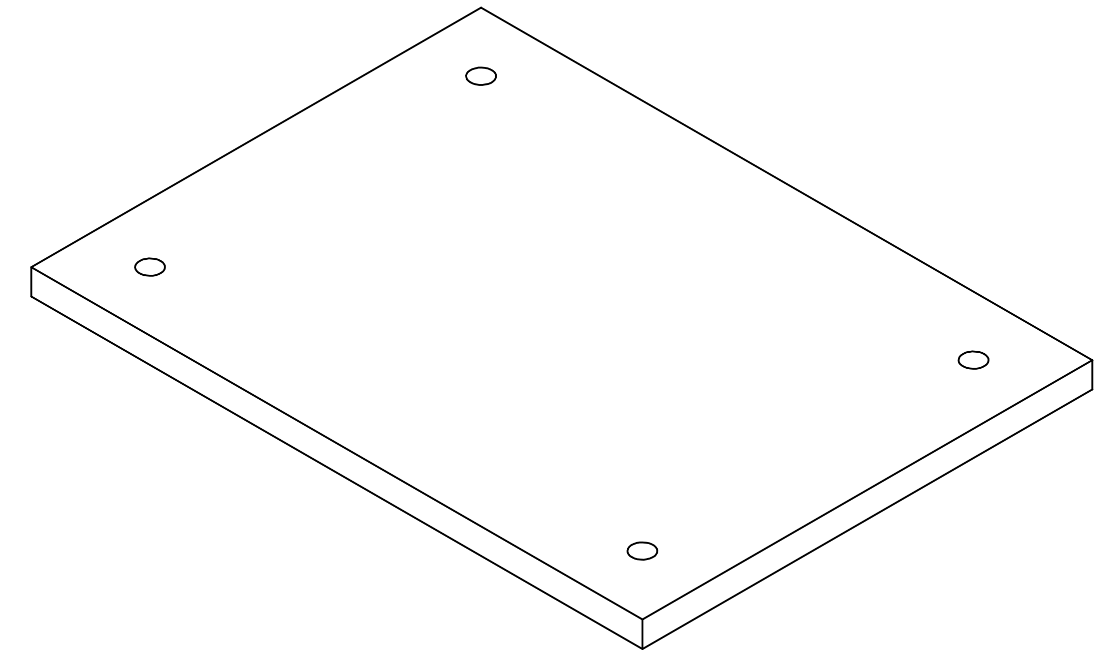



| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON SUPPORT | Title: SHORT FOOT | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: AB08 | Date: 5/23/2017 | Scale: 1:4 | Advisor: EILEEN ROSSMAN |

NOTE:

1. ALL TOLERANCES ARE ±.10 AND ±1° UNLESS OTHERWISE SPECIFIED
2. PARENTHESIS INDICATE STOCK DIMENSIONS
3. THIS PART IS USED IN AA00, AB00 AS WELL AS AC00



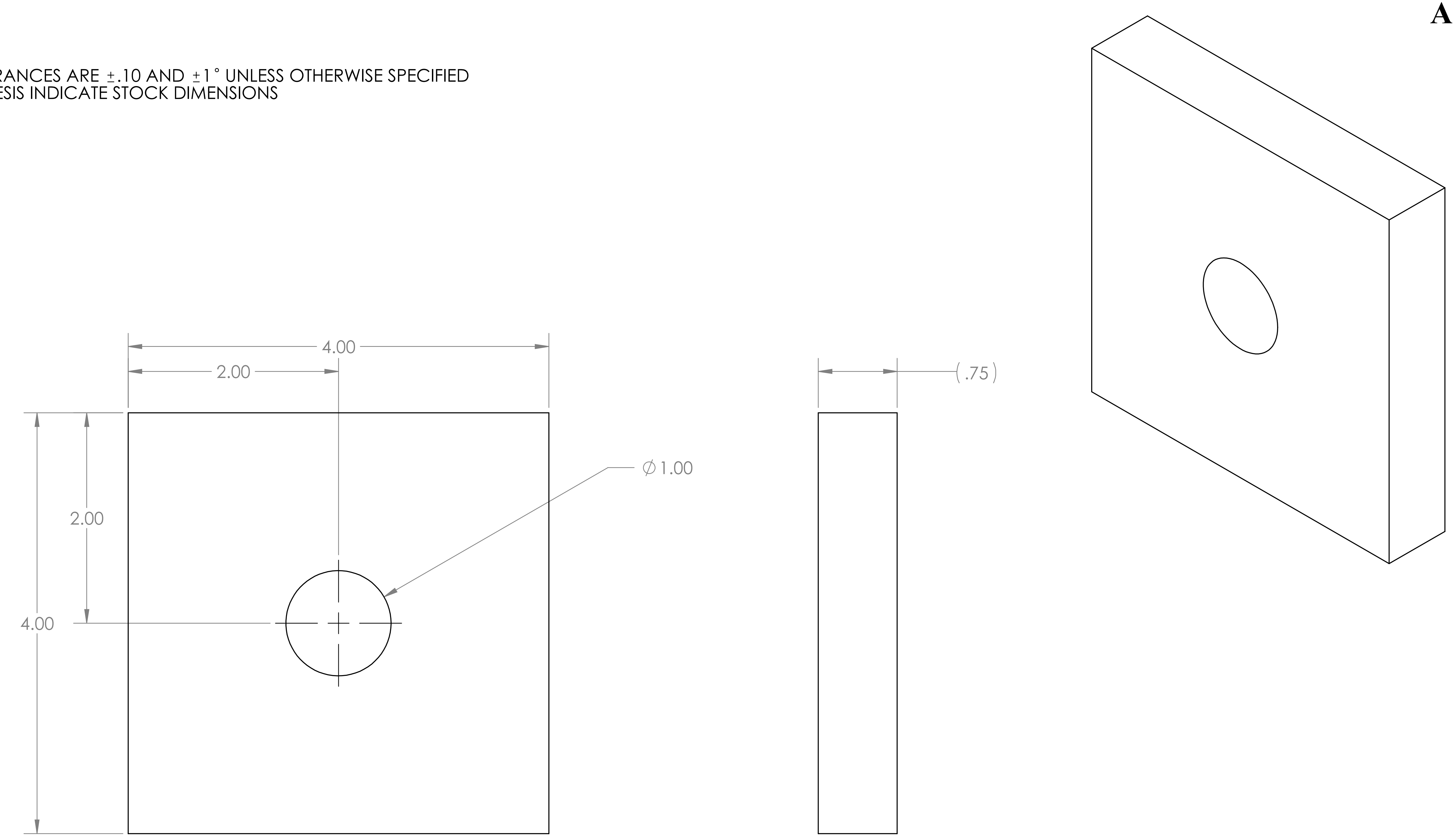





| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: SHIM, INTERFACE PLATE | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: AX01 | Date: 5/23/2017 | Scale: 1:4 | Advisor: EILEEN ROSSMAN |

NOTE:

1. ALL TOLERANCES ARE ±.10 AND ±1° UNLESS OTHERWISE SPECIFIED
2. PARENTHESIS INDICATE STOCK DIMENSIONS

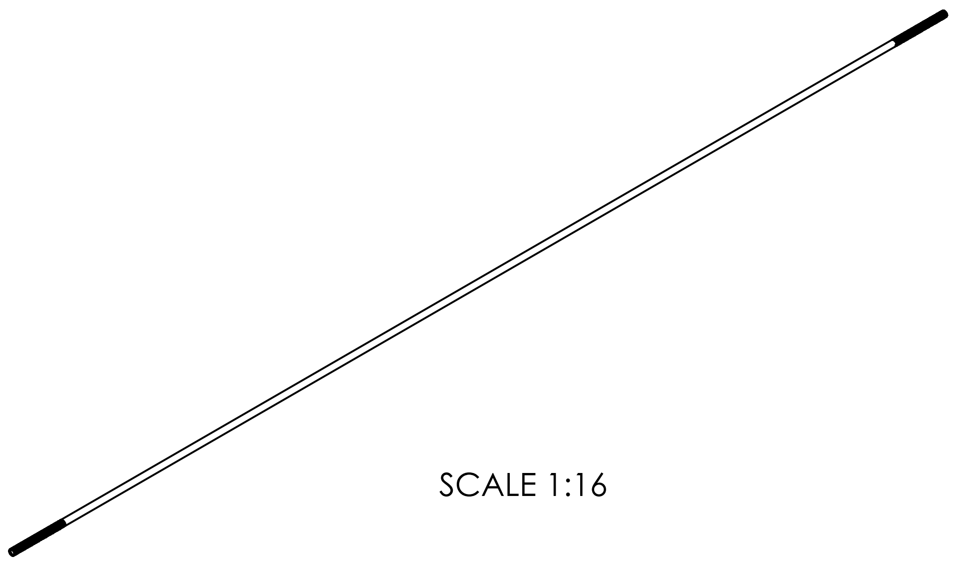





| | | | |
|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: TRAILER BACK PLATE | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: A006 | Date: 5/23/2017 · Scale: 1:1 | Advisor: EILEEN ROSSMAN |

NOTE:

1. ALL TOLERANCES ARE ±.10 AND ±1° UNLESS OTHERWISE SPECIFIED
2. PARENTHESIS INDICATE STOCK DIMENSIONS



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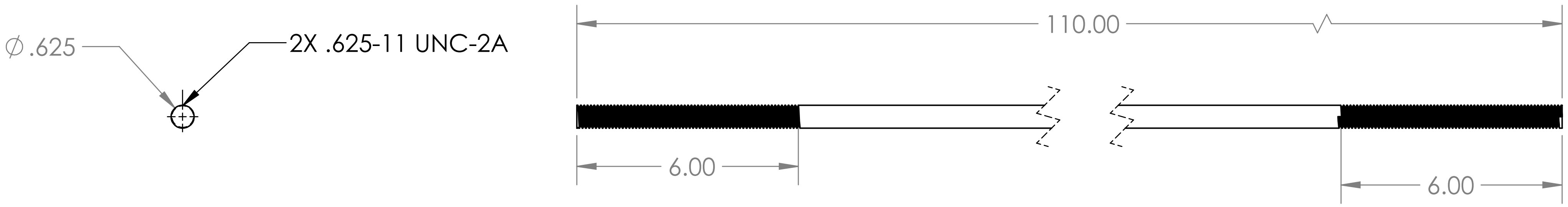


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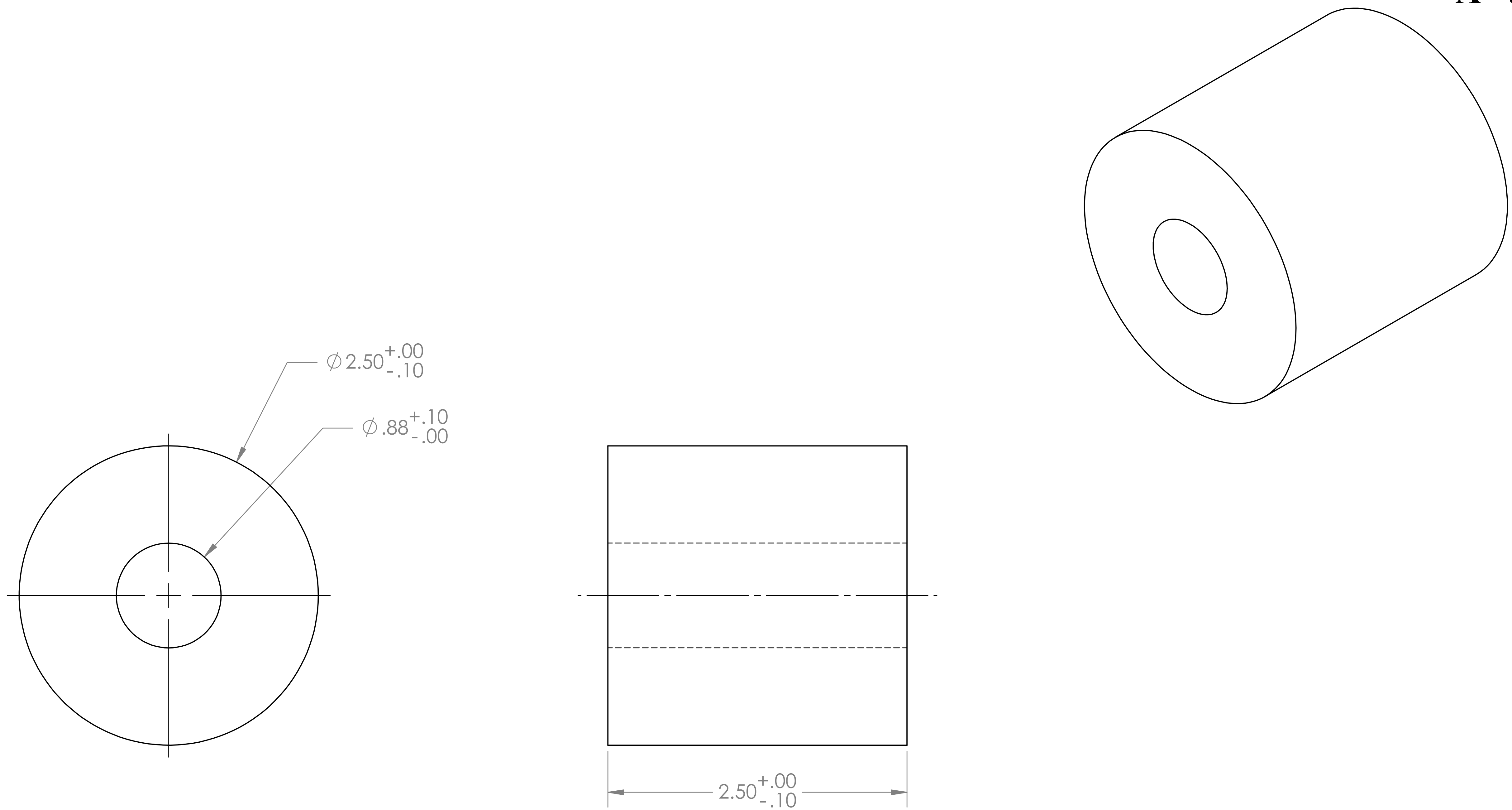
|---|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: STABILITY ROD | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: A007 | Date: 5/23/2017 | Scale: 1:4 | Advisor: EILEEN ROSSMAN |



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|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: TRAILER BUSHING | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: A008 | Date: 5/23/2017 | Scale: 1:1 | Advisor: EILEEN ROSSMAN |

# Appendix S: Failure Modes and Effects Analysis

| ? | | | | | | | | | Action Results |
|---|---|---|---|---|---|---|---|---|---|
| **Item / Function** | **Potential Failure Mode** | **Potential Effect(s) of Failure** | **Severity** | **Potential Cause(s) / Mechanism(s) of Failure** | **Occurence** | **Criticality** | **Recommended Action(s)** | **Responsibility & Target Completion Date** | **Actions Taken** |
| | Yield/Buckling | Break the submarine or the trailer | 8 | Wrong Material | 1 | 8 | Research Material Selection | Winter Quarter | Same material used on all components to avoid corrosion. |
| | | | 8 | Wrong Size | 3 | 24 | Load & Stress Analysis | Winter Quarter | Load & stress analysis performed and confirmed structural stability. |
| | | | 8 | Not Enough Material | 3 | 24 | Load & Stress Analysis | Winter Quarter | Excess material added to overdesign and prevent failure. |
| | | | 8 | Earthquake Overload | 1 | 8 | Design for 0.52g Earthquake | Winter Quarter | All calculations performed using 0.52g. |
| | | | 8 | Rust | 3 | 24 | Apply Protective Coating | Winter Quarter | Specify that all material should be coated in OSPHO, primed, and painted. |
| | | | 8 | Improper Mounting | 3 | 24 | Load & Stress Analysis | Winter Quarter | Load & stress analysis performed and confirmed structural stability. |
| | | | 8 | Stress Concentration | 4 | 32 | Load & Stress Analysis | Winter Quarter | Load & stress analysis performed and confirmed structural stability. |
| | | | 8 | Too many people in sub | 2 | 16 | Determine Limit | Winter Quarter | Additional 2,000lbs added in analysis to account for overload. |
| | | Death/Injury | 10 | Wrong Material | 1 | 10 | Research Material Selection | Winter Quarter | Same material used on all components to avoid corrosion. |
| | | | 10 | Wrong Size | 3 | 30 | Load & Stress Analysis | Winter Quarter | Load & stress analysis performed and confirmed structural stability. |
| | | | 10 | Not Enough Material | 3 | 30 | Load & Stress Analysis | Winter Quarter | Excess material added to overdesign and prevent failure. |
| | | | 10 | Earthquake Overload | 1 | 10 | Design for 0.52g Earthquake | Winter Quarter | All calculations performed using 0.52g. |
| | | | 10 | Rust | 3 | 30 | Apply Protective Coating | Winter Quarter | Specify that all material should be coated in OSPHO, primed, and painted. |
| | | | 10 | Improper Mounting | 3 | 30 | Load & Stress Analysis | Winter Quarter | Load & stress analysis performed and confirmed structural stability. |
| | | | 10 | Stress Concentration | 4 | 40 | Load & Stress Analysis | Winter Quarter | Load & stress analysis performed and confirmed structural stability. |
| | | | 10 | Too many people in sub | 2 | 20 | Determine Limit | Winter Quarter | Additional 2,000lbs added in analysis to account for overload. |
| | | Damage to Private Property | 5 | Wrong Material | 1 | 5 | Research Material Selection | Winter Quarter | Same material used on all components to avoid corrosion. |
| | | | 5 | Wrong Size | 3 | 15 | Load & Stress Analysis | Winter Quarter | Load & stress analysis performed and confirmed structural stability. |
| | | | 5 | Not Enough Material | 3 | 15 | Load & Stress Analysis | Winter Quarter | Excess material added to overdesign and prevent failure. |
| | | | 5 | Earthquake Overload | 1 | 5 | Design for 0.52g Earthquake | Winter Quarter | All calculations performed using 0.52g. |
| | | | 5 | Rust | 3 | 15 | Apply Protective Coating | Winter Quarter | Specify that all material should be coated in OSPHO, primed, and painted. |
| | | | 5 | Improper Mounting | 3 | 15 | Load & Stress Analysis | Winter Quarter | Load & stress analysis performed and confirmed structural stability. |
| | | | 5 | Stress Concentration | 4 | 20 | Load & Stress Analysis | Winter Quarter | Load & stress analysis performed and confirmed structural stability. |
| | | | 5 | Too many people in sub | 2 | 10 | Determine Limit | Winter Quarter | Additional 2,000lbs added in analysis to account for overload. |

# Appendix S: Failure Modes and Effects Analysis (Page 2)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Support Load | Corrosion | Weaken the structure and make it ugly | 3 | Disimiliar Metals | 1 | 3 | Research Material Selection | Winter Quarter | Same material used on all components to avoid corrosion. |
| | | | 3 | Uncoated Surfaces | 2 | 6 | Apply Protective Coating | Winter Quarter | Load & stress analysis performed and confirmed structural stability. |
| | | | 3 | Geometry | 3 | 9 | Avoid Flat Horiz. Surfaces & Crevices | Winter Quarter | We have attempted to reduce horiz. surfaces & crevices and will fill in w/caulking where unavoidable. |
| | Tipping | Damage to Military Property | 8 | Earthquake | 2 | 16 | Design for 0.52g Earthquake | Winter Quarter | All calculations performed using 0.52g. |
| | | | 8 | Wind | 3 | 24 | Design for Worst Case Scenario | Winter Quarter | Designed to withstand earthquake, which will be stronger than any wind. |
| | | | 8 | Accidental Impact | 2 | 16 | Barrier or Location Selection | Winter Quarter | Barriers will be reinstalled around perimeter. |
| | | | 8 | Improper Height Adjustment | 4 | 32 | Determine Max Height | Winter Quarter | Limited height adjustment to 1.' |
| | | Death/Injury | 10 | Earthquake | 2 | 20 | Design for 8.0 Earthquake | Winter Quarter | Designed to withstand lateral acceleration of 0.52g as used by USGS. |
| | | | 10 | Wind | 3 | 30 | Design for Worst Case Scenario | Winter Quarter | Designed to withstand earthquake, which will be stronger than any wind. |
| | | | 10 | Accidental Impact | 2 | 20 | Barrier or Location Selection | Winter Quarter | Barriers will be reinstalled around perimeter. |
| | | | 10 | Improper Height Adjustment | 4 | 40 | Determine Max Height | Winter Quarter | Limited height adjustment to 1.' |
| | | Damage to Private Property | 5 | Earthquake | 2 | 10 | Design for 0.52g Earthquake | Winter Quarter | All calculations performed using 0.52g. |
| | | | 5 | Wind | 3 | 15 | Design for Worst Case Scenario | Winter Quarter | Designed to withstand earthquake, which will be stronger than any wind. |
| | | | 5 | Accidental Impact | 2 | 10 | Barrier or Location Selection | Winter Quarter | Barriers will be reinstalled around perimeter. |
| | | | 5 | Improper Height Adjustment | 4 | 20 | Determine Max Height | Winter Quarter | Limited height adjustment to 1.' |
| | Dissassembled | Replacement Parts Required | 3 | Unbolted | 4 | 12 | Use Locking Fasteners | Winter Quarter | Design is extrememly heavy and diassembly is unlikely. |
| | | | 3 | Vandalism | 6 | 18 | Use Locking Fasteners | Winter Quarter | Design is extrememly heavy and diassembly is unlikely. |
| | Weld Failure | Damage to Military Property | 8 | Bad Welds | 3 | 24 | Follow AISC & AWS Codes | Winter Quarter | All welds specified to code. |
| | | | 8 | Improper Welds | 3 | 24 | Follow AISC & AWS Codes | Winter Quarter | All welds specified to code. |
| | | | 8 | Not Enough Welds | 5 | 40 | Follow AISC & AWS Codes | Winter Quarter | All welds specified to code. |
| | | Death/Injury | 10 | Bad Welds | 3 | 30 | Follow AISC & AWS Codes | Winter Quarter | All welds specified to code. |
| | | | 10 | Improper Welds | 3 | 30 | Follow AISC & AWS Codes | Winter Quarter | All welds specified to code. |
| | | | 10 | Not Enough Welds | 5 | 50 | Follow AISC & AWS Codes | Winter Quarter | All welds specified to code. |
| | | Damage to Private Property | 5 | Bad Welds | 3 | 15 | Follow AISC & AWS Codes | Winter Quarter | All welds specified to code. |
| | | | 5 | Improper Welds | 3 | 15 | Follow AISC & AWS Codes | Winter Quarter | All welds specified to code. |
| | | | 5 | Not Enough Welds | 5 | 25 | Follow AISC & AWS Codes | Winter Quarter | All welds specified to code. |

# Appendix S: Failure Modes and Effects Analysis (Page 3)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Trailer Failure | Damage to Military Property | 8 | Stress Concentration | 5 | 40 | Load & Stress Analysis | Winter Quarter | Load & stress analysis performed and confirmed structural stability. |
| | | | 8 | Weaken from cuts and welds | 2 | 16 | Load & Stress Analysis | Winter Quarter | Load & stress analysis performed and confirmed structural stability. |
| | | | 8 | Wrong Mounting Location | 3 | 24 | Load & Stress Analysis | Winter Quarter | Load & stress analysis performed and confirmed structural stability. |
| | | | 8 | Rust | 7 | 56 | Apply Protective Coating | Winter Quarter | Specify that all material should be coated in OSPHO, primed, and painted. |
| Adjust the Height | Shim Failure | Poor Aesthetics/Leveling | 3 | Friction/Shim Slippage | 1 | 3 | Properly Secure Shim | Winter Quarter | Shims will be held in compression and bolted. |
| | | | 3 | Improperly Secured | 2 | 6 | Use Locking Fasteners | Winter Quarter | Design is extrememly heavy and diassembly is unlikely. |
| | | | 3 | Flatness of Shims | 4 | 12 | GDT for Flatness | Winter Quarter | Tolerance of 1/8" applied. |
| | | | 3 | Shim Size | 3 | 9 | Review Design | Winter Quarter | The MBMM is okay with number of shims used. |
| | | Damage to Military Property | 8 | Friction/Shim Slippage | 1 | 8 | Properly Secure Shim | Winter Quarter | Shims will be held in compression and bolted. |
| | | | 8 | Improperly Secured | 2 | 16 | Use Locking Fasteners | Winter Quarter | Design is extrememly heavy and diassembly is unlikely. |
| | | | 8 | Flatness of Shims | 4 | 32 | GDT for Flatness | Winter Quarter | Tolerance of 1/8" applied. |
| | | | 8 | Shim Size | 3 | 24 | Review Design | Winter Quarter | The MBMM is okay with number of shims used. |
| | Easy-Up Failure | Structure Failure | 8 | Bolt Shear | 4 | 32 | Load & Stress Analysis | Winter Quarter | Load & stress analysis performed and confirmed structural stability. |
| | | | 8 | Weaken Material from Cuts | 4 | 32 | Load & Stress Analysis | Winter Quarter | Load & stress analysis performed and confirmed structural stability. |
| | Unable to adjust to desired height | Poor Aesthetics/Leveling | 3 | Improper Resolution | 5 | 15 | Vary Thickness of Shims | Winter Quarter | The MBMM has confirmed the use of 3/4" shims is acceptable |
| | | | 3 | Aesthetics | 4 | 12 | Get Sponsor's Opinion | Winter Quarter | The MBMM is pleased with the apperance. |
| | | | 3 | Structure Size | 4 | 12 | Limit Structure Size | Winter Quarter | Structure size was limited so as to maintain adjustment capabilities. |

## Appendix T: Analysis Plan

| ANALYSIS PLAN | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ANALYSIS PLAN | | | | | | ANALYSIS REPORT | | | | |
| | | | | | | Analysis RESULTS | | | | |
| Item No | Specification or Clause Reference | Description of Analysis | Acceptance Criteria | Analysis Responsibility | Analysis Stage | Analysis Result | Quantity Pass | Quantity Fail | NOTES |
| 1 | Load on Tires | Observation of design. | 0 lb | Alex | Completed | Load on tires = 0. | x | | |
| 2 | Weight of Structure | Addition of components based on weight per pound of steel, and length of steel used | 5,000 lb | Austin | Completed | 1,700 lb | x | | |
| 3 | Budget | Accounting based on reduced price of materials and reduced welding rate | Under $10,000 | Alex | Completed | Under $10,000 | x | | |
| 4 | Maintenance Period | Research of coating/painting method used as well as specific marine environment in Morro Bay | 1 year | Alex | Completed | Research indicates our maintenance period will be at least a year. | x | | |
| 5 | Visibility Impedance Height | Measurement in SolidWorks of final model | 90% of structure below 69" | Alex | Completed | Structure does not extend above top of trailer. | x | | |
| 6 | Structure Height Variance | Simulation in SolidWorks by varying height of structure | 4" | Octavio | Completed | 4 | x | | |
| 7 | Adjustment Resolution | Simulation in SolidWorks by adding shims to assembly in 3" increments | 3" | Octavio | Completed | 0.75 | x | | |
| 8 | Jacking Height Capability | Simulation in SolidWorks lifting trailer from point of jacking | Lift tires 4" off ground | Octavio | Completed | Santa Maria Tire has agreed to jack the structure up 1ft. | x | | |
| 9 | Structure Extrusion | Measurement in SolidWorks of final model | Less than 1' from existing tires | Octavio | Completed | 2.5-3' | | x | This was deemed necessary for seismic stability. |

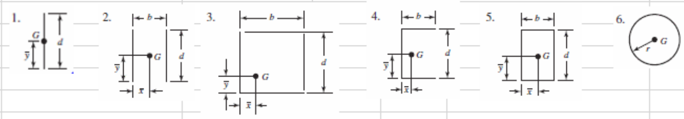
# Appendix T: Analysis Plan (Page 2)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 10 | Lateral Acceleration Tolerance | Statics/Dynamics calculations | 0.52g | Austin | Completed | All analysis performed using 0.52g as assumed load | x | | |
| 11 | Entry Clearance | Measurement in SolidWorks of final model | Increase by 1' | Alex | Completed | We will be able to increase the entry clearance by 1'. | x | | |
| 12 | Weight Load | Measurement in SolidWorks of final model | 32 tons | Octavio | Completed | The structure will be able to support entire weight. | x | | |
| 15 | Connection Box - Static | Check for stresses and deflections. | F.S. > 5 | Austin | Completed | F.S. = 55.4<br>delta <0.001in | x | | |
| 16 | Connection Box - Seismic | Check for stresses | F.S. > 1 | Austin | Completed | F.S. = 3.6 | x | | |
| 17 | H-Beam - Static | Check for stresses and deflections. | F.S. > 5 | Austin | Completed | F.S. = 7.0<br>delta < 0.02 in | x | | |
| 19 | H-Beam - Seismic | Check for stresses | F.S. > 1 | Austin | Completed | F.S = 1.45 | x | | |
| 20 | Column - Static | Check for stresses | F.S. > 5 | Austin | Completed | F.S.= 8.6 | x | | |
| 21 | Column - Seismic | Check for stresses | F.S. > 1 | Austin | Completed | F.S. = 1.07 | x | | |

**Appendix U:** Welding Analysis Spreadsheet

F16 | =0.707*length*((2*b)+d)

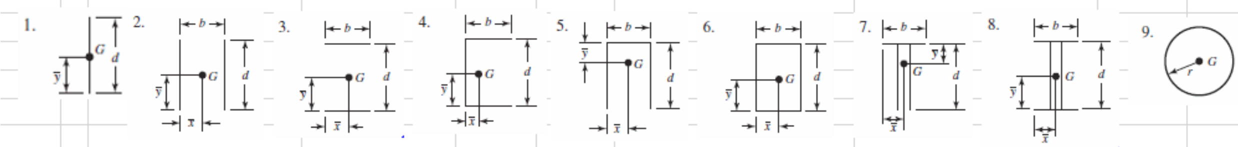
| | | |
|---|---|---|
| Load = | 8000 | [lbs] |
| Plate Thickness = | 0.75 | [in] |
| Fillet Weld Size = | 0.5625 | [in] |
| Throat Length, h = | 0.375 | [in] |
| Horiz. Side, b = | 6 | [in] |
| Vertical Side, d = | 6 | [in] |
| radius, r = | 4 | [in] |
| $\Sigma A_{throat}$ = | 4.772 | [in$^2$] |
| Moment = | | [lbs*in] |
| Primary Shear, τ = | 1257.3 | [lbs/in$^2$] |
| Secondary Shear, τ' = | | [lbs/in$^2$] |



**Stresses in Fillet Welded Joints in Torsion**

| Weld Type | Throat Area [in$^2$] | Location of G: X bar | Location of G: Y bar | Unit Second Polar Moment of Area [in$^3$] | Second Polar Moment of Area [in$^4$] |
|---|---|---|---|---|---|
| 1 | 1.59075 | 0.00 | 3.00 | 18.000 | 4.772 |
| 2 | 3.1815 | 3.00 | 3.00 | 144.000 | 38.178 |
| 3 | 3.1815 | 1.50 | 1.50 | 90.000 | 23.861 |
| 4 | 4.772 | 2.00 | 3.00 | 198.000 | 52.495 |
| 5 | 6.363 | 3.00 | 3.00 | 288.000 | 76.356 |
| 6 | 6.663 | n/a | n/a | 402.124 | 106.613 |

=1.414*PI()*length*radius



in$^2$]
lbs*in]
lbs/in$^2$]
lbs/in$^2$]

**Stresses in Fillet Welded Joints in Bending**

| Weld Type | Throat Area [in$^2$] | Location of G: X bar | Location of G: Y bar | Unit Second Polar Moment of Area [in$^3$] | Second Polar Moment of Area [in$^4$] |
|---|---|---|---|---|---|
| 1 | 1.59075 | 0.00 | 3.00 | 18.000 | 4.772 |
| 2 | 3.1815 | 3.00 | 3.00 | 36.000 | 9.545 |
| 3 | 3.1815 | 3.000 | 3.000 | 108.000 | 28.634 |
| 4 | 4.772 | 2.000 | 3.000 | 126.000 | 33.406 |
| 5 | 4.77225 | 3.000 | 2.000 | 72.000 | 19.089 |
| 6 | 6.363 | 3.000 | 3.000 | 144.000 | 38.178 |
| 7 | 4.77225 | 3.000 | 2.000 | 72.000 | 19.089 |
| 8 | 6.363 | 3.000 | 3.000 | 144.000 | 38.178 |
| 9 | 6.663 | n/a | n/a | 201.062 | 53.307 |

**Appendix U:** Welding Analysis Spreadsheet

| | | |
|---|---|---|
| Fillet Size = | 0.5625 | [in] |
| Density, A500 Steel = | 0.284 | [lbs/in$^3$] |
| Leg = | 0.397748 | [in] |
| $A_{fillet}$ = | 0.079102 | [in$^2$] |
| WM = | 0.008424 | [lbs] |
| FCAW at | 325 | amps: |
| Deposition Rate = | 9.5 | [lbs/hr] |
| Arc time = | 0.000887 | [hr] |
| Operator Factor = | 40 | % |
| Total Man Hours : | 0.02 | [hr] |
| | 1.3 | [min] |

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Book No.

SUBJECT DIMENSIONAL TOLERANCE OF WELDED STRUCTURAL MEMBERS Cont. From Pg.

S. O. AWS D1.1 CONTRACT OTHER GOVT. CLASSIF.

5.23.1 Straightness of Columns and Trusses

Length < 30 ft : $\frac{1}{8} \times \frac{\text{total length (ft)}}{10}$

---

AWS D1.1

73) TABLE 3.7 : Maximum ELECTRODE DIAMETER FOR :

POSITION : FLAT

WELD TYPE : FILLET

SMAW - 5/16 in.

.71) TABLE 3.4 :

| BASE METAL THICKNESS | MINIMUM WELD SIZE |
|---|---|
| OVER 1/4" TO 1/2" | 3/16" |
| OVER 1/2" TO 3/4" | 1/4" |

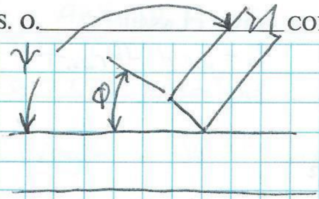
RECORDED BY DATE

WITNESSED & UNDERSTOOD DATE CONTINUED

60 Book No.

SUBJECT AWS D.1.1 4" tubing, thickness = 3/16 Cont. From Pg.

S. O. CONTRACT 1/8 1/4 6" tubing, 1/2 in. thickness OTHER GOVT. CLASSIF.



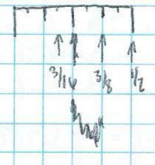



Table 3.4 MIN. Pre-Qual. PJP Weld Size (see 3.12.2

* based on the thicker metal

For 3/16" thick 4x4 tubing; joined to 1/2" 6x6 tubing: 3/16" min weld size

Table 3.4: T = 1/2" ; minimum prequalified PJP weld size (E): 1/4" min weld size

For 1/2" (4x4 or 6x6 tubing); joined to 3/4" plate: 1/4" min weld size

FOR BOT For 3/16" thick 4"x4" tubing; joined to 6x6x 1/2 : 3/16" min weld size

For 6x6x 1/2" to 3/4" plate: 1/4" min weld size

RECORDED BY DATE

WITNESSED & UNDERSTOOD DATE CONTINUED

WITNESSED & UNDERSTOOD DATE ON PG.

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Book No.______

SUBJECT STRESS IN WELDED JOINTS (TORSION) Cont. From Pg.____

S. O.____ CONTRACT____ OTHER____ GOVT. CLASSIF.____

½" Thick I-beam to 6" x 6" x ½" SQ. TUBING : CHORD (TOP)

TOTAL LOAD = 16,000 lbs
LOAD PER CHORD = 8,000 lbs

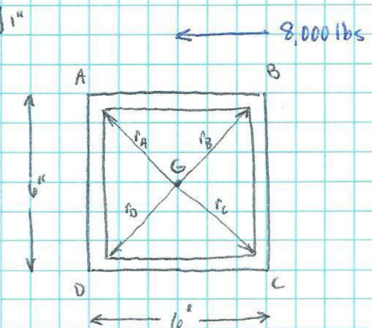
MIN Fillet weld size : $S = 0.75t$ (t of thinner material)
$S = 0.75(0.5 \text{ in})$
$S = 0.375 \text{ in} = 3/8"$

= weld throat
= length of weld

hroat Area, $A = 6.363 \text{ in.}^2$

rimary shear $\tau' = \frac{V}{A} \Rightarrow \tau' = \frac{8000 \text{ lbs}}{6.363 \text{ in.}^2} = 1257.3 \text{ psi}$

ale: 1" x 1"




$\bar{X} = 3.0 \text{ in.}$
$\bar{Y} = 3.0 \text{ in.}$
$r_A = r_B = r_C = r_D = \sqrt{(3 \text{ in})^2 + (3 \text{ in.})^2} = 3\sqrt{2} \text{ in} \approx 4.243 \text{ in.}$

Unit 2nd Polar moment of area, $J_u = \frac{(b+d)^3}{2}$

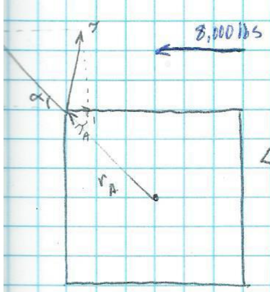
$J_u = 288.0 \text{ in.}^3$

throat width of fillet, $0.707h = 0.707(0.375 \text{ in.}) = 0.265 \text{ in.}$

Second Polar Moment of Area, $J = 0.707h \, J_u$
$J = 76.356 \text{ in.}^4$

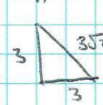
$M = 8{,}000 \text{ lbs}(2 \text{ in.} + 3\sqrt{2} \text{ in.}) = 49{,}941 \text{ lb-in.}$

Secondary Shear stress, $\tau'' = \frac{Mr}{J}$




$\tau_A'' = \tau_B'' = \frac{(49{,}941 \text{ lb-in.})(3\sqrt{2} \text{ in.})}{76.356 \text{ in.}^4} = 2774.92 \text{ psi}$ (same for $\tau_C''$ & $\tau_D''$)

∠ $\tau_A''$ makes with the vertical = ∠ $r_A$ makes with the horizontal




$\therefore \alpha = 45°$

$\tau = \sqrt{\left[(1257.3 \tfrac{\text{lb}}{\text{in}^2}) - (2774.9 \tfrac{\text{lb}}{\text{in}^2})\cos(45)\right]^2 + \left[(2774.9 \tfrac{\text{lb}}{\text{in}^2})\sin(45)\right]^2} =$

$\tau = \sqrt{(-704.85)^2 + (1962.15)^2}$

RECORDED BY____ DATE____

WITNESSED & UNDERSTOOD $\tau = 2084.9 \text{ psi}$ DATE____ CONTINUED

WITNESSED & UNDERSTOOD____ DATE____ ON PG.____

Book No.______

SUBJECT: STRESS IN WELDED JOINTS (TORSION) Cont. From Pg.____

S. O.______ CONTRACT______ OTHER______ GOVT. CLASSIF.______

CHORD (BOTTOM): $s = 0.375$ in. ($3/8''$ fillet)

$\tau' = 1257.3$ psi

$J = 76.356$ in.$^4$

$M = 8{,}000 \text{ lbs} (60 + 3\sqrt{2}) \text{ in} = 513{,}941$ lb-in.

$$\tau'' = \frac{Mr}{J} = \frac{(513{,}941 \text{ lb-in.})(3\sqrt{2} \text{ in.})}{76.356 \text{ in.}^4} = 28{,}557 \text{ psi}$$

$$\tau = \sqrt{\left[1257.3 \tfrac{\text{lb}}{\text{in}^2} - 28{,}557 \cos(45)\right]^2 + \left[28{,}557 \sin(45)\right]^2}$$

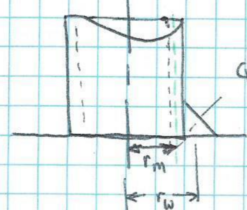
**$\tau = 27{,}682$ psi**

BRANCH LOAD AND RESISTANCE FACTOR DESIGN (LRFD) 2.24.3

$t_b$ = thickness of branch member

$t_w$ = effective throat of the weld

$f_a$ = nominal axial stress in the branch




For: $4'' \times 4'' \times 3/16''$

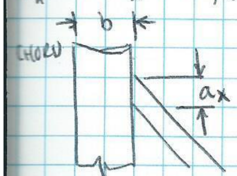
$r_m = 2 \text{ in} - \left(\tfrac{3}{16}/2\right) = \tfrac{61}{32}$

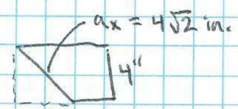
$r_w = 2 \text{ in} + \left(\tfrac{3/8 \text{ in} \cos(45)}{2}\right)$

2.

FROM 2.24.5.2 (Y connection)

$K_a$ $2a_x + b$, for $\theta \leq 45°$




$f_a = \frac{8000 \text{ lbs}}{3 \text{ branches}} = 2667$ lbs

$$f_{a_{weld}} = \frac{t_b}{t_w}\left(\frac{f_a}{K_a}\left(\frac{r_m}{r_w}\right)\right)$$

$$f_{a_{weld}} = \frac{3/16 \text{ in}}{0.707(3/8 \text{ in.})}\left(\frac{2667 \text{ lbs}}{2(4\sqrt{2} \text{ in.}) + 4 \text{ in.}}\right)\left(\frac{61/32 \text{ in}}{2.133 \text{ in}}\right) = (0.7072)(174.16)(0.8937) \text{ psi}$$

**$f_{a_{weld}} = 110$ psi**

RECORDED BY______ DATE______

WITNESSED & UNDERSTOOD______ DATE______ CONTINUED

WITNESSED & UNDERSTOOD______ DATE______ ON PG.______

**Appendix U:** Welding Analysis Spreadsheet

Book No.

JECT LRFD (strength of weld) Cont. From Pg.

CONTRACT OTHER GOVT. CLASSIF.

$P_u = Q_w \cdot L_{eff}$

weld line load capacity ($\frac{kips}{in.}$), $Q_w = 0.6 t_w F_{Exx}$ with $\Phi = 0.8$

$F_{Exx}$ = min tensile strength of weld deposit

weld effective length, $L_{eff}$

$Q_w = 0.6 t_w F_{Exx}$ where E70XX has tensile strength = 70 kpsi

$Q_w = 0.6(0.707(3/8 \text{ in.})(70{,}000 \frac{lbs}{in.^2}) = 11{,}135 \frac{lb}{in.}$

$P_u = Q_w \cdot L_{eff} = (11{,}135.25 \frac{lb}{in.})(24 \text{ in.}) =$ **267,246 lbs** FOR A TOTAL OF 24 in. of weld

**$P_u$ = 66812 lbs per 6 in. weld**

RECORDED BY DATE

WITNESSED & UNDERSTOOD DATE CONTINUED

WITNESSED & UNDERSTOOD DATE ON PG.

**Appendix U:** Welding Analysis Spreadsheet

Book No.

SUBJECT STRENGTH OF WELD (STATIC LOADING) Cont. From Pg.

S. O. CONTRACT OTHER GOVT. CLASSIF.

Table 9-4 (Shigley p. 483) : $h = 3/8''$, $EXX = 70$ : $5.57 \frac{kip}{in.}$

$F = 5.57 \frac{kip}{in.}(6\ in.) = 33.42\ kip$ $kip = 1000\ lbf$

$F = 33420\ lbf$ per every 6 in.

$\tau_{all} = 0.4\ S_y$ where $S_y$ of A500 steel $= 46{,}000\ psi$

$\tau_{all} = 0.4(46{,}000\ psi) = 18{,}400\ psi$

shear stress on base metal adjacent to weld : $\tau = \frac{F}{2hl}$

$\tau = \frac{8000\ lb}{2(3/8\ in.)(6\ in.)} = 1778\ psi$

satisfactory if $\tau_{all} \geq \tau$ ✓

~~Tensile stress in the shank~~

Total Weld Strength $= (33{,}420\ lbf)(24\ in.) = 133{,}680\ lbf$

(in psi) : $\frac{133{,}680\ lbf}{(3/8\ in)(24\ in.)} = 14{,}853\ psi$

RECORDED BY DATE

WITNESSED & UNDERSTOOD DATE CONTINUED

WITNESSED & UNDERSTOOD DATE ON PG.

**Appendix U:** Welding Analysis Spreadsheet

Book No.

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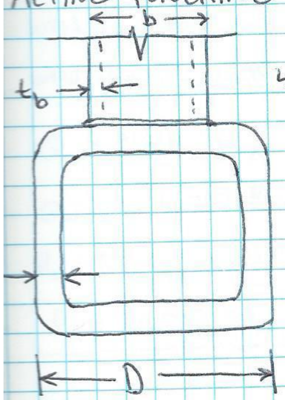
SUBJECT PUNCHING SHEAR STRESS Cont. From Pg.

S. O. CONTRACT OTHER GOVT. CLASSIF.

AWS D1.1 2.25.1.1

ACTING PUNCHING SHEAR STRESS GIVEN BY : $V_p = \tau f_n \sin\theta$




4" x 4" x 3/16"

6" x 6" x 1/2"

$\tau = \frac{t_b}{t_c} = \frac{3/16''}{1/2''} \Rightarrow \tau = 3/8$

$\theta = 45°$

$f_n = \frac{P}{A}$ P = 8,000 lbs for conservative analysis

$\beta = \frac{b}{D} = \frac{4 in}{6 in.} \Rightarrow \beta = 2/3$

FOR $\beta > 0.6$ ; $Q_\beta = \frac{0.3}{\beta(1-0.833\beta)}$

$Q_\beta = \frac{0.3}{2/3(1-0.833(2/3))} = 1.01$

FOR AXIAL LOAD, $Q_q = \left(\frac{1.7}{\alpha} + \frac{0.18}{\beta}\right) Q_\beta^{0.7(\alpha-1)}$

where $\alpha = 1.7$ for axial load in T and Y connections

$Q_q = \left(\frac{1.7}{1.7} + \frac{0.18}{2/3}\right)(1.01)^{0.7(1.7-1)} = (1+0.27)(1.01)^{0.49}$

$Q_q = 1.124$

$\bar{U}^2 = \left(\frac{f_a}{0.6F_{yo}}\right)^2 = \left(\frac{110\ psi}{0.6(46{,}000\ psi)}\right)^2 = 15.88 \times 10^{-6}$

$Q_f = 1.0 - \lambda\gamma\bar{U}^2$ where $\lambda = 0.030$ for axial load in branch member and $\gamma = \frac{D}{2t_c} = 6$

$Q_f = 1.0 - (0.030)(6)(15.88 \times 10^{-6})^2 = 0.9\bar{9} \approx 1$

ALLOWABLE PUNCHING SHEAR STRESS, $V_{p_{all}} = Q_q \cdot Q_f \cdot \frac{F_{yo}}{0.6\gamma}$

$V_{p_{all}} = (1.124)(1)\frac{46{,}000\ psi}{0.6(6)} = 14{,}362.2\ psi$

$\boxed{V_{p_{all}} = 14{,}362\ psi}$

CROSS-SEC. AREA OF 4" x 4" x 3/16" TUBE , $A = 2.86\ in.^2$

$V_p = \tau f_n \sin\theta = 3/8\left(\frac{8{,}000\ lb}{2.86\ in^2}\right)\sin(45)$

$\boxed{V_p = 741.7\ psi}$

RECORDED BY DATE

WITNESSED & UNDERSTOOD DATE CONTINUED

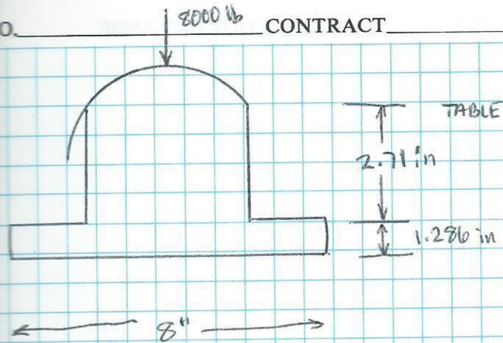
WITNESSED & UNDERSTOOD DATE ON PG.

**Appendix U:** Welding Analysis Spreadsheet

Book No.______ 67

SUBJECT PUCK WELD CALCULATIONS Cont. From Pg.______

S. O.______ CONTRACT______ OTHER______ GOVT. CLASSIF.______




FOR TWO PARALLEL 2.71 in. WELDS

TABLE 9-6: 5/16" FILLET WELD USING E70XX, ALLOWABLE UNIT (0.3125 in.) FORCE PER UNIT LENGTH = 4.64 $\frac{kip}{linear\ in.}$

1 kip = 1000 $lb_f$

$F = (4.64 \frac{kip}{in.})(5.42\ in.) = 25.149\ kip$

SINCE 25,100 $lb_f$ > 8,000 $lb_f$, weld metal strength is satisfactory

A500 $S_y = 46,000$ psi $S_{ut} = 62,000$ psi

STRESSES PERMITTED BY THE AISC CODE FOR WELD METAL: TABLE 9-4

FOR SHEAR LOADING OF A FILLET WELD: $0.30 S_{ut}$ : $0.30(62,000\ psi) = 18,600\ psi$

$0.40 S_y$ : $0.40(46,000\ psi) = 18,400\ psi$

THE ALLOWABLE ATTACHMENT SHEAR STRESS IS $\tau_{all} = 18,400$ psi

THE SHEAR STRESS, $\tau$, ON THE BASE METAL ADJACENT TO THE WELD IS $\tau = \frac{P}{2hl}$

$$\tau = \frac{8000\ lb}{2(0.3125\ in.)(5.42\ in.)} = 2361.6\ psi$$

$\tau = 2,362$ psi

SINCE $\tau_{all} \geq \tau$, THE BASE METAL ATTACHMENT ADJACENT TO THE WELD BEADS IS SATISFACTORY.

STRESSES PERMITTED BY THE AISC CODE FOR WELD METAL: TABLE 9-4

TENSION: $0.60 S_y$

SIMPLE COMPRESSION: $0.60 S_y$

THE ALLOWABLE STRESS FOR TENSION AND SIMPLE COMPRESSION IS $0.60(46,000\ psi) = 27,600\ psi$

$\sigma_{all} = 27,600$ psi

$$\sigma = \frac{P}{tl} \Rightarrow \sigma = \frac{8000\ lb}{(2.25\ in.)(5.42\ in.)} = 656\ psi$$

$\sigma = 656$ psi

SINCE $\sigma \leq \sigma_{all}$, THE TENSILE STRESS IS SATISFACTORY.

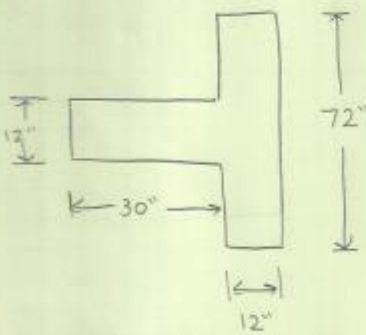
RECORDED BY______ DATE______

WITNESSED & UNDERSTOOD______ DATE______ CONTINUED

WITNESSED & UNDERSTOOD______ DATE______ ON PG.______

**Appendix V: Analysis of Steel Plate Interfacing with Ground**

Check Stress induced on asphalt by steel plate:




$A = (12")(30") + (12")(72")$

$A = 1224 in^2$

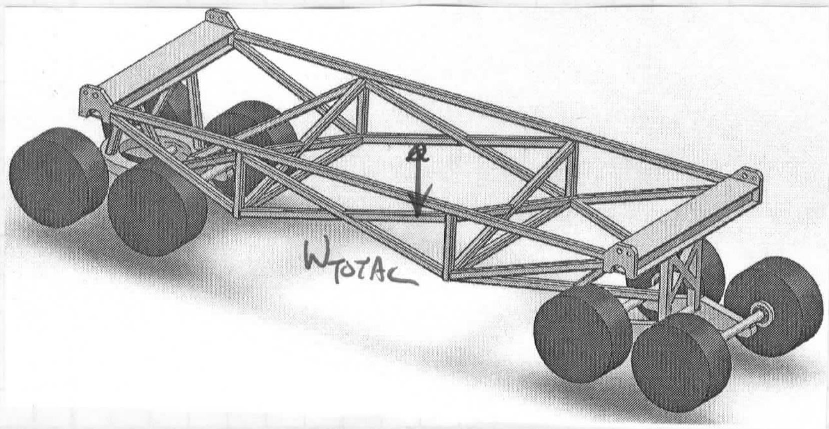
From previous earthquake calculations, each support will see 58,753.8 lbf. This means that each leg of the sawhorse will see 29376.9 lbf.

$$\sigma = \frac{F}{A} = \frac{29376.9 lbf}{1224 in^2}$$

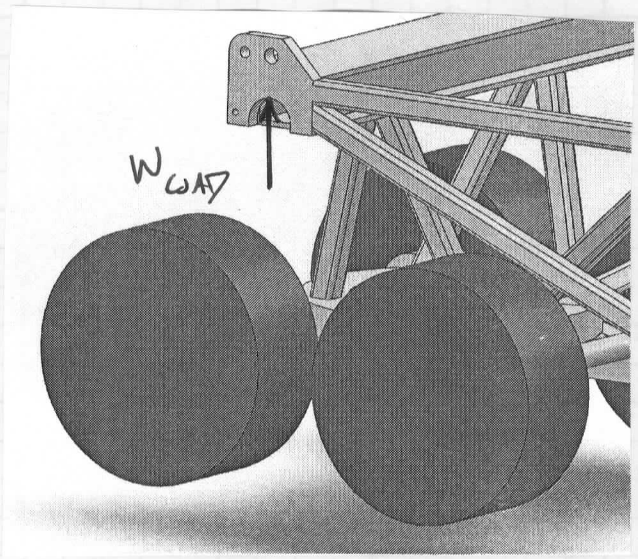
$\sigma = 24$ psi per plate

∴ The asphalt will not be compressed/damaged

# Appendix W: Analysis of Connection Box




ASSUME: CENTER OF GRAVITY IS EQUIDISTANT TO ALL TRAILER PLATES

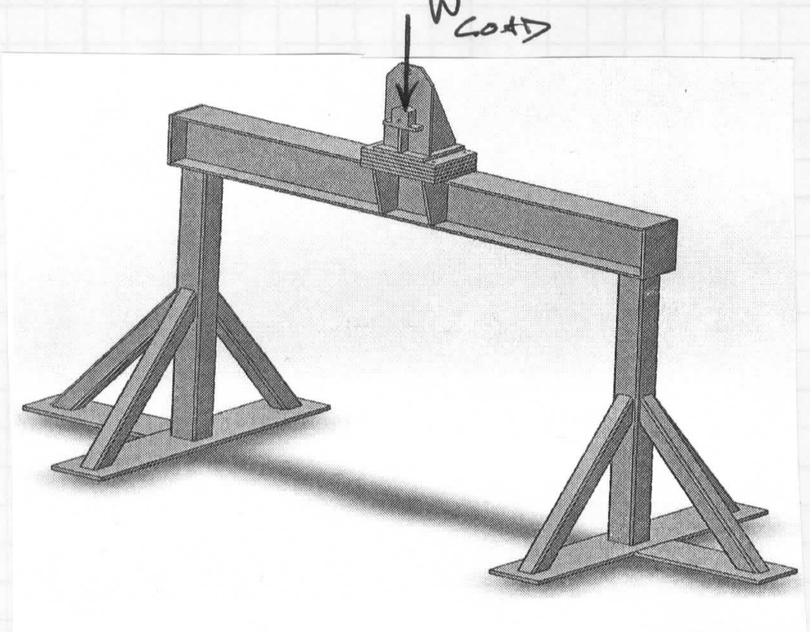



$$W_{LOAD} = \frac{1}{4} W_{TOTAL}$$

ASSUME: TRAILER IS RIGID AND STIFF ENOUGH TO PREVENT TRANSFERING MOMENT.

# STATIC ANALYSIS

LOAD TRANSFER TO STRUCTURE:




VERIFICATION OF LOW BENDING MOMENT THROUGH CONNECTION BOX:

SIMPLIFIED VON MISES STRESS THROUGH BOX AT LOCATION OF MAXIMUM BENDING MOMENT BEFORE HITTING H-BEAM:

Report coordinate values relative to: -- default --

Measurements are based on sectioned model
Section properties of the selected faces of A000

Area = 43.10 inches^2

Centroid relative to assembly origin: ( inches )
X = -4.52
Y = 12.60
Z = 0.00

Moments of inertia of the area, at the centroid: ( inches ^ 4 )

| | | |
|---|---|---|
| Lxx = 1835.12 | Lxy = 0.00 | Lxz = 0.00 |
| Lyx = 0.00 | Lyy = 782.71 | Lyz = 0.00 |
| Lzx = 0.00 | Lzy = 0.00 | Lzz = 1052.40 |

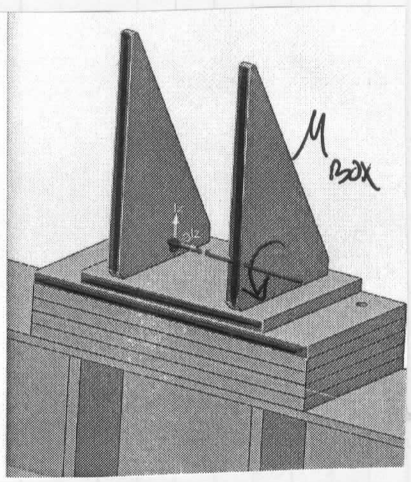
Polar moment of inertia of the area, at the centroid = 1835.12 inches ^ 4

Angle between principal axes and assembly coordinate axes = 0.00 degrees

Principal moments of inertia of the area, at the centroid: ( inches ^ 4 )
Ix = 782.71
Iy = 1052.40

Moments of inertia of the area, at the output coordinate system: ( inches ^ 4 )

| | | |
|---|---|---|
| LXX = 8675.29 | LXY = -2454.06 | LXZ = 0.00 |
| LYX = -2454.06 | LYY = 1663.16 | LYZ = 0.00 |
| LZX = 0.00 | LZY = 0.00 | LZZ = 8773.03 |




$$M_{BOX} = F_{LOAD} \cdot D_e$$

$D_e$ = ECCENTRIC LOADING DISTANCE

$$\sigma_{BOX} = \frac{M_{BOX} Y_{BOX}}{I_{BOX}}$$

FROM PICTURE: $I = 1052.4 \text{ in}^4$

GEOMETRICALLY DETERMINED VALUES:

$Y_{BOX} = 10 \text{ in}$

$I_{BOX} = 1052 \text{ in}^4$

$P_e = 2.0 \text{ in}$

APPLYING THESE VALUES ...

$\sigma_{BOX} = 295 \text{ PSI}$

$\tau = \frac{VQ}{It}$ -- TO MAKE A SIMPLIFYING AND CONSERVATIVE ASSUMPTION.

$\tau_{MAX} = 1.5 \frac{V}{A}$

$V = W_{LOAD} = 15,500 \text{ lb}_f$

$A = 43.10 \text{ in}^2$

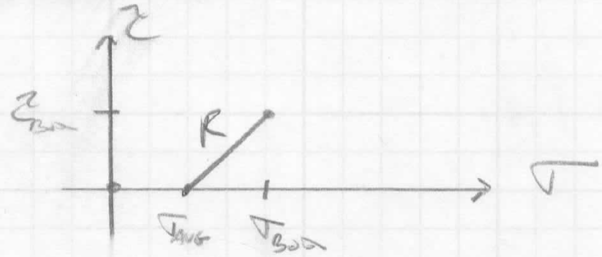
$\tau_{MAX} = 1.5 \frac{(15,500 \text{ lb}_f)}{43.10 \text{ in}^2}$

$\tau_{MAX} = 539 \text{ PSI}$

STATIC LOADING

4

APPLY MOHRS CIRCLE FOR YIELD CRITERIA:




FROM THEORY: $R = \tau_{max}$

$$\sigma_{AVG} = \sigma_{Box}/2$$

$$R = \sqrt{\left(\sigma_{Box} - \frac{\sigma_{Box}}{2}\right)^2 + \tau_{Box}^2}$$

$$\tau_{max} \cong \frac{1}{2}\sigma_{UTS}$$

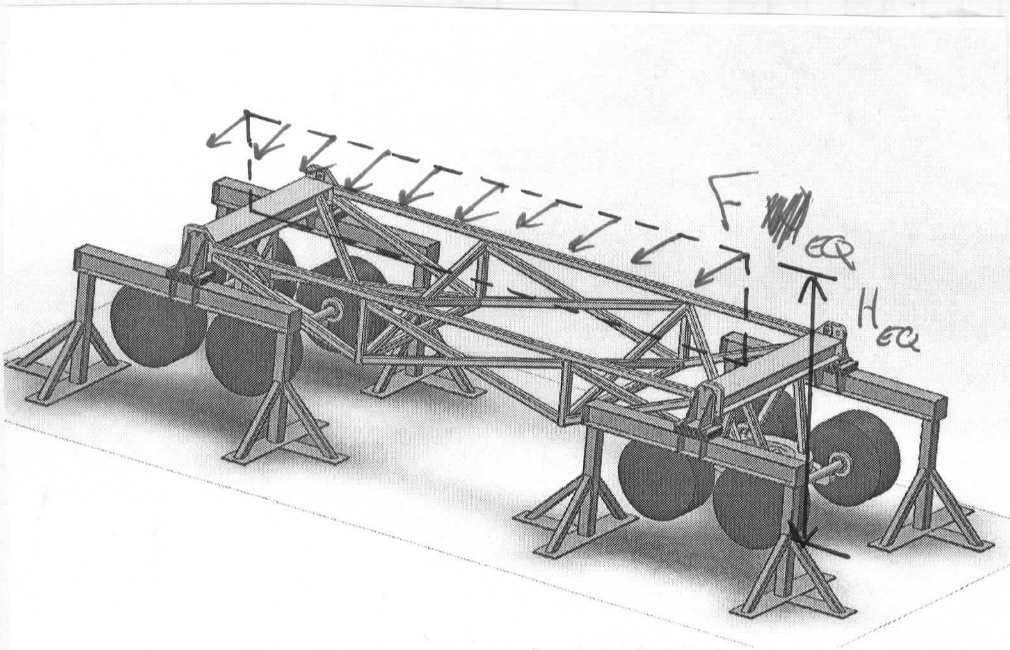
ASSUME: $\sigma_{UTS} \cong 62{,}000$ PSI

$\tau_{MAX} = 559$ PSI

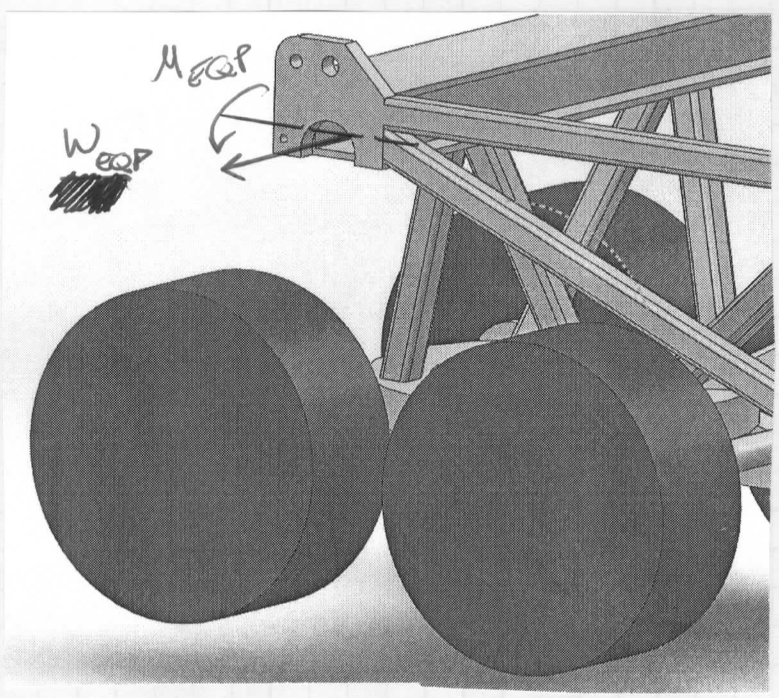
FACTOR OF SAFETY $\cong$ 55.4

**Therefore, the static factor of safety on the connection box is 55.4**

DISTRIBUTED SEISMIC LOAD:




LOAD TRANSFERRED TO TRAILER'S PLATE:



# SEISMIC LOADING

ASSUME: LOAD IS ONLY CARRIED ON ONE SIDE, THE COMPRESSION SIDE.

FROM SEISMIC ANALYSIS:

$$F_{EQ} = 37578 \text{ lb}_f$$

$$H_{EQ} = 8.7 \text{ FT}$$

$$M_{PLATE} = \frac{F_{EQ}}{2}\left(H_{EQ} - H_{PLATE}\right)$$

$H_{PLATE}$ = HEIGHT OF PLATE FROM GROUND
= 65 IN

$$\sigma_{BOX,e} = \frac{M_{PLATE}\, y}{I}$$

$$\sigma_{BOX,e} = 7329 \text{ PSI}$$

$$\tau_{BOX,e} = 1.5\,\frac{V}{A}$$

Measurements are based on sectioned model
Section properties of the selected faces of A000

Area = 22.70 inches^2

Centroid relative to assembly origin: ( inches )
X = -2.46
Y = 9.84
Z = 0.00

Moments of inertia of the area, at the centroid: ( inches ^ 4 )

| | | |
|---|---|---|
| Lxx = 277.34 | Lxy = 0.00 | Lxz = 0.00 |
| Lyx = 0.00 | Lyy = 534.45 | Lyz = 0.00 |
| Lzx = 0.00 | Lzy = 0.00 | Lzz = 257.11 |

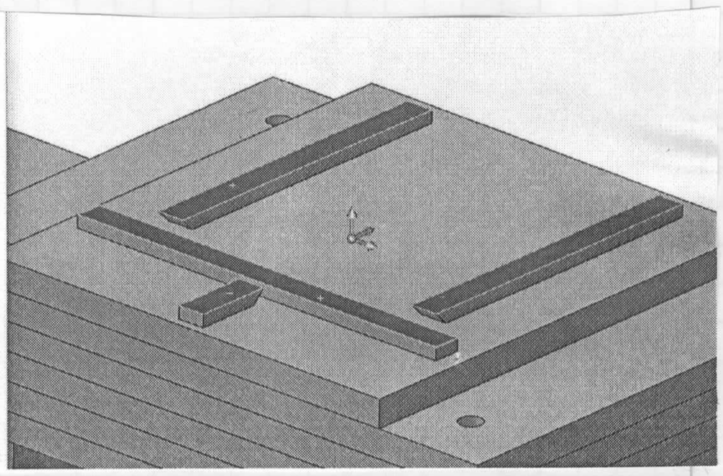
Polar moment of inertia of the area, at the centroid = 534.45 inches ^ 4

Angle between principal axes and assembly coordinate axes = 0.00 degrees

Principal moments of inertia of the area, at the centroid: ( inches ^ 4 )
Ix = 257.11
Iy = 277.34

Moments of inertia of the area, at the output coordinate system: ( inches ^ 4 )

| | | |
|---|---|---|
| LXX = 2475.52 | LXY = -549.32 | LXZ = 0.00 |
| LYX = -549.32 | LYY = 671.73 | LYZ = 0.00 |
| LZX = 0.00 | LZY = 0.00 | LZZ = 2592.57 |



$$\tau_{BOX,e} = 1242 \text{ PSI}$$

TOTAL FAILURE STRESS:

$$\sigma_{TOT} = \sigma_{BOX,e} + \sigma_{BOX}$$

$$\tau_{TOT} = \tau_{BOX,e} + \tau_{BOX}$$

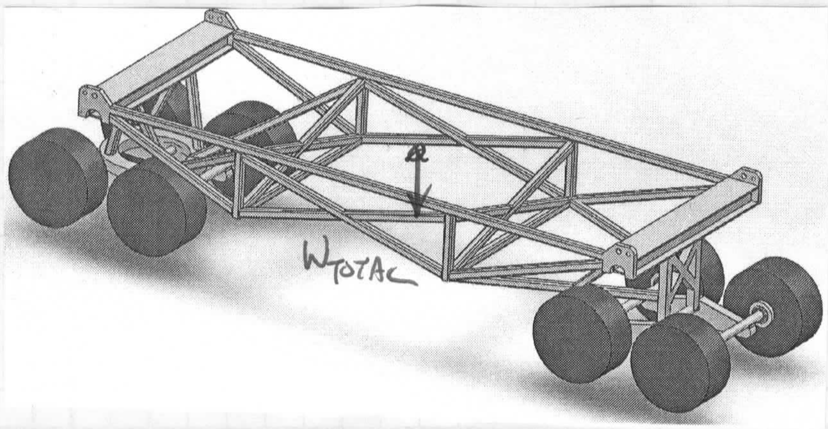
APPLY MOHR'S CIRCLE : SEE PAGE 4

$$\tau_{MAX} = 8698 \text{ PSI}$$

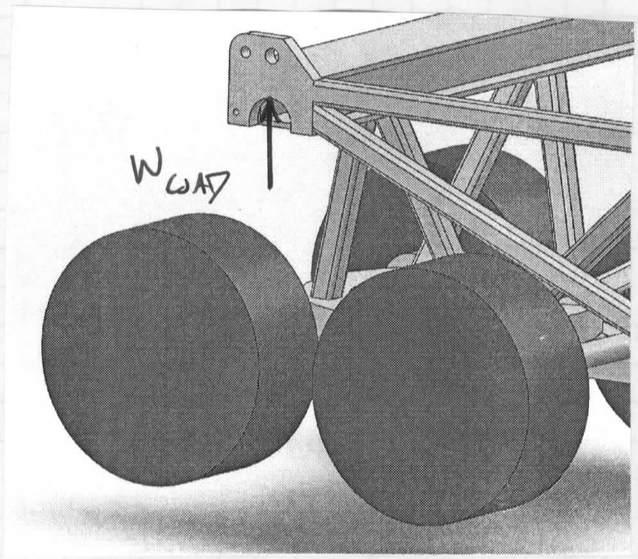
| FACTOR OF SAFETY = 3.6 |
|---|

**Therefore, the seismic factor of safety on the connection box is 3.6.**

**Appendix X: Analysis of H-beam**



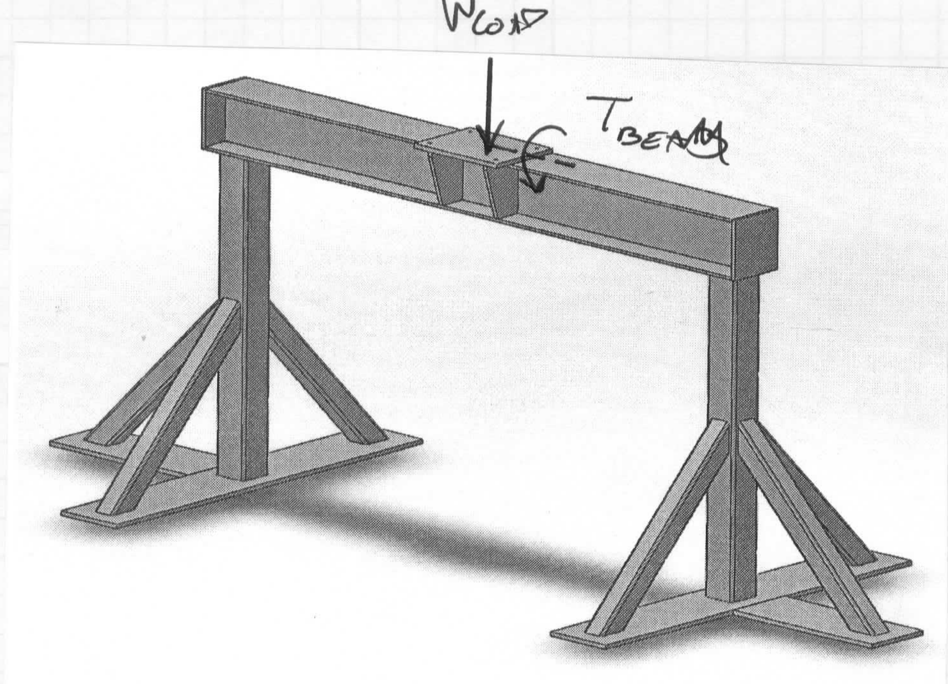

ASSUME: CENTER OF GRAVITY IS EQUIDISTANT TO ALL TRAILER PLATES



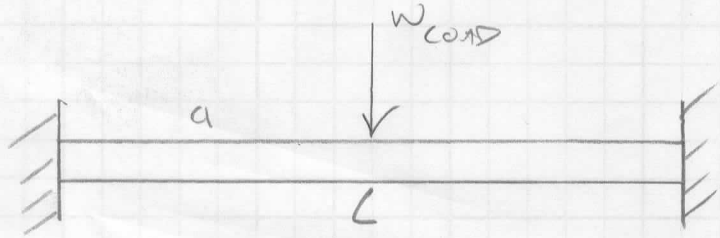

$$W_{LOAD} = \frac{1}{4} W_{TOTAL}$$

ASSUME: TRAILER IS RIGID AND STIFF ENOUGH TO PREVENT TRANSFERING MOMENT.

LOOKING AT SIMPLE, MAX STRESS IN BEAM:




ASSUME:




FIXED-FIXED, POINT LOAD BEAM IN BENDING:

$$M_{MAX} = \frac{P a^3}{L^2}$$

$$\sigma_{BEAM} = \frac{M_{max}\, y}{I}$$

$$M_{BEAM} = 220875 \text{ IN. } lb_f$$

$$\sigma_{BEAM} = \frac{M_{BEAM} Y}{I}$$

Report coordinate values relative to: -- default --

Measurements are based on sectioned model
Section properties of the selected face of AB00

Area = 14.50 inches^2

Centroid relative to assembly origin: ( inches )
X = 0.00
Y = 0.00
Z = 13.21

Moments of inertia of the area, at the centroid: ( inches ^ 4 )

| | | |
|---|---|---|
| Lxx = 256.21 | Lxy = 0.00 | Lxz = 0.00 |
| Lyx = 0.00 | Lyy = 83.43 | Lyz = 0.00 |
| Lzx = 0.00 | Lzy = 0.00 | Lzz = 339.64 |

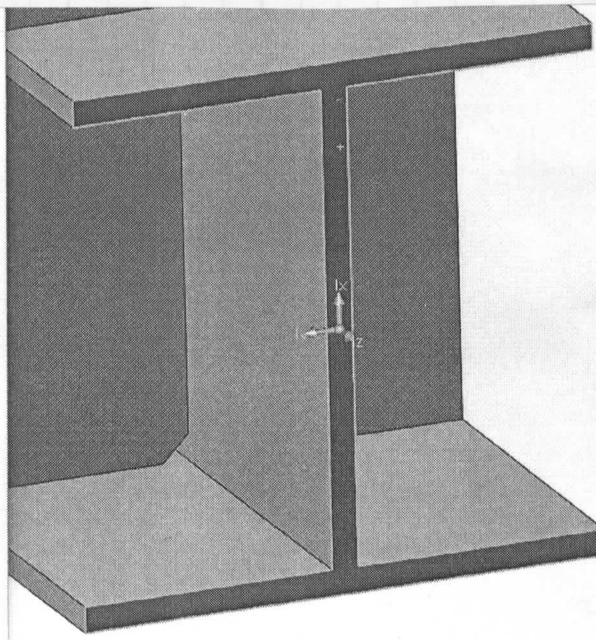
Polar moment of inertia of the area, at the centroid = 339.64 inches ^ 4

Angle between principal axes and assembly coordinate axes = 90.00 degrees

Principal moments of inertia of the area, at the centroid: ( inches ^ 4 )
~~Ix = 83.43~~
Iy = 256.21

Moments of inertia of the area, at the output coordinate system: ( inches ^ 4 )

| | | |
|---|---|---|
| LXX = 2786.52 | LXY = 0.00 | LXZ = 0.00 |
| LYX = 0.00 | LYY = 2613.74 | LYZ = 0.00 |
| LZX = 0.00 | LZY = 0.00 | LZZ = 339.64 |



$$Y = 5 \text{ IN}$$

$$\sigma_{BEAM} = 430 \text{ PSI}$$

$$\tau_{TORSION} = \frac{Tr}{J}$$

r = FURTHEST DISTANCE FROM CENTROID

$$r = \sqrt{(5\text{ IN})^2 + (5\text{ IN})^2}$$

$$r = 7.07 \text{ IN}$$

$$\tau_{TORS} = 2259 \text{ PSI}$$

STATIC LOADING

$$\tau_{BEAM} = 1.5 \frac{W_{LOAD}}{A}$$

$$A = 14.5\ IN^2$$

$$\tau_{BEAM} = 1603\ PSI$$

$$\tau_{TOT} = \tau_{TORS} + \tau_{BEAM}$$

$$\tau_{TOT} = 3862\ PSI$$

MOHR'S YIELD CRITERIA:

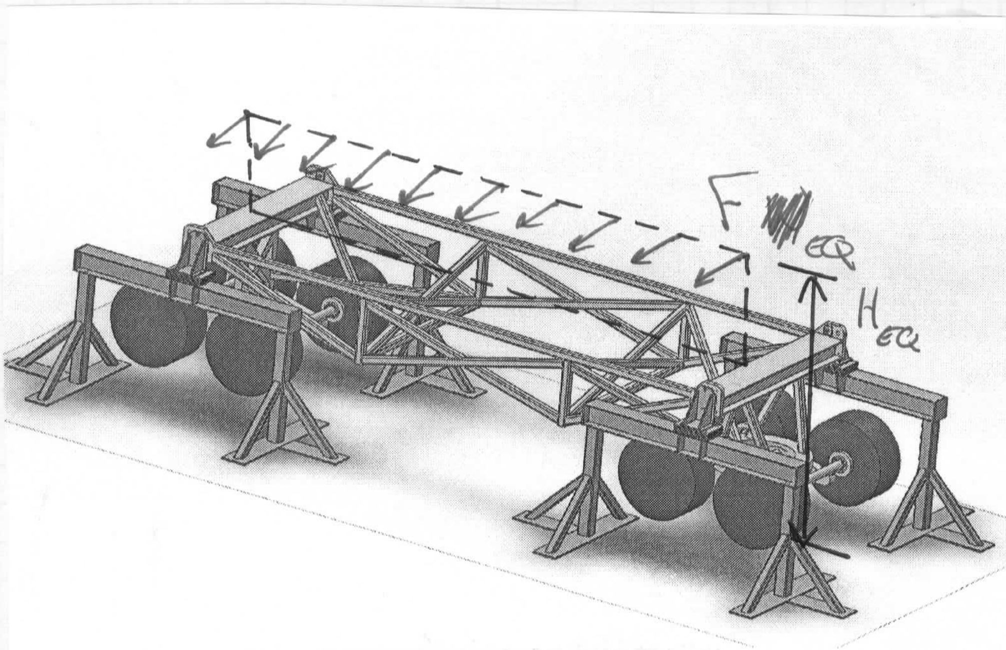
$$\tau_{MAX} = \sqrt{\left(\sigma_{BEAM} - \frac{\sigma_{BEAM}}{2}\right)^2 + \tau_{TOT}^2}$$

$$\tau_{MAX} = 4423\ PSI$$

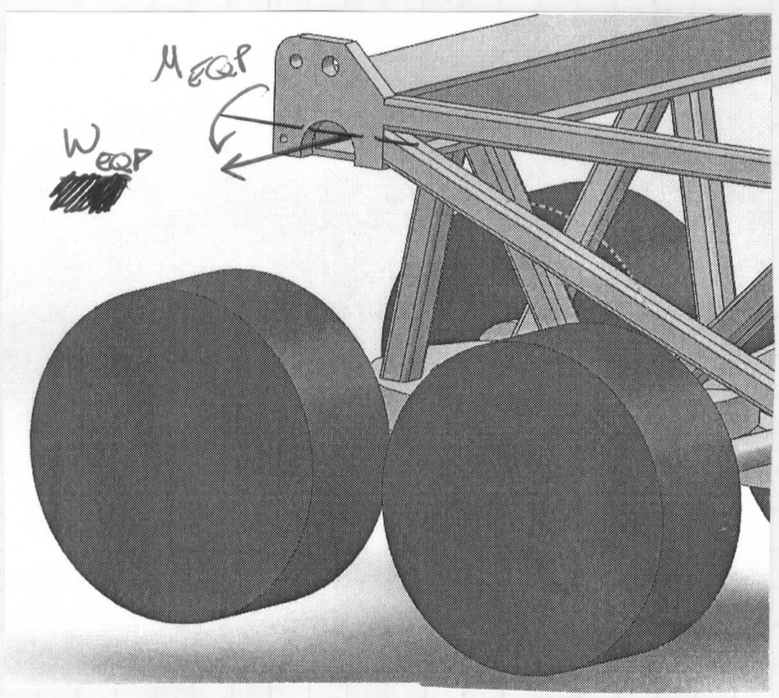
FACTOR OF SAFETY = 7.0

**Therefore, the static factor of safety on the H-beam is 7.0.**

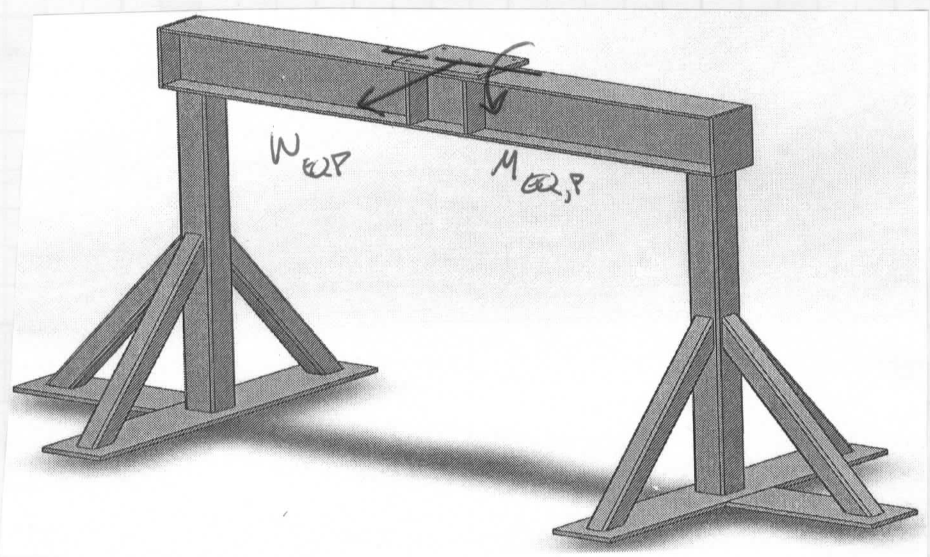
DISTRIBUTED SEISMIC LOAD:




LOAD TRANSFERRED TO TRAILER'S PLATE:



BEAM LOADING:




BENDING STRESS:

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

$y = 5\,IN$

$I = 83.43$

$$\sigma = 1126\ PSI$$

$$\tau_{TORS} = \frac{Tr}{J}$$

$$= \frac{M\_PLATE \; r}{J}$$

$$\tau_{TORS} = 15410$$

$$\tau_{SHEAR} = 1.5\frac{V}{A}$$

$$\tau_{SHEAR} = 1944$$

APPLY MOHR'S CIRCLE:

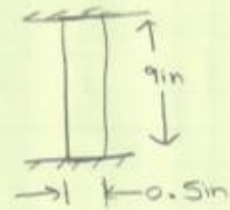
$\tau_{MAX} = 21389$ PSI

| SAFETY FACTOR = 1.45 |
|---|

**Therefore, the seismic safety factor on the H-beam is 1.45**

# Check for Buckling on Gusset

$$F = \frac{n\pi^2 EI}{L^2}$$




n=4 for fixed-fixed

$L = 9in$

$E = 30\times10^6\ psi$

$$I = \frac{bh^3}{12} = \frac{(0.75in)(9in)^3}{12} = 45.56in^4$$

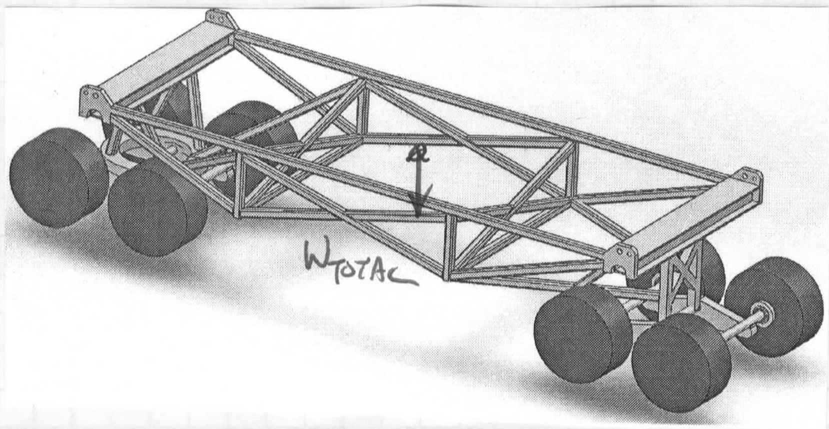
$$F = \frac{4\pi^2\left(30\times10^6 \frac{lb}{in^2}\right)(45.56in^4)}{(9in)^2}$$

$F = 212{,}009000\ lb \gg 29{,}376.9\ lb$ ∴ Buckling is not a concern

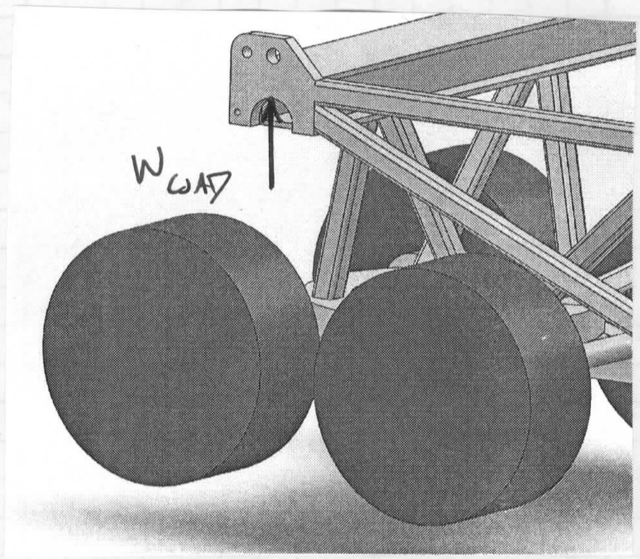
where 29,376.9 is induced force due to earthquake.

STATIC ANALYSIS 

# Appendix Y: Analysis of Square Tube Column




ASSUME: CENTER OF GRAVITY IS EQUIDISTANT TO ALL TRAILER PLATES

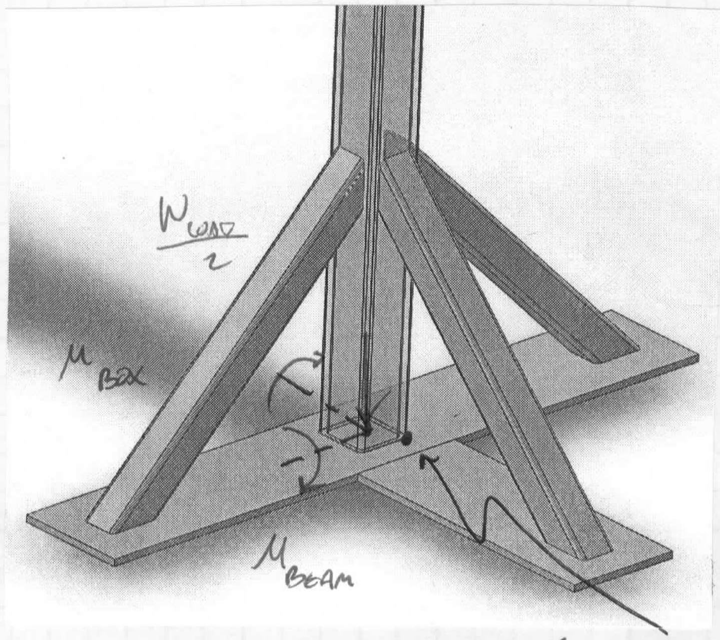



$$W_{LOAD} = \frac{1}{4} W_{TOTAL}$$

ASSUME: TRAILER IS RIGID AND STIFF ENOUGH TO PREVENT TRANSFERING MOMENT.

## STRESS ESTIMATION IN LEGS:

ASSUME: NO LOAD IS TRANSFERRED TO 4" OUTBOARD LEG STRUTS




LOCATION OF MAX BENDING STRESS

$$\sigma_{COMP} = \frac{P}{A}$$

$$\sigma_{BENDING} = \frac{My}{I}$$

$$\sigma_{TOT} = \frac{P}{A} + \frac{(M_{LOAD/2})\,Y}{I} + \frac{M_{BOX}\,Y}{I}$$

Measurements are based on sectioned model
Section properties of the selected face of AB00

Area = 11.00 inches^2

Centroid relative to assembly origin: ( inches )
X = 0.00
Y = -15.75
Z = 53.00

Moments of inertia of the area, at the centroid: ( inches ^ 4 )

| | | |
|---|---|---|
| Lxx = 55.35 | Lxy = 0.00 | Lxz = 0.00 |
| Lyx = 0.00 | Lyy = 110.70 | Lyz = 0.00 |
| Lzx = 0.00 | Lzy = 0.00 | Lzz = 55.35 |

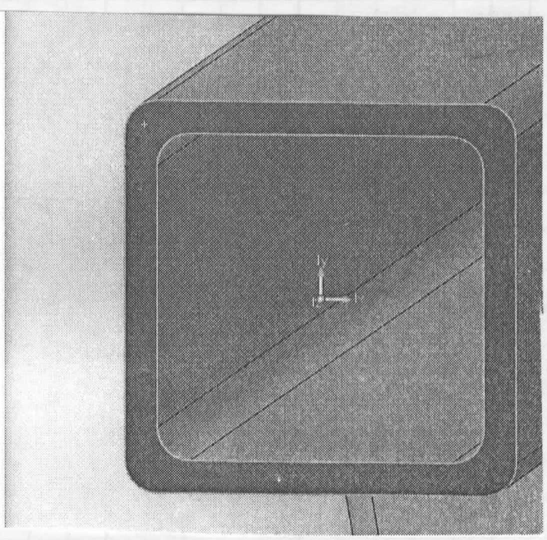
Polar moment of inertia of the area, at the centroid = 110.70 inches ^ 4

Angle between principal axes and assembly coordinate axes = 0.00 degrees

Principal moments of inertia of the area, at the centroid: ( inches ^ 4 )
Ix = 55.35
Iy = 55.35

Moments of inertia of the area, at the output coordinate system: ( inches ^ 4 )

| | | |
|---|---|---|
| LXX = 33683.04 | LXY = 0.00 | LXZ = 0.00 |
| LYX = 0.00 | LYY = 31009.70 | LYZ = -9182.25 |
| LZX = 0.00 | LZY = -9182.25 | LZZ = 2784.04 |



STATIC LOADING



$I = 55.35$

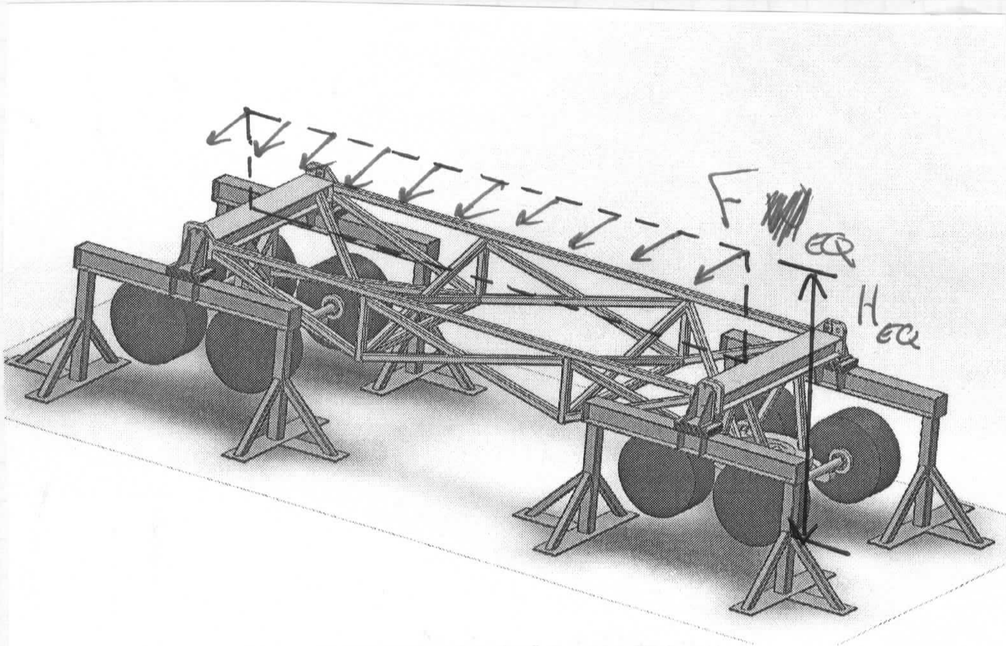
$y = 3\ IN$

$\sigma_{TOT} = 5325\ PSI$

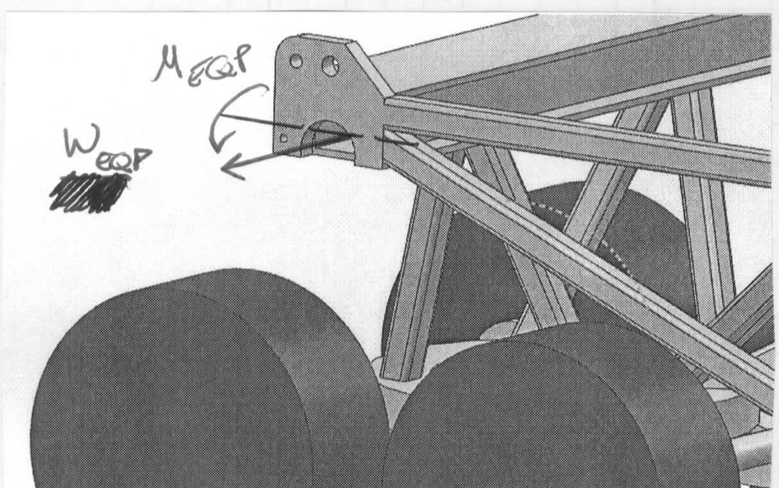
FACTOR OF SAFETY = 8.6

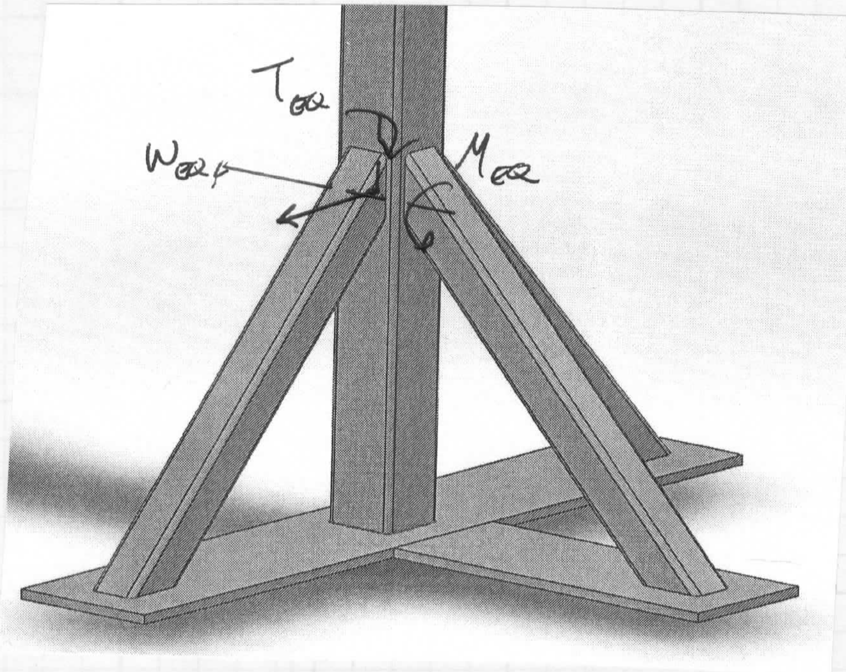
**Therefore, the static factor of safety for the struts is 8.6.**

DISTRIBUTED SEISMIC LOAD:




LOAD TRANSFERRED TO TRAILER'S PLATE:






POTENTIAL FAILURE IN LEG . . .

$$\sigma_{EQ,M} = \frac{M_{EQ}\, y}{I}$$

$$\sigma_{EQ,M} = 42975 \text{ PSI}$$

$$\tau_{EQ} = \frac{Tr}{J} + 1.5\frac{V}{A}$$

$$\tau_{TOT} = 15793 \text{ PSI}$$

APPLY MOHR'S CIRCLE AND STATIC LOADING

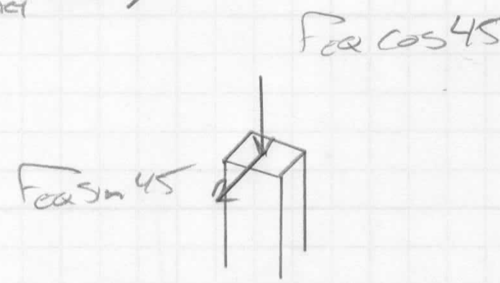
$$\tau_{MAX} = 28856 \text{ PSI}$$

**FACTOR OF SAFETY = 1.07**

**Therefore, the seismic factor of safety on the struts is 1.07.**

NOTE: THIS F.S. IS VERY CONSERVATIVE IN ASSUMING ALL SEISMIC LOAD WAS TRANSFERRED TO ONLY 2 OF THE LEGS

Assume: Kicked out CEG only carries shear and compressive bending. All topping moment is carried in vertical CEG... FBD:


$$\sigma = \frac{F_{EQ} \cos 45}{I} \qquad \tau = 1.5 \frac{F_{EQ} \cos 45}{A}$$

$$\sigma = 1954$$

$$\tau = 6894$$

Apply Mohr's Circle

$$\tau_{max} = 6894 \text{ PSI}$$

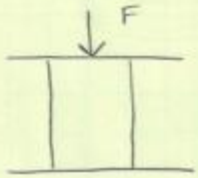
| Factor of Safety = 4.50 |
|---|

**Therefore, the revised seismic factor of safety on the struts is 4.50.**

Check for Buckling on Center Tube (chord) of Sawhorse

Ignoring the 3 additional feet (worst case scenario):

worst case: force applied directly at the top of the 6×6" square tubing.




$$F = \frac{n\pi^2 EI}{L^2}$$

n = 0.25 for fixed-free (conservative)

L = 4½ ft or 54 in

E = $30 \times 10^6$ psi

I = 48.3 $in^4$

$$F = \frac{(0.25)(\pi^2)(30 \times 10^6 \frac{lb}{in^2})(48.3 in^4)}{(54 in)^2}$$

F = 1,226,000 lb >> 29,376.9 lb ∴ Buckling is not a concern

where 29,376.9 is induced force due to earthquake

## Appendix Z: Bill of Materials For Final Product

| Item | Quantity | | Cost ($) | Supplier |
|---|---|---|---|---|
| Trailer Bolt | 4 | | $34.20 | McMaster-Carr* |
| Trailer Interface Nut | 4 | | $9.56 | McMaster-Carr* |
| Trailer Back Plate | 64 | in^2 | $6.72 | Dwight Peterson |
| Trailer Bushing | 10 | in | $24.40 | Speedy Metals* |
| Long Interface Bolt | 16 | | $258.72 | McMaster-Carr* |
| Nut | 16 | | $7.59 | McMaster-Carr* |
| Stability Rod | 220 | in | $34.60 | Metals Depot* |
| Clamping Nut | 1 | pkg | $7.10 | McMaster-Carr* |
| **Connection Box** | | | | |
| Puck | 12x18 | ft | $194.59 | Speedy Metals* |
| Back Plate | 187 | $in^2$ | $19.64 | Dwight Peterson |
| Box Gusset | 570 | $in^2$ | $59.85 | Dwight Peterson |
| Box Plate | 636 | $in^2$ | $66.78 | Dwight Peterson |
| Puck Gusset | 45 | $in^2$ | $4.73 | Dwight Peterson |
| **Sawhorse** | | | | |
| Main Beam | 19 | ft | $465.50 | Dwight Peterson |
| Vertical Column | 432 | in | $2,871.84 | Metals Depot* |
| Long Foot | 6912 | $in^2$ | $725.76 | Dwight Peterson |
| Beam Cap | 800 | $in^2$ | $84.00 | Dwight Peterson |
| Beam Gusset | 171 | $in^2$ | $35.91 | Dwight Peterson |
| Torsion Gusset | 285 | $in^2$ | $59.85 | Dwight Peterson |
| Stability Strut | 84 | ft | $908.46 | Dwight Peterson |
| Short Foot | 2880 | $in^2$ | $302.40 | Dwight Peterson |
| Interface Plate | 954 | $in^2$ | $100.17 | Dwight Peterson |
| **Welding** | | | | |
| Labor | 60 | hrs | $2,900.00 | Ron Cole |
| **Painting and Coating** | | | | |
| Rustoleum Paint | 2 | gal | $55.96 | Home Depot |
| OSPHO | 1 | gal | $25.99 | ACE Hardware |
| Macro-Epoxy Coating | 2 | gal | $120.00 | Sherwin Williams |
| | Total Cost | | $9,377.21 | |

Notes: * Indicates that the material will most likely be purchased from B&B Steel in Santa Maria at a reduced rate but due to limited pricing information has been specified from another supplier for reference.

**Vendor Contact Information**

**McMaster-Carr**
Sales and Customer Service
(562) 692-5911
(562) 641-2800
la.sales@mcmaster.com

**Dwight Peterson**
(805) 466-3806
El Camino Real, Atascadero, CA 93422

**Speedy Metals**
(866) 938-6061
sales@speedymetals.com

**Metals Depot**
1-859-745-2650 Customer Service
1-859-745-0898 Distribution Center

**Home Depot**
(805) 596-0857
1551 Froom Ranch Way, San Luis Obispo, CA 93405

**Miner's Ace Hardware**
(805) 543-2191
2034 Santa Barbara Ave, San Luis Obispo, CA 93401

**Sherwin-Williams Paint Store**
(805) 543-3800
3281 S Higuera St, San Luis Obispo, CA 93401

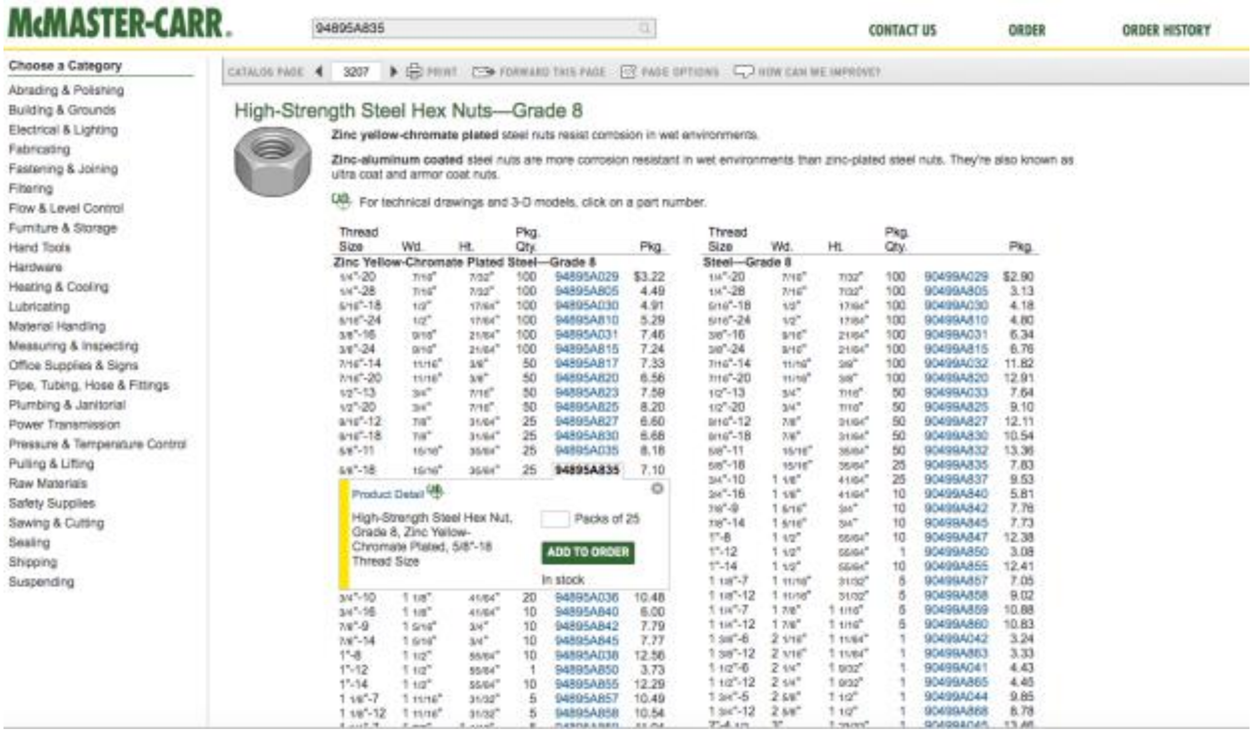
# Appendix AA: Bill of Materials for Prototypes

| | | | | | | |
|---|---|---|---|---|---|---|
| Starting Budget | | $500.00 | | | | |
| | | | | | | |
| **Category** | | **Item** | **Quantity** | **Planned Expense** | **Actual Expense** | **Balance** |
| **Materials for Steel Prototype** | | | | | | |
| | **Supplier** | **Item** | | | | |
| | Metals Depot | S 3" x 5.7# Steel I-beam | 1 | N/A | $45.65 | $454.35 |
| | Metals Depot | 1-1/2" x 1-1/2" x 11GA Steel Square Tube | 3 | N/A | $25.53 | $428.82 |
| | Metals Depot | 1" x 1" x 16GA Steel Square Tube | 7 | N/A | $37.52 | $391.30 |
| | Metals Depot | 3/16" A-36 Steel Plate | 1 | N/A | $32.06 | $359.24 |
| | Metals Depot | Shipping on Metals Depot Order | 1 | N/A | $38.86 | $320.38 |
| | McMaster-Carr | 1215 1-1/2" Square, 1' Length Carbon Steel Square | 1 | N/A | $23.38 | $297.00 |
| | McMaster-Carr | Zinc Yellow-Chromate Plated Hex Head Screw Grade 8 | 1 | N/A | $11.90 | $285.10 |
| | McMaster-Carr | Shipping on McMaster-Carr Order | 1 | N/A | $0.00 | $285.10 |
| | Mustang 60 Scrap | 7/8" Steel Plate | 1 | N/A | $30.00 | $255.10 |
| | Orchard Supply Hardware | Grade 8 Bolt, Split Washers, Hex Nut, Nylon Lock Nuts | 1 | N/A | $3.22 | $251.88 |
| | Orchard Supply Hardware | Metal Cutoff 4-1/2 Wheeel | 1 | N/A | $3.59 | $248.29 |
| | Miner's Ace Hardware | 60 Grit 4-1/2 Flap Disk | 1 | N/A | $5.99 | $242.30 |
| | Orchard Supply Hardware | Hex Nuts, Bolts, and Washers | 2 | N/A | $4.56 | $237.74 |
| | ACE Hardware | Grade 8 Nuts, Bolts and Washers | 1 | N/A | $44.37 | $193.37 |
| | | | | | | |
| | | | | | | |
| **Materials for Wooden Model** | | | | | | |
| | **Supplier** | Item | | | | |
| | Home Depot | 4x4x8" #2 Douglas Fir | 3 | N/A | $27.90 | $165.47 |
| | Home Depot | 2x4x96" #2 Pressure Treated Pine | 2 | $35.46 | $6.10 | $159.37 |
| | Home Depot | 15/32" x 4' x 8' Sheathing Plywood | 2 | $47.55 | $31.70 | $127.67 |
| | Home Depot | Glidden Speed-Wall White Latex Paint & Supplies | 1 | $14.98 | $15.72 | $111.95 |
| | Home Depot | 23/32" x 4' x 8' Plywood | 1 | N/A | $26.48 | $85.47 |
| | Home Depot | 3" screws box, 1 1/4"screws box, 1/4 x 3" lag screws | 1 | NA | $9.68 | $75.79 |
| | Home Depot | California Lumber Fees | 4 | N/A | $0.89 | $74.90 |
| | Home Depot | Sales Tax | N/A | N/A | $9.27 | $65.63 |
| | | | | | | |
| | | | | | Total Spent | Total Remaining |
| | | | | | **$434.37** | **$65.63** |

## Appendix BB: Vendor Supplied Component Specifications

## Final Design

### Clamping Nut: (McMaster-Carr)



McMASTER-CARR. 94895A835 CONTACT US ORDER ORDER HISTORY

Choose a Category: Abrading & Polishing, Building & Grounds, Electrical & Lighting, Fabricating, Fastening & Joining, Filtering, Flow & Level Control, Furniture & Storage, Hand Tools, Hardware, Heating & Cooling, Lubricating, Material Handling, Measuring & Inspecting, Office Supplies & Signs, Pipe, Tubing, Hose & Fittings, Plumbing & Janitorial, Power Transmission, Pressure & Temperature Control, Pulling & Lifting, Raw Materials, Safety Supplies, Sawing & Cutting, Sealing, Shipping, Suspending

CATALOG PAGE 3207 PRINT FORWARD THIS PAGE PAGE OPTIONS HOW CAN WE IMPROVE?

**High-Strength Steel Hex Nuts—Grade 8**

**Zinc yellow-chromate plated** steel nuts resist corrosion in wet environments.

**Zinc-aluminum coated** steel nuts are more corrosion resistant in wet environments than zinc-plated steel nuts. They're also known as ultra coat and armor coat nuts.

For technical drawings and 3-D models, click on a part number.

| Thread Size | Wd. | Ht. | Pkg. Qty. | | Pkg. |
|---|---|---|---|---|---|
| **Zinc Yellow-Chromate Plated Steel—Grade 8** | | | | | |
| 1/4"-20 | 7/16" | 7/32" | 100 | 94895A029 | $3.22 |
| 1/4"-28 | 7/16" | 7/32" | 100 | 94895A805 | 4.49 |
| 5/16"-18 | 1/2" | 17/64" | 100 | 94895A030 | 4.91 |
| 5/16"-24 | 1/2" | 17/64" | 100 | 94895A810 | 5.29 |
| 3/8"-16 | 9/16" | 21/64" | 100 | 94895A031 | 7.46 |
| 3/8"-24 | 9/16" | 21/64" | 100 | 94895A815 | 7.24 |
| 7/16"-14 | 11/16" | 3/8" | 50 | 94895A817 | 7.33 |
| 7/16"-20 | 11/16" | 3/8" | 50 | 94895A820 | 6.56 |
| 1/2"-13 | 3/4" | 7/16" | 50 | 94895A823 | 7.59 |
| 1/2"-20 | 3/4" | 7/16" | 50 | 94895A825 | 8.20 |
| 9/16"-12 | 7/8" | 31/64" | 25 | 94895A827 | 6.60 |
| 9/16"-18 | 7/8" | 31/64" | 25 | 94895A830 | 6.68 |
| 5/8"-11 | 15/16" | 35/64" | 25 | 94895A035 | 8.18 |
| 5/8"-18 | 15/16" | 35/64" | 25 | **94895A835** | 7.10 |
| 3/4"-10 | 1 1/8" | 41/64" | 20 | 94895A036 | 10.48 |
| 3/4"-16 | 1 1/8" | 41/64" | 10 | 94895A840 | 6.00 |
| 7/8"-9 | 1 5/16" | 3/4" | 10 | 94895A842 | 7.79 |
| 7/8"-14 | 1 5/16" | 3/4" | 10 | 94895A845 | 7.77 |
| 1"-8 | 1 1/2" | 55/64" | 10 | 94895A038 | 12.56 |
| 1"-12 | 1 1/2" | 55/64" | 1 | 94895A850 | 3.73 |
| 1"-14 | 1 1/2" | 55/64" | 10 | 94895A855 | 12.29 |
| 1 1/8"-7 | 1 11/16" | 31/32" | 5 | 94895A857 | 10.49 |
| 1 1/8"-12 | 1 11/16" | 31/32" | 5 | 94895A858 | 10.54 |

Product Detail

High-Strength Steel Hex Nut, Grade 8, Zinc Yellow-Chromate Plated, 5/8"-18 Thread Size

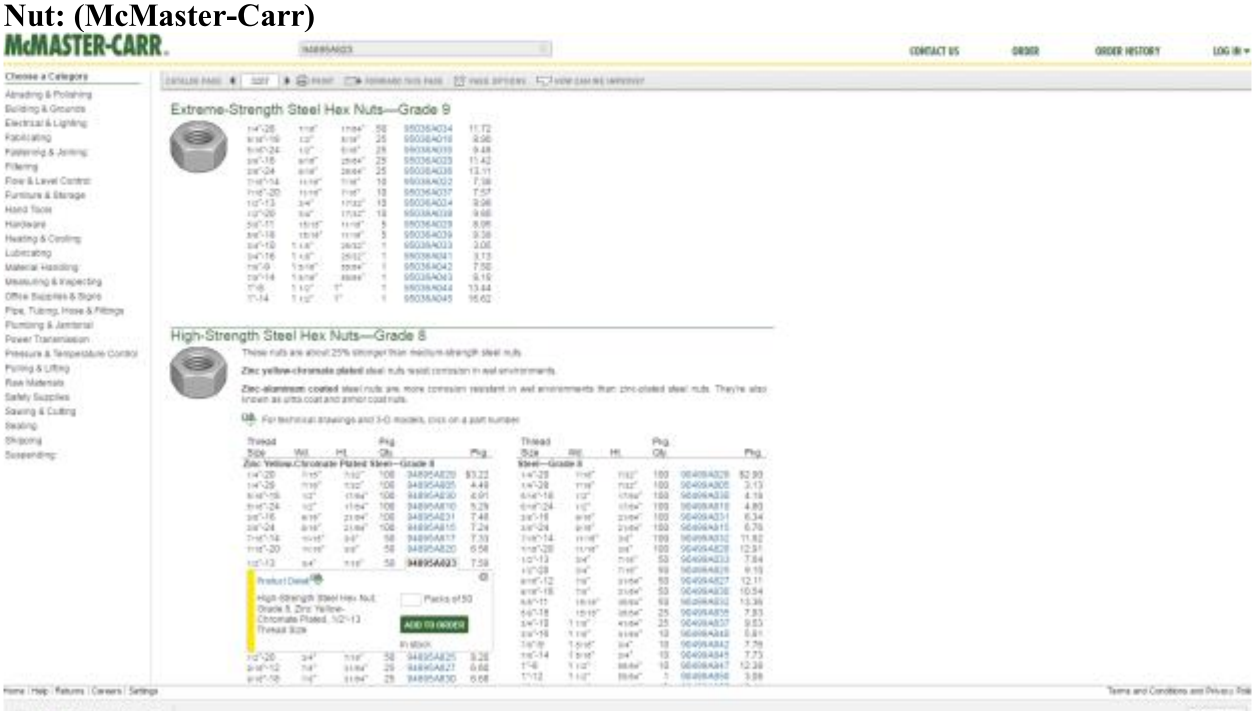
Packs of 25

ADD TO ORDER

In stock

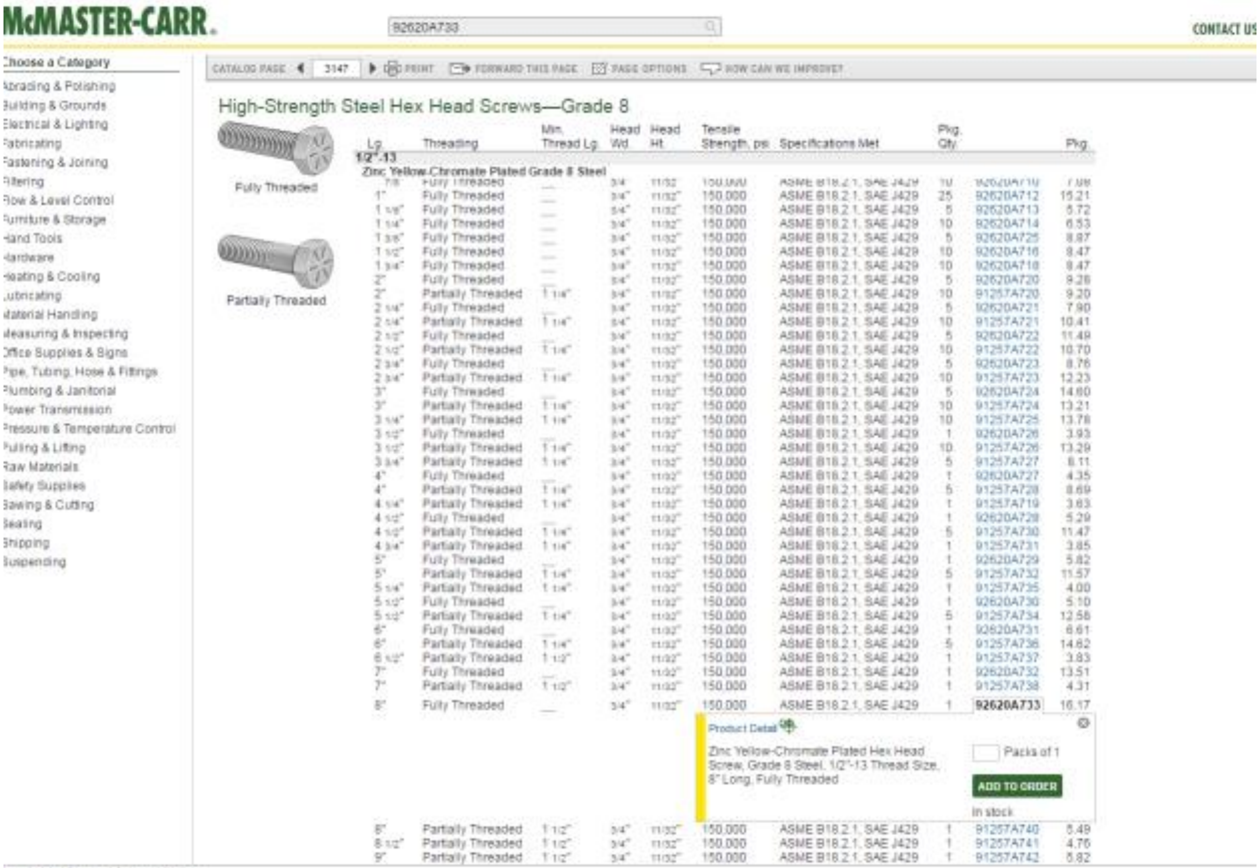
| Thread Size | Wd. | Ht. | Pkg. Qty. | | Pkg. |
|---|---|---|---|---|---|
| **Steel—Grade 8** | | | | | |
| 1/4"-20 | 7/16" | 7/32" | 100 | 90499A029 | $2.90 |
| 1/4"-28 | 7/16" | 7/32" | 100 | 90499A805 | 3.13 |
| 5/16"-18 | 1/2" | 17/64" | 100 | 90499A030 | 4.18 |
| 5/16"-24 | 1/2" | 17/64" | 100 | 90499A810 | 4.80 |
| 3/8"-16 | 9/16" | 21/64" | 100 | 90499A031 | 6.34 |
| 3/8"-24 | 9/16" | 21/64" | 100 | 90499A815 | 6.76 |
| 7/16"-14 | 11/16" | 3/8" | 100 | 90499A032 | 11.82 |
| 7/16"-20 | 11/16" | 3/8" | 100 | 90499A820 | 12.91 |
| 1/2"-13 | 3/4" | 7/16" | 50 | 90499A033 | 7.64 |
| 1/2"-20 | 3/4" | 7/16" | 50 | 90499A825 | 9.10 |
| 9/16"-12 | 7/8" | 31/64" | 50 | 90499A827 | 12.11 |
| 9/16"-18 | 7/8" | 31/64" | 50 | 90499A830 | 10.54 |
| 5/8"-11 | 15/16" | 35/64" | 50 | 90499A832 | 13.36 |
| 5/8"-18 | 15/16" | 35/64" | 25 | 90499A835 | 7.83 |
| 3/4"-10 | 1 1/8" | 41/64" | 25 | 90499A837 | 9.53 |
| 3/4"-16 | 1 1/8" | 41/64" | 10 | 90499A840 | 5.81 |
| 7/8"-9 | 1 5/16" | 3/4" | 10 | 90499A842 | 7.78 |
| 7/8"-14 | 1 5/16" | 3/4" | 10 | 90499A845 | 7.73 |
| 1"-8 | 1 1/2" | 55/64" | 10 | 90499A847 | 12.38 |
| 1"-12 | 1 1/2" | 55/64" | 1 | 90499A850 | 3.08 |
| 1"-14 | 1 1/2" | 55/64" | 10 | 90499A855 | 12.41 |
| 1 1/8"-7 | 1 11/16" | 31/32" | 5 | 90499A857 | 7.05 |
| 1 1/8"-12 | 1 11/16" | 31/32" | 5 | 90499A858 | 9.02 |
| 1 1/4"-7 | 1 7/8" | 1 1/16" | 5 | 90499A859 | 10.88 |
| 1 1/4"-12 | 1 7/8" | 1 1/16" | 5 | 90499A860 | 10.83 |
| 1 3/8"-6 | 2 1/16" | 1 11/64" | 1 | 90499A042 | 3.24 |
| 1 3/8"-12 | 2 1/16" | 1 11/64" | 1 | 90499A863 | 3.33 |
| 1 1/2"-6 | 2 1/4" | 1 9/32" | 1 | 90499A041 | 4.43 |
| 1 1/2"-12 | 2 1/4" | 1 9/32" | 1 | 90499A865 | 4.46 |
| 1 3/4"-5 | 2 5/8" | 1 1/2" | 1 | 90499A044 | 9.85 |
| 1 3/4"-12 | 2 5/8" | 1 1/2" | 1 | 90499A868 | 8.78 |

### Nut: (McMaster-Carr)



## Appendix BB: Vendor Supplied Component Specifications

### Long Interface Bolt: (McMaster-Carr)

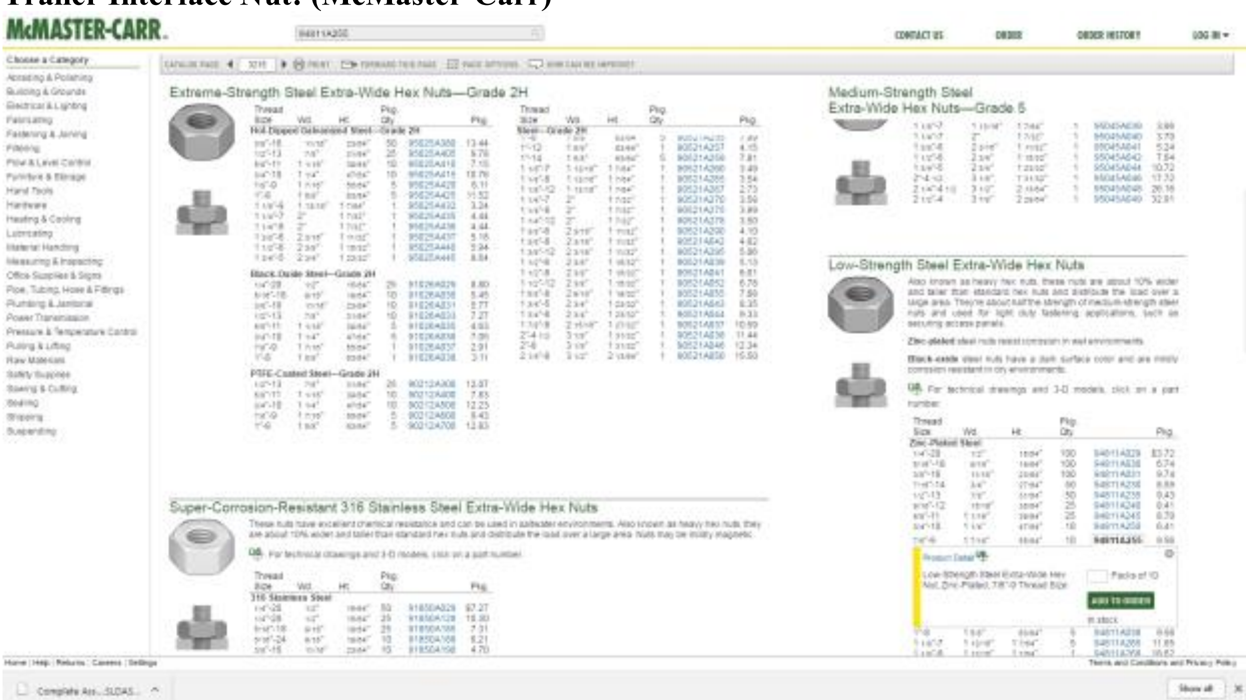




| Lg. | Threading | Min. Thread Lg. | Head Wd. | Head Ht. | Tensile Strength, psi | Specifications Met | Pkg. Qty. | | Pkg. |
|---|---|---|---|---|---|---|---|---|---|
| **1/2"-13** | | | | | | | | | |
| **Zinc Yellow-Chromate Plated Grade 8 Steel** | | | | | | | | | |
| 7/8" | Fully Threaded | — | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 10 | 92620A710 | 7.08 |
| 1" | Fully Threaded | — | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 25 | 92620A712 | 15.21 |
| 1 1/8" | Fully Threaded | — | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 5 | 92620A713 | 5.72 |
| 1 1/4" | Fully Threaded | — | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 10 | 92620A714 | 6.53 |
| 1 3/8" | Fully Threaded | — | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 5 | 92620A725 | 8.87 |
| 1 1/2" | Fully Threaded | — | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 10 | 92620A716 | 8.47 |
| 1 3/4" | Fully Threaded | — | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 10 | 92620A718 | 8.47 |
| 2" | Fully Threaded | — | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 5 | 92620A720 | 9.28 |
| 2" | Partially Threaded | 1 1/4" | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 10 | 91257A720 | 9.20 |
| 2 1/4" | Fully Threaded | — | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 5 | 92620A721 | 7.90 |
| 2 1/4" | Partially Threaded | 1 1/4" | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 10 | 91257A721 | 10.41 |
| 2 1/2" | Fully Threaded | — | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 5 | 92620A722 | 11.49 |
| 2 1/2" | Partially Threaded | 1 1/4" | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 10 | 91257A722 | 10.70 |
| 2 3/4" | Fully Threaded | — | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 5 | 92620A723 | 8.76 |
| 2 3/4" | Partially Threaded | 1 1/4" | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 10 | 91257A723 | 12.23 |
| 3" | Fully Threaded | — | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 5 | 92620A724 | 14.60 |
| 3" | Partially Threaded | 1 1/4" | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 10 | 91257A724 | 13.21 |
| 3 1/4" | Partially Threaded | 1 1/4" | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 10 | 91257A725 | 13.78 |
| 3 1/2" | Fully Threaded | — | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A726 | 3.93 |
| 3 1/2" | Partially Threaded | 1 1/4" | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 10 | 91257A726 | 13.29 |
| 3 3/4" | Partially Threaded | 1 1/4" | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 5 | 91257A727 | 8.11 |
| 4" | Fully Threaded | — | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A727 | 4.35 |
| 4" | Partially Threaded | 1 1/4" | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 5 | 91257A728 | 8.69 |
| 4 1/4" | Partially Threaded | 1 1/4" | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A719 | 3.63 |
| 4 1/2" | Fully Threaded | — | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A728 | 5.29 |
| 4 1/2" | Partially Threaded | 1 1/4" | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 5 | 91257A730 | 11.47 |
| 4 3/4" | Partially Threaded | 1 1/4" | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A731 | 3.85 |
| 5" | Fully Threaded | — | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A729 | 5.82 |
| 5" | Partially Threaded | 1 1/4" | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 5 | 91257A732 | 11.57 |
| 5 1/4" | Partially Threaded | 1 1/4" | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A735 | 4.00 |
| 5 1/2" | Fully Threaded | — | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A730 | 5.10 |
| 5 1/2" | Partially Threaded | 1 1/4" | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 5 | 91257A734 | 12.56 |
| 6" | Fully Threaded | — | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A731 | 6.61 |
| 6" | Partially Threaded | 1 1/4" | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 5 | 91257A736 | 14.62 |
| 6 1/2" | Partially Threaded | 1 1/2" | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A737 | 3.83 |
| 7" | Fully Threaded | — | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A732 | 13.51 |
| 7" | Partially Threaded | 1 1/2" | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A738 | 4.31 |
| 8" | Fully Threaded | — | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A733 | 16.17 |
| 8" | Partially Threaded | 1 1/2" | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A740 | 5.49 |
| 8 1/2" | Partially Threaded | 1 1/2" | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A741 | 4.76 |
| 9" | Partially Threaded | 1 1/2" | 3/4" | 11/32" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A742 | 5.82 |



### Trailer Interface Nut: (McMaster-Carr)



# Appendix BB: Vendor Supplied Component Specifications

## Trailer Bolt: (McMaster-Carr)

**McMASTER-CARR.** 91257A941 CONTACT US ORDER

Choose a Category

- Abrading & Polishing
- Building & Grounds
- Electrical & Lighting
- Fabricating
- Fastening & Joining
- Filtering
- Flow & Level Control
- Furniture & Storage
- Hand Tools
- Hardware
- Heating & Cooling
- Lubricating
- Material Handling
- Measuring & Inspecting
- Office Supplies & Signs
- Pipe, Tubing, Hose & Fittings
- Plumbing & Janitorial
- Power Transmission
- Pressure & Temperature Control
- Pulling & Lifting
- Raw Materials
- Safety Supplies
- Sawing & Cutting
- Sealing
- Shipping
- Suspending

CATALOG PAGE 3146 PRINT FORWARD THIS PAGE PAGE OPTIONS HOW CAN WE IMPROVE?

### High-Strength Steel Hex Head Screws—Grade 8

Fully Threaded

Partially Threaded

| Lg. | Threading | Min. Thread Lg. | Head Wd. | Head Ht. | Tensile Strength, psi | Specifications Met | Pkg. Qty. | | Pkg. |
|---|---|---|---|---|---|---|---|---|---|
| 2" | Fully Threaded | — | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A896 | 2.72 |
| 2 1/2" | Fully Threaded | — | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A911 | 3.10 |
| 3" | Fully Threaded | — | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A912 | 12.37 |
| 3" | Partially Threaded | 2" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A913 | 3.51 |
| 3 1/2" | Fully Threaded | — | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A913 | 13.74 |
| 3 1/2" | Partially Threaded | 2" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A915 | 3.85 |
| 4" | Fully Threaded | — | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A914 | 16.82 |
| 4" | Partially Threaded | 2" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A917 | 4.50 |
| 4 1/4" | Partially Threaded | 2" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A918 | 7.73 |
| 4 1/2" | Fully Threaded | — | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A915 | 17.78 |
| 4 1/2" | Partially Threaded | 2" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A919 | 4.84 |
| 4 3/4" | Partially Threaded | 2" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A920 | 8.34 |
| 5" | Fully Threaded | — | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A916 | 20.37 |
| 5" | Partially Threaded | 2" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A921 | 6.70 |
| 5 1/2" | Fully Threaded | — | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A917 | 22.19 |
| 5 1/2" | Partially Threaded | 2" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A923 | 6.84 |
| 6" | Fully Threaded | — | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A918 | 30.40 |
| 6" | Partially Threaded | 2" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A925 | 7.15 |
| 6 1/2" | Partially Threaded | 2 1/4" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A927 | 8.71 |
| 7" | Partially Threaded | 2 1/4" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A929 | 9.09 |
| 7 1/2" | Partially Threaded | 2 1/4" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A224 | 10.58 |
| 8" | Partially Threaded | 2 1/4" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A228 | 8.41 |
| 9" | Partially Threaded | 2 1/4" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A930 | 10.50 |
| 10" | Partially Threaded | 2 1/4" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A931 | 15.38 |
| **7/8"-14** | | | | | | | | | |
| Zinc Yellow-Chromate Plated Grade 8 Steel | | | | | | | | | |
| 1 1/2" | Fully Threaded | — | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A920 | $4.30 |
| 1 3/4" | Fully Threaded | — | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A922 | 4.84 |
| 2" | Fully Threaded | — | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A924 | 5.09 |
| 2 1/4" | Fully Threaded | — | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A926 | 3.64 |
| 2 1/2" | Fully Threaded | — | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A928 | 5.11 |
| 2 3/4" | Fully Threaded | — | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 92620A930 | 4.86 |
| 3" | Partially Threaded | 2" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A932 | 5.45 |
| 3 1/4" | Partially Threaded | 2" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A933 | 6.74 |
| 3 1/2" | Partially Threaded | 2" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A936 | 6.80 |
| 3 3/4" | Partially Threaded | 2" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A937 | 6.94 |
| 4" | Partially Threaded | 2" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A934 | 7.52 |
| 4 1/2" | Partially Threaded | 2" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A939 | 8.24 |
| 5" | Partially Threaded | 2" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | **91257A941** | 8.55 |
| 5 1/2" | Partially Threaded | 2" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A943 | 9.17 |
| 6" | Partially Threaded | 2" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A945 | 9.86 |
| 6 1/2" | Partially Threaded | 2 1/4" | 1 5/16" | 35/64" | 150,000 | ASME B18.2.1, SAE J429 | 1 | 91257A948 | 10.59 |

Product Detail

Zinc Yellow-Chromate Plated Hex Head Screw, Grade 8 Steel, 7/8"-14 Thread Size, 5" Long

Packs of 1

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## Trailer Bushing: (Speedy Metals)

### Hot Rolled Bars

Analysis Mechanical Properties Applications Machineability and Weldability Heat Treating Tolerances Speedy Metals items

ASTM A36 A mild steel for general purpose applications. Excellent for mild cold and hot forming, very suitable for general usage in production and maintenance work, and easily welds. Good material for machining, drilling, tapping, punching and grinding. Suitable for applications that do not require the greater strength oh high carbon or alloy steels. The very thin rectangles are generally sold as strip, and size selection is not as great as cold roll C1018. Larger diameters in ASTM A36 are not generally produced, as C1018 hot roll rounds are usually used.

#### ANALYSIS

*Manganese levels may be trace on 3/4" and under

#### MECHANICAL PROPERTIES

The above values are for 1" round and may be considered as representative of this grade

#### APPLICATIONS

ASTM A36 is used for general purpose structural, machinery parts, frames, fixtures, automotive and agricultural implements and equipment, brackets, stakes, ornamental works, forgings, base plates, and miscellaneous \non-critical applications that involve mild cold bending, mild hot forming, punching, machining, and welding

#### MACHINEABILITY AND WELDABILITY

ASTM A36 has a machinability rating of 72%, based on 1212 at 100%. Average surface cutting feed 120 ft/min.

ASTM A36 is easily welded by all welding processes and the welds and joints produced are of extremely high quality.

#### HEAT TREATING

ASTM A36 is generally not heat treated but is typically stress relieved prior to grinding or machining or after welding and prior to machining. ASTM A-36 can be carburized, however, for a higher surface hardness.

Stress Relieve 1100°-1250°F. Typical Stress relieve soak time
one hour per inch of thickness.
Carburize 1650°-1700° F.

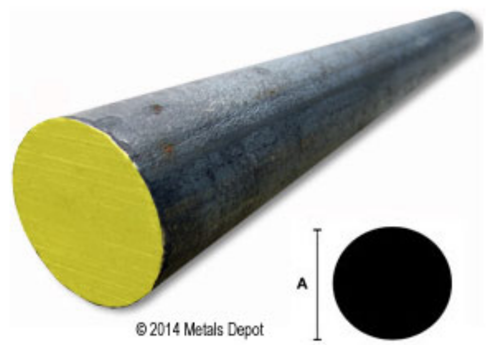
# Appendix BB: Vendor Supplied Component Specifications

## Stability Rod: (Metals Depot)

Email Friend

### A36 Steel Round Bar

**A36 Steel Round Bar** is a hot rolled, mild steel solid steel bar that is ideal for all general fabrication, manufacturing and repairs. Steel Rounds are widely used in industrial maintenance, agricultural implements, transportation equipment, ornamental iron work, fencing, artwork, etc. This steel shape is easy to weld, cut, form and machine with the proper equipment and knowledge. Metals Depot stocks hundreds of sizes of steel round at wholesale prices in ready to ship precut and mill lengths or you can order online just what you need custom cut to size in small or large quantity.

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**SPECIFICATIONS:** ASTM A36 Steel Round Bar

**FINISH:** Blue/Gray slightly grainy

**MECHANICAL PROPERTIES:**
Yield Point = 36,000 psi
Tensile Strength = 58-80,000 psi
Elongation = 23% in 2" ; Elasticity = 29 ksi
Brinell Hardness = 119-158
Machinabilty Rate = 72%

**CHEMICAL PROPERTIES:**
Iron - 98%, Carbon - .25%-.29%,
Copper - .20%, Silicon - .04% Max,
Manganese - .60%-.90% Max,
Phosphorous - .04% Max,
Sulfur - .05% Max

**AVAILABLE STOCK SIZES:**
2ft, 4ft. 6ft, 8ft, 10ft, 20ft, or Cut to Size
*Stock lengths may vary +/- 1/4"*

**HOW TO MEASURE:**
Diameter (A) X Length

## Puck: (Speedy Metals)

### Hot Rolled Carbon Steel Plate

Applications Machineability and Weldability Heat Treating Tolerances Speedy Metals items

ASTM A36 A basic oxygen process steel, ASTM A36 has good forming and welding ability, and can be hardened within its carbon limitations. Generally supplied flame cut to size (BTS) or flame cut to print shape (BPP), it can be sheared easily in thin thicknesses, typically Å¼" thick and smaller. Stress relieving is recommended prior to machining if dimensional stability or specific flatness tolerances are required.

#### APPLICATIONS

ASTM A36 is used for general purpose structural, machinery parts, frames, fixtures, automotive and agricultural implements and equipment, brackets, stakes, ornamental works, forgings, base plates, gears, cams, sprockets, jigs, rings, templates, fixtures, bearing plates, tanks, bins, various parts obtained by flame cutting, and miscellaneous non-critical applications that involve mild cold bending, mild hot forming, punching, machining, and welding

#### MACHINEABILITY AND WELDABILITY

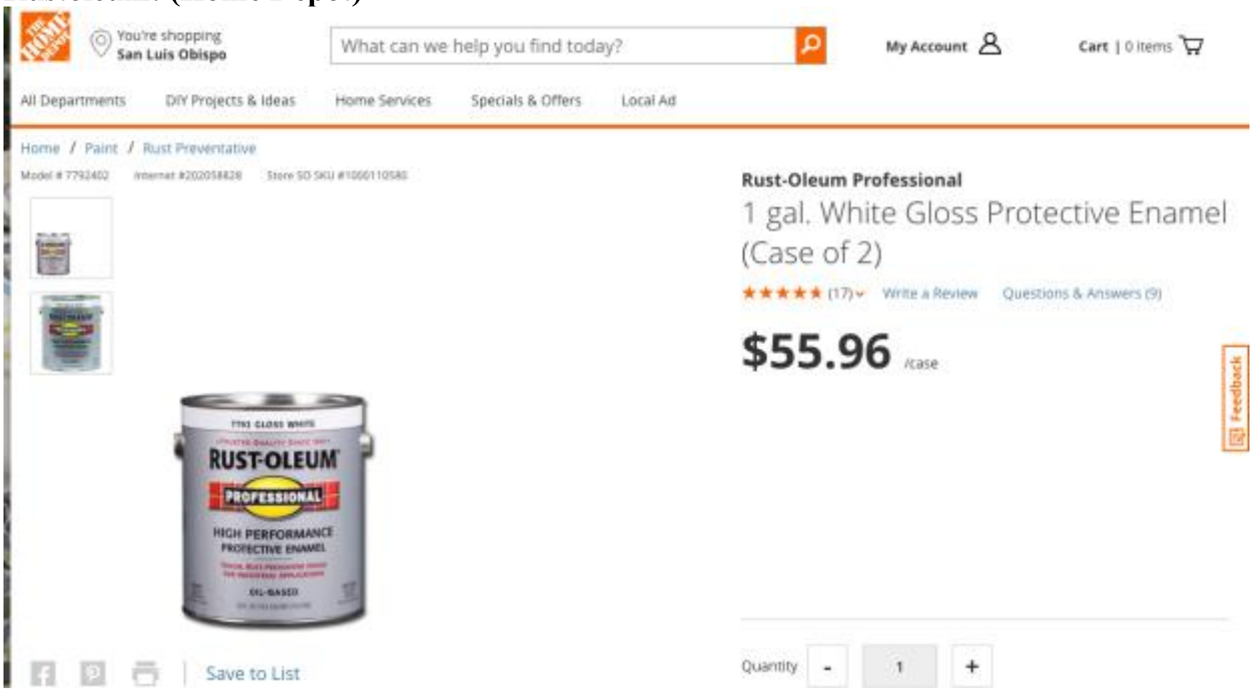
ASTM A36 has a machinability rating of 72%, based on 1212 at 100%. Average surface cutting feed 120 ft/min. ASTM A36 plate is easily welded by all welding processes and the welds and joints produced are of extremely high quality.

#### HEAT TREATING

ASTM A36 will respond to any of the standard carburizing and subsequent hardening methods used for such grades as 1018.
Normalize 1650-1750F Anneal 1550-1600F Stress Relieve 1250-1700F Carburize 1650-1700F Harden 1450-1500F

## Appendix BB: Vendor Supplied Component Specifications

### Rustoleum: (Home Depot)

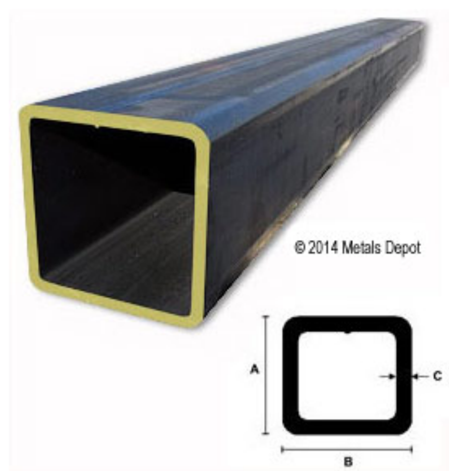



### Vertical Column: (Metals Depot)

Email Friend

# Square Steel Tube A513 / A500

**Square Steel Tube** is a welded structural grade tubing that is available in either type A513 or A500 Grade B, depending on its size and wall thickness. Either grade is ideal for all structural applications, general fabrication, manufacturing and repairs. Steel square tube is widely used in industrial maintenance, agricultural implements, transportation equipment, truck beds, trailers, frames, etc. Its box-shape configuration allows for much greater strength and rigidity compared to angles or channels. This steel shape is easy to weld, cut, form and machine with the proper equipment and knowledge. Metals Depot stocks hundreds of sizes of square tube at wholesale prices in ready to ship precut and mill lengths or you can order just what you need custom Cut to Size in any quantity.

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**SPECIFICATIONS:** ASTM A513 (1020-1026); ASTM A500 Grade B

**FINISH:** A513 - Dark Blue/Black, smooth slight oil coating;
A500 - Blue/Dark Gray, slighty grainy, dry

**MECHANICAL PROPERTIES:**
Yield Point = 72 ksi (A513); 46 ksi (A500)
Tensile Strength = 87 ksi (A513); 58 ksi (A500)
Elongation in 2" = 10% (A513); 23% (A500)
Outside Corner Radius = 3X wall max.

**CHEMICAL PROPERTIES:**
Iron - 99%,
Carbon - .05%-.23%,
Manganese - .3%-.6% Max,
Phosphorous - .04% Max,
Sulfur - .04% Max

**AVAILABLE STOCK SIZES:**
2ft, 4ft. 6ft, 8ft, 12ft, 24ft, or Cut to Size
*Stock lengths may vary +/- 1/4"*

**HOW TO MEASURE:**
Height (A) X Width (B) X Wall Thickness (C) X Length

Protective & Marine Coatings

# MACROPOXY® 646 FAST CURE EPOXY

| | | |
|---|---|---|
| PART A | B58-600 | SERIES |
| PART B | B58V600 | HARDENER |

Revised: October 19, 2016

## PRODUCT INFORMATION

4.53

### PRODUCT DESCRIPTION

**MACROPOXY 646 FAST CURE EPOXY** is a high solids, high build, fast drying, polyamide epoxy designed to protect steel and concrete in industrial exposures. Ideal for maintenance painting and fabrication shop applications. The high solids content ensures adequate protection of sharp edges, corners, and welds. This product can be applied directly to marginally prepared steel surfaces.

- Low VOC
- Low odor
- Outstanding application properties
- Meets Class A requirements for Slip Coefficient, 0.36 @ 6 mils / 150 microns dft (Mill White only)
- Chemical resistant
- Abrasion resistant

### PRODUCT CHARACTERISTICS

| | |
|---|---|
| **Finish:** | Semi-Gloss |
| **Color:** | Mill White, Black and a wide range of colors available through tinting |
| **Volume Solids:** | 72% ± 2%, mixed, Mill White |
| **Weight Solids:** | 85% ± 2%, mixed, Mill White |
| **VOC (EPA Method 24):** mixed | Unreduced: <250 g/L; 2.08 lb/gal<br>Reduced 10%: <300 g/L; 2.50 lb/gal |
| **Mix Ratio:** | 1:1 by volume |

**Recommended Spreading Rate per coat:**

| | Minimum | Maximum |
|---|---|---|
| **Wet mils** (microns) | **7.0** (175) | **13.5** (338) |
| **Dry mils** (microns) | **5.0*** (125) | **10.0*** (250) |
| **~Coverage sq ft/gal** (m²/L) | **116** (2.8) | **232** (5.7) |
| Theoretical coverage **sq ft/gal** (m²/L) @ 1 mil / 25 microns dft | **1152** (28.2) | |

*May be applied at 3.0-10.0 mils (75-250 microns) dft in a multi-coat system. Refer to Recommended Systems and Performance Tips Sections.

*NOTE: Brush or roll application may require multiple coats to achieve maximum film thickness and uniformity of appearance.*

**Drying Schedule @ 7.0 mils wet (175 microns):**

| | @ 35°F/1.7°C | @ 77°F/25°C *50% RH* | @ 100°F/38°C |
|---|---|---|---|
| **To touch:** | 4-5 hours | 2 hours | 1.5 hours |
| **To handle:** | 48 hours | 8 hours | 4.5 hours |
| **To recoat:** | | | |
| **minimum:** | 48 hours | 8 hours | 4.5 hours |
| **maximum:** | 1 year | 1 year | 1 year |
| **To cure:** | | | |
| **Service:** | 10 days | 7 days | 4 days |
| **Immersion:** | 14 days | 7 days | 4 days |

*If maximum recoat time is exceeded, abrade surface before recoating.*
*Drying time is temperature, humidity, and film thickness dependent.*
Paint temperature must be at least 40°F (4.5°C) minimum.

| | | | |
|---|---|---|---|
| **Pot Life:** | 10 hours | 4 hours | 2 hours |
| **Sweat-in-time:** | 30 minutes | 30 minutes | 15 minutes |

**When used as an intermediate coat as part of a multi-coat system:**

**Drying Schedule @ 5.0 mils wet (125 microns):**

| | @ 35°F/1.7°C | @ 77°F/25°C *50% RH* | @ 100°F/38°C |
|---|---|---|---|
| **To touch:** | 3 hours | 1 hour | 1 hour |
| **To handle:** | 48 hours | 4 hours | 2 hours |
| **To recoat:** | | | |
| **minimum:** | 16 hours | 4 hours | 2 hours |
| **maximum:** | 1 year | 1 year | 1 year |

### PRODUCT CHARACTERISTICS (CONT'D)

| | |
|---|---|
| **Shelf Life:** | 36 months, unopened<br>Store indoors at 40°F (4.5°C) to 110°F (43°C). |
| **Flash Point:** | 91°F (33°C), TCC, mixed |
| **Reducer/Clean Up:** | Reducer, R7K15 |
| In California: | Reducer R7K111 or Oxsol 100 |

### PERFORMANCE CHARACTERISTICS

**Substrate***: Steel
**Surface Preparation***: SSPC-SP10/NACE 2
**System Tested***:
1 ct. Macropoxy 646 Fast Cure @ 6.0 mils (150 microns) dft
*unless otherwise noted below

| Test Name | Test Method | Results |
|---|---|---|
| **Abrasion Resistance** | ASTM D4060, CS17 wheel, 1000 cycles, 1 kg load | 84 mg loss |
| **Accelerated Weathering-QUV**[1] | ASTM D4587, QUV-A, 12,000 hours | Passes |
| **Adhesion** | ASTM D4541 | 1,037 psi |
| **Corrosion Weathering**[1] | ASTM D5894, 36 cycles, 12,000 hours | Rating 10 per ASTM D714 for blistering; Rating 9 per ASTM D610 per rusting |
| **Nuclear Decontamination** | ASTM D4256/ANSI N 5.12 | 99% Water Wash; 95% Overall |
| **Direct Impact Resistance**[2] | ASTM D2794 Modified | **120 in. lb. |
| **Dry Heat Resistance** | ASTM D2485 | 250°F (121°C) |
| **Exterior Durability** | 1 year at 45° South | Excellent, chalks |
| **Flexibility** | ASTM D522, 180° bend, 3/4" mandrel | Passes |
| **Fuel Contribution** | NFPA 259 | 5764 btu/lb |
| **Humidity Resistance** | ASTM D4585, 6000 hours | No blistering, cracking, or rusting |
| **Immersion** | 1 year fresh and salt water | Passes, no rusting, blistering, or loss of adhesion |
| **Radiation Tolerance** | ASTM D4082 / ANSI 5.12 | Pass at 21 mils (525 microns) |
| **Pencil Hardness** | ASTM D3363 | 3H |
| **Salt Fog Resistance**[1] | ASTM B117, 6,500 hours | Rating 10 per ASTM D610 for rusting; Rating 9 per ASTM D1654 for corrosion |
| **Slip Coefficient, Mill White*** | AISC Specification for Structural Joints Using ASTM A325 or ASTM A490 Bolts | Class A, 0.36 |
| **Surface Burning** | ASTM E84/NFPA 255 | Flame Spread Index 20; Smoke Development Index 35 (at 18 mils or 450 microns) |
| **Water Vapor Permeance** | ASTM D1653, Method B | 1.16 US perms |

Epoxy coatings may darken or discolor following application and curing.
*Refer to Slip Certification document
** Performed on 1/16 inch blasted steel

Footnotes:
[1] *Zinc Clad II Plus Primer*
[2] *Two coats of* Macropoxy 646 Fast Cure Epoxy

### DISCLAIMER

The information and recommendations set forth in this Product Data Sheet are based upon tests conducted by or on behalf of The Sherwin-Williams Company. Such information and recommendations set forth herein are subject to change and pertain to the product offered at the time of publication. Consult your Sherwin-Williams representative to obtain the most recent Product Data Information and Application Bulletin.


continued on back

Protective & Marine Coatings

# MACROPOXY® 646 FAST CURE EPOXY

| | | |
|---|---|---|
| PART A | B58-600 | SERIES |
| PART B | B58V600 | HARDENER |

Revised: October 19, 2016

## PRODUCT INFORMATION

4.53

### RECOMMENDED USES

- Marine applications
- Fabrication shops
- Pulp and paper mills
- Power plants
- Offshore platforms
- Nuclear Power Plants
- Nuclear fabrication shops
- Refineries
- Chemical plants
- Tank exteriors
- Water treatment plants
- DOE Nuclear Fuel Facilities
- DOE Nuclear Weapons Facilities
- Mill White and Black are acceptable for immersion use for salt water and fresh water, not acceptable for potable water
- Suitable for use in USDA inspected facilities
- Acceptable for use in Canadian Food Processing facilities, categories: D1, D2, D3 (Confirm acceptance of specific part numbers/rexes with your SW Sales Representative)
- Conforms to AWWA D102 OCS #5
- Conforms to MPI # 108
- This product meets specific design requirements for non-safety related nuclear plant applications in Level II, III and Balance of Plant, and DOE nuclear facilities*.

* Nuclear qualifications are NRC license specific to the facility.

- Suitable for use in the Mining & Minerals Industry
- Acceptable for use over and/or under Loxon S1 and Loxon H1 Caulking

### RECOMMENDED SYSTEMS

| | | Dry Film Thickness / ct. Mils | (Microns) |
|---|---|---|---|
| **Immersion and atmospheric:** | | | |
| **Steel:** | | | |
| 2 cts. | Macropoxy 646 Fast Cure Epoxy | 5.0-10.0 | (125-250) |
| **Concrete/Masonry, smooth:** | | | |
| 2 cts. | Macropoxy 646 Fast Cure Epoxy | 5.0-10.0 | (125-250) |
| **Concrete Block:** | | | |
| 1 ct. | Kem Cati-Coat HS Epoxy Filler/Sealer *as needed to fill voids and provide a continuous substrate.* | 10.0-20.0 | (250-500) |
| 2 cts. | Macropoxy 646 Fast Cure Epoxy | 5.0-10.0 | (125-250) |
| **Atmospheric:** | | | |
| **Steel:** (Shop applied system, new construction, AWWA D102, can also be used at 3 mils / 75 microns minimum dft when used as an intermediate coat as part of a multi-coat system) | | | |
| 1 ct. | Macropoxy 646 Fast Cure Epoxy | 3.0-6.0 | (75-150) |
| 1-2 cts. | of recommended topcoat | | |
| **Steel:** | | | |
| 1 ct. | Recoatable Epoxy Primer | 4.0-6.0 | (100-150) |
| 2 cts. | Macropoxy 646 Fast Cure Epoxy | 5.0-10.0 | (125-250) |
| **Steel:** | | | |
| 1 ct. | Macropoxy 646 Fast Cure Epoxy | 5.0-10.0 | (125-250) |
| 1-2 cts. | Acrolon 218 Polyurethane | 3.0-6.0 | (75-150) |
| *or* | Hi-Solids Polyurethane | 3.0-5.0 | (75-125) |
| *or* | SherThane 2K Urethane | 2.0-4.0 | (50-100) |
| *or* | Hydrogloss | 2.0-4.0 | (50-100) |
| **Steel:** | | | |
| 2 cts. | Macropoxy 646 Fast Cure Epoxy | 5.0-10.0 | (125-250) |
| 1-2 cts. | Tile-Clad HS Epoxy | 2.5-4.0 | (63-100) |
| **Steel:** | | | |
| 1 ct. | Zinc Clad II Plus | 2.0-4.0 | (50-100) |
| 1 ct. | Macropoxy 646 Fast Cure Epoxy | 3.0-10.0 | (755-250) |
| 1-2 cts. | Acrolon 218 Polyurethane | 3.0-6.0 | (75-150) |
| **Steel:** | | | |
| 1 ct. | Zinc Clad III HS | 3.0-5.0 | (75-125) |
| *or* | Zinc Clad IV | 3.0-5.0 | (75-125) |
| 1 ct. | Macropoxy 646 Fast Cure Epoxy | 3.0-10.0 | (75-250) |
| 1-2 cts. | Acrolon 218 Polyurethane | 3.0-6.0 | (75-150) |
| **Aluminum:** | | | |
| 2 cts. | Macropoxy 646 Fast Cure Epoxy | 2.0-4.0 | (50-100) |
| **Galvanizing:** | | | |
| 2 cts. | Macropoxy 646 Fast Cure Epoxy | 2.0-4.0 | (50-100) |
| **FIRETEX M89/02, M90, M90/02, and M93/02:** | | | |
| **Steel & Galvanized Substrates being primed for FIRETEX only:** | | | |
| 1 ct. | Macropoxy 646 Fast Cure Epoxy | 2.0-5.0 | (50-125) |

The systems listed above are representative of the product's use, other systems may be appropriate.

### SURFACE PREPARATION

Surface must be clean, dry, and in sound condition. Remove all oil, dust, grease, dirt, loose rust, and other foreign material to ensure adequate adhesion.

Refer to product Application Bulletin for detailed surface preparation information.

Minimum recommended surface preparation:

Iron & Steel
- Atmospheric: SSPC-SP2/3 or SSPC-SP WJ-2/NACE WJ-2L
- Immersion: SSPC-SP10/NACE 2, 2-3 mil (50-75 micron) profile or SSPC-SP WJ-3/NACE WJ-3L

Aluminum: SSPC-SP1

Galvanizing: SSPC-SP1; See Surface Preparations section on page 3 for application of FIRETEX intumescent coating systems

Concrete & Masonry
- Atmospheric: SSPC-SP13/NACE 6, or ICRI No. 310.2R, CSP 1-3
- Immersion: SSPC-SP13/NACE 6-4.3.1 or 4.3.2, or ICRI No. 310.2R, CSP 2-4

**Surface Preparation Standards**

| | Condition of Surface | ISO 8501-1 BS7079:A1 | SSPC | NACE |
|---|---|---|---|---|
| White Metal | | Sa 3 | SP 5 | 1 |
| Near White Metal | | Sa 2.5 | SP 10 | 2 |
| Commercial Blast | | Sa 2 | SP 6 | 3 |
| Brush-Off Blast | | Sa 1 | SP 7 | 4 |
| Hand Tool Cleaning | Rusted | C St 2 | SP 2 | - |
| | Pitted & Rusted | D St 2 | SP 2 | - |
| Power Tool Cleaning | Rusted | C St 3 | SP 3 | - |
| | Pitted & Rusted | D St 3 | SP 3 | - |

### TINTING

Tint Part A with Maxitoners at 150% strength. Five minutes minimum mixing on a mechanical shaker is required for complete mixing of color.

Tinting is not recommended for immersion service.

### APPLICATION CONDITIONS

Temperature: 35°F (1.7°C) minimum, 120°F (49°C) maximum (air and surface)
40°F (4.5°C) minimum, 120°F (49°C) maximum (material)
At least 5°F (2.8°C) above dew point

Relative humidity: 85% maximum

Refer to product Application Bulletin for detailed application information.

### ORDERING INFORMATION

Packaging:
- Part A: 1 gallon (3.78L) and 5 gallon (18.9L) containers
- Part B: 1 gallon (3.78L) and 5 gallon (18.9L) containers

Weight: 12.9 ± 0.2 lb/gal ; 1.55 Kg/L mixed, may vary by color

### SAFETY PRECAUTIONS

Refer to the MSDS sheet before use.

Published technical data and instructions are subject to change without notice. Contact your Sherwin-Williams representative for additional technical data and instructions.

### WARRANTY

The Sherwin-Williams Company warrants our products to be free of manufacturing defects in accord with applicable Sherwin-Williams quality control procedures. Liability for products proven defective, if any, is limited to replacement of the defective product or the refund of the purchase price paid for the defective product as determined by Sherwin-Williams. NO OTHER WARRANTY OR GUARANTEE OF ANY KIND IS MADE BY SHERWIN-WILLIAMS, EXPRESSED OR IMPLIED, STATUTORY, BY OPERATION OF LAW OR OTHERWISE, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE.

Protective & Marine Coatings

SHERWIN WILLIAMS

# MACROPOXY® 646 FAST CURE EPOXY

| | | |
|---|---|---|
| PART A | B58-600 | SERIES |
| PART B | B58V600 | HARDENER |

Revised: October 19, 2016

## APPLICATION BULLETIN

4.53

### SURFACE PREPARATIONS

Surface must be clean, dry, and in sound condition. Remove all oil, dust, grease, dirt, loose rust, and other foreign material to ensure adequate adhesion.

**Iron & Steel, Atmospheric Service:**
Minimum surface preparation is Hand Tool Clean per SSPC-SP2. Remove all oil and grease from surface by Solvent Cleaning per SSPC-SP1. For better performance, use Commercial Blast Cleaning per SSPC-SP6/NACE 3, blast clean all surfaces using a sharp, angular abrasive for optimum surface profile (2 mils / 50 microns). Prime any bare steel within 8 hours or before flash rusting occurs.

**Iron & Steel, Immersion Service:**
Remove all oil and grease from surface by Solvent Cleaning per SSPC-SP1. Minimum surface preparation is Near White Metal Blast Cleaning per SSPC-SP10/NACE 2. Blast clean all surfaces using a sharp, angular abrasive for optimum surface profile (2-3 mils / 50-75 microns). Remove all weld spatter and round all sharp edges by grinding. Prime any bare steel the same day as it is cleaned.

**Aluminum**
Remove all oil, grease, dirt, oxide and other foreign material by Solvent Cleaning per SSPC-SP1.

**Galvanized Steel**
Allow to weather a minimum of six months prior to coating. Solvent Clean per SSPC-SP1 (recommended solvent is VM&P Naphtha). When weathering is not possible, or the surface has been treated with chromates or silicates, first Solvent Clean per SSPC-SP1 and apply a test patch. Allow paint to dry at least one week before testing adhesion. If adhesion is poor, brush blasting per SSPC-SP7 is necessary to remove these treatments. Rusty galvanizing requires a minimum of Hand Tool Cleaning per SSPC-SP2, prime the area the same day as cleaned. In preparing galvanized steel substrates for the application of FIRETEX intumescent coating systems, Surface Preparation Specification SSPC-SP 16 must be followed obtaining a surface profile of minimum 1.5 mils (38 microns). Optimum surface profile will not exceed 2.0 mils (50 microns).

**Concrete and Masonry**
For surface preparation, refer to SSPC-SP13/NACE 6, or ICRI No. 310.2R, CSP 1-3. Surfaces should be thoroughly clean and dry. Concrete and mortar must be cured at least 28 days @ 75°F (24°C). Remove all loose mortar and foreign material. Surface must be free of laitance, concrete dust, dirt, form release agents, moisture curing membranes, loose cement and hardeners. Fill bug holes, air pockets and other voids with Steel-Seam FT910.

**Concrete, Immersion Service:**
For surface preparation, refer to SSPC-SP13/NACE 6, Section 4.3.1 or 1.3.2 or ICRI No. 310.2R, CSP 2-4.

**Follow the standard methods listed below when applicable:**
ASTM D4258 Standard Practice for Cleaning Concrete.
ASTM D4259 Standard Practice for Abrading Concrete.
ASTM D4260 Standard Practice for Etching Concrete.
ASTM F1869 Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete.
SSPC-SP 13/Nace 6 Surface Preparation of Concrete.
ICRI No. 310.2R Concrete Surface Preparation.

**Previously Painted Surfaces**
If in sound condition, clean the surface of all foreign material. Smooth, hard or glossy coatings and surfaces should be dulled by abrading the surface. Apply a test area, allowing paint to dry one week before testing adhesion. If adhesion is poor, or if this product attacks the previous finish, removal of the previous coating may be necessary. If paint is peeling or badly weathered, clean surface to sound substrate and treat as a new surface as above.

**Surface Preparation Standards**

| | Condition of Surface | ISO 8501-1 BS7079:A1 | SSPC | NACE |
|---|---|---|---|---|
| White Metal | | Sa 3 | SP 5 | 1 |
| Near White Metal | | Sa 2.5 | SP 10 | 2 |
| Commercial Blast | | Sa 2 | SP 6 | 3 |
| Brush-Off Blast | | Sa 1 | SP 7 | 4 |
| Hand Tool Cleaning | Rusted | C St 2 | SP 2 | - |
| | Pitted & Rusted | D St 2 | SP 2 | - |
| Power Tool Cleaning | Rusted | C St 3 | SP 3 | - |
| | Pitted & Rusted | D St 3 | SP 3 | - |

### APPLICATION CONDITIONS

| | |
|---|---|
| Temperature: | 35°F (1.7°C) minimum, 120°F (49°C) maximum (air and surface)<br>40°F (4.5°C) minimum, 120°F (49°C) maximum (material)<br>At least 5°F (2.8°C) above dew point |
| Relative humidity: | 85% maximum |

### APPLICATION EQUIPMENT

The following is a guide. Changes in pressures and tip sizes may be needed for proper spray characteristics. Always purge spray equipment before use with listed reducer. Any reduction must be compliant with existing VOC regulations and compatible with the existing environmental and application conditions.

**Reducer/Clean Up** ...........Reducer R7K15
In California...................Reducer R7K111

**Airless Spray**
Pump.............................30:1
Pressure.........................2800 - 3000 psi
Hose..............................1/4" ID
Tip ..................................017" - .023"
Filter..............................60 mesh
Reduction.......................As needed up to 10% by volume

**Conventional Spray**
Gun ...............................DeVilbiss MBC-510
Fluid Tip .........................E
Air Nozzle.......................704
Atomization Pressure.....60-65 psi
Fluid Pressure...............10-20 psi
Reduction.......................As needed up to 10% by volume
Requires oil and moisture separators

**Brush**
Brush.............................Nylon/Polyester or Natural Bristle
Reduction.......................As needed up to 10% by volume

**Roller**
Cover ............................3/8" woven with solvent resistant core
Reduction.......................As needed up to 10% by volume

**Plural Component Spray**...Acceptable
Refer to April 2010 Technical Bulletin - "Application Guidelines for Macropoxy 646 Fast Cure Epoxy & Recoatable Epoxy Primer Utilizing Plural Component Equipment"
If specific application equipment is not listed above, equivalent equipment may be substituted.


continued on back

Protective & Marine Coatings

# MACROPOXY® 646 FAST CURE EPOXY

| | | |
|---|---|---|
| Part A | B58-600 | Series |
| Part B | B58V600 | Hardener |

Revised: October 19, 2016

## Application Bulletin

4.53

### Application Procedures

Surface preparation must be completed as indicated.

Mix contents of each component thoroughly with low speed power agitation. Make certain no pigment remains on the bottom of the can. Then combine one part by volume of Part A with one part by volume of Part B. Thoroughly agitate the mixture with power agitation. Allow the material to sweat-in as indicated prior to application. Re-stir before using.

If reducer solvent is used, add only after both components have been thoroughly mixed, after sweat-in.

Apply paint at the recommended film thickness and spreading rate as indicated below:

**Recommended Spreading Rate per coat:**

| | Minimum | Maximum |
|---|---|---|
| **Wet mils** (microns) | **7.0** (175) | **13.5** (338) |
| **Dry mils** (microns) | **5.0*** (125) | **10.0*** (250) |
| **~Coverage sq ft/gal** ($m^2$/L) | **116** (2.8) | **232** (5.7) |
| Theoretical coverage **sq ft/gal** ($m^2$/L) @ 1 mil / 25 microns dft | **1152** (28.2) | |

*May be applied at 3.0-10.0 mils (75-250 microns) dft in a multi-coat system. Refer to Recommended Systems and Performance Tips Sections.

*NOTE: Brush or roll application may require multiple coats to achieve maximum film thickness and uniformity of appearance.*

**Drying Schedule @ 7.0 mils wet (175 microns):**

| | @ 35°F/1.7°C | @ 77°F/25°C *50% RH* | @ 100°F/38°C |
|---|---|---|---|
| **To touch:** | 4-5 hours | 2 hours | 1.5 hours |
| **To handle:** | 48 hours | 8 hours | 4.5 hours |
| **To recoat:** | | | |
| **minimum:** | 48 hours | 8 hours | 4.5 hours |
| **maximum:** | 1 year | 1 year | 1 year |
| **To cure:** | | | |
| **Service:** | 10 days | 7 days | 4 days |
| **Immersion:** | 14 days | 7 days | 4 days |

*If maximum recoat time is exceeded, abrade surface before recoating.*

*Drying time is temperature, humidity, and film thickness dependent.*

Paint temperature must be at least 40°F (4.5°C) minimum.

| | | | |
|---|---|---|---|
| **Pot Life:** | 10 hours | 4 hours | 2 hours |
| **Sweat-in-time:** | 30 minutes | 30 minutes | 15 minutes |

**When used as an intermediate coat as part of a multi-coat system:**

**Drying Schedule @ 5.0 mils wet (125 microns):**

| | @ 35°F/1.7°C | @ 77°F/25°C *50% RH* | @ 100°F/38°C |
|---|---|---|---|
| **To touch:** | 3 hours | 1 hour | 1 hour |
| **To handle:** | 48 hours | 4 hours | 2 hours |
| **To recoat:** | | | |
| **minimum:** | 16 hours | 4 hours | 2 hours |
| **maximum:** | 1 year | 1 year | 1 year |

Application of coating above maximum or below minimum recommended spreading rate may adversely affect coating performance.

### Clean Up Instructions

Clean spills and spatters immediately with Reducer R7K15. Clean tools immediately after use with Reducer R7K15. In California use Reducer R7K111. Follow manufacturer's safety recommendations when using any solvent.

### Performance Tips

Stripe coat all crevices, welds, and sharp angles to prevent early failure in these areas.

When using spray application, use a 50% overlap with each pass of the gun to avoid holidays, bare areas, and pinholes. If necessary, cross spray at a right angle

Spreading rates are calculated on volume solids and do not include an application loss factor due to surface profile, roughness or porosity of the surface, skill and technique of the applicator, method of application, various surface irregularities, material lost during mixing, spillage, overthinning, climatic conditions, and excessive film build.

Excessive reduction of material can affect film build, appearance, and adhesion.

Do not mix previously catalyzed material with new.

Do not apply the material beyond recommended pot life.

In order to avoid blockage of spray equipment, clean equipment before use or before periods of extended downtime with Reducer R7K15. In California use Reducer R7K111.

Tinting is not recommended for immersion service.

Use only Mill White and Black for immersion service.

Insufficient ventilation, incomplete mixing, miscatalyzation, and external heaters may cause premature yellowing.

Excessive film build, poor ventilation, and cool temperatures may cause solvent entrapment and premature coating failure.

Quik-Kick Epoxy Accelerator is acceptable for use. See data page 4.99 for details.

When coating over aluminum and galvanizing, recommended dft is 2-4 mils (50-100 microns).

Acceptable for Concrete Floors.

Can be used as a metalizing sealer. Consult Technical Bulletin - Sealers for Thermal Spray Metalizing, or your local Sherwin-Williams representative.

Refer to Product Information sheet for additional performance characteristics and properties.

### Safety Precautions

Refer to the MSDS sheet before use.

Published technical data and instructions are subject to change without notice. Contact your Sherwin-Williams representative for additional technical data and instructions.

### Disclaimer

The information and recommendations set forth in this Product Data Sheet are based upon tests conducted by or on behalf of The Sherwin-Williams Company. Such information and recommendations set forth herein are subject to change and pertain to the product offered at the time of publication. Consult your Sherwin-Williams representative to obtain the most recent Product Data Information and Application Bulletin.

### Warranty

The Sherwin-Williams Company warrants our products to be free of manufacturing defects in accord with applicable Sherwin-Williams quality control procedures. Liability for products proven defective, if any, is limited to replacement of the defective product or the refund of the purchase price paid for the defective product as determined by Sherwin-Williams. NO OTHER WARRANTY OR GUARANTEE OF ANY KIND IS MADE BY SHERWIN-WILLIAMS, EXPRESSED OR IMPLIED, STATUTORY, BY OPERATION OF LAW OR OTHERWISE, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE.

# Appendix BB: Vendor Supplied Component Specifications

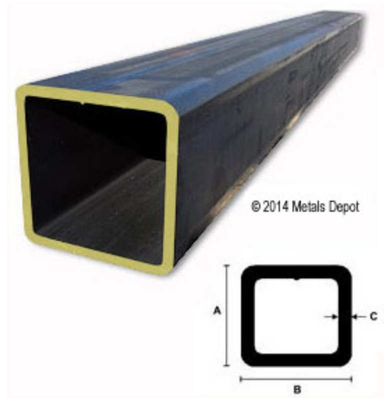
## Steel Scaled Prototype (Metals Depot)

### Vertical Columns and Stability Struts

Email Friend

## Square Steel Tube A513 / A500

**Square Steel Tube** is a welded structural grade tubing that is available in either type A513 or A500 Grade B, depending on its size and wall thickness. Either grade is ideal for all structural applications, general fabrication, manufacturing and repairs. Steel square tube is widely used in industrial maintenance, agricultural implements, transportation equipment, truck beds, trailers, frames, etc. Its box-shape configuration allows for much greater strength and rigidity compared to angles or channels. This steel shape is easy to weld, cut, form and machine with the proper equipment and knowledge. Metals Depot stocks hundreds of sizes of square tube at wholesale prices in ready to ship precut and mill lengths or you can order just what you need custom Cut to Size in any quantity.




**SPECIFICATIONS:** ASTM A513 (1020-1026); ASTM A500 Grade B

**FINISH:** A513 - Dark Blue/Black, smooth slight oil coating;
A500 - Blue/Dark Gray, slighty grainy, dry

**MECHANICAL PROPERTIES:**
Yield Point = 72 ksi (A513); 46 ksi (A500)
Tensile Strength = 87 ksi (A513); 58 ksi (A500)
Elongation in 2" = 10% (A513); 23% (A500)
Outside Corner Radius = 3X wall max.

**CHEMICAL PROPERTIES:**
Iron - 99%,
Carbon - .05%-.23%,
Manganese - .3%-.6% Max,
Phosphorous - .04% Max,
Sulfur - .04% Max

**AVAILABLE STOCK SIZES:**
2ft, 4ft. 6ft, 8ft, 12ft, 24ft, or Cut to Size
*Stock lengths may vary +/- 1/4"*

**HOW TO MEASURE:**
Height (A) X Width (B) X Wall Thickness (C) X Length

### Short Feet, Long Feet, End Caps, Gussets

Email Friend

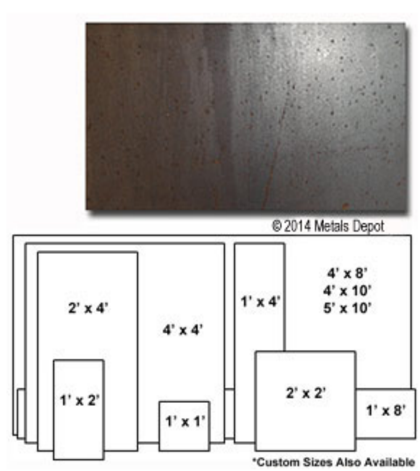
## Steel Plate

**Steel Plate**, also known as Hot Rolled A36 Steel Plate is a structural quality steel plate used for a large variety of general construction and industrial applications.

- Specifications: ASTM A36, AISI A-36
- Applications: base plates, gussets, liners, road plates, trench covers, etc.
- Workability: Easy to Weld, Cut, Form and Machine
- Mechanical Properties: Magnetic, Brinell = 112, Tensile = 58,000 +/-, Yield = 36,000 +/-
- How is it Measured? thickness X width X length
- Available Stock Sizes: 1ft x 1ft, 1ft x 2ft, 2ft x 2ft, 2ft x 4ft, 4ft x 4ft, 4ft x 8ft, 5ft x 10ft or Cut to Size and Custom Shapes

Ordering Note: Stock sizes may vary +/- 1/8". Please call if you need specific sizes. Mill tolerances on thickness & flatness applies.

**Need thinner material? Click Here for Steel Sheet**




| Stock Number | Product Type | Item Size & Description (inches) | Weight (lbs. / ft.) | Click! Arrow to Select Size | Qty | Select / Price |
|---|---|---|---|---|---|---|
| P1316 | A36 Steel Plate | 3/16 inch THICK | 7.66 | Select ... | 1 | Get Price |

## Appendix BB: Vendor Supplied Component Specifications

**I-Beam:**

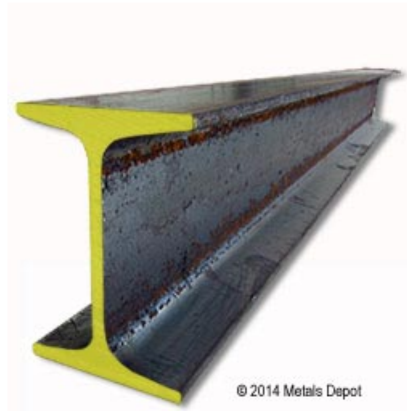
Email Friend

# Steel Beams

## Structural Steel "H" Beam

**Wide Flange Steel Beams**, aka W Beam or H Beams have non-tapered flanges that are wider than the Standard "S" or "I" beams.

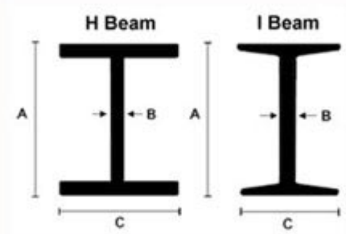
- Specifications:ASTM A-992 / A572 Gr. 50, the standard specification for steel structural shapes for use in building framing.
- Applications:House & building construction, trailer & truck bed framing, mezzanines, platforms, machine bases, bridges, etc.
- Mechanical Properties: Tensile = 65,000 PSI, Yield = 50,000 PSI, Brinell Hardness = 143 (+/-)
- How is it Measured?Height(A) X Web (B) X Flange (C) X Length
- Available Stock Sizes: 5ft, 10ft, 20ft or Cut to Size




## Structural Steel "I" Beam

**Standard American Beams,** aka Junior Beam, S Beam, or I Beams have tapered flanges for increased strength of the flanges compared to the wide flange or "H" beams.

- Specifications:ASTM A36 / A572 Gr. 50, the standard specification for steel structural shapes for use in general construction.
- Applications:Trolley ways, lifts, hoists, house & building construction, trailer & truck bed framing, mezzanines, etc.
- Mechanical Properties: Tensile = 60/80,000 PSI, Yield = 36,000 PSI, Brinell Hardness = 137 (+/-)
- How is it Measured?Height(A) X Web (B) X Flange (C) X Length
- Available Stock Sizes: 5ft,10ft, 20ft or Cut to Size




***Just give us a call if you need assistance!***

**Unable to add product to cart:**

- **Please select a length for item B1357**

| Stock Number | Product Type | Item Size & Description A x B x C (Inches) | Weight (lbs. / ft.) | Click! Arrow to Select Size | Qty | Select / Price |
|---|---|---|---|---|---|---|
| B1357 | A36/A572-50 Steel I Beam | S 3 x 5.7 lb (3.00" x .170" x 2.33") | 6.00 | Select ... | 1 | Get Price |

**Appendix BB: Vendor Supplied Component Specifications**

**Hexagonal Nut ¼-20, Grade 8, Yellow Zinc:**

Crown Bolt Hexagonal Nut, 1/4-20, Grade 8, Yellow Zinc, 50/Box

SKU: 1749779

Price $3.49

**In Store Only**

Hex nuts are for general applications and are used with bolts and washers of the same finish.

More Product Information

**Hexagonal Nut ¼-13, Grade 8, Yellow Zinc:**

Crown Bolt Hexagonal Nut, 1/2-13, Grade 8, Yellow Zinc, 25/Box

SKU: 1749811

Price $4.99

**In Store Only**

Hex nuts are for general applications and are used with bolts and washers of the same finish.

More Product Information

**Appendix BB: Vendor Supplied Component Specifications**

**Cap Screw, ½-13 x 1 inch, Coarse, Grade 8:**

Crown Bolt Cap Screw, 1/2-13 x 1 Inch, Coarse, Grade 8, Yellow Zinc, 25/Box

SKU: 1748946

Price $15.79

**In Store Only**

These yellow zinc-plated steel hex head cap screws can help you finish a variety of fastening jobs with ease.

More Product Information

**Cap Screw, ½-20 x 2-1/2 inch, Coarse, Grade 8:**

Crown Bolt Cap Screw, 1/4-20 x 2-1/2 Inch, Coarse, Grade 8, Yellow Zinc, 25/Box

SKU: 1748680

Price $0.12

**In Store Only**

These yellow zinc-plated steel hex head cap screws can help you finish a variety of fastening jobs with ease.

More Product Information

# Very Easy-to-Machine 1215 Carbon Steel
## Square Bar, 1-1/2" Square

4416T51

| | |
|---|---|
| Material | 1215 Carbon Steel |
| Cross Section Shape | Rectangle |
| Construction | Solid |
| Appearance | Plain |
| Thickness | 1 1/2" |
| Thickness Tolerance | -0.003" to 0" |
| Tolerance Rating | Undersized |
| Width | 1 1/2" |
| Width Tolerance | -0.003" to 0" |
| Yield Strength | 60,000 psi |
| Fabrication | Cold Worked |
| Temper Rating | Hardened |
| Hardness | Rockwell B85 |
| Hardness Rating | Medium |
| Heat Treatable | Yes |
| Maximum Hardness after Heat Treatment | Not Rated |
| Temperature Range | Not Rated |
| Specifications Met | ASTM A108 |
| Straightness Tolerance | Not Rated |
| Density | 0.28 lbs./cu. in. |
| Elongation | 10% |
| Material Composition | |
| Iron | 98.42-98.95% |
| Carbon | 0.09% Max. |
| Manganese | 0.75-1.05% |
| Phosphorus | 0.04-0.09% |
| Sulfur | 0.26-0.35% |

McMASTER-CARR®

# Zinc Yellow-Chromate Plated Hex Head Screw

## Grade 8 Steel, 1/2"-20 Thread Size, 2" Long, Partially Threaded

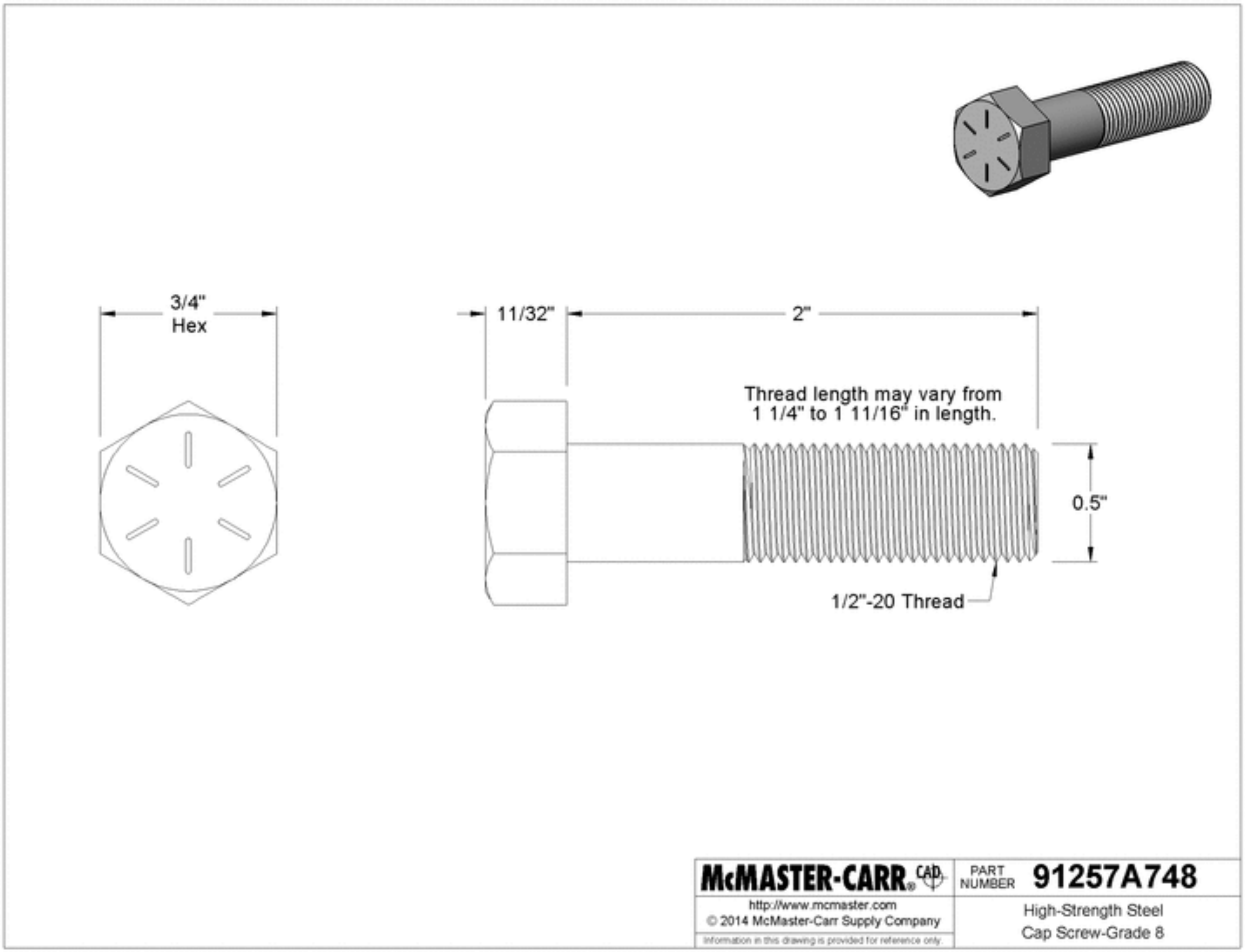
In stock
$11.90 per pack of 10
91257A748

| | |
|---|---|
| Thread Size | 1/2"-20 |
| Length | 2" |
| Threading | Partially Threaded |
| Minimum Thread Length | 1 1/4" |
| Head Width | 3/4" |
| Head Height | 11/32" |
| Material | Zinc Yellow-Chromate Plated Steel |
| Fastener Strength Grade/Class | Grade 8 |
| Hardness | Rockwell C33 |
| Tensile Strength | 150,000 psi |
| Screw Size Decimal Equivalent | 0.500" |
| Thread Type | UNF |
| Thread Spacing | Fine |
| Thread Fit | Class 2A |
| Thread Direction | Right Hand |
| Head Type | Hex |
| Hex Head Profile | Standard |
| Drive Style | External Hex |
| Specifications Met | ASME B18.2.1, SAE J429 |
| System of Measurement | Inch |

| | |
|---|---|
| RoHS | Compliant |

Good for demanding applications such as suspension systems, these screws are at least 25% stronger than medium-strength steel screws. Length is measured from under the head.

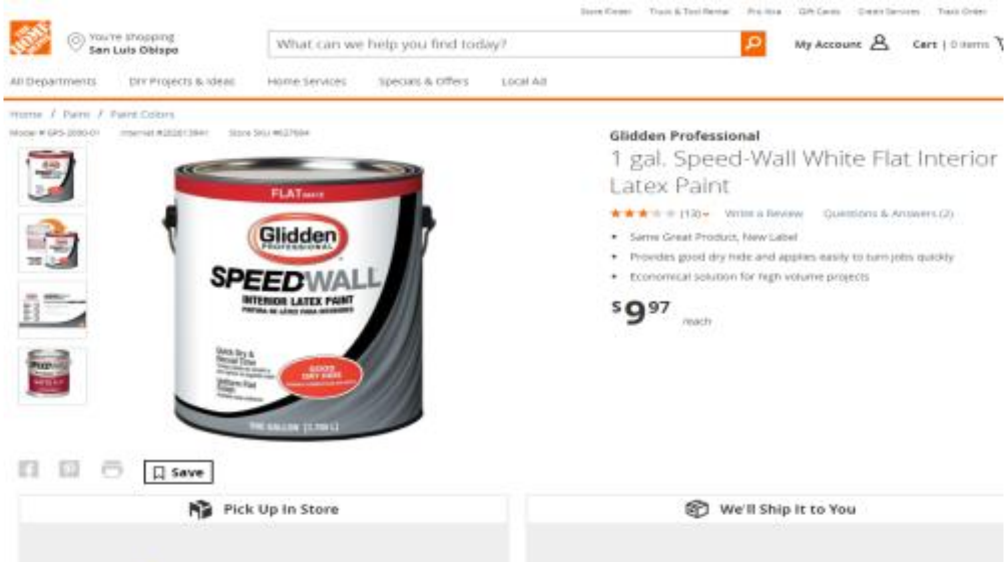
Zinc yellow-chromate plated steel screws resist corrosion in wet environments.



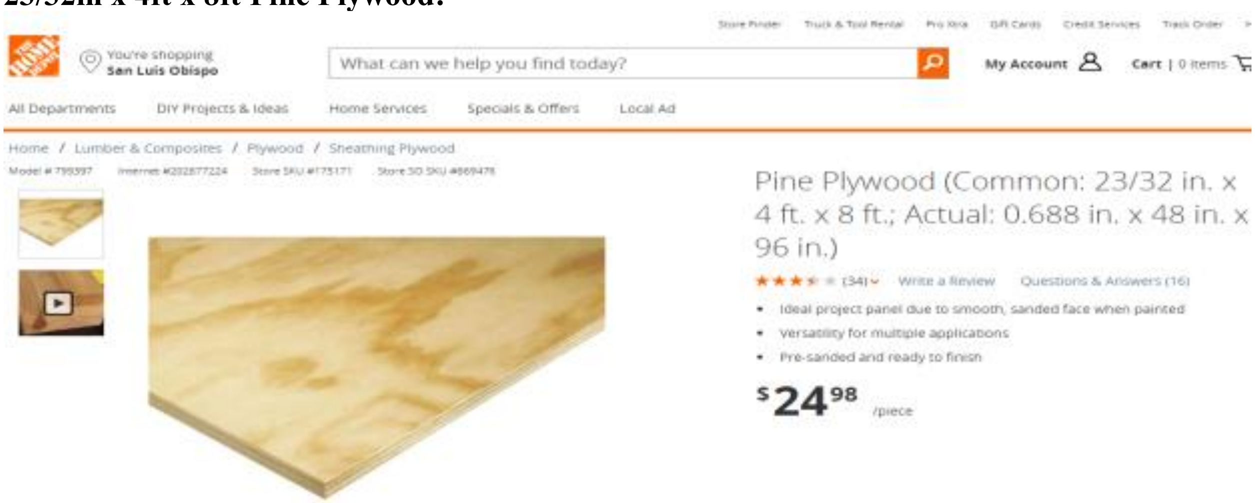

The information in this 3-D model is provided for reference only.

## Wooden Full-Scale Prototype (Home Depot)

**Paint:**

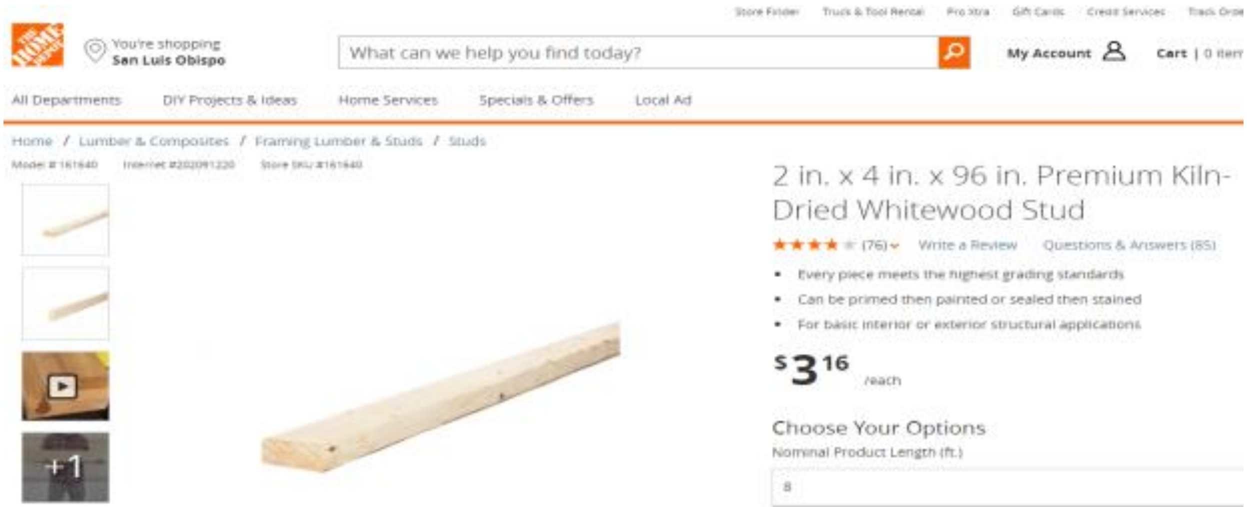



**23/32in x 4ft x 8ft Pine Plywood:**



**Appendix BB: Vendor Supplied Component Specifications**

**2 in x 4 in x 96 in Premium Kiln-Dried Whitewood Stud:**




**15/32 in x 2 ft x 2 ft BC Sanded Plywood:**

## Appendix BB: Vendor Supplied Component Specifications

### 4 in x 4 in x 12 ft Prime #2 and Better Douglass Fir Lumber:

4 in. x 4 in. x 12 ft. Prime #2 and Better Douglas Fir Lumber
Model# 603759
(2)
$13.96 /piece

### 1 1/4 in Philips Bugle-head Coarse Thread Sharp Point Drywall Screw:

3 Options Available

**Grip-Rite** #6 x 1-1/4 in. Philips Bugle-Head Coarse Thread Sharp Point Drywall Screws (1 lb -Pack)
Model# 114CDWS1
(25)
Was $3.78
$3.58

## Appendix BB: Vendor Supplied Component Specifications

### 3 in Powerlag Hex Drive Washer Head Lag Screw:

**SPAX** 1/4 in. x 3 in. Powerlag Hex Drive Washer Head Zinc Coated Lag Screw

Model# 4571010700757

★★★★★ (1)

25¢

### 3 in Flathead Partial Thread Multi-Material Screw:

**SPAX** #10 x 3 in. T-Star Drive Flat-Head Partial Thread Yellow Zinc Coated Multi-Material Screw (72 per Box)

Model# 4191020500756

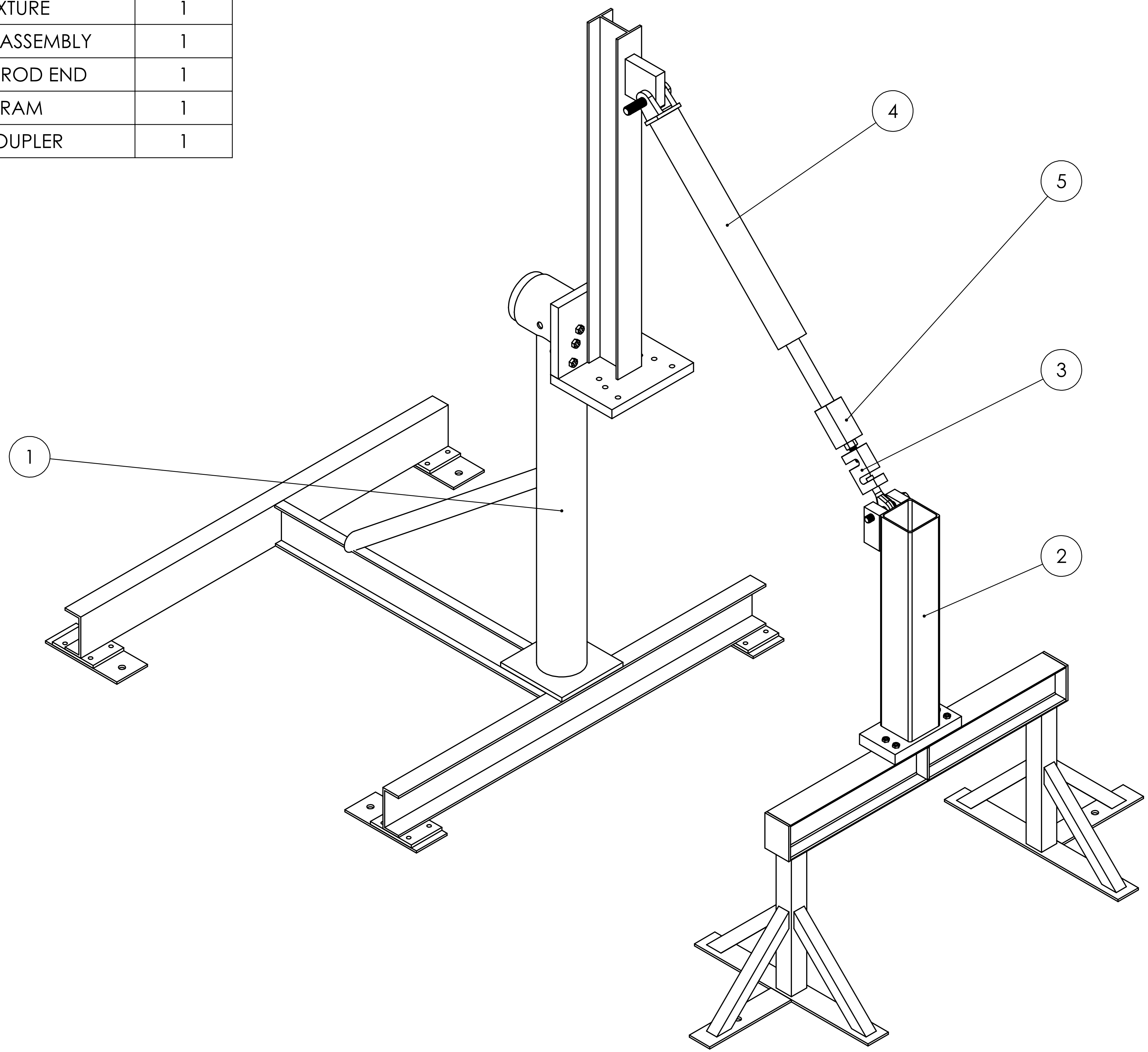
★★★★☆ (12)

$7.97

| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | S000 | REACTION FIXTURE | 1 |
| 2 | B000 | STRUCTURAL TEST ASSEMBLY | 1 |
| 3 | Load Cell | LOAD CELL AND ROD END | 1 |
| 4 | Ram | HYDRAULIC RAM | 1 |
| 5 | LC00 | LOAD CELL COUPLER | 1 |

NOTE:

BOLTS AND T-NUT USED TO CONNECT REACTION FIXTURE AND SCALE D SAWHORSE TO THE STRONG FLOOR NOT SHOWN





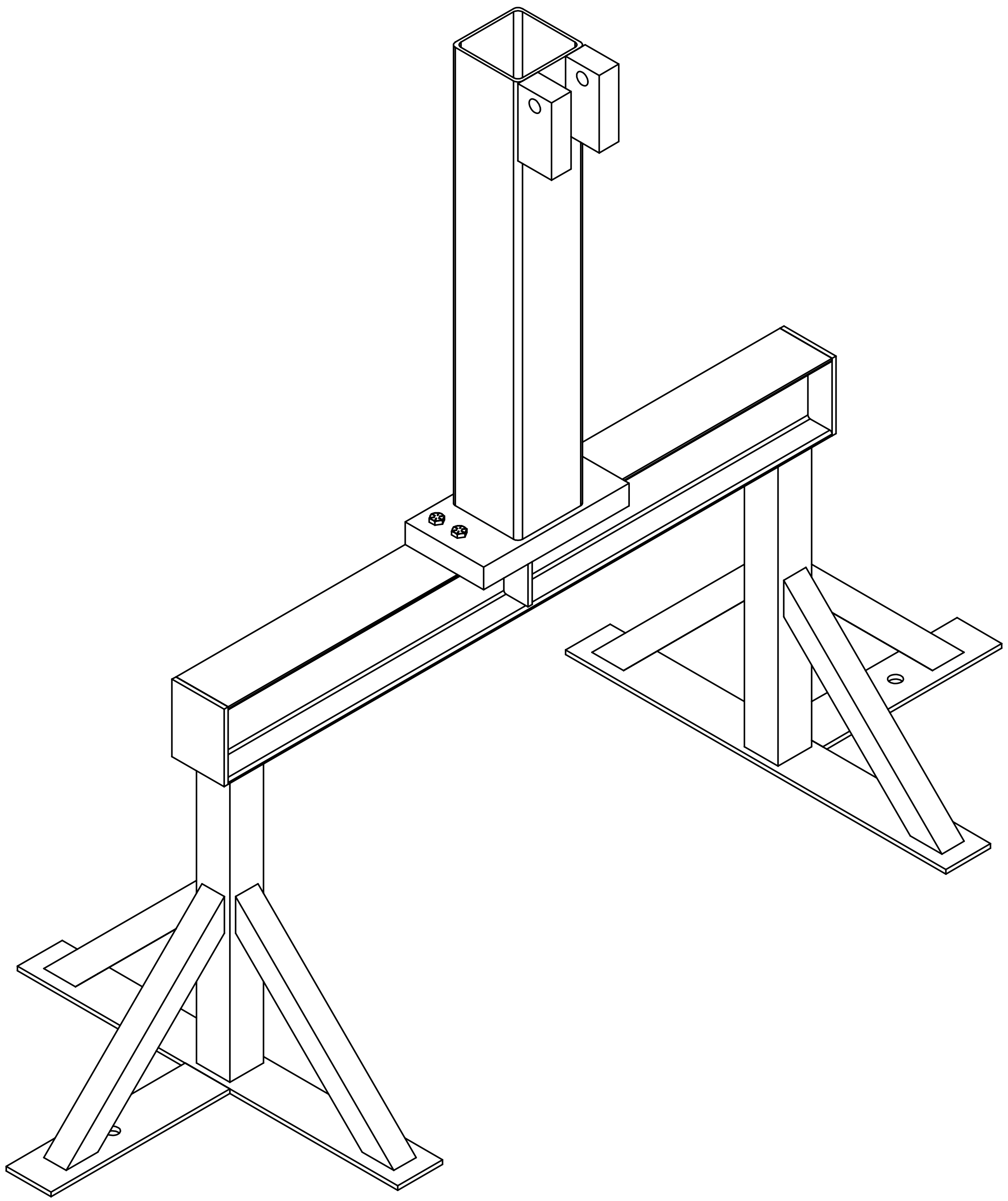

| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: TEST SET UP | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: 0000 | Date: 4/30/2017 | Scale: 1:8 | Advisor: EILEEN ROSSMAN |

| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | BA00 | SAWHORSE | 1 |
| 2 | BB00 | FIXTURE | 1 |
| 3 | 91286A111 | HIGH STRENGTH BOLT | 4 |
| 4 | 90499A029 | HIGH STRENGTH NUT | 4 |



NOTE:

1. STEEL SCALE MODEL USED FOR SEISMIC STRENGTH VALIDATION
2. ALL MATERIAL A36 STEEL UNLESS OTHERWISE SPECIFIED
3. ALL HARDWARE NUMBERS ARE MCMASTER-CARR PART NUMBERS



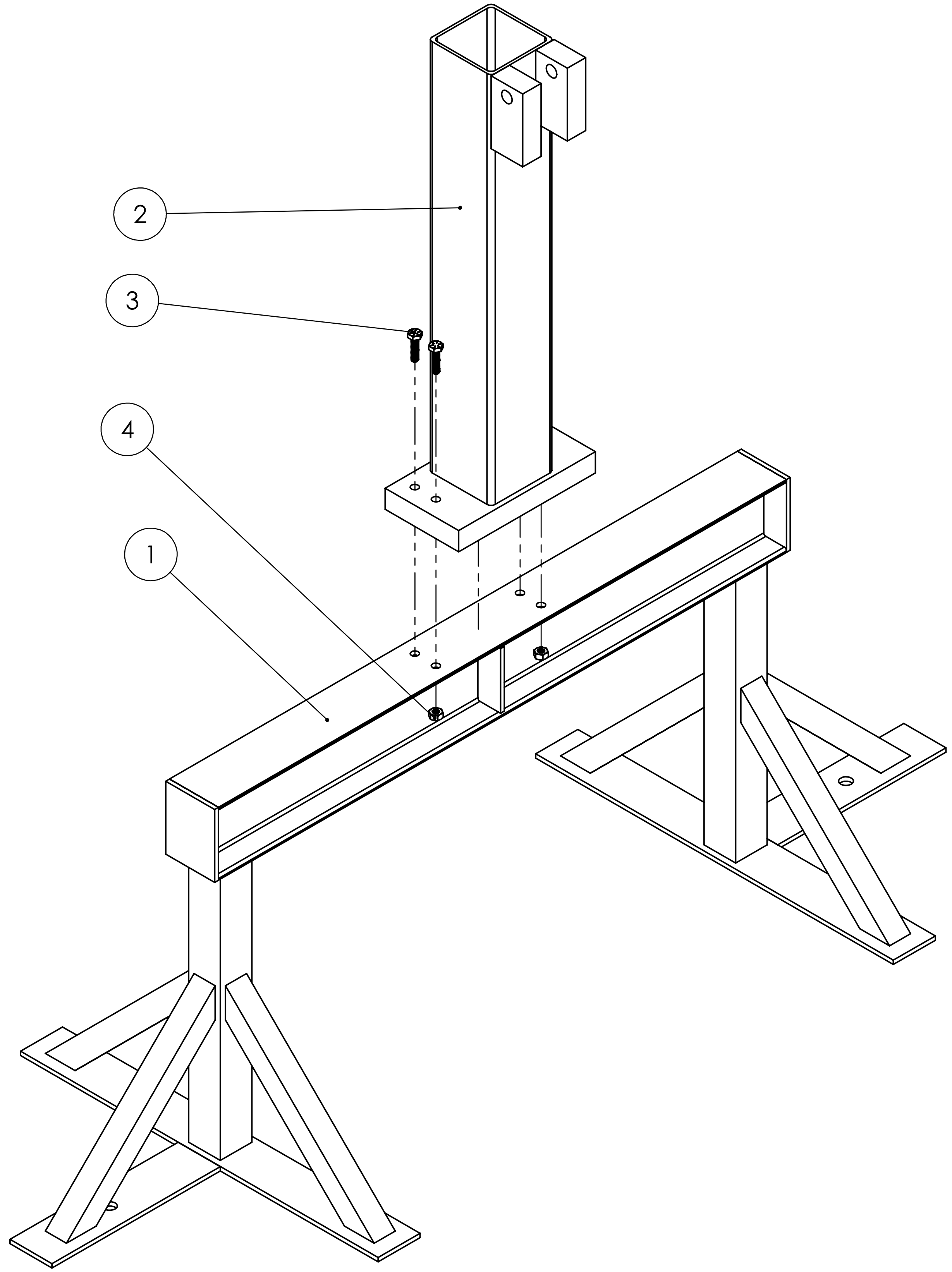


| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: STRUCTURAL TEST ASSEMBLY | | Drwn. By: SUBLIME SQUAD |
|---|---|---|---|---|
| | Dwg. #: B000 | Date: 4/6/2017 | Scale: 1:5 | Advisor: EILEEN ROSSMAN |

| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | BA00 | SAWHORSE | 1 |
| 2 | BB00 | FIXTURE | 1 |
| 3 | 91286A111 | HIGH STRENGTH BOLT | 4 |
| 4 | 90499A029 | HIGH STRENGTH NUT | 4 |

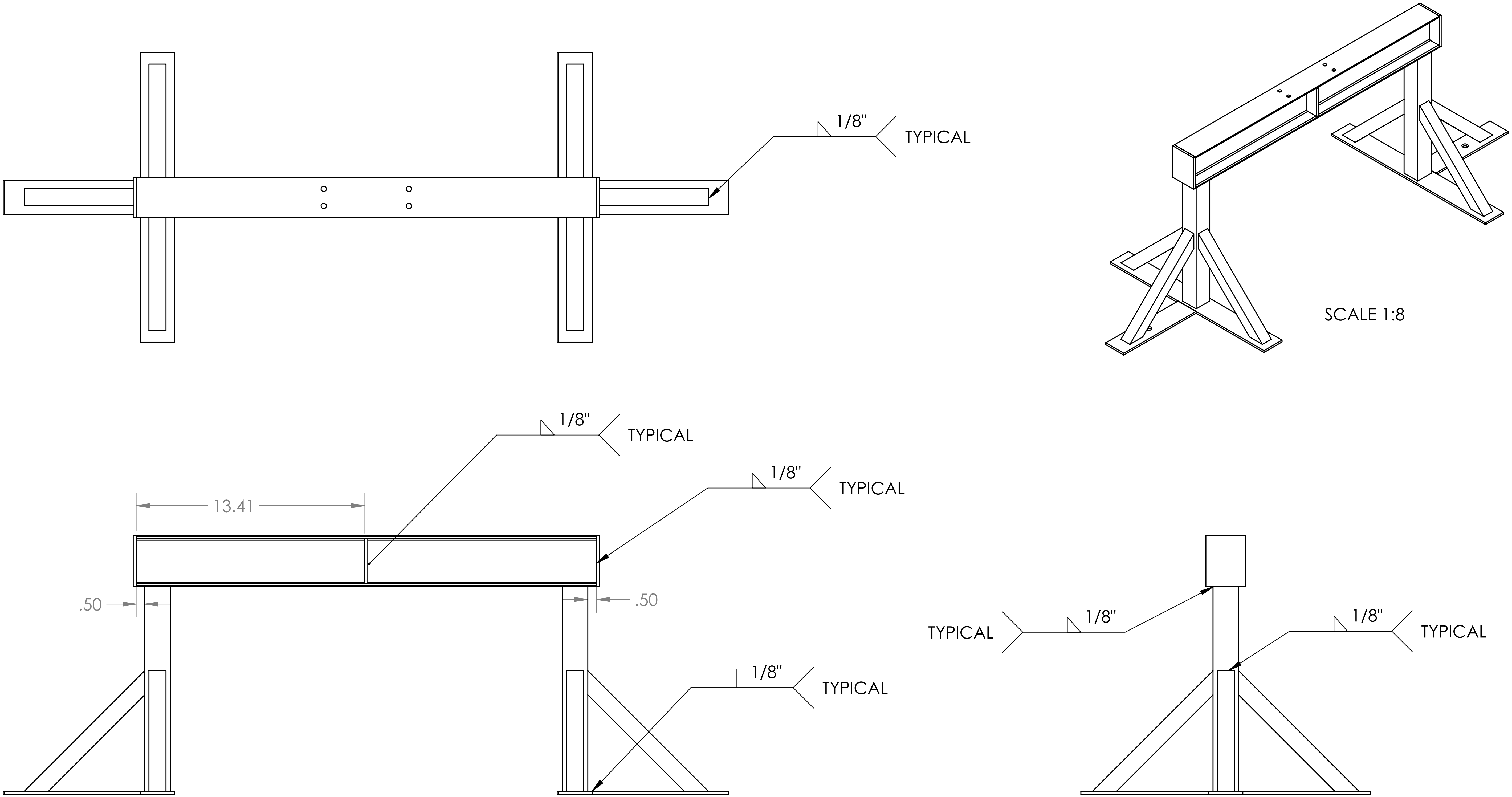
NOTE:

1. TWO OF FOUR HIGH STRENGTH NUTS NOT SHOWN





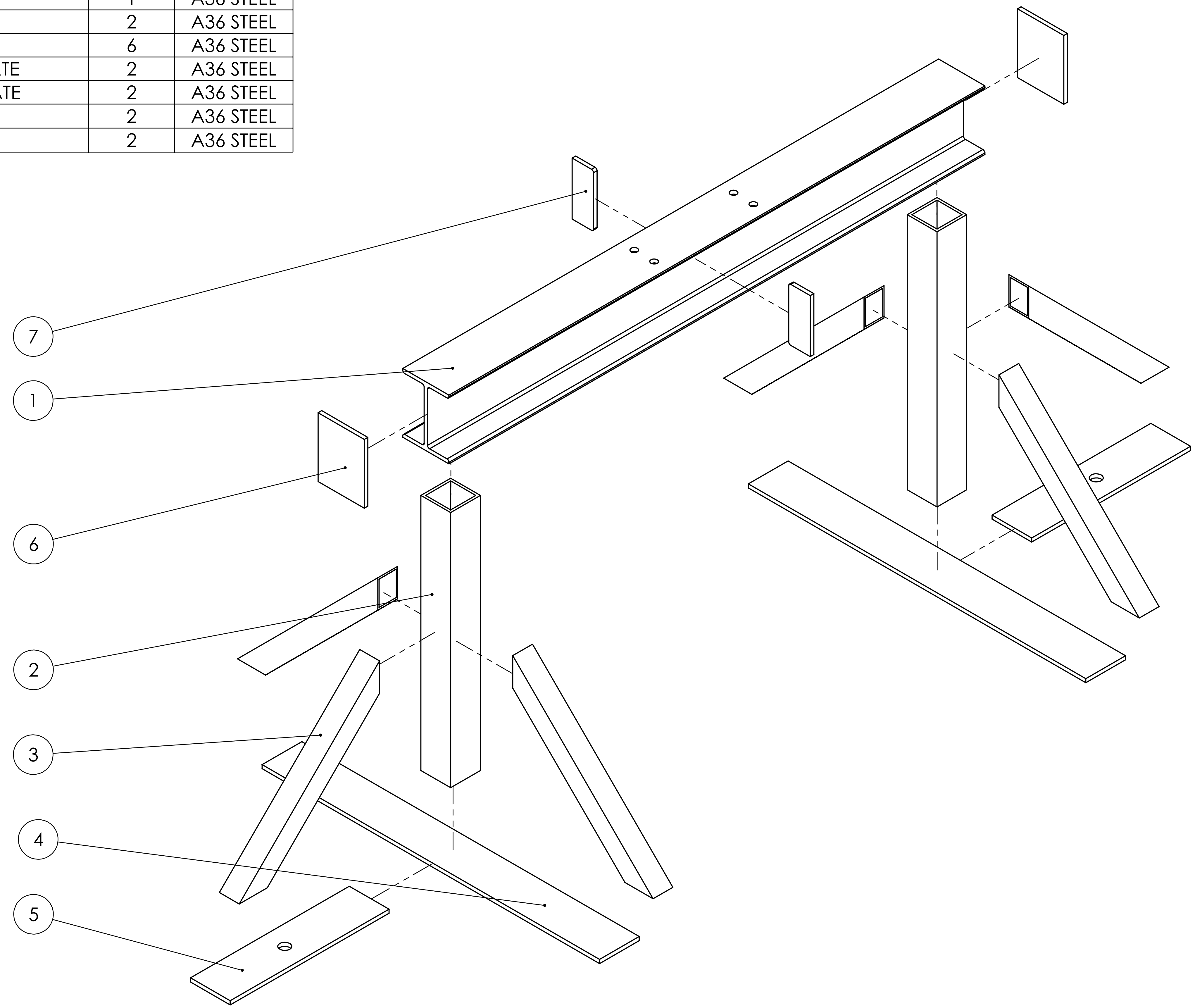

| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: EXPLODED TEST ASSEMBLY | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: B000-E | Date: 4/6/2017 | Scale: 1:5 | Advisor: EILEEN ROSSMAN |






| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: SAWHORSE | | Drwn. By: SUBLIME SQUAD |
|---|---|---|---|---|
| | Dwg. #: BA00 | Date: 4/6/2017 | Scale: 1:6 | Advisor: EILEEN ROSSMAN |

| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. | MATERIAL |
|---|---|---|---|---|
| 1 | BA01 | I - BEAM | 1 | A36 STEEL |
| 2 | BA02 | COLUMN | 2 | A36 STEEL |
| 3 | BA03 | STRUT | 6 | A36 STEEL |
| 4 | BA04 | LONG BASE PLATE | 2 | A36 STEEL |
| 5 | BA05 | SHORT BASE PLATE | 2 | A36 STEEL |
| 6 | BA06 | END PLATE | 2 | A36 STEEL |
| 7 | BA07 | GUSSET | 2 | A36 STEEL |

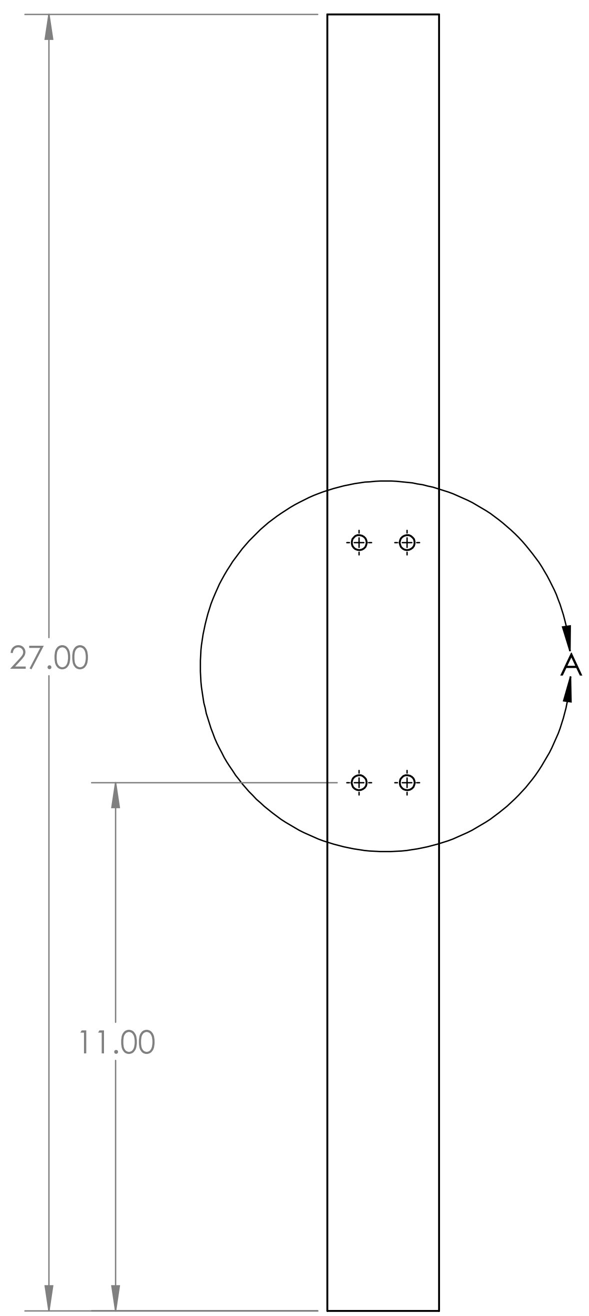


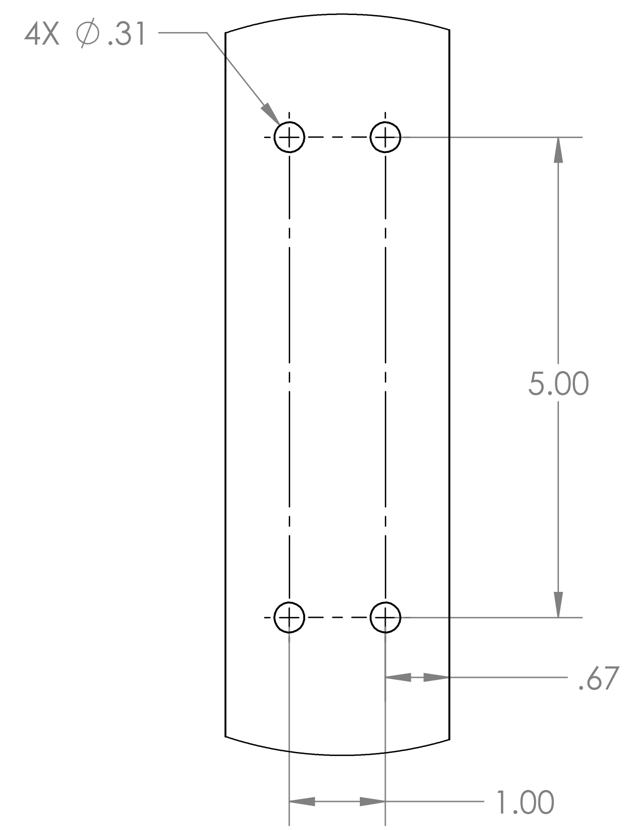



| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: EXPLODED SAWHORSE | | Drwn. By: SUBLIME SQUAD |
|---|---|---|---|---|
| | Dwg. #: BA00-E | Date: 4/6/2017 | Scale: 1:4 | Advisor: EILEEN ROSSMAN |

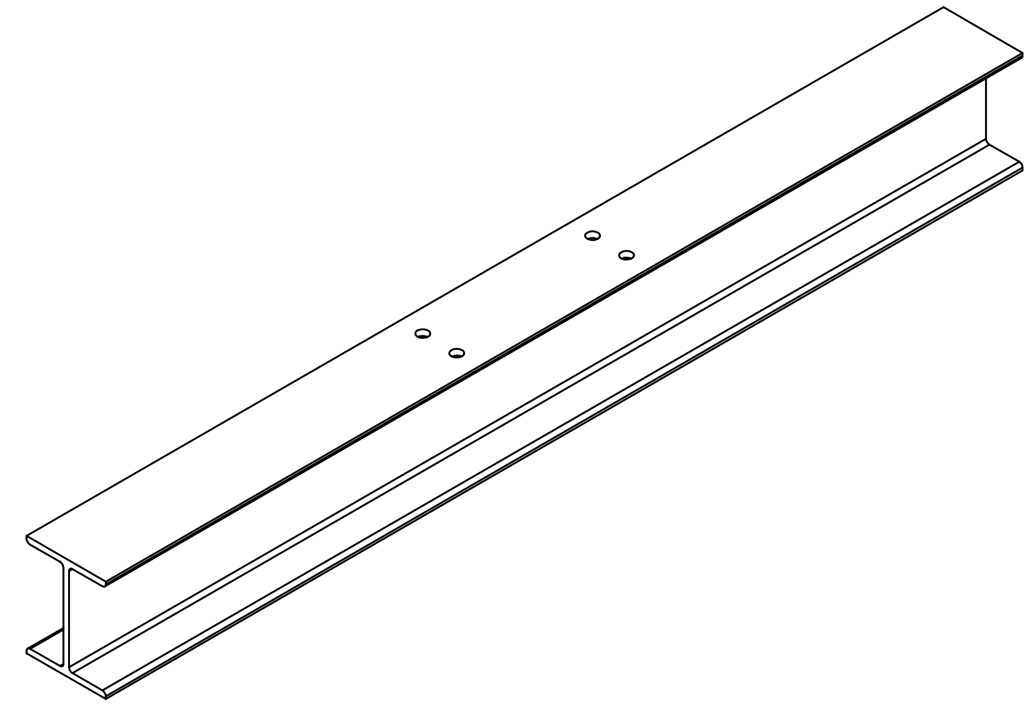
NOTE:

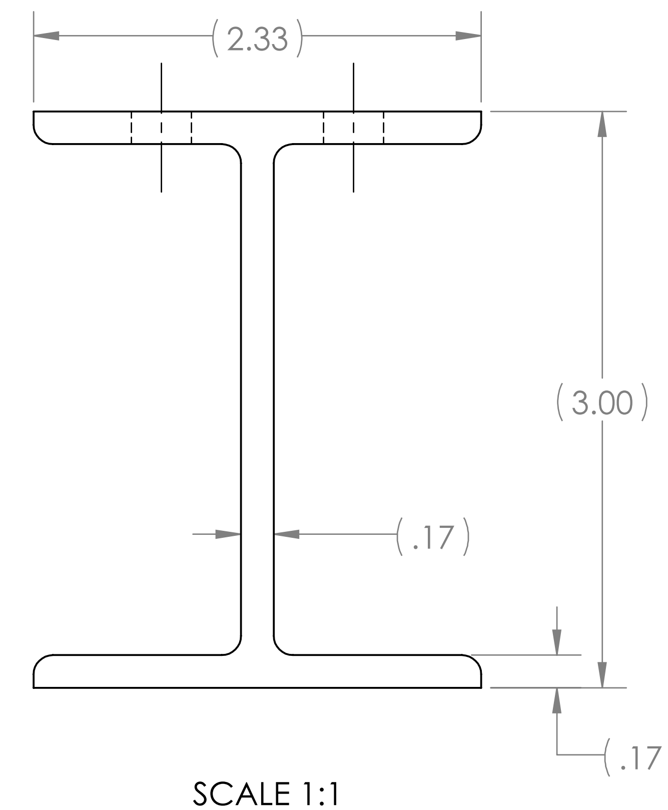
1. ALL TOLERANCES ARE ±.13 AND ±1° UNLESS OTHERWISE SPECIFIED
2. DIMENSIONS WITH PARENTHESIS ARE STOCK DIMENSIONS




DETAIL A
SCALE 1 : 2






SCALE 1:1

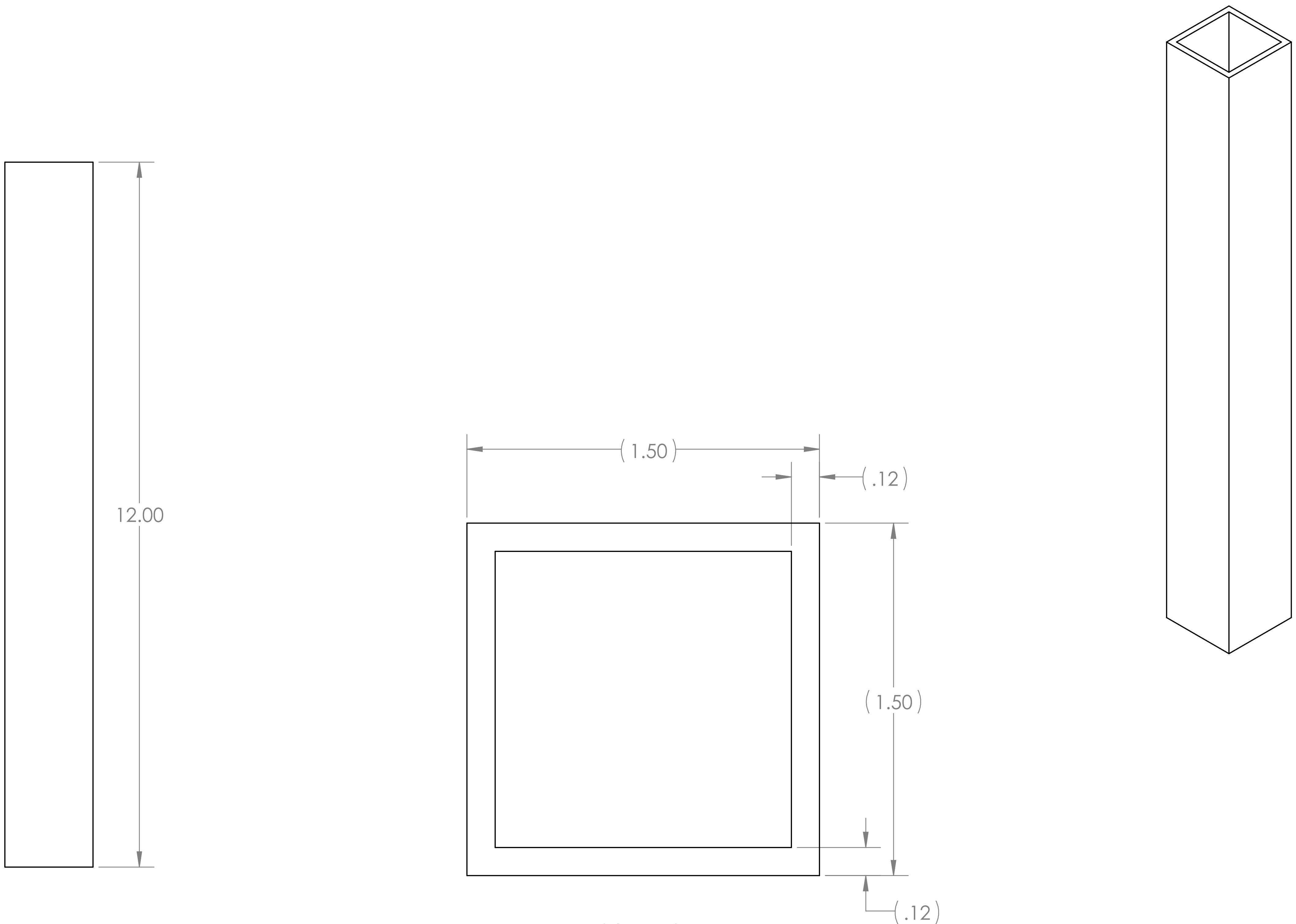


| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: I-BEAM | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: BA01 | Date: 4/6/2017 | Scale: 1:4 | Advisor: EILEEN ROSSMAN |

A - 120

NOTE:

1. ALL TOLERANCES ARE ±.13 AND ±1° UNLESS OTHERWISE SPECIFIED
2. DIMENSIONS WITH PARENTHESIS ARE STOCK DIMENSIONS



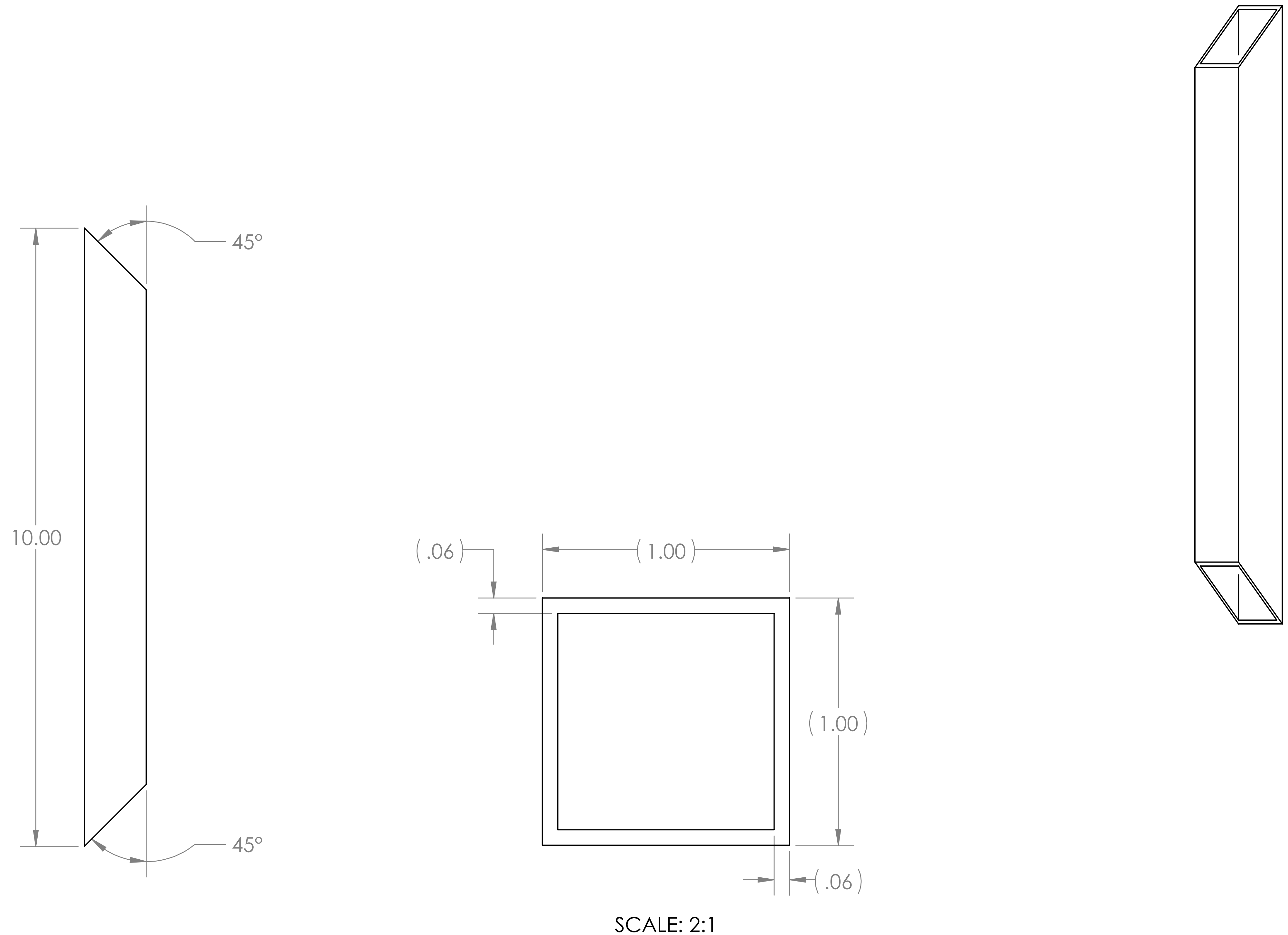

SCALE: 2:1



| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: COLUMN | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: BA02 | Date: 4/6/2017 | Scale: 1:2 | Advisor: EILEEN ROSSMAN |

NOTE:

1. ALL TOLERANCES ARE ±.13 AND ±1° UNLESS OTHERWISE SPECIFIED
2. DIMENSIONS WITH PARENTHESIS ARE STOCK DIMENSIONS

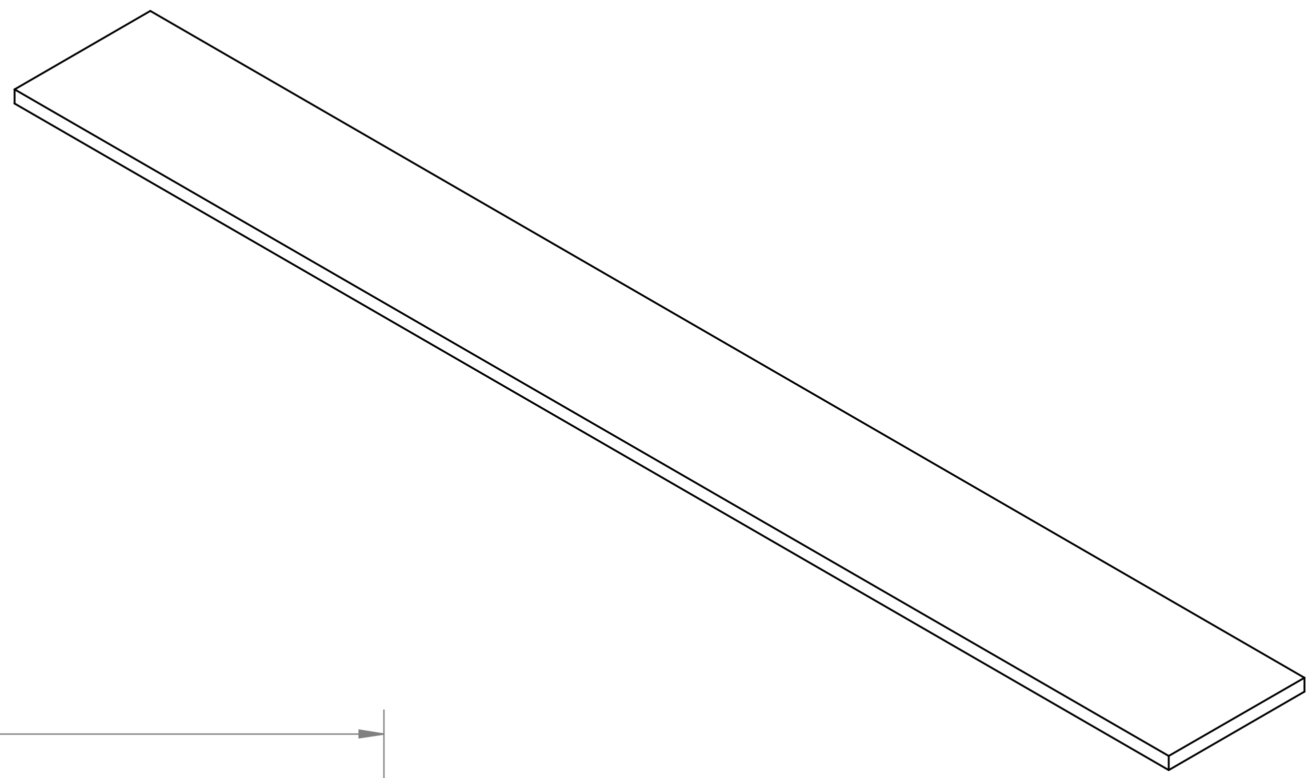


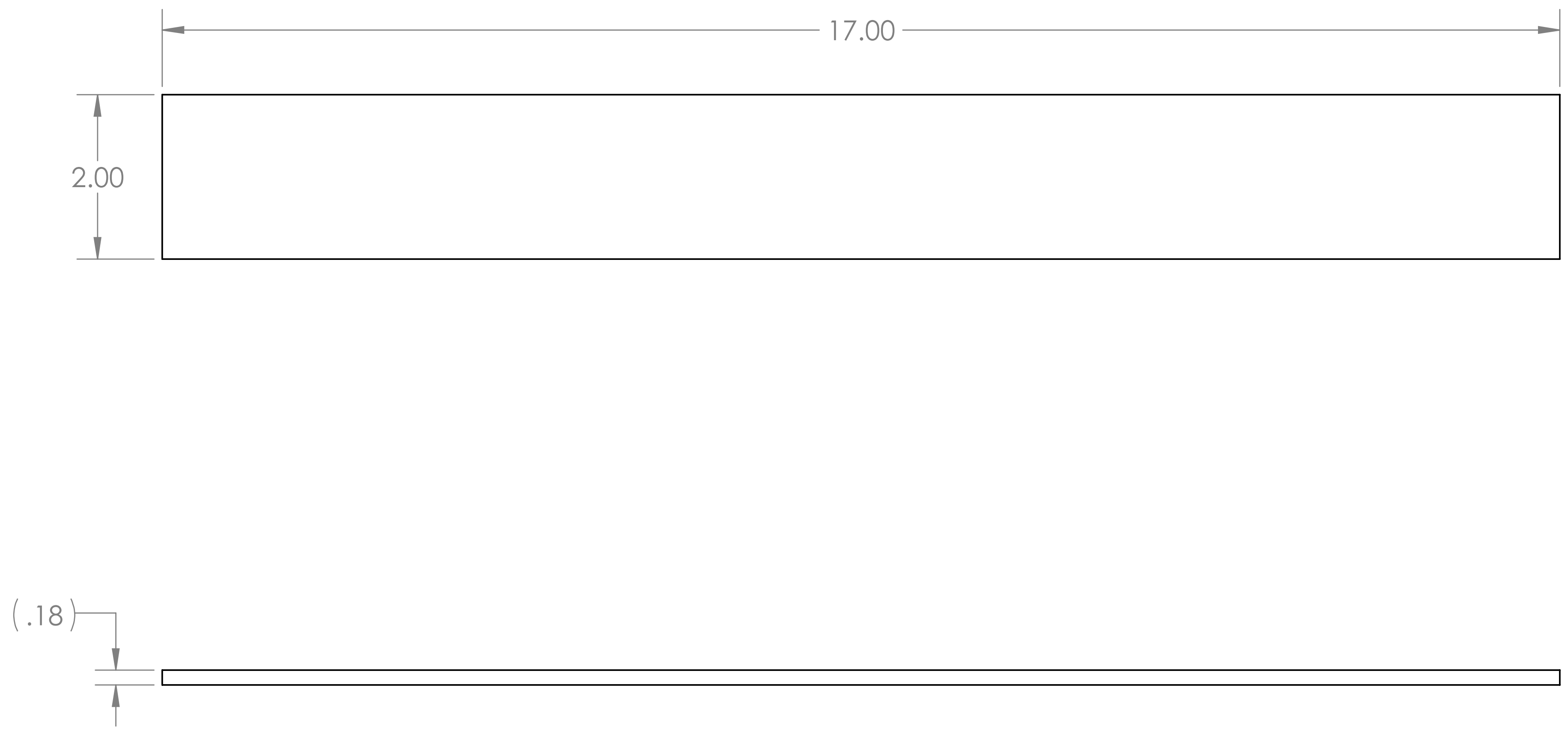



| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: STRUT | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: BA03 | Date: 4/6/2017 | Scale: 1:2 | Advisor: EILEEN ROSSMAN |

NOTE:

1. ALL TOLERANCES ARE ±.13 AND ±1° UNLESS OTHERWISE SPECIFIED
2. DIMENSIONS WITH PARENTHESIS ARE STOCK DIMENSIONS



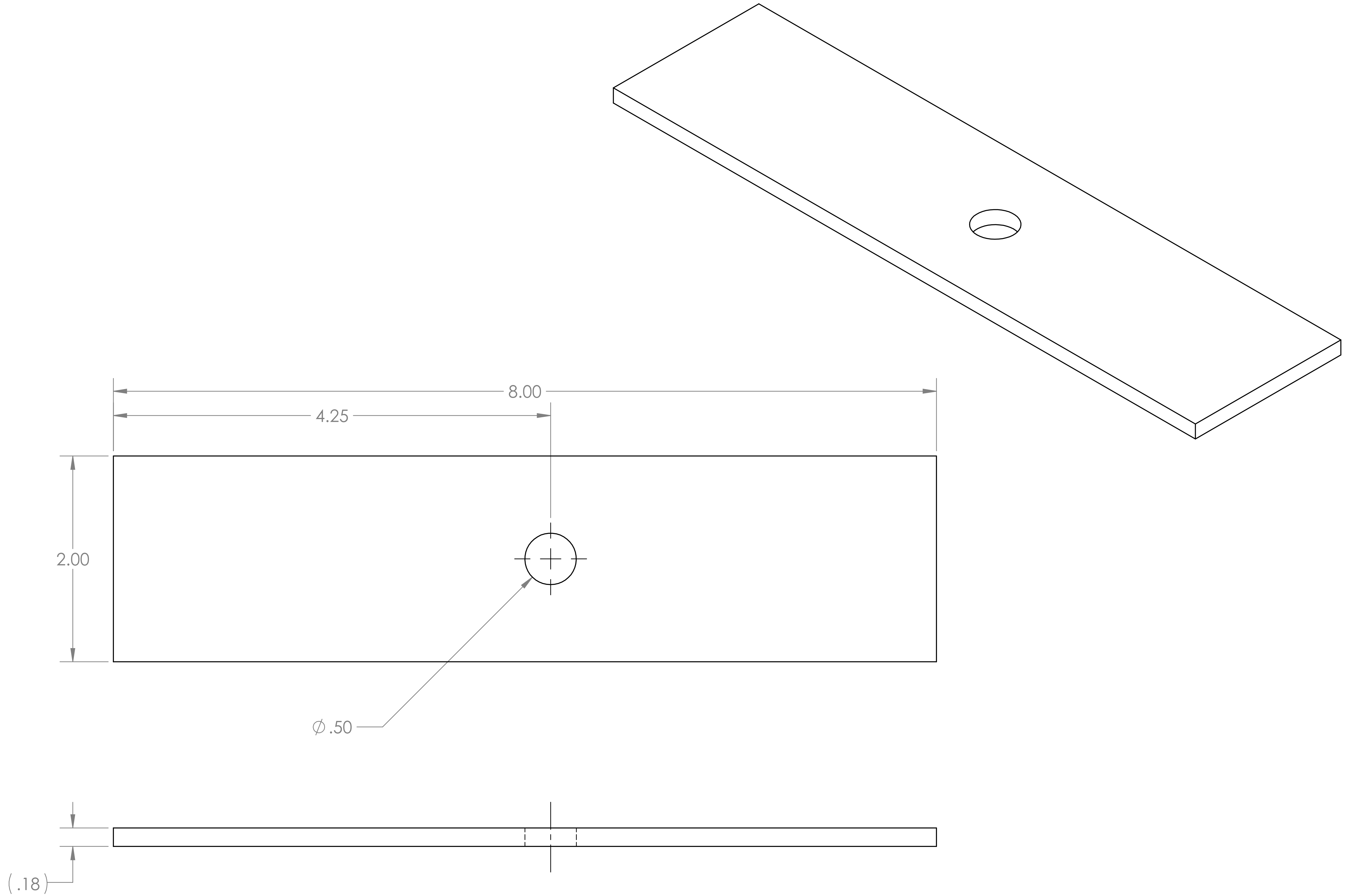





| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: LONG BASE PLATE | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: BA04 | Date: 4/6/2017 | Scale: 1:2 | Advisor: EILEEN ROSSMAN |

NOTE:

1. ALL TOLERANCES ARE ±.13 AND ±1° UNLESS OTHERWISE SPECIFIED
2. DIMENSIONS WITH PARENTHESIS ARE STOCK DIMENSIONS



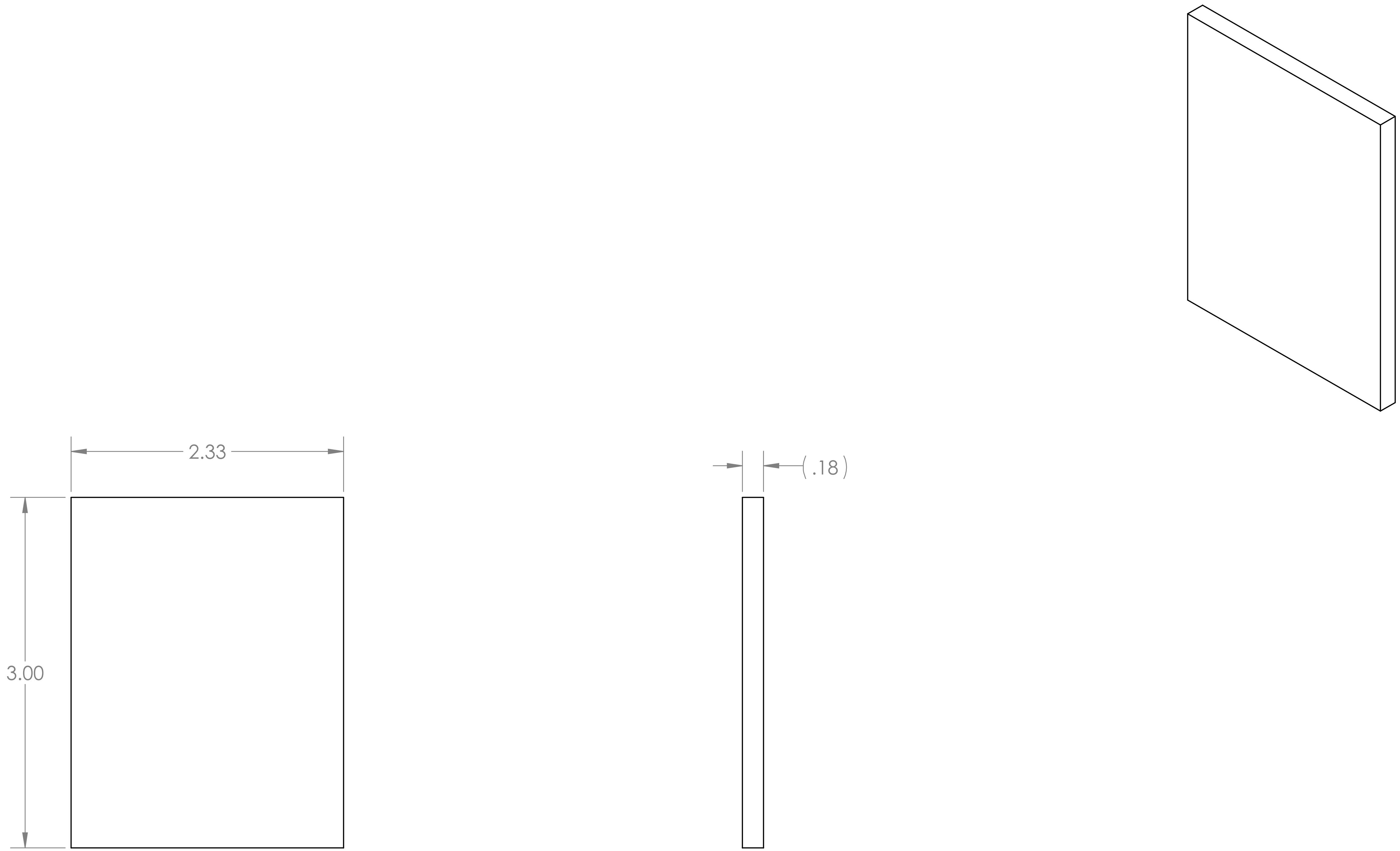



| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: SHORT BASE PLATE | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: BA05 | Date: 4/6/2017 | Scale: 1:1 | Advisor: EILEEN ROSSMAN |

**A - 124**

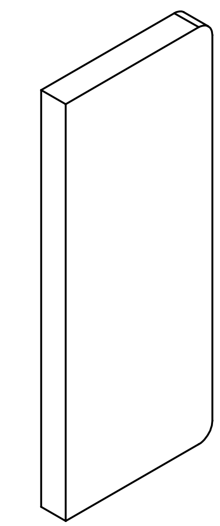
NOTE:

1. ALL TOLERANCES ARE ±.13 AND ±1° UNLESS OTHERWISE SPECIFIED
2. DIMENSIONS WITH PARENTHESIS ARE STOCK DIMENSIONS



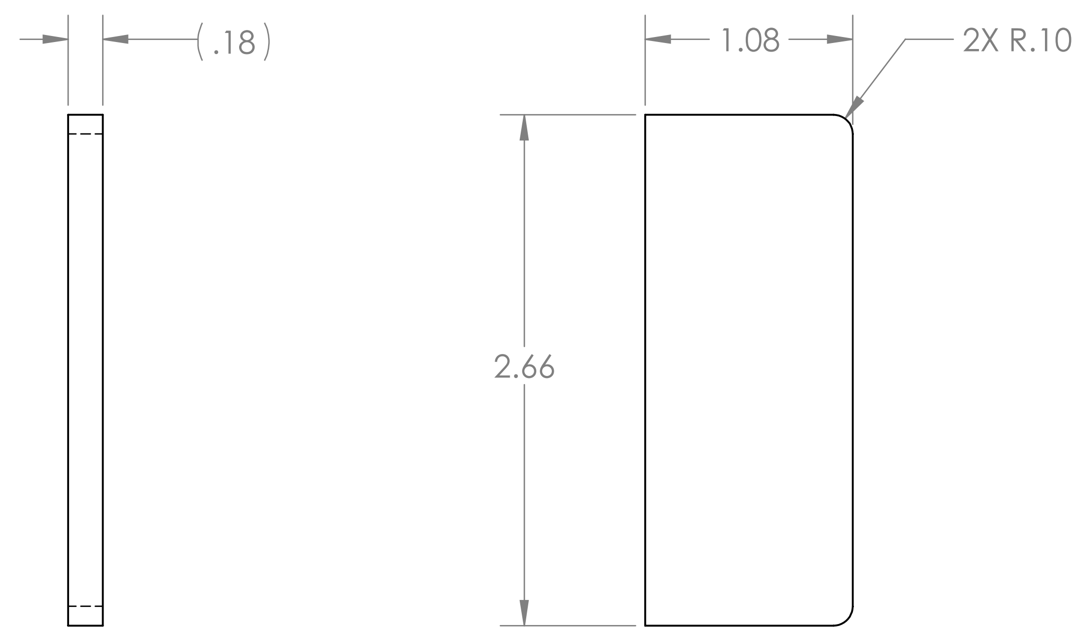



| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: END PLATE | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: BA06 | Date: 4/30/17 | Scale: 1:1 | Advisor: EILEEN ROSSMAN |



NOTE:

FILLETS SPECIFIED WILL NEED TO BE GRINDED FURTHER TO FIT INNER I-BEAM PROFILE

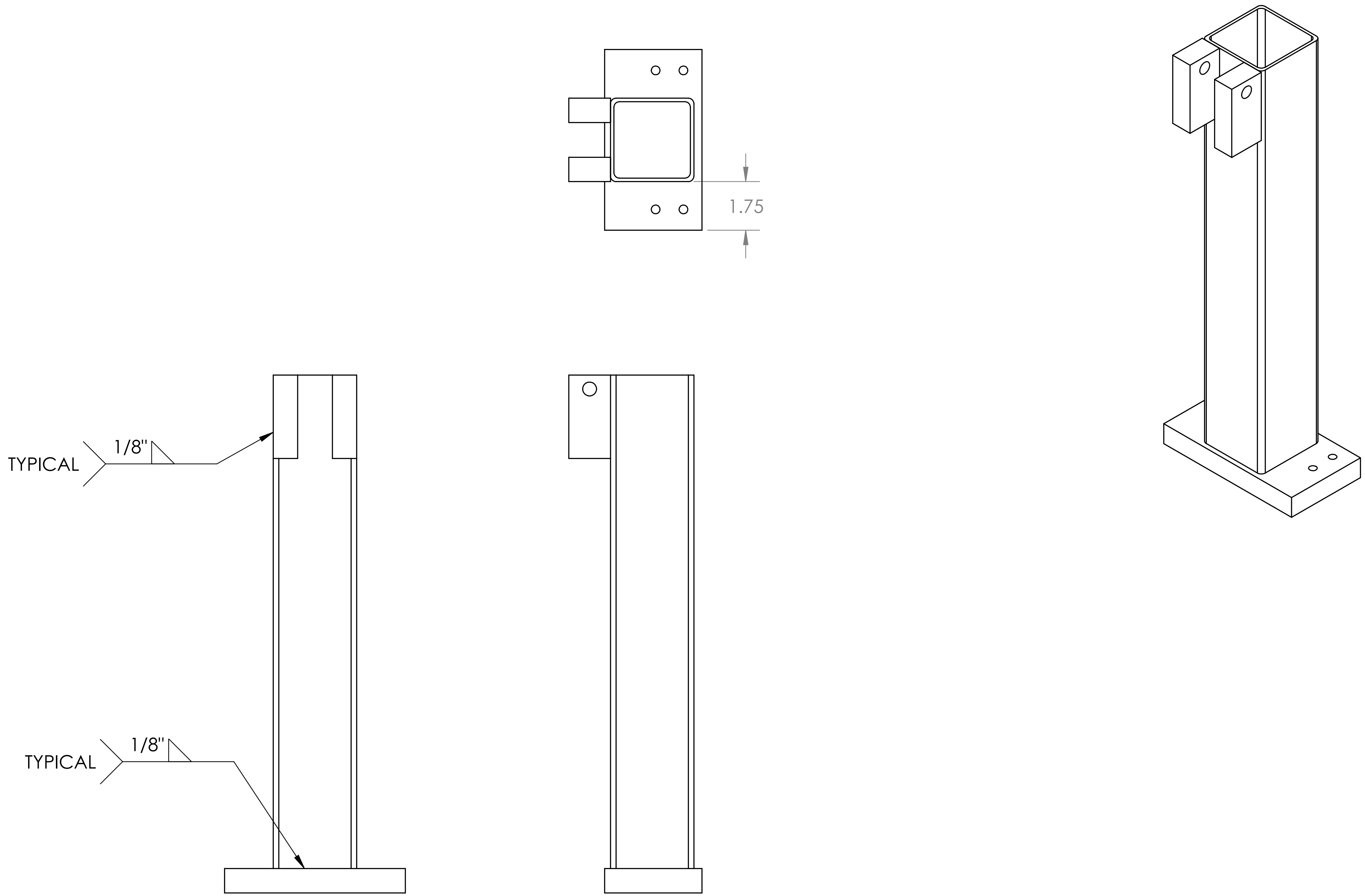





| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: GUSSET | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: BA07 | Date: 4/30/2017 | Scale: 1:1 | Advisor: EILEEN ROSSMAN |

NOTE:

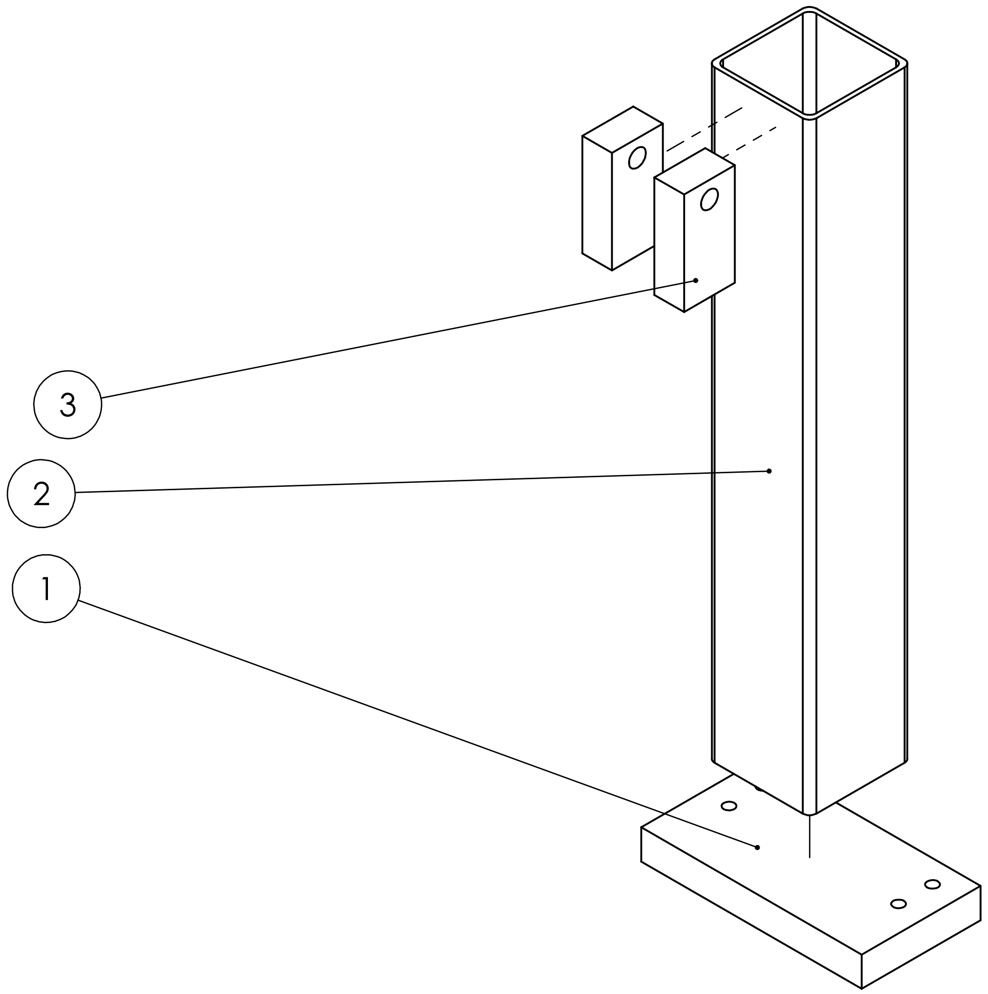
1. ALL TOLERANCES ARE ±.13 AND ±1° UNLESS OTHERWISE SPECIFIED
2. DIMENSIONS WITH PARENTHESIS ARE STOCK DIMENSIONS






| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering<br>SENIOR PROJECT | Project: AVALON STRUCTURE | Title: MOMENT FIXTURE | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: BB00 | Date: 4/6/2017 | Scale: 1:4 | Advisor: EILEEN ROSSMAN |

| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. | MATERIAL |
|---|---|---|---|---|
| 1 | BB01 | FIXTURE BASE PLATE | 1 | A36 STEEL |
| 2 | BB02 | MOMENT COLUMN | 1 | A36 STEEL |
| 3 | BB03 | RAM CONNECTION PLATE | 2 | A36 STEEL |

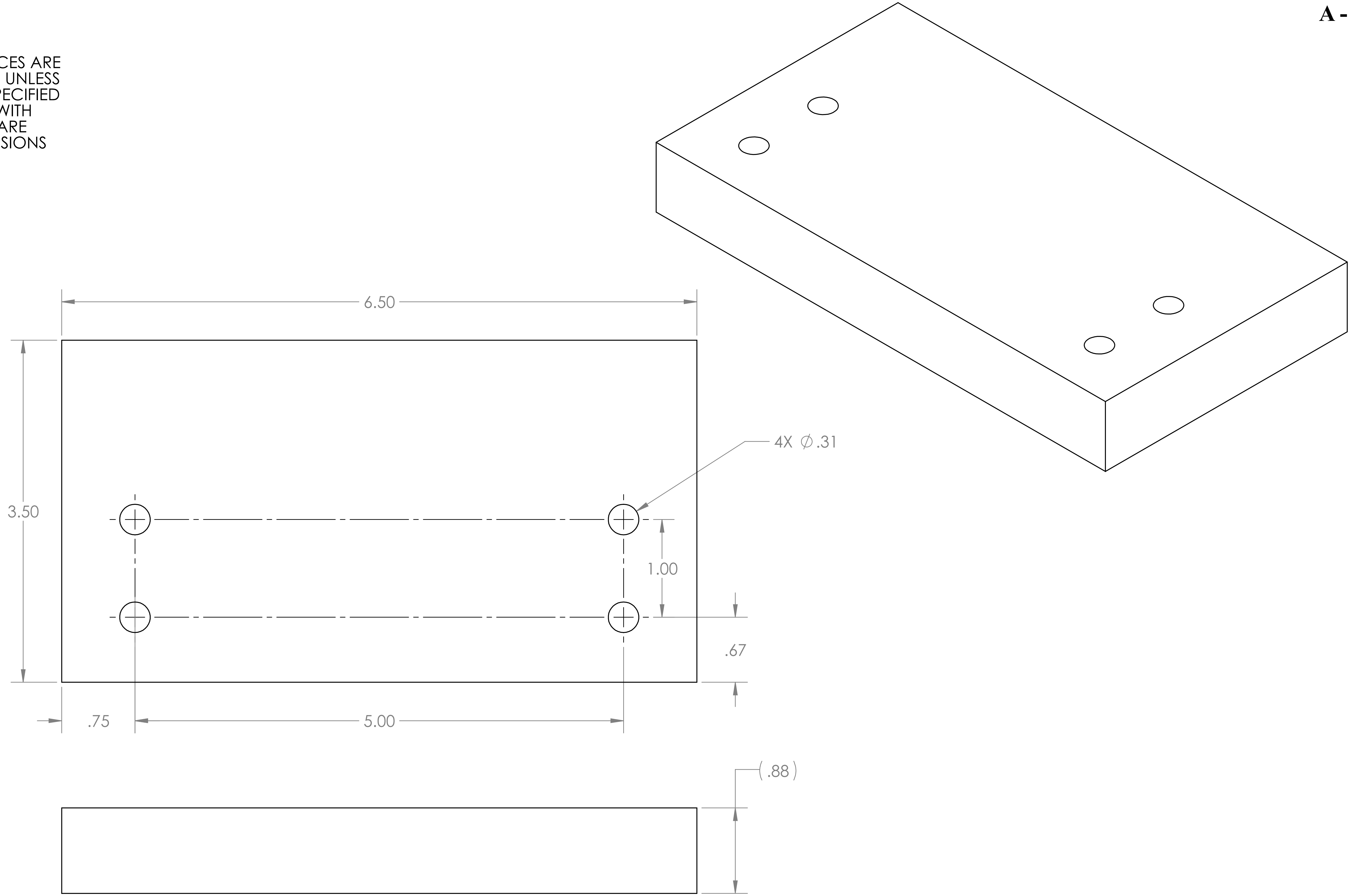





| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: EXPLODED MOMENT FIXTURE | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: BB00-E | Date: 4/6/2017 | Scale: 1:4 | Advisor: EILEEN ROSSMAN |

NOTE:

1. ALL TOLERANCES ARE ±.13 AND ±1° UNLESS OTHERWISE SPECIFIED
2. DIMENSIONS WITH PARENTHESIS ARE STOCK DIMENSIONS

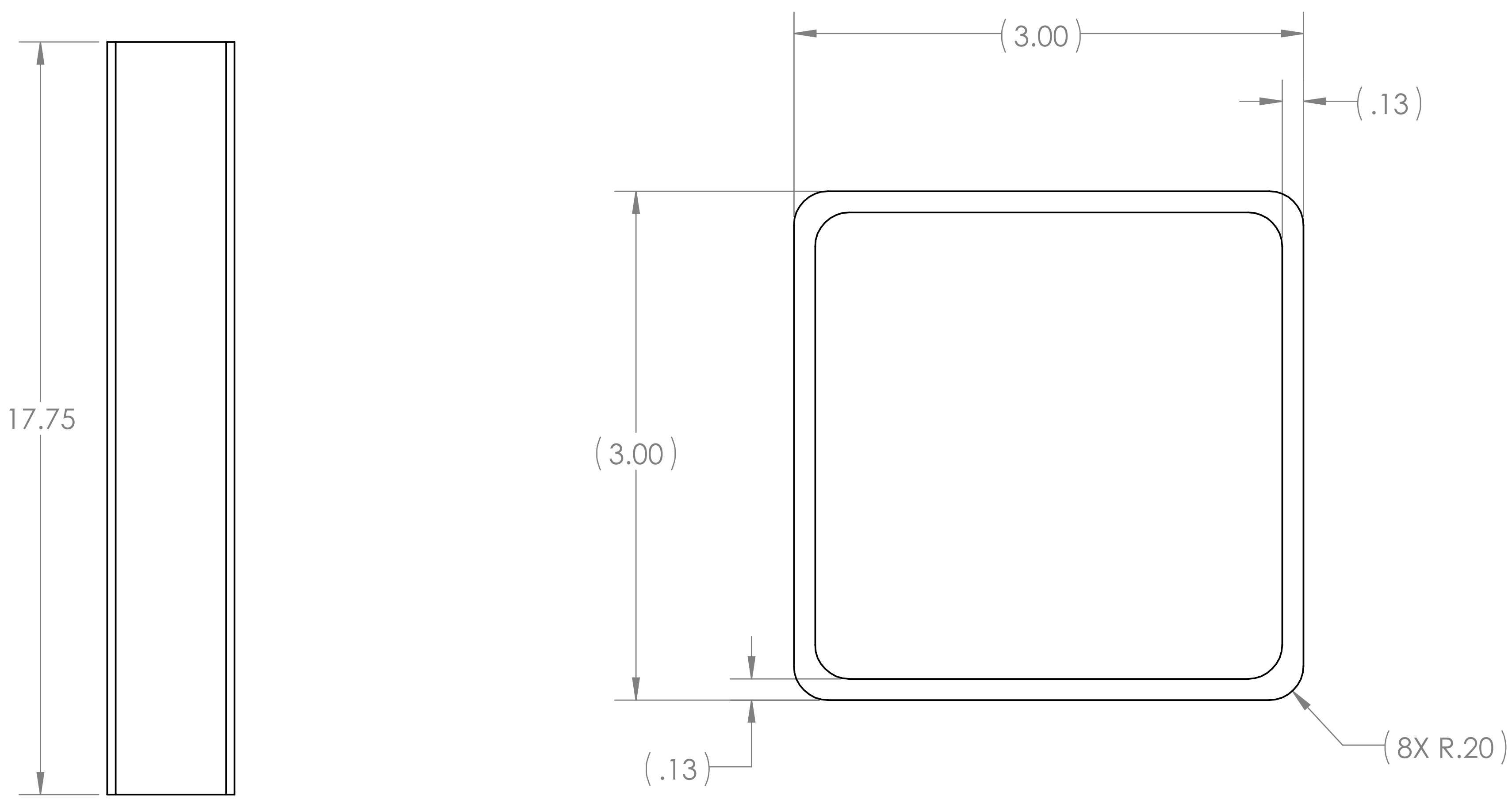




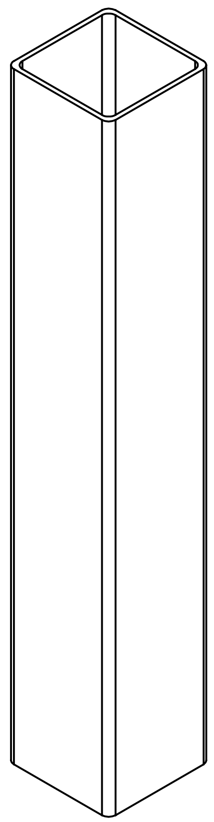

| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: FIXTURE BASE PLATE | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: BB01 | Date: 4/6/2017 | Scale: 1:1 | Advisor: EILEEN ROSSMAN |

NOTE:

1. ALL TOLERANCES ARE ±.13 AND ±1° UNLESS OTHERWISE SPECIFIED
2. DIMENSIONS WITH PARENTHESIS ARE STOCK DIMENSIONS




SCALE: 1:1

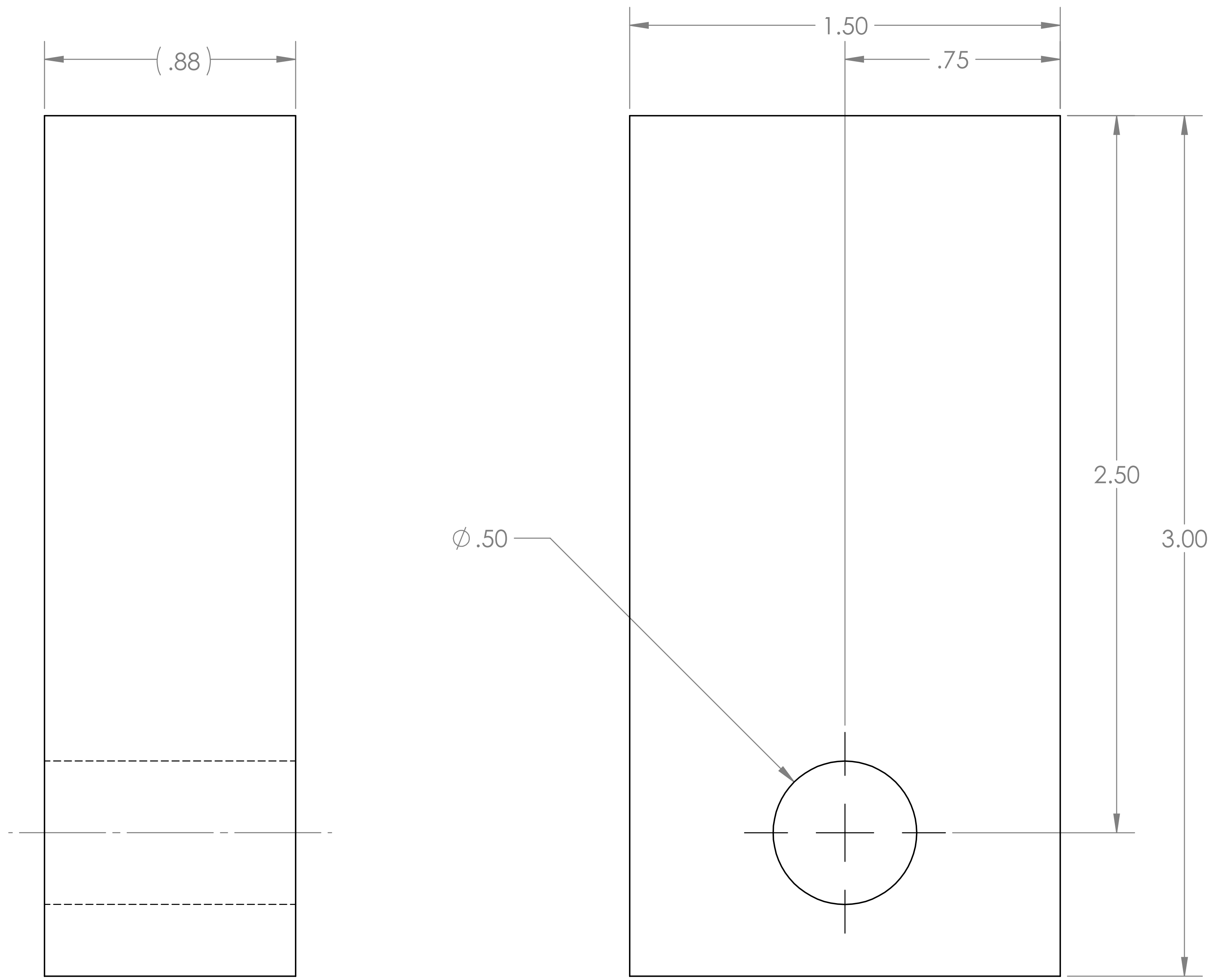


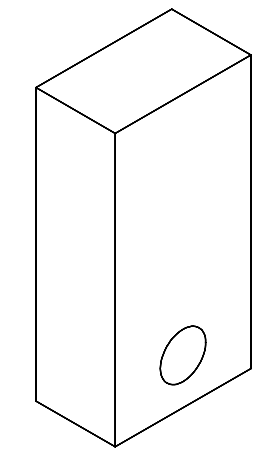


| | | | |
|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: MOMENT COLUMN | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: BB02 | Date: 4/6/2017 — Scale: 1:4 | Advisor: EILEEN ROSSMAN |

NOTE:

1. ALL TOLERANCES ARE ±.13 AND ±1° UNLESS OTHERWISE SPECIFIED
2. DIMENSIONS WITH PARENTHESIS ARE STOCK DIMENSIONS



SCALE 2:3

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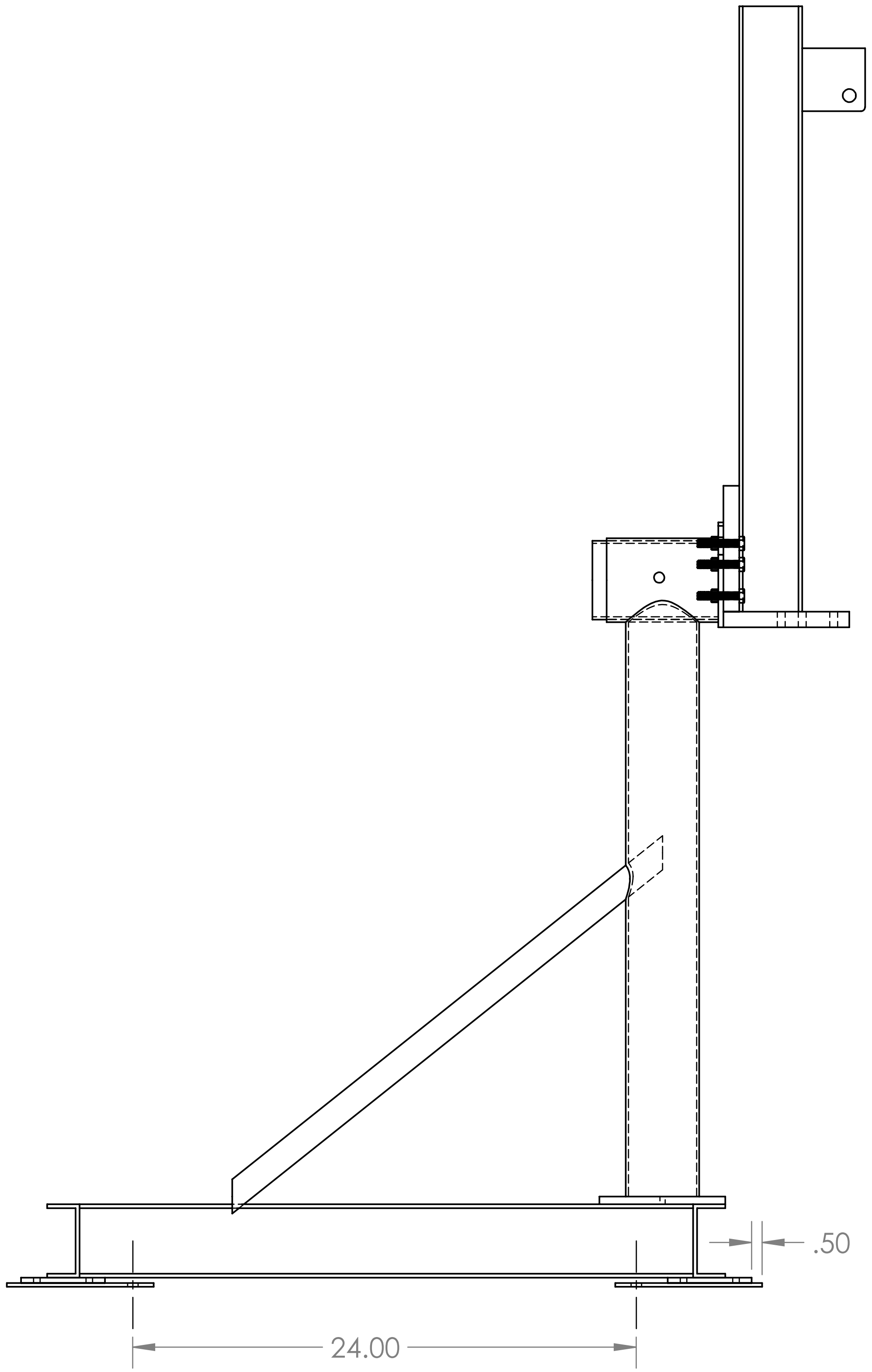
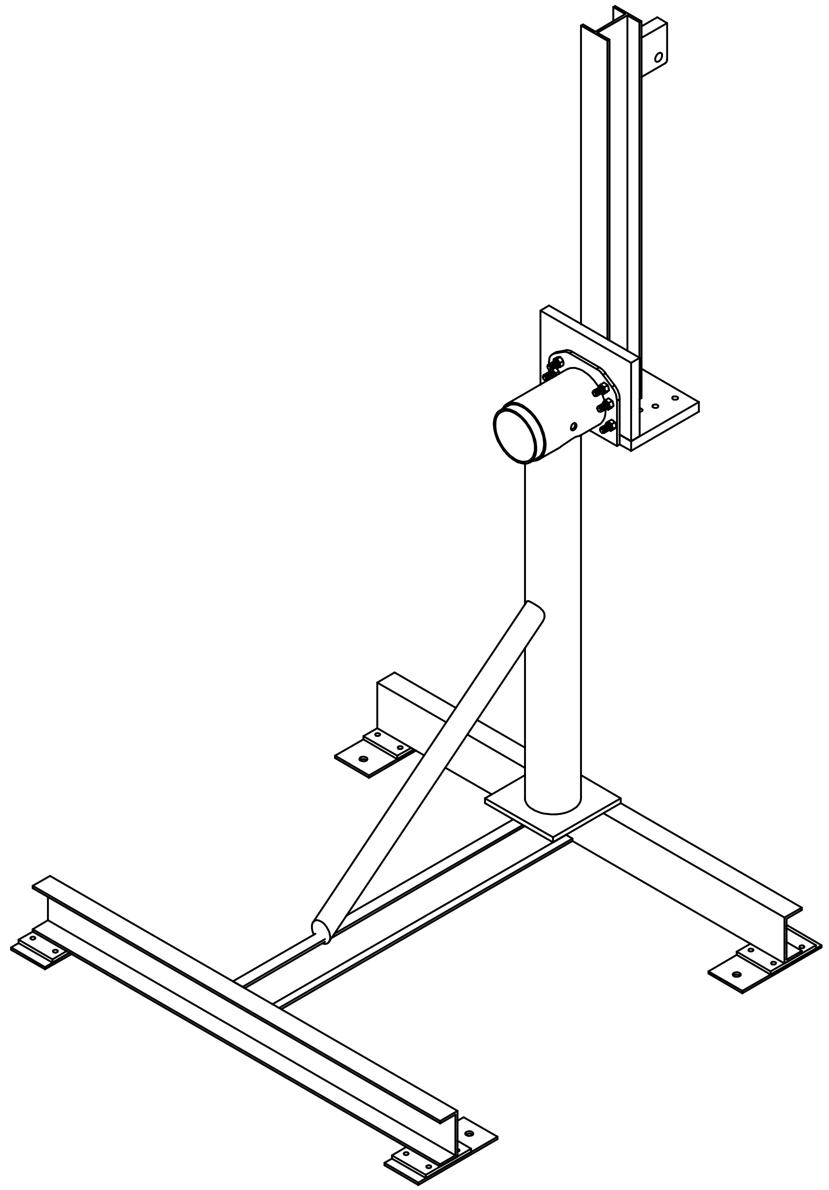
| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering<br>SENIOR PROJECT | Project: AVALON STRUCTURE | Title: RAM CONNECTION PLATE | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: BB03 | Date: 4/6/2017 | Scale: 2:1 | Advisor: EILEEN ROSSMAN |



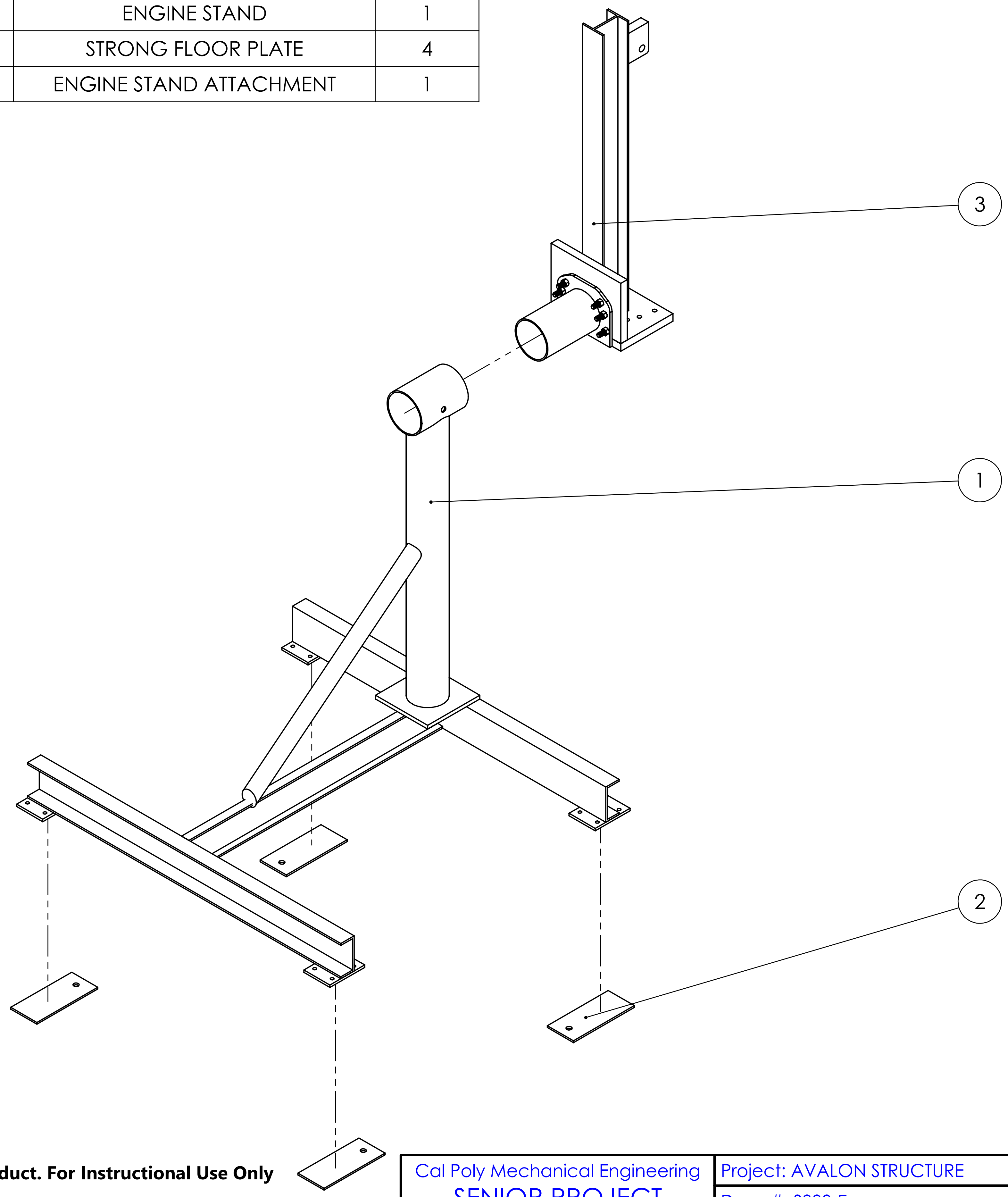
SCALE: 1:12



| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: REACTION FIXTURE | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: S000 | Date: 4/30/2017 | Scale: 1:8 | Advisor: EILEEN ROSSMAN |

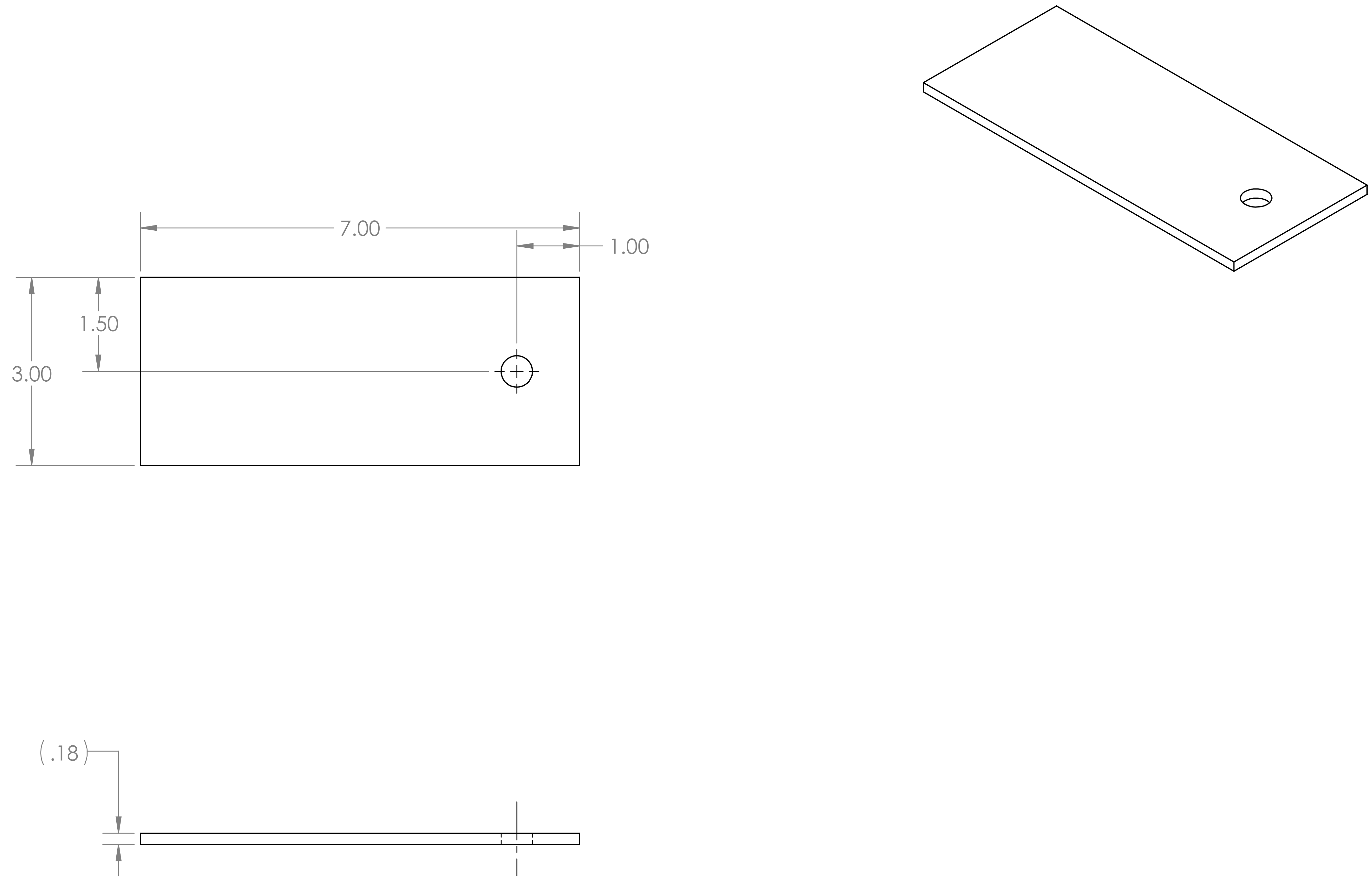
| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | S002 | ENGINE STAND | 1 |
| 2 | S001 | STRONG FLOOR PLATE | 4 |
| 3 | SA00 | ENGINE STAND ATTACHMENT | 1 |








| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering<br>SENIOR PROJECT | Project: AVALON STRUCTURE | Title: EXPLODED REACTION FIXTURE | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: S000-E | Date: 4/30/2017 | Scale: 1:10 | Advisor: EILEEN ROSSMAN |

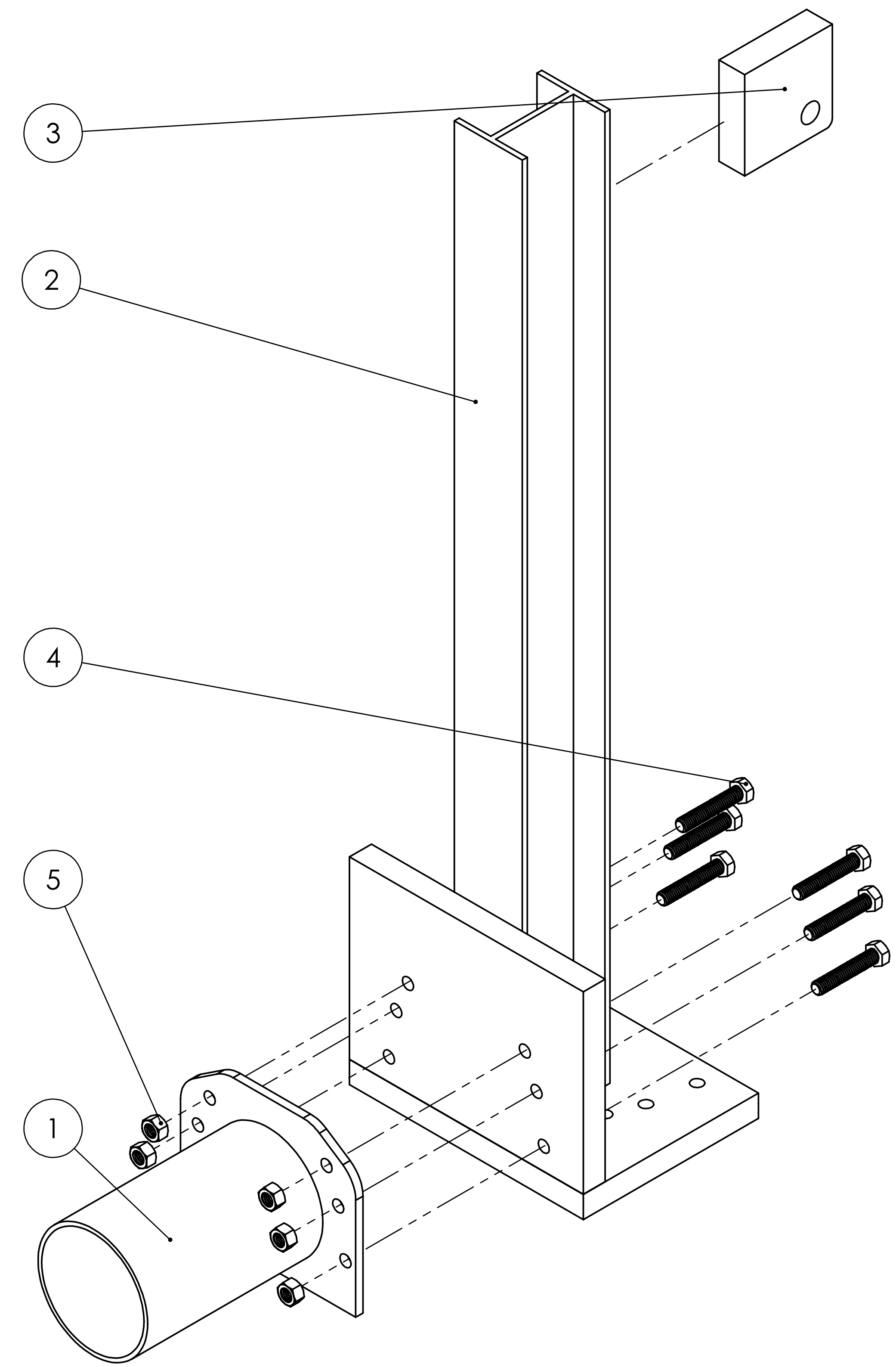





| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: STRONG FLOOR PLATE | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: S001 | Date: 4/30/2017 | Scale: 2:1 | Advisor: EILEEN ROSSMAN |

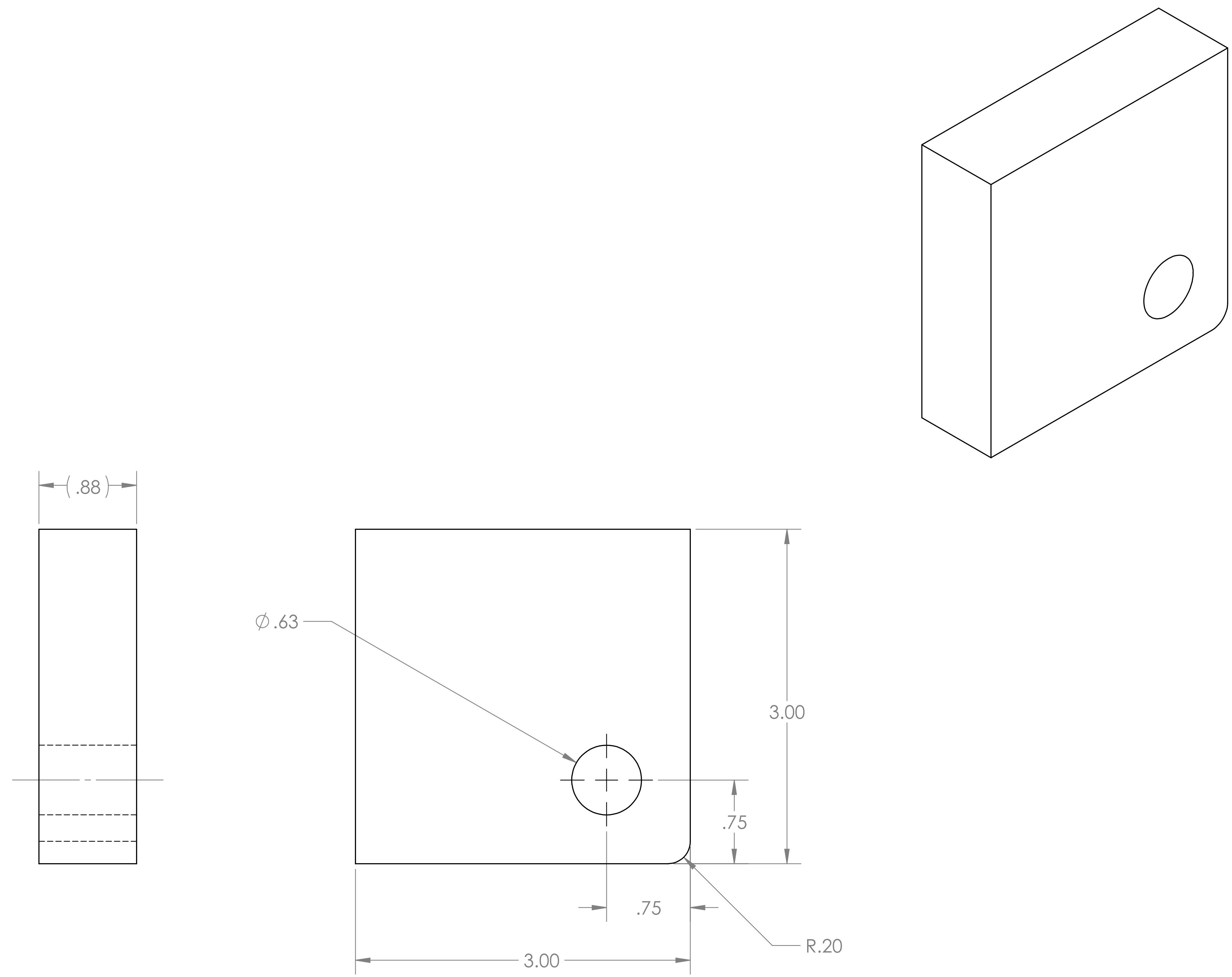
| ITEM NO. | PART NUMBER | DESCRIPTION | For Drawings/QTY. |
|---|---|---|---|
| 1 | SA01 | ENGINE STAND INSERT | 1 |
| 2 | SA02 | PRE-WELDED STRUCTURE | 1 |
| 3 | SA03 | ATTACHMENT PLATE | 1 |
| 4 | 92620A632 | 3/8" HEX BOLT | 6 |
| 5 | 90499A031 | 3/8" HEX NUT | 6 |








| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: ENGINE STAND ATTACHMENT | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: SA00-E | Date: 4/30/2017 | Scale: 1:4 | Advisor: EILEEN ROSSMAN |

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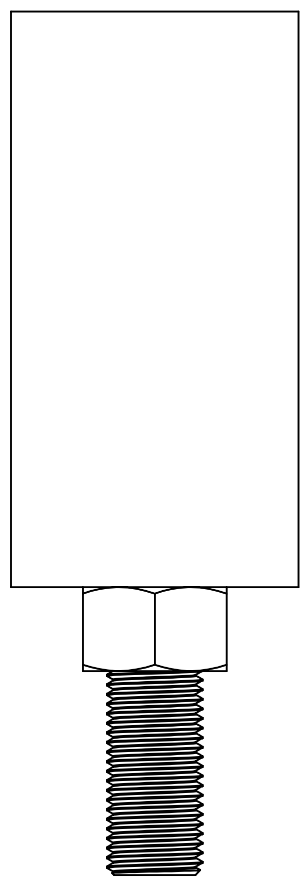
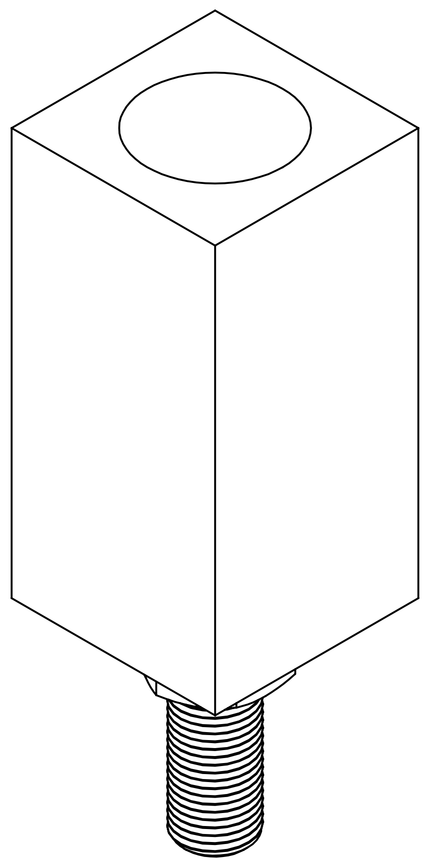
| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: ATTACHMENT PLATE | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: SA03 | Date: 4/30/2017 | Scale: 1:1 | Advisor: EILEEN ROSSMAN |





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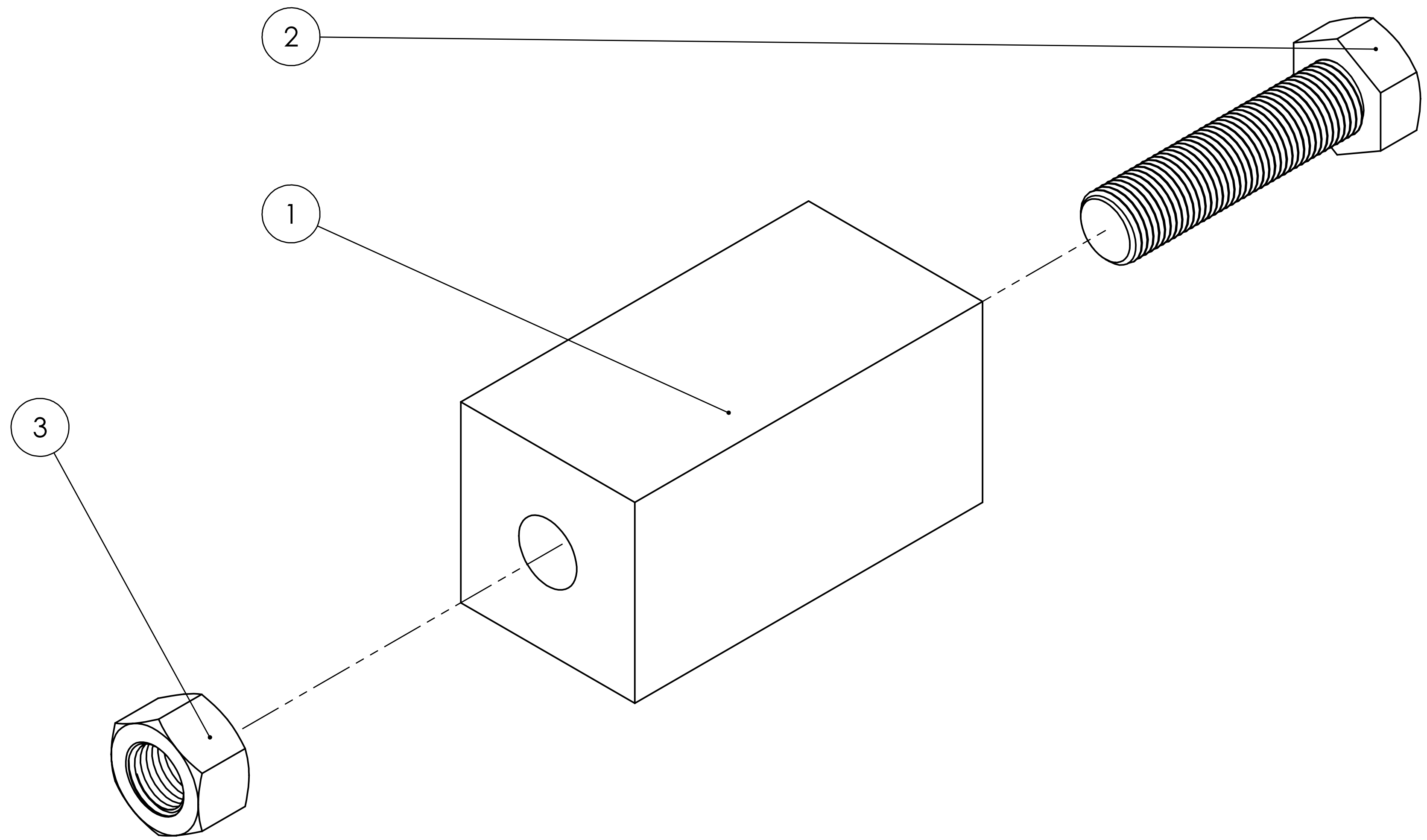
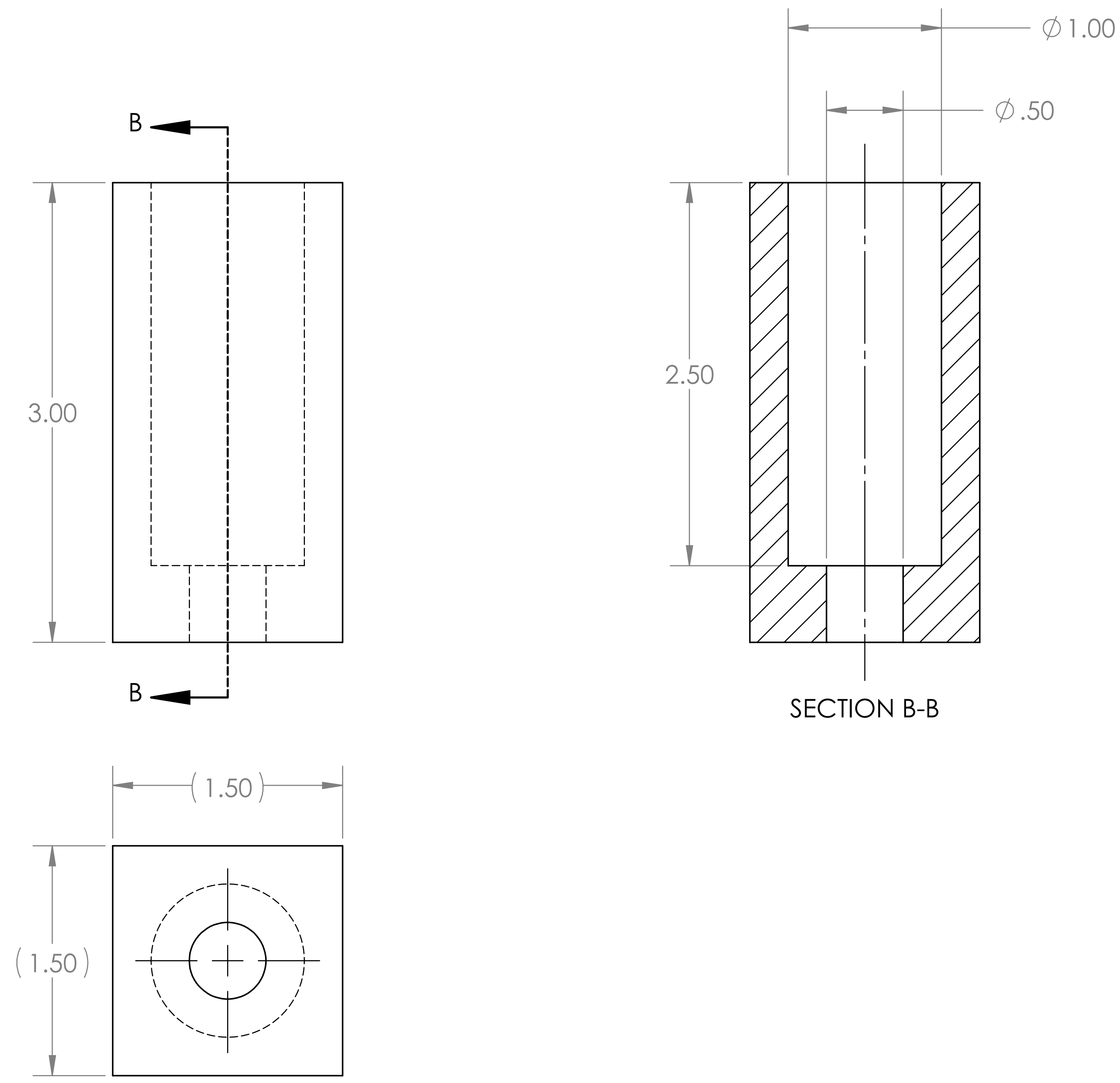
|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: LOAD CELL COUPLER | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: LC00 | Date: 4/30/2017 / Scale: 1:1 | Advisor: EILEEN ROSSMAN |

| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | LC01 | RAM-LOAD CELL COUPLER | 1 |
| 2 | 92620A746 | 1/2-20 HEX BOLT | 1 |
| 3 | 94895A825 | 1/2-20 HEX NUT | 1 |





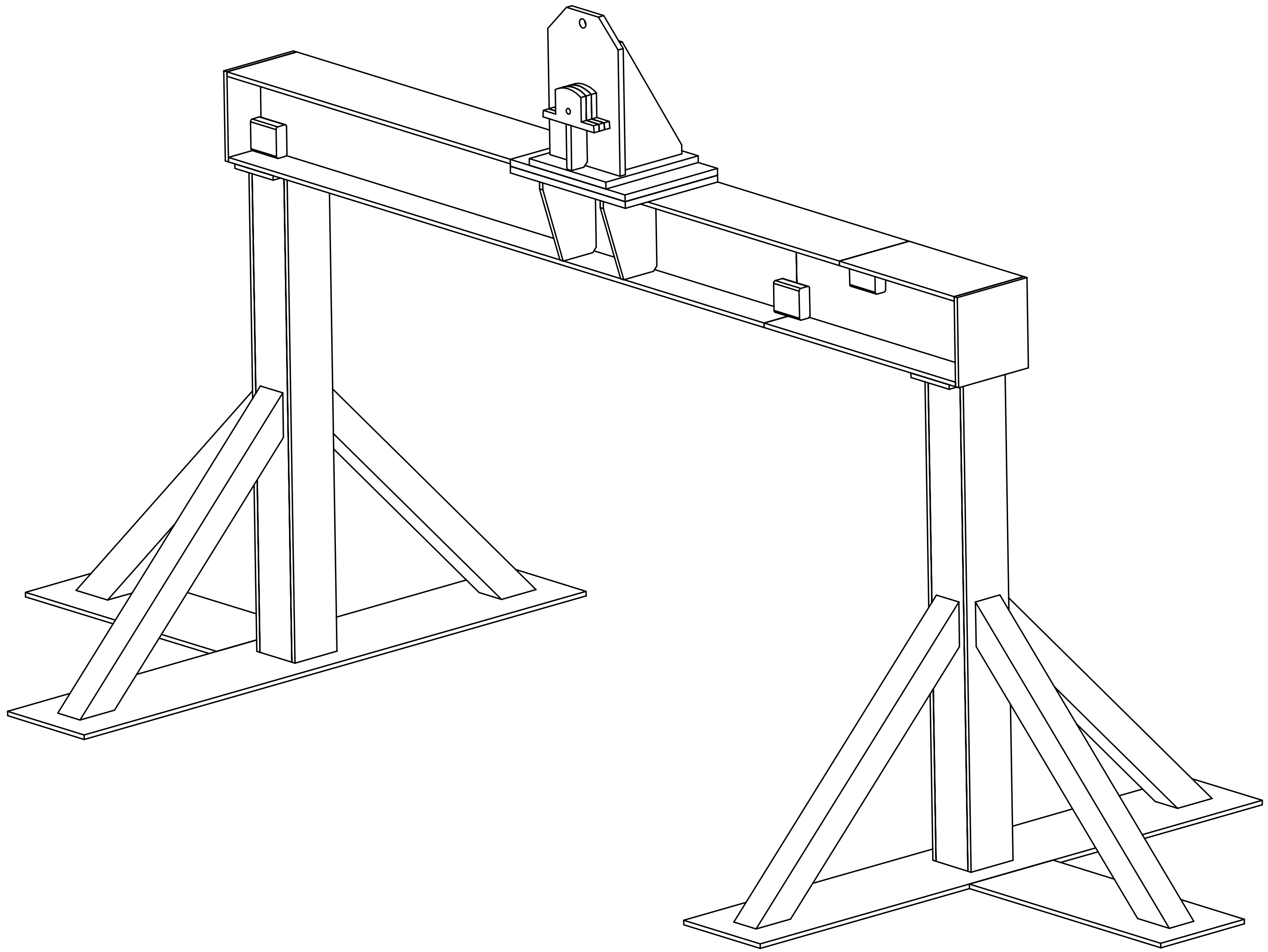

| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: EXPLODED COUPLER | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: LC00-E | Date: 4/30/2017 | Scale: 1:1 | Advisor: EILEEN ROSSMAN |






| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: COUPLER BASE | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: LC01 | Date: 4/30/2017 | Scale: 1:1 | Advisor: EILEEN ROSSMAN |

NOTE:
1. DRAWING IS FOR FULL SCALE WOODEN PROTOTYPE
2. NO BOLTING OR FASTENING HARDWARE IS SHOWN
3. ALL MATERIAL IS FROM READILY AVAILABLE LUMBER

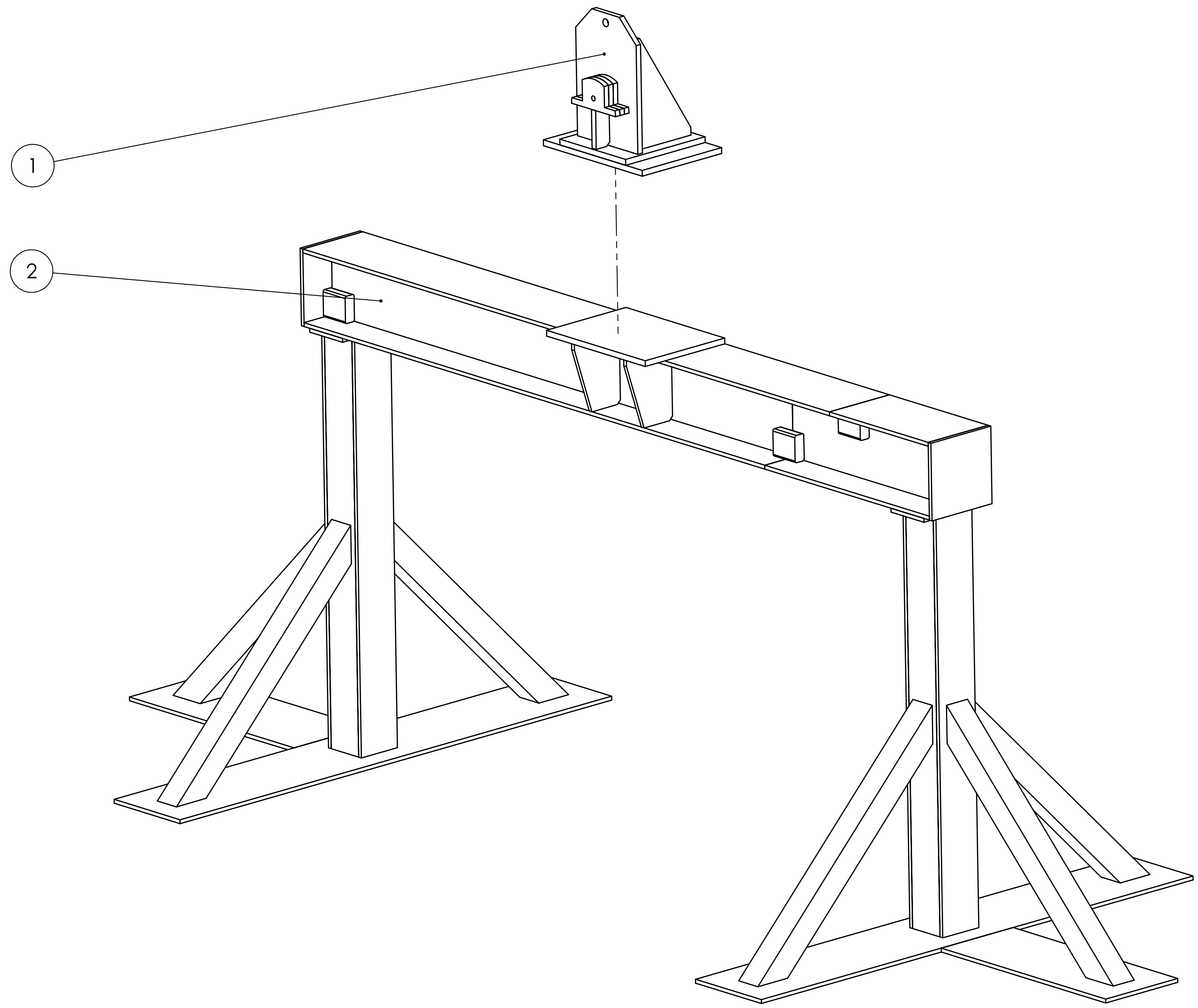




| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: TOTAL ASSEMBLY | | Drwn. By: SUBLIME SQUAD |
|---|---|---|---|---|
| | Dwg. #: C000 | Date: 4/21/2017 | Scale: 1:15 | Advisor: EILEEN ROSSMAN |

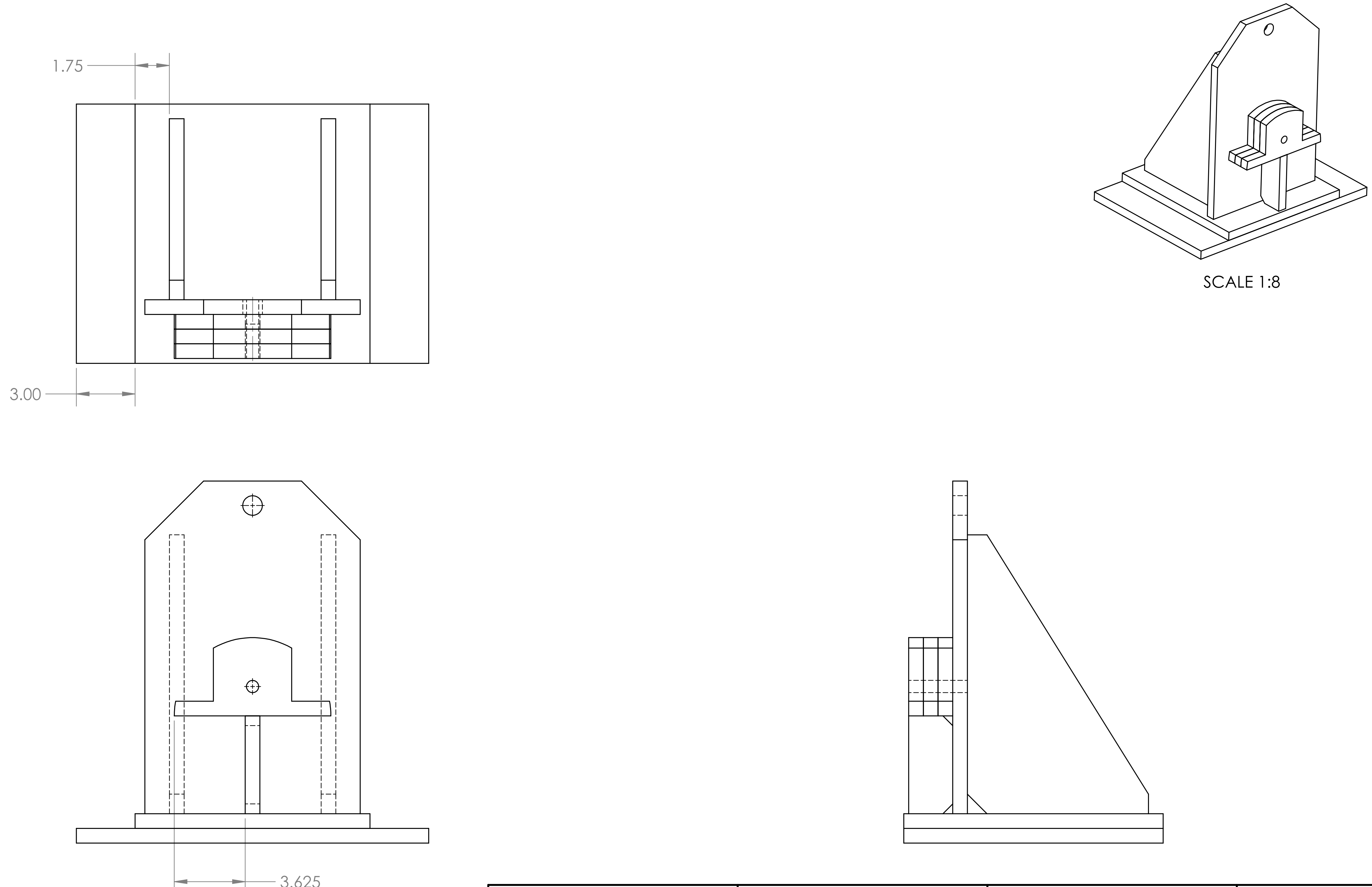
| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | CA00 | CONNECTION BOX | 1 |
| 2 | CB00 | SAWHORSE | 1 |







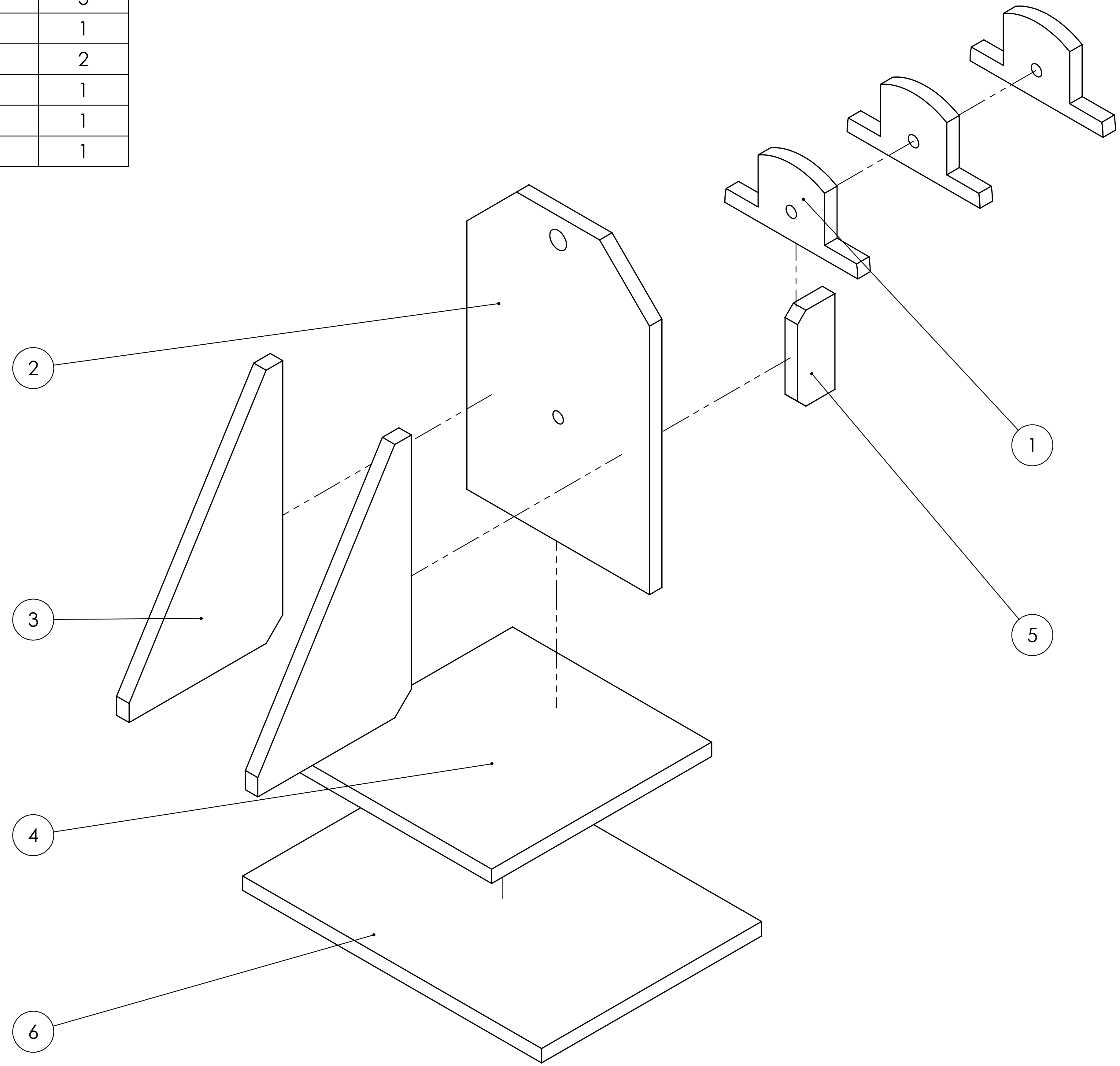

| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: TOTAL ASSEMBLY EXPLOSION | | Drwn. By: SUBLIME SQUAD |
|---|---|---|---|---|
| | Dwg. #: C000-E | Date: 4/21/2017 | Scale: 1:15 | Advisor: EILEEN ROSSMAN |





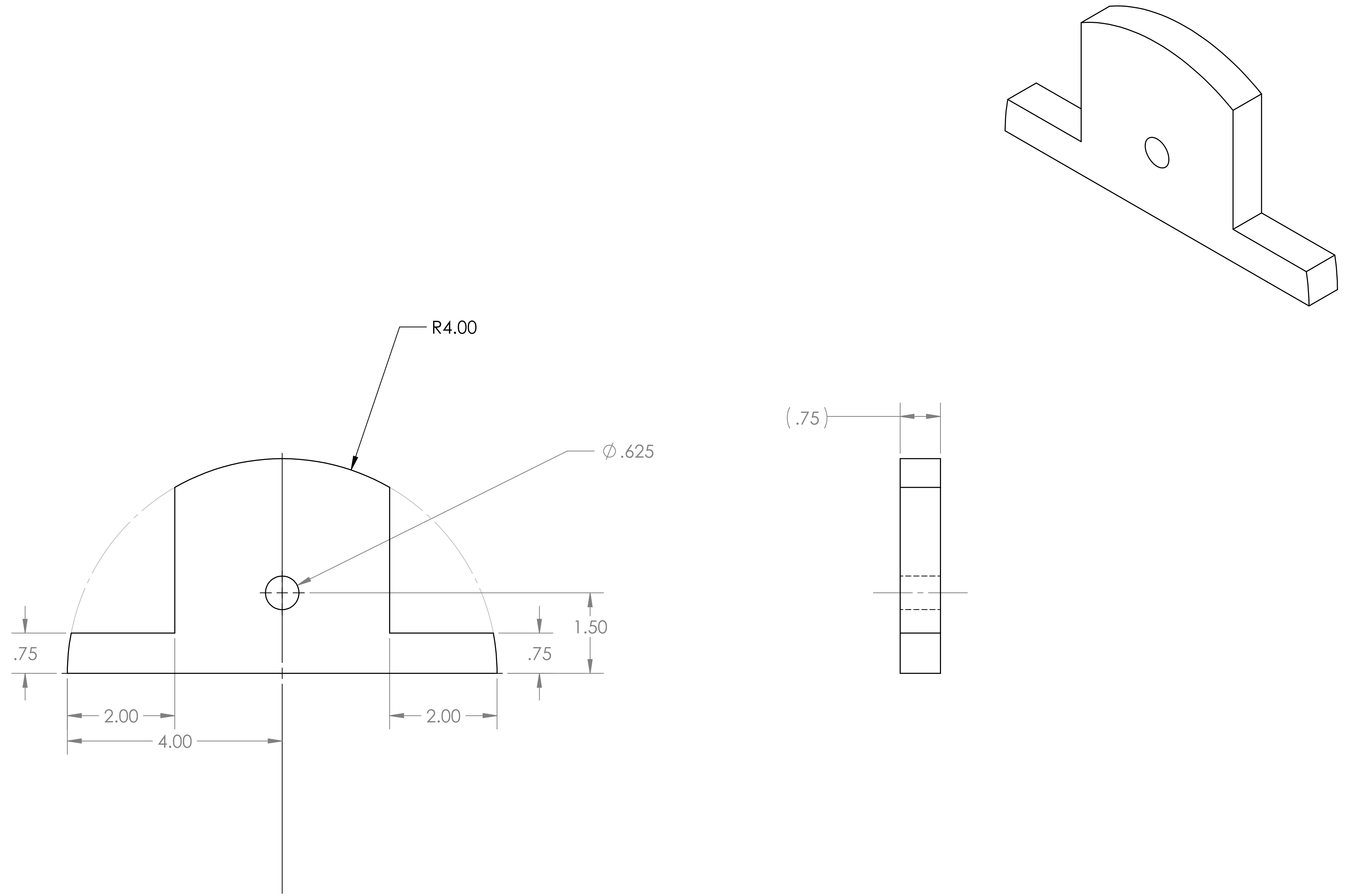

| | | | |
|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: CONNECTION BOX | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: CA00 | Date: 4/21/2017 / Scale: 1:5 | Advisor: EILEEN ROSSMAN |

| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | CA01 | LOAD BEARING PUCK | 3 |
| 2 | CA02 | BACK PLATE | 1 |
| 3 | CA03 | BOX GUSSET | 2 |
| 4 | CA04 | BOX PLATE | 1 |
| 5 | CA05 | PUCK GUSSET | 1 |
| 6 | C00X | INTERFACE PLATE | 1 |



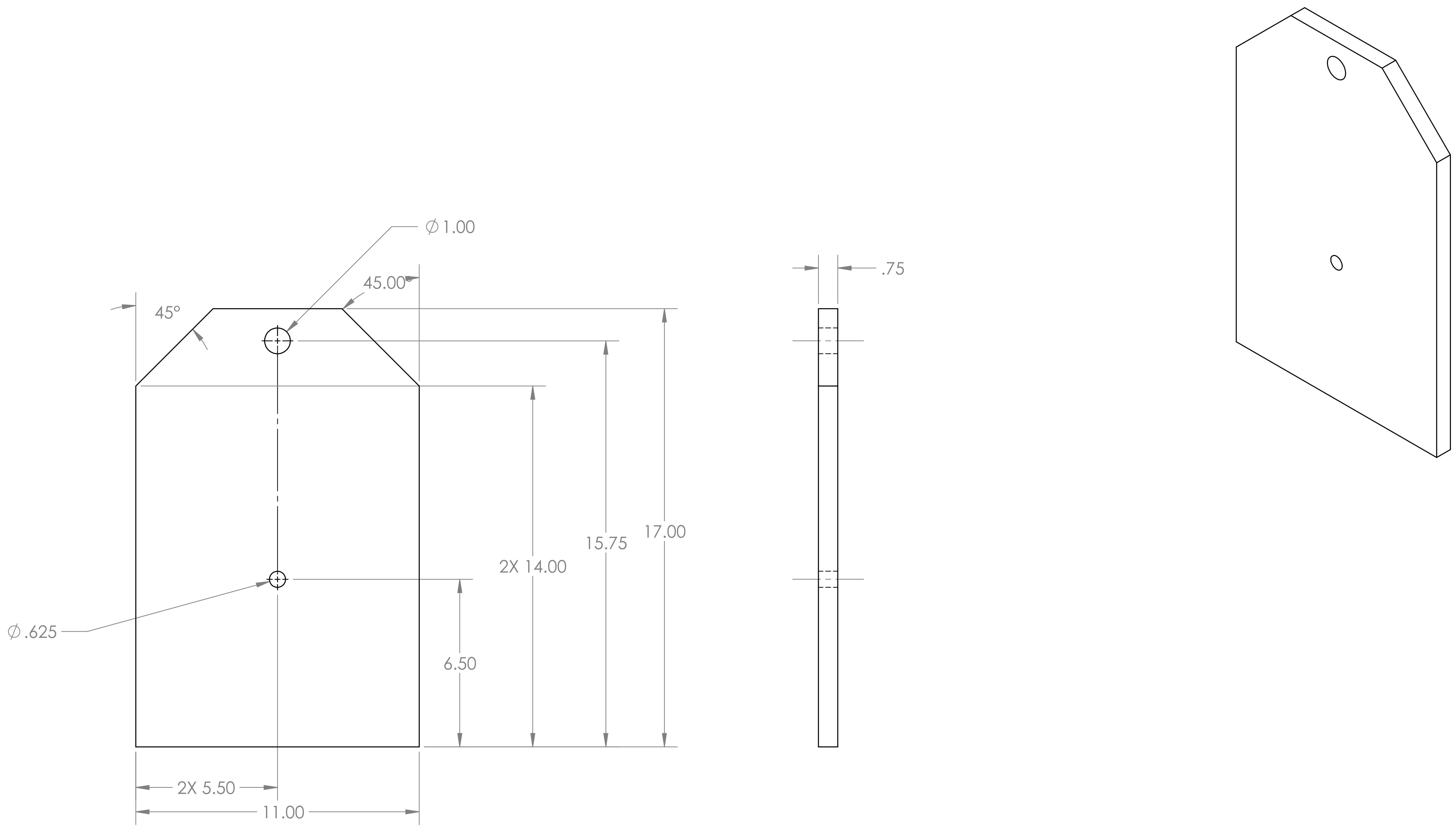



| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering<br>SENIOR PROJECT | Project: AVALON STRUCTURE | Title: EXPLODED CONNECTION BOX | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: CA00-E | Date: 4/21/2017 | Scale: 1:5 | Advisor: EILEEN ROSSMAN |



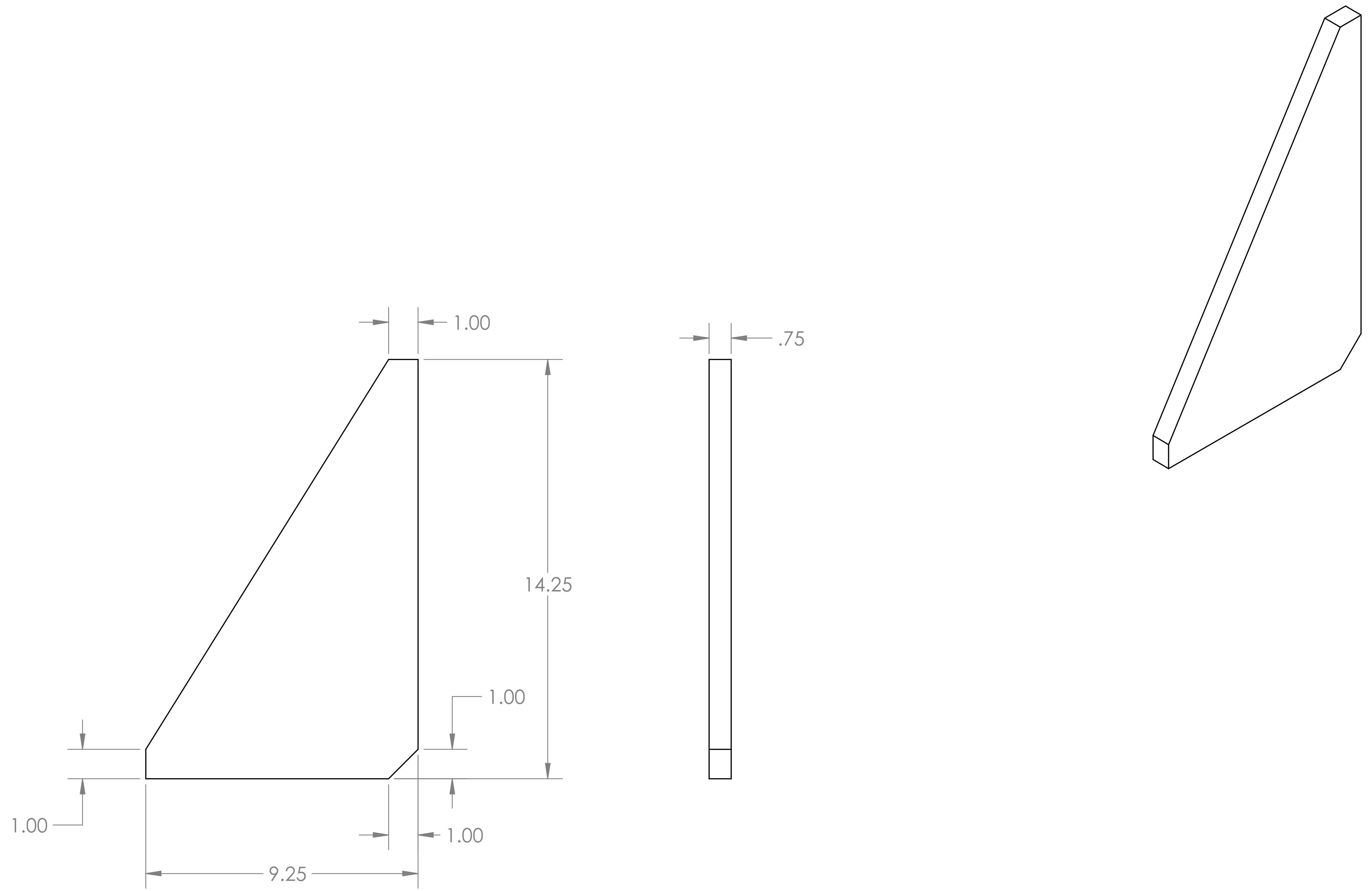



| | | | |
|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: LOAD BEARING PUCK | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: CA01 | Date: 4/21/2017 Scale: 1:2 | Advisor: EILEEN ROSSMAN |



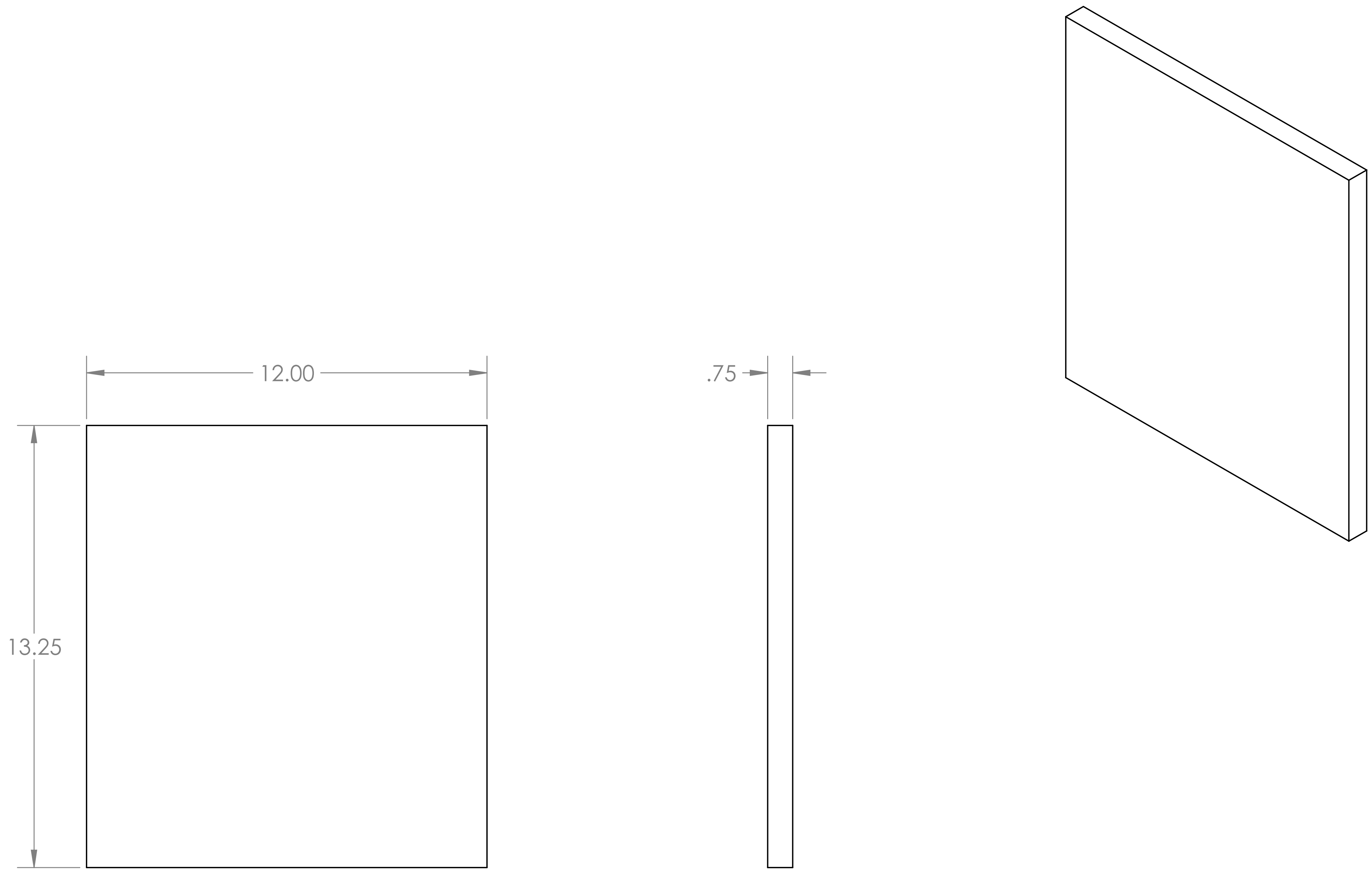



| | | | |
|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: BACK PLATE | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: CA02 | Date: 4/21/2017 — Scale: 1:4 | Advisor: EILEEN ROSSMAN |






| | | | |
|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: BOX GUSSET | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: CA03 | Date: 4/21/2017 Scale: 1:4 | Advisor: EILEEN ROSSMAN |

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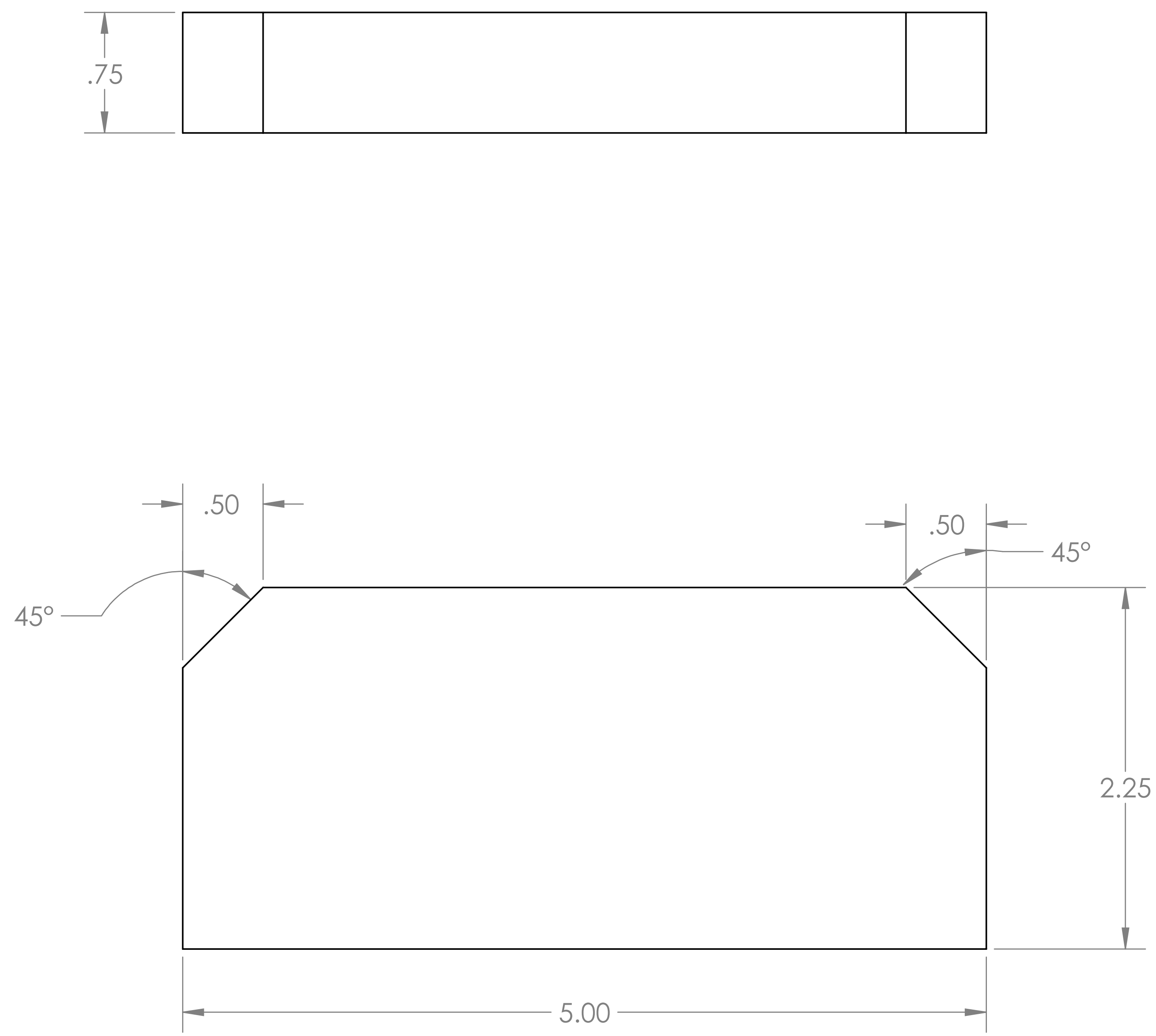
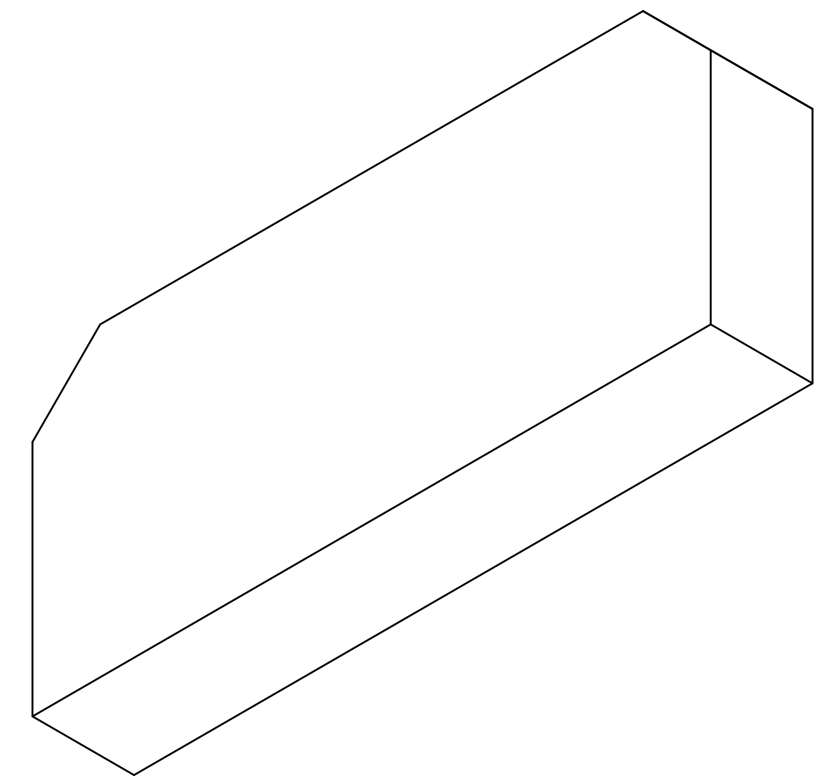
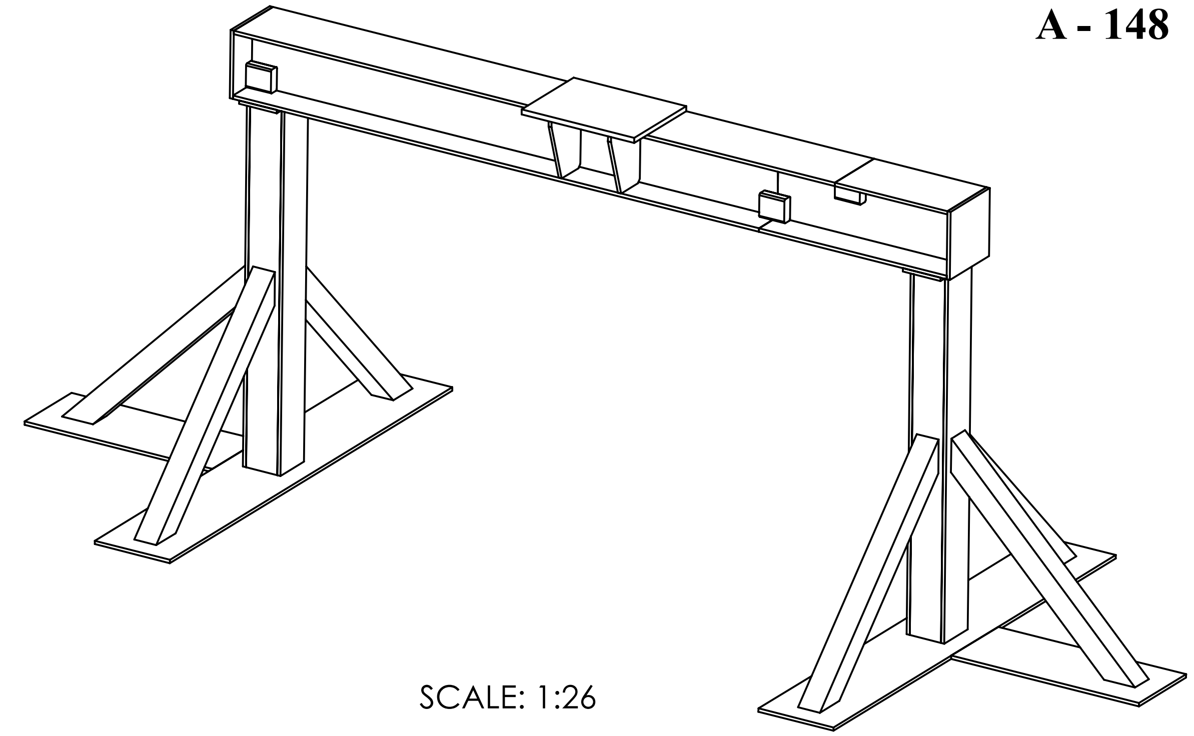
|---|---|---|---|---|
| Cal Poly Mechanical Engineering<br>SENIOR PROJECT | Project: AVALON STRUCTURE | Title: BOX PLATE | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: CA04 | Date: 4/21/2017 | Scale: 1:4 | Advisor: EILEEN ROSSMAN |



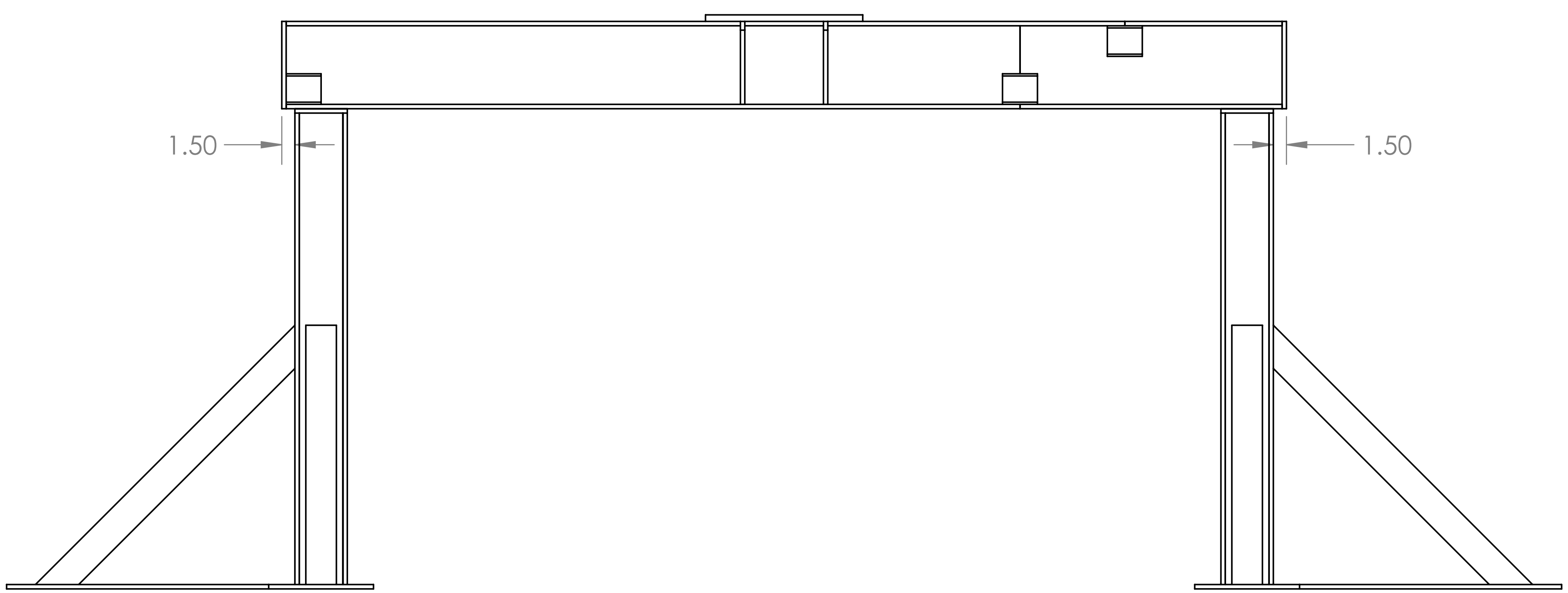



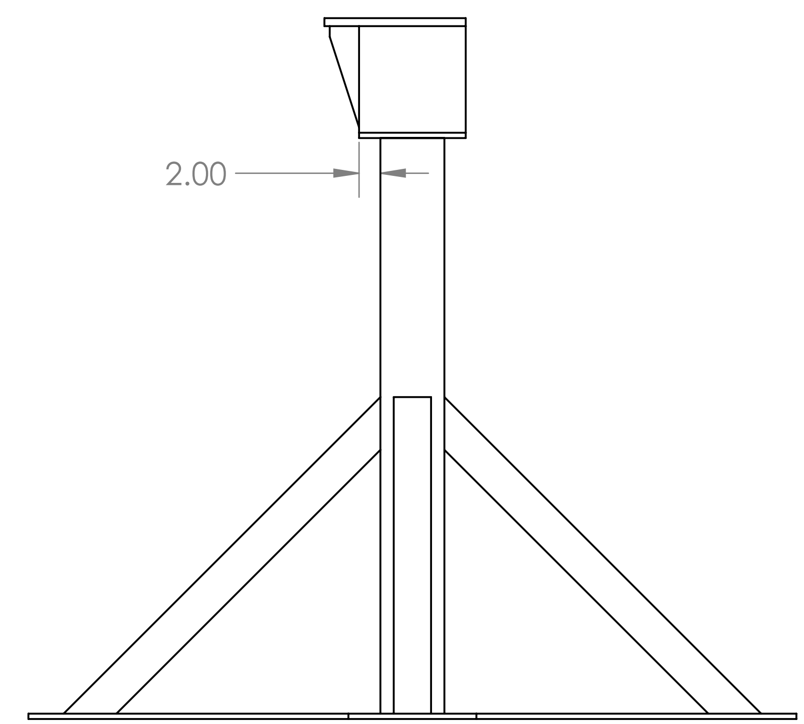


| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: PUCK GUSSET | | Drwn. By: SUBLIME SQUAD |
|---|---|---|---|---|
| | Dwg. #: CA05 | Date: 4/21/2017 | Scale: 1:1 | Advisor: EILEEN ROSSMAN |



SCALE: 1:26

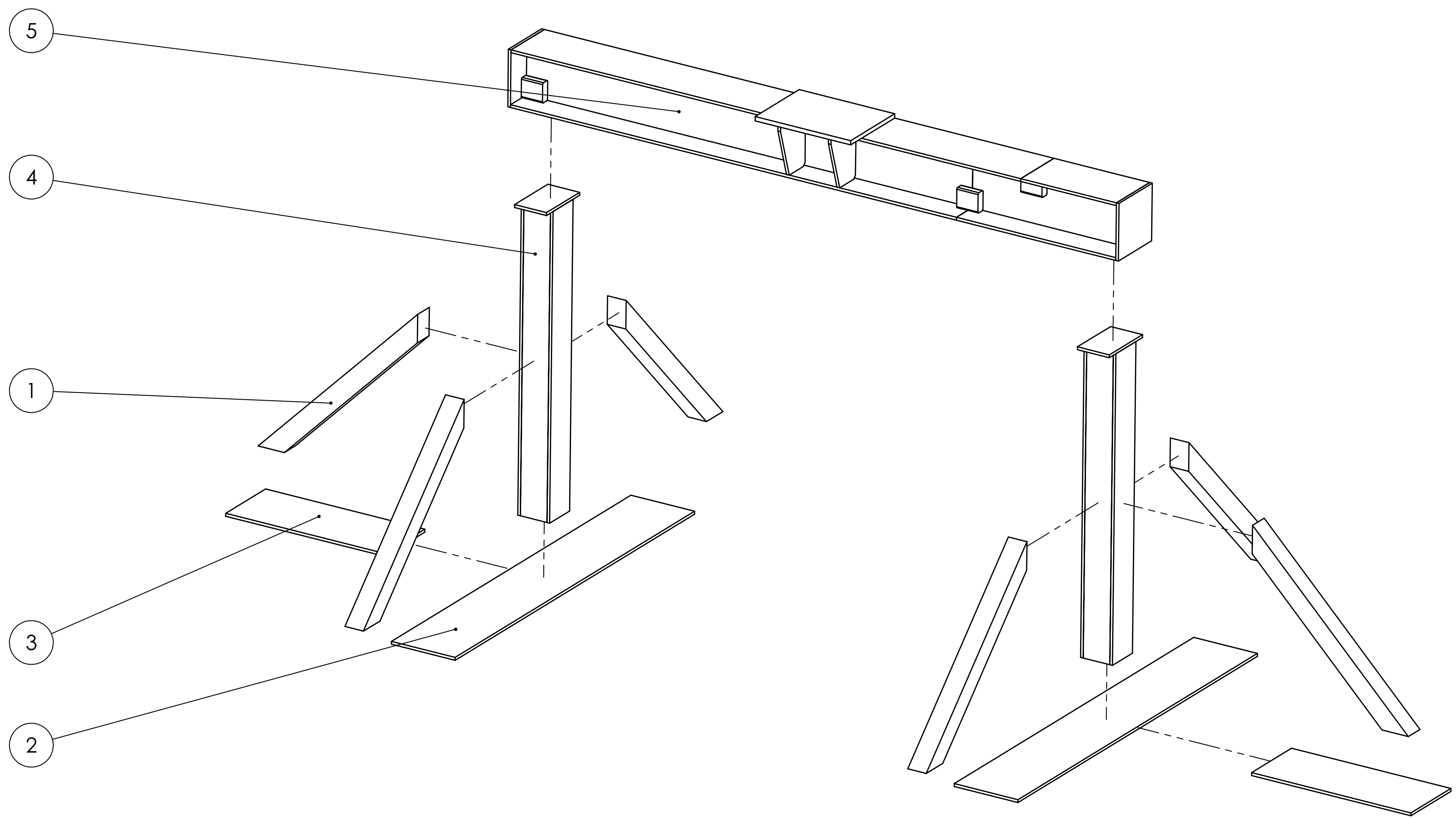




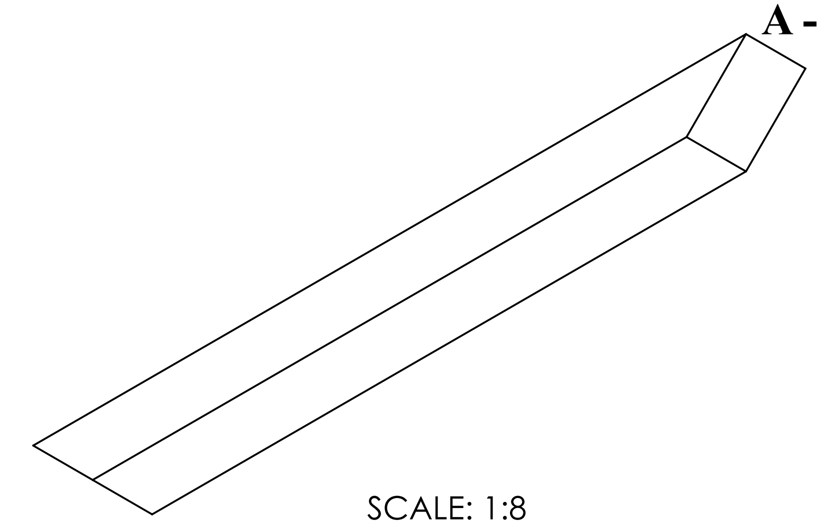

| Cal Poly Mechanical Engineering<br>SENIOR PROJECT | Project: AVALON STRUCTURE | Title: SAWHORSE | | Drwn. By: SUBLIME SQUAD |
|---|---|---|---|---|
| | Dwg. #: CB00 | Date: 4/21/2017 | Scale: 1:18 | Advisor: EILEEN ROSSMAN |

| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | CB01 | STRUT | 6 |
| 2 | CB02 | LONG FOOT | 2 |
| 3 | CB03 | SHORT FOOT | 2 |
| 4 | CBA0 | COLUMN ASSEMBLY | 2 |
| 5 | CBB0 | BEAM ASSEMBLY | 1 |






| | | | |
|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: EXPLODED SAWHORSE | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: CB00-E | Date: 4/21/2017 Scale: 1:20 | Advisor: EILEEN ROSSMAN |



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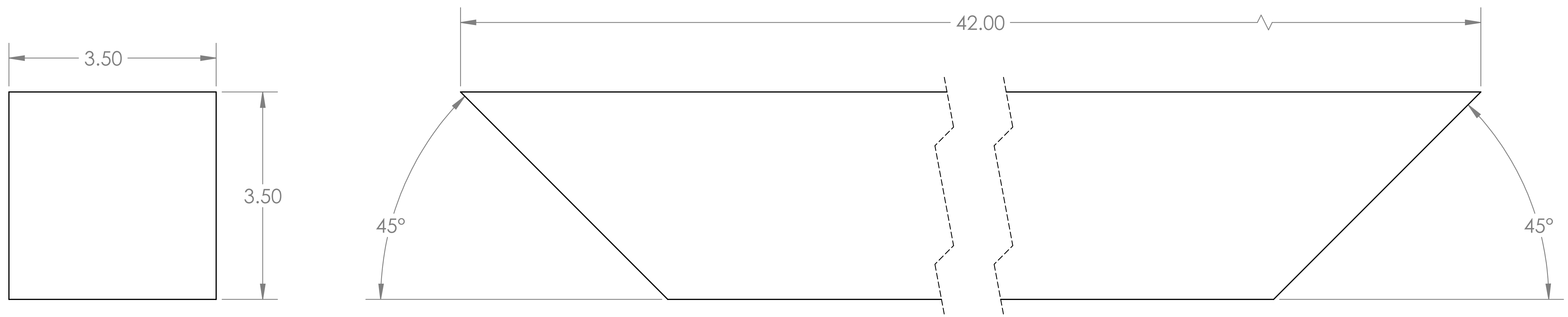
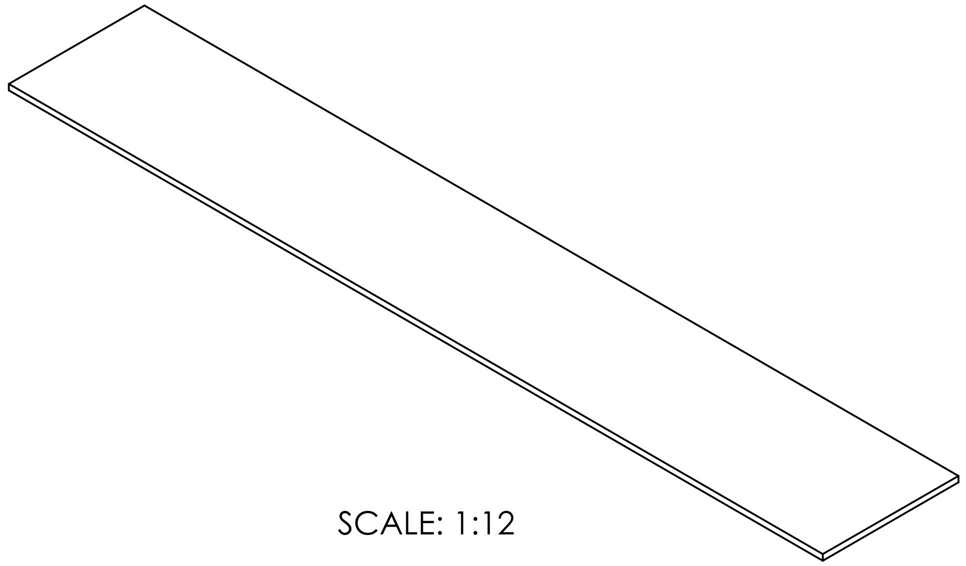





| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: STRUT | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: CB01 | Date: 4/21/2017 | Scale: 1:2 | Advisor: EILEEN ROSSMAN |



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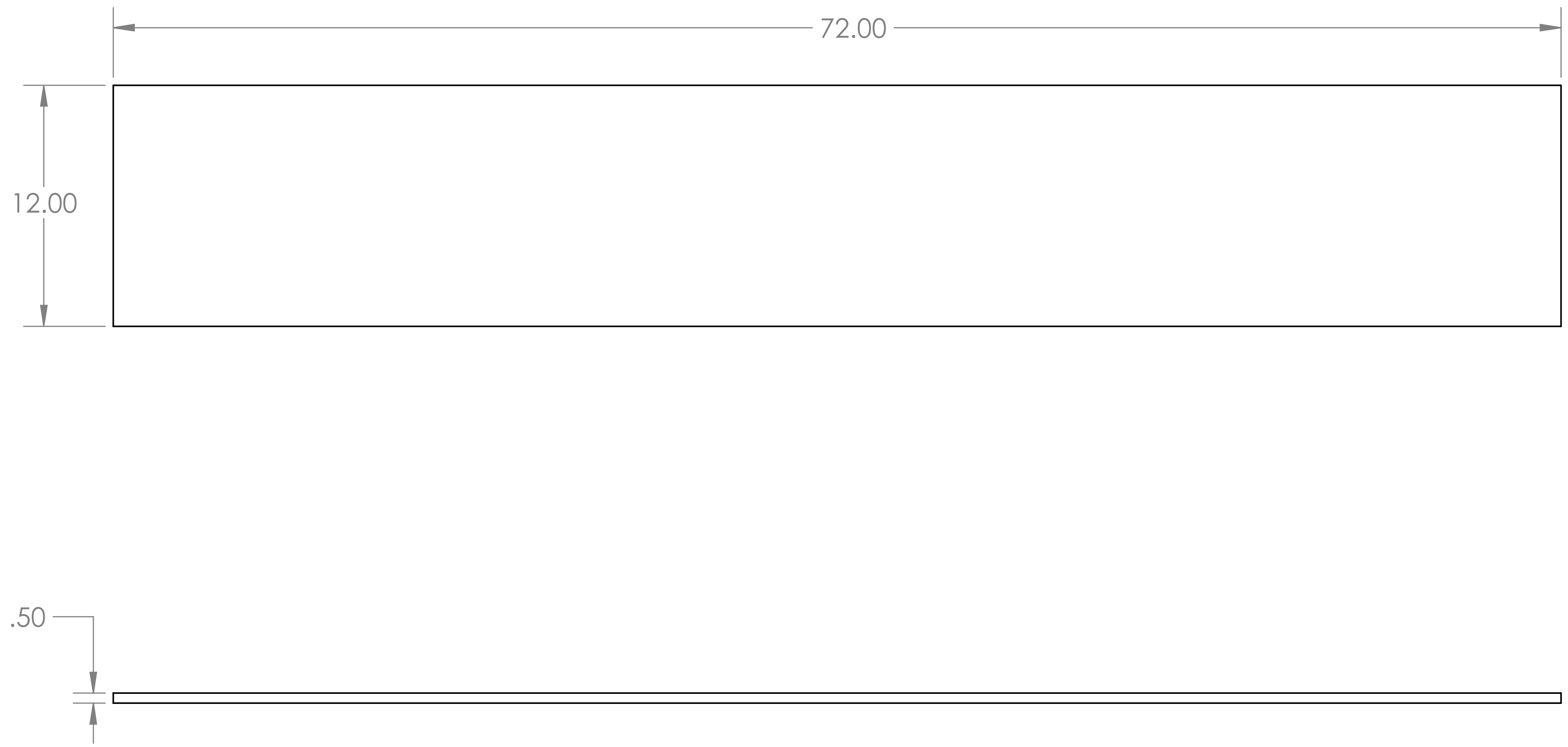
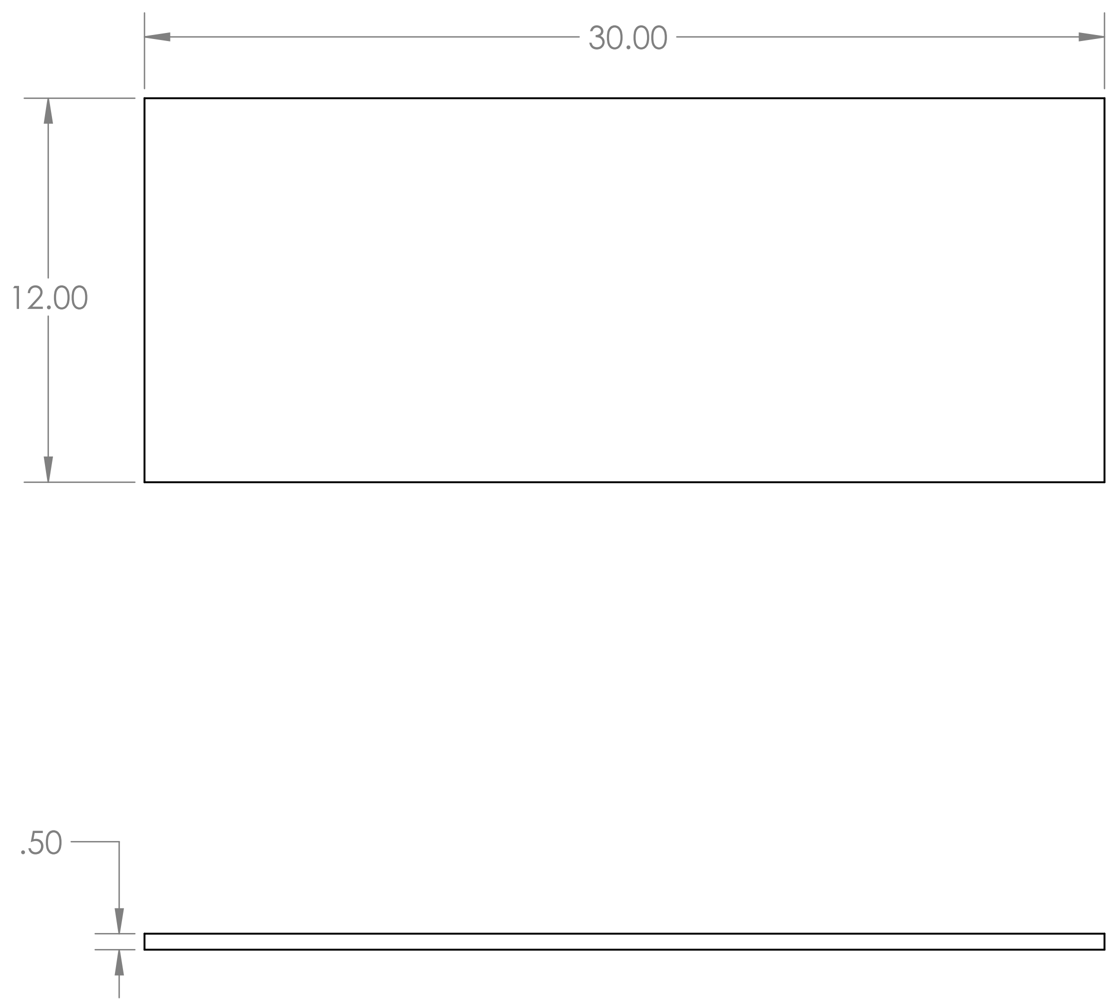
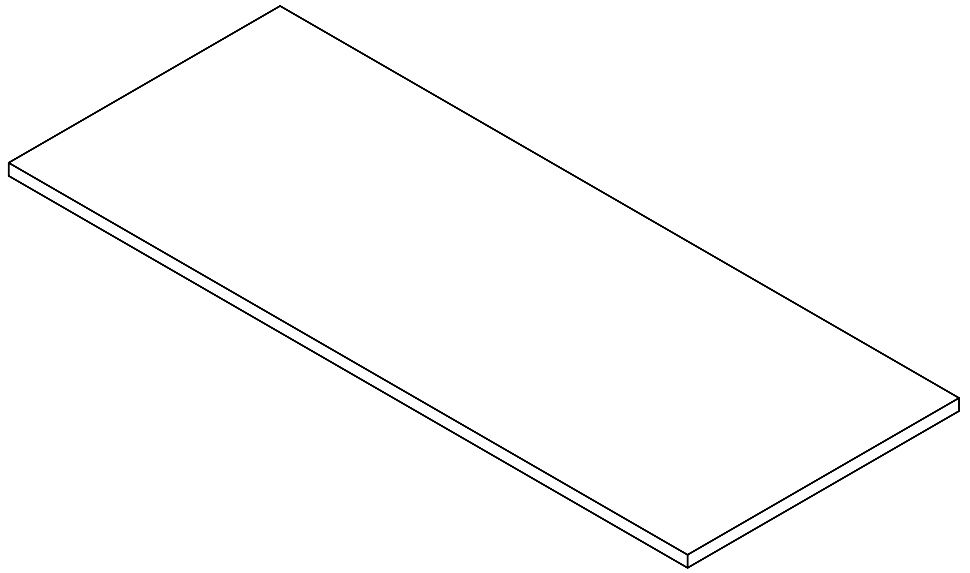





| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: LONG FOOT | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: CB02 | Date: 4/21/2017 | Scale: 1:8 | Advisor: EILEEN ROSSMAN |



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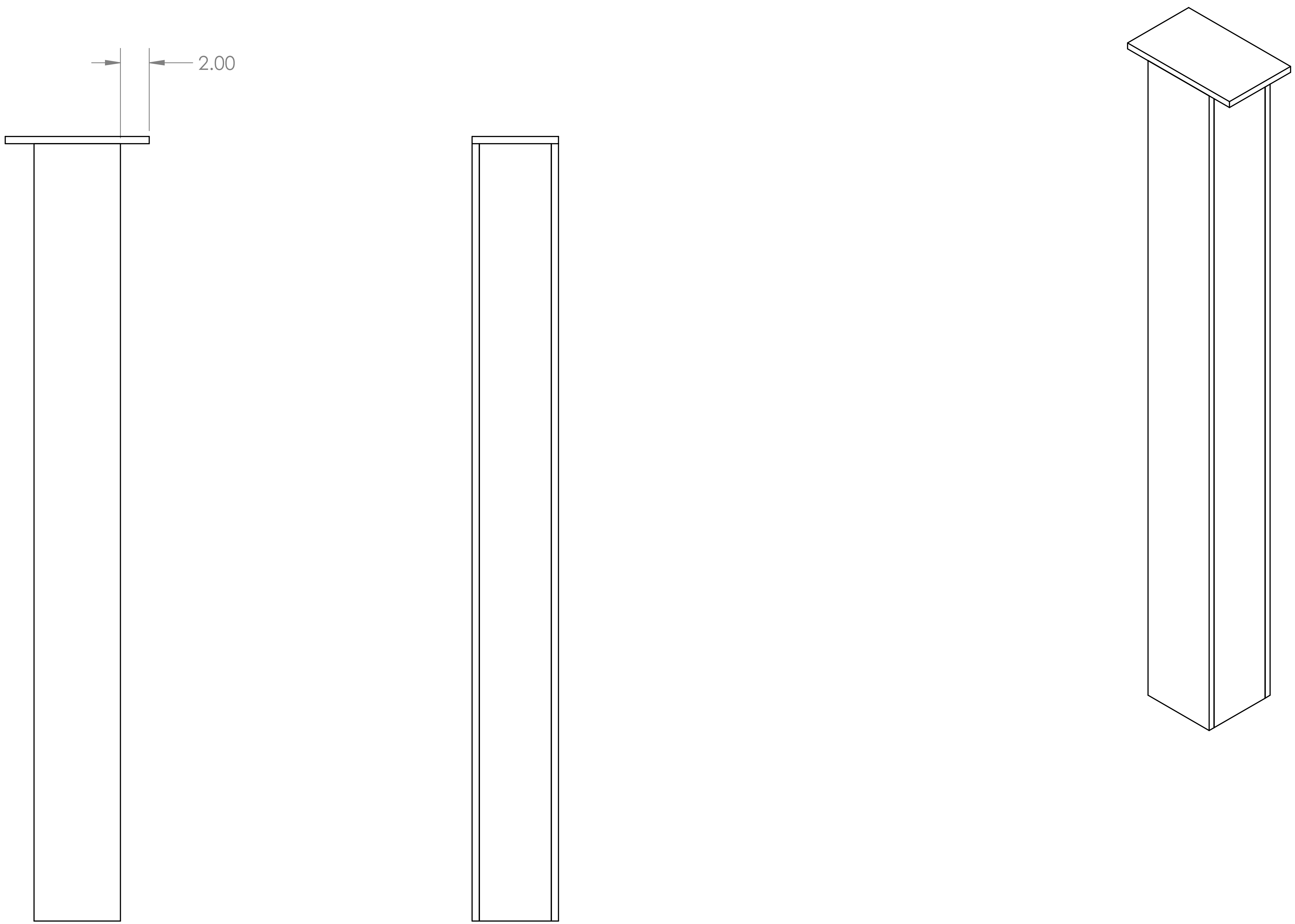
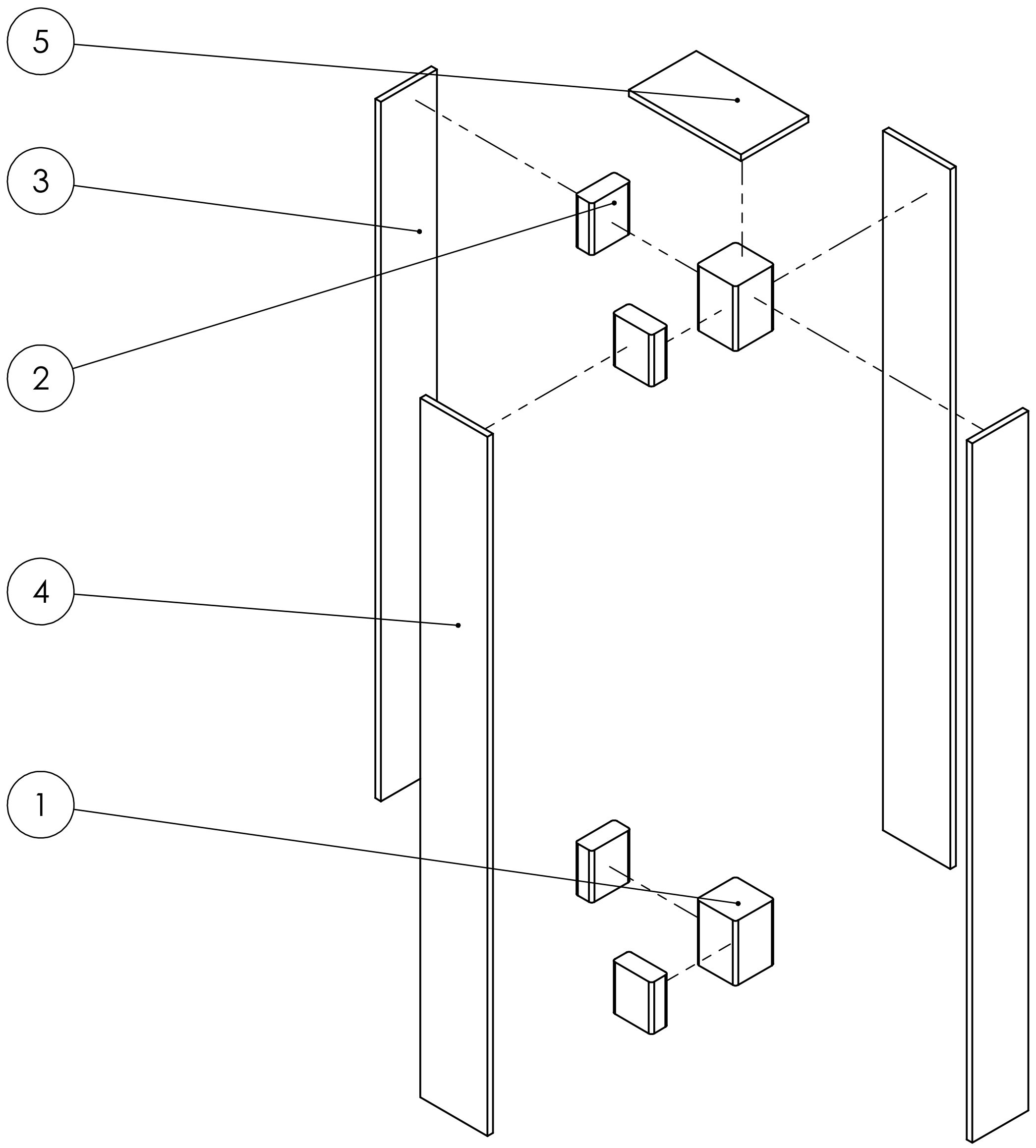
| | | | |
|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: SHORT FOOT | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: CB03 | Date: 4/21/2017 / Scale: 1:6 | Advisor: EILEEN ROSSMAN |





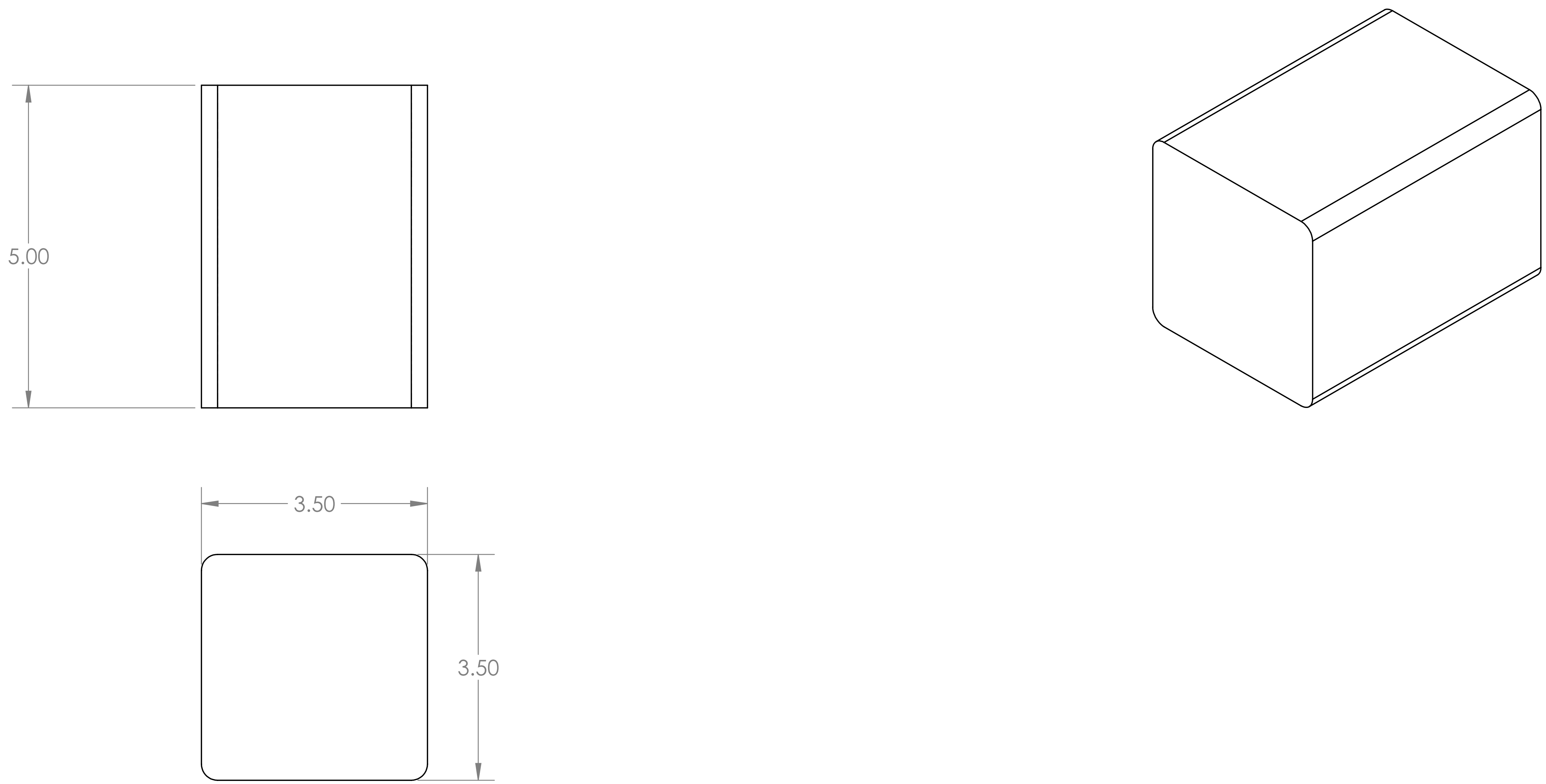

| Cal Poly Mechanical Engineering<br>SENIOR PROJECT | Project: AVALON STRUCTURE | Title: COLUMN ASSEMBLY | | Drwn. By: SUBLIME SQUAD |
|---|---|---|---|---|
| | Dwg. #: CBA0 | Date: 4/21/2017 | Scale: 1:8 | Advisor: EILEEN ROSSMAN |

| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | CBA1 | 4x4 BLOCK | 2 |
| 2 | CBA2 | 2X4 BLOCK | 4 |
| 3 | CBA3 | 5 INCH PLANK | 2 |
| 4 | CBA4 | 6 INCH PLANK | 2 |
| 5 | CBA5 | TOP ATTACHMENT PLATE | 1 |



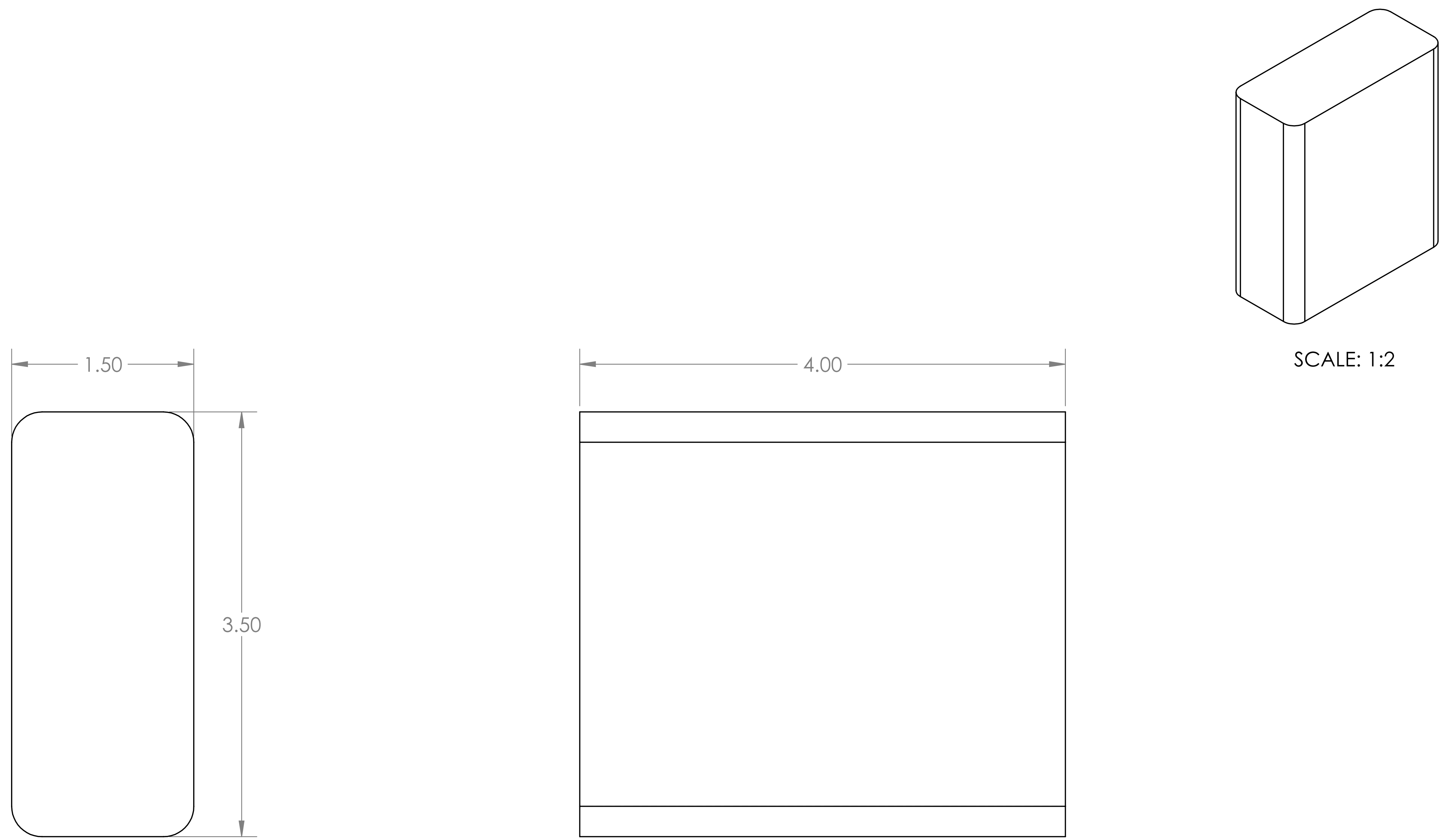



| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: | Date: 4/21/2017 | Scale: | Advisor: EILEEN ROSSMAN |



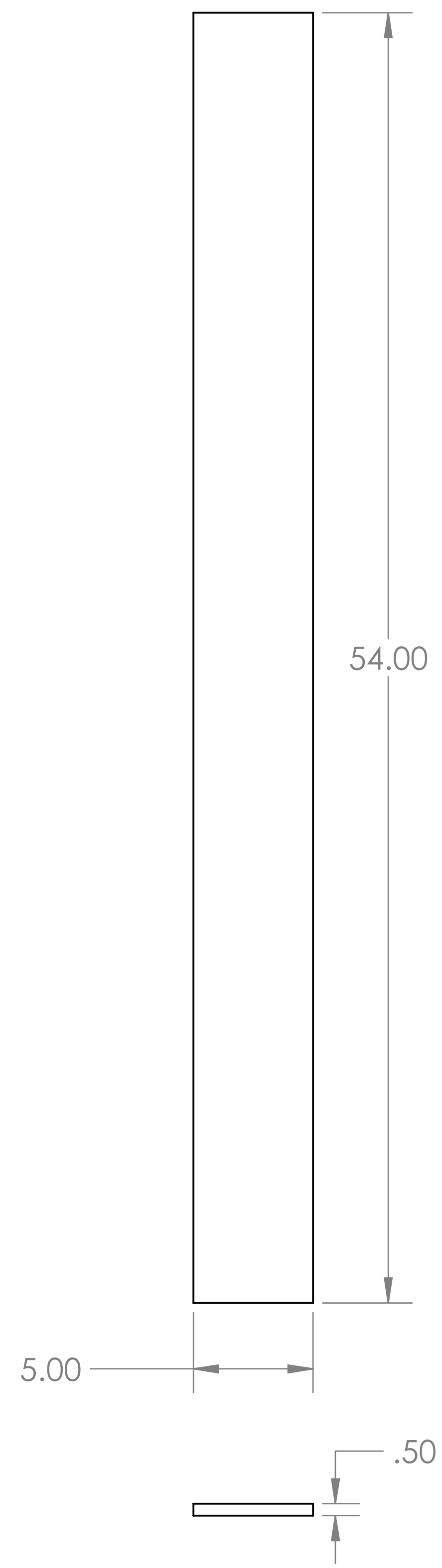


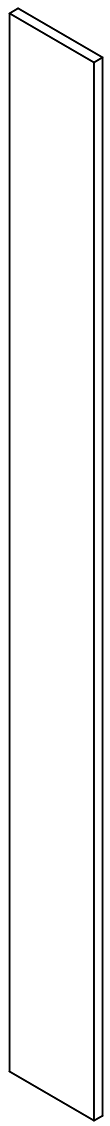

| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: 4X4 BLOCK | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: CBA1 | Date: 4/21/2017 | Scale: 1:2 | Advisor: EILEEN ROSSMAN |





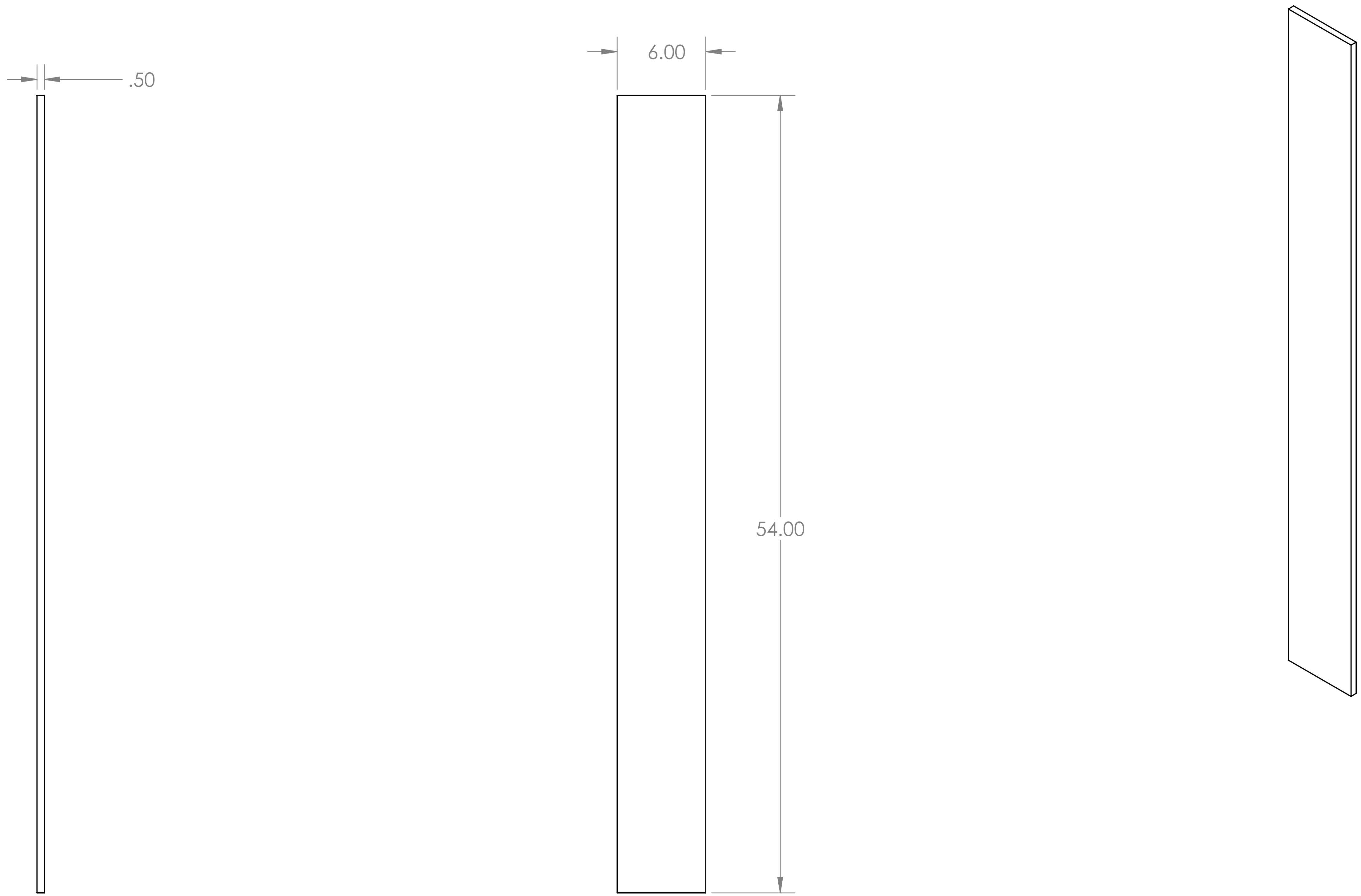

| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: 2X4 BLOCK | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #:CBA2 | Date: 4/21/2017 | Scale: 1:1 | Advisor: EILEEN ROSSMAN |



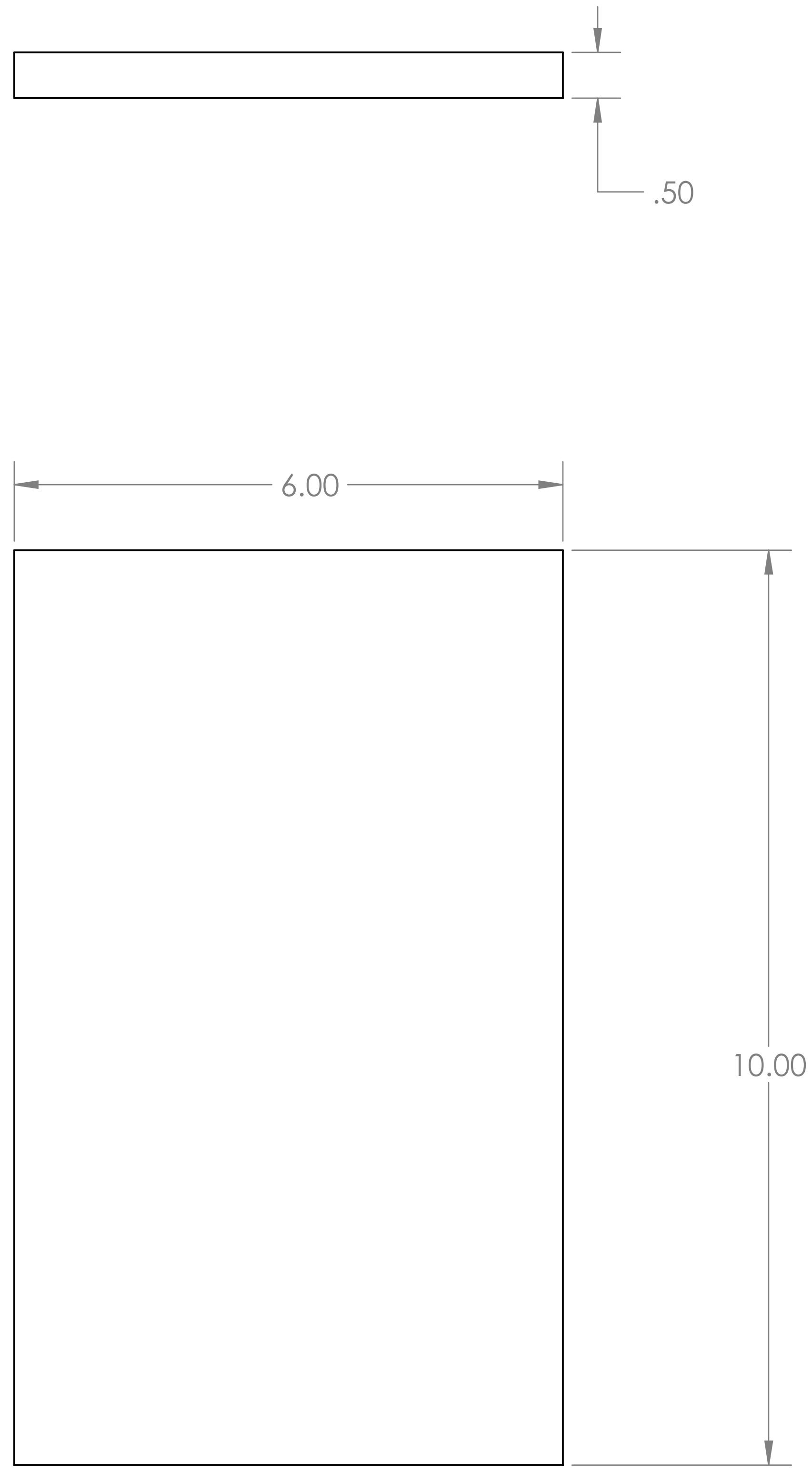


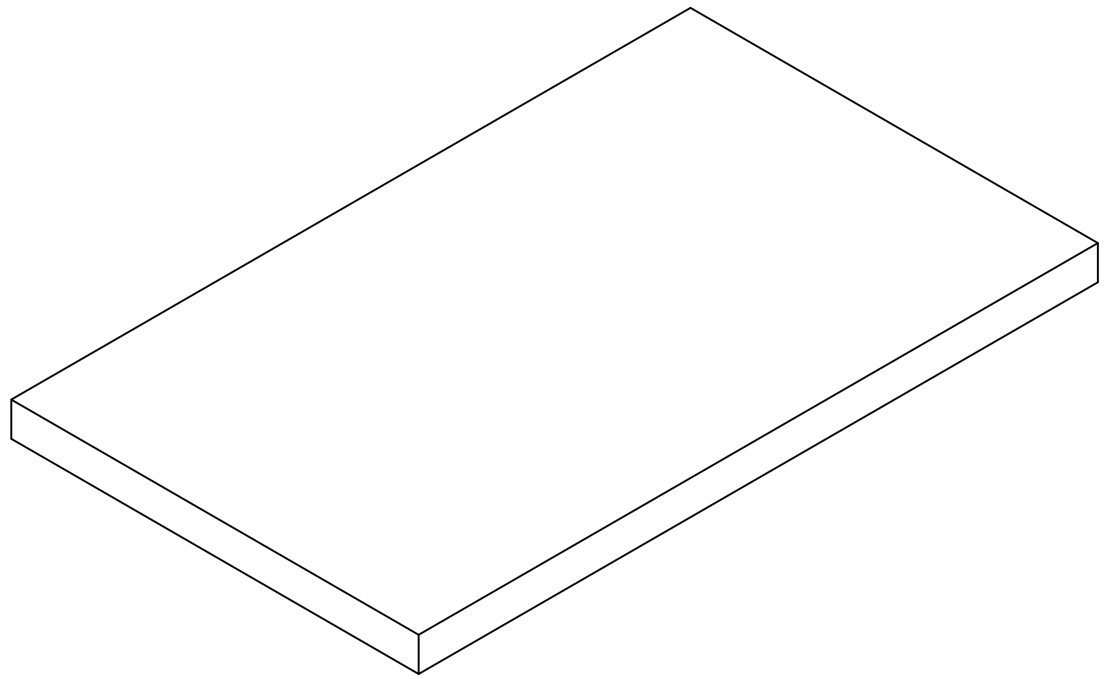
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: 5 INCH PLANK | | Drwn. By: SUBLIME SQUAD |
|---|---|---|---|---|
| | Dwg. #: CBA3 | Date: 4/21/2017 | Scale: 1:8 | Advisor: EILEEN ROSSMAN |





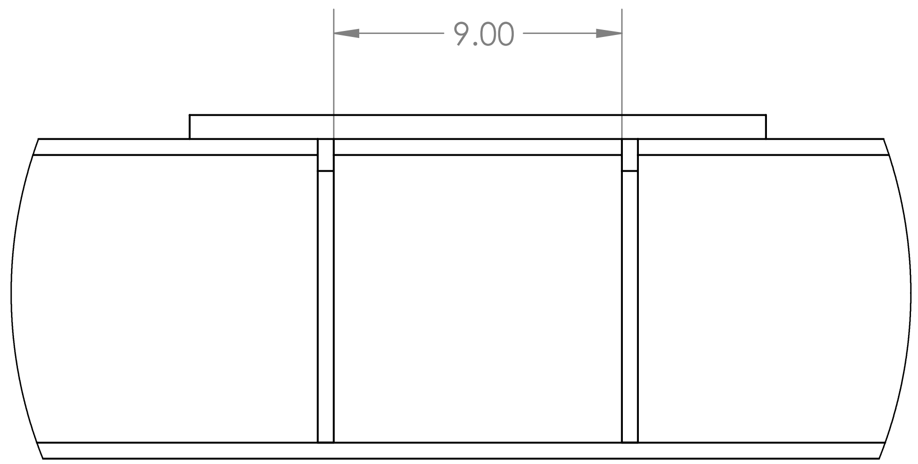

| | | | |
|---|---|---|---|
| Cal Poly Mechanical Engineering<br>SENIOR PROJECT | Project: AVALON STRUCTURE | Title: 6 INCH PLANK | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: CBA4 | Date: 4/21/2017 / Scale: 1:8 | Advisor: EILEEN ROSSMAN |



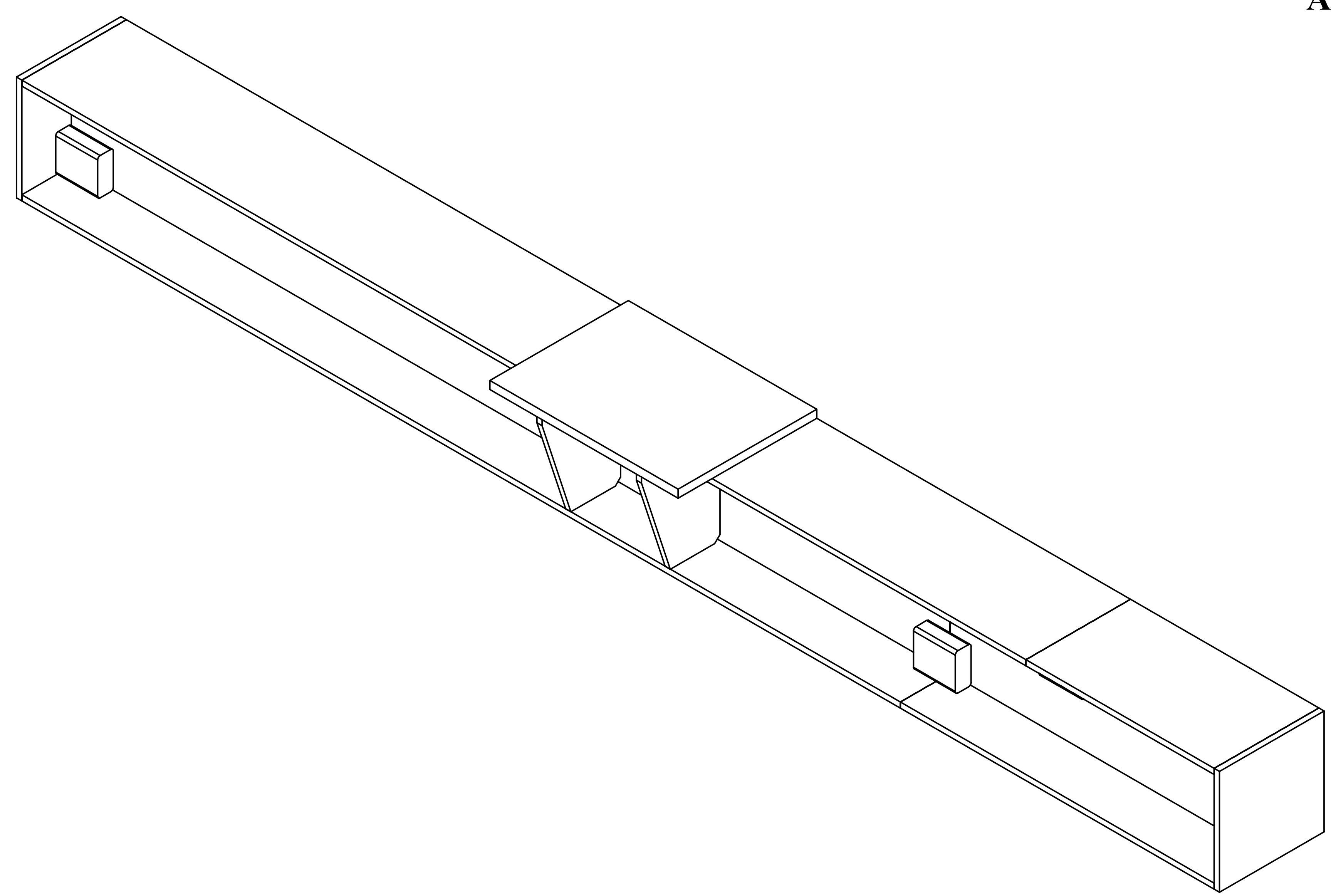



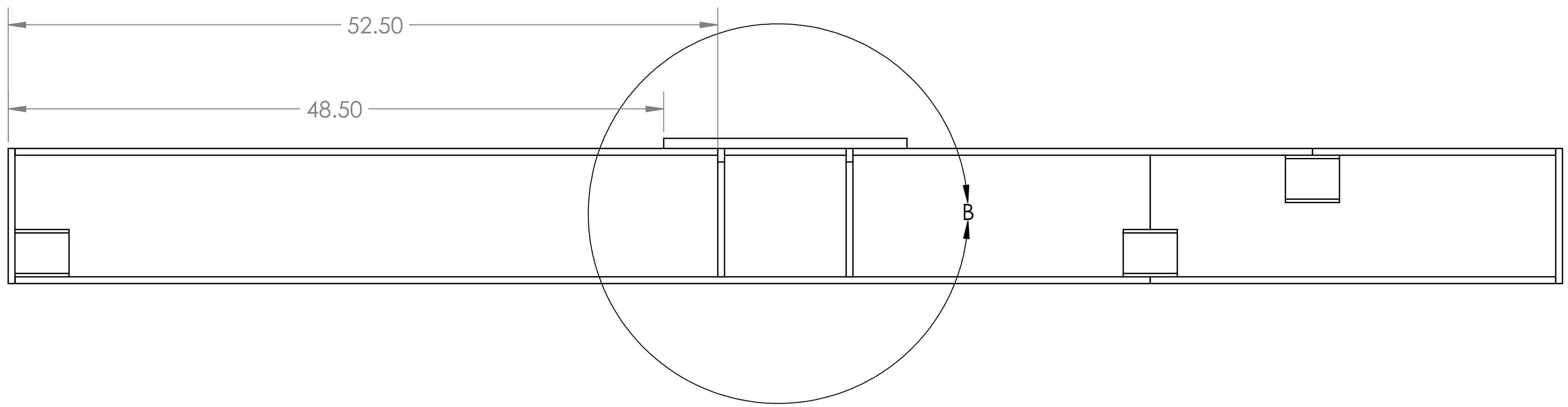


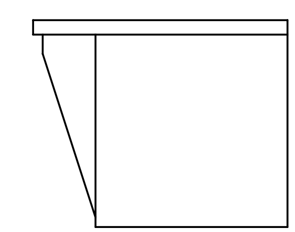
| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: TOP ATTACHMENT PLATE | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: CBA5 | Date: 4/21/2017 | Scale: 1:2 | Advisor: EILEEN ROSSMAN |




DETAIL B
SCALE 1 : 6





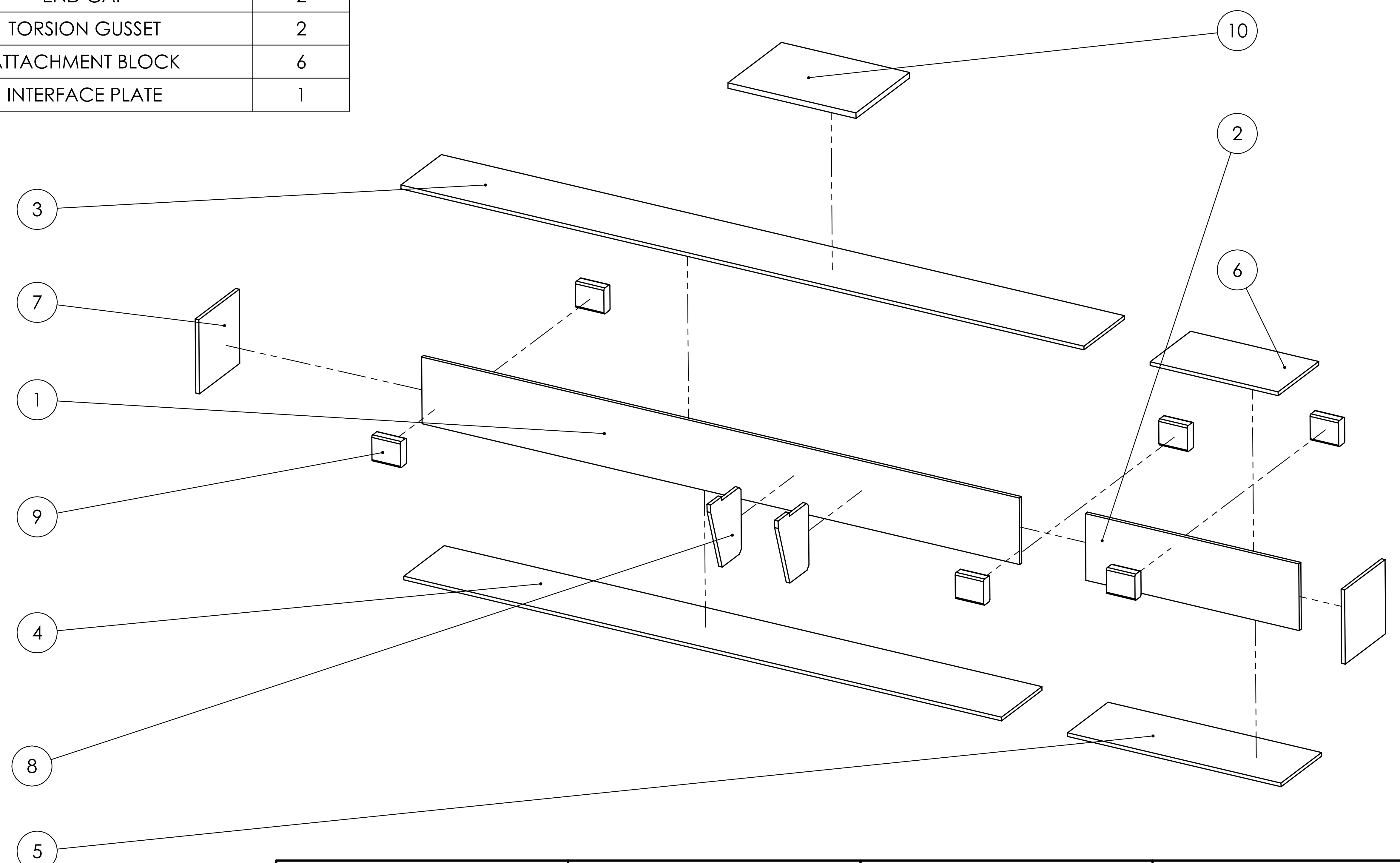





| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: BEAM ASSEMBLY | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: CBB0 | Date: 4/21/2017 | Scale: 1:10 | Advisor: EILEEN ROSSMAN |

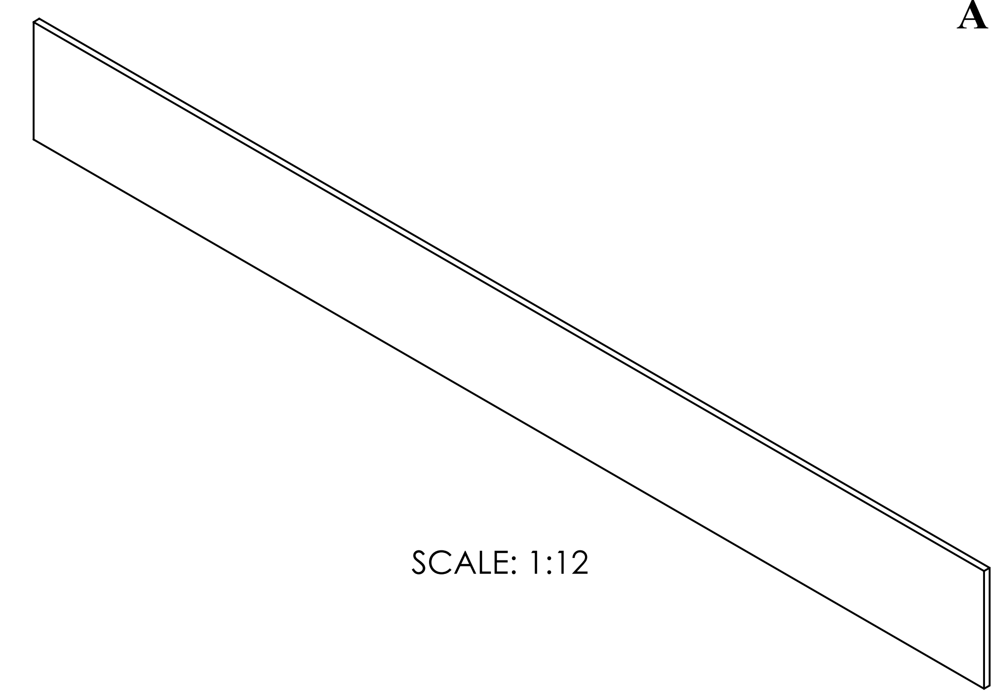
| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | CBB1 | 7FT WEB | 1 |
| 2 | CBB2 | 2.5FT WEB | 1 |
| 3 | CBB3 | 8FT FLANGE | 1 |
| 4 | CBB4 | 7FT FLANGE | 1 |
| 5 | CBB5 | 2.5FT FLANGE | 1 |
| 6 | CBB6 | 1.5FT FLANGE | 1 |
| 7 | CBB7 | END CAP | 2 |
| 8 | CBB9 | TORSION GUSSET | 2 |
| 9 | CBB8 | ATTACHMENT BLOCK | 6 |
| 10 | C00X | INTERFACE PLATE | 1 |








| Cal Poly Mechanical Engineering SENIOR PROJECT | Project: AVALON STRUCTURE | Title: | | Drwn. By: SUBLIME SQUAD |
|---|---|---|---|---|
| | Dwg. #: | Date: 4/21/2017 | Scale: | Advisor: EILEEN ROSSMAN |



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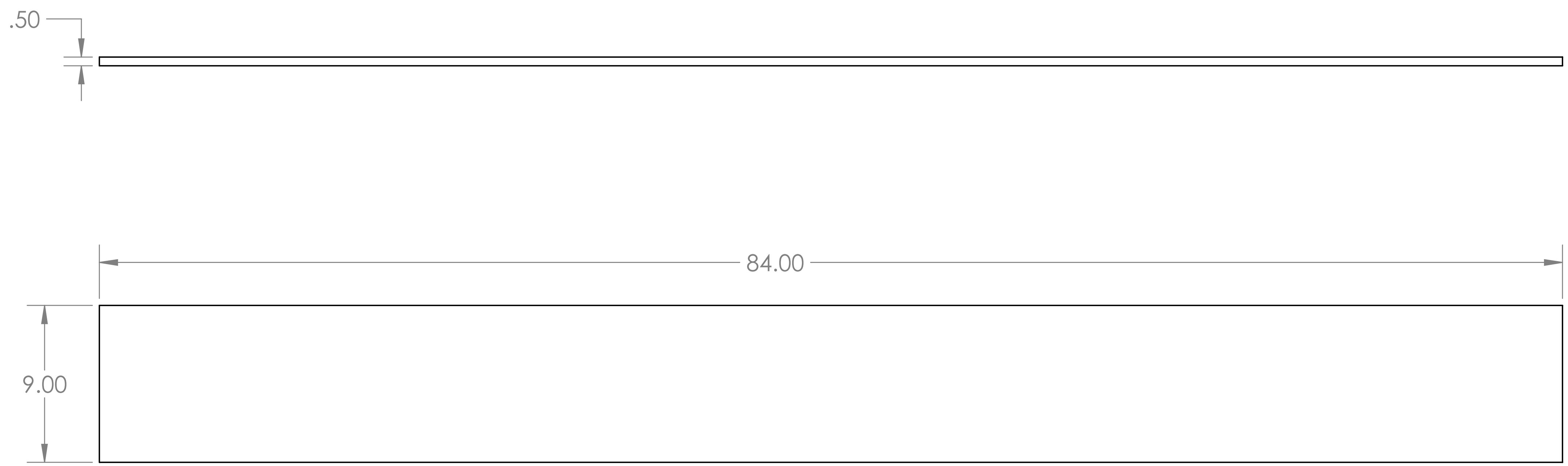




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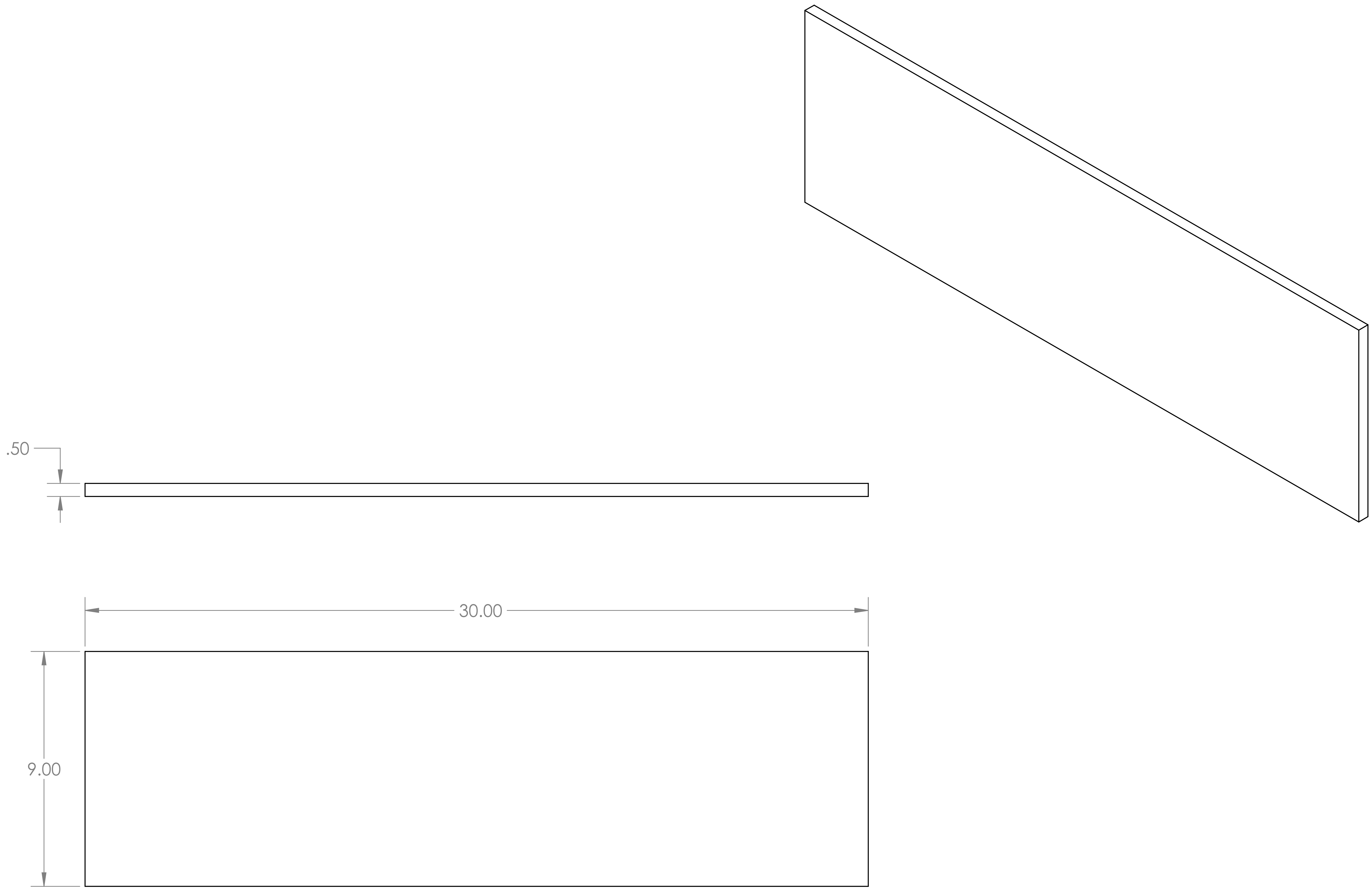
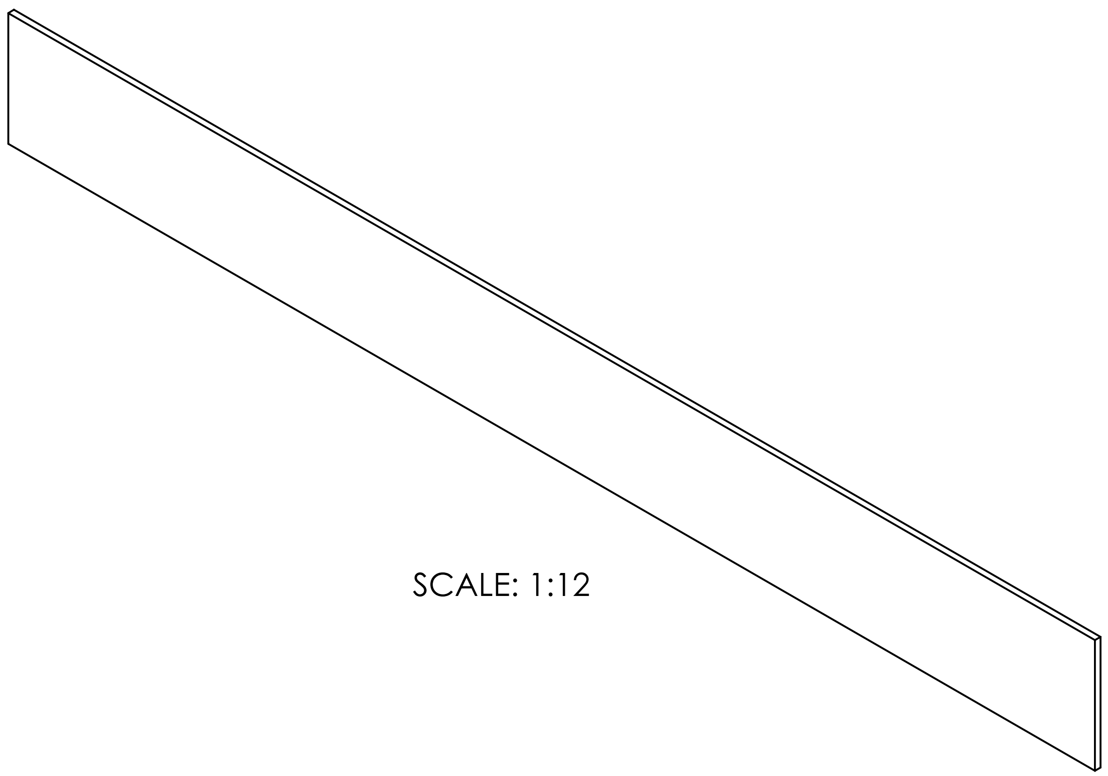
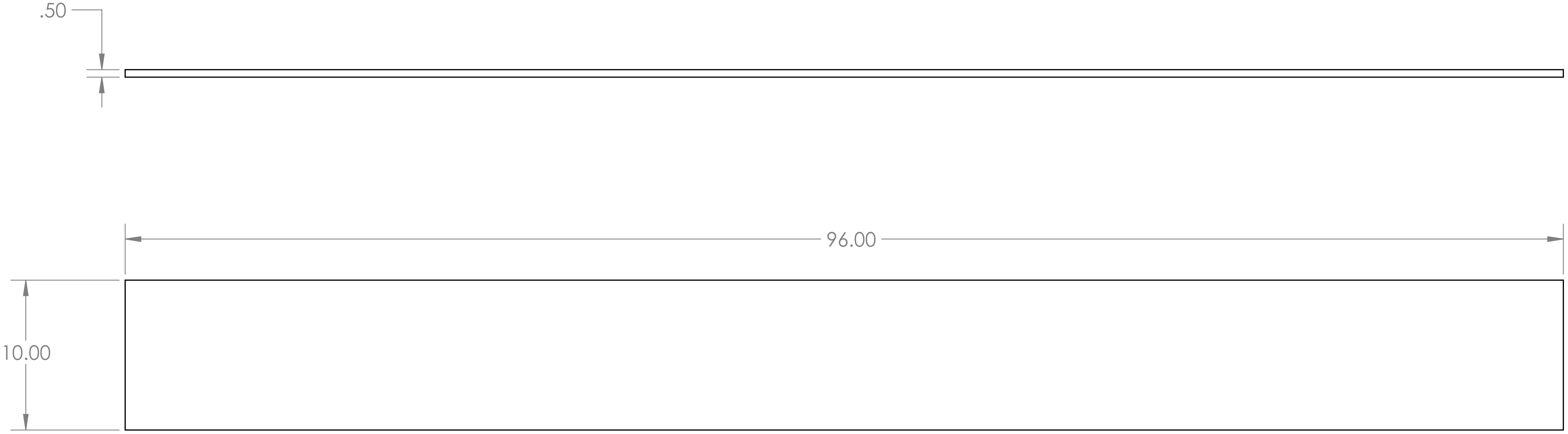
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: 7 FT WEB | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: CBB1 | Date: 4/21/2017 | Scale: 1:8 | Advisor: EILEEN ROSSMAN |





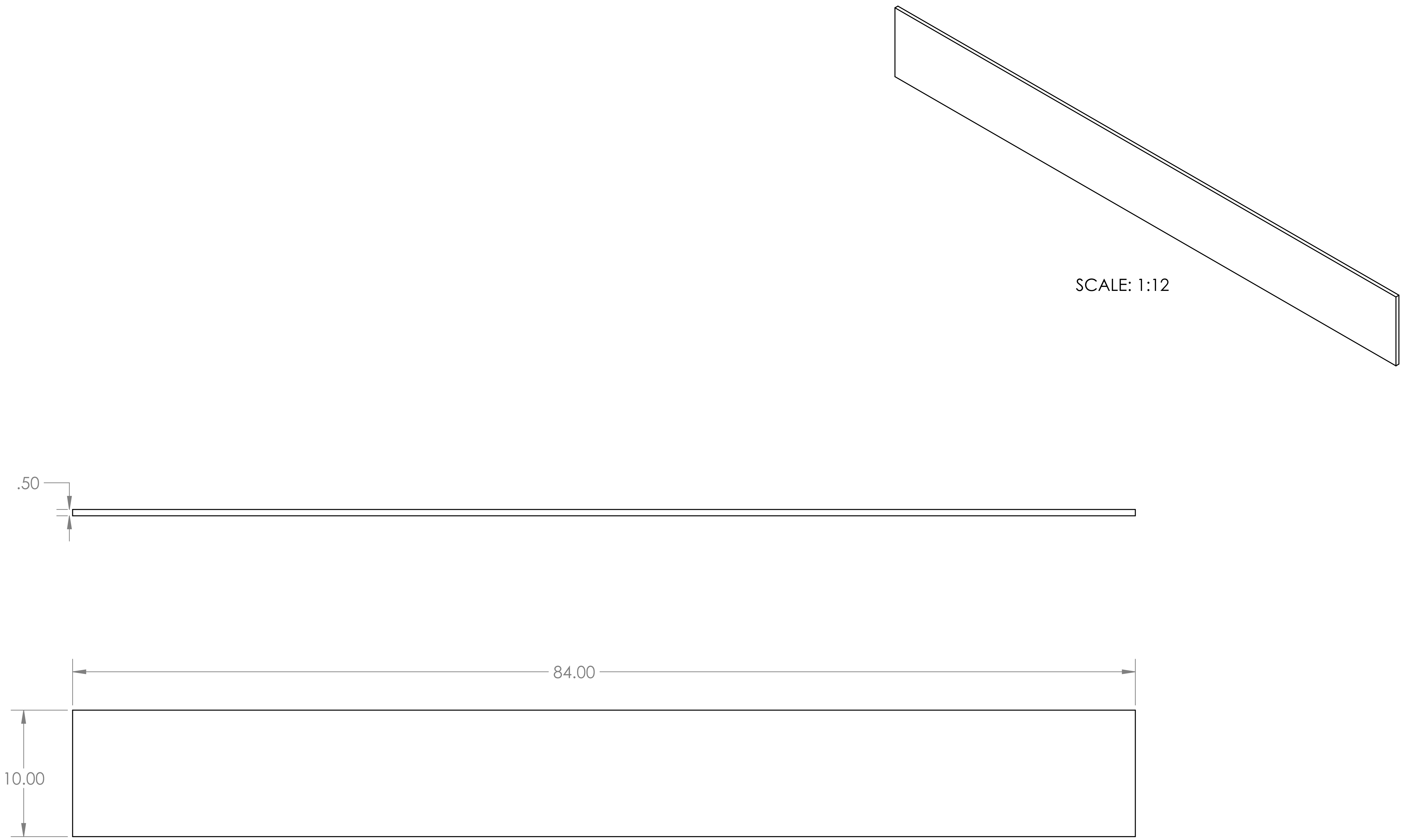

| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering<br>SENIOR PROJECT | Project: AVALON STRUCTURE | Title: 2.5 FT WEB | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: CBB2 | Date: 4/21/2017 | Scale: 1:4 | Advisor: EILEEN ROSSMAN |






| | | | |
|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: 8 FT FLANGE | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: CBB3 | Date: 4/21/2017 / Scale: 1:8 | Advisor: EILEEN ROSSMAN |



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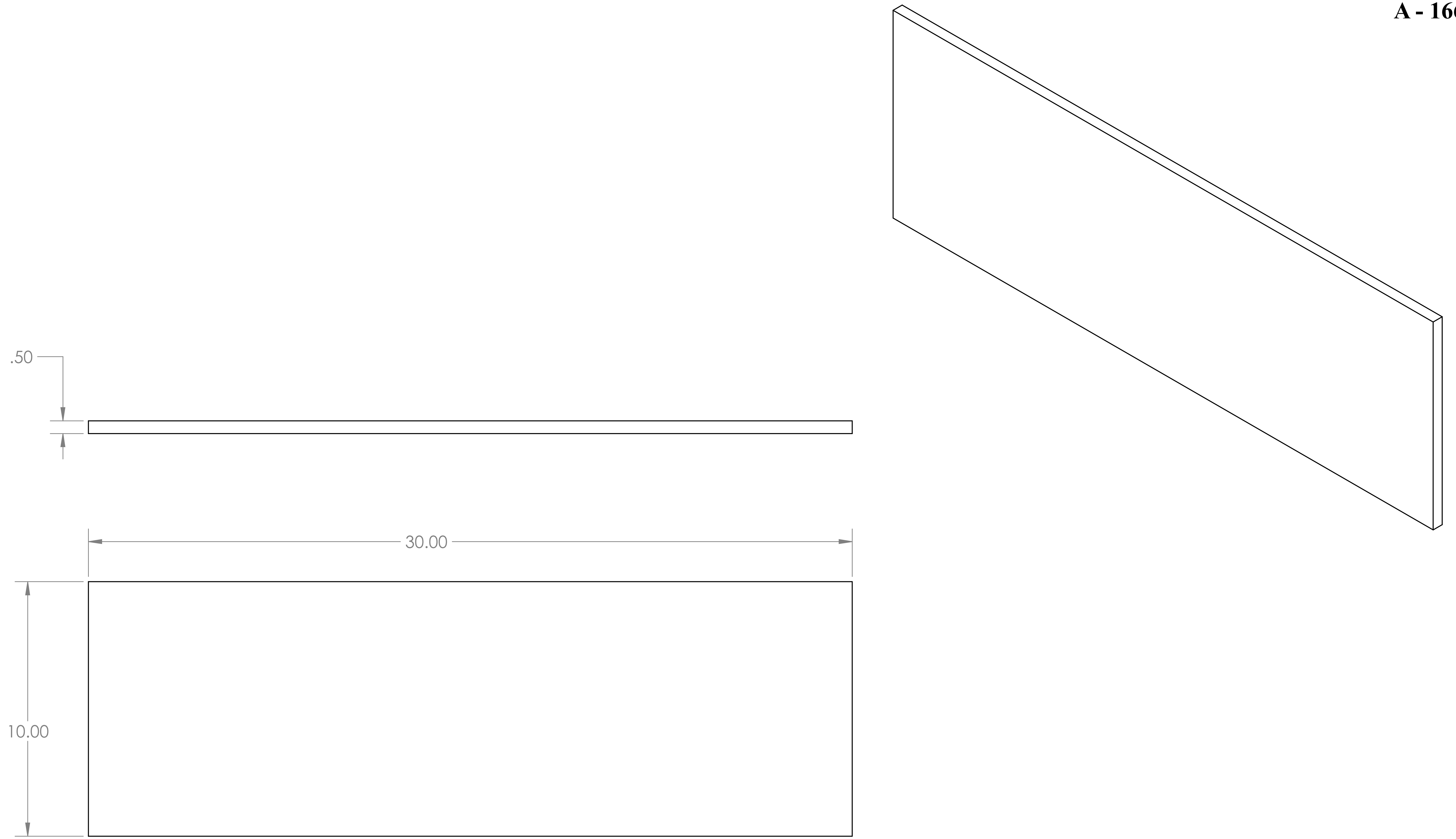
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: 7 FT FLANGE | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: CBB4 | Date: 4/21/2017 | Scale: 1:8 | Advisor: EILEEN ROSSMAN |

A - 166



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|---|---|---|---|
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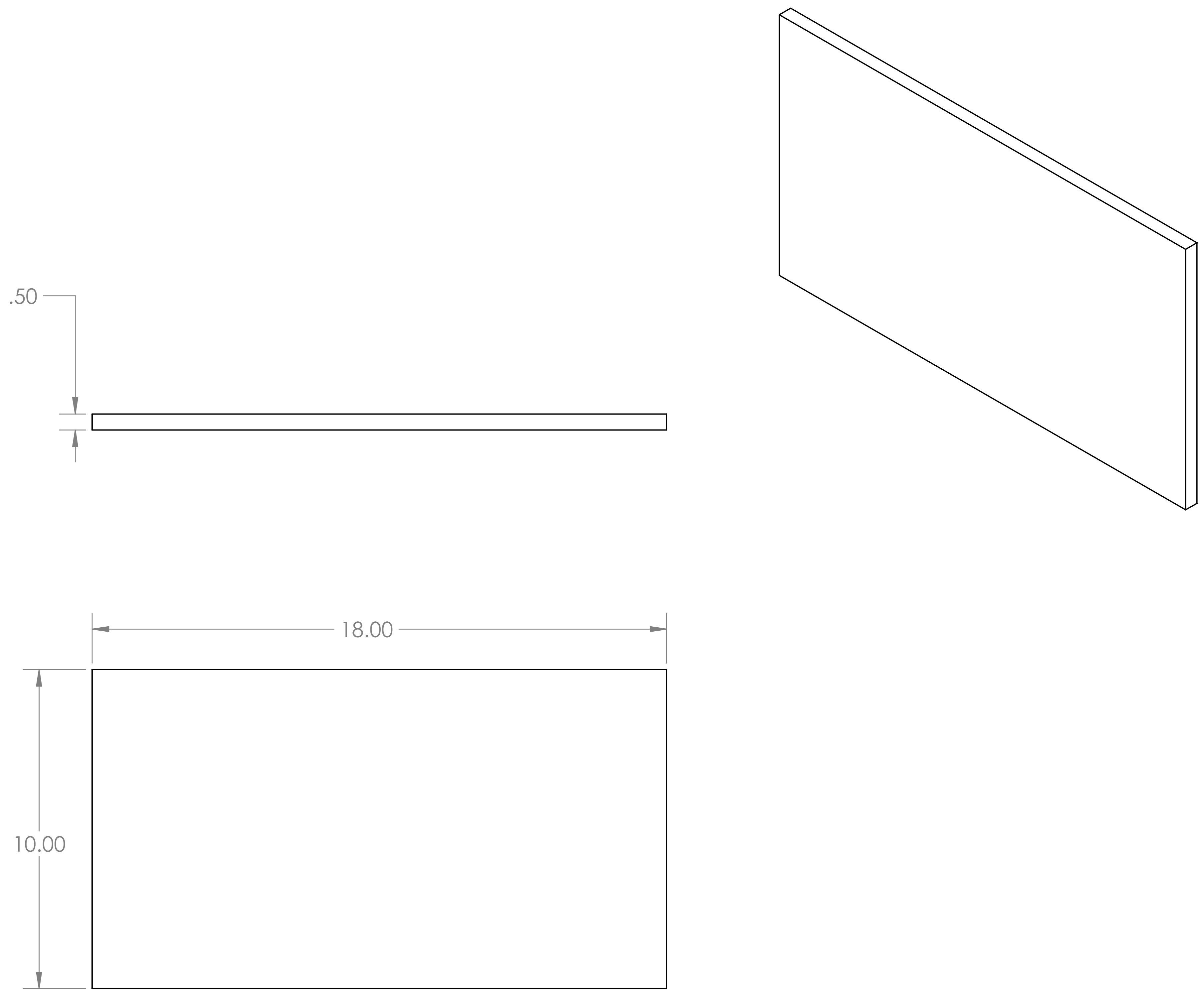
| | Dwg. #: CBB5 | Date: 4/21/2017 Scale: 1:4 | Advisor: EILEEN ROSSMAN |



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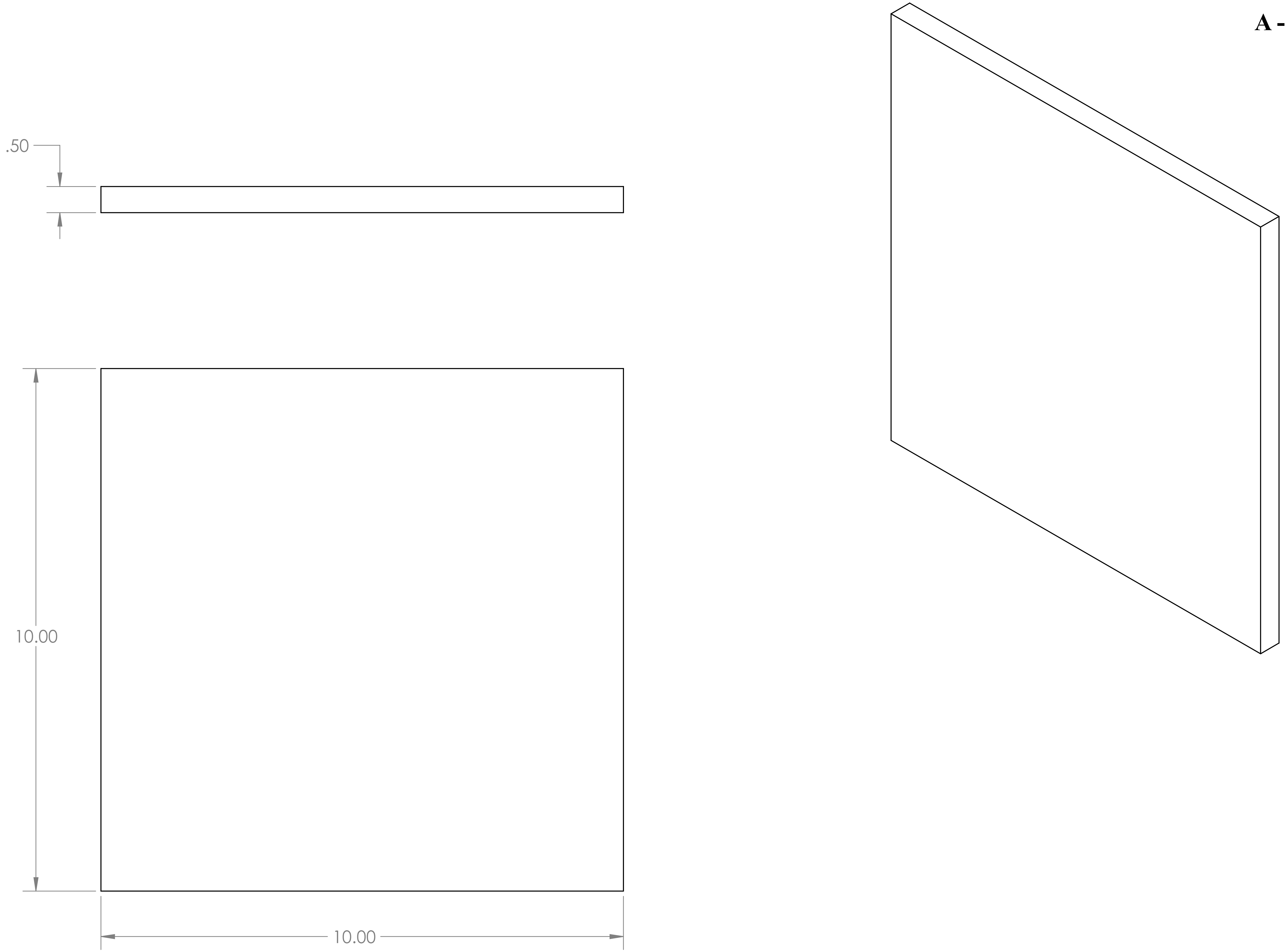
|---|---|---|---|---|
| Cal Poly Mechanical Engineering<br>SENIOR PROJECT | Project: AVALON STRUCTURE | Title: 1.5 FT FLANGE | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: CBB6 | Date: 4/21/2017 | Scale: 1:4 | Advisor: EILEEN ROSSMAN |

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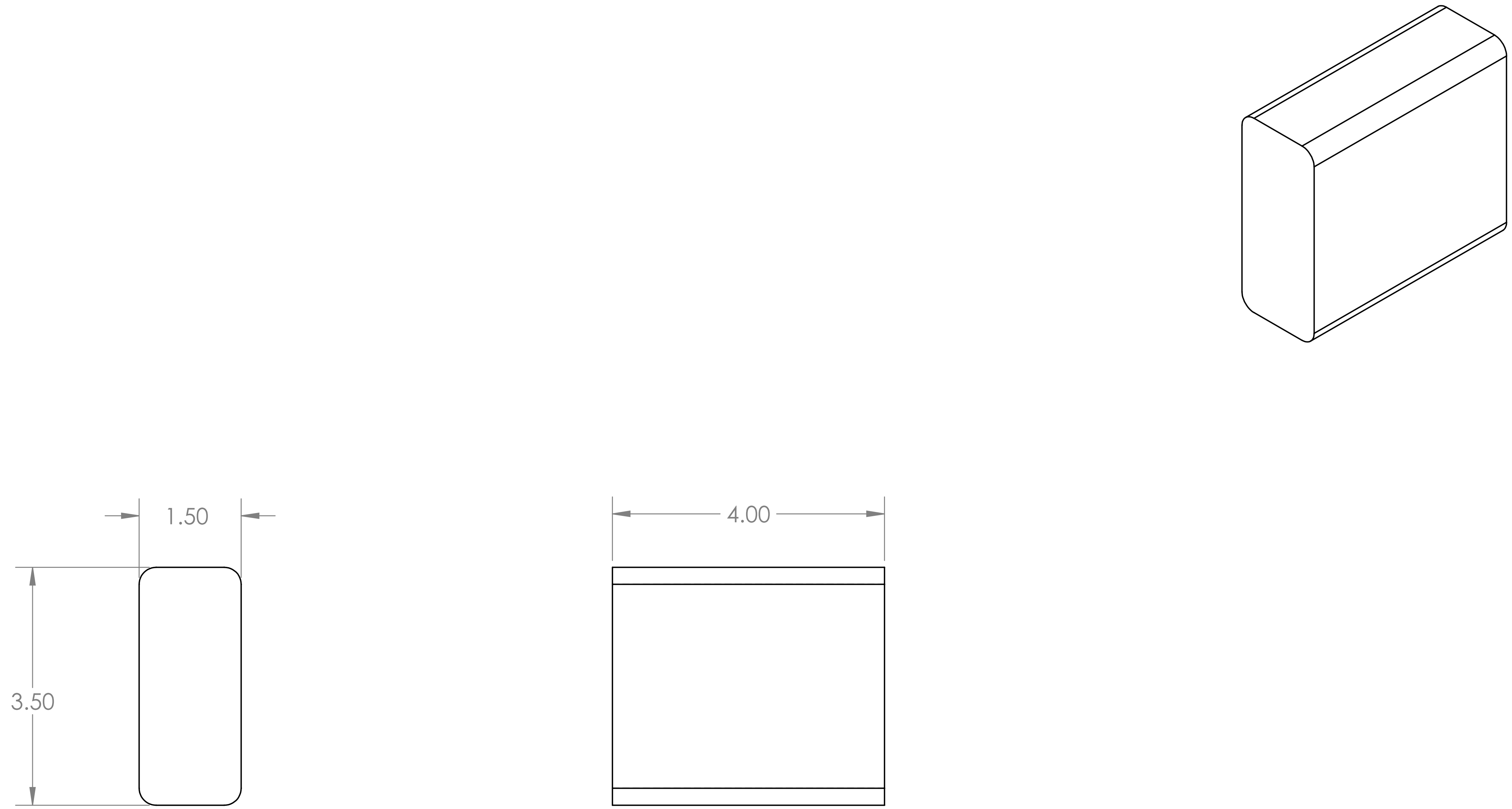
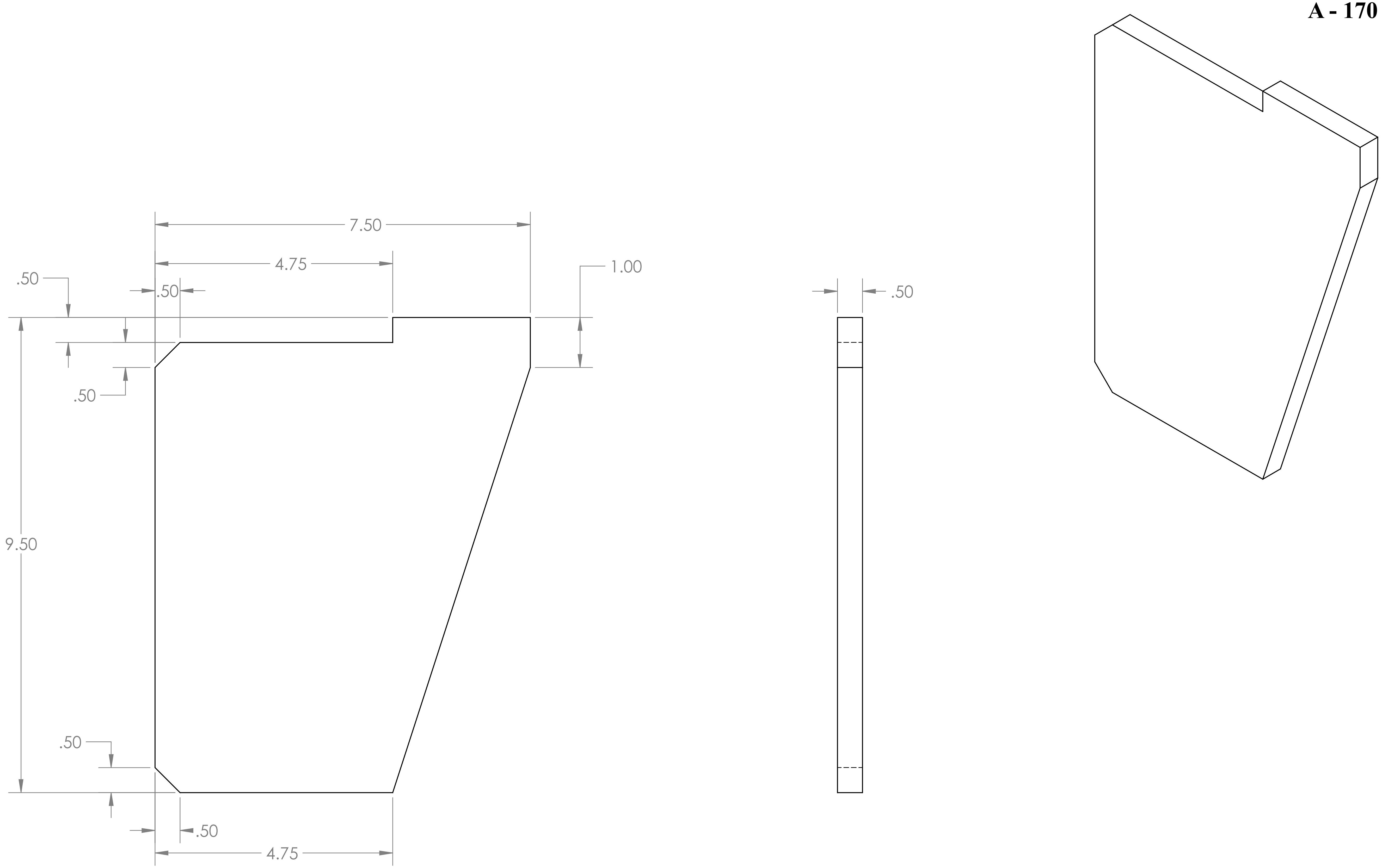
| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering<br>SENIOR PROJECT | Project: AVALON STRUCTURE | Title: END CAP | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: CBB7 | Date: 4/21/2017 | Scale: 1:2 | Advisor: EILEEN ROSSMAN |






| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: ATTACHMENT BLOCK | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: CBB8 | Date: 4/21/2017 | Scale: 1:2 | Advisor: EILEEN ROSSMAN |

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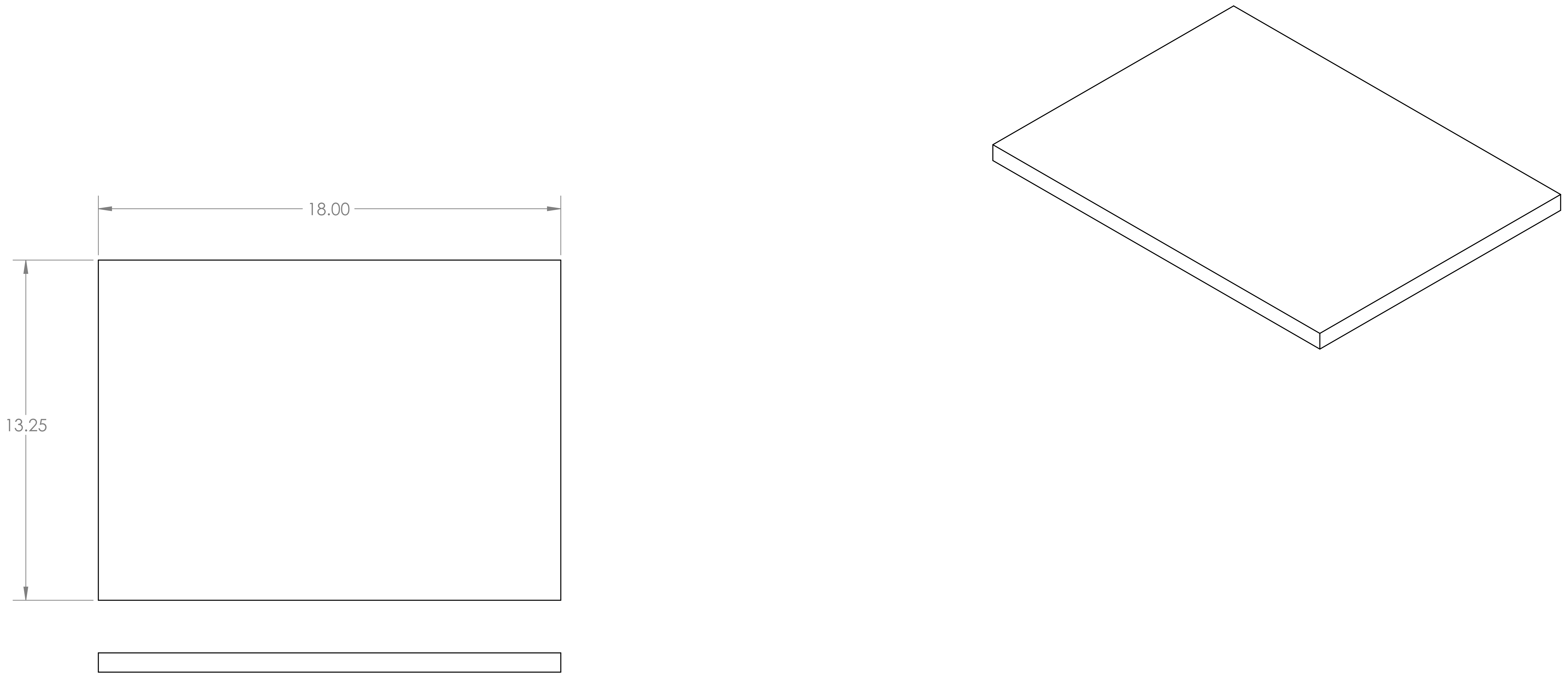
| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering | Project: AVALON STRUCTURE | Title: TORSION GUSSET | | Drwn. By: SUBLIME SQUAD |
| SENIOR PROJECT | Dwg. #: CBB9 | Date: 4/21/2017 | Scale: 1:2 | Advisor: EILEEN ROSSMAN |






| | | | | |
|---|---|---|---|---|
| Cal Poly Mechanical Engineering<br>SENIOR PROJECT | Project: AVALON STRUCTURE | Title: | | Drwn. By: SUBLIME SQUAD |
| | Dwg. #: | Date: 4/21/2017 | Scale: | Advisor: EILEEN ROSSMAN |

# Appendix EE: DVP and Anticipated Test Plan for Steel Scaled Model

| ME430 DVP&R Format | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TEST PLAN | | | | | | | | | | | TEST REPORT | | | |
| | | | | | | | SAMPLES TESTED | | TIMING | | TEST RESULTS | | | |
| Item No | Model Being Tested | Specification or Clause Reference | Test Description | Acceptance Criteria | Test Responsibility | Test Stage | Quantity | Type | Start date | Finish date | Test Result | Quantity Pass | Quantity Fail | NOTES |
| 1 | Steel Scaled Prototype | Static and Dynamic Load on the Sawhorse | Test the static and dynamic load on the sawhorse by loading a testing fixture attached to the sawhorse at 45 degrees with 1500 lbs. | No obvious yielding | All | Complete | 1 | Steel Model | 5/5/17 | 5/6/17 | Structure yielded at approximately 1000 lbs. | | x | Results presented to sponsors and seismic reqiurement lowered. Test results meet lower seismic requirement. |
| 2 | Wooden Full-Scale Prototype | Structure Extrusion | Measurement of wooden prototype when placed against the trailer. | Less than 3.5 ' from existing tires | All | Complete | 1 | Wooden Model | 5/13/17 | 5/13/17 | Structure sticks out 3.5' from existing tires. | x | | |
| 3 | Wooden Full-Scale Prototype | Tire Clearance | Check to make sure sufficient clearance exists between our structures and the tires of the trailer by measuring distance between tires and wooden model. | No less than 6". | All | Complete | 1 | Wooden Model | 5/13/17 | 5/13/17 | Clearance between tires and structures is 6". | x | | |
| 4 | Wooden Full-Scale Prototype | Puck Clearance | Hold the wooden connection box up against the trailer and determine if the puck has been sized correctly. | The puck fits in the semicircular hole on the trailer. | All | Complete | 1 | Wooden Model | 5/13/17 | 5/13/17 | The puck is slightly oversized. | | x | The puck diameter will be reduced from 4" to 3.75". |
| 5 | Wooden Full-Scale Prototype | Torsion Gusset Clearance | Check to make sure sufficient clearance exists between the flanges of the actual steel material and the wooden torsion gussets. | The gussets fit snugly between the flanges. | All | Complete | 1 | Wooden Model | 5/13/17 | 5/13/17 | The gussets are sized correctly but will need to be ground down to fit perfectly between the flanges (the flanges are not perfectly horizontal) | x | | Each H-beam will differ slightly and this "grind and check" procedure will need to be done on each gusset before welding is complete. |

# Avalon Submersible Support Structure

# Anticipated Test Plan

*Sponsor: Bob McCay, Morro Bay Maritime Museum*

*Mechanical Engineering Department*
*California Polytechnic State University, San Luis Obispo*
*2017*

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**Appendix EE: DVP and Anticipated Test Plan for Steel Scaled Model**

# Test Plan

For the steel scaled model, we will primarily be testing the strength of the sawhorse under both a static and seismic load. The following section outlines the details of our test plan for verifying our design.

## A. Summary of Testing Equipment

To provide the loading case on our steel scaled model, we will be using a Harbor Freight Hydraulic Actuator that will be borrowed from the ME department. All testing on the steel model will be performed in the Composites Lab, 192-135. Our model as well as the testing fixture will be bolted to the strong floor using T-nuts provided by the Lab. We will also be borrowing a load cell kit from the ME department. This kit will contain an Omega load cell rated at 2000 $lb_f$, a load cell indicator, and a rod end. To record data off of the load cell, we will also be borrowing an Omega DAQ from the ME department. All necessary wiring to connect the DAQ to a laptop and the load cell will be provided by the ME department with the DAQ. We will be using the computer next to the strong floor in the Composites Lab to record data on. A protractor will be used to verify the angle between the hydraulic RAM and the steel scaled model. Finally, all team members will be wearing safety glasses during the test and each member will provide his or her own glasses.

## B. Testing Procedure

1. First, all team members will don their safety glasses.

2. Second, we will bolt the steel scaled model as well as the testing fixture to the strong floor, using T-nuts provided by the Composites Lab. An image of the strong floor has been provided below in Figure 1.

**Figure 1.** An image of the strong floor in the Composites Lab that our steel scaled model and testing fixture will bolt into.

3. Next the load cell will be attached to the rod end, and the rod end will be bolted to the RAM connection plate. This step has been shown below in Figure 2.

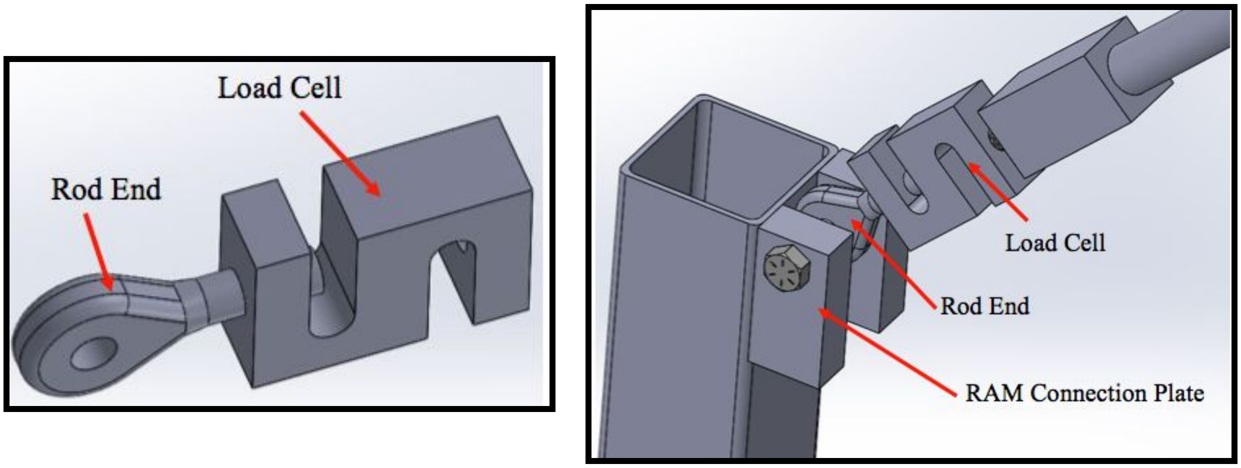



**Figure 2.** On the left, an image of the load cell being attached to the rod end. On the right, an image of the load cell and rod end attaching to the RAM connection plate.

4. The bolt will then be placed inside the load cell coupler. This step has been shown below in Figure 3.

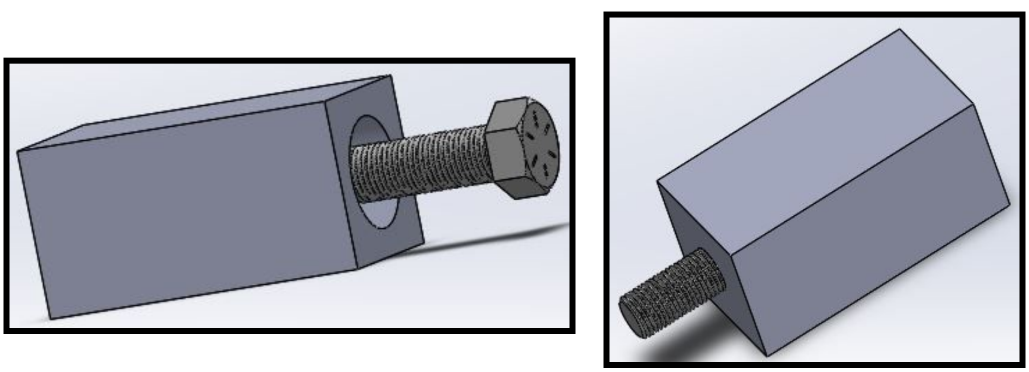


**Figure 3.** On the left, an image of the bolt being placed inside the load cell coupler. On the right, an image of the bolt after it is inside the load cell coupler.

5. Next, the hydraulic RAM will be bolted to the testing fixture at the attachment plate. This connection has been highlighted below in Figure 4.

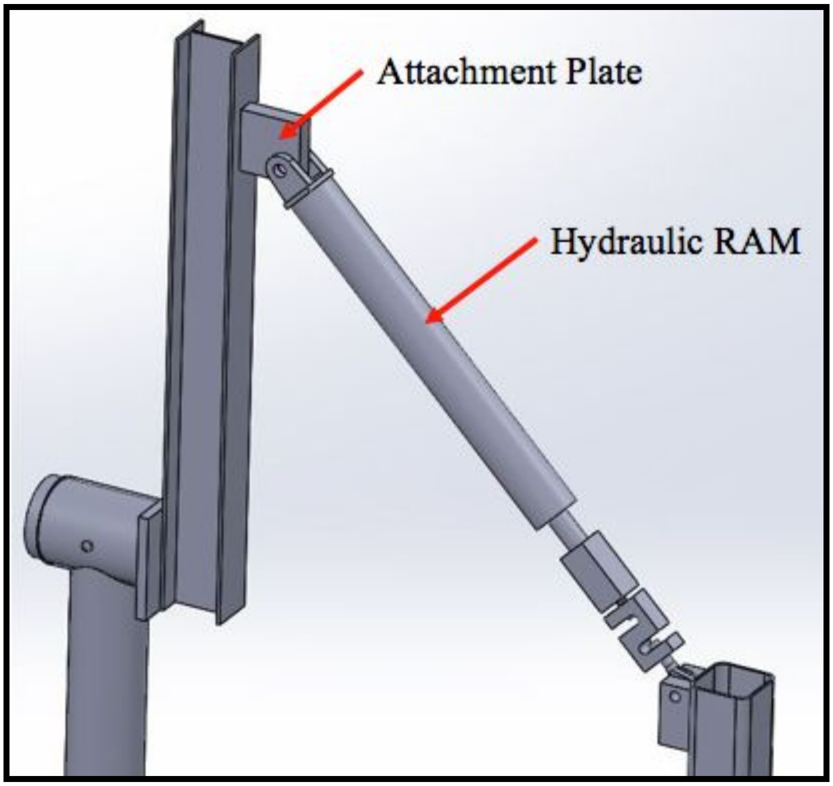



**Figure 4.** An image of the connection between the hydraulic RAM and the testing fixture.

6. The DAQ will now be connected to the computer in the Composites Lab. Storing the data on a computer will allow us to determine what load the structure fails at, should it fail at a load below the testing load of 1500 $lb_f$.

7. Next, the DAQ will be connected to the load cell indicator to allow data in the form of applied load to be recorded.

8. Now, the hydraulic RAM will be placed inside the load cell coupler. An image of this connection has been provided below in Figure 5.

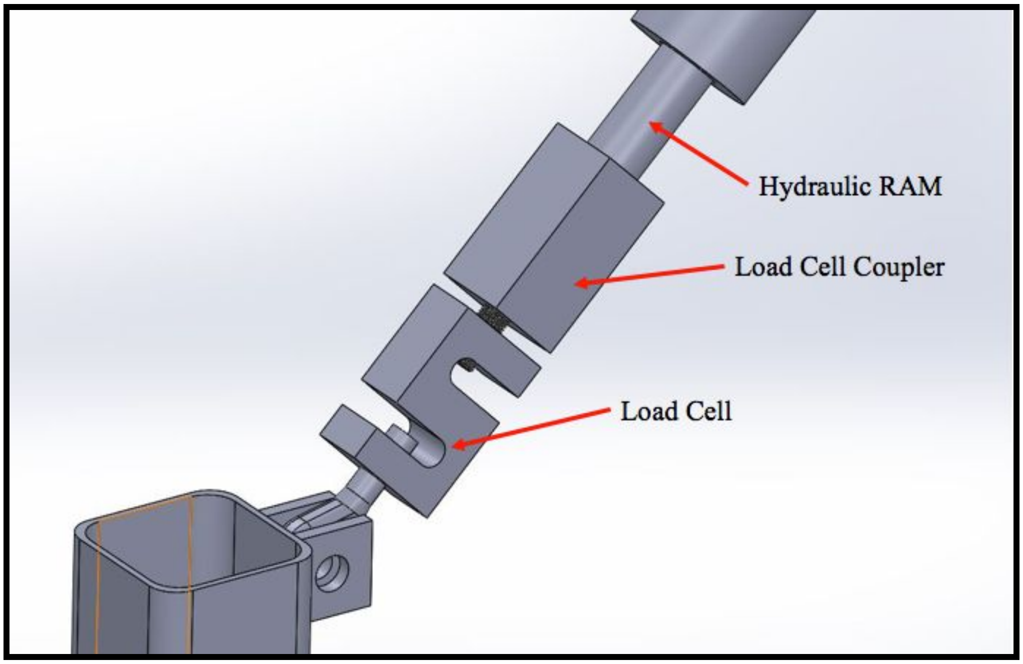



**Figure 5.** An image depicting how the hydraulic RAM should be placed inside the load cell coupler.

9. At this point, any necessary adjustments will be made so that the RAM sits snugly inside the load cell coupler, and the angle between the RAM and the steel scaled model is 45 degrees. This angle will be verified using a protractor.

10. We will now begin recording data on the DAQ.

11. One team member will load the hydraulic RAM by pumping it until 1500 $lb_f$ is registered by the load cell indicator and recorded on the DAQ.

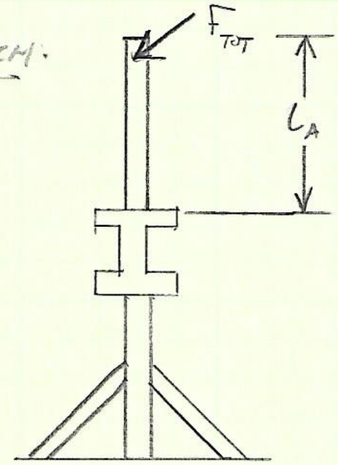
12. After the test is complete, we will cease recording data.

13. We will now observe the effects of the load case.

## C. Contingency Plan

Should the structure fail at the applied load of 1500 $lb_f$, or fail at a load below that, we plan to analyze the locations of failure in great detail to determine how we can alter the design to prevent failure at these locations. We will incorporate these changes into the final design presented to the MBMM, as well as in both the wooden full-scale model and the 3D printed scale model. Unfortunately, in the interest of time, we will not be able to manufacture another steel scaled model to test any changes we make to the design.

SIDE VIEW SKETCH:




LOAD ANGLE = 45°

$\therefore \quad F_x = F_y = F_{TOT} \cos(45°)$

FROM TEST RESULTS: $F_{TOT} = 989 \text{ lb}_f$

$F_x = F_y = 989 \cos(45°)$

$F_x = 699 \text{ lb}_f$ $\quad F_y = 699 \text{ lb}_f$

FAILURE POINT IN MIDDLE OF BEAM.

FAILURE MODE = WELD SHEAR BETWEEN GUSSET AND I-BEAM.

* LOOK AT MAX SHEAR STRESS IN MIDDLE OF BEAM.

STRESS TYPES:
1. STRONG SIDE BENDING STRESS
2. WEAK SIDE BENDING STRESS
3. TORSIONAL SHEAR
4. X-DIRECTION TRANSVERSE SHEAR
5. Y-DIRECTION TRANSVERSE SHEAR

## STRUCTURAL TESTING VALIDATION

### ① STRONG SIDE BENDING STRESS

$$\sigma_{STRONG} = \frac{My}{I}$$

*I = MOMENT OF INERTIA

FROM BEAM EQUATIONS FOR A POINT LOAD ASSUMING SIMPLE SUPPORTS.

$$M = \frac{Fl}{4}$$

*SIMPLE SUPPORTS INCREASE THE MOMENT CARRIED IN THE MIDDLE OF THE BEAM

$$\sigma_{STRONG} = \frac{Fly}{4I}$$

Y = DISTANCE FROM EDGE OF BEAM TO CENTROID

h = HEIGHT OF BEAM.

$$y = \frac{h}{2}$$

$$\sigma_{STRONG} = \frac{F_y l h}{8 I_{STRONG}}$$

### ② WEAK SIDE BENDING STRESS

SAME EQUATION, HOWEVER GEOMETRIC PROPERTIES CHANGE

$$y = \frac{w}{2}$$

*WIDTH TAKEN INTO ACCOUNT, NO HEIGHT

$I_{WEAK}$ IS ALSO DIFFERENT.

$$\sigma_{WEAK} = \frac{F_x l w}{8 I_{WEAK}}$$

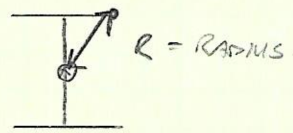
STRUCTURAL TESTING VALIDATION

## (3) Torsional Shear Stress

$$\tau_{tors} = \frac{Tr}{J}$$

*T = Torque
r = Effective Radius
J = Polar Moment of Inertia

Assume:




$$r = \sqrt{\left(\frac{h}{2}\right)^2 + \left(\frac{w}{2}\right)^2}$$

$$T = F_x \cdot L_A$$

$$\tau_{tors} = \frac{F_x L_A \sqrt{\left(\frac{h}{2}\right)^2 + \left(\frac{w}{2}\right)^2}}{J}$$

## (4) X-Direction Transverse Shear Stress

Assume: $\tau_{trans,x} = \frac{F}{A}$ * Simplified Version of Real Equation

A = Cross Sectional Area of Beam

$$\tau_{trans,x} = \frac{F_x}{A}$$

## (5) Y-Direction Transverse Shear Stress

$\tau_{trans,y} = \frac{F}{A}$ * Same As Above...

$$\tau_{trans,y} = \frac{F_y}{A}$$

# STRUCTURAL TESTING VALIDATION

## MAXIMUM SHEAR STRESS FAILURE THEORY:

$$\tau_{MAX} = 0.5\,\sigma_{UTS}$$

$$\tau_{MAX} = \sqrt{\frac{1}{2}\sigma_{TOT}^2 + \tau_{TOT}^2}$$

$$\sigma_{TOT} = \sigma_{STRONG} + \sigma_{WEAK}$$

$$\tau_{TOT} = \tau_{TORS} + \tau_{TRANS,X} + \tau_{TRANS,Y}$$

$$\tau_{MAX} = \sqrt{\frac{1}{2}\left(\sigma_{STRONG} + \sigma_{WEAK}\right)^2 + \left(\tau_{TORS} + \tau_{TRANS,X} + \tau_{TRANS,Y}\right)^2}$$

$$\boxed{\tau_{MAX} = \sqrt{\frac{1}{2}\left(\frac{F_Y \ell h}{8 I_{STRONG}} + \frac{F_X \ell w}{8 I_{WEAK}}\right)^2 + \left(\frac{F_X L_A\left(\sqrt{\left(\frac{h}{2}\right)^2 + \left(\frac{w}{2}\right)^2}\right)}{J} + \frac{F_X}{A} + \frac{F_Y}{A}\right)^2}}$$

* $\tau_{MAX}$ EQUATION NOW A FUNCTION OF GEOMETRIC QUANTITIES AND LOADS. SINCE WE KNOW LOADS FROM THE TEST AND ALL GEOMETRIC QUANTITIES FROM BOTH OUR REAL DESIGN AND OUR SCALED MODEL, WE CAN NUMERICALLY SOLVE FOR THE EQUIVILANT LATERAL SEISMIC LOAD. BY EQUATING MAXIMUM SHEAR STRESSES!!!

$$\tau_{MAX,REAL} = \tau_{MAX,MODEL}$$

# STRUCTURAL TESTING VALIDATION

VARIABLE NAMES AND VALUES FROM $\tau_{MAX}$ EQUATION:

$F_Y$ = FORCE IN Y-DIRECTION. STATIC LOAD

$l$ = LENGTH OF BEAM

$I_{STRONG}$ = MOMENT OF INERTIA OF BEAM IN STIFF DIRECTION

$h$ = HEIGHT OF BEAM

$F_X$ = FORCE IN X-DIRECTION, SEISMIC LOAD

VARIABLE WE ARE SOLVING FOR ON REAL DESIGN

---

$\omega$ = WIDTH OF BEAM

$I_{WEAK}$ = MOMENT OF INERTIA OF BEAM IN WEAK, OR FLEXIBLE DIRECTION.

$L_A$ = EQUIVILANT HEIGHT OF SEISMIC MOMENT ARM.

J = POLAR MOMENT OF INERTIA., GEOMETRIC RESISTANCE TO TORSION

A = CROSS SECTIONAL AREA OF BEAM.

| Seismic | | | |
|---|---|---|---|
| Variable | Scale | Real | Unit |
| F_tot | 989 | - | lb |
| Fx | 699 | 9297 | lb |
| Fy | 699 | 15500 | lb |
| L | 27 | 114 | in |
| w | 2.33 | 10 | in |
| h | 3 | 10 | in |
| I_weak | 0.35 | 83.43 | in^4 |
| I_strong | 1.85 | 256.41 | in^4 |
| J | 2.2 | 339.64 | in^4 |
| L_a | 18 | 40 | in |
| A | 1.24 | 14.5 | in^2 |

USING EXCEL SOLVER:

1. PLUGGED TEST DATA AND GEOMETRIC QUANTITIES INTO $\tau_{max}$ EQUATION
2. $\tau_{max}$ = 15470 PSI FOR MODEL

   $\tau_{max} = 0.5\ \sigma_{UTS}$

   $\sigma_{UTS,\ STEEL} \cong 60{,}000$ PSI

   $\tau_{max} = 30{,}000$ PSI.

   FOR WELD SHEAR:

   $\tau_{ALL} = 0.6\ \tau_{MAX}$

   * FROM SHIGLEY'S MECHANICAL DESIGN TEXTBOOK...

   $\tau_{ALL} = 18{,}000$ PSI

   15470 PSI AND 18000 PSI ARE PRETTY SIMILAR... THIS METHOD IS REASONABLE FOR ESTIMATING MAX STRESS FOR THIS PARTICULAR FAILURE MODE.
3. SET UP $\tau_{,max}$ EQUATION FOR REAL STRUCTURE.
4. RUN OPTIMIZER TO FIND $F_{x,REAL}$ FOR

   $\tau_{MAX,\ REAL} = \tau_{MAX,\ MODEL}$

   $F_x = 9297$ lbf

ASSUME: $F_{SEISMIC} = 4F_x$, LOAD IS EVENLY DISTRIBUTED TO ALL 4 STRUCTURES

$F_{SEISMIC} = 37188$ lbf

STRUCTURAL TESTING VALIDATION

FROM PREVIOUS SEISMIC ANALYSIS:

FOR MAX EXPECTED LATERAL ACCELERATION...

$S_A = 0.52g$, $F_{SEISMIC} = 37{,}612$ lbf

FOR DESIGN LATERAL ACCELERATION...

$S_A = 0.36g$, $F_{SEISMIC} = 26{,}039$ lbf

MAX EXPECTED: $S.F. = \frac{37188 \text{ lbf}}{37612 \text{ lbf}}$

SAFETY FACTOR = 0.99 X

DESIGN: $S.F. = \frac{37188 \text{ lbf}}{26039 \text{ lbf}}$

SAFETY FACTOR = 1.43 ✓

CONCLUSION: OUR STRUCTURE MEETS USGS PEAK LATERAL ACCELERATION DESIGN REQUIREMENTS, BUT NOT MAX EXPECTED ACCELERATIONS. WE FEEL CONFIDENT THAT OUR DESIGN IS STABLE FOR THE FOLLOWING REASONS:

1. LOCALIZED GUSSET FAILURE WILL BE MITIGATED BY THE ADDITIONAL GUSSET ON THE REAL DESIGN
2. WE COMFORTABLY MEET USGS DESIGN REQUIREMENTS. INITIALLY DESIGNING FOR THE MAX EXPECTED ACCELERATION WAS USED AS A SAFETY NET.

# UNCERTAINTY ANALYSIS

## LOAD CELL:

± X.XX ← READ OUT ACCURACY

FROM CALIBRATION CURVE:

$Y = -1499x$

$X$ = READOUT FROM INDICATOR
$Y$ = LOAD

UNCERTAINTY = ± 0.005 FOR INDICATOR

UNCERTAINTY = 1499(0.005)

**UNCERTAINTY = ± 7.5 $lb_f$**

# Avalon Submersible Support Structure

# Operator’s Manual

*Sponsor: Bob McCay, Morro Bay Maritime Museum*

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# I. Introduction

The Morro Bay Maritime Museum (MBMM) is a non-profit organization committed to providing the public "an easily accessible educational venue for maritime history, science, and technology" [1]. The museum, represented by our sponsor Bob McCay, is currently looking for a new way to support the Deep Submergence Rescue Vehicle (DSRV), Avalon, that they have on display. The DSRV is currently sitting on a Short Haul Vehicle (SHV) trailer and the total weight (32 tons) is being supported by the SHV's tires. This is a source of concern for the MBMM due to the weathering the tires have undergone combined with the amount of time that they have been supporting the weight. The MBMM is looking for a support structure that will take the weight off of the tires so that they can be removed at their convenience. Our senior project team, under the direction of our advisor Eileen Rossman, has designed a series of four structures that will allow the museum to support the submersible, keep as much of it visible for viewing as possible, and allow the museum to transport it to its final location at their proposed Interpretive Center in the future. What follows is a detailed operator's manual for the four structures. This includes the following: a summary of the terminology used, instructions on how to assemble and install the structures, instructions on how to adjust the height of the structures, and instructions on how to remove the structures. A CAD model depicting how the four structures will look when installed on the trailer can be found below in Figure 1.

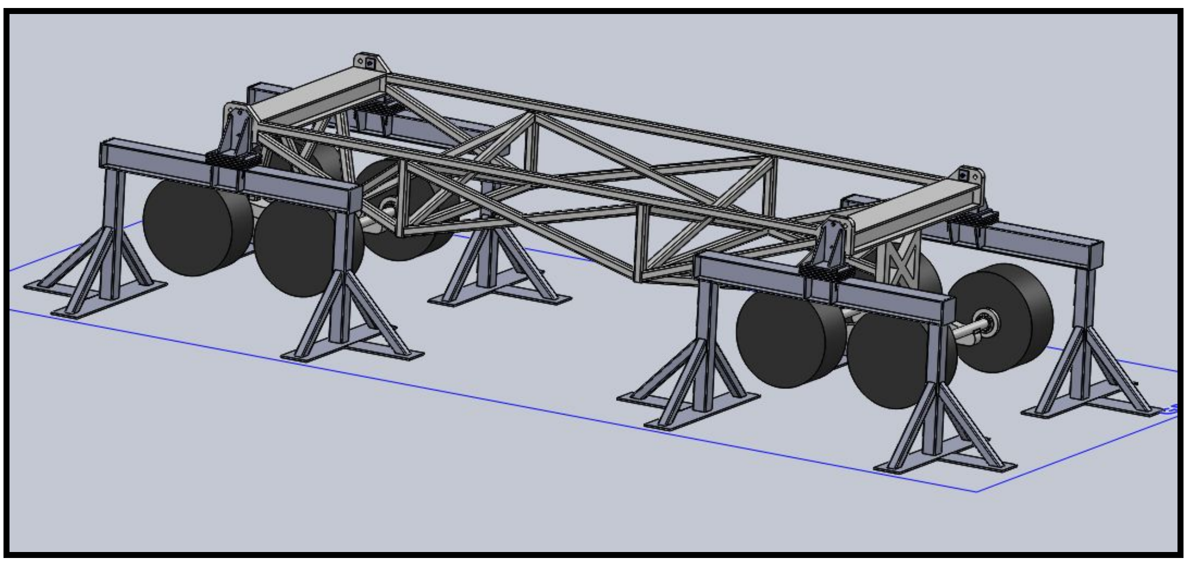

**Figure 1.** A CAD model depicting our final design as it would interface with the trailer that the DSRV currently sits on.

# II. A Summary of Terminology

For the purposes of this operator's manual, we will refer to each component of the design by specific names. The four main components of our design are the connection box, the shim pack, the sawhorse, and the stability rod. These components are defined below in Figures 2 and 3.

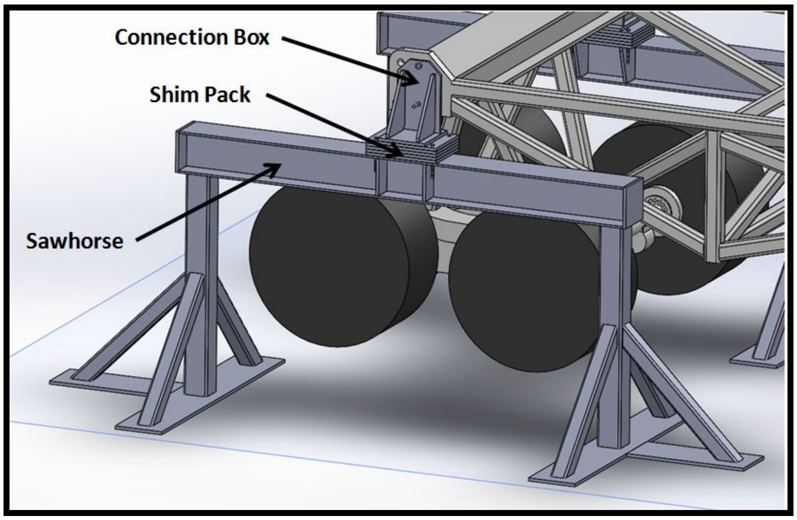


**Figure 2.** A close-up on one of the four structures that will be installed on the trailer, with the connection box, shim pack, and sawhorse defined.

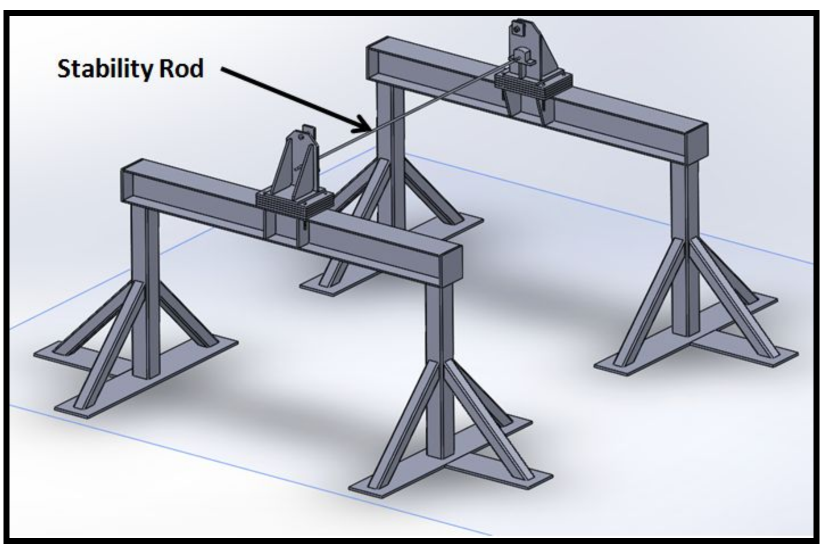


**Figure 3.** An image of two structures connected by the ⅝" diameter rod, the stability rod, that will run between two beams on the trailer.

The components of the connection box and sawhorse can be further broken down into specifically named parts. These are defined below in Figures 4, 5, and 6.

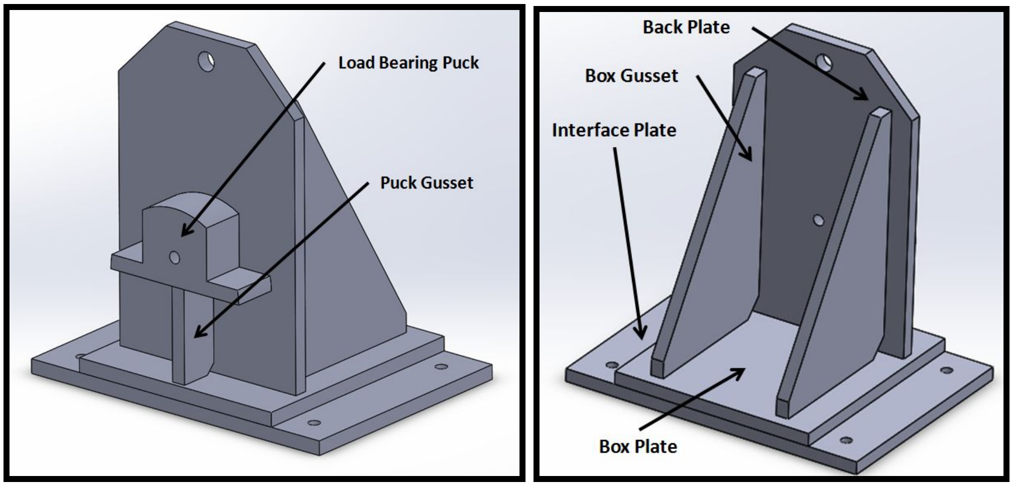


**Figure 4.** A closer look at the connection box that interfaces with the trailer, with the components of the connection box defined.

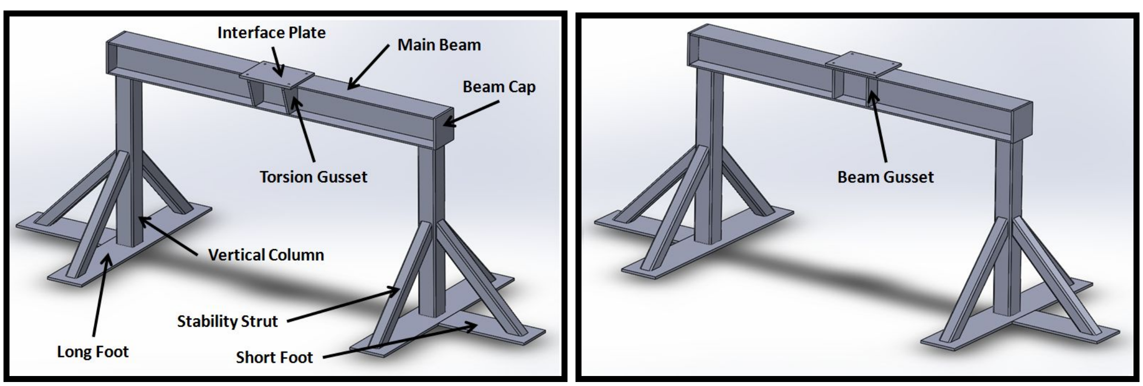


**Figure 5.** An image of the sawhorse with each component defined. The image on the left depicts the side of the sawhorse closest to the trailer. The image on the right depicts the side of the sawhorse that will face away from the trailer, or the side that is most readily seen by the public.

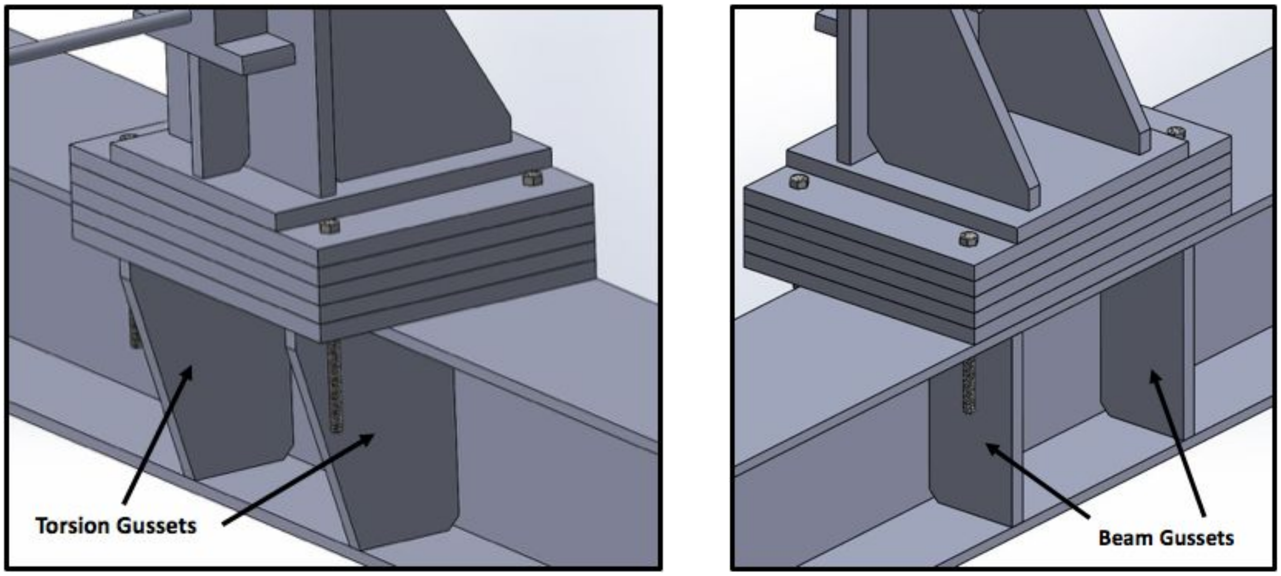


**Figure 6.** A closeup of the two sets of gussets on the sawhorse. The torsion gussets, the gussets on the side of the sawhorse closest to the trailer, can be seen in the image on the left. The beam gussets, the gussets on the side of the sawhorse that faces away from the trailer, can be seen in the image on the right.

# III. Assembly and Installation

The assembly and installation of the structure will be a combination of efforts on the part of the MBMM, the welder, and the forklift driver. The assembly and installation should take place in the following order:

1. The sawhorses should be brought into place by the forklift, and set down on heavy-duty moving dollies. Ideally, the backs of the main beams would only be about ¼" away from the plate on the trailer where the connection boxes will interface with the trailer. This step is shown below in Figure 7.

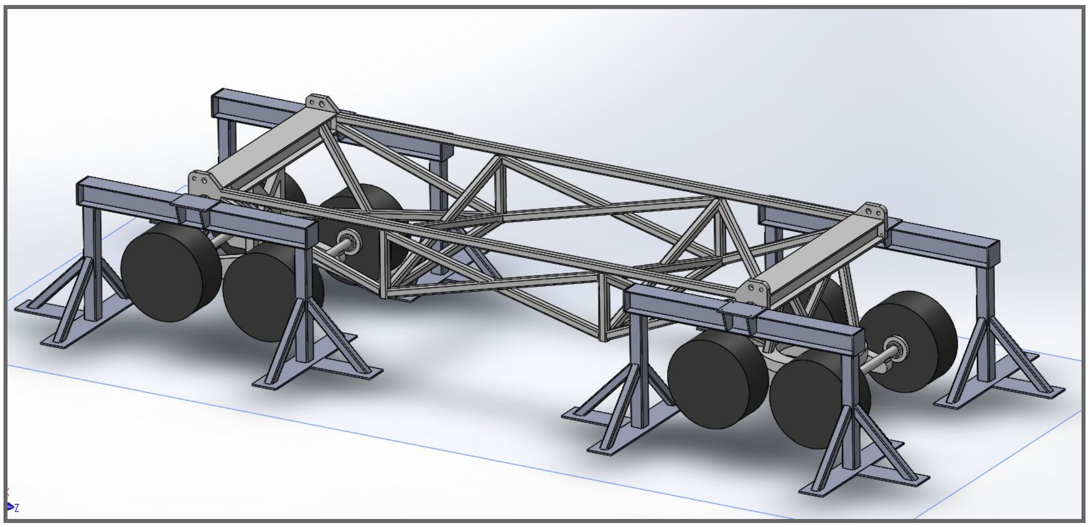

**Figure 7.** An image of the sawhorses, depicting where they should be placed by the forklift.

2. If the MBMM wishes to remove the tires at some point, we recommend breaking the nuts on the tires before the structure is jacked up. It would be difficult to break the nuts with the tires off of the ground, because they will simply want to spin.

3. The trailer should be jacked up 1' off of the ground by Santa Maria Tire. The jacks need to be placed under the center of each yoke, thus allowing all four corners of the trailer to be raised at the same time. This step is shown below in Figure 8.

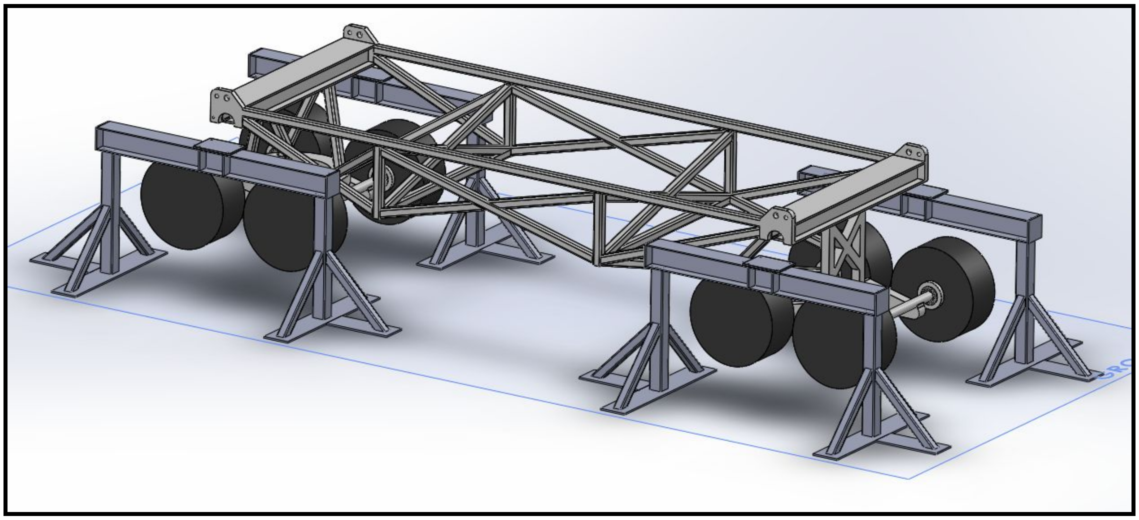

**Figure 8.** An image of the trailer as it would appear in relation to the sawhorses when jacked.

4. Each sawhorse should now be rolled into place, directly under the semicircular shaped holes on the face plates. We recommend that AT LEAST four people per vertical column move the sawhorse.
5. The sawhorse will then need to be lowered off of the dollies. We recommend that AT LEAST 6 people per vertical column do this. All 6 people should lift one side of the sawhorse, while someone else removes the dolly from underneath. They would then set the sawhorse on the ground. We recommend a spotter for this operation to ensure that the other end of the sawhorse will not tip. The same procedure now needs to be completed for the other end of the sawhorse.

6. Next the stability rod needs to be fed through between the two I-beams on the trailer. An image showing how the stability rod passes through the trailer and connects to the connection box can be found below in Figure 9.

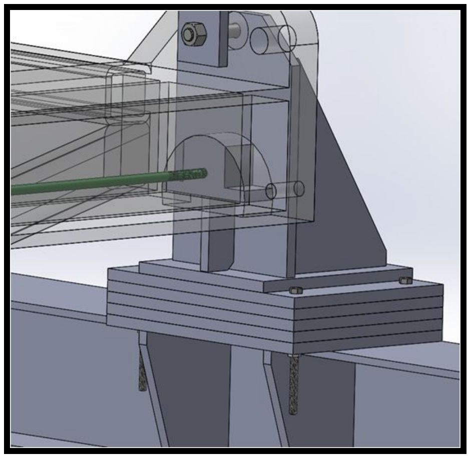

**Figure 9.** A close-up showing the stability rod (highlighted in green for reference) as it would run through the I-beams beams on the trailer, which has been made transparent in this image.

7. Now the connection boxes will be brought into place. Each connection box weighs approximately 167 lbs. Therefore, we recommend that the connection boxes be brought into place using the forklift. This step is shown below in Figure 10.

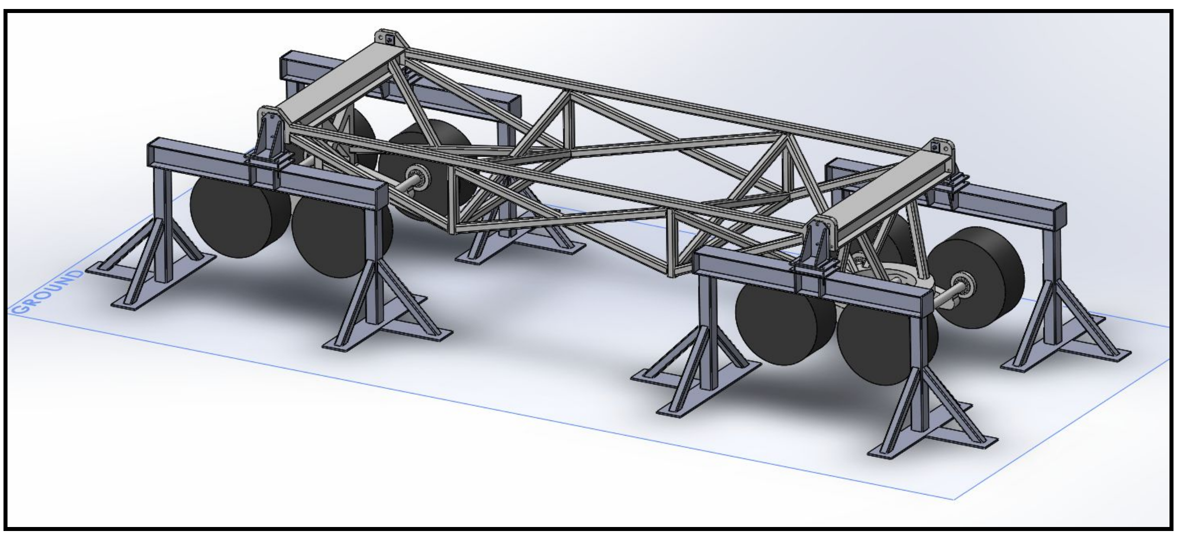


**Figure 10.** An image showing how the design interfaces with the trailer after the connection boxes have been brought into place.

A plastic pallet like the one seen in Figure 11 can be purchased for approximately $37 and has a floor capacity that exceeds 7,500 lbs and a forklift capacity of 3,000 lbs. We recommend that the connection boxes be placed on a pallet and brought into place using the forklift.

**Figure 11.** An example of a pallet that can be used to support and maneuver the connection box [2].

8. The stability rod should now be bolted to the connection box. While the forklift supports the connection box, an installer on the other side of the trailer should feed the stability rod through the ⅝" diameter hole on the connection box. We recommend a spotter for this operation to ensure that the connection box does not move on the forklift while the rod is being fed through.
9. Now the nut on the stability rod should be installed and tightened. We recommend that the nut not be tightened all the way so that the rod will be able to deflect a small amount until the connection box on the other side of the trailer can be installed. The connection for the stability rod is highlighted below in Figure 12.

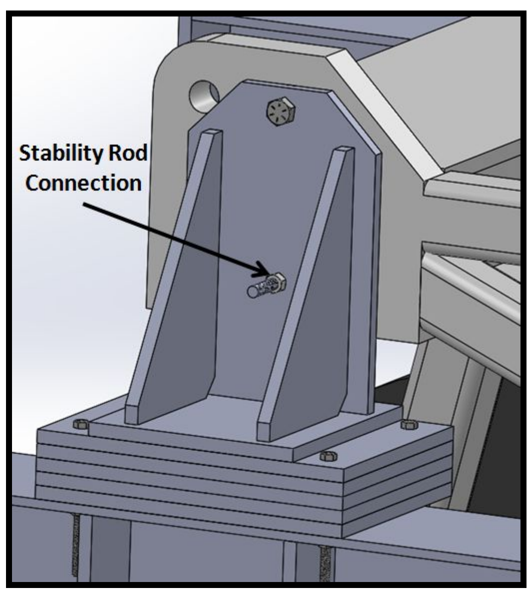


**Figure 12.** A close-up of the connection box with the stability rod connection highlighted.

10. While still being supported by the forklift, the upper bolt now needs to be installed. First the bushing should be put into place. Then the bolt should be run through the hole. Finally, the nut should be installed on the back of the corresponding plate on the trailer, with the trailer back plate placed against the plate on the trailer. The nut should be tightened with a wrench. The upper bolt connection is highlighted below in Figures 13 and 14.

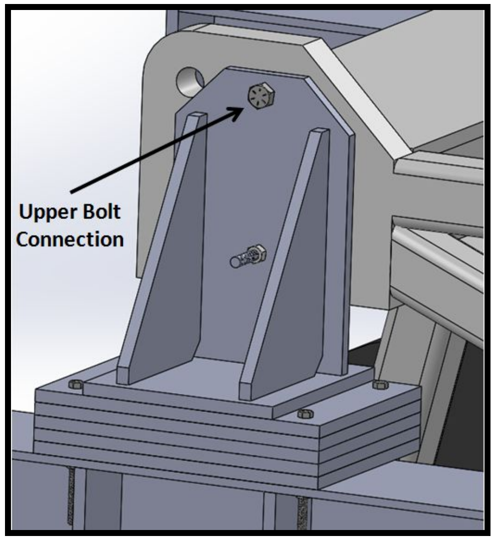


**Figure 13.** A close-up of the connection box with the upper bolt connection highlighted.

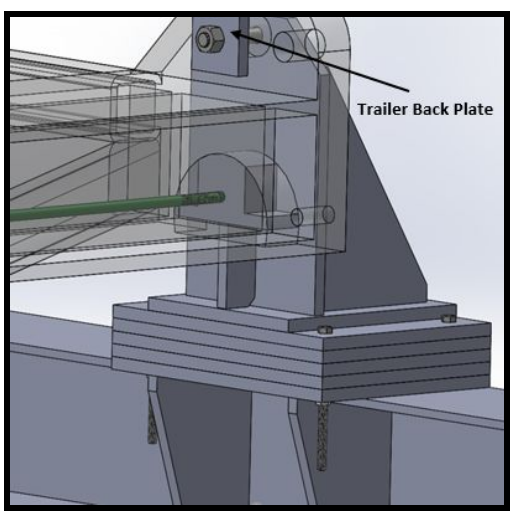


**Figure 14.** A close-up of the connection between the trailer and the connection box with the trailer back plate highlighted.

11. Using a level, the MBMM can now add in three shims between the connection box and the sawhorse, plus the necessary number of shims to account for the uneven ground that the trailer currently rests on. With the addition of three ¾" thick shims placed between the connection box and the sawhorse, a total of 1' of clearance between the entry point of the DSRV and the ground will be achieved. The shim connection has been highlighted below in Figure 15.

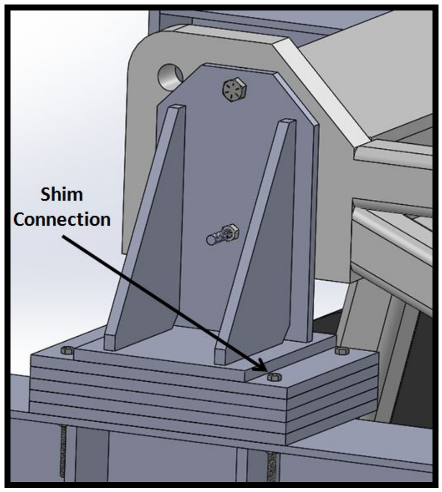


**Figure 15.** A close-up of the connection box and shim pack, with the shim connection highlighted.

12. The shims can then be bolted in place, by running the Grade 8, 8" long bolts through the upper and lower interface plates, and each of the shims. The use of lock washers and nylon-insert lock nuts is advised in order to prevent the bolts from loosening. An exploded view of this connection can be found below in Figure 16.

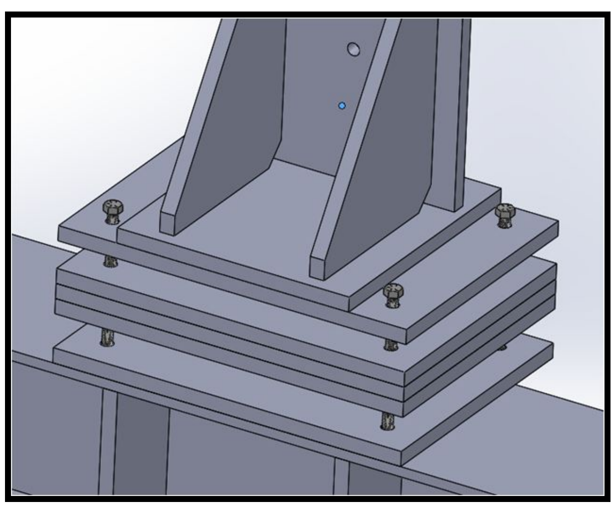

**Figure 16.** An exploded view of the shim pack to illustrate how the shims interface and connect via the Grade 8, 8" long bolts.

13. Now the trailer will be lowered off of the jacks, and the DSRV and the trailer will rest on the four structures.
14. If the MBMM wishes to remove the tires, this would be the ideal time to remove them. If not, this would be the time to cover the tires.
15. Finally, all nuts and bolts should be checked again to ensure they are properly tightened. Make sure to tighten the stability rod connection that was left loose earlier. Additionally, any touch up painting should be performed immediately after installation to prevent corrosion from beginning.

# IV. Height Adjustment

Should the MBMM decide to additionally adjust the height of the trailer after the installation is complete, the following procedure should be followed:

1. Santa Maria Tire should place jacks under each yoke of the trailer that corresponds to the side of the trailer that needs to be adjusted. This should be done so that the trailer is always lifted with two sets of tires at a time.
2. The sawhorses should be disconnected from the connection box by unbolting the connection through the shims, and removing the shims.
3. The MBMM should now add in the desired number of shims between the connection box and the sawhorse, using a level to verify when the trailer has been successfully adjusted.
4. Next the Grade 8 bolts should be run through the upper and lower interface plates, and each of the shims, and the lock washers and nylon-insert lock nuts installed. The length of the bolt will need to be determined based on the number of shims that are to be used, should the number exceed that allowed by the 8" bolt.
5. Finally, the jacks should be released, and the trailer lowered back onto the sawhorse.

# V. Removal

In the event that the MBMM needs to move the trailer and DSRV, perhaps to its final location in the interpretive center, the four structures will need to be removed, and the tires will need to be reinstalled. This section outlines the procedure for removing the structures and reinstalling the tires.

1. Santa Maria Tire needs to place jacks under each yoke of the trailer.
2. The sawhorses need to be disconnected from the connection box by unbolting the connection through the shims, and removing the shims.
3. The trailer needs to be jacked up a couple of inches so that the sawhorses can be removed.
4. The tires need to be reinstalled, and then the trailer lowered back down onto the tires by releasing the jacks.
5. Next the connection boxes need to be removed. It is important to have a means of supporting the connection box from underneath before loosening any of the fasteners. The forklift and pallet can be used to provide a support for the connection box. To remove the connection box, first unbolt the stability rod and then remove the upper bolt that attaches the connection plate to the trailer. After all four connection boxes have been removed, the stability rod should be removed from between the beams on the trailer.
6. The sawhorses need to be removed using the forklift.

# VI. A List of Figures



# VII. References

[1] Angus, R., 2013, "Fitted for Purpose: The Retelling of Morro Bay's Maritime Culture," San Luis Obispo County Visitor's Guide, from http://www.slovisitorsguide.com/fitted-for-purpose/ (accessed 10/11/16).

[2] "Double Deck Plastic Pellet 48x40 Capacity 3000lbs", GLOBAL, from http://www.globalindustrial.com/p/storage/pallets/rackable/double-deck-plastic-pallet-48x40-capacity-3000-lbs?infoParam.campaignId=T9F&gclid=CLjDx9eGxdICFc2JfgodgnsFvw (accessed 3/7/2017).