Storm Shelter Design with BRB Roofing

Reese Hundley
Heidi Stair
Sean Mallory
Katie Whitehurst

Spring 2014

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Background

Tornados

A tornado is defined as a rotating column of air that extends from the ground to a cumulonimbus cloud bank that has the capability of causing catastrophic danger to structures. Tornados can be categorized based on the enhanced Fujita Scale. The scale can be seen in Table 1.

Table 4: Enhanced Fujita Scale (FEMA 361)

Enhanced Fujita Scale	
Scale	**Wind Speed (MPH)**
EF0	65-85
EF1	86-100
EF2	111-135
EF3	136-165
EF4	166-200
EF5	>200

Tornados in Oklahoma generally travel in a southwest to northeast direction and are most commonly caused by super cell thunderstorms. EF4 and EF5 tornados are extremely rare where the probability of an impacted structure in the Midwestern United States is 0.002%. This probability was calculated at 50,000 MRI (FEMA P361 6.1.5). MRI, or Mean Recurrence Interval, is the time interval estimate between occurrences of an event happening when determining risk analysis. MRI can be calculated using the following equation:

$$MRI = n/m \qquad \textbf{(eq. 1)}$$

Where:

n = number of years on record

m= number of recorded incidences of the event being considered

FEMA (Federal Emergency Management Agency) standards require that a storm shelter must withstand wind loads from extreme events with MRIs up to 20,000 to 100,000 years (FEMA P-361, 6.2.1). The frequency of different tornado intensities in the United States can be seen in Table 2

Table 5: Tornado Frequency and Size (FEMA P-361)

Fujita Scale	Number of Tornados	Percentage	Cumulative Percentage
F0	20,728	43.685	43.68
F1	16,145	34.026	77.71
F2	7,944	16.742	94.45
F3	2,091	4.407	98.86
F4	491	1.035	99.89
F5	50	0.105	100.00
Total	47,449	100	

Due to the risk of catastrophic damage caused by extreme tornados, storm shelters must be built according to certain standards. These standards are discussed later in the report along with the design constraints.

Company Overview and Project Justification

BRB Roofing is located in Muskogee, Oklahoma. They specialize in converting flat roofs to sloped roofs. The company has a unique panel design for their roofs called standing seam roofing. This design allows the roofs to be free of exposed bolts, making the roofs leak proof. The corrugated panel design also allows for the panels to be a constant cross section with any length desired. Although BRB Roofing specializes in roofs, the recent devastating tornados have spiked an interest in expanding their product line. Since the company already manufactures the materials that could be used for a storm shelter, BRB Roofing hopes to become a player in this industry.

Objectives

Problem Statement

The Storm Shelter Senior Design Team has been tasked with designing an above ground storm shelter that utilizes the Weatherboss 412 panel already available from BRB Roofing as the primary building material of the storm shelter.

Objective

To design a safe, cost effective, and quickly manufactured above ground storm shelter with BRB's metal roof materials to be implemented into their business.

Constraints

The shelter must use the metal roofing materials provided by BRB Roofing. The panels used in the design must be the current panel dimensions of the Weatherboss 412 panel as seen in Figure 3. The panel thickness will be 18 gauge with an assumed yield stress of 50 ksi. The shelter must be small enough to fit inside a small room in a house or in a garage with a previously established concrete foundation. Due to pressure changes in the event of a tornado, a vent must be placed in the shelter. The vent will allow for sudden pressure changes to equalize the pressure in the shelter to prevent the shelter from exploding. The vent will also allow those using the shelter to breathe comfortably. The shelter must meet FEMA Test Standards. The FEMA Test Standards state that the structure must withstand a wind gust of 250 miles per hour for three seconds. The structure must also withstand impact by a plank of wood with dimensions two inches tall (nominal) by four inches wide (nominal) by six feet long (2”x4”x6’) that weighs 15 pounds. The plank must travel 100 miles per hour horizontally, and 67 miles per hour vertically when impacting the structure.

Design Research

Researching the U.S. Patent Database for previous shelter designs resulted in numerous above ground sheet metal shelters. However, due to the unique design of BRB’s roofing panels, none of the current patents were relevant.

Deliverables

The Storm Shelter Senior Design Team provided a design report to BRB Roofing in December 2013. This design report included:

- Problem statement
- Mission statement
- Initial parameters
- Design standards to be met
- Initial below ground design challenges
- Overview of initial above ground design
- SolidWorks drawings
- All design research
- Budget proposal
- Gantt chart with task list

This design report will be delivered to BRB Roofing by May 7, 2014. The report includes:

- Problem statement
- Mission statement
- Design standards to be met
- Detailed design with SolidWorks drawings
- Test analysis
- Financial analysis
- Conclusions and recommendations

Work Breakdown Structure

The team, as a whole, assisted each other in all areas including design research, report and presentation development, and testing procedures. The general responsibilities that each person was in charge of are listed below.

Reese- Performed design, research, and testing analysis.

Heidi- Created SolidWorks drawings and performed digital video editing.

Sean- Completed financial and marketing analysis.

Katie- Executed project management tasks.

Time Line for Completion

The Storm Shelter Senior Design Team developed a Gantt chart to assist in keeping on track with a specific schedule. The Gantt chart is provided in the Appendix A.

Proposed Methodology

Analysis

The occupancy, design loads, vent sizing, pull out effects, uplift and blow away effects, and sizing of the wall connections are discussed below.

Occupancy

The mobility of the occupants (i.e. handicapped, elderly, etc.), as well as the time they will remain in the shelter determines the appropriate size of the shelter. For a community shelter, a minimum of five square feet per person is recommended (FEMA P-361, Table 3-1).

Design loads

The design load, or the wind load, on the storm shelter is caused by a 250 mile per hour gust of wind lasting three seconds as defined by the FEMA and ASCE (American Society of Civil Engineers) standards. The FEMA standards call for Equation 6-13 from the ASCE 7-98 standards to be used to calculate the wind load.

$$qz = 0.00256 * Kz * Kzt * Kd * V^2 * I \qquad \textbf{(eq. 2)}$$

Where:

qz = wind load (lb. /ft^2)

V = velocity, 250mph

Kz, Kzt, Kd, and I = constants, 1

The wind load pressure equates to 160 pounds per square foot. The loads on the wall section are calculated by simulating a wall section as a modified cantilever beam in which the wall section is anchored to the ground on the left hand side of the beam. The wind load is triangularly distributed where the pressure experienced by the panels increases with the height of the beam or wall section. As the wind decreases elevation, the roughness of the ground will cause air resistance.

The shear force on the wall section can be calculated by multiplying the pressure by the height of the wall section and depth of the walls.

$$V = H * d \qquad \textbf{(eq. 3)}$$

Where:

V= Shear force (lb.)

H = height (ft.)

d = depth (ft.)

The calculated shear force is 390 lb. which is shown in the diagram below. The equivalent force acts two thirds from the supporting end of the beam. Therefore, the distance of the equivalent force is 4.33 ft. or 53 in. The moment reaction experienced at the supporting end can be calculated by multiplying the shear force by the distance of the equivalent force.

$$Moment\ Reaction = V * H \qquad \textbf{(eq. 4)}$$

Where:

V= Shear force (lb.)

H= distance of equivalent force (height, lb.)

The moment experienced at the supporting end is 1690 lb.*ft.

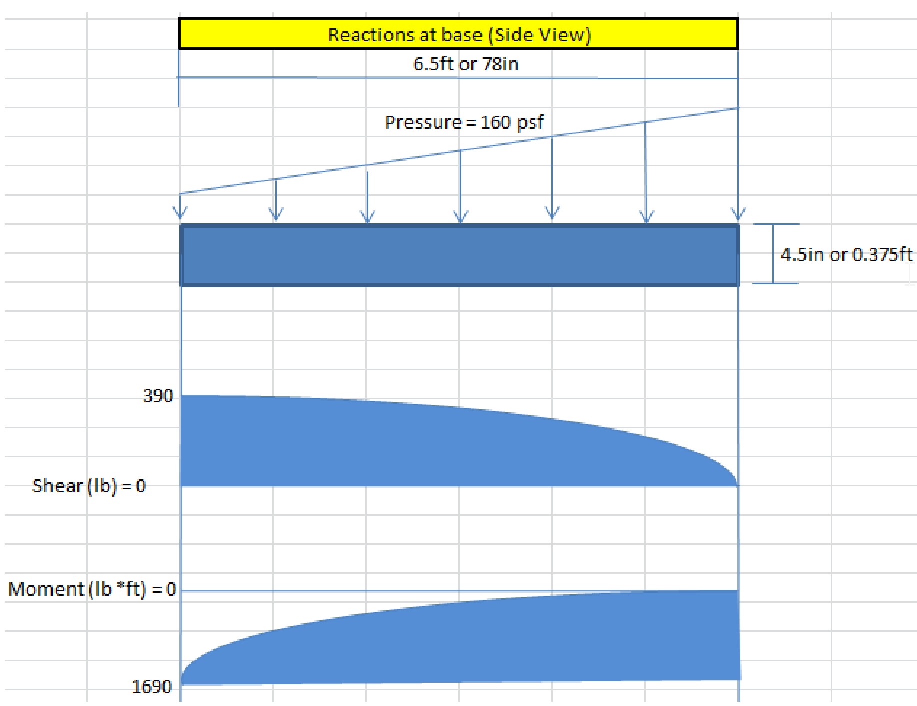

Figure 1: Wind load on wall sections

Vent Sizing

A ventilation system must be included in the design to allow for pressure equalization in the event of a tornado moving over the shelter. A rapid pressure drop occurs as the center of a tornado moves over a structure. This pressure difference has been known to cause structures to explode. Active or passive ventilation may be used to prevent structure failure due to this pressure difference. A passive ventilation system was designed because it is simple and doesn't require power. The inside dimensions of the shelter designed is 6 ft. by 5.3 ft., by 5.3 ft. These dimensions result in an inside volume of 64 cubic feet. The Oklahoma Cooperative Extension Service BAE-1010 provides some information for selecting tornado shelters as well as the equation to size the vent. The required minimum area of the vent can be calculated using the following equation:

$$A = 0.001 * V \qquad \textbf{(eq. 5)}$$

Where:

A = area of the vent (ft^2)

V = inside volume of the shelter (ft^3), 64 ft^3

The required minimum area of the vent for the shelter is 0.0064 square feet or 9.2 square inches. The vent design can be seen below in Figure 2.

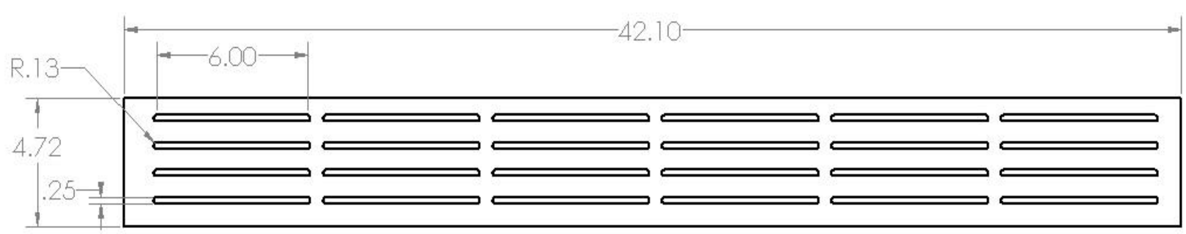

Figure 2: Vent Design

Pull Out

The minimum area required to prevent the connectors (screws or bolts) from pulling out of the wall can be determined using the following equation:

$$\tau = \sigma * A \qquad \textbf{(eq. 6)}$$

Where:

τ = total shear force experienced by the connectors (lb.)

σ = strength of the panel (assumed to be 50 ksi)

A = Area the connector must pull through to fail (thickness of the panel times the perimeter of the connector being pulled out, in^2)

This method can be used to size the connector head. If the head is too small, a washer can be added to increase area.

The perimeter of a circular connector head is calculated with the following equation:

$$P = 2 * \pi * r \qquad \textbf{(eq. 7)}$$

Where:

P = perimeter (in.)

r = radius of the connector head (in.)

Sizing Wall Connectors

With the connectors spaced at 18 inches apart, the required strength of the connectors can be determined. The moment of inertia of the square shaped wall section is 2.824 in^4. The shear flow is calculated to be 125.811 lb./in. using the following equation:

$$Shear\ flow = (V * Qc)/(Moment\ of\ Inertia) \qquad \textbf{(eq. 8)}$$

Where:

V= 390 lb. (From previous equation)

Qc= y*A' =0.911 in^3

Moment of Inertia = 2.824 in^4.

The required strength of the connection between panels is calculated to be 2264.6 lb. using the following equation:

$$Spacing\ of\ connector = \frac{Strength\ of\ connector}{Shear\ Flow} \qquad \textbf{(eq. 9)}$$

Where:

Spacing of connector = 18 in

Shear Flow = 125.811 lb. /in

The strength requirement per connector is calculated to be 453 lb. using the following equation:

$$Strength\ of\ connector = (Required\ Strength)/(Connections\ per\ webbing) \qquad \textbf{(eq. 10)}$$

Where:

Required strength = 2264.6 lb.

Connections per webbing = 5

Given a safety factor of two, the required strength of each connector is 907 lbs.

Overall Design

All SolidWorks drawings can be seen in Appendix B.

The Weatherboss 412 flat panel provided by BRB Roofing can be seen in Figure 3 below:

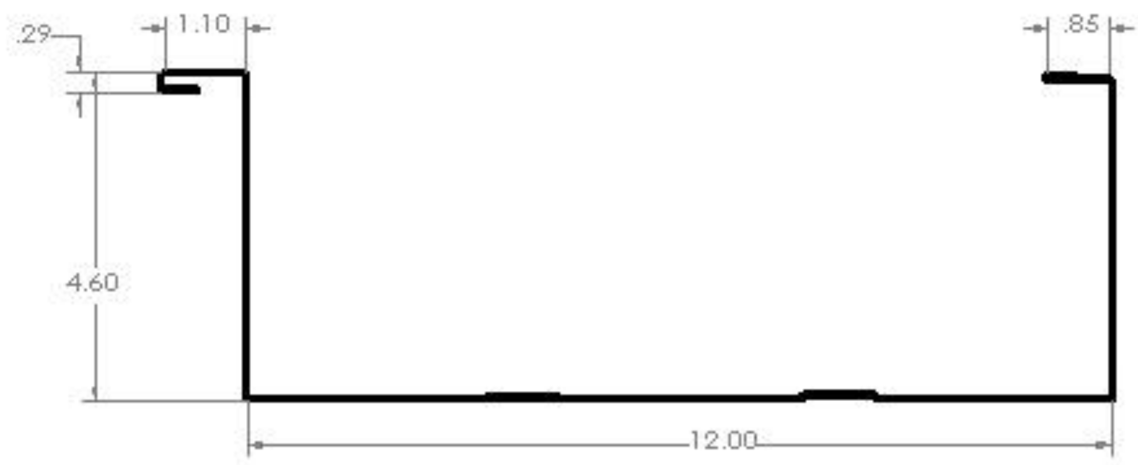

Figure 3: Flat Panel Cross Section (Units are in inches)

Wall Panels

The panel used for the walls and roof of the shelter is the Weatherboss 412 panel which is currently used by BRB Roofing for new and retrofitted roofing projects. The Weatherboss 412 is ASTM-653 Galvalume or a galvanized based material, according to the BRB roofing website, with a modulus of elasticity of 50 ksi. The panels have a thickness of 0.0478 in. (18 gauge). In order to construct walls from panels originally designed for roofing, two panels must be interlinked face to face. The panels will be connected at an offset, allowing them to be reinforced every six inches as seen in Figure 4 below. This will leave a void between them which will be filled with an aggregate material to reduce deflection caused by wind or oncoming debris.

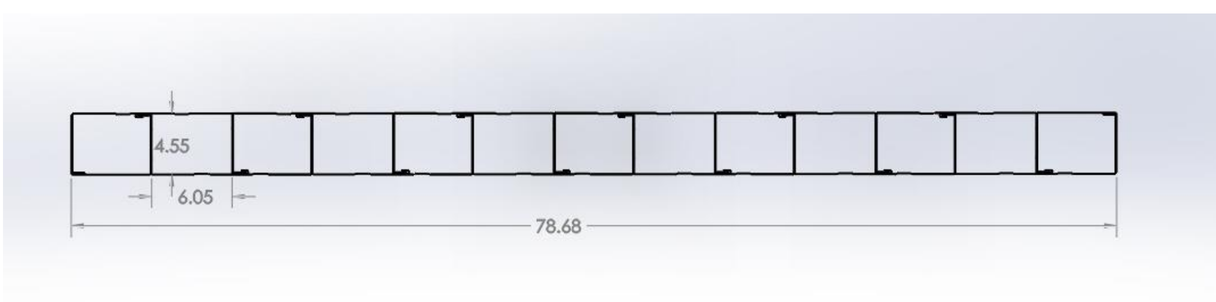

Figure 4: Panel Assembly (Units are in inches)

The wall panels are six and a half feet long by the dimensions shown in Figure 3. The right side of each panel will slide into the “hook” on the left side of the panel. These panels will be reinforced with five pairs of screws equally spaced along the length of the four and half inch ribbing as calculated in the previous section. In order to connect the two panel assemblies, five equally spaced screws must be connected from the outside into the “hook” of the adjacent panel.

Roof

The roof of the structure will be constructed with the same design strategy as the walls and laid over top of the structure as seen in Figure 5. The roof panels will be approximately six feet long. The length of the roof panels will vary depending on the geometry of the shelter. In order for the roof to fit flush with the width of the walls, the panels used for the corners of the structure must be adjusted to the dimensions seen in the drawings provided in Appendix B.

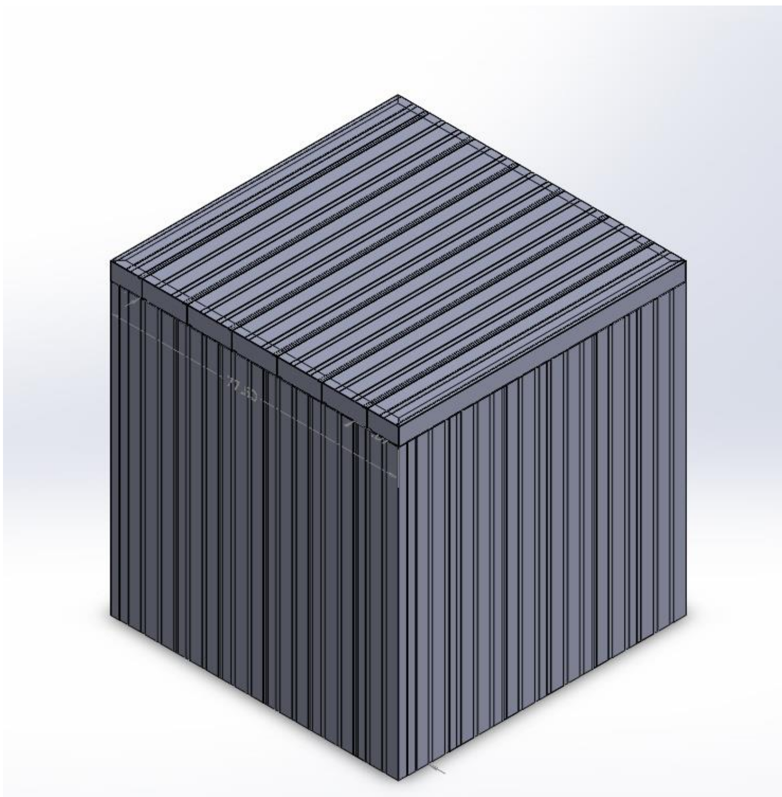

Figure 5: Roof/Wall Assembly

In order to anchor the roof to the rest of the shelter, L-shaped brackets will be placed inside and outside of the structure. The inside bracket will be placed under the roof and along the inside wall. Similarly, the outside bracket will be placed over the roof and along the outside wall. The inside and outside brackets will be connected together using bolts that pass from one side of the wall to the other.

Ground Anchoring System

In order to prevent the structure from failing or blowing away, an anchoring system must be used. The anchoring system consists of anchor bolts and purlins with connections to wall sections. The anchoring mechanism must be strong enough to resist both tensile and shear effects due to uplift, racking, and sliding.

Uplift and Shear Forces

According to FEMA P-361 section 4.3.2, the uplift forces are dependent on the roof size and geometry. Due to the small size of this structure, it can be assumed that only corner and edge geometries have an uplift effect of the structure. According to FEMA P-361 Figure 4-3, the flat roof corner uplift forces are 396 psf. and the edge geometry experiences 238 psf. The total corner area is four square feet and the remaining roof edge area is 42 square feet. Therefore, the uplift forces can be calculated with the following equations:

$$Edge\ Uplift\ Force = Edge\ Area * Edge\ Uplift\ Pressure \qquad \textbf{(eq. 11)}$$

Where:

Edge Uplift Force = 9996 lb.

Edge Area = 42 ft^2

Edge Uplift Pressure = 238 psf.

$$Corner\ Uplift\ Force = Corner\ Area * Corner\ Uplift\ Pressure \qquad \textbf{(eq. 12)}$$

Where:

Corner Uplift Force = 1584 lb.

Corner Area = 4 ft^2

Corner Uplift Pressure = 396 psf.

By taking the sum of the previous equations the total uplift force is 11,580 lbs. The total shear can be calculated with the following equation:

$$Total\ Shear = Wall\ Area * Wind\ Load\ Pressure \qquad \textbf{(eq. 13)}$$

Where:

Total Shear = 6720 lb.

Wall Area = 6 ft. *7 ft. = 42 ft^2

Wind Load Pressure = 160 psf. (refer to Design Loads Section)

By combining shear and uplift there is a total force on the anchor mechanism of 18,300 lbs. The shelter will be anchored to the ground with a combination of heavy C-shaped purlin channels, anchor bolts, and self-tapping screws.

C-Shaped Purlin Channels

The dimensions of the channel are three inches high by approximately five inches wide. The length of channel will change depending on the shelter dimensions. The purlin channels will be fastened to the concrete foundation with anchor bolts. The thickness of the C-shaped purlin channel can be determined by calculating the amount of force on each anchor bolt with the following equations:

$$\frac{Force}{Bolt} = \frac{Total\ Anchoring\ Force}{Number\ of\ Bolts} \qquad \textbf{(eq. 14)}$$

Where:

Force/Bolt = 2287.5 lbs.

Total Anchoring Force = 18,300 lbs.

Number of Bolts = 8

$$Area = \frac{Force/_{Bolt}}{Stength\ of\ C{-}Shaped\ Pulin/_{Safety\ Factor}} \qquad \textbf{(eq. 15)}$$

Where:

Area = 0.1525 in^2

Force per Bolt = 2287.5 lbs.

Strength of C-Shaped Purlin Channel = 30000 lbs.

Safety Factor = 2

$$Thickness = \frac{Area}{\pi * Diameter\ of\ Washer} \qquad \textbf{(eq. 16)}$$

Where:

Thickness = 0.0661 in

Area = 0.1525 in^2

Diameter of Washer = 0.734 in

In this case, the strength of the C-shaped purlin channel is a property of A-36 steel. The thickness of the C-Shaped purlin channel is a function of the calculated area and perimeter of the material pulled through the C-channel if failure occurs. The perimeter is determined by the outside diameter of the bolt head or washer multiplied by Pi. The selected washer per anchor bolt is a ¼ inch chrome plated grade 2 steel washer. The calculated thickness of the C-channel is closest to a 15 gauge steel at 0.0673 inches.

Anchor Bolts

A total of 8 anchor bolts are used with a bolt on all corners and in the center of each wall section. The total force per bolt is 2287.5 lbs. given that the combined shear and uplift forces are 18300 lbs. The shear strength of a bolt is estimated to be 60% of the ultimate tensile strength. Therefore, a grade 2 bolt with a tensile strength of 74 ksi. would result in a maximum allowable shear stress of 44.4 ksi. The required bolt diameter can then be calculated with the following equations:

$$Diameter\ of\ Bolt = \sqrt{\frac{\left(\frac{\frac{Force}{Bolt} * Safety\ Factor}{Maximum\ Allowable\ Shear\ Stress}\right) * 4}{\pi}} \qquad \textbf{(eq. 17)}$$

Where:

Diameter of Bolt = 0.36 in

Force/Bolt = 2287.5 lbs.

Safety Factor = 2

Maximum Allowable Shear Stress = 44,400 lbs. /in^2

A staggered offset screw formation will need to be used in order to connect the purlin channels to the walls. This formation can be seen in Figure 6.

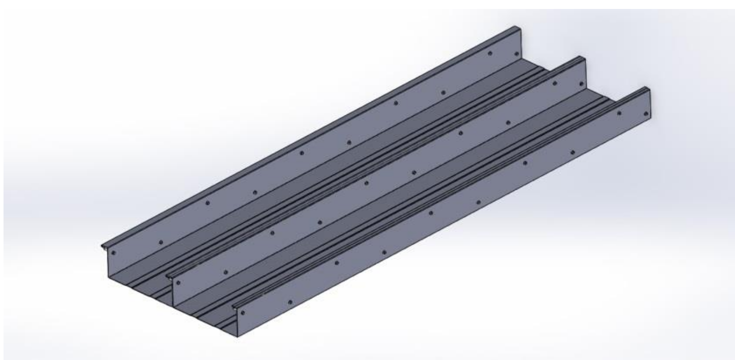

Figure 6: Screw Formation

Entryway

The door/wall assembly will be required to complete the structure, see Figure 6. The entryway of the shelter will be a purchased FEMA certified door that opens inward. FEMA P-361 is a strictly regulated standard for the door and door frame. According to these FEMA standards, a steel door composed of at least 12-gauge steel is suitable for storm shelters. Doors of this strength are able to withstand gusts of wind up to 250 mph. The doors can have a width of up to three feet (FEMA P-361, 7.1). Each door needs to be attached with three local points on the hinge side and three local points on the latch side (FEMA P-

361, 7.4.4). The door frame must have 3/8" lag screws in the door jamb and 3/8" lag screws in the door head. The latch is recommended to have three points of locking mechanisms.

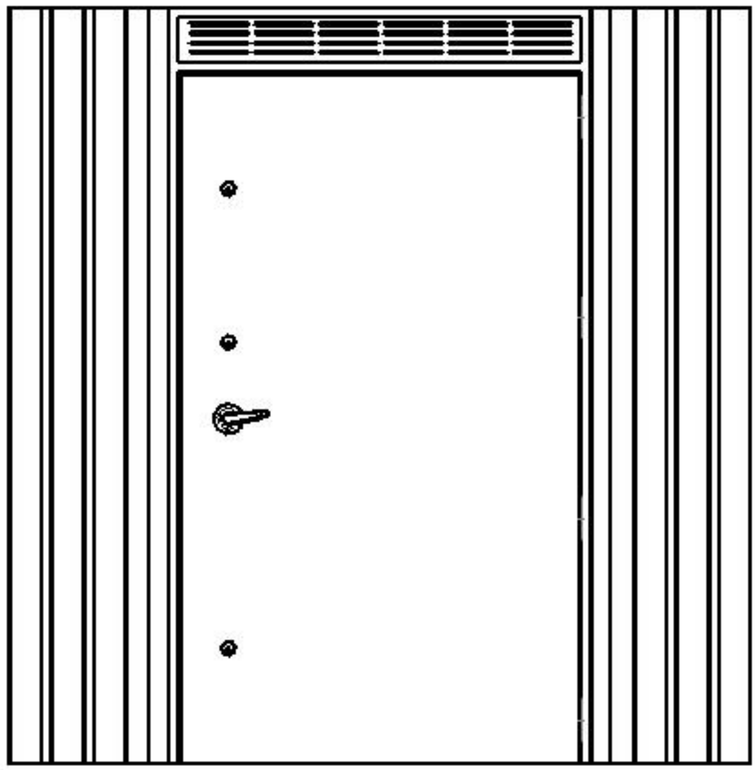

Figure 7: Door/Wall Assembly

Aggregate Material

The aggregate materials that are most practical in this application are high density foam, concrete, and sand. GRA Services International Secure Set 6 is high density polyurethane water blown foam that is designed to be pumped, sprayed, or poured. This is the foam that was originally under high consideration to use as the aggregate material. While foam has high yield strength and adheres well to metal to help create a composite structure between the panel and foam, it is also the most expensive option. It requires two ingredients that are to be mixed at the site of installation. Besides the cost, the main concern with the foam is the possibility of it expanding too fast and causing the wall panels to bow out.

Concrete cannot be considered as an aggregate material because it would render the metal panels obsolete, therefore disregarding the mission statement to make a shelter out of the roofing materials supplied by BRB Roofing Inc.

After much research it was concluded that sand would be the best aggregate for this application. Not only is sand the most cost effective option, it will absorb much of the energy from an impact, as well as allow for simple installation.

Test Analysis

Procedure

Impact

The Storm Shelter Senior Design Team must provide a proof of concept before moving forward in the design process. Texas Tech University has a high pressure air cannon used to certify tornado shelters. However, due to the high cost of using the air cannon, the concept will first be tested by simulating Texas Tech's impact test. The test consists of the impact of a 15 pound two by four travelling at 100 miles per hour. This will be simulated by dropping a two by four modified with concrete on to a wall section. Using the concept of conservation of energy, kinetic energy can be set equal to potential energy as seen in the equations below.

$$Kinetic\ Energy = \frac{1}{2} * Mass * Velocity^2 \qquad \textbf{(eq. 18)}$$

Where:

Mass= 0.47 lb_f.

Velocity = 100 mph or 146.67 ft/s

Therefore, Kinetic energy is 161,340.67 ft*lb_f. The following equation can be used to solve for mass:

$$Potential\ Energy = mass * gravity * height \qquad \textbf{(eq. 19)}$$

Where:

Height = 30 ft. (height that can be achieved with a crane)

Potential energy = Kinetic energy =161,340.67 ft*lb_f

Gravity = 32.2 ft./s^2

Mass = 167 lb_f.

Based on the density of concrete (145 lbs./ft^3), the volume of concrete required is 1.15 ft^3. A cylindrical tube can be used as a form for concrete and a two by four can be placed through the center and exposed at the top and bottom of the cylinder. Given volume and diameter, the height of the concrete cylinder required can be calculated with the following equation:

$$Height = volume\ of\ cylinder\ / \left(\frac{\pi}{4} * Diameter^2\right) \qquad \textbf{(eq. 20)}$$

Where:

Diameter =8 in

Volume of cylinder = 1.15 ft^3

Height = 3.3 ft. or 39.6 in.

The wall section will be simply supported on two sides along the top and bottom edge of the wall section. This will simulate the reactions to resist impact forces at the base of the wall section anchored to the ground. The testing missile (two by four modified with concrete) will be dropped from a crane by pulling a release latch. This set up can be seen in Figure 33 in Appendix C. Multiple tests will be performed to increase accuracy of the results. The wall sections will pass the impact test if the deflection caused by impact is less than three inches. This will allow for further design and testing of the shelter as a whole.

Load test

According to FEMA test standards, the shelter must be able to withstand a three second gust of a 250 mile per hour wind. This can be tested by simulating the wind load. The wind load can be calculated with the following equation:

$$Wind\ load\ = 0.00256 * Velocity^2 \quad \textbf{(eq. 21)}$$

Where:

Velocity = 250 mph or 367 ft. /s

Wind load = 160 psf.

A maximum weight of 5267 lb. will be evenly distributed over a surface area of 33 ft^2 in order to simulate the wind load. To perform a simulated load test, the wall section will be supported on two sides similarly to the impact test. If the wall section is not able to support the load for three seconds the test will be considered a failure.

Results

Impact

The Storm Shelter Senior Design Team tested at the BRB roofing facility on April 9, 2014. The walls were sealed with 18 gauge steel C-channels. The two missile assemblies are weighted at 125 lb. and 160 lb., respectively rather than the projected 167 lb at an assumed height of 30 ft. The deviation in weight between the two missiles is a result of variations in the concrete cylinder form diameter size and concrete densities. The missile assembly that weighed 125 lb. used a concrete cylinder form with a diameter of 7.5 inches, while the missile assembly that weighed 160 lb. used a concrete cylinder form with a diameter of 8.5 inches.

Two impact tests were performed on the wall sections by using a crane to drop each missile with a modified release system. A picture of the release system can be seen in Figure 11 in Appendix C. The unexpected weight differences of the missiles were compensated for by increasing the height dropped for the 160 lb. missile to 32 ft. and increasing the height of the 125 lb. missile to 40 ft. The wall was simply supported on the top and bottom of the wall sections shown in Figure 16 in Appendix C.

On both impact tests the missile did not pass through the wall section. Deflection did take place during both tests and resulted in more than the maximum three inches allowed by FEMA standards (FEMA P-361, 7.3.2). The measured deflection was approximately four inches for both impacts. The deflection is shown in Figures 25 and 26 in Appendix C. The 125 lb. missile impacted the wall section between the ribs and caused tearing through the first wall panel layer, shown in Figure 24 in Appendix C. The 160lb missile impacted the wall section along the wall webbing, shown in Figure 35 in Appendix C. No tearing took place on the second impact. A summary of these results can be seen below in Table 3. The C-channels for the caps were deformed and the screws pulled out on the ends. These deformities are shown in Figure 35 in Appendix C. This most likely played a role in the amount of deformation that was experienced.

Table 6: Impact Test Results Summary

Impact Results				
Weight (lb.)	**Initial Height (ft.)**	**Damage**	**Meets Standards**	**Reason**
125	40	Tearing and deflection	No	Deflection > 3 in
160	32	Deflection	No	Deflection > 3 in

Wind Load

The wind load was simulated with a static load test. The wall section was simply supported and weight was evenly distributed along the wall section. First, a single layer of sand bags was evenly placed along the surface of the wall section. Then, two spools of metal were placed on top of the sandbag layer along with a pallet. The total weight loaded on the wall during the test was 5291 lb. and was loaded for approximately five minutes. This total weight was distributed between the items as follows: The wall section containing sand weighed approximately 1180 lbs. The layer of sand bags weighed 1566 lbs. The two concrete missiles weighed 285 lb. together. The two metal spools weighed 2260 lbs. Therefore, we tested with a total load of 5291 lbs. which is 24 lbs. more than required to simulate the wind load on the wall section. The wall section yielded slightly but showed no indication of plastic deformation. Therefore, the wall meets FEMA standards for being able to withstand a 250 mph gust of wind lasting three seconds. Testing pictures can be seen in Appendix C, Figures 29-32.

Financial Analysis

Cost of Shelter Material

It is suggested that each shelter will be equipped with a SecurAll FEMA certified storm shelter door. The door meets FEMA standards and has passed the Door Pressure & Debris Impact Test at Texas Tech. The purchase cost is $1660.00 with a shipping cost of approximately $315, bringing the total cost of the door to $1975.00. The cost of sheet metal is about 0.80₵/lb. The total cost of metal used in the shelter can be seen in the calculation below.

$$54\ pannels * \frac{2\ lin.ft.}{pannel} * \frac{3\ lb.}{lin.ft.} * \frac{\$0.80}{lb.} = \$259.20\ cost\ of\ sheet\ metal \qquad \textbf{(eq. 22)}$$

The void filling aggregate that was chosen for the shelter was sand. The amount of sand needed to fill all voids in the structure will equal 65 ft^3. This will come out to a cost of $9.55 per shelter. Sand is cheaper when purchased in bulk and can be used as each shelter is built. Lastly, the connectors will cost $183.90. The #14 – 7/8" lap screws run $30.65 per bag (250 screws per bag) shipping included and 6 bags will be needed for the structure. The anchor bolts used for the shelter will be the WA385 Confast 3/8" x 5" expanding wedge anchor bolts. A bag of 50 bolts with shipping will cost $32.94, but only 8 of the bolts will be needed of the entire structure, thus, bringing the total cost of the bolts per shelter to $5.27. The total cost of materials per shelter is $2432.92. The cost breakdown can be seen in the table below:

Table 7: Material Cost for Storm Shelter

	Cost w/ Shipping
FEMA Certified Storm Door	$1975.00
Cost of sheet metal	$259.20
Sand	$9.55
Connectors	Screws - 6 bags * $30.65 each = $183.90 Anchor Bolts - $5.27
Total Cost of Materials	$2432.92

Cost of Testing

Cost of testing at BRB in Muskogee, OK totaled $122.68. This money was used for the construction of the missiles dropped during testing. Items purchased to test the shelter walls included the following: four bags of concrete, two eight inch round concrete forms, one 10 foot long two by four, four cinder blocks, three different types of latches, and 100 feet of nylon rope. The cost of these items was minimal compared to high cost that Texas Tech charges for their certified FEMA Door Pressure & Debris Impact Test.

Conclusions/Recommendations

Although the wall section prototype met FEMA standards for simulated wind load, it failed to meet FEMA impact standards due to deflection greater than three inches. Testing calculations are based on an energy balance between kinetic and potential energy. This simulates the amount of work energy a two by four shot out of a cannon transfers to the storm shelter verses potential energy. The testing procedure is evaluated in terms of impulse, which transmits between 2.88 and 3.30 times more potential energy than FEMA test standards. This impulse can be calculated using the following equation:

$$Impulsive\ energy = Mass * Change\ in\ Velocity \qquad \textbf{(eq. 23)}$$

Where:

Impulsive energy = 196.91 lb. ft./s (for the 125 lb. missile) and 225.638 lb. ft./s (for the 160 lb. missile) and 68.93 lb. ft./s (for the 2 x 4 shot with a cannon)

Mass = 3.88 lb_f (125 lb.), 4.97 lb_f (160 lb.), and 0.47lb_f (15 lb.)

Change in Velocity = 50.75 ft. /s (for the 125 lb. missile) and 45.4 ft. /s (for the 160 lb. missile)

Velocity can be solved for both cases with an energy balance between kinetic and potential energy as seen in the following equation:

$$.5 * Mass * Velocity^2 = Mass * Gravity * Height \qquad \textbf{(eq. 24)}$$

Where:

Velocity = 50.75 ft./s (for the 125 lb. missile) and 45.4 ft./s (for the 160 lb. missile)

Mass = 3.88 lb_f (125 lb.) and 4.97 lb_f (160 lb.)

Gravity = 32.2 ft. /s^2

Height = 32 ft. (for the missile weighing 125 lb.) and 40 ft. (for the missile weighing 160 lb.)

According to the calculations, it is concluded that the 125 lb. missile impulsive energy is 2.88 times greater than the 15 lb. two by four impulsive energy. The 160 lb. missile impulsive energy is 3.30 times greater than the 15 lb. two by four impulsive energy. Therefore, while both wall sections failed the impact test, this testing procedure is more rigorous, when looking at impulsive energy, than the FEMA standard impact test with the 15 lb. two by four. Based on the results of the impact test, there are some recommendations for improvements.

First, expanding the head area of the screw will resist the pull out that can be seen in Figures 23 and 38 in Appendix C. To connect each panel together, as well as to connect the panels to the C- shaped purlin channel, 1/4 in. x 7/8 in. HWH TEK Lap Seam Screw with a Bond Seal Washer should be used in lieu of 12x3/4 TEK. The wall panels should also be mechanically seamed together before adding the connectors to provide extra reinforcement. The connectors should be placed approximately nine inches apart instead of the current 18 inches. Given the change in connector spacing, the number of connectors per web of 10, and a safety factor of two, the required strength per connector is 227 lbs. Please refer to sizing wall connectors section for calculation procedures to determine connector strength required for self-tapping screws. 18 gauge C-shaped purlin channels were used for the prototype. A thicker material, such as 15 gauge A-36 steel, should be used in order to prevent screw pull out at the base of the wall. This thicker steel will also provide further support for the ground anchoring system. The number of anchor bolts is suggested to be increased from eight to twelve with two bolts per corner and one bolt in the middle of each wall. The increase in the number of bolts increases the factor of safety for the anchoring system from two to three.

The primary focus of this project is to prove the concept of the innovative wall design which uses BRB's roofing panels. Testing of the wall prototype was the main priority in order to proceed with the overall design. Improvements to the wall need to be made before moving on to testing other aspects of the design. Further analysis and testing of the anchoring system both at the ground and the roof need to be done in order to pass all FEMA standards for a storm shelter. Additional requirements that must be addressed when constructing the shelter as a whole are the entryway and ventilation. This unique storm shelter is a promising new design that if implemented into the BRB Roofing and Manufacturing business could provide a safe escape for those seeking shelter during a tornado event

Works Cited

"1/4 In. X 7/8 In. HWH TEK Lap Seam Screw W/ Bond Seal Washer (250)." *Best Materials*. N.p., n.d. Web. 17 Apr. 2014. <http://www.bestmaterials.com/detail.aspx?ID=16711>.

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Budynas, R.G. and J.K. Nisbett. 2011. Chapter 8: Screws, Fasteners, and Design of Nonpermanent Joints. In Shigley's: Mechanical Engineering Design. 9th ed. New York, NY.:McGraw-Hill.

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Mahoney, George W. A., and Raymond L. Huhnke. "Selecting Tornado Shelters."*OCES Tulsa County*. N.p., n.d. Web. 14 Oct. 2013. <http://www.oces.tulsacounty.org/ag/agNewsletter/torshelters.pdf>.

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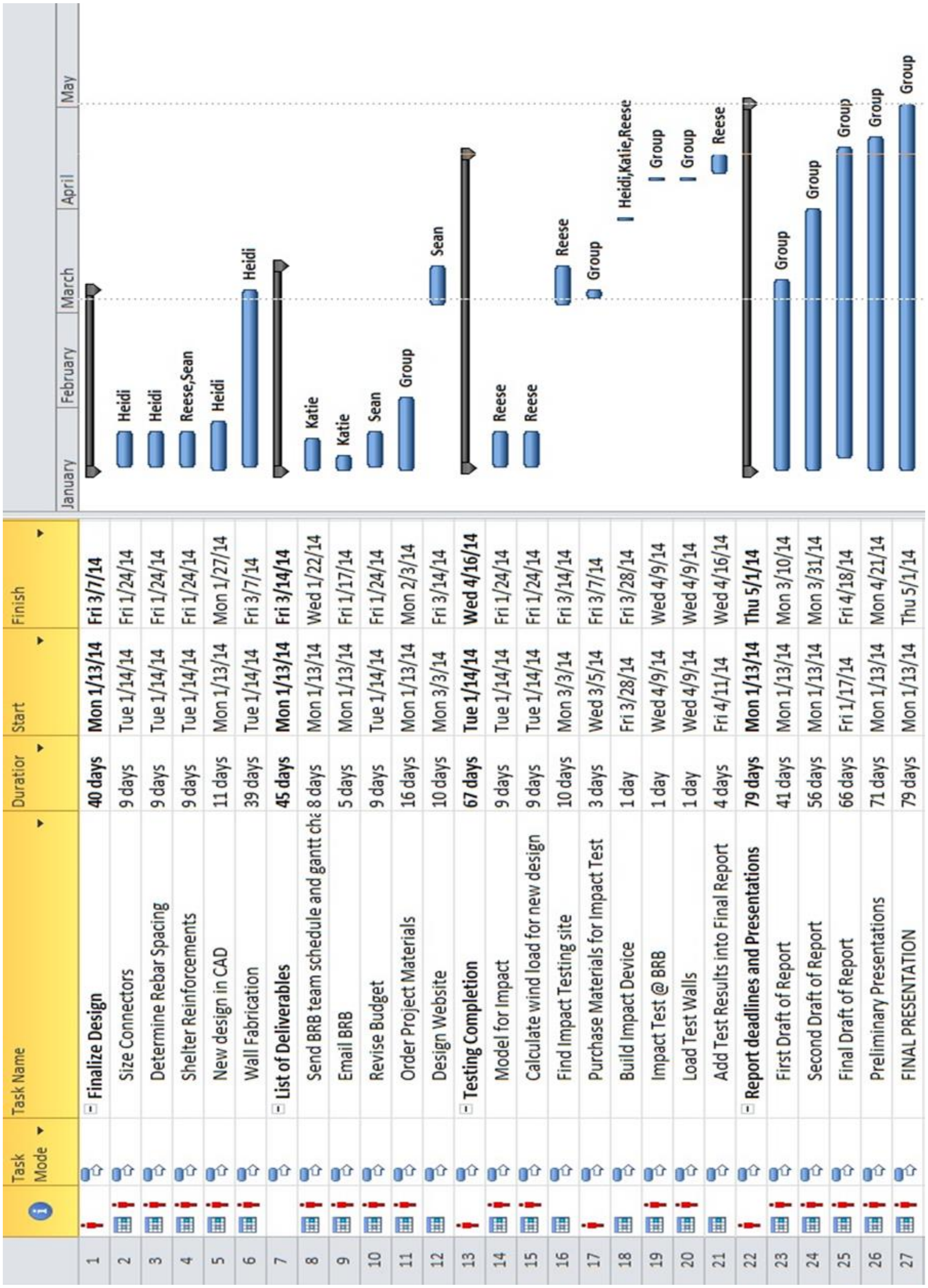
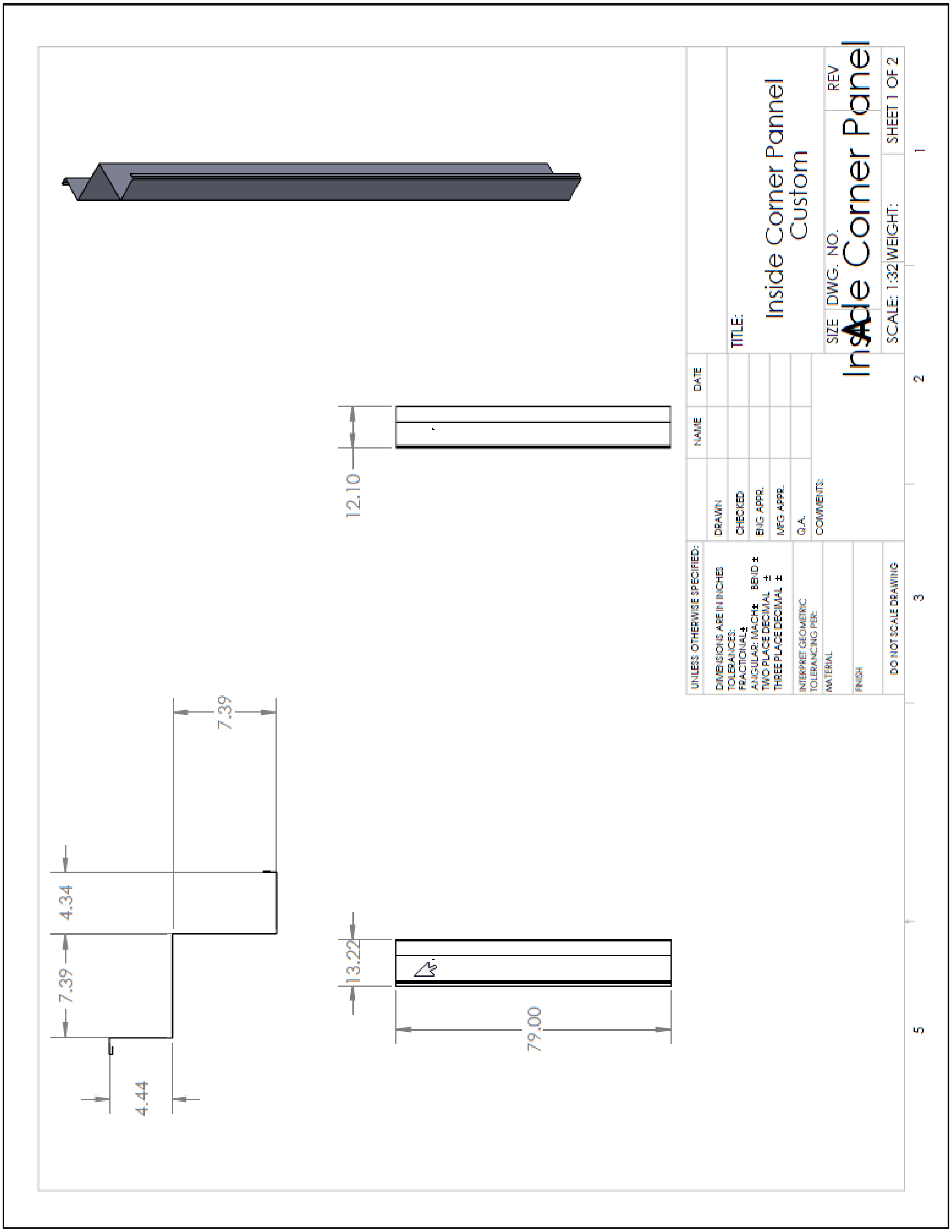
Appendix

A. Schedule



	Task Mode	Task Name	Duration	Start	Finish
1		**Finalize Design**	**40 days**	**Mon 1/13/14**	**Fri 3/7/14**
2		Size Connectors	9 days	Tue 1/14/14	Fri 1/24/14
3		Determine Rebar Spacing	9 days	Tue 1/14/14	Fri 1/24/14
4		Shelter Reinforcements	9 days	Tue 1/14/14	Fri 1/24/14
5		New design in CAD	11 days	Mon 1/13/14	Mon 1/27/14
6		Wall Fabrication	39 days	Tue 1/14/14	Fri 3/7/14
7		**List of Deliverables**	**45 days**	**Mon 1/13/14**	**Fri 3/14/14**
8		Send BRB team schedule and gantt cha	8 days	Mon 1/13/14	Wed 1/22/14
9		Email BRB	5 days	Mon 1/13/14	Fri 1/17/14
10		Revise Budget	9 days	Tue 1/14/14	Fri 1/24/14
11		Order Project Materials	16 days	Mon 1/13/14	Mon 2/3/14
12		Design Website	10 days	Mon 3/3/14	Fri 3/14/14
13		**Testing Completion**	**67 days**	**Tue 1/14/14**	**Wed 4/16/14**
14		Model for Impact	9 days	Tue 1/14/14	Fri 1/24/14
15		Calculate wind load for new design	9 days	Tue 1/14/14	Fri 1/24/14
16		Find Impact Testing site	10 days	Mon 3/3/14	Fri 3/14/14
17		Purchase Materials for Impact Test	3 days	Wed 3/5/14	Fri 3/7/14
18		Build Impact Device	1 day	Fri 3/28/14	Fri 3/28/14
19		Impact Test @ BRB	1 day	Wed 4/9/14	Wed 4/9/14
20		Load Test Walls	1 day	Wed 4/9/14	Wed 4/9/14
21		Add Test Results into Final Report	4 days	Fri 4/11/14	Wed 4/16/14
22		**Report deadlines and Presentations**	**79 days**	**Mon 1/13/14**	**Thu 5/1/14**
23		First Draft of Report	41 days	Mon 1/13/14	Mon 3/10/14
24		Second Draft of Report	56 days	Mon 1/13/14	Mon 3/31/14
25		Final Draft of Report	66 days	Fri 1/17/14	Fri 4/18/14
26		Preliminary Presentations	71 days	Mon 1/13/14	Mon 4/21/14
27		FINAL PRESENTATION	79 days	Mon 1/13/14	Thu 5/1/14

B. Drawings



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TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
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MFG APPR.
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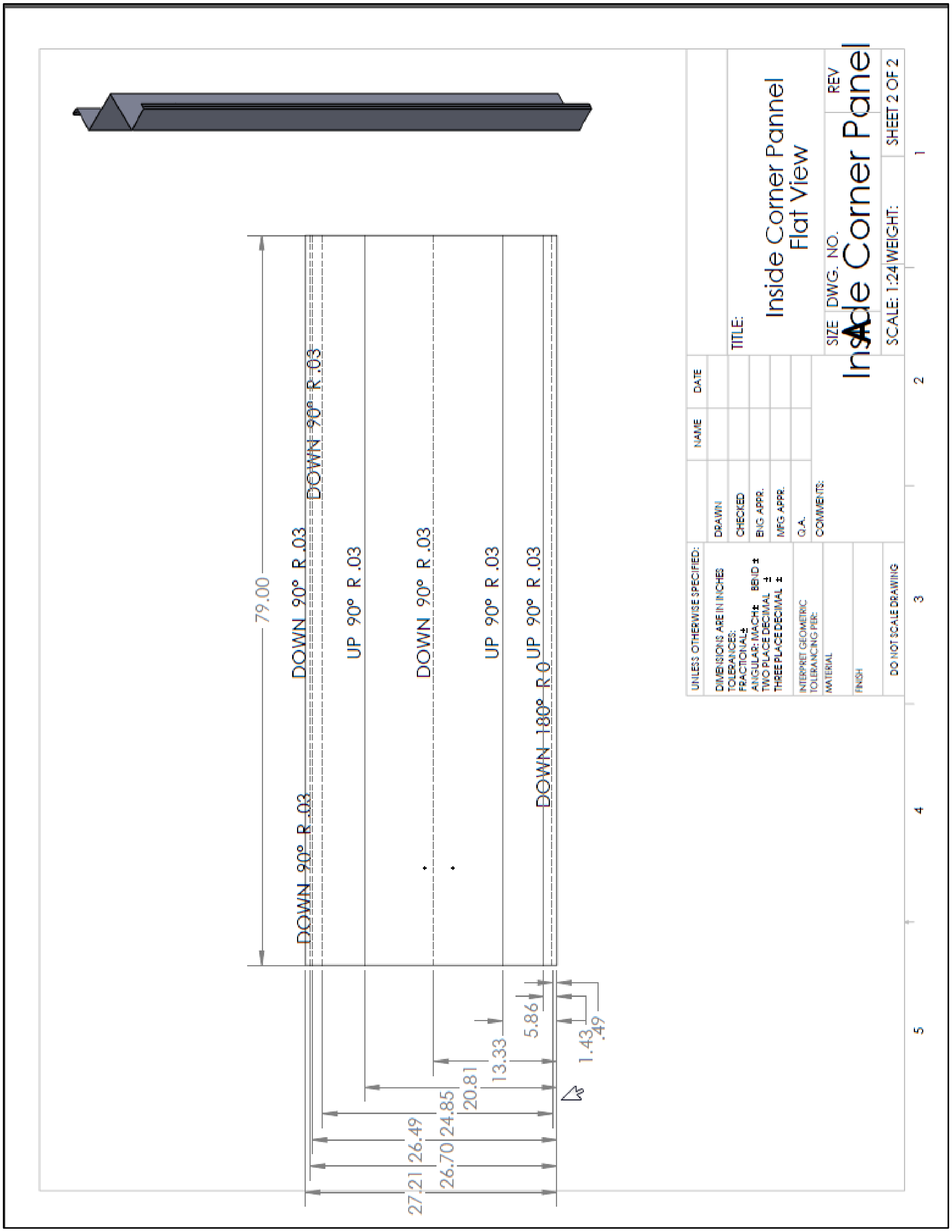
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SHEET 2 OF 2
1
2
3
4
5

ITEM NO.	PART NUMBER	Material	QTY.
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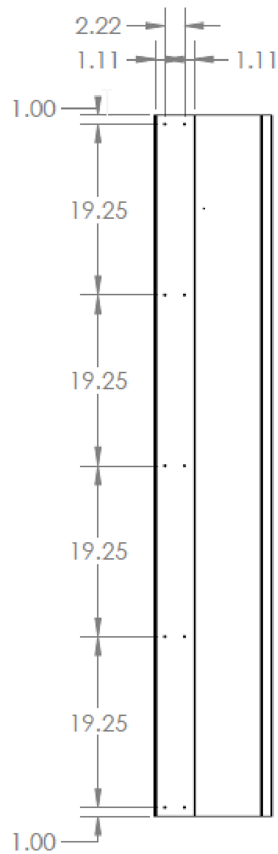
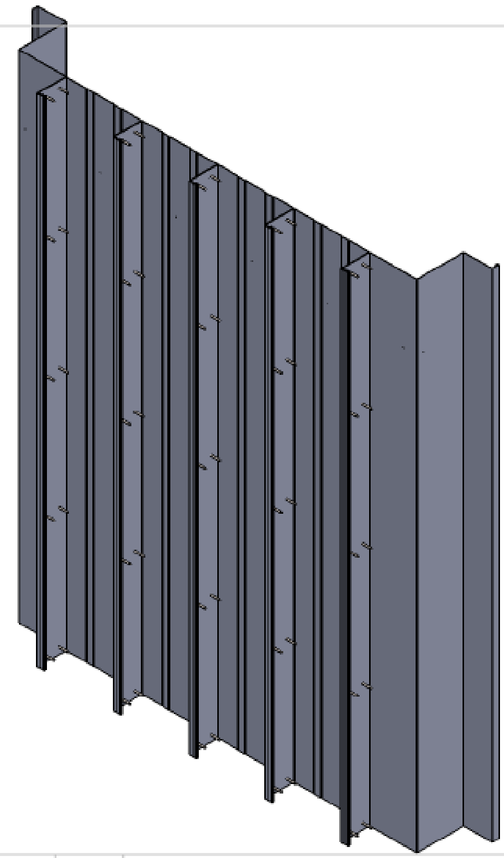
2	Inside Corner Pannel_1	ASTM-653 Steel	2
3	FHTS 0.216-14-AB-1.625-N		50





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MATERIAL
ASTM-653 Steel
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MFG APPR.		
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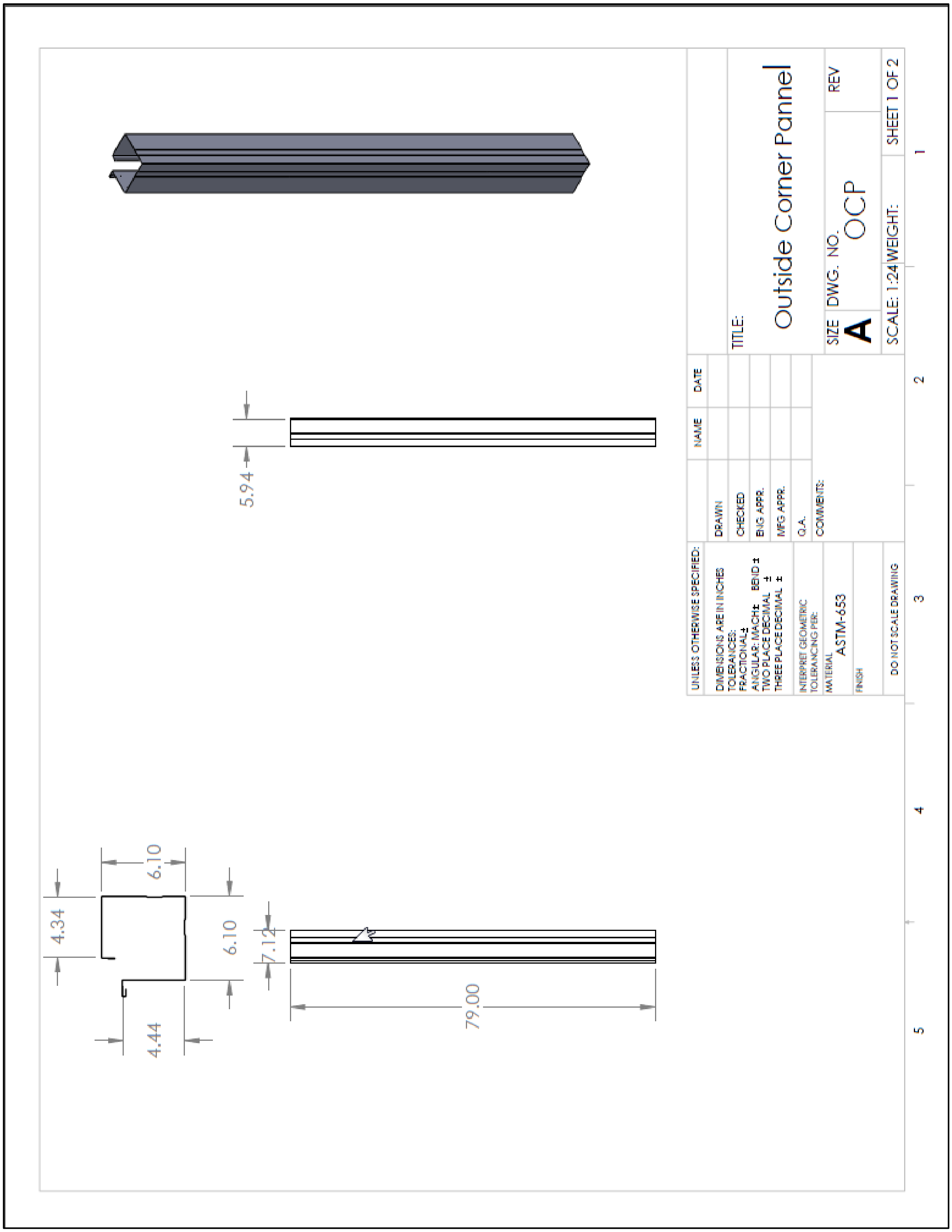
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TWO PLACE DECIMAL ±
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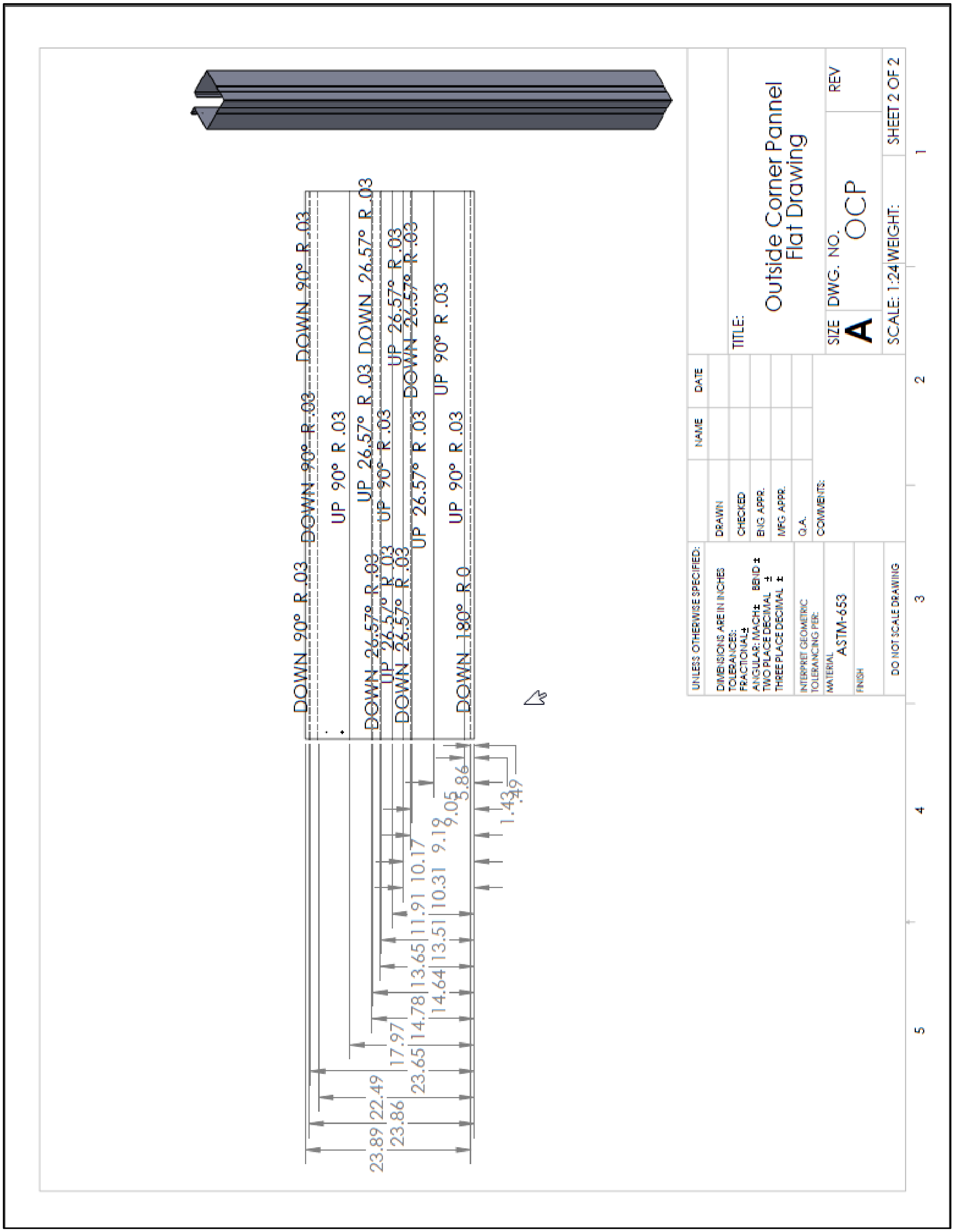
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TWO PLACE DECIMAL ±
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MFG APPR.
Q.A.
COMMENTS:
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DATE
TITLE:
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Flat Drawing
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DWG. NO.
OCP
REV
SCALE: 1:24
WEIGHT:
SHEET 2 OF 2

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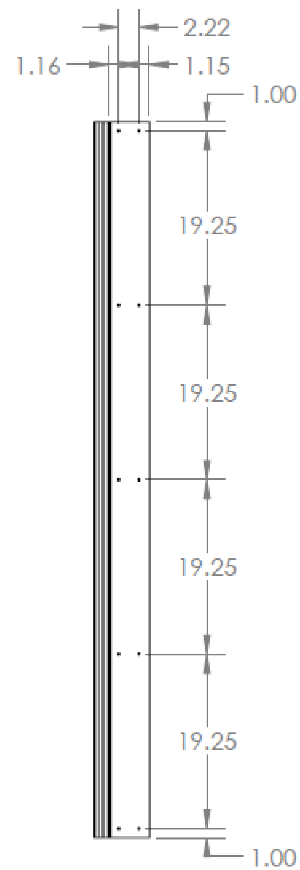
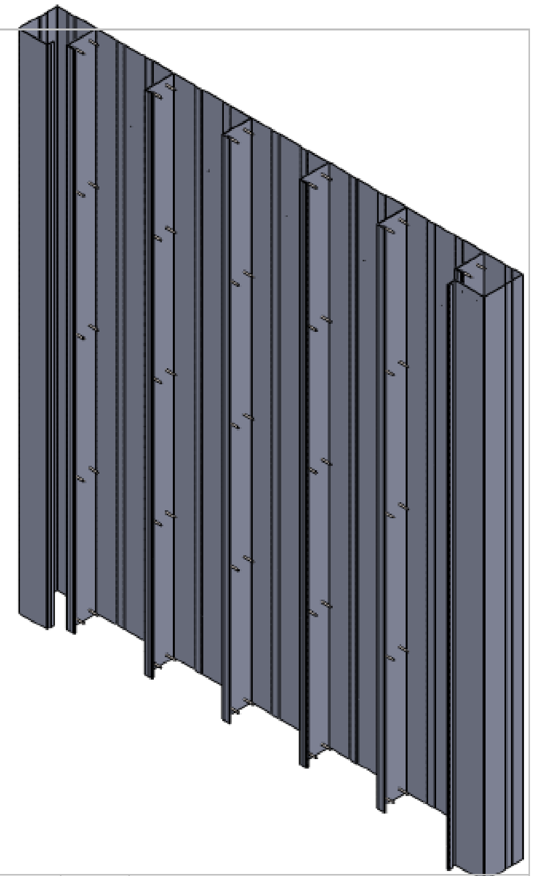
2	Outside Corner Pannel		2
3	FHTS 0.216-14-AB-1.625-N		60





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TWO PLACE DECIMAL ±
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MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
Outside Wall Section Screw Spacing

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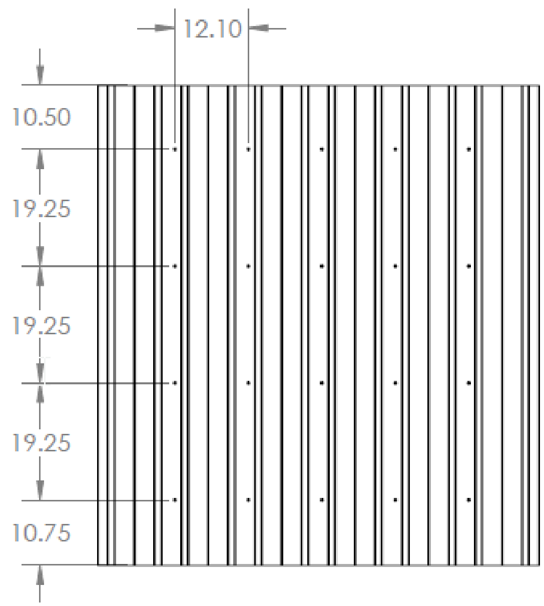
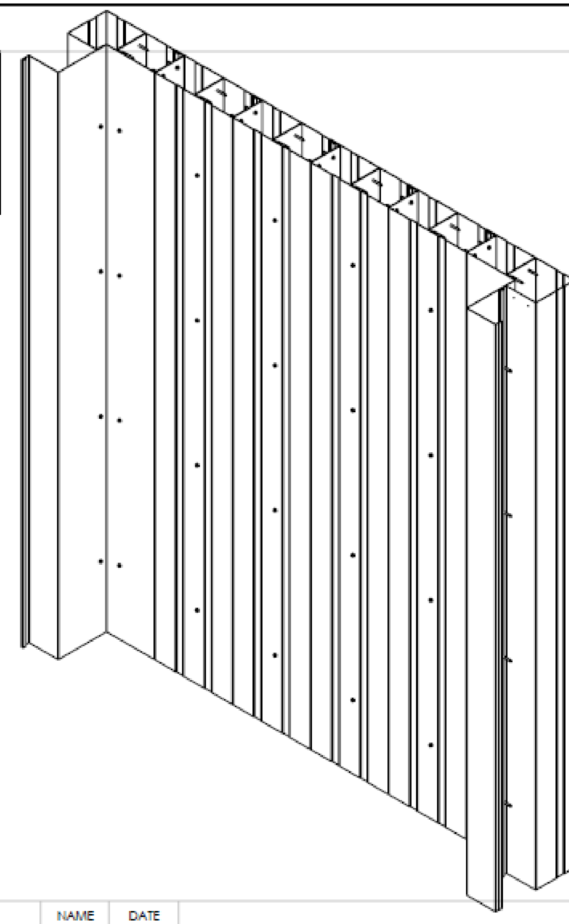
5 4 3 2 1

ITEM NO.	PART NUMBER	Material	QTY.
1	Outside Wall Section	ASTEM-653 Steel	1
2	Inside Wall Section	ASTM-653 Steel	1
3	FHTS 0.216-14-AB-1.625-N		52





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MATERIAL
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ENG APPR.		
MFG APPR.		
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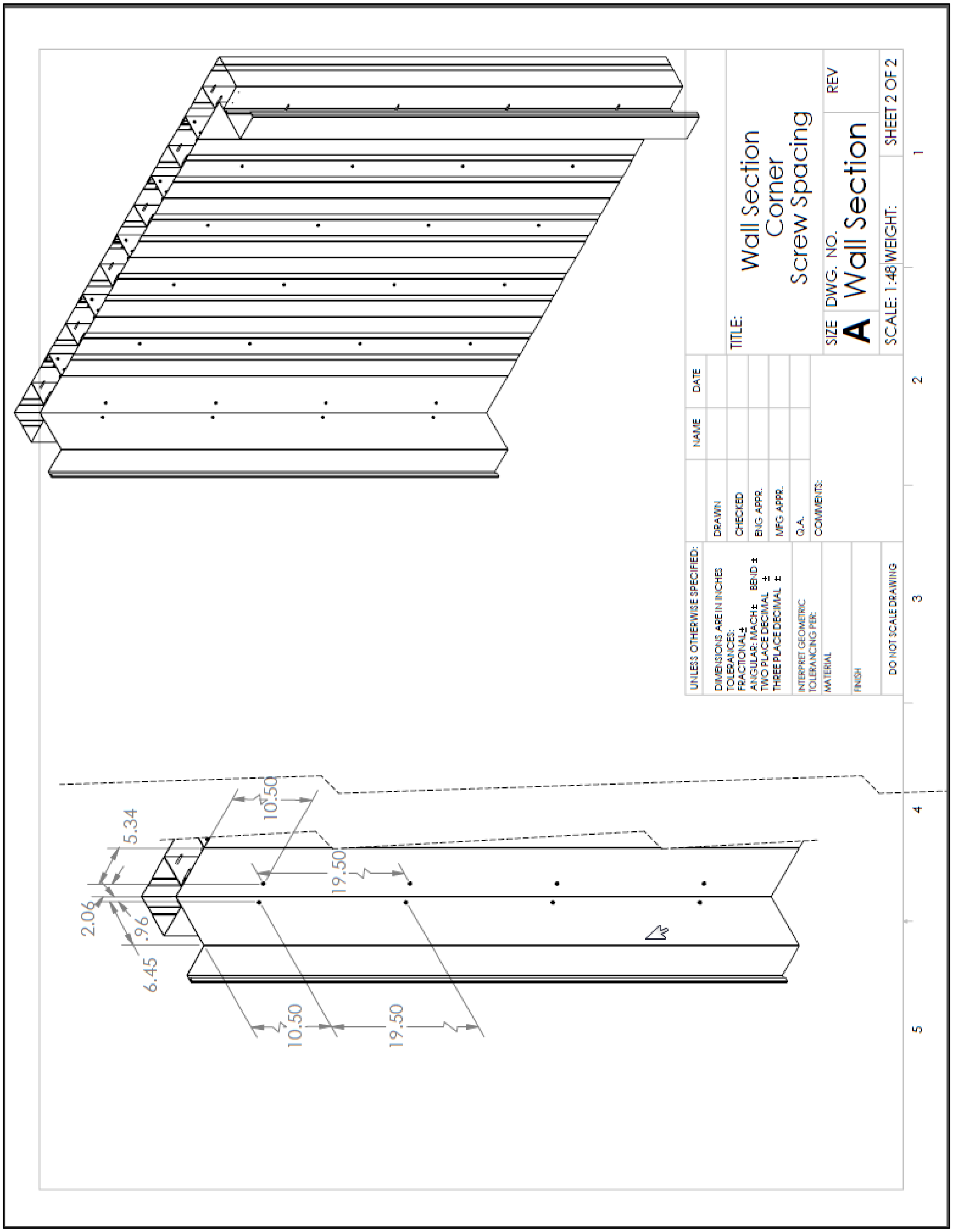
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Corner
Screw Spacing
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SHEET 2 OF 2
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DIMENSIONS ARE IN INCHES
TOLERANCES:
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ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
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5

ITEM NO.	PART NUMBER	Material	QTY.
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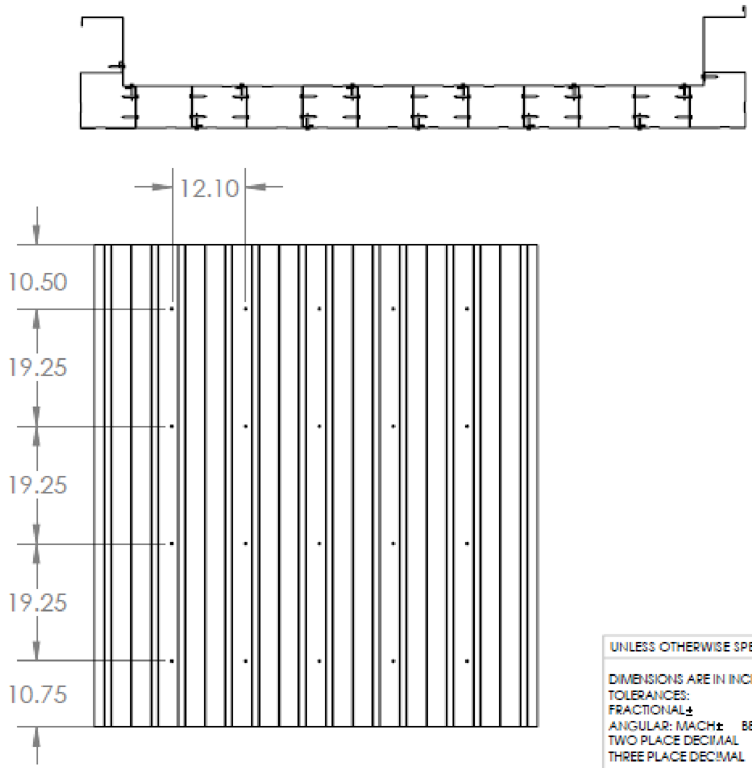
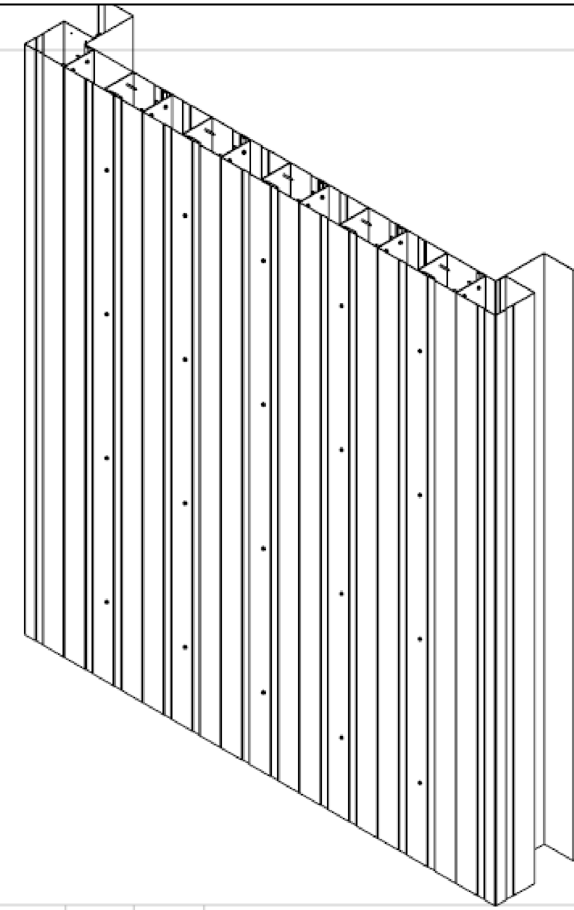
2	Inside Wall Section	ASTM-653 Steel	1
3	FHTS 0.216-14-AB-1.625-N		52





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TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

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MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

Wall Section
Front Side
Screw Spacing

SIZE A DWG. NO. Wall Section REV

SCALE: 1:24 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

C. Test Pictures

Figure 8: Building the Test Missiles

Figure 10: Putting the Finishing Touches on the Test Missiles

Figure 9: Ready for Testing

Figure 11: Getting Harnessed in For a Test Drop

Figure 12: Modified Release System

Figure 13: Rigging the Missile for Launch

Figure 14: Ready for Testing!

Figure 15: Making Sure Everything is Working Properly

Figure 16: Loading the Test Wall on Simply Supported Beams

Figure 17: Simply Supported Wall Section

Figure 18: Katie, Ready for Testing

Figure 20: Heidi and Katie

Figure 19: Heidi and Katie Prepared to Test

Figure 21: Tethering the Missile to the Crane Basket

Figure 22: Missile Dropping on Wall

Figure 24: Impact Damage

Figure 23: Screw Pull Out Resulting from Impact

Figure 25: Puncture of Panels and Screw Pull Out Resulting from Impact

Figure 26: Underneath Deflection

Figure 27: Deflection Along the Panels

Figure 28: Analyzing Missile Damage

Figure 29: Missile Damage after Dropping

Figure 30: Simulated Wind Load Test

Figure 31: Adding Weight for Simulated Load

Figure 32: Final Load

Figure 33: Holding the Load

Figure 34: The Missile Tethered to Hang Centered Under the Basket

Figure 35: Prepping for Impact Test 2

Figure 36: Damage from Test 2 and C-channel Deformations

Figure 37: Test 2 Set Up

Figure 39: Indention from 2x4

Figure 38: Screw Pull Out

Figure 40: The Team

Storm Shelter Senior Design Team

Reese Hundley

Sean Mallory

Heidi Stair

Katie Whitehurst

What to Expect

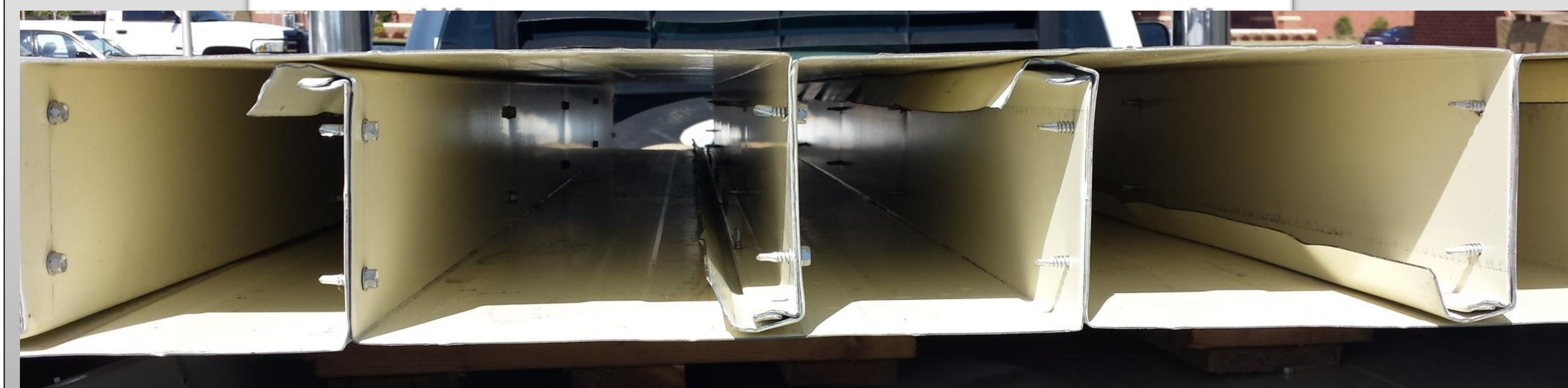
- Project Objective
- Company Background
- Last Semester
- FEMA Standards
- Design/Testing Procedures
- Conclusion/Recommendations

Project Objective

To design a safe, cost effective, and quickly manufactured above ground storm shelter with BRB's metal roof materials to be implemented into their business.

BRB Roofing - Muskogee, OK

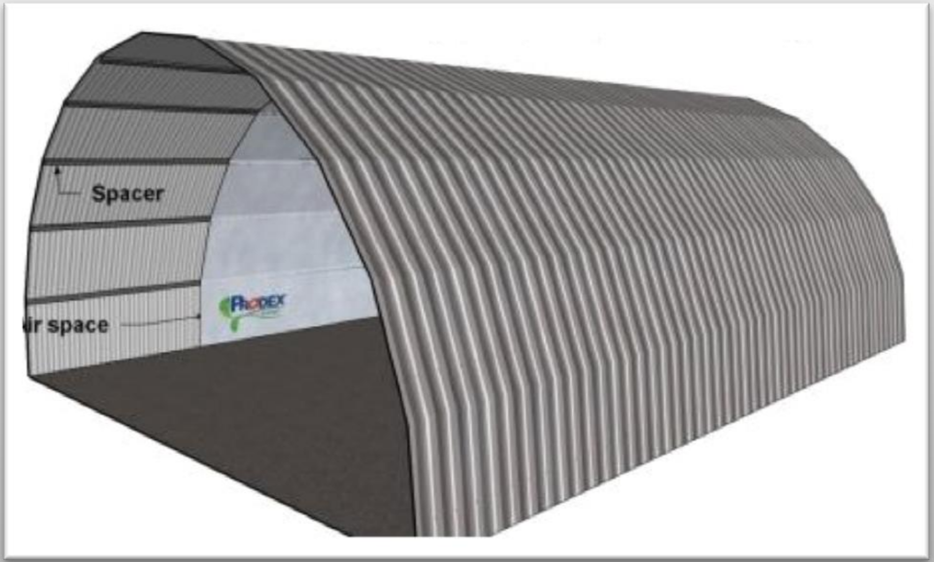
- Specialize in converting flat roofs into sloped metal roofs
- Roofing panels shaped in a way that doesn't require connectors
- Contact: Doss Briggs



http://www.brbroofing.com/products/weatherboss-reg-216-panels/weatherboss-412-panels/

Last Semester

- Tasked with designing above and below ground storm shelter
- Could not consider underground shelter due to bend radius of panels
- Focus switched to above ground shelter
- Conducted patent search



http://www.insulation4less.com/InsulationMethods-27-Quonset-Hut-click-for-Installation-Instructions.aspx

FEMA Test Standards

- Federal Emergency Management Agency
- Must withstand an impact of a 6 ft. long 2 x 4, weighing 15 lb. traveling 100 miles per hour horizontally
- Must withstand 250 mile per hour gust of wind for 3 seconds

The Shelter Parameters

- Use BRB's Weatherboss 412 panels to create a composite structure reinforced with aggregate material within the panels to limit deflection

- Design to fit it into a closet or covered garage with a previously established concrete foundation

- Must be more cost effective than current storm shelters

Initial Considerations

- Occupancy
- Vent Sizing
- Design Loads
- Connector Analysis
- Anchor Loads

Occupancy

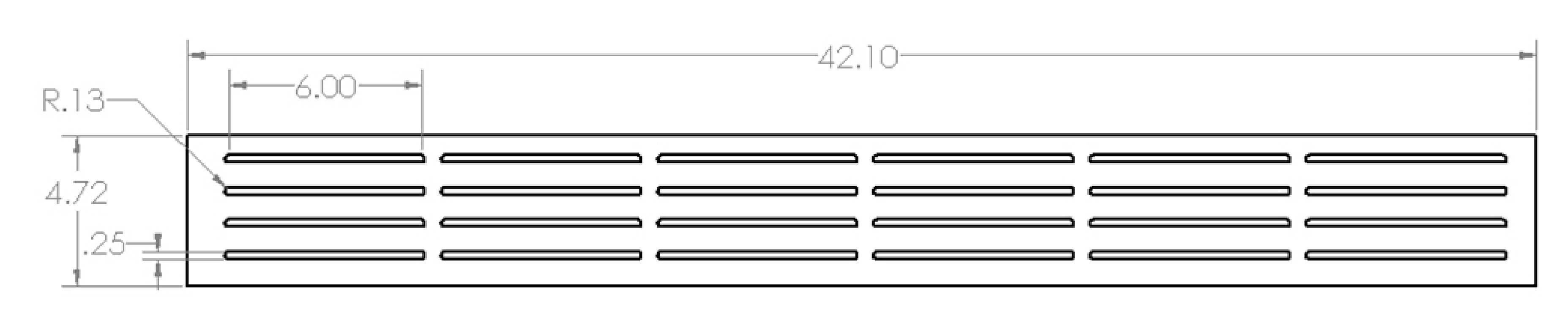
- Community Shelter – 5 ft^2 per person
- Shelter occupancy 5 people given floor area of 27 ft^2
- Recommended by FEMA P-361, Table 3-1

Tornado Safe Room Occupant	Minimum Recommended Usable Floor Area[1] in Square Feet per Safe Room Occupant
Standing or Seated	5
Wheelchair-bound	10
Bedridden	30

www.fema.gov/media-library-data/20130726-1508-20490-8283/fema_p_361.pdf

Vent Design

- A ventilation system must be added to allow for sudden pressure changes to equalize in the shelter to prevent the shelter from exploding
- Required minimum area of the vent = 0.0064 ft^2
- Passive ventilation system



http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-2179/BAE-1010web.pdf

Design Wind Speed

Formula 5.1 Velocity Pressure*

$$q_z = (0.00256)(K_z)(K_{zt})(K_d)(V^2)(I)$$

where: q_z = velocity pressure (psf) calculated at height z above ground
K_z = velocity pressure exposure coefficient at height z above ground
K_{zt} = topographic factor
K_d = directionality factor = 1.0
V = design wind speed (mph) (from Figure 2-2)
I = importance factor = 1.0

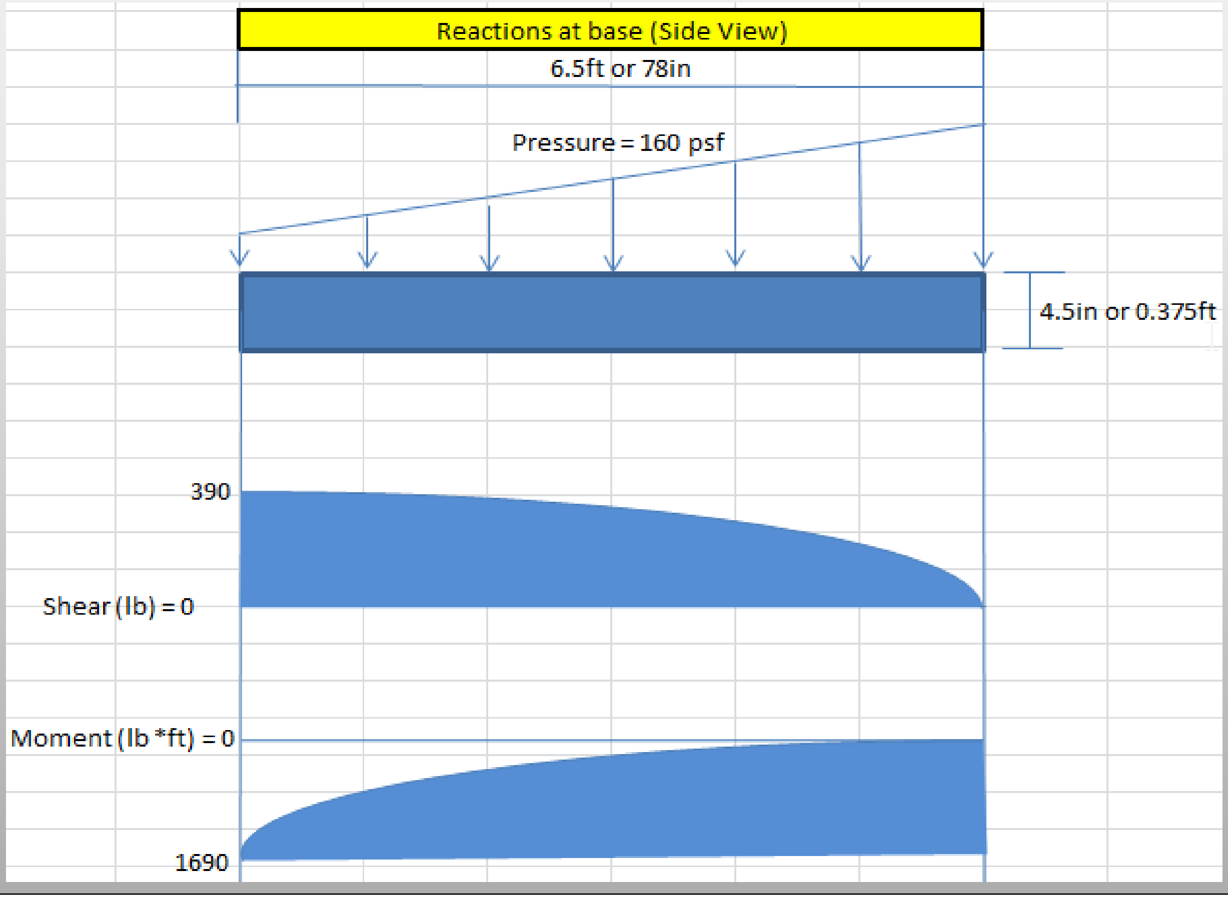
*From ASCE 7-98, EQ. 6-13

- q_z = 160 psf
- Design wind speed for 250 mph

(5 Load Determination and Structural Design Criteria, 9)

Wind Load

- Wall simulated as a cantilevered beam
- Wall section maximum bending moment = 1690 lb*ft
- Wall section maximum shear = 390 lb.

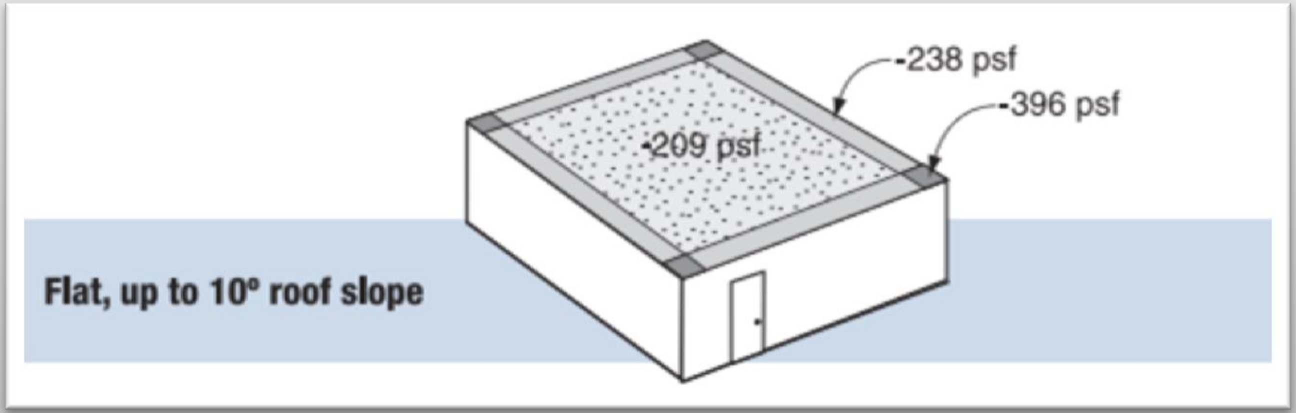


Connector Analysis

- Panels first connected using 12 x 3/4 TEK screws
- The required strength of each connector was calculated given an assumed spacing per connector and shear flow with a safety factor of 2
- Spacing of Connector = 18 in. , 9in. (1/4 in. x 7/8 in. HWH TEK Lap Seam Screw)
- Shear flow = 126 lb./in.
  - Function of shear experienced by the wall and wall geometric properties
- Required strength per connector = 907 lb. , 227 lb. (1/4 in. x 7/8 in. HWH TEK Lap Seam Screw)

Anchor Loads

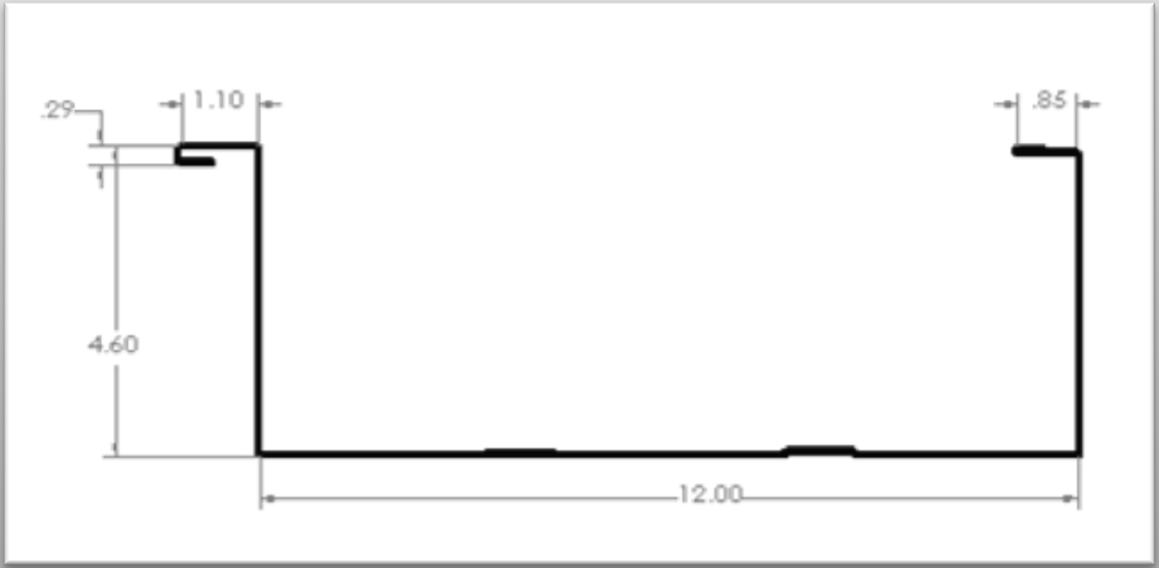
- Uplift forces are dependent on roof size and geometry according to FEMA P-361.
- The estimated total required anchoring force is the expected total uplift and shear force of 18,300 lbs.



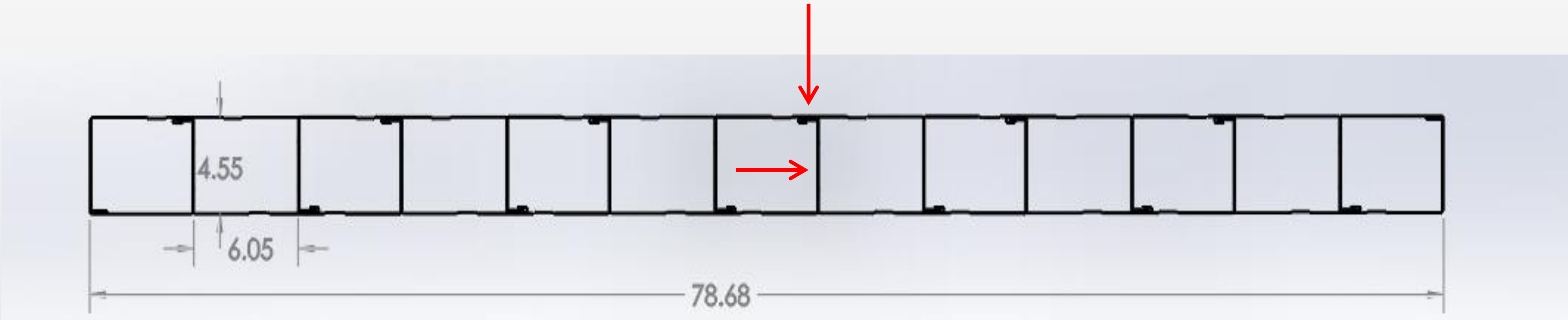
From FEMA P-361, figure 4-3
http://www.fema.gov/media-library-data/20130726-1508-20490-8283/fema_p_361.pdf

Overall Design

- Wall Panels
- Roof
- Ground Anchoring System
- Entryway
- Aggregate Material

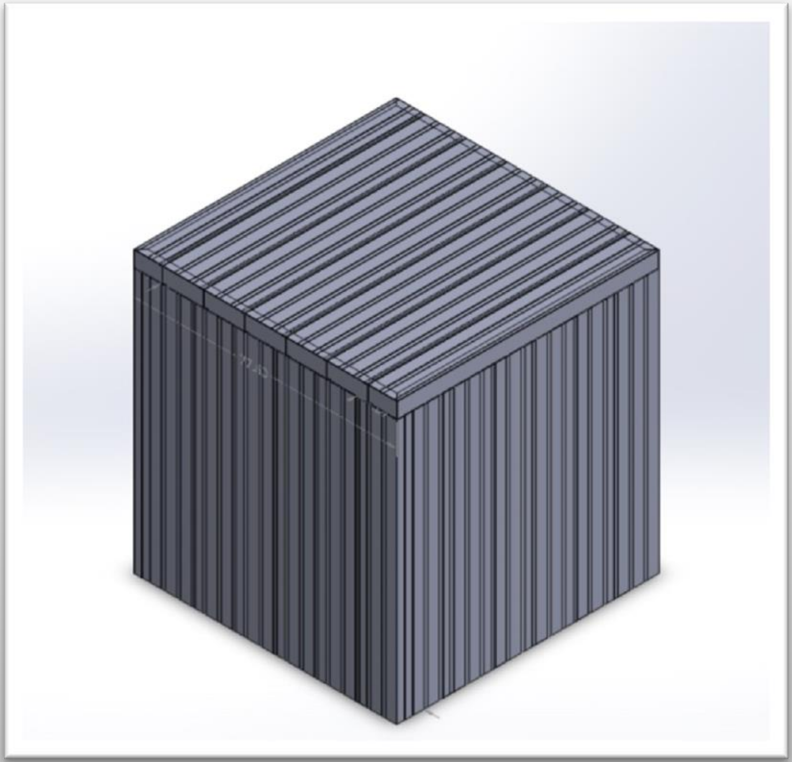


Wall Panels



- Interlinked face to face
- Connected at a 6 in. offset
- 6 and half ft. long
- Reinforced along ribbing and outside wall as shown above

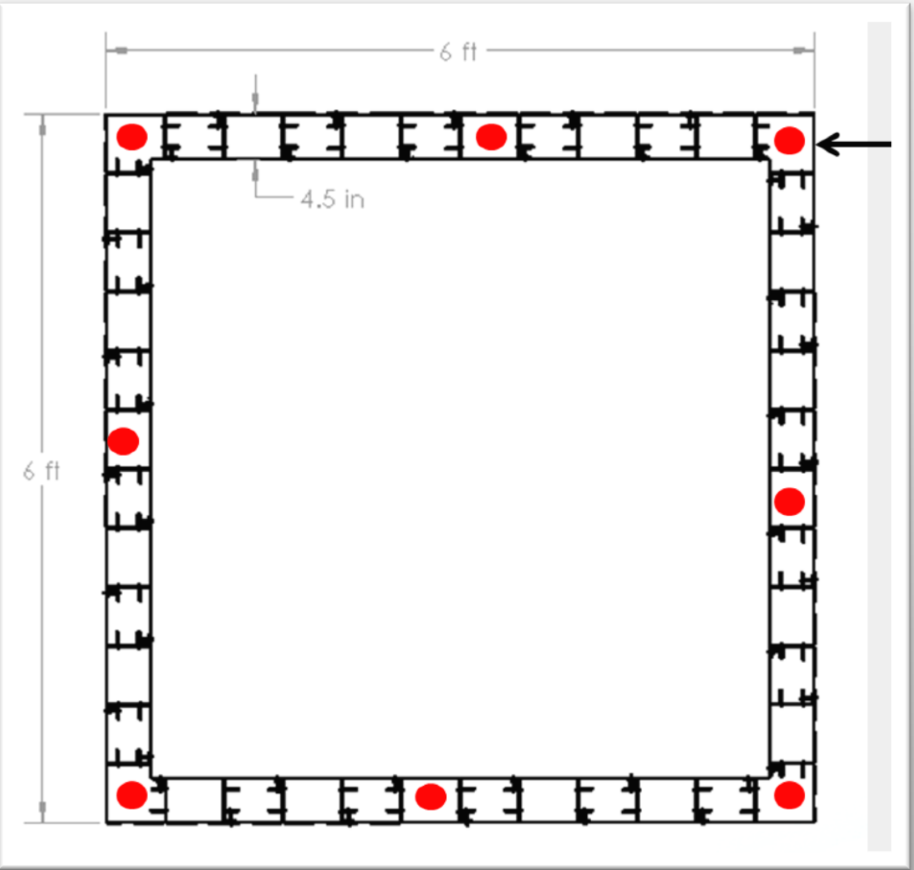
Roof



- Roof fits flush with width of walls
- Length varies with shelter geometry
- Same design strategy as walls
- Anchored with L-shaped brackets and through bolts

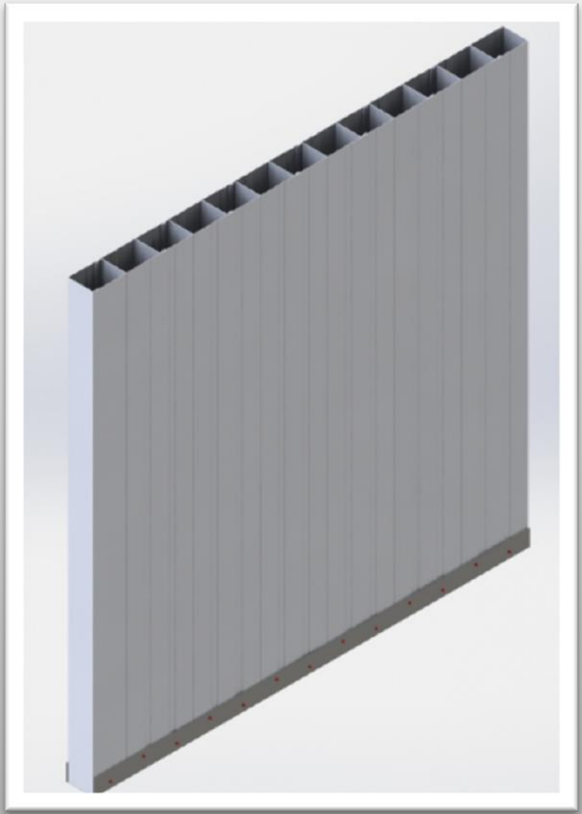
Ground Anchoring System

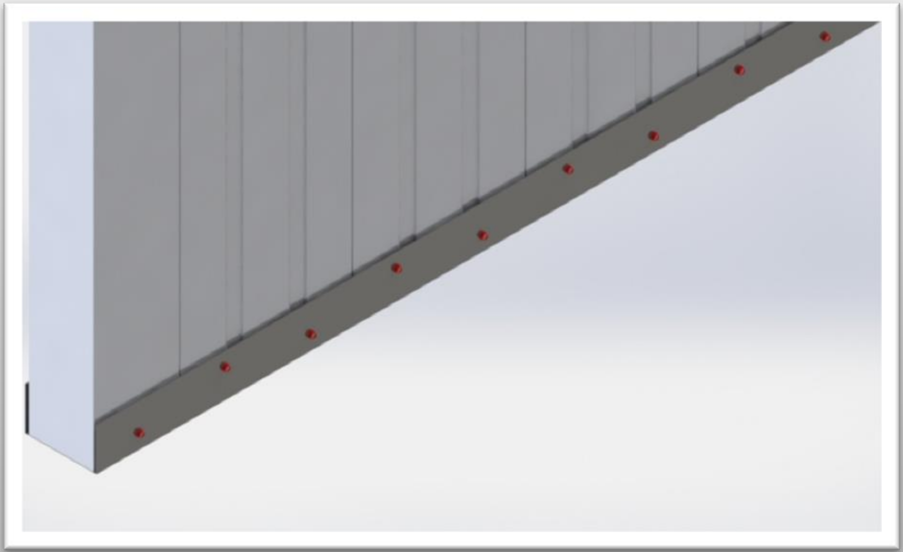
- Anchored with heavy C-shaped purlin channels, anchor bolts, and self-tapping screws
- Total of 8 anchor bolts will be used per shelter estimated with a safety factor of 2 and a force per bolt of 2287 lbs.



Screw Formation

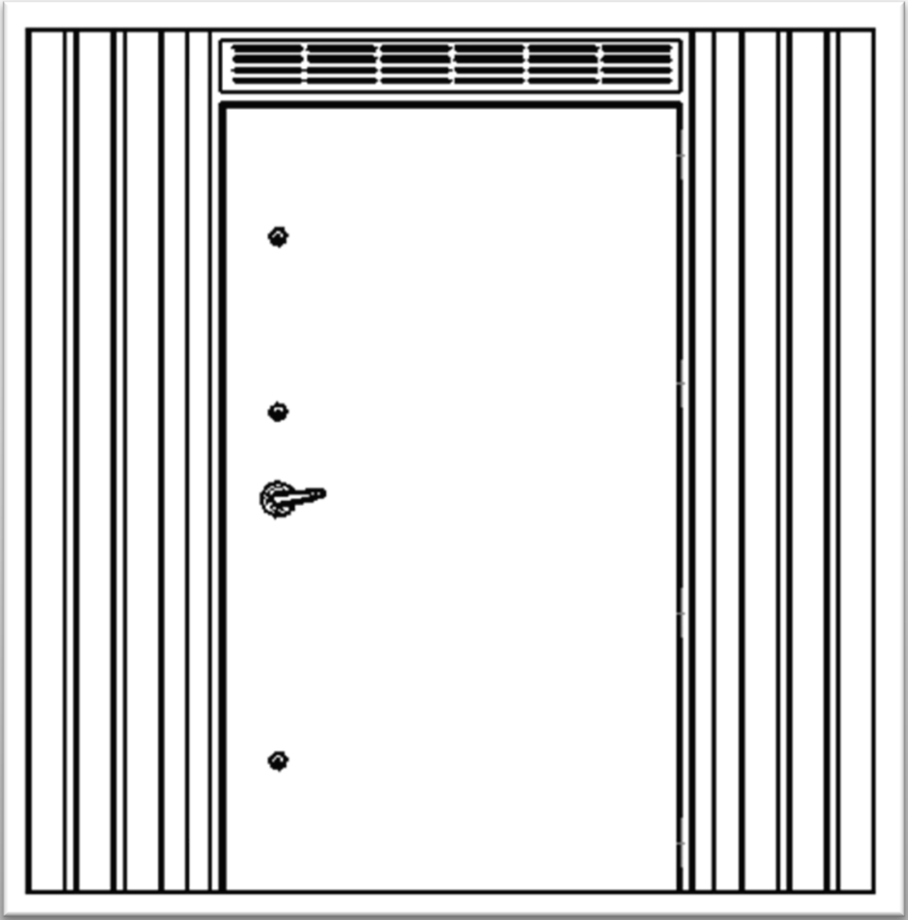
- A staggered offset screw formation will be used to connect the channels to the walls





Entryway

- Purchased FEMA certified door that opens inward from SecurAll
- Cost $1975.00, includes shipping
- Door passed the Door Pressure & Debris Impact Test at Texas Tech



Aggregate Material

- Most practical materials: high density foam, concrete, and sand
- Foam had high costs and concerns with expanding too fast causing the panels to bow out
- Concrete would render the panels obsolete, disregarding the mission statement
- Sand is the most cost effective, has simple installation and will absorb significant amount of energy on impact

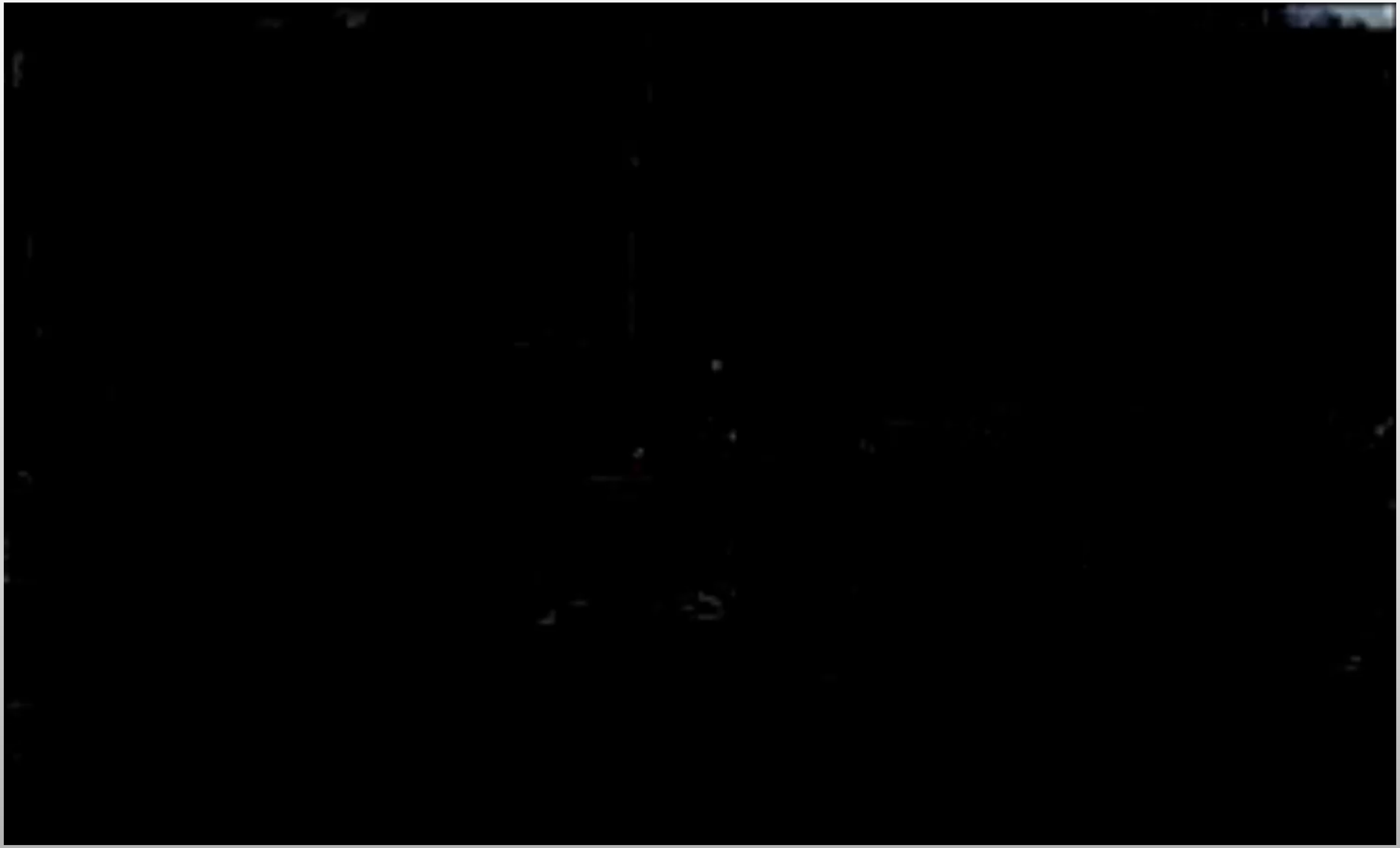
Testing

- Impact Test
  - Consists of the impact of a 15 lb. 2 x 4 traveling at 100 mph
  - Simulated by dropping a 2 x 4 modified with concrete from a set distance onto wall section
- Load test
  - Consists of a 3 second wind gust at 250 mph.
  - Simulated by loading the wall section with 5267 lb. for at least 3 seconds

Test Preparation

- Determined 167 lb. was needed to achieve same kinetic energy from FEMA certified air cannon
- Constructed modified 2 x 4 (missile) to be dropped
- Modified horse release for release mechanism

Testing Video



Test Results

- Impact Results

Impact Results				
Weight (lb.)	Initial Height (ft.)	Damage	Meets Standards	Reason
125	40	Tearing and deflection	No	Deflection > 3 in
160	32	Deflection	No	Deflection > 3 in

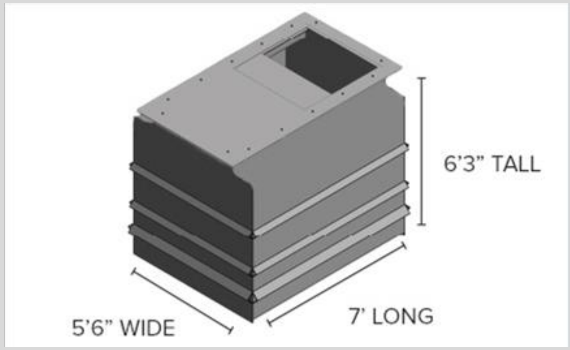
- Wind Load Results
  - Yielded slightly
  - No visible plastic deformation
  - Meets standards

Financial Analysis

	Cost w/ Shipping
FEMA Certified Storm Door	$1975.00
Cost of sheet metal	$259.20
Sand	$9.55
Connectors	Screws - 6 bags * $30.65 each = $183.90 Anchor Bolts - $5.27
Total Cost of Materials	$2432.92

Note: The selected door contributes to 81% of the material cost

Market Comparison

	Thunder Ground Storm Shelters	GFS Storm Shelters	Oklahoma Shelters
Size	5.5' x 7' x 6.25'	4' x 8' x 6.25'	6' x 6'
Cost	$5,500.00	$4,900.00	$4,100.00
Pictures			

Conclusions

- Potential and kinetic energy balance calculations were used to compare the drop test to an air cannon test

$$.5 * M * V^2 = M * G * H$$

	125 lb. Missile	160 lb. Missile
Velocity (ft/s)	50.75	45.4
Mass (lb_m)	3.88	4.97
Gravity (ft/s^2)	32.2	
Height (ft)	40	32

Conclusions

- The drop test transmitted approximately 3 times more impulsive energy when compared to the air cannon test

$$Impulsive\ energy = \ Mass * Change\ in\ Velocity$$

	125 lb. Missile	160 lb. Missile	2 x 4
Impulsive Energy (lb ft/s)	196.91	225.638	68.9349
Mass (lb_m)	3.88	4.97	0.47
Change in Velocity (ft/s)	50.75	45.4	146.67

- This means the drop test was more rigorous than the FEMA Standard impact test

Recommendations

- To prevent pull out:
  - 1/4 in. x 7/8 in. HWH TEK Lap Seam Screw with a Bond Seal Washer should be used in lieu of 12x3/4 TEK
  - Reduce connector spacing from 18 in. to 9 in.
  - Position screws within panels in a staggered offset formation

Recommendations

- Mechanically seam wall panels
- Use thicker steel (at least 15 gauge) for C-shaped purlin channel
- Increase number of anchor bolts from 8 to 12 where there are 2 bolts per corner and 1 in the middle of each wall. This increases the safety factor of the anchoring system to 3 rather than 2
- Future testing on roof and ground anchoring system

References

- "1/4 In. X 7/8 In. HWH TEK Lap Seam Screw W/ Bond Seal Washer (250)." *Best Materials*. N.p., n.d. Web. 17 Apr. 2014. <http://www.bestmaterials.com/detail.aspx?ID=16711>.
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- http://www.thundergroundss.com/ourshelters.aspx
- http://gfsstormshelters.com/product/large-above-ground-storm-shelter/
- http://oklahomashelters.com/Oklahoma_Shelters_-_Standar.html

Thank you

- Dr. Paul Weckler
- Dr. Dan Thomas
- Mr. Wayne Kiner
- Mr. Doss Briggs
- Mr. Win Adams
- Ms. Judy McCombs
- BRB Manufacturing Team
  - Mr. Trevor McGowan – crane operator
  - Mr. Tim Acker
  - Mr. Doug Harrison – forklift operator

Questions?

Storm Shelter Design with BRB Roofing

Reese Hundley

Sean Mallory

Heidi Stair

Katie Whitehurst

Abstract

BRB Roofing hopes to expand their products by taking their current materials and using them to manufacture above ground, in home storm shelters. The storm shelter design team was tasked by BRB Roofing with designing, building, and testing a safe, cost effective, and quickly manufactured storm shelter. The storm shelter must follow Federal Emergency Management Agency Standards. In order to take materials used for roofing purposes and utilize them to manufacture an effective storm shelter, the panels must be assembled in such a way that allows for aggregate materials to be used to provide additional strength. The door to the shelter will not be manufactured by the company, but will be purchased from an outside source. The storm shelter design team will have a completed design by December 13th, 2013 and a completed prototype by May 9th 2013.

Background

Company Overview

BRB Roofing is located in Muskogee, Oklahoma. They specialize in converting flat roofs to sloped roofs. The company has a unique panel design for their roofs called standing seam roofing. This design allows the roofs to be free of exposed bolts, making the roofs leak proof. The corrugated panel design also allows for the panels to be a constant cross section with any length desired. Although BRB Roofing specializes in roofs, the recent devastating tornados have spiked an interest in expanding their product line. Since the company already manufactures the materials that could be used for a storm shelter, BRB Roofing hopes to become a player in this industry.

Objectives

Problem Statement

The storm shelter design team was tasked with designing an above ground storm shelter that uses the Weatherboss 412 panel already available from BRB Roofing.

Mission Statement

The team plans to develop a storm shelter design that implements metal roof materials to make a safe, cost effective, and quickly manufactured above ground storm shelter for BRB Roofing to implement into their business.

Constraints

The shelter must use the metal roofing materials provided by BRB Roofing. The panels used in the design must be the current panel dimensions of the Weatherboss 412 panel as seen in figure 1. The panel thickness will be 18 gauge with a yield stress of either 40 ksi or 50 ksi. The shelter must be small enough to fit inside of a small room in a house or garage with a previously established concrete foundation. The shelter must meet FEMA (Federal Emergency Management Agency) Test Standards. The FEMA Test Standards state that our structure must be able to withstand a wind pressure of 250 miles per hour gust for three seconds. Our structure must also be able to withstand an impact by a plank of wood with dimensions 2'' x 4'' x 6', weighing 15 pounds, traveling over 100 miles per hour horizontally, and 67 miles per hour vertically. After the devastating tornados in recent history the storm shelter is designed to withstand a wind speed of 300 miles per hour. Due to pressure changes in the event of a tornado, a vent must be placed in the shelter. The vent will allow for sudden pressure changes to equalize in the shelter to prevent the shelter from exploding or imploding.

Proposed Methodology

Design

The Weatherboss 412 flat panel provided by BRB Roofing can be seen in the following figure:

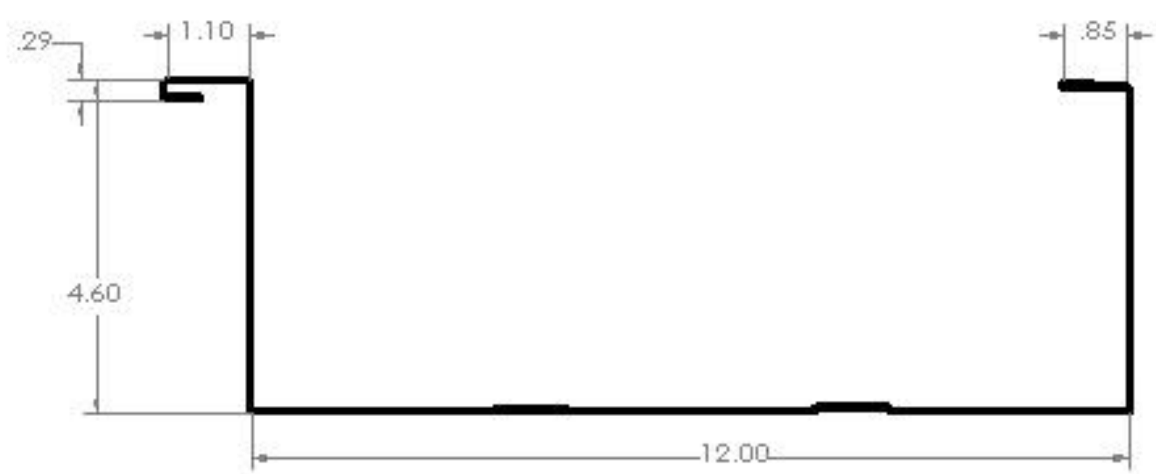


Figure 1: Flat Panel Cross Section

In order to create walls out of panels that were originally designed for roofing, two panels must be interlinked face to face. This will cause the two panels to connect at the edges and leave a void between them. This void will be filled with an aggregate material to reduce bending caused by wind or oncoming debris.

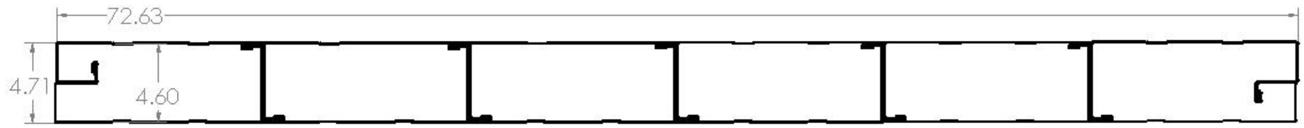


Figure 2: Panel Assembly

The wall panels will be six and a half feet long by the dimensions shown in figure 1. The right side of each panel will slide into the "hook" on the left side of the panel. Six panels will be crimped together side by side to make a wall six feet wide as seen in figure 2. The inner walls of the panels will need to be bolted together with Hex head .5 inch structural bolts. The roof of the structure will be constructed with the same design strategy as the walls and laid over top of the structure. The roof panels will be six feet long. In order for the roof to fit flush with the width of the walls, the panels used for the ends of each wall must be adjusted to the dimensions seen in figures 3 and 4. This design requires a total of 4 panel assemblies as seen in figure 2. The roof with be anchored to the concrete slab of the home. Since the ends of the panel assemblies will be exposed, caps will be needed to be placed on the ends in order to prevent particulates from entering the panel assembly. This will require a total of 14 caps.

Figure 3: End Panel 1 Cross Section

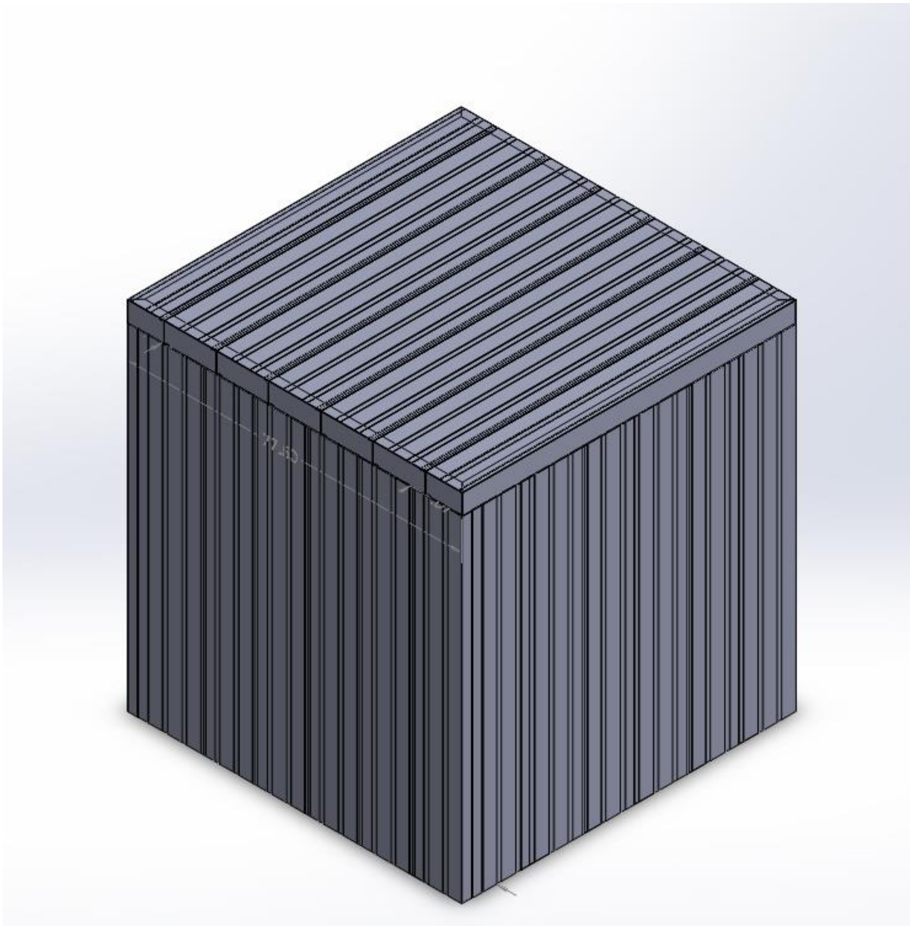


Figure 5: Storm Shelter Walls and Roof Assembly

The door/wall assembly will be required to complete the structure, see figure 6 and Preliminary Door Design, Appendix D. The entry way of the shelter will be a purchased FEMA certified door that opens inward. The vent that is needed to reduce pressure forces can be seen in figure 7. The calculations for this vent can be seen in Appendix B.

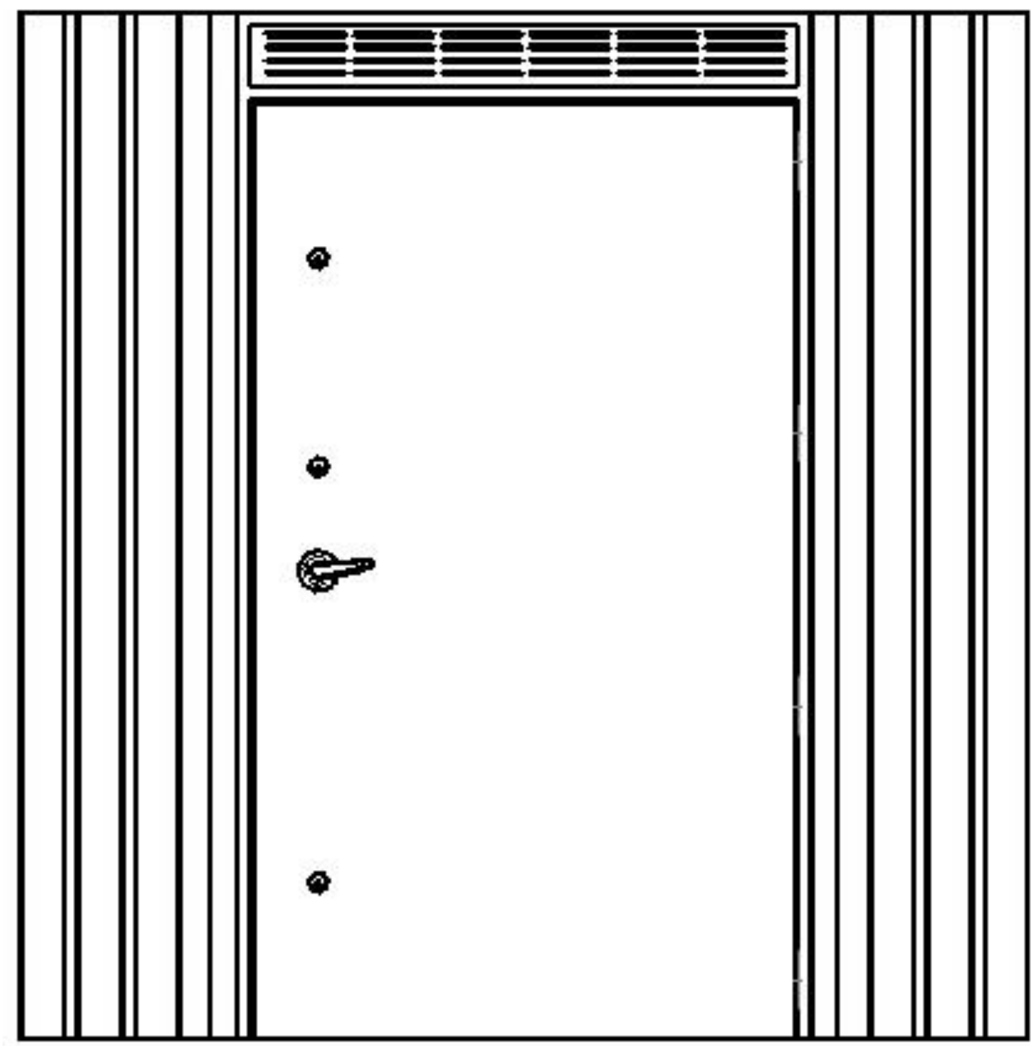


Figure 6: Door/Wall Assembly

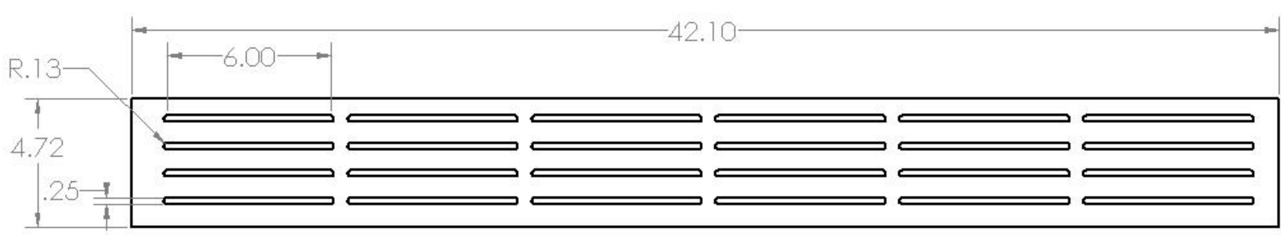


Figure 7: Vent

Aggregate Material

The aggregate materials that are most practical in this application are high density foam, concrete, sand, or gravel. After much research, it was concluded that foam is a promising choice because it has high yield strength and it adheres well to metal to help create a composite structure between the panel and foam. GRA Services International Secure Set 6 is high density polyurethane water blown foam that can be designed to be pumped, sprayed, or poured. Unfortunately, the foam is expensive when compared to sand, gravel, or concrete. Please refer to budget section for pricing. The cost of sand, gravel and concrete may be cheaper but the use of these materials will require ribbing to be welded on the insides of the panels for the panel-aggregate structure to act as a composite. This ribbing will most likely require welding on each panel increasing the cost of manufacturing, therefore, increasing the cost of the shelter as a whole.

Design Alternatives

The two main designs will be dependent on the type of aggregate we use on the insides of the panels. The foam design will be consistent with the current drawings. If concrete, sand, or gravel is used, ribbing will need to be added to the panels. A testing procedure will take place at the beginning of next semester to observe how each of the aggregate materials adds to the strength of the structure. Each material will fill a wall section. The wall section will then be loaded and observed in order to more accurately understand the wall strength.

Patent Search

The patent search resulted in no concepts similar to this design.

Supporting Information

Some of the technical information needed was found in 5 Load Determination and Structural Design Criteria provided by FEMA. (http://www.rhinovault.com/361_ch05.pdf)The ASCE design standards define how to calculate wind loads on the structure for a designed wind speed of 300 miles per hour. Wind load equation is based on the velocity pressure equation 6-13 from ASCE 7-98. The Oklahoma Cooperative Extension Service BAE-1010 provided some information for selecting tornado shelters as well as the equation to size our vent. (http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-2179/BAE-1010web.pdf)

Budget

Please see Appendix C for detail of budget calculations. The total estimated cost of the storm shelter using foam is $4087.66. The total estimated cost of the storm shelter using sand is $3117.21. The total estimated cost of the storm shelter using gravel is $3129.27. The total estimated cost for the storm shelter using concrete is 3157.66 if it costs about $50.00 for concrete. The estimated cost for the sand, the gravel, and the concrete doesn't account for the cost of welding ribbing on the inside of each panel that will be required for the panels and aggregate to act as a composite structure.

Time Line for Completion

Gantt Chart

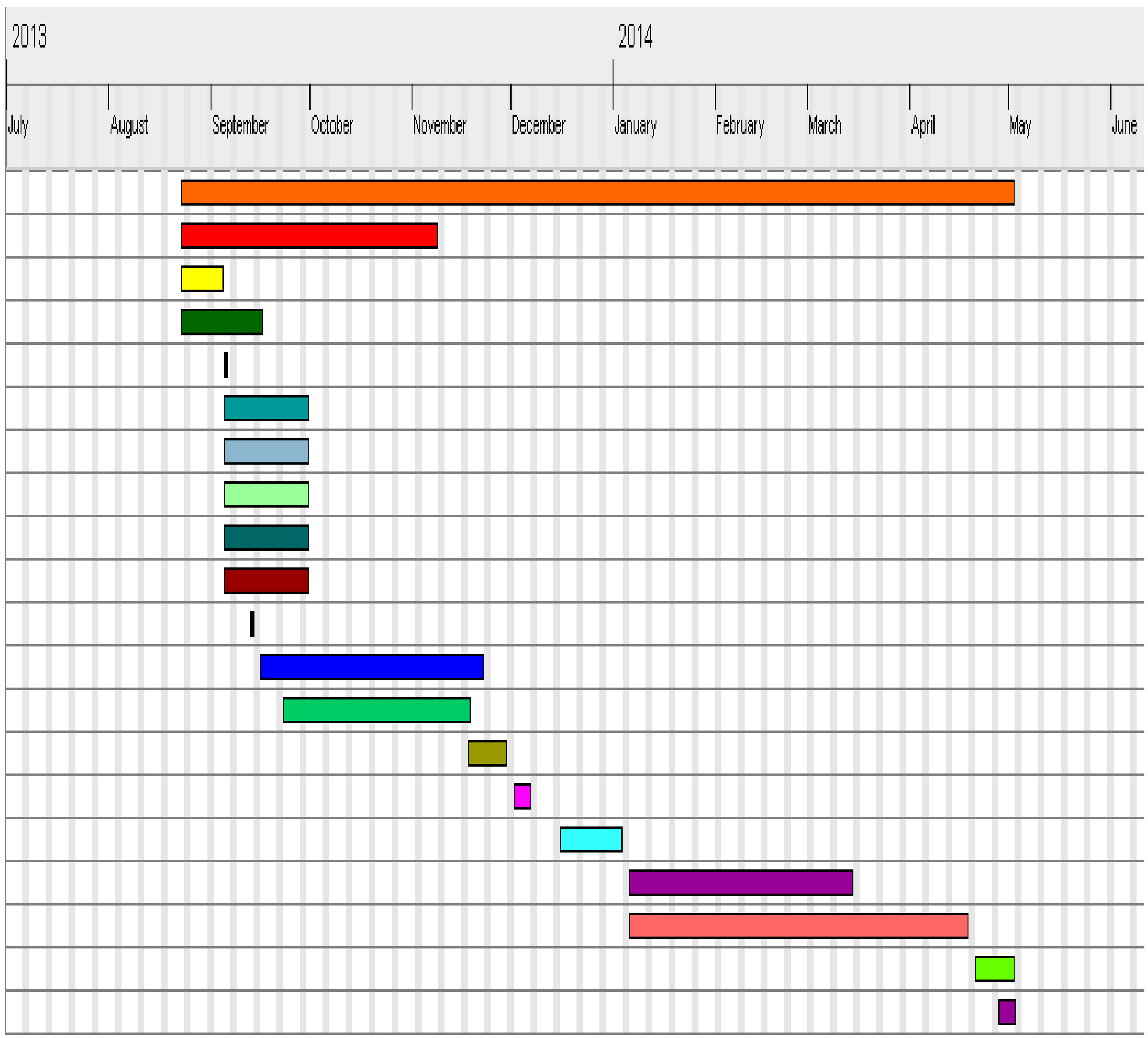
The storm shelter design team developed a Gantt chart to assist in keeping on track with a specific schedule. The Gantt chart is provided in the Appendix.

Appendix

A. Schedule

GANTT project

Name	Begin date	End date
Time Frame	8/23/13	5/2/14
Design	8/23/13	11/8/13
Arrange to meet with BRB	8/23/13	9/4/13
Determine statement of work	8/23/13	9/16/13
Meet with Doss Briggs @ BRB	9/5/13	9/5/13
Research possible Designs for Hatch/Door	9/5/13	9/30/13
Research Properties of Foams, Sand, and Rock	9/5/13	9/30/13
Research Sealents	9/5/13	9/30/13
Research Anchoring Systems	9/5/13	9/30/13
Copy_Research possible Designs for Hatch/Do...	9/5/13	9/30/13
Meet with Win Adams @ OSU	9/13/13	9/13/13
Create a SoldWorks Design	9/16/13	11/22/13
Supervise Freshman Projects	9/23/13	11/18/13
Meet with Doss and Win	11/18/13	11/29/13
Presentations - Dead Week	12/2/13	12/6/13
Christmas Break	12/16/13	1/3/14
Build Prototype	1/6/14	3/14/14
Testing	1/6/14	4/18/14
Meet with Doss and Win for final Design	4/21/14	5/2/14
Presentations - Finals Week	4/28/14	5/2/14


2013
2014
July
August
September
October
November
December
January
February
March
April
May
June

B. Calculations

Venting

Inside Volume ($\forall$)

$6\,ft \cdot 5.3\,ft \cdot 5.3\,ft \Rightarrow \forall = 64\,ft^3$

Vent Equation

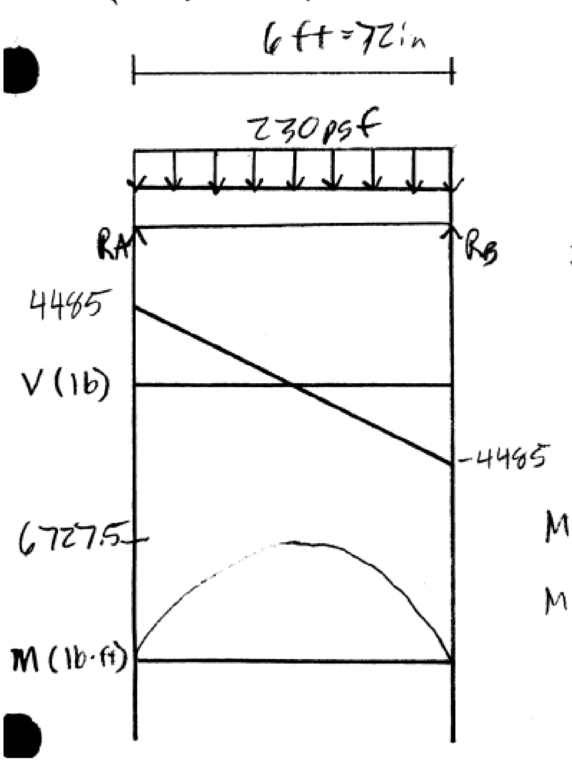
$0.001 \times \forall\,(ft^3) = \text{Area of vent}\,(ft^2$

$0.001 \times 64\,ft^3 = 0.064\,ft^2$

$\text{Area vent} \geq 9.2\,in^2$

Wall Section Shear and Moment Wind Load

Wall section shear and Moment due to 300 mph wind
(Simple Span)



$P(psf) = [V(mph)]^2\,(0.00256)$

$= (300\,mph)^2\,(0.00256)$

$P = 230\,psf$ ⇐ simplified pressure eqn from ASCE Standards.

$F = PA = 230\,lb/ft^2\,(6ft \cdot 6.5ft)$

$F = 8970\,lb$

$\circlearrowleft\!+ \;\Sigma M_B = 0 = 8970\,(3ft) - R_A\,(6ft)$

$R_A = 4485\,lb$

$+\!\uparrow \Sigma F_y = 0 = 4485 - 8970 + R_B$

$R_B = 4485\,lb$

$M_{max} = \tfrac{1}{2}(3ft)(4485\,lb)$

$M_{max} = 6727.5\,lb \cdot ft$

Corner Connections (Bolt Shear Strength)

Corner Connections

$V_{connector} =$ lb

$V_{internal} = 4485$ lb

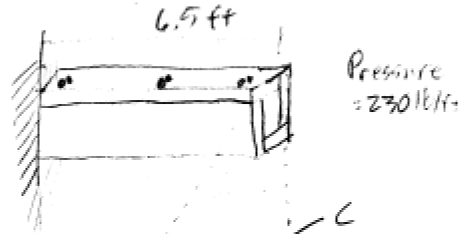
Section Properties

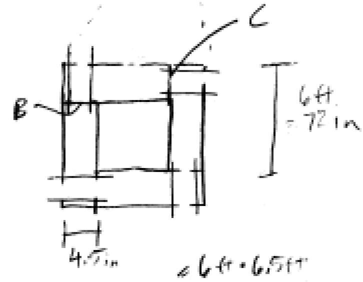
$$I = \frac{(76.5)(76.5)^3}{12} - \frac{(67.5)(67.5)^3}{12}$$

$$I = 1.12412 \times 10^6 \text{ in}^4$$

$$Q_B = \bar{y}'A' = (36 \text{ in})(76.5)(4.5) = 12393 \text{ in}^3$$

$$Q_C = \bar{y}'A' = (36 \text{ in})(67.5)(4.5) = 10935 \text{ in}^3$$

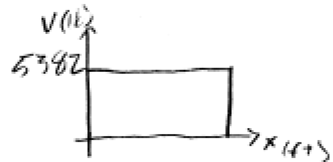




$A = 39$ ft² $= 6 \text{ ft} \cdot 6.5 \text{ ft}$

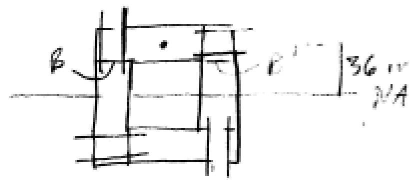
$P = 4485$ lb

Shear Flow



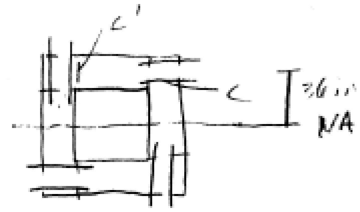
$$q_B = \frac{V Q_B}{I} = \frac{4485 \text{ lb}(12393 \text{ in}^3)}{1.12412 \times 10^6 \text{ in}^4}$$

$q_B = 49.4$ lb/in



$$q_C = \frac{V Q_C}{I} = \frac{4485 \text{ lb}(10935 \text{ in}^3)}{1.12412 \times 10^6 \text{ in}^4}$$

$q_C = 43.6$ lb/in



q_B and q_C represent shear force/unit length, that must be resisted by connector B and fibers B' and connectors at C and the fibers at C'

$$s_B, s_C = 2\frac{V_{connector}}{\text{Shear Flow}}$$

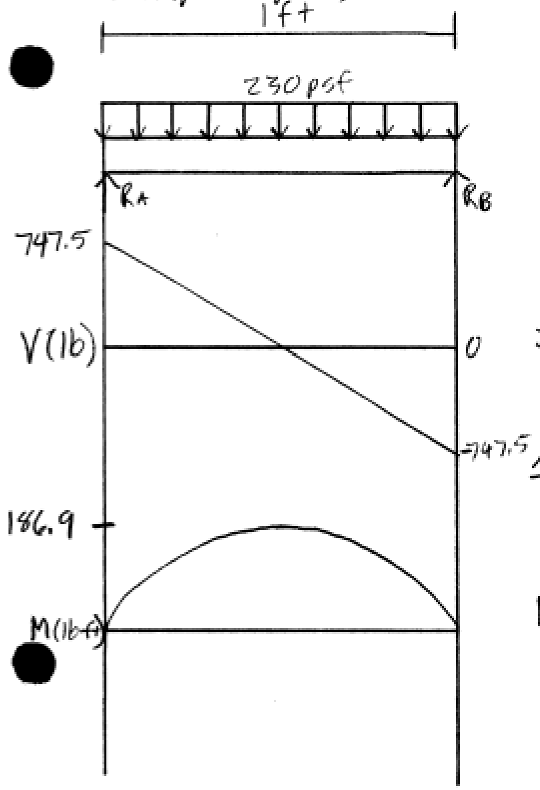
if $s = 1.6$ ft $= 39.2$ in

$V_B = 474.24$ lb

$V_C = 418.56$ lb

Panel Shear and Moment Wind Load

Panel Shear and Moment due to 300 mph Wind
(Simple span)



$$P\,(psf) = [V\,(mph)]^2(0.00256)$$

$$= (300\,mph)^2(0.00256)$$

$$P = 230\ psf$$

$$F = PA = 230\,psf\,(1ft \cdot 6.5ft)$$

$$F = 1495\ lb$$

$$\circlearrowleft+\ \Sigma M_B = 0 = 1495(0.5) - R_A(1)$$

$$R_A = 747.5\ lb$$

$$\uparrow+\ \Sigma F_y = 0 = 747.5 - 1495 + R_B$$

$$R_B = 747.5\ lb$$

$$M_{max} = 1/2(0.5)(747.5)$$

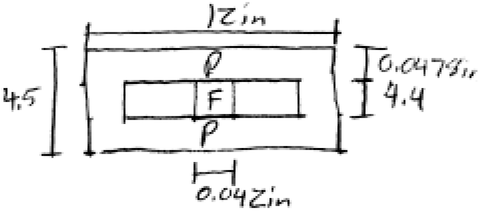
$$M_{max} = 186.875\ lb \cdot ft$$

Foam – Sheet Metal Composite Maximum Bending Moment

Composite Panel (Foam – sheet metal)

Panel ⇒ σ_p = 40ksi   18 gauge panel = 0.0478 in

- Foam ⇒ $\sigma_{max} = -140\,psi$
  $\sigma_{max} = +180\,psi$



$$n = \frac{E_P}{E_F} = \frac{40000}{140} = 285.7$$

$$\text{Foam width} = \frac{12in}{285.7} = 0.042\ in$$

$$I = \frac{(12)(4.5)^3}{12} - \frac{(12-0.042-2(0.0478))\,4.4^3}{12} = I = 6.91778\,in^4$$

$$c = \frac{4.5}{2} = 2.25$$

Allowed sheet metal bending

- $\sigma_S = \frac{Mc}{I} \Rightarrow 40\,000\,psi = \frac{M(2.25in)}{6.91778\,in^4} \Rightarrow (M_{max})_S = 122983\,lb\cdot in$

  $(M_{max})_S = 10249\,lb\cdot ft$

Allowed foam bending

$$\sigma_F = \frac{Mcn}{I} \Rightarrow 140psi = \frac{M(2.2in)(285.7)}{6.91778\,in^4} \Rightarrow (M_{max})_F = 1.54\ lb\cdot in$$

$(M_{max})_F = 0.128\ lb\cdot ft$

Total Bending Moment Allowed

$M_{max} = 10249\ lb\cdot ft > 187\ lb\cdot ft$ max wind moment

✓

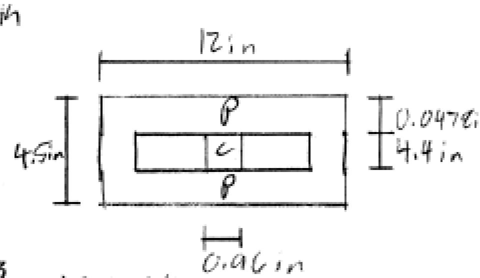
Concrete – Sheet Metal Composite Maximum Bending Moment

Composite Panel (Concrete – sheet Metal)

Panel ⇒ $E_p = 40 ksi$ 18 gauge Panel ⇒ $t = 0.0478 in$

Concrete ⇒ $E_c = 3.2 ksi$ ⇐ Low strength

$4.2 ksi$ ⇐ high strength



$$n = \frac{E_p}{E_c} = \frac{40}{3.2} = 12.5$$

$$\text{Concrete width} = \frac{12in}{12.5} = 0.96in$$

$$I = \frac{(12)(4.5)^3}{12} - \frac{(12 - 0.96 - 0.0478(2))(4.4)^3}{12} = 13.4344$$

$$c = \frac{4.5}{2} = 2.25in$$

Allowed sheet metal bending

$$\sigma_p = \frac{Mc}{I} \Rightarrow 40000 psi = \frac{M(2.25in)}{13.4344in^4} \Rightarrow (M_{max})_p = 238833 \text{ lb}\cdot\text{in}$$

$$= 19902 \text{ lb}\cdot\text{ft}$$

Allowed concrete bending

$$\sigma_c = \frac{Mc}{I} n \Rightarrow 3{,}200 psi = \frac{M(2.2in)(12.5)}{12.7557in^4} \Rightarrow (M_{max})_c \ 1563.27 \text{ lb}\cdot\text{in}$$

$$= 130 \text{ lb}\cdot\text{ft}$$

Total allowed bending moment

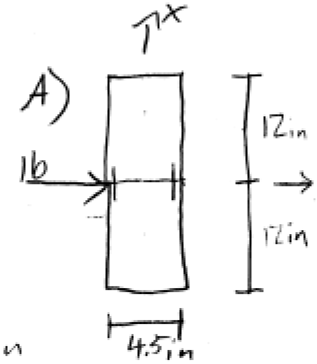
$M_{max} = 20{,}033$ lb·ft

Panel Connection (Sizing Required Bolt Shear Strength)

Panel connection strength

$V_{connector} =$ lb

$V_{internal} = 747.5 \text{ lb}$



Section properties

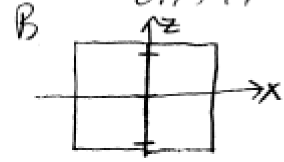
$\bar{y}_A = \dfrac{18(12 \cdot 4.5) + 6(12 \cdot 4.5)}{12 \cdot 4.5 + 12 \cdot 4.5}$

$\bar{y}_A = 12 \text{ in}$

* $I_z = \dfrac{(6.5in)(24in)^3}{12} = 7488 \text{ in}^4$

$\bar{y}_z = 3.25 \text{ ft}$ $A = 108 \text{ in}^2 = 0.75 \text{ ft}^2$

$I_x = \dfrac{24(4.5)^3}{12} = 182.25 \text{ in}^4$



$Q_A = \bar{y}_A' A' = (12in)(12in)(4.5in) = 648 \text{ in}^3$

$Q_B = \bar{y}_z' A' = (39in)(39in)(24in) = 1872 \text{ in}^3$

Shear flow

$q_A = \dfrac{VQ}{I} = \dfrac{747.5 \text{ lb}(648 \text{ in}^3)}{182.25 \text{ in}^4} = 2657.78 \text{ lb/in} = q_A$

$q_z = 186.875 \text{ lb/in}$

Spacing of Double connectors

$s_z = \dfrac{2(V_{connector})}{\text{shear flow}} = \dfrac{2(V_{connector})}{186.875 \text{ lb/in}}$

$s_A = \dfrac{2(V_{connector})}{2657.78 \text{ lb/in}}$

if spacing @ every 1.6 ft

$V_{connector} = 25514.7 \text{ lb}$

$= 26 \text{ kips}$

C. Budget Calculations

Density of Crusher Run = $95\ lb/ft^3$

Gravel 1½" Crusher Run - $\$7.00/Ton \rightarrow \$5.50/Ton$ for Delivery

#9 gravel - $\$9.75/Ton \rightarrow \$5.50/Ton$ for Delivery

Density of #9 gravel = $100\ lb/ft^3$

Crusher Run

$$\frac{65\ ft^3}{} \cdot \frac{95\ lb}{ft^3} \cdot \frac{1\ ton}{2000\ lb} = 3.09\ tons$$

$$\frac{3.09\ tons}{} \cdot \frac{\$7.00}{ton} = \boxed{\$21.61}\ \text{w/o Delivery} \qquad \frac{3.09\ tons}{} \cdot \frac{\$12.50}{ton} = \boxed{\$38.63}\ \text{w/ Delivery}$$

#9 gravel

$$\frac{65\ ft^3}{} \cdot \frac{100\ lb}{ft^3} \cdot \frac{1\ ton}{2000\ lb} = 3.25\ ton$$

$$\frac{3.25\ tons}{} \cdot \frac{\$9.75}{ton} = \boxed{\$31.69}\ \text{w/o Delivery} \qquad \frac{3.25\ ton}{} \cdot \frac{\$15.25}{ton} = \boxed{\$49.56}$$

Sheet Metal Costs

$\approx 80¢/lb.$ $3\ lb/\text{Linear ft}$ of Material @ 6½' height of Shelter

2 Linear ft / Pannel

$$\frac{54\ pannels}{} \cdot \frac{2\ \text{Linear ft}}{pannel} \cdot \frac{3\ lb}{\text{Linear ft}} \cdot \frac{\$0.80}{lb} = \boxed{\$259.20}$$

Storm Door

12 gauge door / 3 dead bolts / Grade 1 hardware

13 anchors / 4 hinges /

1660 - Built — Just below \$2000 w/shipping

315 - Shipped

Costs

Door	\$2000		\$2000		\$2000
Metal	\$259.20		\$259.20		\$259.20
Foam	\$980	Sand	\$9.55	Gravel	\$21.61
Fasteners	\$848.46		\$848.46		\$848.46
	\$4087.66		**\$3117.21**		**\$3129.27**

Filler Options for $\underline{65 ft^3}$

Foam GRA Services International
5000 E. 2nd Street Edmond, OK
(405) 330-2395

Secure Set #6 = \$1100

$$\frac{65\ ft^3 \mid 7.48\ gal}{\mid 1\ ft^3} = 486.20 \text{ gal of expanded Foam}$$

$$\frac{486.20\ gal \mid 1 \text{ gal of foam mix}}{\mid 14 \text{ gal of Expanded Foam}} = 34.73 \text{ gal of Foam Mix}$$

35 gal need @ \$28 per gallon
$\boxed{\$980}$

Sand & Gravel Sand By the Ton
Arkhola Sand & Gravel Co.
3300 W. 40th Street N. Muskogee, Ok
(918) 682-2160 (918) 687-4771

By the Bag Sakrete - 70 lb tube Sand Density of sand = 100 lb/ft³
\$4.58/70 lb bag

$$\frac{65 ft^3 \mid 100 lb}{\mid ft^3} = \frac{6500\ lb \mid \$4.58}{\mid 70\ lb} = \boxed{\$425.29}$$

By the Ton Fill Sand - \$2.94/Ton / Concrete Sand - \$3.78/Ton
Delivery - \$167 for 17.4 tons / Delivery - \$180 for 17.4 tons

Fill Costs → $\frac{6500 lb \mid 1\ ton \mid \$2.94}{\mid 2000\ lb \mid 1\ ton} = \boxed{\$9.55}$

Concrete Sand Cost → $\frac{6500\ lb \mid 1\ ton \mid \$3.78}{\mid 2000\ lb \mid Ton} = \boxed{\$12.29}$

Connectors

Grade 9 Bolts

1"

192 Pannel fasteners

Washer -$113.95

Bolt - $278.40

Nut -$126.24

5"

32 Wall fasteners

Washers -$18.99

Bolts -$144.24

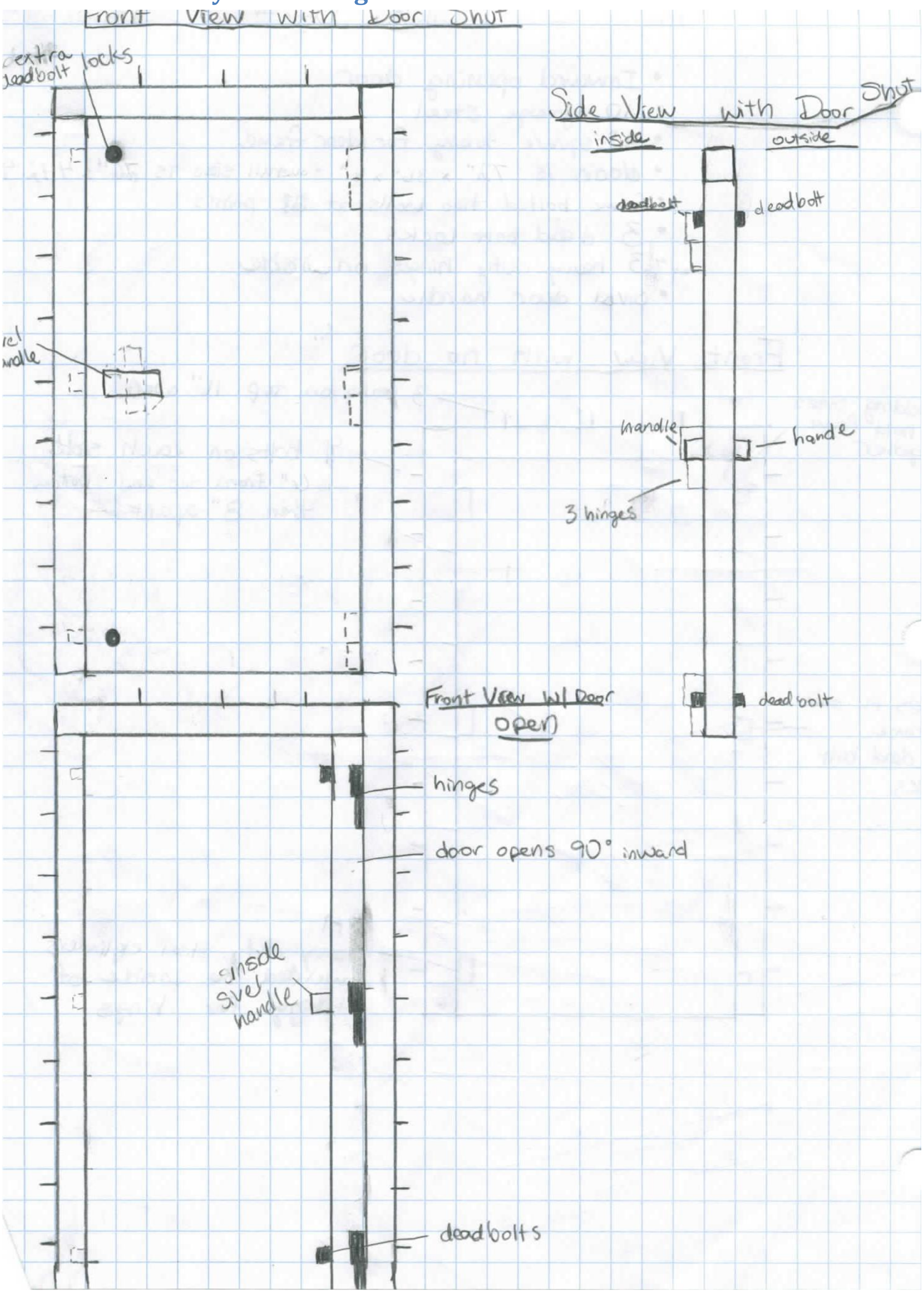
Nuts -$31.04

$822.86

Expanding Bolt -$25.60

$848.46

D. Preliminary Door Design



STORM SHELTER

SENIOR DESIGN TEAM

Reese Hundley
Katie Whitehurst
Heidi Stair
Sean Mallory

What to expect

- Background
- FEMA Standards
- Design and ASCE Standards
- What's Next?
- Questions

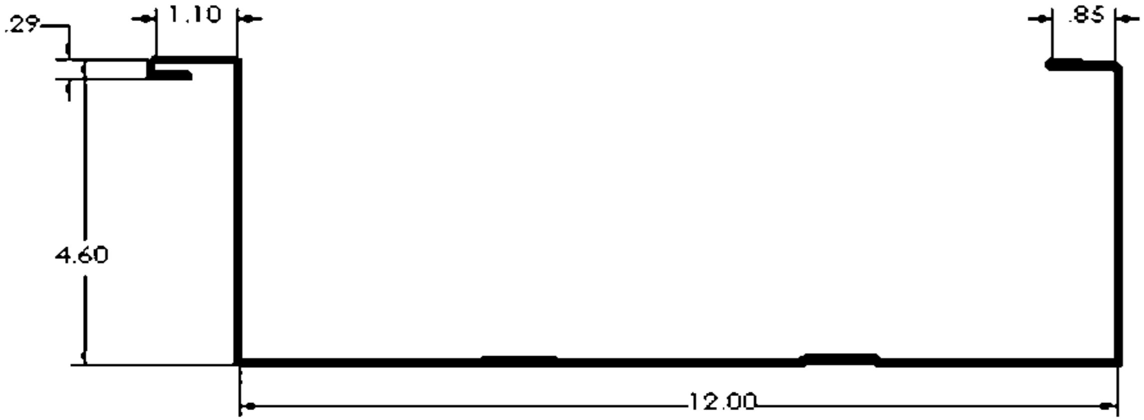
Mission Statement

We plan to develop a storm shelter design that implements metal roof materials to make a safe, cost effective, and quickly manufactured above ground storm shelter for BRB Roofing to integrate into their business.

BRB Roofing - Muskogee, Ok

- Specialize in converting flat roofs into sloped metal roofs
- Roofing panels shaped in a way that doesn’t require connectors
- Contact: Doss Briggs

ROOFING AND MANUFACTURING



http://www.brbroofing.com/products/weatherboss-reg-216-panels/weatherboss-412-panels/

Background

- Recent devastating tornados have caused a spike in demand for storm shelters
- How can we make a cost effective tornado shelter out of roofing materials currently available?

Initial Parameters

- Both above and below ground storm shelter designs
- Below ground arch shaped
- Above ground box shaped shelter
- All designs must meet FEMA Test Standards
- All designs must use the current panel dimensions used for roofing

Design Standards

- FEMA Test Standards

- Must be able to withstand an
  impact of a 6 foot long 2 x 4,
  weighing 15 lbs. traveling 100 miles per hour
  horizontally, and 67 miles per hour vertically

- Must withstand a three second gust of wind at
  250 mile per hour

Below Ground Storm Shelter

- Arch shaped with targeted dimensions of
  8 to 10 feet tall by 10 to 12 feet wide

- Similar design concept to traditional root cellars

- Drainage system without the use of pumps

- How might the soil moisture effect
  the material life of the sheet metal?

Challenges With Below Ground Shelter

- Panels would not allow bending to fall within reasonable targeted dimensions

- Acidic Oklahoma soils on thin metal leads us to concerns with the structural integrity of the arch degrading in a short period of time

Below Ground Storm Shelter

Due to the bend radius of the metal, we are unable to consider the underground shelter design

Above Ground Shelter

- Use BRB's C-shaped panels to create a composite structure with a aggregate material within the panels to limit bending

- Consider aggregate materials: sand, gravel, foam, and concrete
- Design to fit it into a closet or covered garage with a previously established concrete foundation

Patents

- We did not find any patents that were relevant to our project.

Design Pressures

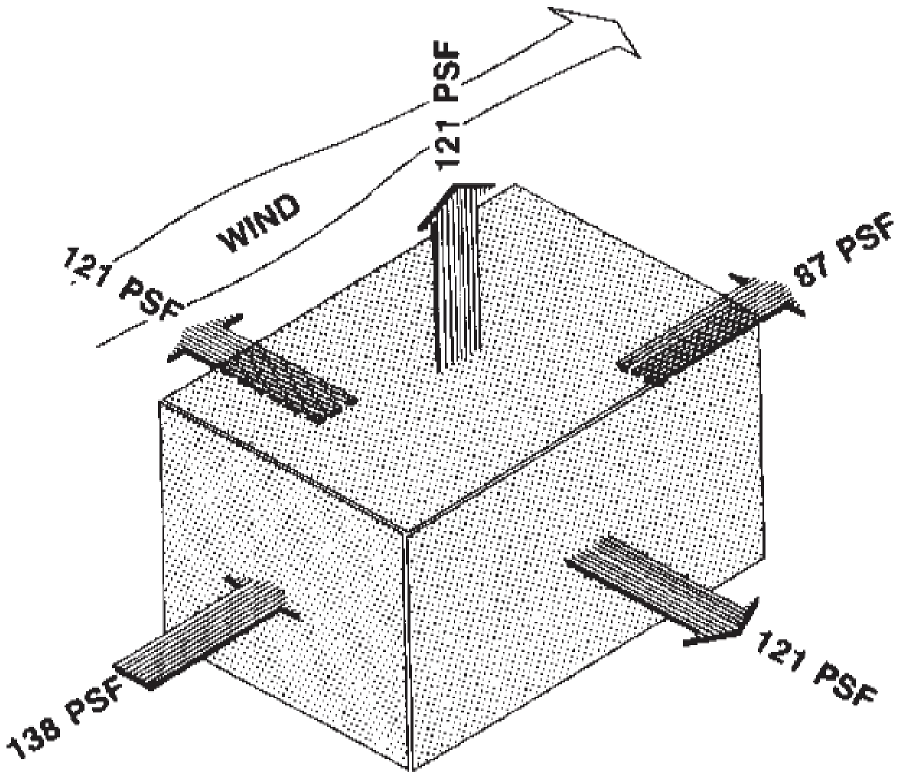


Figure 1. Pressure forces created by 240 mph wind.

http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-2179/BAE-1010web.pdf

Pressure Forces

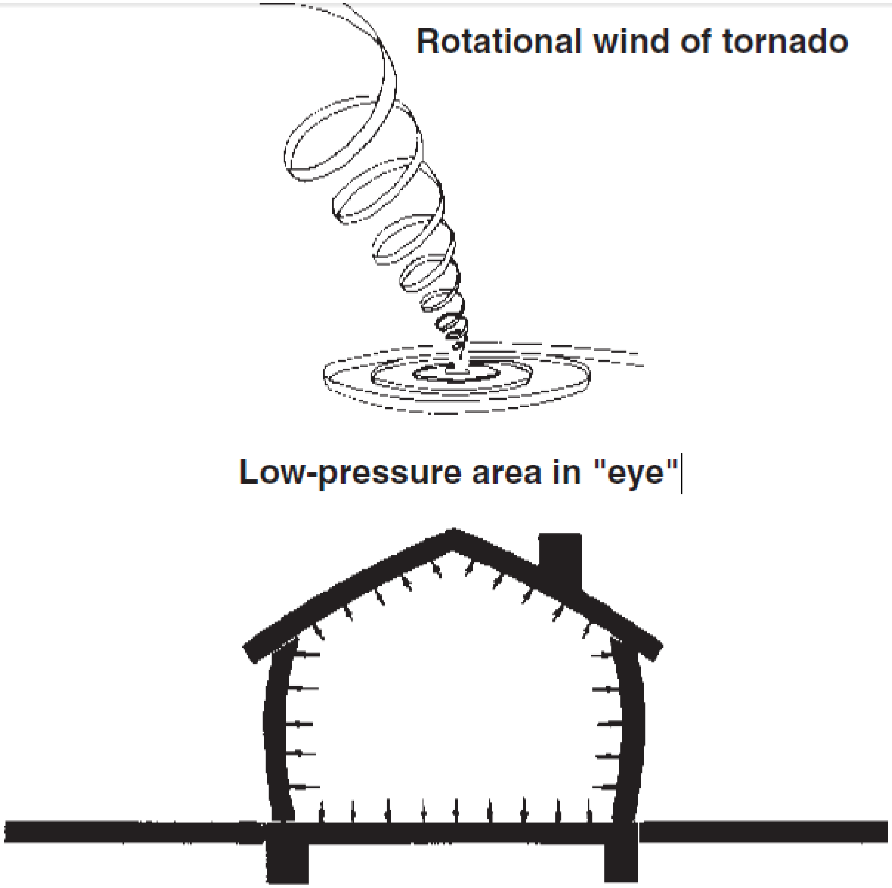


Figure 2. Pressure forces created by sudden pressure drop.

http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-2179/BAE-1010web.pdf

Pressure Change Design

- We add a vent to allow for sudden pressure changes to equalize in the shelter to prevent the shelter from exploding or imploding

Inside Volume ($\forall$)

$6\,ft \cdot 5.3\,ft \cdot 5.3\,ft \Rightarrow \forall = 64\,ft^3$

Vent Equation

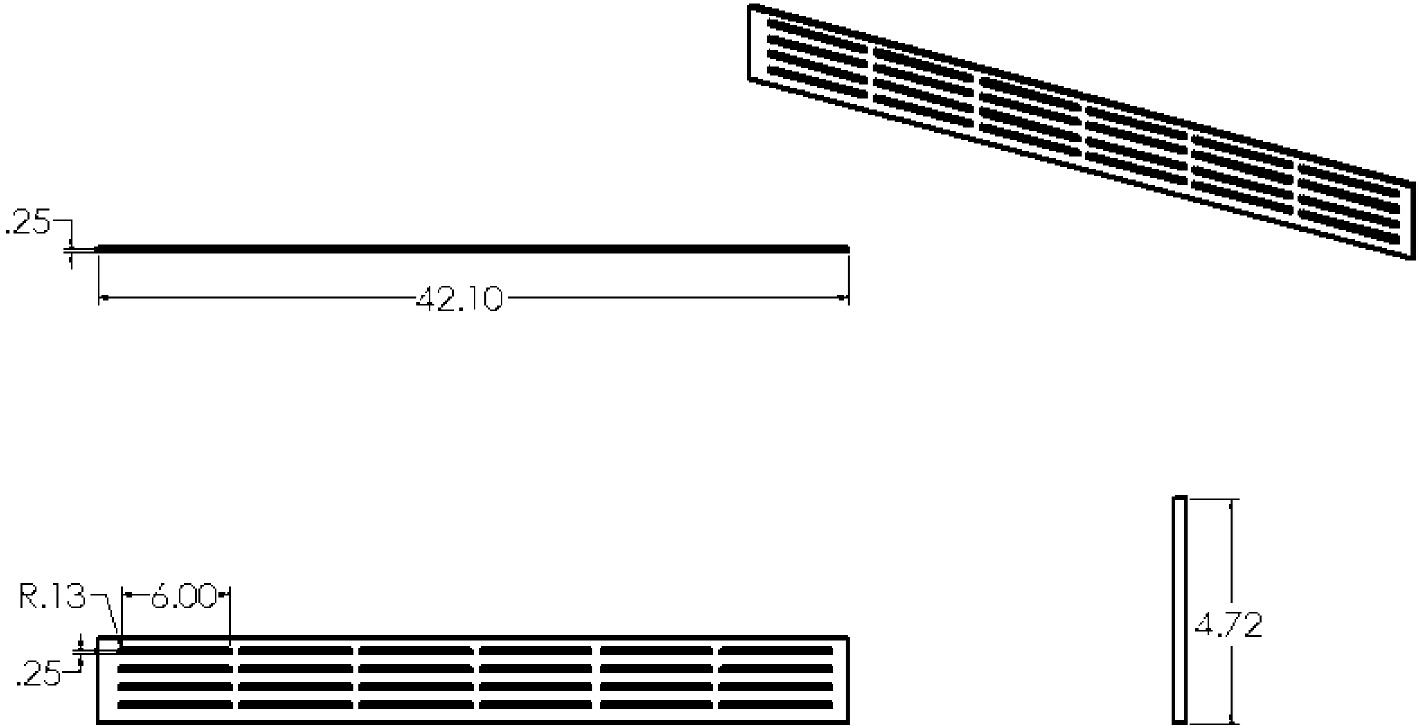
$0.001 \times \forall\,(ft^3) = \text{Area of vent}\,(ft^2$

$0.001 \times 64\,ft^3 = 0.064\,ft^2$

$\text{Area vent} \geq 9.2\,in^2$

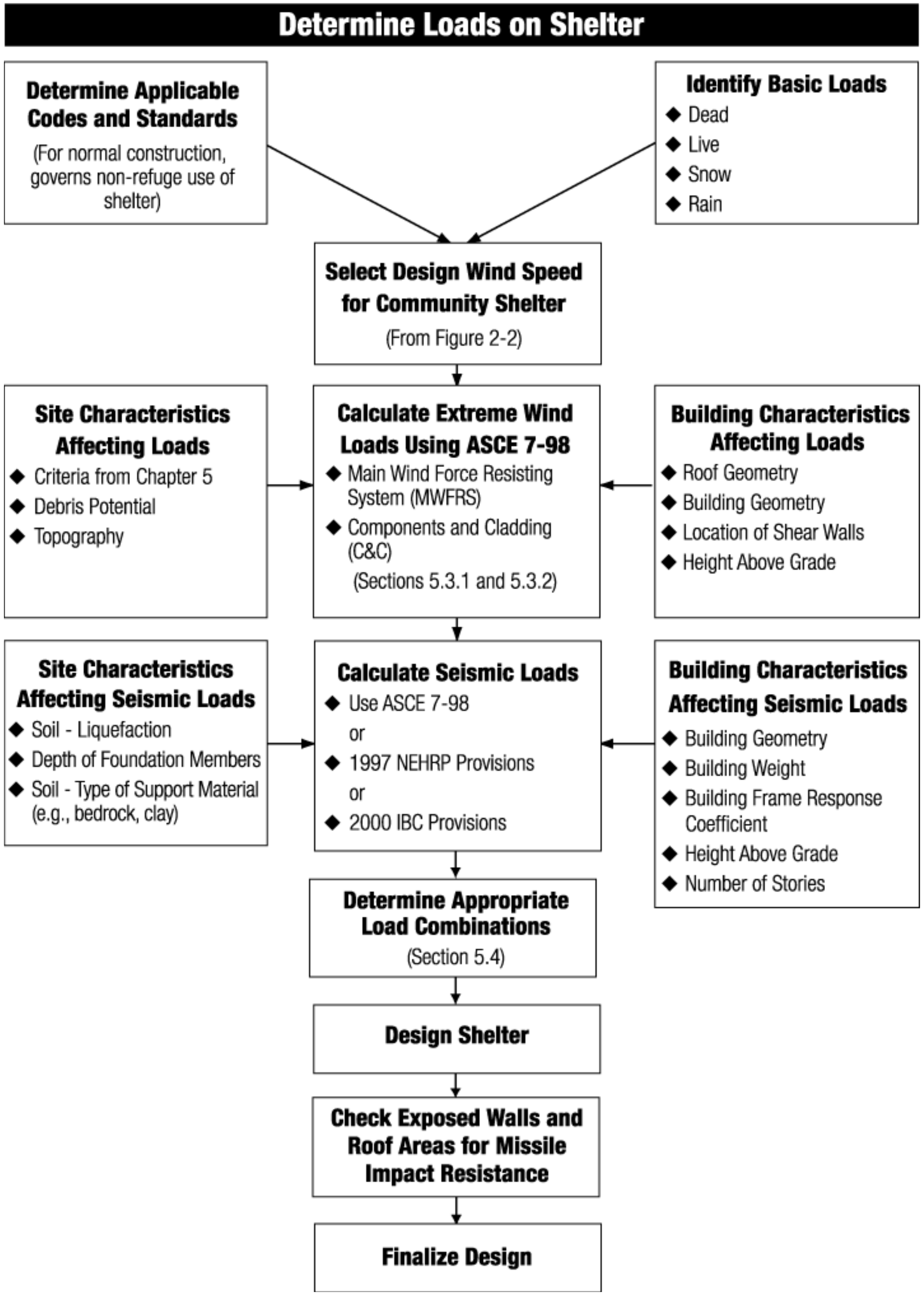
(http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-2179/BAE-1010web.pdf)

Vent Design



Shelter Design

Load Determination and Structural Design Criteria Flowchart - FEMA



Loads on shelter

- FEMA recommends the use of ASCE 7-98 to determine wind loads
- Design Wind Speed
- Main Wind Force Resisting System (MWFRS)
- Components and Cladding (C&C)

Design Wind Speed

Formula 5.1 Velocity Pressure*

$$q_z = (0.00256)(K_z)(K_{zt})(K_d)(V^2)(I)$$

where: q_z = velocity pressure (psf) calculated at height z above ground
K_z = velocity pressure exposure coefficient at height z above ground
K_{zt} = topographic factor
K_d = directionality factor = 1.0
V = design wind speed (mph) (from Figure 2-2)
I = importance factor = 1.0

*From ASCE 7-98, EQ. 6-13

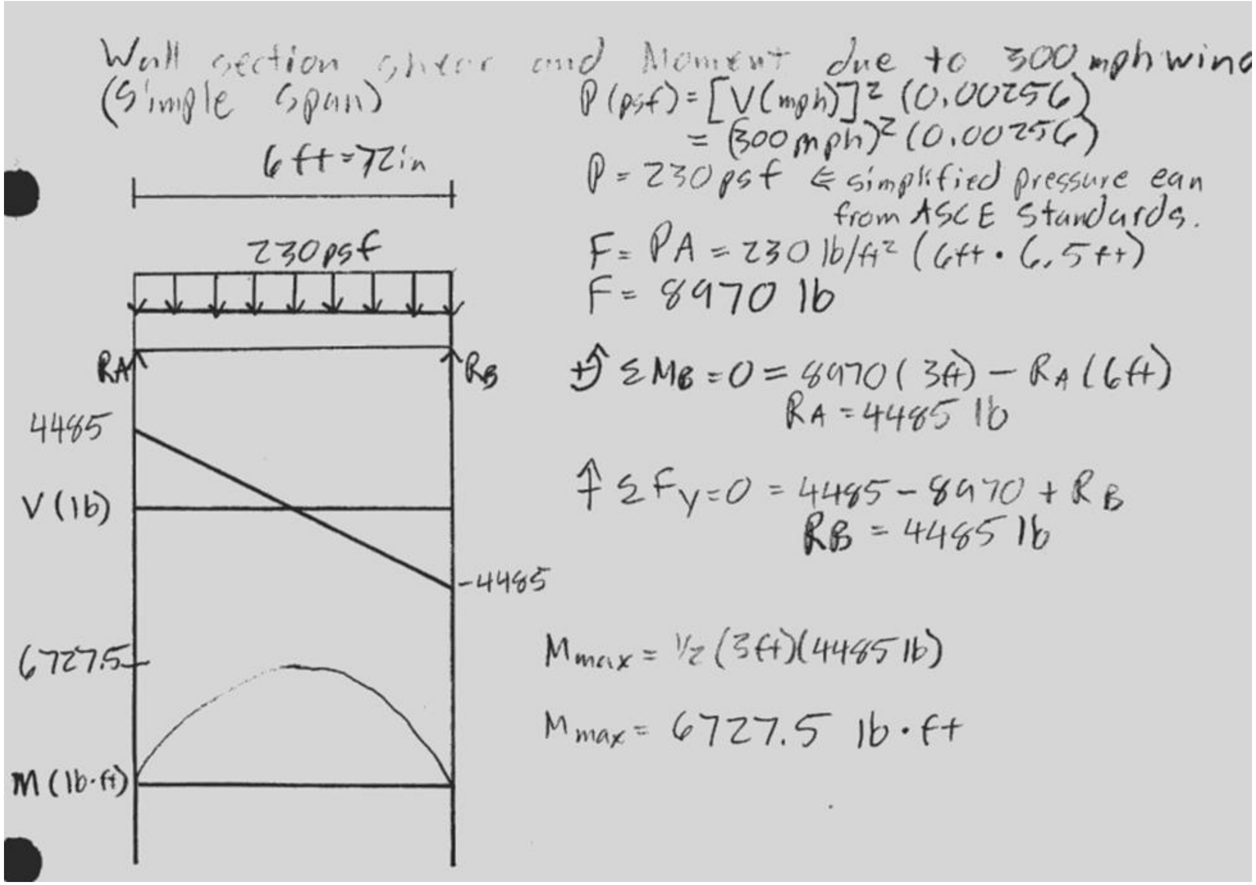
- (5 Load Determination and Structural Design Criteria, 9)

Design Wind Speed

- K constants simplify to 1
- Design velocity for 250 mph
- q_z = 160 psf

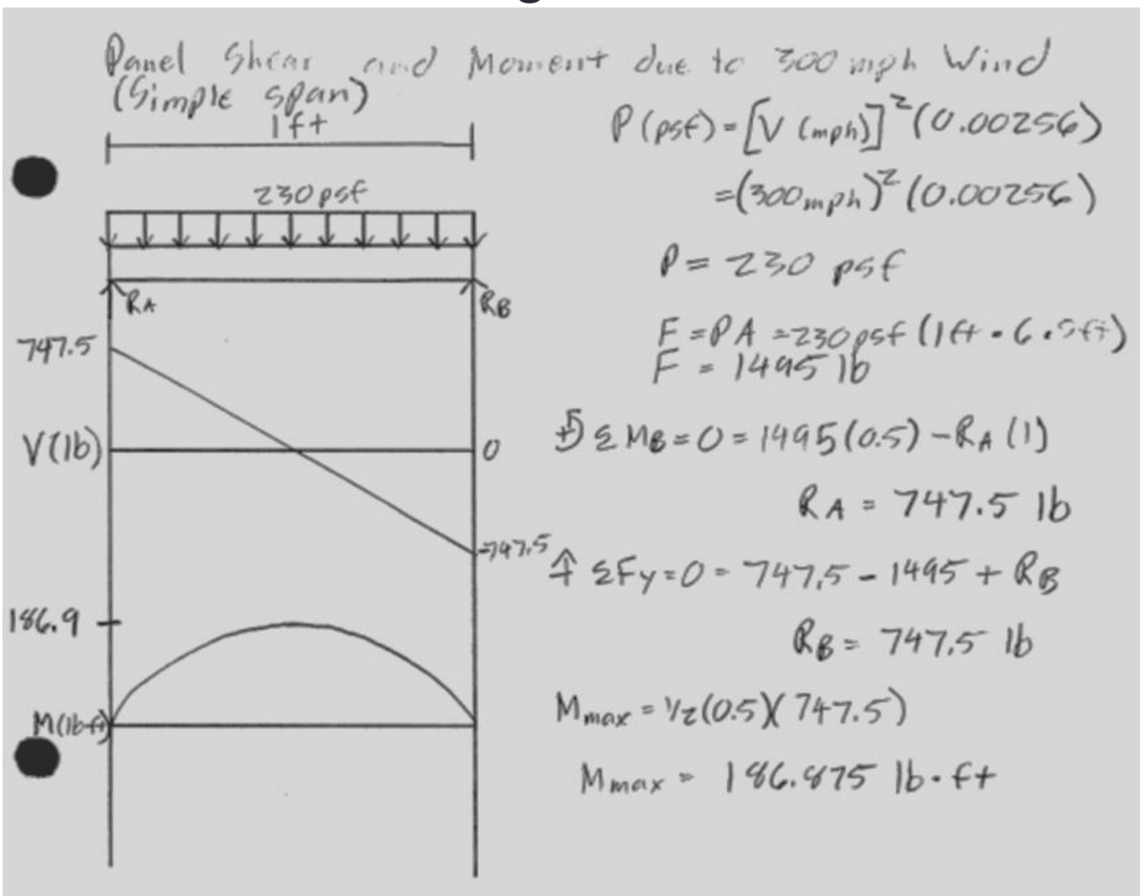
Wind Loads per Wall Section

- Wall section maximum bending moment = 6728 lb*ft
- Wall section maximum shear = 4485 lb

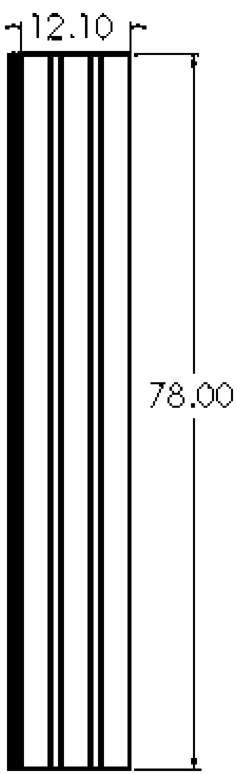


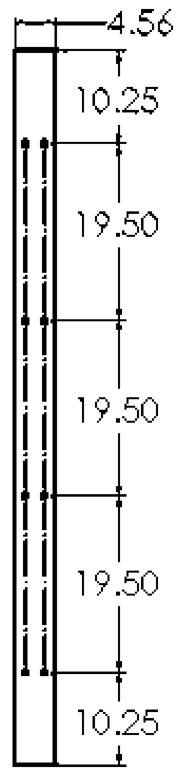
Wind Loads per Panel

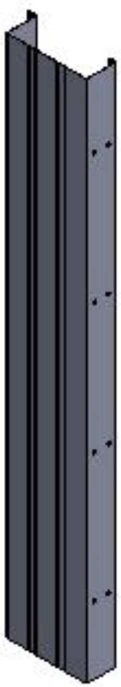
- Panel Maximum Bending Moment = 187 lb*ft
- Panel Maximum Bending Shear = 748 lbs



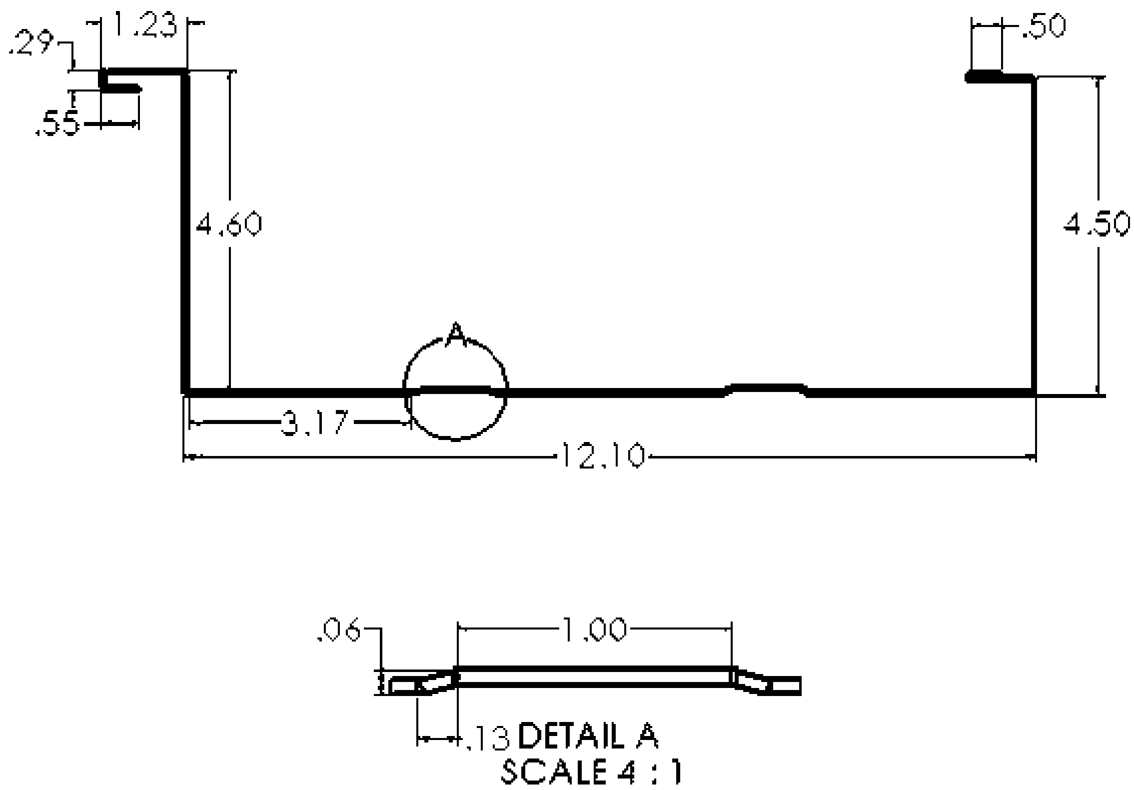
Single Panel Design



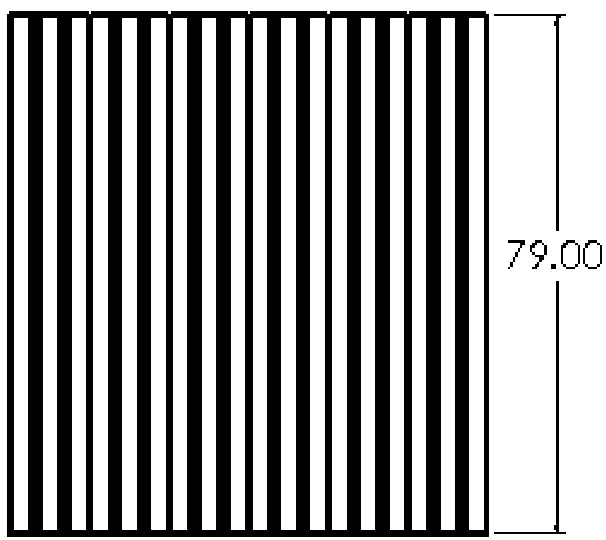


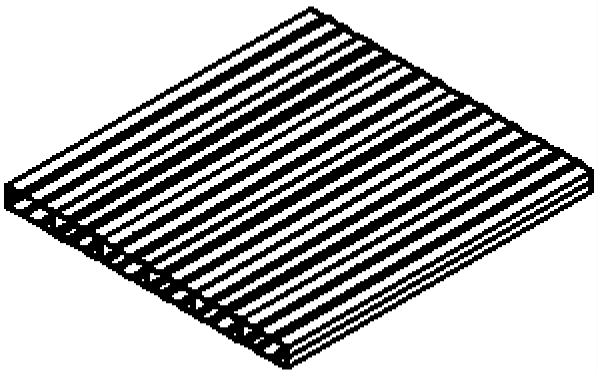


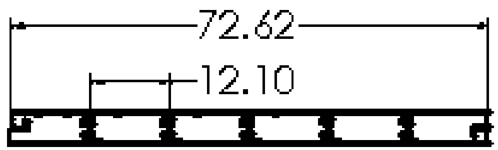
Single Panel Cross Section



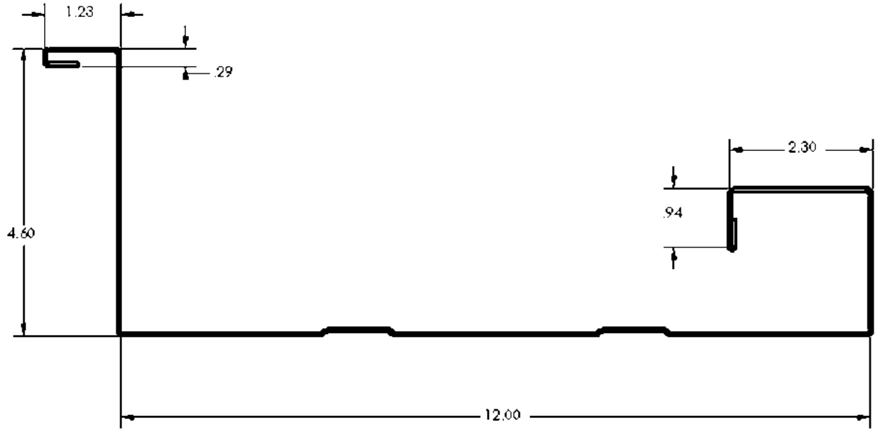
Panel Assembly

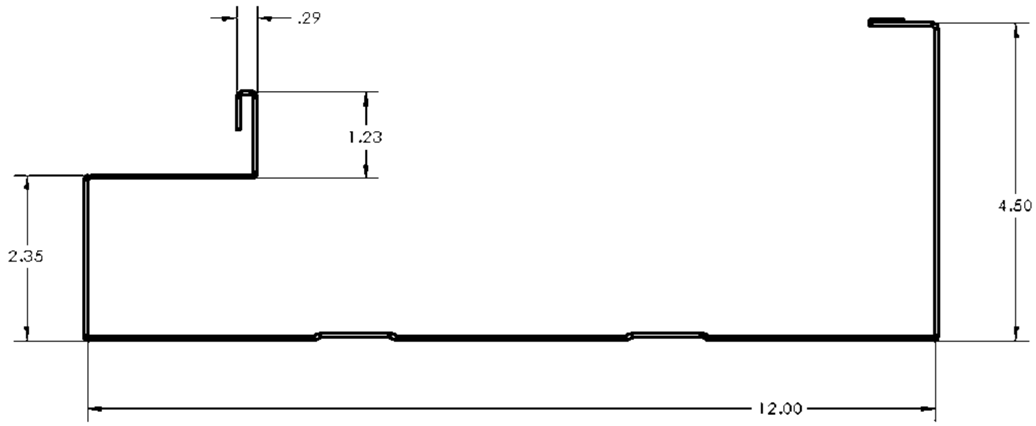




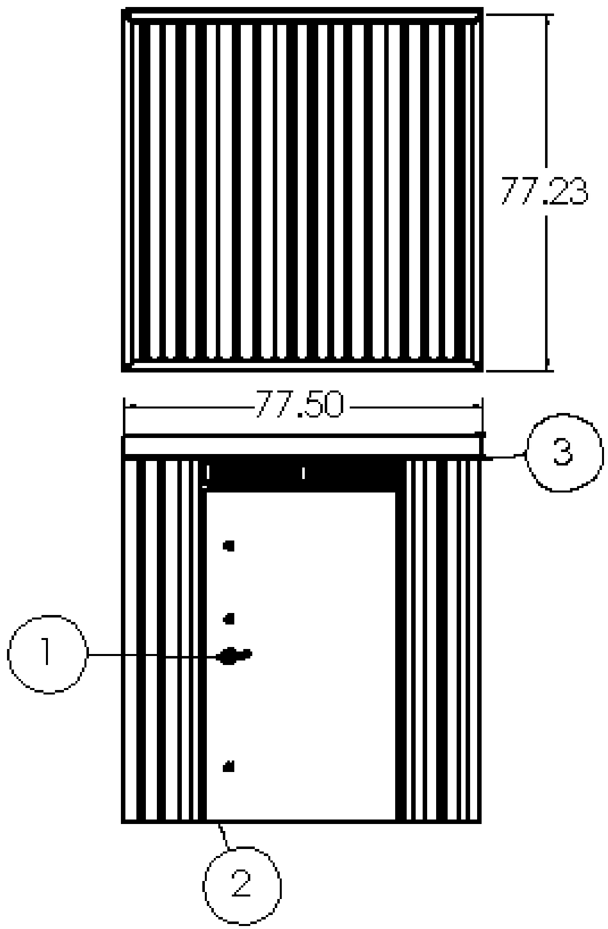


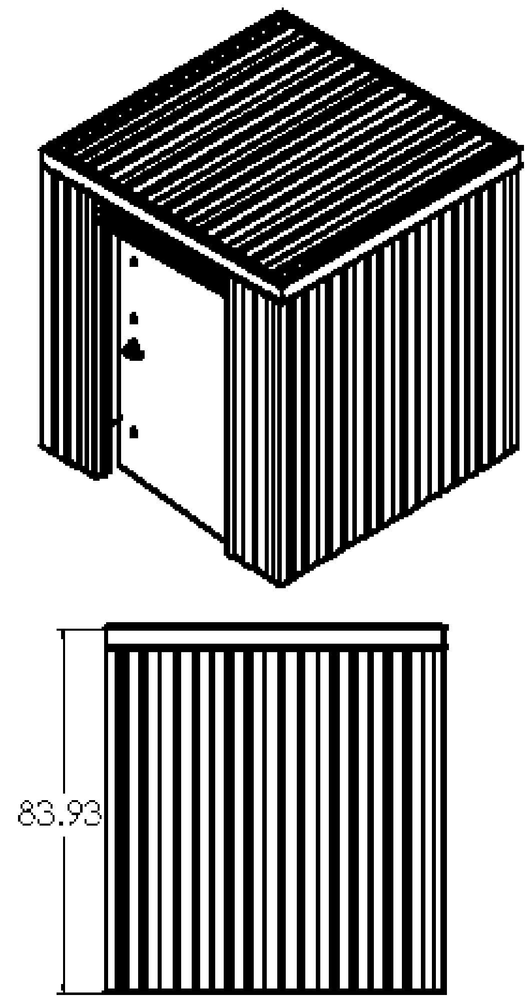
End Panels





Shelter Design





Panel Connections

- Required Bolt Strength

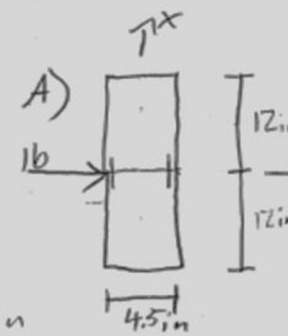
 = 26 kips

- Assuming 2 bolts together every 1.6 ft

Panel connection strength

$V_{connector} =$ lb

$V_{internal} = 747.5$ lb



Section properties

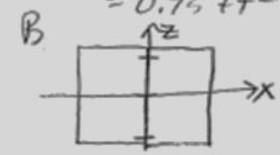
$\bar{y}_A = \frac{18(12\cdot4.5)+6(12\cdot4.5)}{12\cdot4.5+12\cdot4.5}$

$\bar{y}_A = 12$ in

$* \; I_z = \frac{(6.5in)(24in)^3}{12} = 7488 \; in^4$

$\bar{y}_z = 3.25$ ft $\quad A = 108 in^2 = 0.75 ft^2$

$I_x = \frac{24(4.5)^3}{12} = 182.25 \, in^4$



$Q_A = \bar{y}_A' A' = (12in)(12in)(4.5in) = 648 \; in^3$

$Q_B = \bar{y}_z' A' = (39in)(39in)(24in) = 1872 \; in^3$

Shear flow

$q_A = \frac{VQ}{I} = 747.5 \, lb \frac{(648 \, in^3)}{182.25 in^4} = 2657.78$ lb/in $= q_A$

$q_z = 186.875$ lb/in

Spacing of Double connectors

$s_z = \frac{2(V_{connector})}{shear\ flow} = \frac{2(V_{connector})}{186.875\ lb/in}$

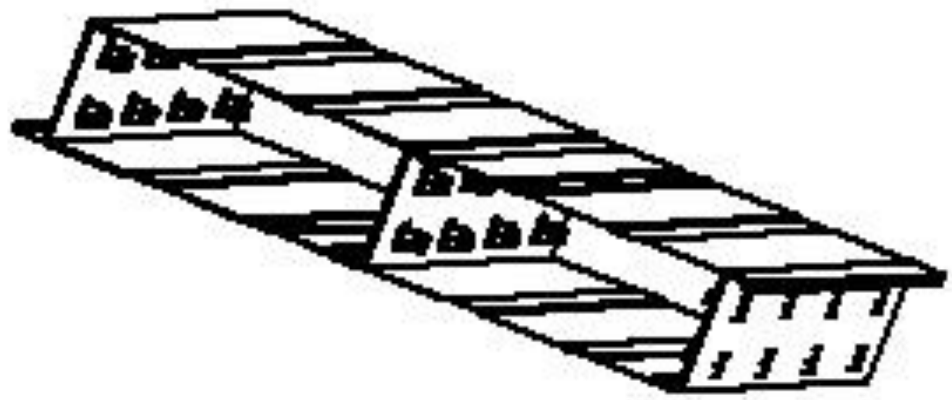
$s_A = \frac{2(V_{connector})}{2657.78\ lb/in}$

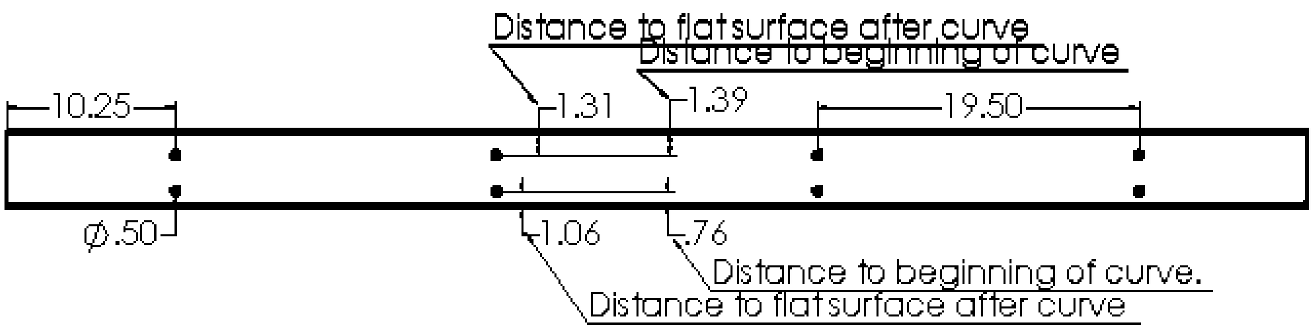
if spacing @ every 1.6 ft

$V_{connector} - 25514.7$ lb

$= 26$ kips

Panel Connection





Above Ground Shelter Foam Filling

- GRA Services - Secure Set 6
- Used when setting distribution or transmission utility poles, street light poles, mine tunnel closures...etc

Composite Maximum Bending Moment (Foam – Sheet Metal)

- Total Bending Moment Allowed

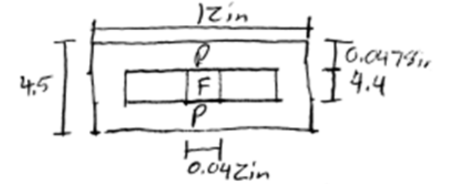
  = 10,249 lb*ft
- Wind Load Moment = 187 lb*ft

Composite Panel (Foam – sheet metal)

Panel ⇒ $\sigma_p = 40\,ksi$ 18 gauge panel = 0.0478 in

- Foam ⇒ $\sigma_{min} = -140\,psi$

  $\sigma_{max} = +190\,psi$



$$n = \frac{E_P}{E_F} = \frac{40000}{140} = 285.7$$

Foam width = $\frac{12\,in}{285.7} = 0.042\,in$

$$I = \frac{(12)(4.5)^3}{12} - \frac{(12-0.042-2(0.0478))\,4.4^3}{12} = I = 6.91778\,in^4$$

$$c = \frac{4.5}{2} = 2.25$$

Allowed sheet metal bending

- $\sigma_S = \frac{Mc}{I} \Rightarrow 40\,000\,psi = \frac{M(2.25\,in)}{6.91778\,in^4} \Rightarrow (M_{max})_S = 122983\,lb\cdot in$

  $(M_{max})_S = 10249\,lb\cdot ft$

Allowed foam bending

$\sigma_F = \frac{Mc}{I}n \Rightarrow 140\,psi = \frac{M(2.2\,in)(285.7)}{6.91778\,in^4} \Rightarrow (M_{max})_F = 1.54\,lb\cdot in$

$(M_{max})_F = 0.129\,lb\cdot ft$

Total Bending Moment Allowed

$M_{max} = 10249\,lb\cdot ft > 187\,lb\cdot ft$ max wind moment

✓

Composite Maximum Bending Moment (Concrete – Sheet Metal)

- Total Bending Moment Allowed

  = 20,033 lb*ft
- Wind Load Moment = 187 lb*ft

Composite Panel (Concrete – sheet Metal)

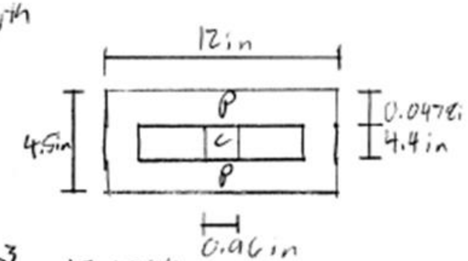
Panel ⇒ $E_p = 40ksi$ 18 gauge Panel ⇒ t = 0.0478in

Concrete ⇒ $E_c = 3.2 ksi$ ⇐ Low strength

$4.2 ksi$ ⇐ high strength

$n = \frac{E_p}{E_c} = \frac{40}{3.2} = 12.5$

Concrete width $= \frac{12in}{12.5} = 0.96in$



$I = \frac{(12)(4.5)^3}{12} - \frac{(12-0.96-0.0478(2))(4.4)^3}{12} = 13.4344$

$c = \frac{4.5}{2} = 2.25in$

Allowed sheet metal bending

$\sigma_p = \frac{Mc}{I} \Rightarrow 40000\ psi = \frac{M(2.25in)}{13.4344in^4} \Rightarrow (M_{max})_p = 238833\ lb \cdot in$

$= 19902\ lb \cdot ft$

Allowed concrete bending

$\sigma_c = \frac{Mc}{I} n \Rightarrow 3{,}200\ psi = \frac{M(2.2in)(12.5)}{12.7557in^4} \Rightarrow (M_{max})_c\ 1563.27\ lb \cdot in$

$= 130\ lb \cdot ft$

Total allowed bending moment

$M_{max} = 20{,}033\ lb \cdot ft$

Testing

- Load test
  - Run simulation with modeling software
  - Construct a wall assembly with aggregate materials
  - Perform pull test to determine failure point

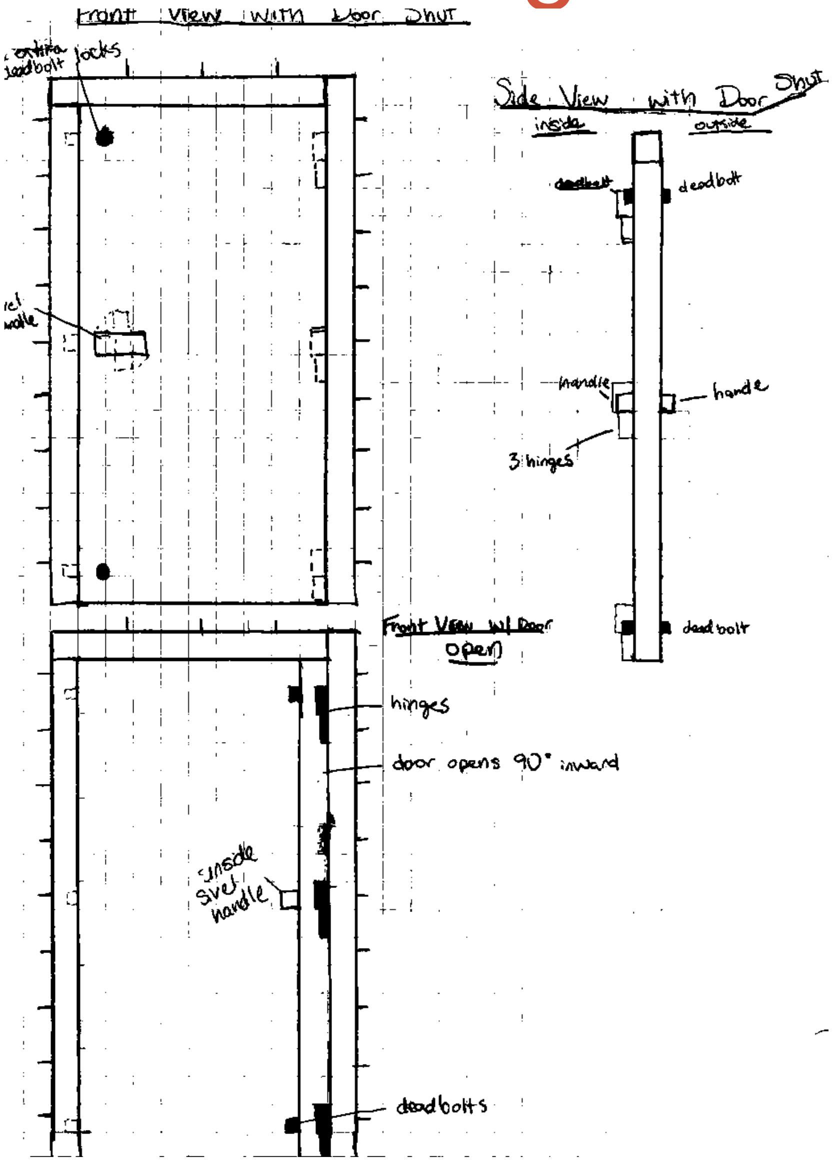
- Impact Test
  - Run simulation with modeling software
  - Prototype constructed after connections and anchor system are determined
  - Using 2 x 4 with FEMA standards

Freshman Team

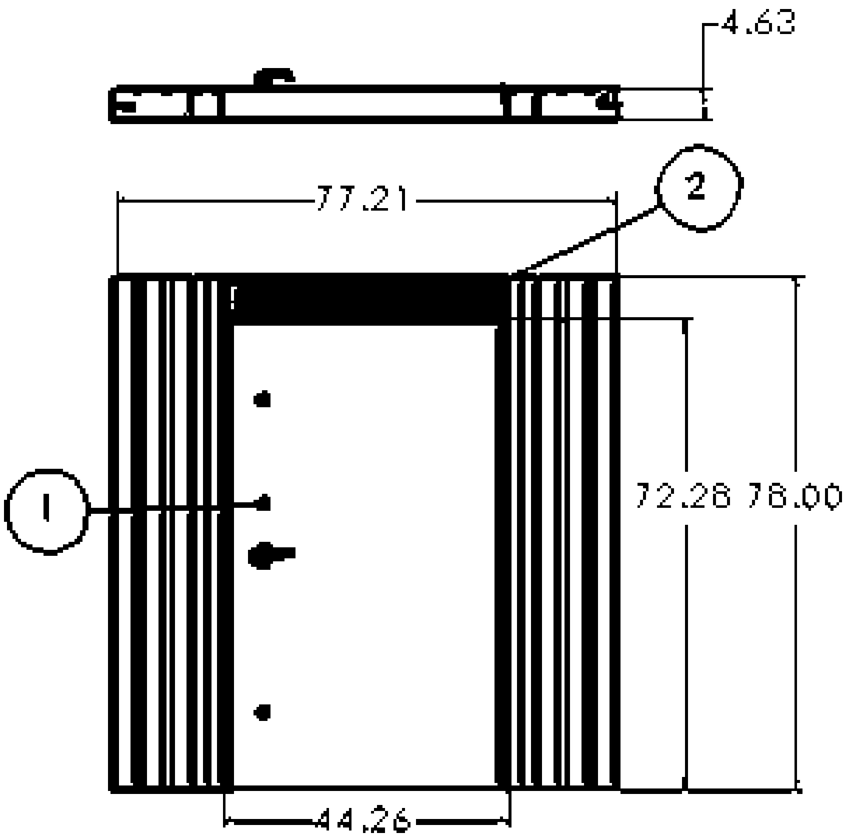
- We challenged our freshman team to determine how the entry system will be implemented into our shelter

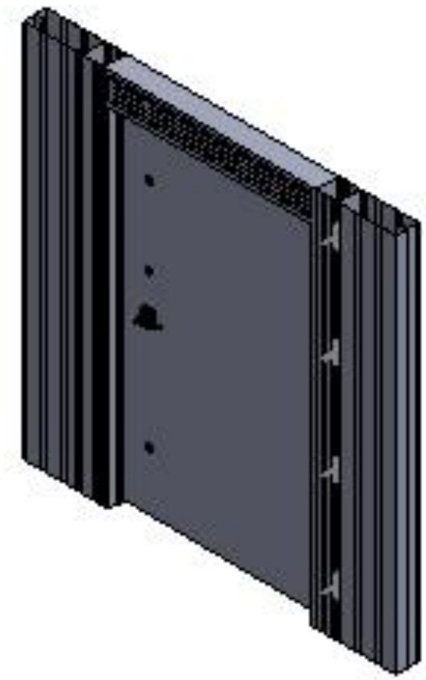
- We asked for three different entry designs for the above ground shelter and three different designs for a similar shelter design below ground

Freshman Door Design



Door Assembly





Expected Labor

- Time for total build completion : 8-16 hrs.
- 3 skilled workers or more needed for construction.
- Assumed wages for skilled workers required for build completion : $12-$15 per hour
- Final wages are up to the discretion of BRB Roofing.
- Total cost of labor : $288 - $720 per build

Cost of Materials

Cost of Storm Shelter Materials				
Aggregate Material	w/ Foam	w/ Sand	w/ Concrete	w/ Gravel
FEMA Strom Door w/ shipping	$2,000.00	$2,000.00	$2,000.00	$2,000.00
Cost of Sheet Metal	$259.20	$259.20	$259.20	$259.20
Fasteners	$848.46	$848.46	$848.46	$848.46
Cost of Aggregate Material	$980.00	$9.55	$44.38	$21.61
Cost of Labor				
Pay for 3 skilled workers @ $12/hr.	$288.00	$288.00	$576.00	$288.00
Total Cost	**$4,375.66**	**$3,405.21**	**$3,728.04**	**$3,417.27**

Location of Materials

- Foam
  - GRA services - Edmond
- Sand & Gravel
  - Arkola Sand & Gravel – Muskogee
- Concrete
  - Dolese Bros Co. – Oklahoma City
- Storm Door
  - Secure-all Storm Doors – LaPorte, Indiana
- Fasteners
  - Fastenal.com

What's Next?

- Determine bolt design and anchor system
- Build and test wall assemblies
- Model for impact testing
- Build and test prototype
- Benefit cost analysis for our storm shelter and other typical shelters

Schedule

Name	Begin date	End date
Time Frame	8/23/13	5/2/14
Design	8/23/13	11/8/13
Arrange to meet with BRB	8/23/13	9/4/13
Determine statement of work	8/23/13	9/16/13
Meet with Doss Briggs @ BRB	9/5/13	9/5/13
Research possible Designs for Hatch/Door	9/5/13	9/30/13
Research Properties of Foams, Sand, and Rock	9/5/13	9/30/13
Research Sealents	9/5/13	9/30/13
Research Anchoring Systems	9/5/13	9/30/13
Copy_Research possible Designs for Hatch/Do...	9/5/13	9/30/13
Meet with Win Adams @ OSU	9/13/13	9/13/13
Create a SoldWorks Design	9/16/13	11/22/13
Supervise Freshman Projects	9/23/13	11/18/13
Meet with Doss and Win	11/18/13	11/29/13
Presentations - Dead Week	12/2/13	12/6/13
Christmas Break	12/16/13	1/3/14
Build Prototype	1/6/14	3/14/14
Testing	1/6/14	4/18/14
Meet with Doss and Win for final Design	4/21/14	5/2/14
Presentations - Finals Week	4/28/14	5/2/14

Sources

- Federal Emergency Management Agency Chapter 5 Load Determination and Structural Design Criteria, FEMA TR-83B

  (http://www.rhinovault.com/361_ch05.pdf)
- ASCE 7-02 (Revision of 7-98)
- Selecting Tornado Shelters, Oklahoma Cooperative Extension Service BAE 1010 (http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-2179/BAE-1010web.pdf)
- Foam filling
- http://graservices.com/products/secureSet/
- http://graservices.com/products/secureSet/technical/

Thank you

- Dr. Stone
- Wayne Kiner
- Doss Briggs
- Win Adams
- Judy McCombs
- Dr. Thomas
- Hunter Parsons
- Garrett Dollins
- Hammons Hepner
- Nolan Wilson

Questions?