The Wood Tornado Shelter

Prepared by Home Innovation Research Labs for the Forest Products Laboratory

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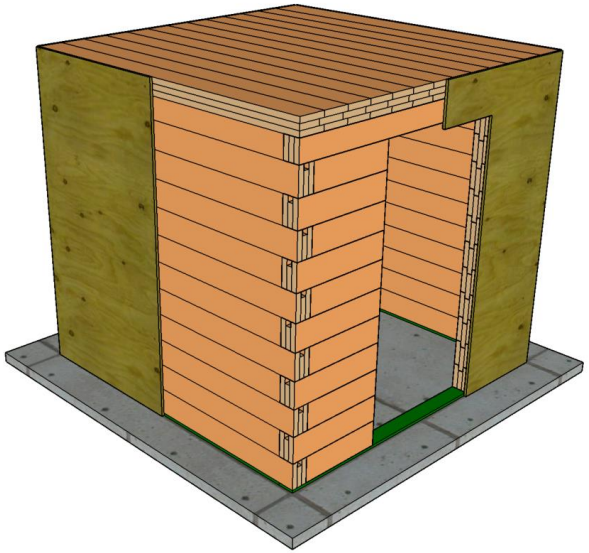

Introduction

This 8 foot by 8 foot tornado shelter was developed by engineers at the US Department of Agriculture's Forest Products Laboratory to provide a design that is adaptable for existing construction and that is easily constructed.

Design Information

The tornado shelter presented here was laboratory tested to meet impact and wind pressure requirements. The following information may be required with construction documents.

- Type of shelter: Residential tornado
- The design meets the impact and wind pressure requirements of *ICC 500-2014: Standards for the Design and Construction of Storm Shelters.*
- Design Wind Speed: 250 mph
- Wind Exposure Category: C
- Internal pressure coefficient, GC_{pi}: +-0.55
- Topographic factor, K_{zt}: 1.0
- Directionality factor, K_d: 1.0
- A statement must be provided that the floor of the shelter has been constructed above the highest recorded flood elevation if a flood hazard study has been conducted for the area or the minimum elevation required by authority having jurisdiction.
- Extensive laboratory testing was performed to assure that this 8'x8' tornado shelter meets the impact and wind pressure requirements of Chapters 3 and 8 of *ICC*

Note to Reader

Before ordering materials or starting construction:

- **Read all instructions as construction options can affect quantity and size of materials needed. Many steps are not reversible, so having a complete understanding of the construction process prior to starting will minimize costly mistakes.**
- **Obtain approval of the plans and construction guide from your local building official to assure that this design is suitable for your jurisdiction.**

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500-2014: Standards for the Design and Construction of Storm Shelters. Design assumptions and test results can be found in the following two documents:
www.fpl.fs.fed.us/documnts/fplgtr/fpl_gtr253.pdf
www.fpl.fs.fed.us/documnts/fplgtr/fpl_gtr254.pdf
Other shelter sizes have not been tested.

Wind speed/wind pressure calculations can be found in the following document:
https://www.fpl.fs.fed.us/documnts/fplrp/fpl_rp688.pdf

- The door shown in this construction guide was laboratory tested for debris impact for a 3'-0" width.
- Location of the tornado shelter within a host building and a drawing of the entire building.
- A shelter section or elevation indicating the height of the shelter relative to the finished grade, finished floor and the host building, where applicable.
- Hold down design capacity: 4000 lb
- Assumed friction coefficient for concrete cast on soil, f: 0.50
- Occupant Load: 9 people
- Usable floor area: 49 sf
- Venting area: 18.8 in^2
- Concrete foundation minimum requirements:
    a. 4" thick concrete slab
    b. 4000 psi minimum strength
    c. 6x6 – W1.4xW1.4 welded wire reinforcement over the entire area OR No. 4 bars, at a maximum spacing of 18 in. on center in two perpendicular directions.
    d. Minimum 5' slab extension on each side of shelter to prevent foundation sliding and overturning.

Design Limitations

This shelter design meets the missile impact and wind load requirements of national standards for tornado shelters. As part of your planning process it is important to contact your local building department to determine if there are other requirements for tornado shelters in your area. For example, some jurisdictions have requirements on door swing direction, which may affect the suitability of this design to your location.
Because the door design presented here is self-built, it may not meet the door labeling requirements (Section 108.2) of the ICC-500 standard. However, extensive laboratory testing confirms that the door meets the impact and wind pressure requirements of the standard:
https://www.fpl.fs.fed.us/documnts/fplrp/fpl_rp686.pdf

Siting

Before beginning construction of the shelter, ensure that the installation site meets the following requirements:

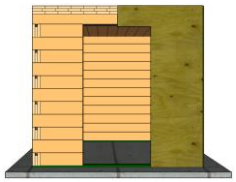
- **Proximity.** If not located in the home, the shelter must be located a maximum distance of 150 ft. from the home.
- **Protection from Rain and Snow.** This shelter is not designed to be water-resistant and must be built inside the home, in a garage, or other structure that protects the shelter from the elements.
- **Concrete Foundation.** If the foundation does not meet the requirements stated earlier, FEMA P-320 provides foundation construction details:
https://www.fema.gov/media-library-data/1418837502817-920f09bb8187ee15436712a3e82ce709/FEMA_P-320_2014-ConstructionPlans_508.pdf
- **Detachment from Host Building.** Do not attach any portion of the shelter to an adjoining wall or to the floor or roof framing of the enclosing structure (or vice versa).

Costs

The designers of this tornado shelter estimate a material cost of between $3500 - $4000 (2016 dollars). See the Appendix of the following document for a material list and costs:
www.fpl.fs.fed.us/documnts/fplgtr/fpl_gtr253.pdf

Lumber and Plywood Requirements

- #2 grade stamped softwood lumber with engineering properties at least equivalent to the Spruce Pine Fir (SPF) species group.
- 22/32 softwood plywood sheathing.



General Safety

Follow these general safety instructions:

- Keep a first aid kit nearby
- The work area should be clean and organized
- Ensure the construction area is well ventilated
- Never leave an active power tool unattended
- Do not use a power tool with a frayed or damaged power cord
- Wear protective eyewear to protect against airborne particles
- Ladders should be set on level surfaces, and locked in the open position
- Tools used in damp conditions should be connected to a ground fault circuit interrupter (GFCI)
- Nail gun: never aim a nail gun towards anyone; do not press the trigger unless the nose is pressed firmly against the nailing surface; do not use a nail gun that is not functioning as specified by manufacturer; remove air supply before clearing jams
- Power drill: change drill bit only after disconnecting power supply; tighten chuck securely and remove chuck key before starting the drill; apply proper pressure to drill
- Hammer drill: never operate with one hand, firmly grasp the trigger handle and auxiliary handle for maximum control; wear cushioned gloves to reduce vibration

Circular Saw Safety

- Never look away from your work
- Keep hands away from the cutting area behind the blade
- Stand to the side of the blade when cutting
- Do not use a dull saw blade
- Secure metal materials with clamps before sawing
- Make sure the cutting material is not touching the blade before starting the saw

→ Follow all tool manufacturer safety instructions.
→ Additional guidance available from the Occupational Safety and Health Administration.

Sequence of Construction

The construction of this shelter design can be broken down into the following 8 phases:

1. **Cutting the lumber.** The lumber is cut to length. Some pieces will also be rip cut to the correct width. The installer must keep careful track of which pieces have been cut to which length.
2. **Constructing the beams.** The triple beams that make up the walls and ceiling of the shelter are made from three same-length 2x8s. The middle 2x8 is offset by 1-1/2" to give each beam a tongue-and-groove cross section. The 2x8s are joined with construction adhesive and nails to form a laminated beam.
3. **Building the walls.** The walls are constructed by laying one course of horizontal beams at a time for the entire perimeter of the shelter. The next course's tongue will fit into the lower course's groove and is joined using construction adhesive. The beams are laid up such that the walls lock together in a log cabin fashion. The beams are joined at the corners with 8" long wood screws and construction adhesive.
4. **Installing the ceiling beams.** Twelve ceiling beams made from 2x8s are installed individually in place. Once the last 2x8 beam is installed, a final beam is custom cut from three 2x10s to complete the 8 ft. x 8 ft. ceiling. All thirteen beams are attached to the walls using 8" long wood screws and to each other using construction adhesive. The screws are driven into the exterior of a wall at a 45° angle and into the ceiling beam above. This allows the beams to be attached in sites where a low ceiling exists, such as a basement.
5. **Attaching the sheathing.** The 23/32 plywood sheathing is cut to size and attached with nails and construction adhesive to the interior and exterior faces of all four walls and the interior of the ceiling (as well as the top of the ceiling if it is accessible).
6. **Building and hanging the door.** The door is made up of three sheets of 22/32 plywood sandwiched between two sheets of 18 gauge cold-rolled steel, a material that must be sourced locally. The door is hung on bolt hooks installed on the exterior of the shelter wall, and has latches on its interior surface for locking the shelter when occupied. Sheet metal angles are used to reinforce the door opening. These need custom fabrication and are sourced locally. Most cities have a steel fabricator that can supply, cut, punch, and bend sheet metal to custom sizes.
7. **Ventilation.** Ventilation holes are drilled through the wall at specified locations to provide fresh air to the interior of the shelter.
8. **Anchoring the shelter.** The shelter is secured to the concrete slab using Simpson Strong-Tie (or equivalent) hold-downs nailed to the shelter's exterior. 5/8" dia. anchor bolts secure the hold-downs to the slab with an epoxy adhesive per anchor manufacturer's requirements.

Materials List

ITEM	QTY	NOTES
2x8 lumber @ 8 ft.	169	Used for wall and roof beams
2x10 lumber @ 8 ft.	3	Used for one roof beam
2x6 lumber @ 8 ft.	3	Used for door jambs
2x4 lumber @ 8 ft.	2	Used for door latch offset
1x6 lumber @ 8 ft.	4	Preservative-treated boards; used for decay protection between shelter walls and concrete foundation
23/32" plywood sheathing	21	4 ft. x 8 ft. Sheets, Performance Category Grade
42" x 84" sheet metal	2	18-gauge cold rolled steel. Custom fabrication locally.
Custom sheet metal angles	3	14-gauge steel, for the entrance header and both door jambs. Custom fabrication locally.
Nails, 1 box, 5000 count	1	16d, 3-1/4" x 0.131"
Nails, 1 box, 500 count	1	16d, 3-1/4" for tie downs (hand driven)
Construction adhesive (Liquid Nails Heavy Duty or equivalent)	5 cases	24 count cases of 10 oz. tubes. Quantity needed may vary depending on how liberally applied. Better to apply a generous bead rather than too little. 29 oz. tubes are also available.
5/8" dia. gate latch	3	Slide bolt
3/4" bolt hook/door hinges	3	Bolt hook and strap hinge (separate pieces)
7-gauge 5" x 3" heavy angle	3	Simpson Strong Tie HL53 or equivalent
3/8" dia. bolts. Length varies.	About 30	For door construction and hanging hinges and latches.
#14 x 8" wood screws	150	Multipurpose star drive
3/8"dia. x 3" lag bolts	85	For sheet metal angles, heavy angles
11-gauge 16" heavy hold-down (tension tie)	16	Simpson Strong Tie HTT5 or equivalent
5/8" dia.-11 UNC threaded anchors and epoxy system	16	Per anchor manufacturer specifications

Materials List Notes

Note 1: Actual dimensions for lumber differ from the nominal dimensions. A nominal 2x8 board actually measures 1-1/2" x 7-1/4". The actual thickness of 23/32 plywood can vary from 0.69" to 0.75".

Note 2: The lumber quantities above are the minimum required to make each component. It is advised that actual lumber orders include a waste factor (i.e., additional boards) to account for warpage, waste, loss or mistakes.

Tools List

1. Measuring tape
2. Hammer
3. Circular saw
4. Sawhorses
5. Hand saw or reciprocating saw (Sawzall)
6. 12" woodworking clamps
7. Pneumatic framing nail gun with air compressor
8. Socket set / wrenches (various sizes)
9. Drill capable of driving 8" screws through 6" of wood
10. Drill bits:
    a. 1" auger drill bit for ventilation holes
    b. 1/2" drill bit for bolt holes in door
    c. 3/4" auger drill bit for door hinges
    d. Step drill (3/4" minimum)
    e. Drill bit for concrete anchors
11. Anchor installation tools per manufacturer
12. Caulking gun
13. Drywall lift (optional)
14. Table saw (optional)
15. Miter saw (optional)

Before You Begin

The designers estimate that this tornado shelter takes two people several days to construct from scratch.

To avoid assembly and fitting complications due to warped wood, the lumber for the tornado shelter should be delivered to the work site immediately prior to construction.

SECTION 1: CUTTING THE LUMBER

The first step in constructing the shelter is to cut the lumber to the appropriate length and width.

111 of the 2x8s will make up the non-door walls and will need to be cut to be 91-1/2” long. The 22 remaining 2x8s will be cut to two shorter lengths (28-1/2” or 24”) in order to accommodate the door opening. 11 2x8s will also be rip-cut to modify their width. The ripped pieces will be used for the bottom and top courses of the wall to provide a flat surface at the slab and at the ceiling.

Materials Needed In This Section:

- 133 2x8 boards, 8 ft. (96”) long

Tools Needed For This Section:

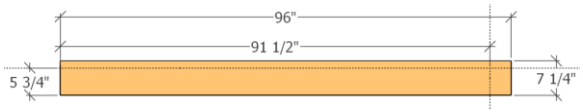
- Measuring tape
- Circular saw
- Sawhorses
- Woodworking clamps

BEFORE YOU BEGIN: Inspect the lumber for warp and twist. Excessively warped and twisted boards should be set aside.

NOTE: Rip cutting lumber is more easily accomplished using a table saw. However rip cutting with a hand-held circular saw is an option.

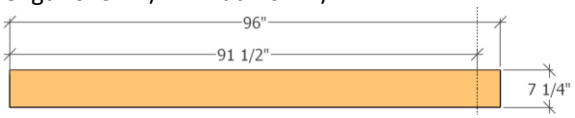
Long Boards

Ⓐ Rip cut 11 boards to a width of 5-3/4”. Then cross cut each of these 2x8s to a length of 91-1/2”. These boards will be used as the inner board of three of the bottom beams, and the two outer boards of the four top beams in the shelter’s walls.



Rip cut and cross cut lines (91-1/2” boards)

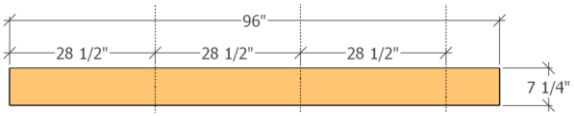
Ⓑ Next, cross cut an additional 100 boards to a length of 91-1/2” Width is 7-1/4”



Cross cut line (91-1/2” boards)

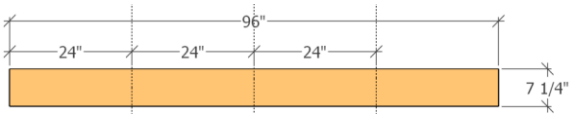
Shorter Boards

Ⓒ Cross cut 11 2x8s into three sections measuring 28-1/2” long.



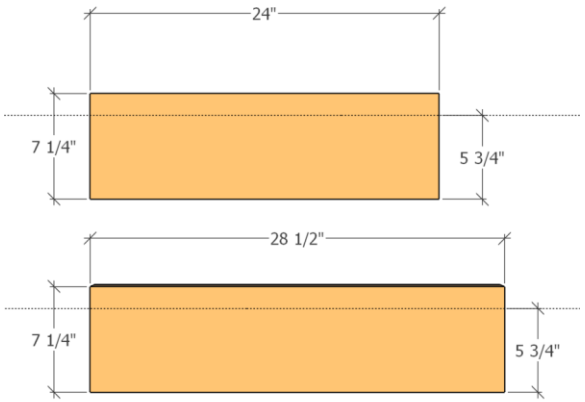
Cross cut lines (28-1/2” boards)

Ⓓ Next, cross cut 11 2x8s into three sections measuring 24” long.



Cross cut lines (24” boards)

Finally, select one Ⓔ 28-1/2” long segment and one Ⓕ 24” long segment. Rip cut each of these shorter segments to a width of 5-3/4”.

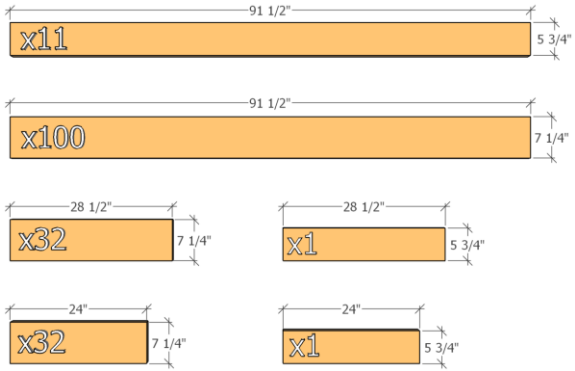


Rip cut lines (24” and 28-1/2”” boards)

Final Lumber Cut List

133 2x8 boards used to make 177 individual pieces for constructing the wall beams (next section):

- 11 pieces Ⓐ, 2” x 5-3/4” x 91-1/2”
- 100 pieces Ⓑ, 2” x 8” x 91-1/2”
- 32 pieces Ⓒ, 2” x 8” x 28-1/2”
- 1 piece Ⓔ, 2” x 5-3/4” x 28-1/2”
- 32 pieces Ⓓ, 2” x 8” x 24”
- 1 piece Ⓕ, 2” x 5-3/4” x 24”



Final board dimensions and quantity

NOTE: You should have at least 36 untouched 2x8s from the original lumber order after this section.

SECTION 2: CONSTRUCTING THE BEAMS

The beams that will make up the walls and ceiling are made by nailing and gluing three 2x8s together. You will make 71 beams of various lengths.

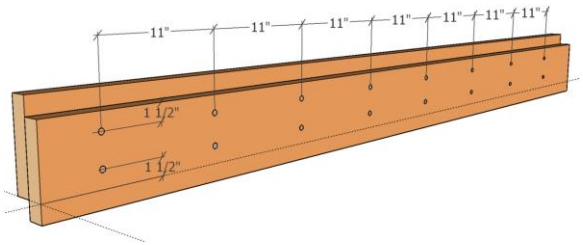
Materials Needed In This Section:

- Cut boards from previous section
- 36 untouched 2x8s
- 16d nails and construction adhesive

Tools Needed For This Section:

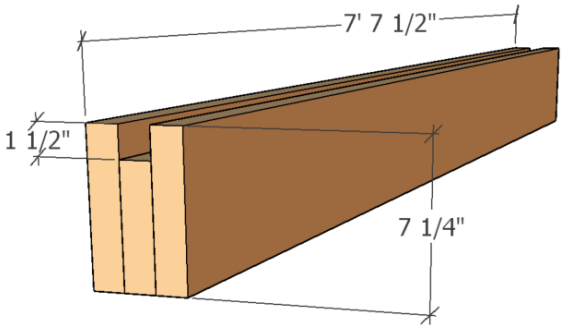
- Sawhorses
- Caulking gun
- Woodworking clamps
- Pneumatic framing nail gun
- Hand saw

For each beam: two rows of nails spaced a maximum of 11” on center as well as two beads of construction adhesive between the boards for added structural strength. Apply a thick bead of adhesive to assure adequate contact and only apply on overlapping portion. Take care that adhesive does not squeeze out from between two boards and dry in the tongue or groove as it will complicate wall and ceiling assembly later. Image shows the nailing pattern for two boards; actual number of nails depends on beam length.



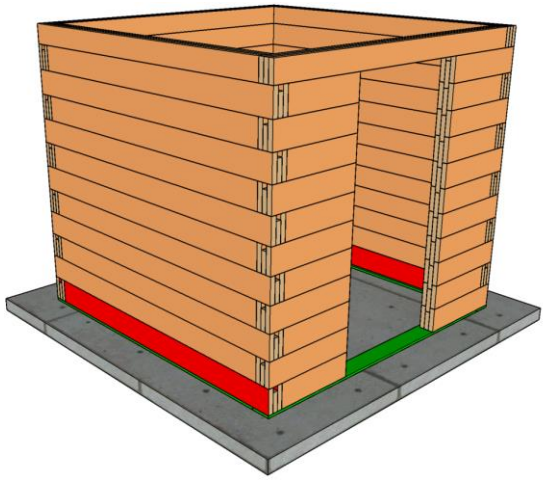
Bottom Course Wall Beams (Long)

Three bottom beams are made from three pieces of lumber that were cross cut to 91-1/2” long. Two of the pieces of lumber are full width (8” nominal, 7-1/4” actual) and one was rip cut to 5-3/4” wide.



Dimensions: bottom course wall beams (91-1/2” long)

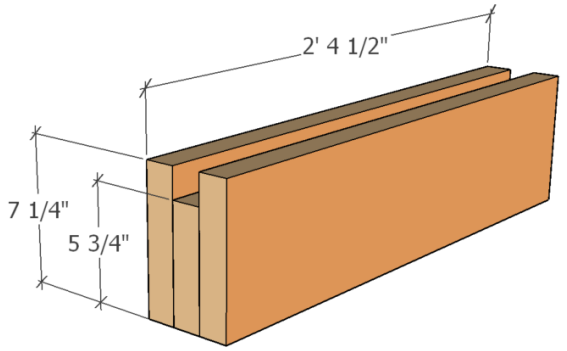
Create these bottom beams by gluing and nailing the three pieces of lumber together.



Location: bottom course wall beams (91-1/2” long)

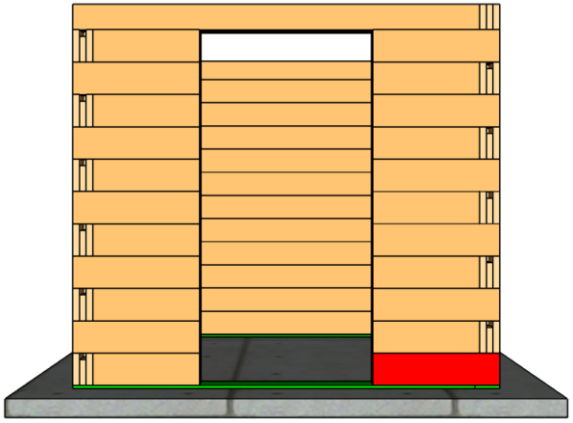
Bottom Course Wall Beams (Short)

One bottom beam is made from three pieces of lumber that were cross cut to be 28-1/2” long. Two of the pieces of lumber are full width (8” nominal, 7-1/4” actual) and one was rip cut to 5-3/4” wide.



Dimensions: bottom course wall beam (28-1/2” long)

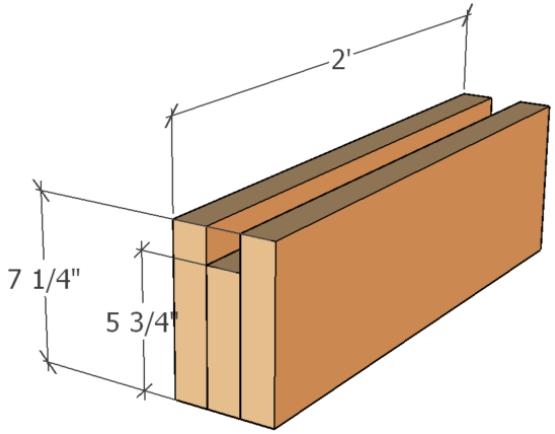
Create this bottom beam by gluing and nailing the three pieces of lumber together.



Location: bottom course wall beam (28-1/2” long)

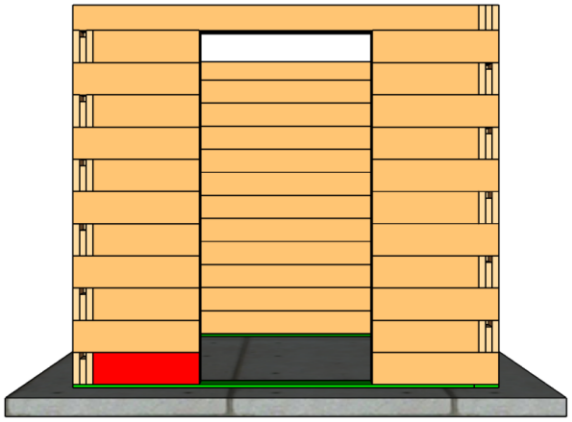
A second short beam is made from three pieces of lumber that were cross cut to 24” Two of the pieces

of lumber are full width and one was rip cut to 5-3/4" wide.



Dimensions: bottom course wall beam (24" long)

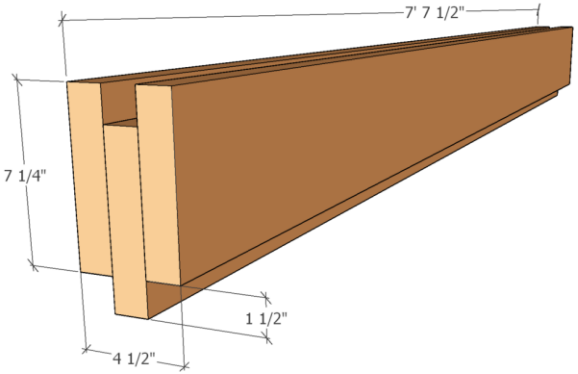
Create this bottom beam by gluing and nailing the three pieces of lumber together.



Location: bottom course wall beam (24" long)

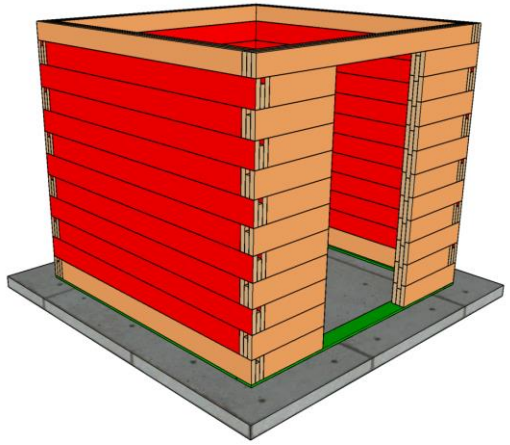
Middle Courses Wall Beams (Long)

Thirty middle beams are made from three pieces of lumber that were cross cut to be 91-1/2" long. All three pieces of lumber will be 7-1/4" wide (nominal 2x8s).



Dimensions: middle courses of wall beams (91-1/2" long)

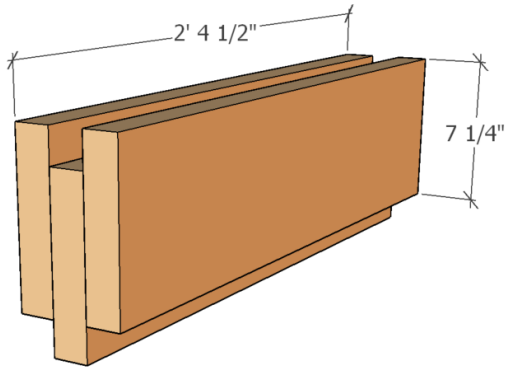
Create these middle wall beams by gluing and nailing the three pieces of lumber together.



Location: middle courses of wall beams (91-1/2" long)

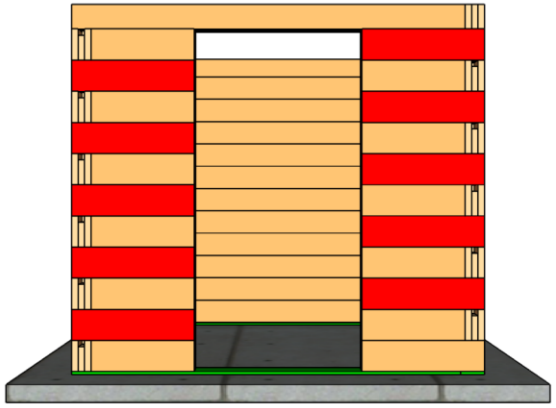
Middle Courses Wall Beams (Short)

Ten middle beams are made from three pieces of lumber that were cross cut to be 28-1/2" long. All three pieces of lumber will be 7-1/4" wide.



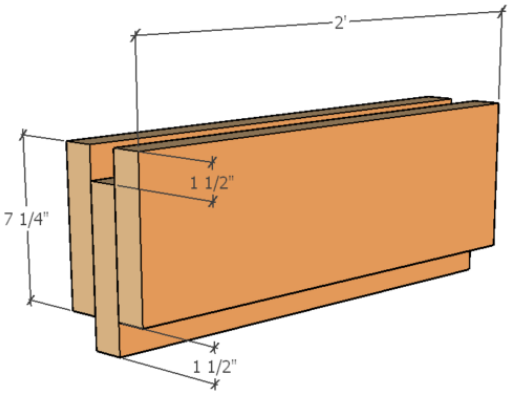
Dimensions: middle courses of wall beams (28-1/2" long)

Create these middle of wall beams by gluing and nailing the three pieces of lumber together.



Location: middle courses of wall beams (28-1/2" long)

Ten middle beams are made from three pieces of lumber that were cross cut to 24" long. All three pieces of lumber are 7-1/4" wide.



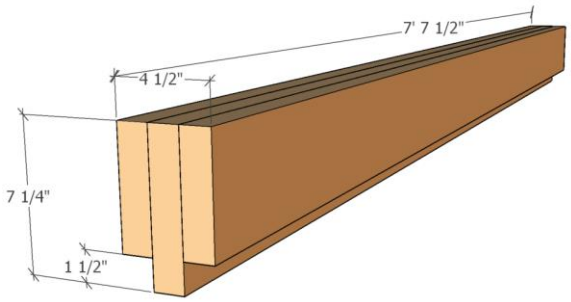
Dimensions: middle courses of wall beams (24” long)

Create these middle of wall beams by gluing and nailing the three pieces of lumber together.

Location: middle courses of wall beams (24” long)

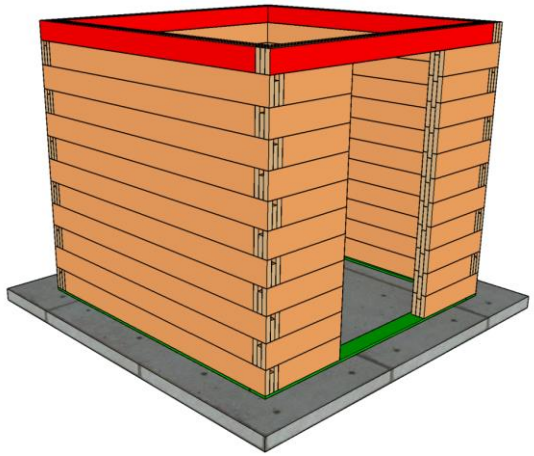
Top Course Wall Beams

The four top beams are made from three pieces of lumber that were cross cut to 91-1/2” long. Two of the pieces of lumber were rip cut to 5-3/4” wide and one is full width.



Dimensions: top course of wall beams

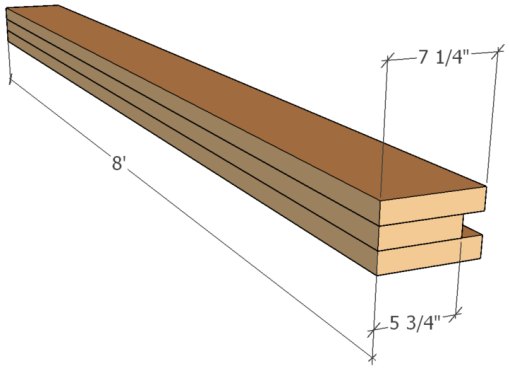
Create the top beams by gluing and nailing the three pieces of lumber together.



Location: top course of wall beams

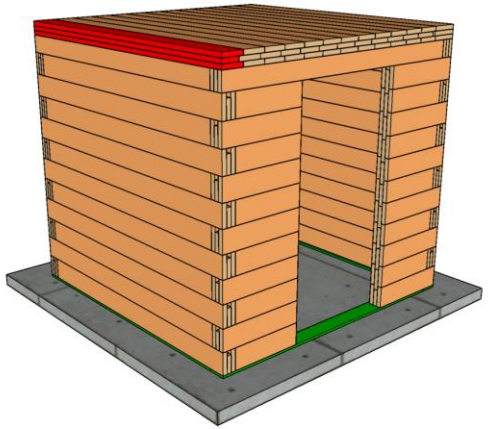
Roof Panel Beams

All lumber used for the roof beams are 8 ft. long. Rip cut one of the pieces of lumber to 5-3/4” wide. Two of the pieces of lumber are full width



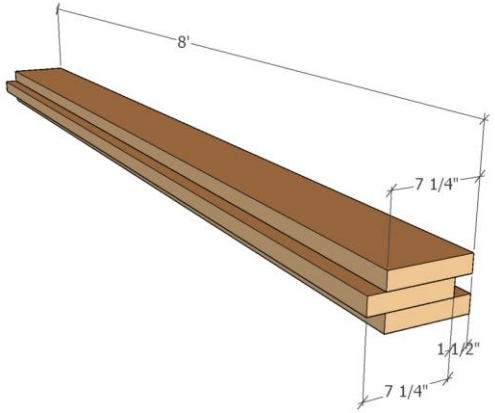
Dimensions: first roof beam

Create this ceiling beam by gluing and nailing the three pieces of lumber together.



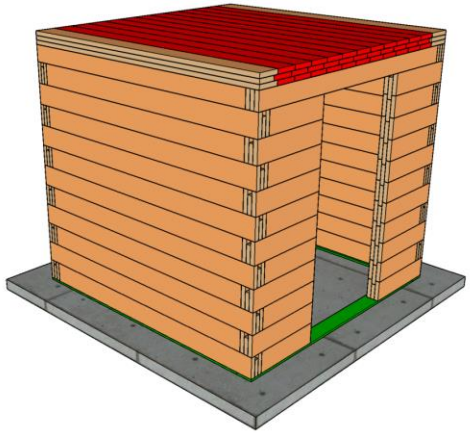
Location: first roof beam

The next eleven roof beams are made from three pieces of lumber that are offset as was done with the wall beams. All three pieces of lumber are 7-1/4” wide.



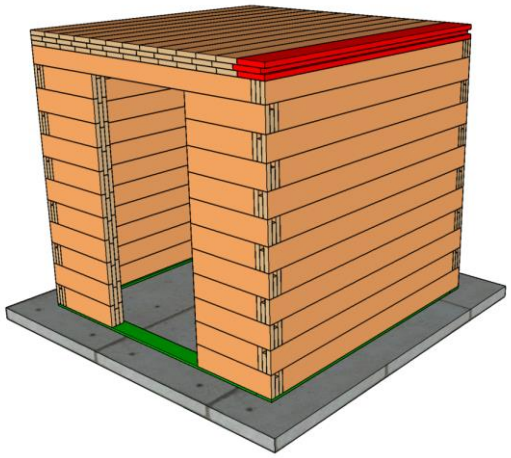
Dimensions: Eleven 2x8 roof beams

Create these roof beams by gluing and nailing the three pieces of lumber together.



Location: Eleven 2x8 roof beams

The last roof beam is custom fit and will be covered in the next section.



Location: Final, custom-fit, beam

Final Beam List

- Four top, 91-1/2” long
- Three bottom, 91-1/2” long
- One bottom, 28-1/2” long
- One bottom, 24” long
- Thirty middle, 91-1/2” long
- Ten middle, 28-1/2 long
- Ten middle, 24” long
- Twelve roof, 8 ft. long

SECTION 3: ASSEMBLING THE WALLS

The walls are built by stacking courses of beams around the perimeter of the shelter, until 12 courses have been laid. Each beam connects to the one above and below in a tongue-and-groove fashion, with construction adhesive securing them together. The corners are interlocked in a log cabin manner and then reinforced with long screws. One of the walls will have an opening for the door which extends from the floor through the eleventh course (one full-length beam will be above the opening). The walls rest on a layer of 1x6 preservative-treated boards to prevent decay in the first course of beams. The final step is to install the door head and side jambs.

Lumber dimensions can vary slightly, so it is important to check that the shelter remains square and plumb during the construction process. Assure that each row of wall beams is level before adding the next row.

Materials Needed In This Section:

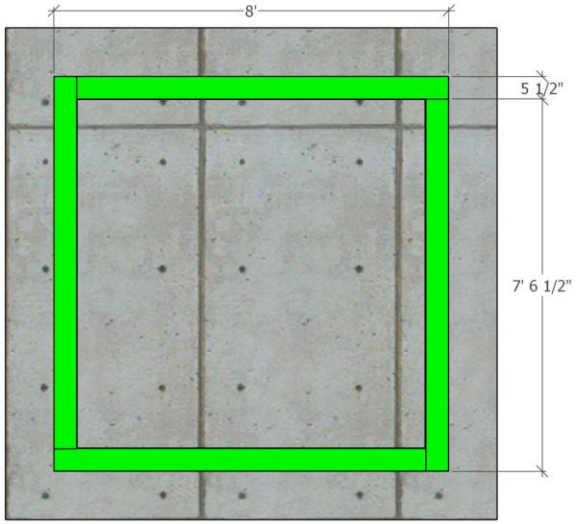
- 4 preservative-treated 1x6s, 8 ft. long
- 37 triple beams, 96” long
- 11 triple beams, 28-1/2” long
- 11 triple beams, 24” long
- 3 2x6s, 96” long
- 96 wood screws, 8” long
- Construction adhesive

Tools Needed For This Section:

- Hand saw
- Level
- Caulking gun
- Hammer
- Power drill
- Level

Base

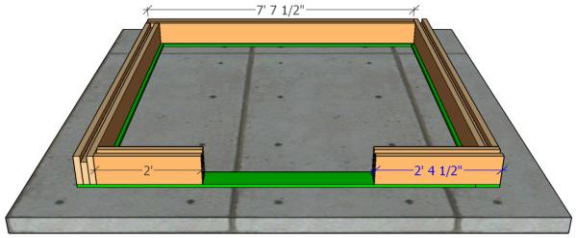
Cut each of the four preservative treated 1x6s to 90.5” long and lay on the floor to serve as the base for the shelter’s walls. Assure that the base is square and level. Position the shelter on slab so there is adequate distance for door swing to allow easy entry and egress and room to work on all sides.



Preservative treaded base

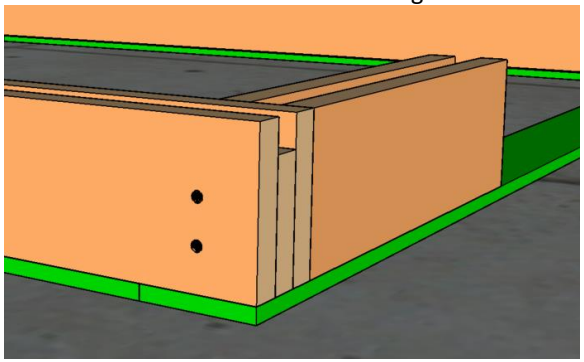
Walls

The first course consists of three beams that are 91-1/2” long, one beam that is 28-1/2” long, and one beam that is 24” long, all with one flat face (bottom) and a groove on the opposite (top) face. Lay the first course of beams down with the flat face down on the preservative treated 1x6 base and the 1-1/2” groove facing up. Note that there will be a 39” opening for the entrance.



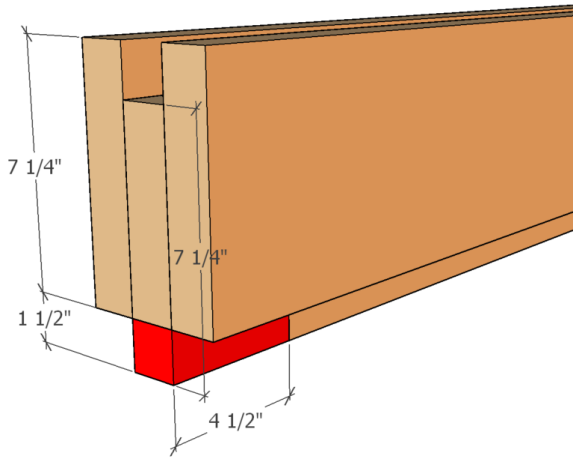
First course of beams over preservative treated base

Reinforce the corners with two 8” long screws.

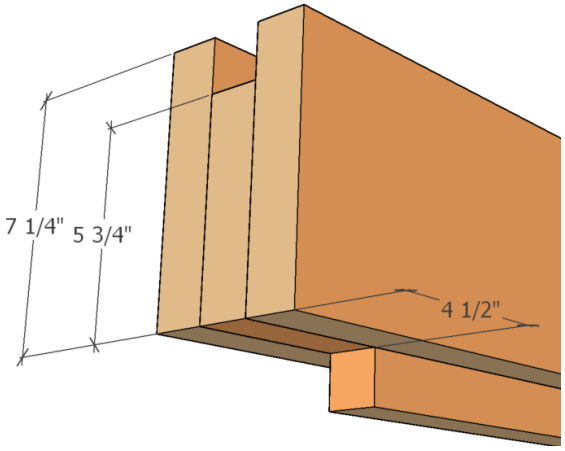


Reinforcing screws at corners

The second course consist of five beams just like the first, except the bottom face is not flat but instead has a protruding 1-1/2” tongue. For the 91-1/2” long and the 28-1/2” long beams: cut off a 4-1/2” long section of the tongue from one end. A reciprocating saw or handsaw works well for this.



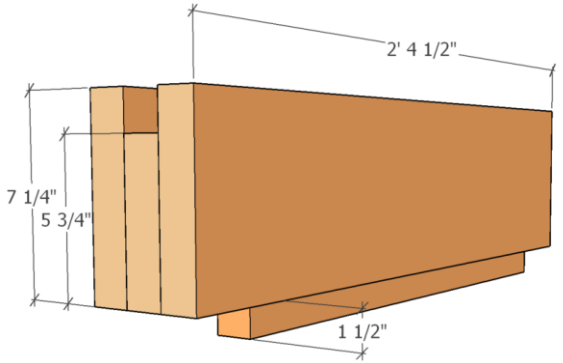
Dimensions: 4-1/2” cutout at the end of 91-1/2” beam



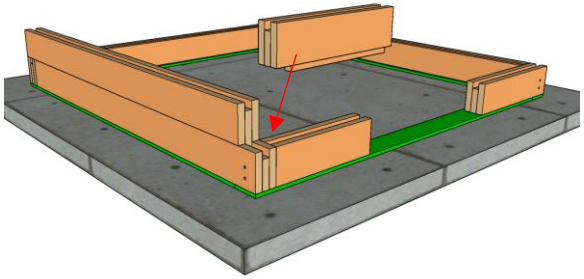
Long beam with cutout removed

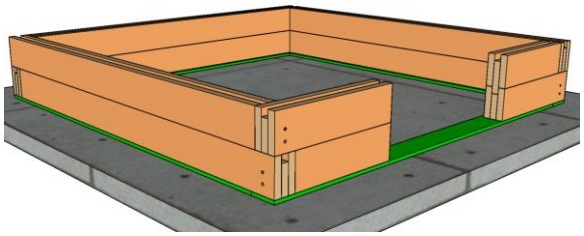
Apply construction adhesive to the inside faces of the groove of the first layer as well as to the abutting beam ends, and lay each beam in place so that the corners overlap. The 28-1/2” long beam of the second course rests on top of the 24” long beam in the first course to keep the door jamb plumb.

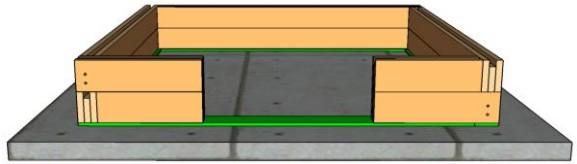
Hammer the top of the second course so that it fits tightly into the first course and the top is level.



28-1/2” beam with notch removed

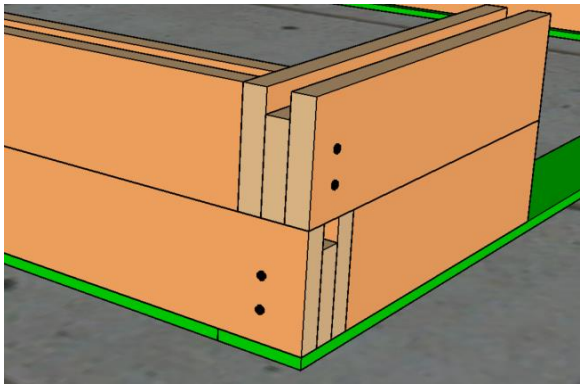






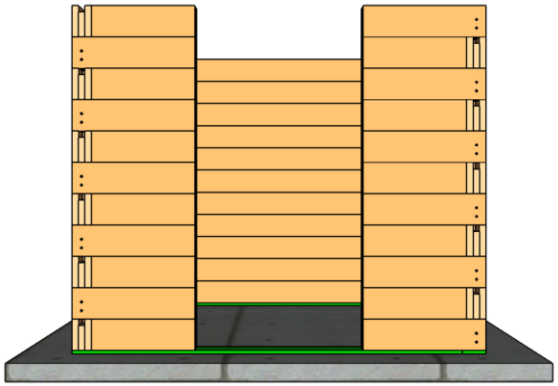
Second course of beams installed over first course – note alternating 24” and 28-1/2” beams

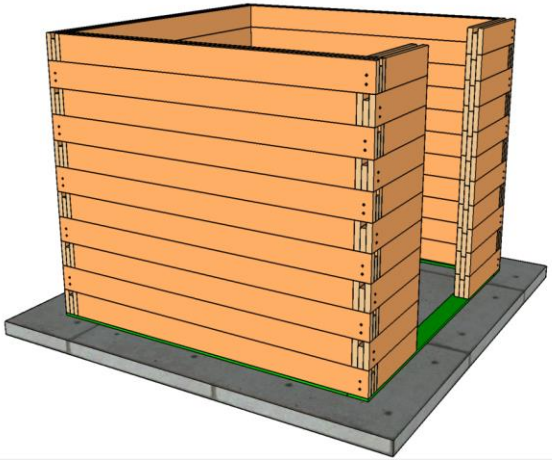
Reinforce the corners with two 8” long screws. Make sure to apply adhesive to the abutting beam ends.



Reinforcing screws at corners

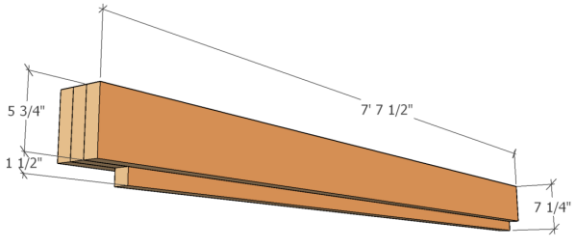
Repeat for the next 10 courses ensuring the corners overlap and that each course is level and the door opening plumb. Shim courses to assure level, if necessary. If there are height restrictions (basement) a course can be eliminated. Note, however, that the door and associated sheet metal sizes will need to be modified.





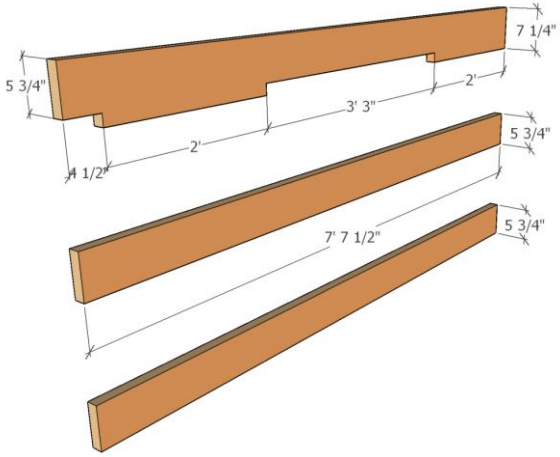
First eleven courses of beams installed

Only the four top beams rema” They are all 91-1/2” long, and have one flat face (top) and a protruding 1-1/2” tongue on the opposite (bottom) face. Cut off a 4-1/2” section of the tongue from one end of each beam.

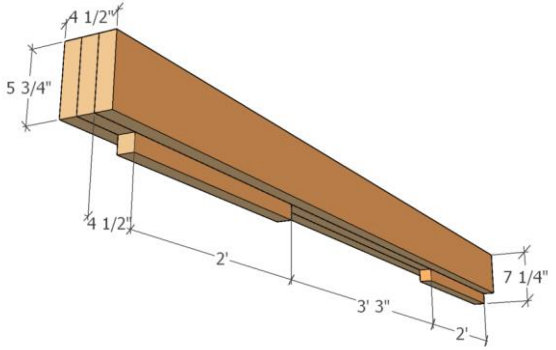


Notch cut out of three top course beams

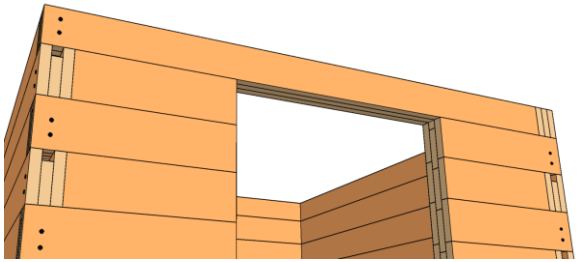
For top beam over the entrance, remove an additional portion of the tongue to make a flat surface for the entrance header. The two outer boards in the beam above the door are 5-3/4” tall.

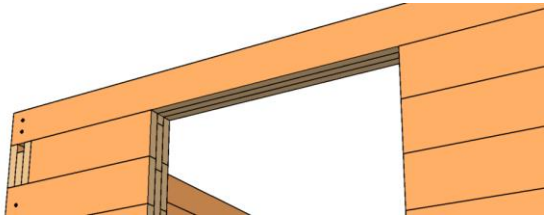


Dimensions of beam above entrance with additional notch removed to make flat entrance



Beam above entrance





Flat entrance header

Install final course following the same procedures.

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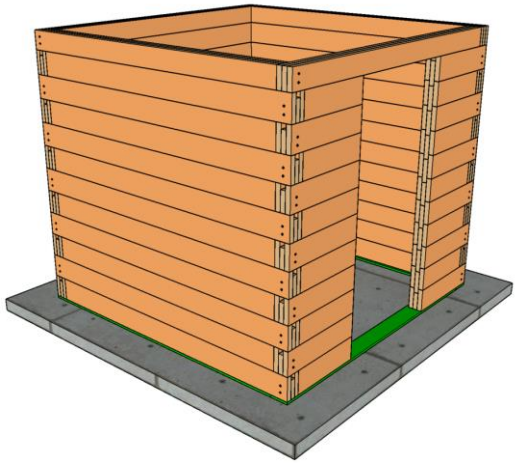
Final course in place

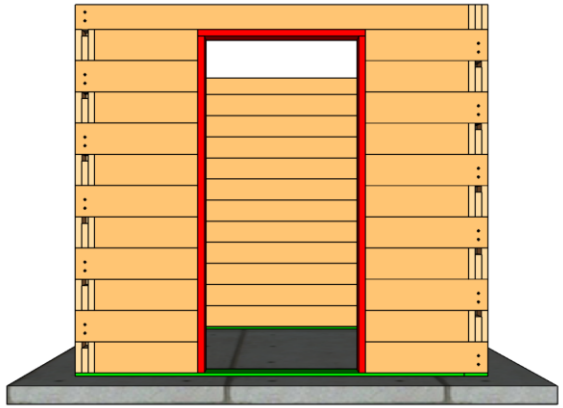
The wall height is 85-1/2” (not including the preservative treated base). The entrance opening (not including the preservative treated base) measures 79-3/4” tall by 39 inches wide.



Walls completely built up

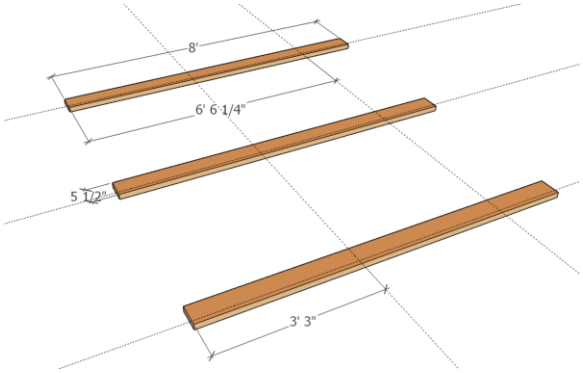
Entrance Header and Jambs

Rip and cross-cut the three 2x6s to make the header and jambs for the entrance.

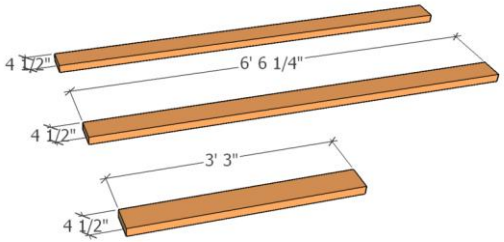


Location: entrance header and jamb

All three 2x6 are rip-cut to match the wall thickness (4-1/2”). Two of the 2x6s are cross cut to length for the door jambs and one 2x6 is cross cut to a length for the header.

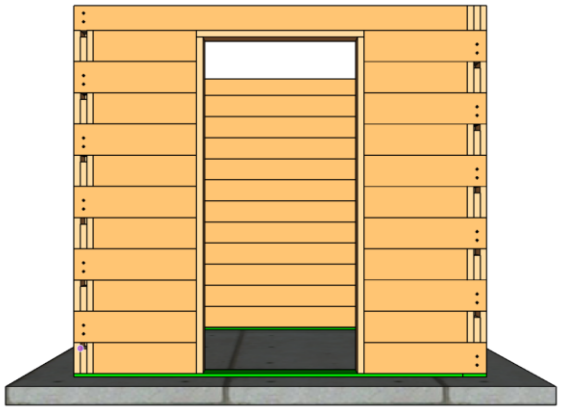


Cross cuts (78-1/2” and 39”) and rip cuts (4-1/2”) for entrance header and jambs



Dimensions of entrance header and jambs

Securely nail the header and jambs in place beginning with the header, by using two framing nails into each wall beam



Shelter with all beams and entrance header and jambs

SECTION 4: CONSTRUCTING THE ROOF PANEL

The roof panel is composed of 12 triple beams made from 2x8s, and one beam made from 2x10s. The 2x8 triple beams were constructed in Section 2. Construction of the 2x10 triple beam is discussed at the end of this section. Install all 2x8 roof beams before constructing the 2x10 triple beam.

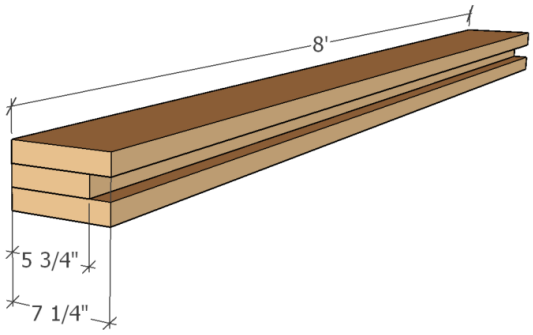
Materials Needed In This Section:

- 12 2x8 triple beams, 96” long
- 3 2x10s, 96” long
- 16d nails
- Construction adhesive
- 52 wood screws, 8” long

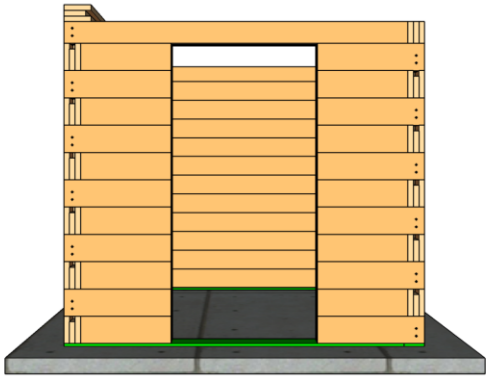
Tools Needed For This Section:

- Measuring tape
- Circular saw
- Sawhorses
- Caulking gun
- Woodworking clamps
- Pneumatic framing nail gun
- Hammer
- Drill

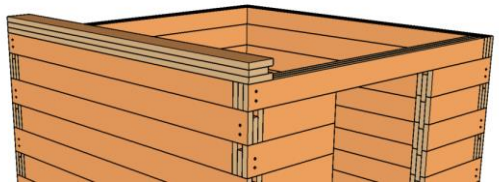
The first roof beam is 96” long, has one face that is flat while the other has a 1-1/2” groove. Lay the beam on top of one wall so that the flat face is flush with exterior surface of the wall below it and the two ends of the beam are also flush with the walls below. [Note: If there is a height restriction, the ceiling beams may need to be slid into place horizontally from below.]



Dimension: first roof beam (note the flat edge)

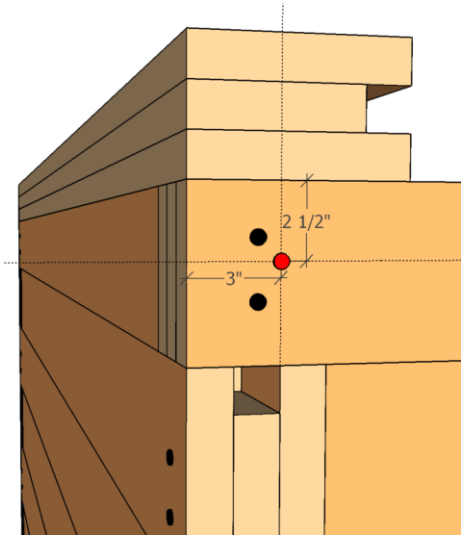


Location: first roof beam

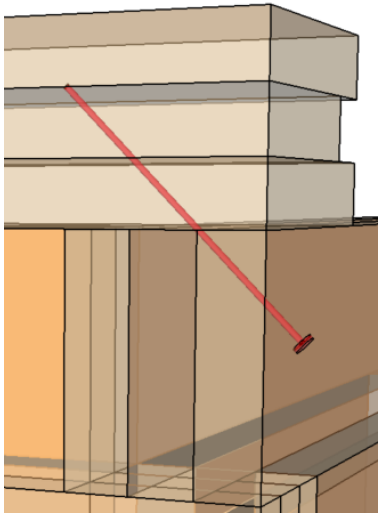


Location: first roof beam (note that flat edge is flush with wall below as are the ends of the beam)

Fasten the beam in place by driving two 8” screws up at 45 degree angles through the walls below each end. The screws penetrate the wall and beam, joining the two together.

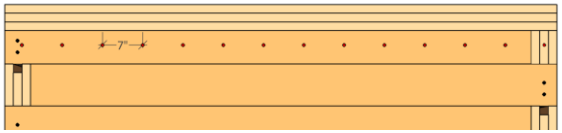


Location: screw (red) to fasten end of first roof beam



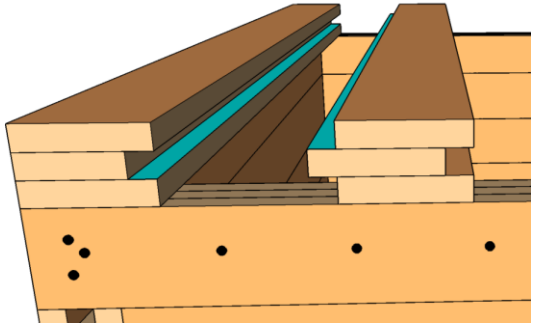
Screw to fasten roof beams are angled 45°

Use 14 screws spaced approximately 7” o.c. to attach the beam to the wall below its full length.



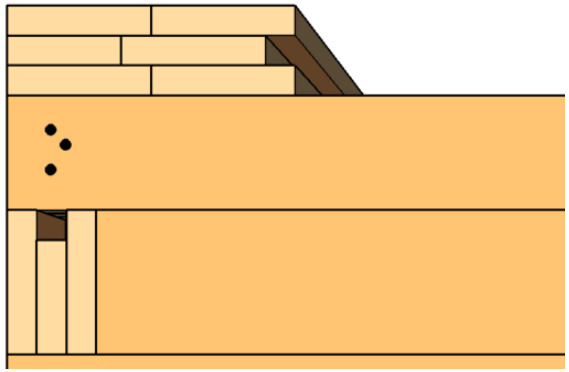
14 screws along length of first ceiling beam, spaced 7-1/4” o.c.

As shown in the accompanying video, apply construction adhesive to the inside edges of the grooved face of first beam and tongue of the second beam (blue below). Note that adhesive applied to the bottom of the groove is not as effective as adhesive applied to the mating surfaces shown.

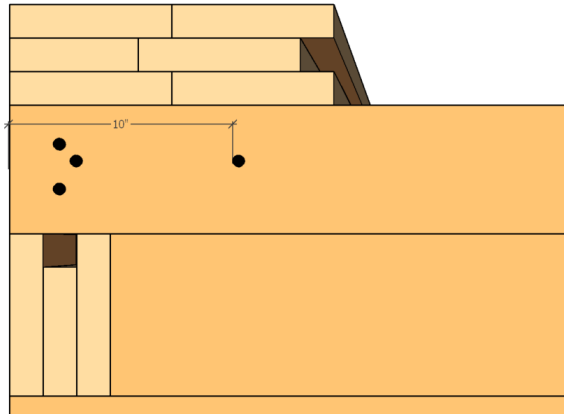


Construction adhesive between first and second roof beams

Slide the second beam into place so that its tongue fits into the groove. Hammer the second beam for a tight fit. Adjust the second beam so that its two ends are flush with the walls below. Fasten the second beam in place using two screws driven up at 45 degree angles through the walls below each end.

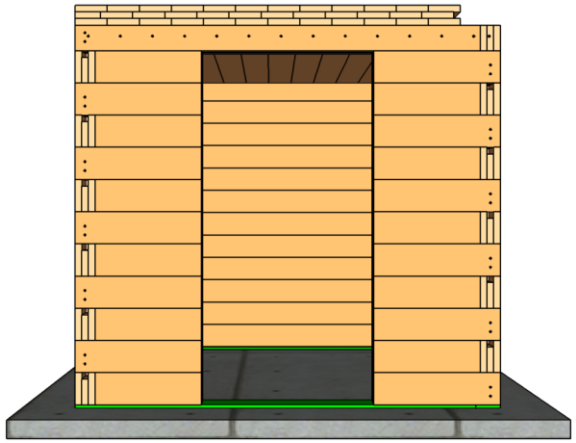


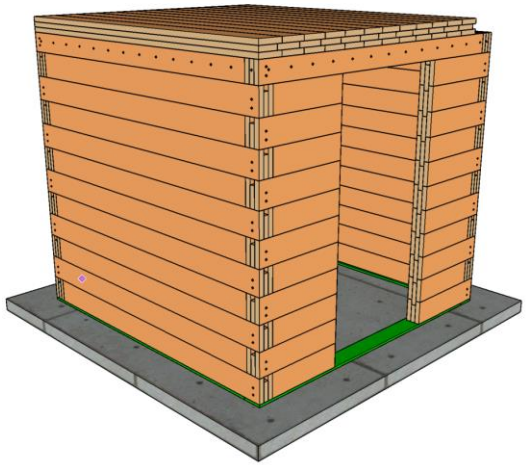
First and second roof beams



Location of screw to fasten end of second roof beam – note that screw is locate approximately at middle of ceiling beam above and must be angled 45° up

Install the remaining ten roof beams in place following the same procedure. Assure that each beam is installed parallel to the shelter walls. Doing so will assure that the last ceiling beam doesn’t end up wedge shaped and difficult to fabricate and install.



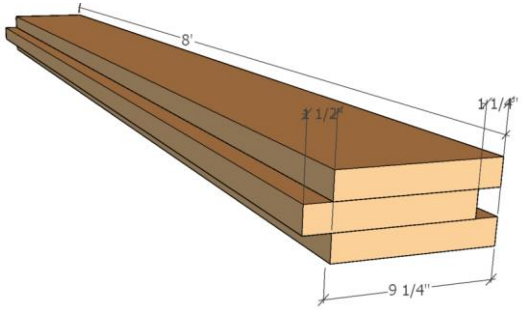


First twelve ceiling beams installed

The roof panel must extend to the outer edge of each wall (with no overhang). This assures a tight fit between the roof beams and the exterior wall plywood, which helps secure the roof to the walls. Because the 12 2x8 triple beams may not mate up without some gaps, the final roof beam is cut to a

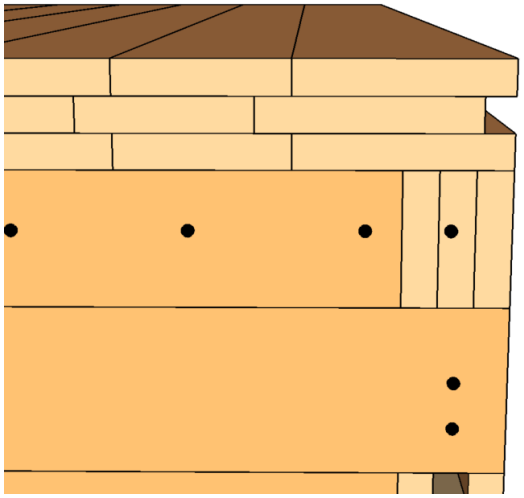
custom width from three 96” long 2x10s (actual dimensions 1.5” x 9.25 in).

After installing the first twelve roof beams, measure the space left and rip-cut the 2x10’s to fill the remaining width.

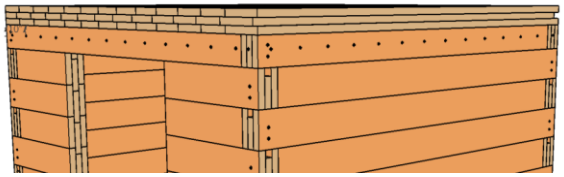


Dimensions: final ceiling beam custom made from 2x10s

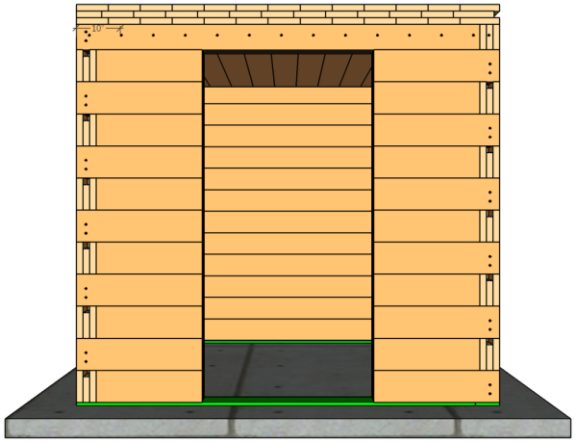
Construct the final beam to fit the opening to the edge of the wall.



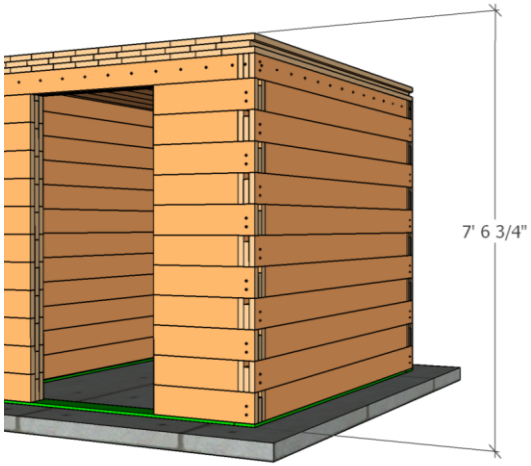
Screws used to fasten ends of final (custom) roof beam



Screws along the length of final roof beam



All thirteen roof beams installed



Final shelter height

The shelter height (wall + roof panel + preservative treated base) is 90.75 inches.

SECTION 5: ATTACHING THE SHEATHING

The shelter's sheathing provides helps the shelter withstand the impact force of flying debris and is necessary to tie the walls and ceiling together. For this design, four sheets of plywood are attached to each wall, two on the interior and two on the exterior. Two sheets of plywood are attached to the interior of the ceiling. If the location of the shelter allows access to the top of the ceiling, two sheets of plywood may be attached to the exterior of the ceiling.

Materials Needed In This Section:

- 18 sheets of 23/32 plywood, 48" x 96"
- 16d nails
- Construction adhesive

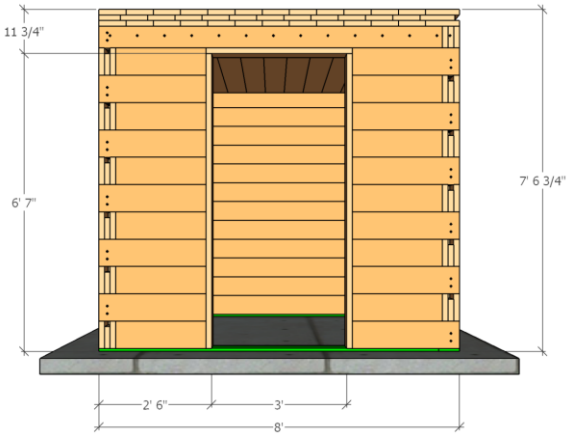
Tools Needed For This Section:

- Measuring tape
- Circular saw
- Sawhorses
- Pneumatic framing nail gun

Note: Though exact dimensions of plywood sheathing are given, it is best to measure the walls as constructed and cut sheathing to fit.

Exterior Surfaces

With the doorway jambs and roof beams in place, the tornado shelter measures 90-3/4" tall (7' 6-3/4") and 96" wide (8 feet). The doorway is 36" wide and 79" tall (6' 7") from the slab.

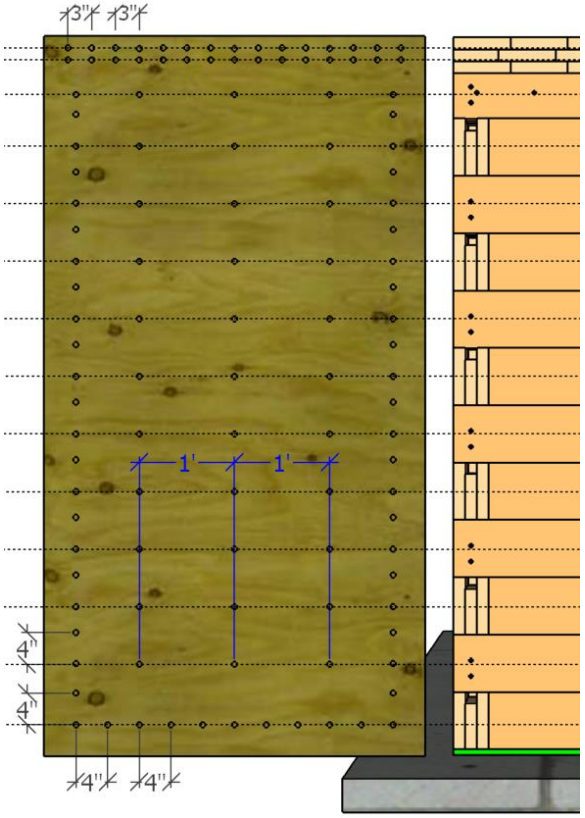


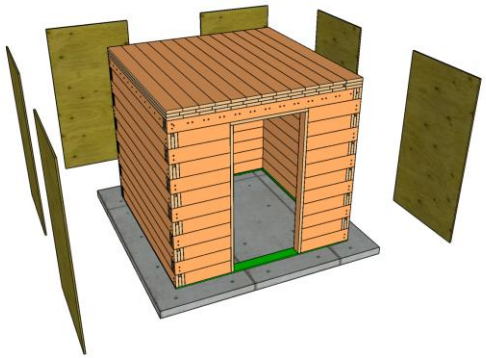
Shelter dimensions with wall and ceiling beams installed

Create cutting guides on the six sheets of plywood that will be the exterior sheathing of the three non-entrance walls. Cut the sheets to size.

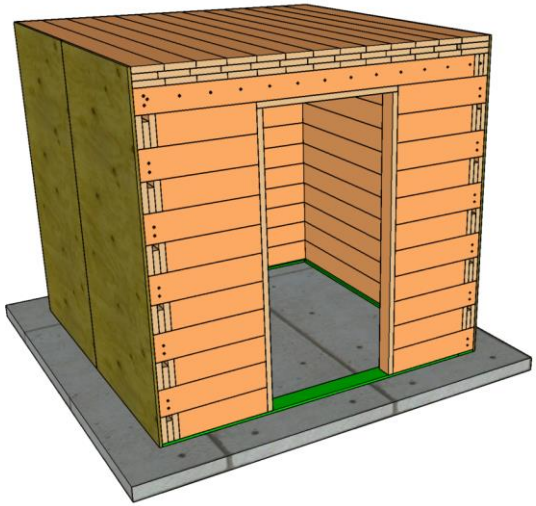
Dimensions: exterior sheathing (not including entrance wall)

Install each sheet on one half of the exterior surface of a non-entrance wall. Each sheet is attached by applying generous beads of construction adhesive to each wall beam and to the ceiling beams, and then nailing the plywood in place. One row of 16d nails are nailed to each beam in the wall (12" o.c.). Nails are driven at approximately 4" o.c. around the perimeter of the plywood except where the plywood overlaps the ceiling beams. Two rows of nails are driven at 3" o.c. into the 2x8's of the ceiling beams. Shoot these two rows of nails into the center of the top two 2x8's of the ceiling beams. The rows of field nails should align with the center of each beam row as shown below.



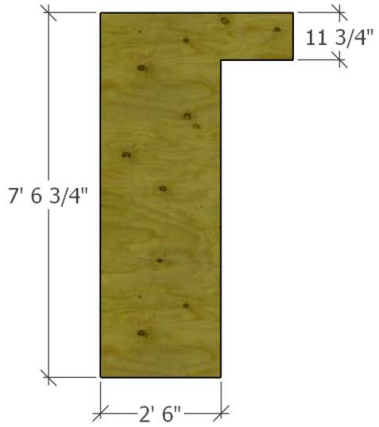


Location: exterior sheathing (not including entrance wall)



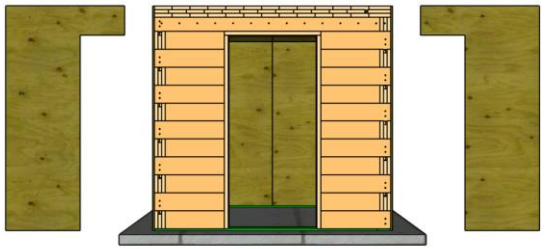
Exterior sheathing (not including entrance wall) installed

Cut the sheets to size for the entrance wall exterior.



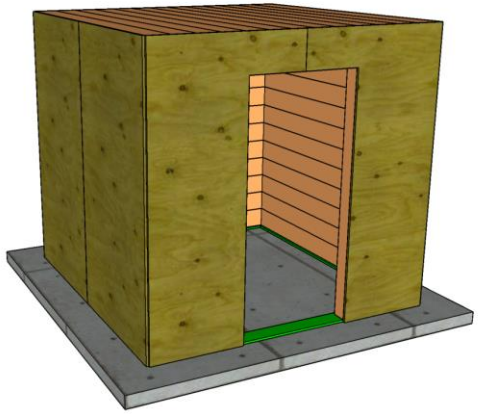
Dimensions: exterior sheathing for entrance wall

Install each sheet on one half of the exterior surface of the entrance wall.

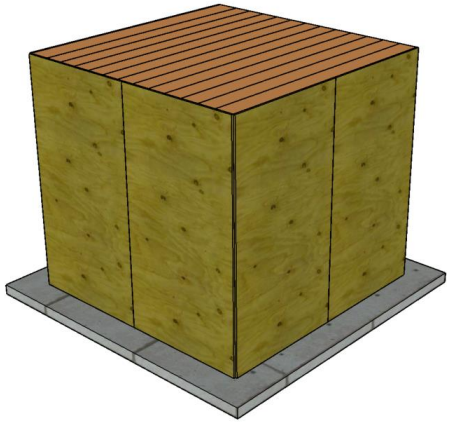


Location: exterior sheathing for entrance wall

Note: Sheathing is not specified for the exterior of the ceiling unless access for nailing is provided. If possible to nail sheathing to the exterior of the ceiling it will provide added protection.



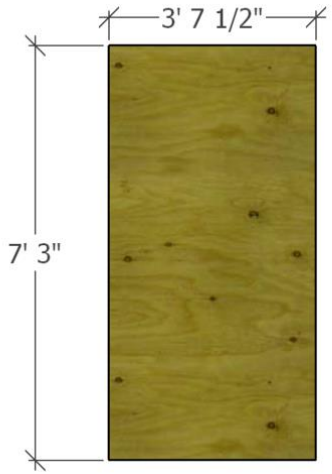
Front view of shelter with exterior sheathing installed



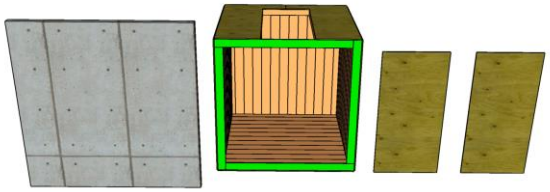
Rear view of shelter with exterior sheathing installed

Interior Surfaces

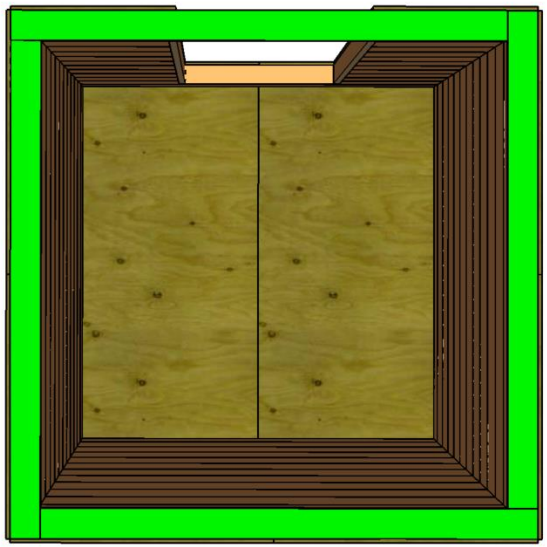
Measure ceiling dimensions and cut two sheets of plywood that will be the sheathing of the interior ceiling. If necessary, a drywall lift can be used to install the sheets.



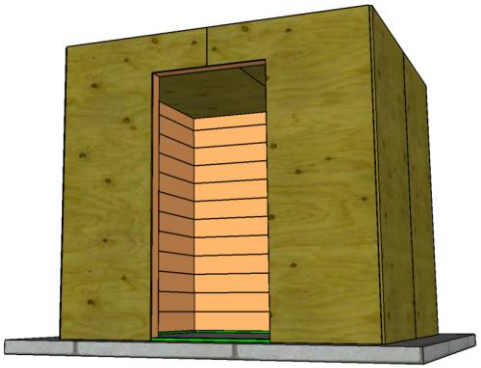
Dimensions: interior ceiling sheathing



View of shelter from below with slab moved to side, ceiling sheathing to the right



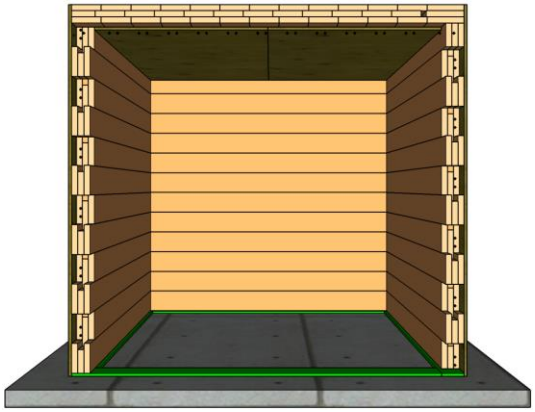
Interior ceiling sheathing installed (view from below, green is preservative treated base of walls)

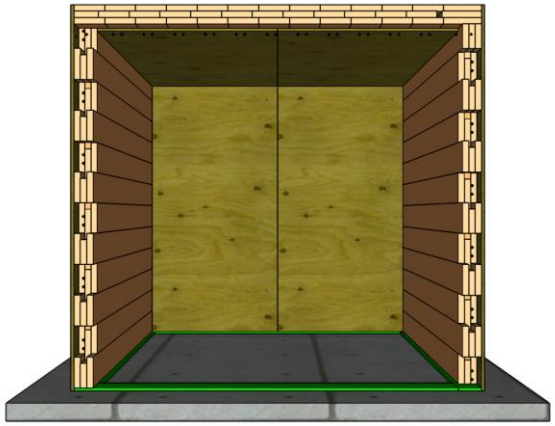


Shelter with interior ceiling sheathing installed

Measure interior and cut six sheets of plywood that will be the interior sheathing of the three non-entrance walls. Install like exterior sheathing.

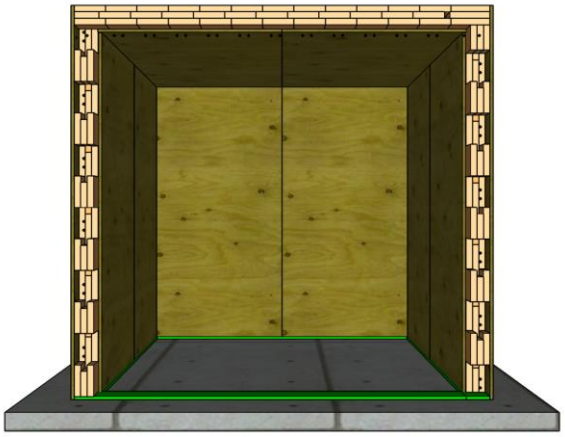
You can begin with the interior back wall followed by the interior side walls.





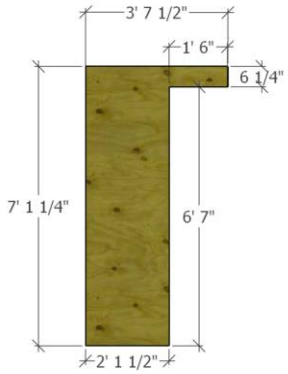
Location: interior sheathing for back wall opposite entrance

.



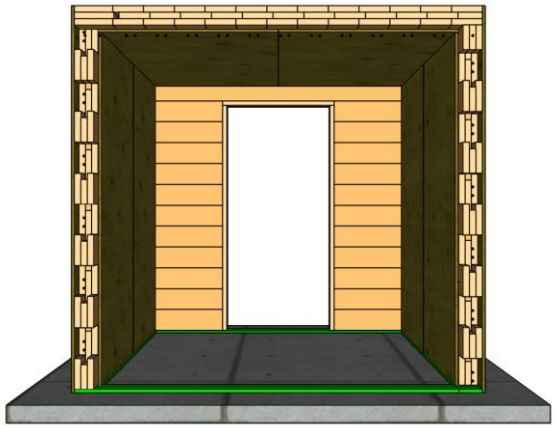
Location: interior sheathing for walls adjacent to entrance

Measure interior and cut two sheets of plywood that will be the interior sheathing of the entrance wall.

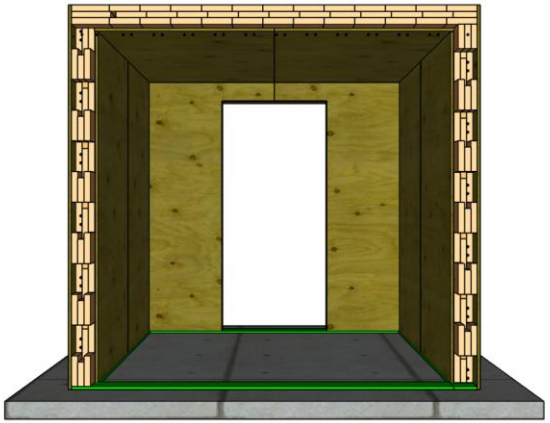


Dimensions: interior sheathing for entrance wall

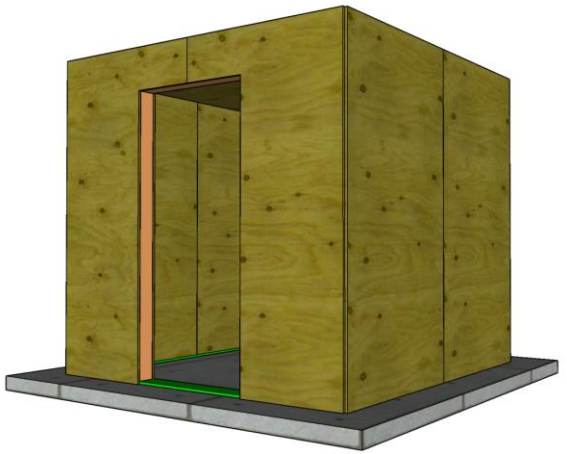
Install each sheet on one half of the interior surface of the entrance wall.



Interior entrance wall



Location: interior sheathing for entrance wall



Shelter with full interior and exterior sheathing

Nailing pattern and adhesive for interior and exterior surfaces are identical: Each plywood sheet is attached by applying generous beads of construction adhesive to the wall surface and then nailing the plywood in place. Two generous beads of adhesive should be applied to each beam and under each plywood edge. Extra adhesive should be applied to the ends and sides of the roof beams as well as to the door jambs.

SECTION 6: BUILDING AND HANGING THE DOOR

The door is made up of five layers: three sheets of plywood bolted between two layers of sheet metal. The door is an overlay door that swings outward. The design was chosen in order to effectively transfer the impact force of an airborne 'missile' from the door to the wall. As noted earlier, make sure your local jurisdiction allows outswing doors on shelters before initiating this project.

Materials Needed In This Section:

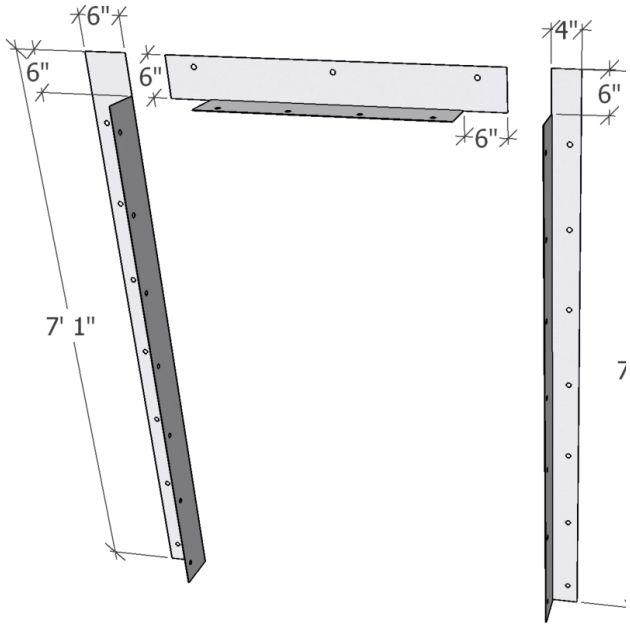
- 3 sheets of 23/32 plywood, 48" x 96"
- 3 custom fabricated 14 gauge steel angles
- 2 sheets of cold rolled (or galvanized) 18 GA steel, 42" x 84"
- 1 2x4, 96" long
- 15 bolts with nuts and washers, 3/8" diameter and 2-1/2" length
- 3 gate latches with 5/8 dia." slide bolts
- 3 door hinges, 3/4" bolt hook and strap hinge
- 6 bolts with nuts and washers, 3/8" diameter, 2-1/2" length
- 3 Simpson Strong Tie HL53 heavy angles (or equivalent)
- 85 lag bolts, 3/8" diameter, 3" long

Tools Needed For This Section:

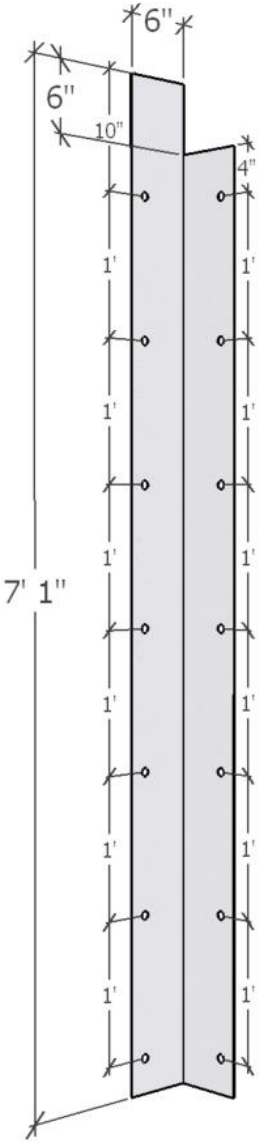
- Drill
- 3/8" diameter drill bit
- 1/2" diameter drill bit
- Woodworking clamps

Note: As shown, the steel sheathing is the exact same dimensions (42"x84') as the plywood. The door may be more comfortable to handle if you order the sheet steel ½" shorter in each dimension. This will prevent the possibility of the steel from slightly overhanging the edge of the plywood that can create a sharp edge to the door.

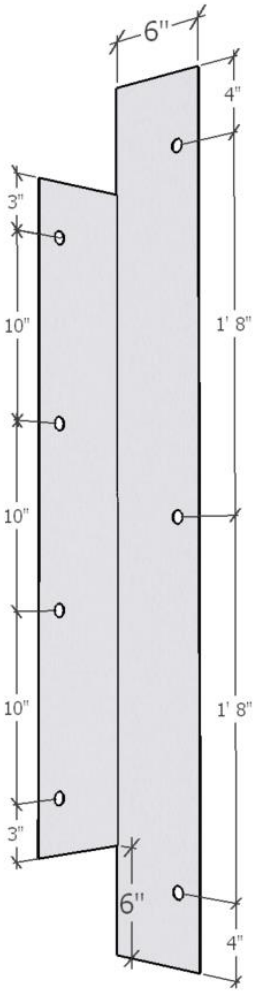
Install the custom-made jamb reinforcement angles made of 14 gauge steel in the shelter door opening.



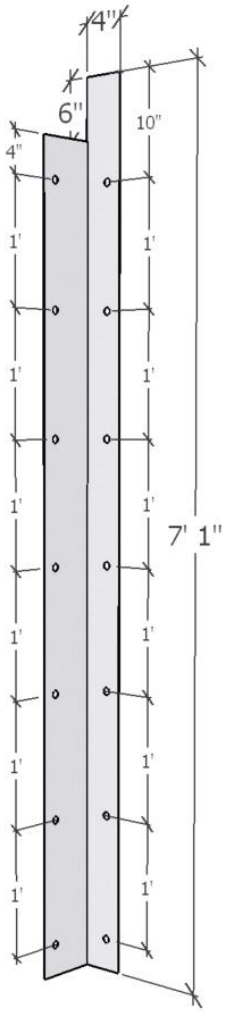
Three reinforcing sheet metal angles: 6" jamb angle, head angle, 4" jamb angle



Dimensions: detail of 6" jamb angle



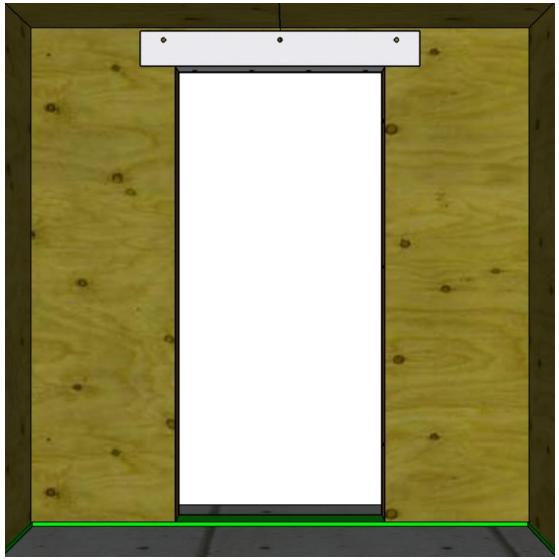
Dimensions: detail of head angle



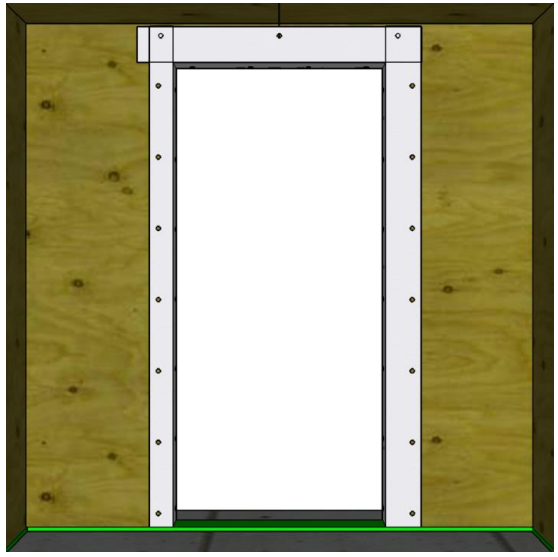
Dimensions: detail of 4" jamb angle

Use 3" lag bolts (3/8" diameter) to install the header angle first, followed by the two jamb angles.

Field drill a hole for a lag bolt where the jamb angles overlap the header angle.



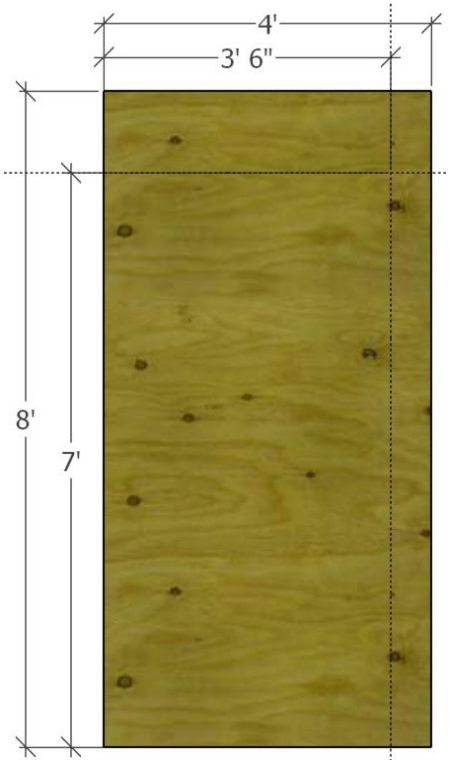
Location: first, reinforcing sheet metal angle on entrance header



Location: second, reinforcing sheet metal angles installed on the entrance jambs

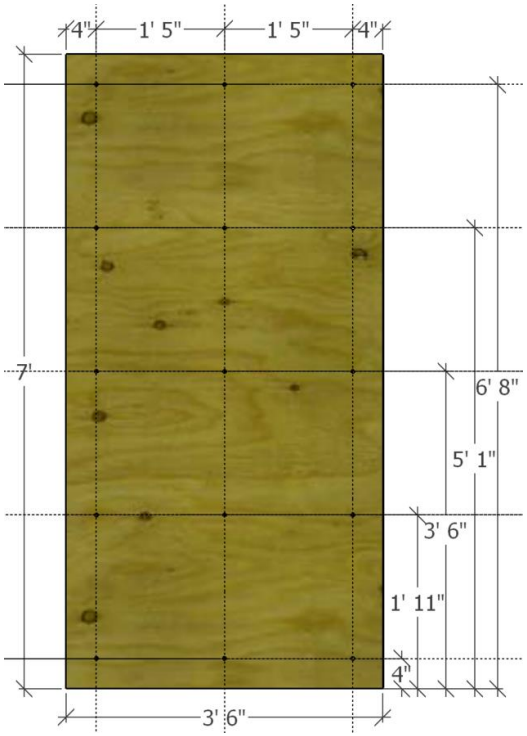
Next, build the shelter door.

Create cutting guides on three sheets of plywood. Cut the three sheets to size.

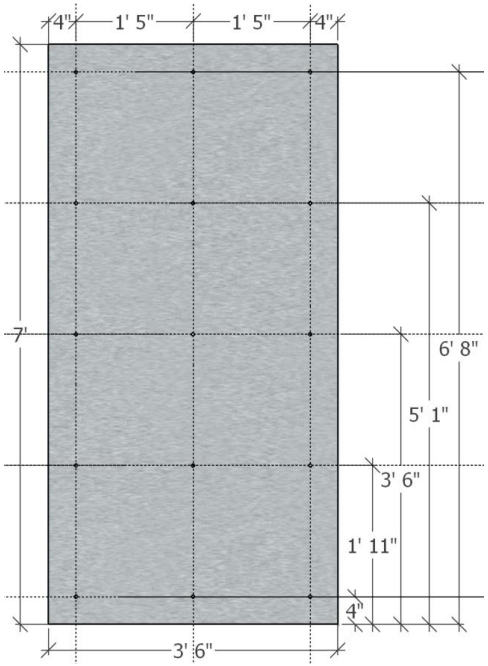


Cut lines on three plywood sheets for door

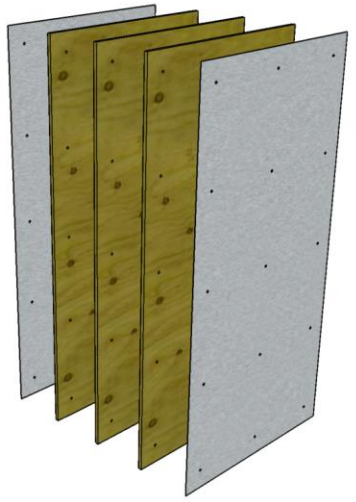
Lay one sheet of steel on sawhorses, then center the three sheets of plywood over the steel. Place the second sheet of steel on top of the plywood and center. Clamp together the five pieces making sure the door remains flat. Drill five rows of three bolt holes, 1/2” diameter through the five layers. Bolt together before unclamping.



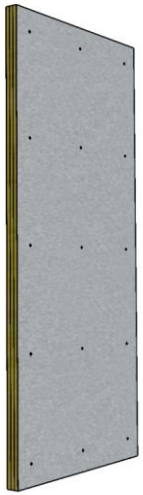
Location: fifteen 1/2” bolt holes on plywood



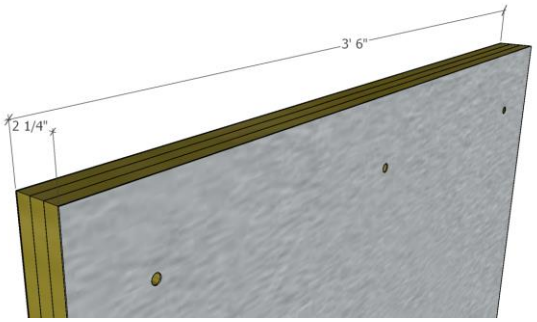
Location: fifteen 1/2" bolts holes in sheet metal skins



Five layers of door (3 plywood, 2 sheet metal)



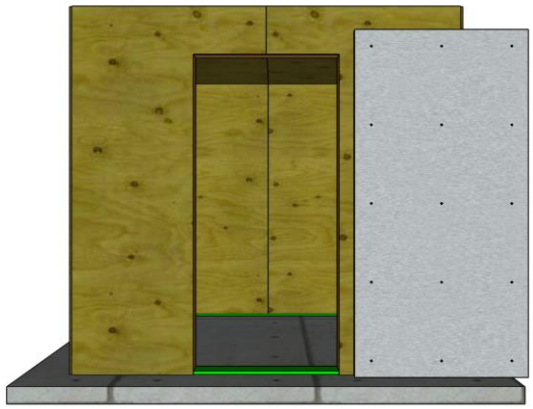
Door layers bolted together



Dimensions: completed door

Hanging the Door:

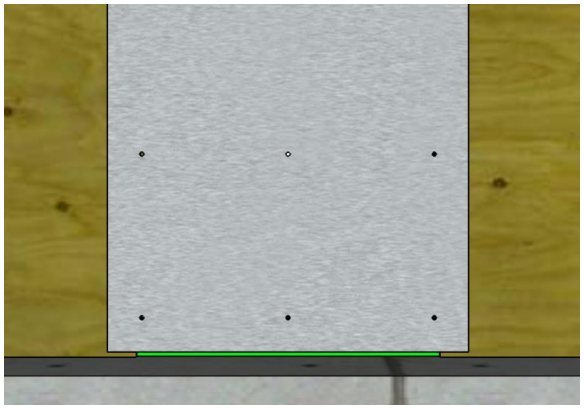
NOTE: the following sequence (**Option A**) requires that one person be inside the shelter while the door is being hung. This person will need a flashlight, wrenches, and nuts for the bolt hooks. Moving the door into place requires two people, so Option A is only possible if there are three installers.



Door next to open entrance

Shim the door up off the floor to allow clearance from the floor to swing when fully installed. This can be done with a scrap strip of plywood.

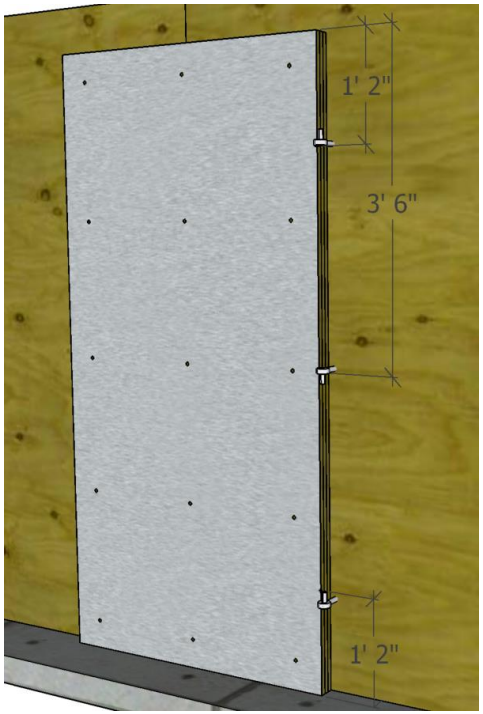
Temporarily secure the door in place over the entrance using a long screw driven into each door edge (see video).



Door raised off floor

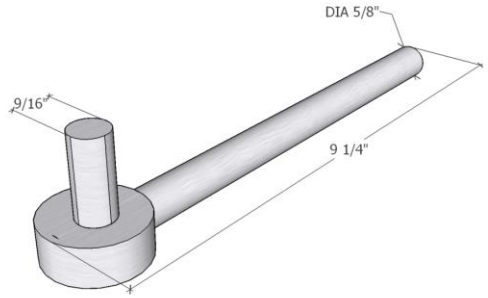
Drill three 3/4" diameter holes through the wall doors corresponding to the locations of the hinges.

The holes are located 5" to the right of the edge of the door opening. Locate the bolt hook holes 14" from the top of the door, at the center of the door, and 14" from the bottom of the door as show below. Take care to drill the hinge holes perpendicular to the wall face, otherwise the door may not swing smoothly. An easy way to do this is to have one person hold the drill and another hold a carpenters square against the wall and sight the drill. If you do this both horizontally and vertically and drill a little at a time, you can drill a perpendicular hole. Have the installer inside the shelter install the inside bolts of the hinge bolts. Adjust the protrusion of the bolts so the door hinge sits flat on the door fare. Tighten bolts from inside the shelter.



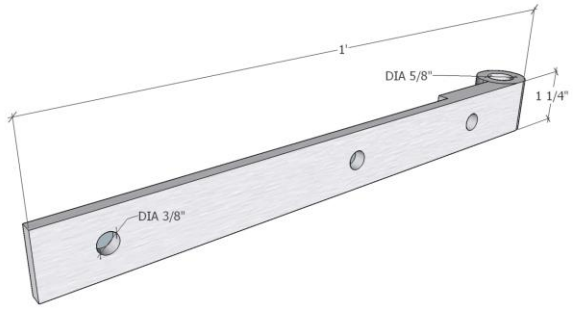
Location of bolt hooks.

Note that the middle bolt hook faces down so that the door cannot be lifted off by strong winds.

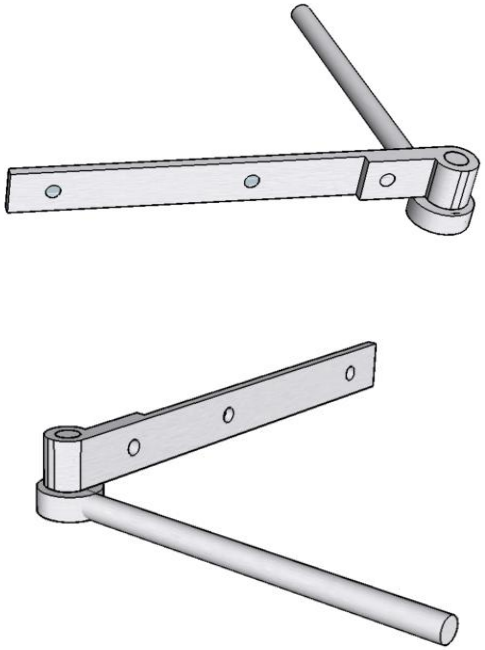


Dimensions: bolt hook (not shown: bolt threads and nuts used to secure bolt hook to the wall)

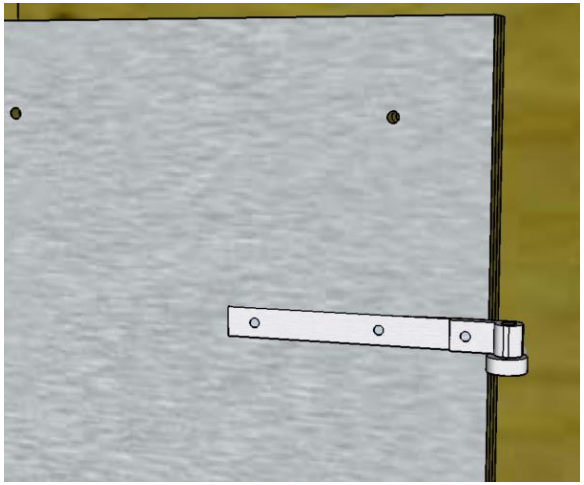
Hang the hinges on the bolt hooks and mark the location of each hinge's two outermost holes on the door surface.



Dimensions: hinge

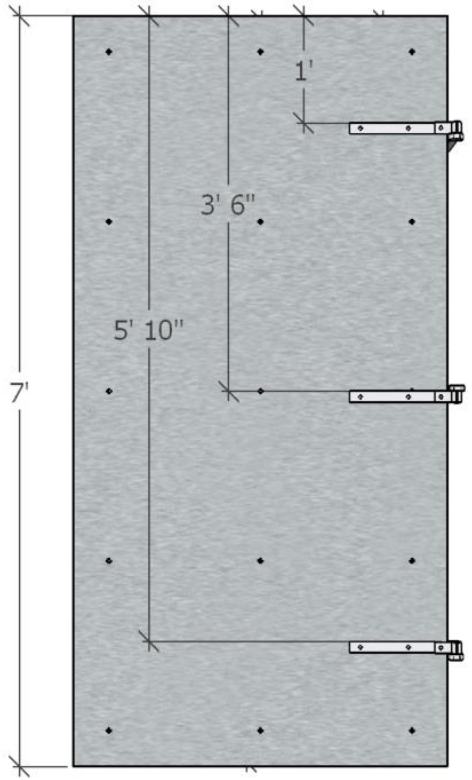


Hinge and bolt hook



Mark the two holes farthest from the bolt hook

Drill 3/8"" holes on the markings that correspond to the outermost holes on each hinge (six holes total, two per hinge). The hinges will be attached to the exterior surface of the door using 3/8" bolts.

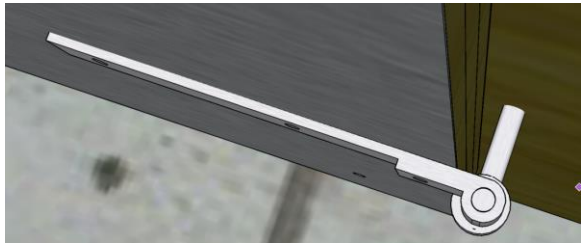


<u>Approximate</u> location of the hinges on the exterior surface of door. Ensure the hinges are level BEFORE drilling holes to attached them to exterior of door.

Attach each hinge with two 3/8" bolts but do not tighten the nuts on the interior of the door all the way until the last hinge is installed.

If there are only two installers or they simply prefer not to have one person inside the dark shelter for the duration of the installation, the door can be hung entirely from the outside (**Option B**) following this modified sequence:

1. DO NOT temporarily secure the door over the entrance as a first step. Instead, first locate and drill the three bolt hooks holes in the locations shown above. The holes must aligned vertically.
2. Insert a bolt hooks in the holes so that they protrude enough to accommodate the thickness of the door (2-1/4") once the hinges are in place. See image below.

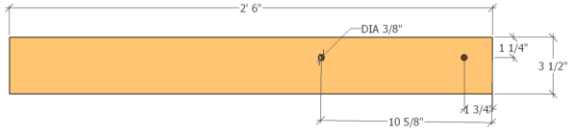


3. Hand tighten the nuts on the interior of the shelter to fix each bolt hook in place.
4. Shim the door off the floor and temporarily secure it over the shelter entrance.
5. Hang the hinges on the bolt hooks, level them on the exterior surface of the door and drill two 3/8" holes through the door for the hinge bolts.
6. Use 3/8" lag screws to temporarily attach the three hinges.
7. Carefully swing open the door and remove the shim.
8. Replace each lag screw, one by one, with a bolt and nut to permanently attach the hinges to the door.

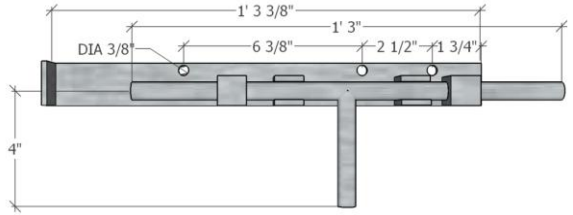
Next, install the three latch mechanisms on the interior surface of the door. These will be used to lock the door during a storm.

Cut a 2x4 into three segments that are 30" long. These are the door latch offsets. Drill two 3/8" diameter holes into each 2x4 segment, spaced to match the holes in the door latch (just shy of 9" apart). Locate the offsets on the door and level.

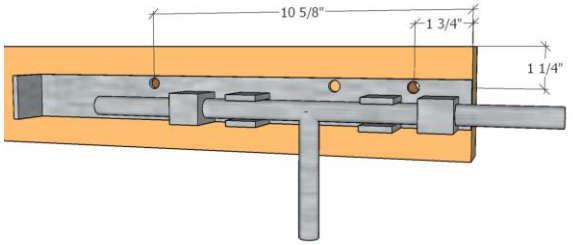
Set the offset back 3-1/2" from the edge of the door to account for the door overlapping the jamb. Drill two corresponding holes into the door.



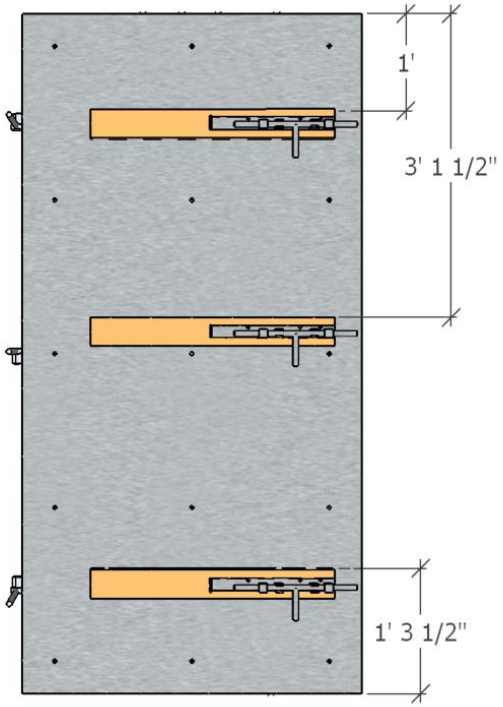
Dimensions: door latch offset, including bolts for bolting on latch



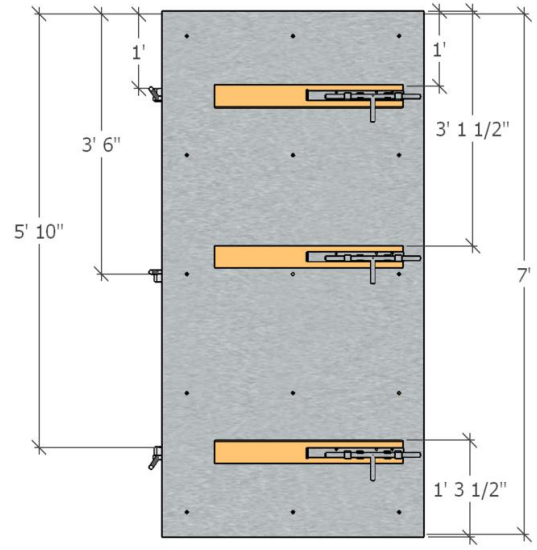
Dimensions: latch and slide bolt
(Dimensions may differ from that currently available. Latch bolt holes may need to be enlarged to 3/8". Check actual dimensions before drilling holes in door.)



Latch and slide bolt installed on door latch offset

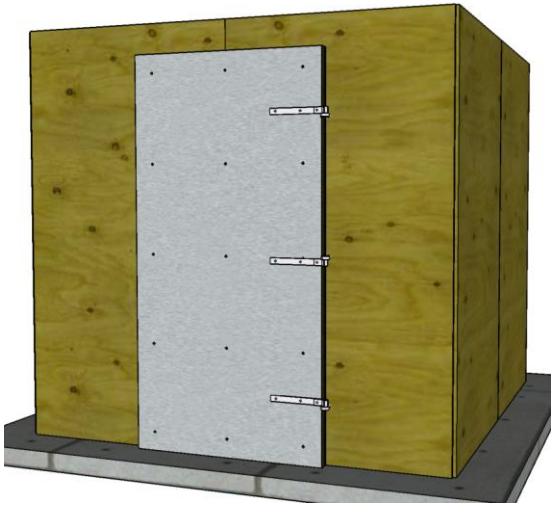


Location of three latches/slide bolts on interior of door
(Dimensions to top of door latch offsets. If necessary, adjust the location of the middle latch to avoid overlap with the bolts securing the door together.)



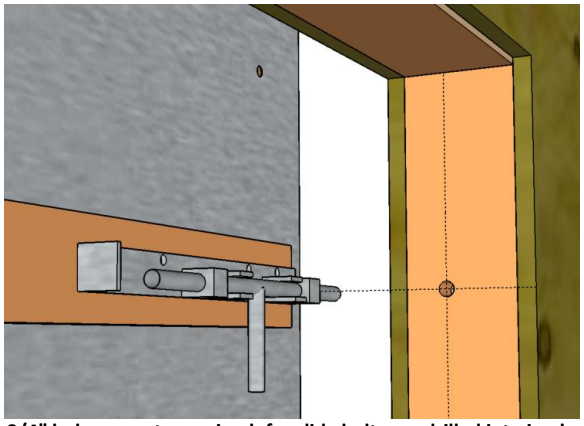
Position of hinges/bolt hooks (door exterior, left side of image) and latches/slide bolts (door interior, right side of image)

The door is now fully installed.

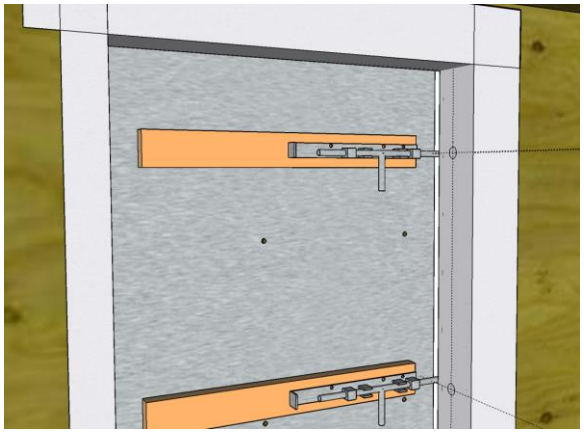


Exterior view of door once installed

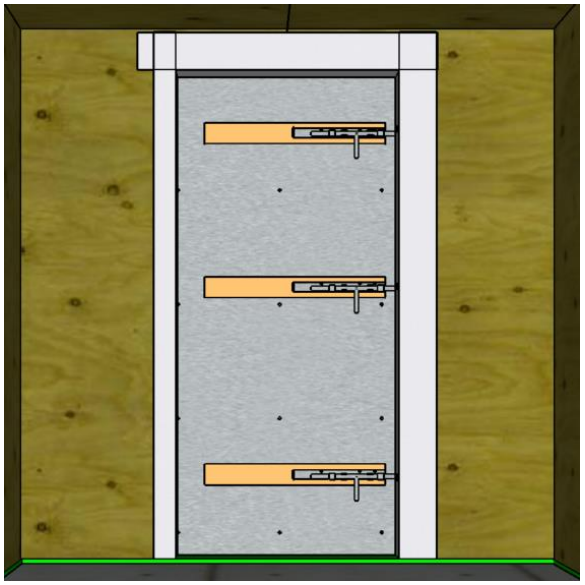
Drill 3/4 inch diameter holes at the jamb that correspond with the location of the slide bolts to allow the door to lock.



3/4" holes on entrance jamb for slide bolts are drilled into jamb; sheet metal angles not shown for clarity
[Note: a step drill may be needed to drill the sheet metal before using a bit to drill the wood]

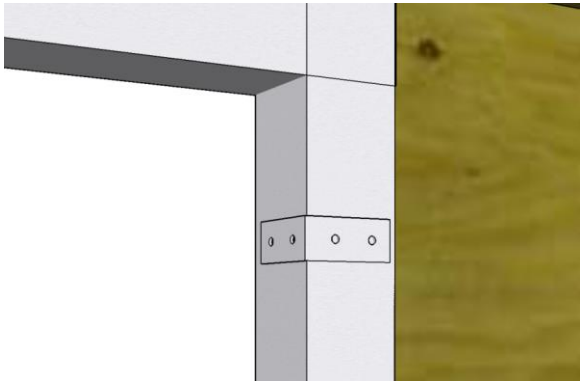


Slide bolt holes on entrance jamb with sheet metal angles shown



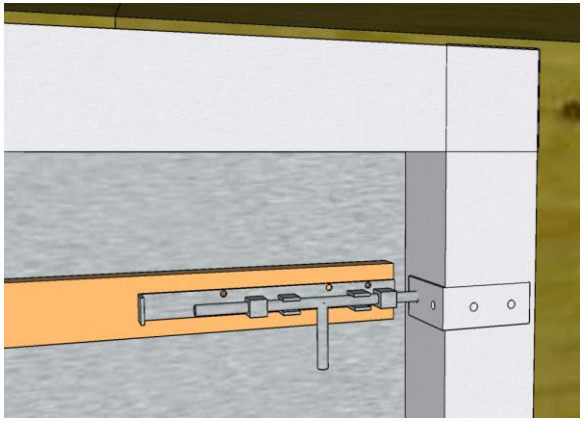
Sheet metal angles provide reinforcement when 5/8 dia." diameter slide bolts are in position

Install each heavy angle so the hole nearest to the shelter's exterior is centered over the holes drilled in the door jamb for the slide bolts.

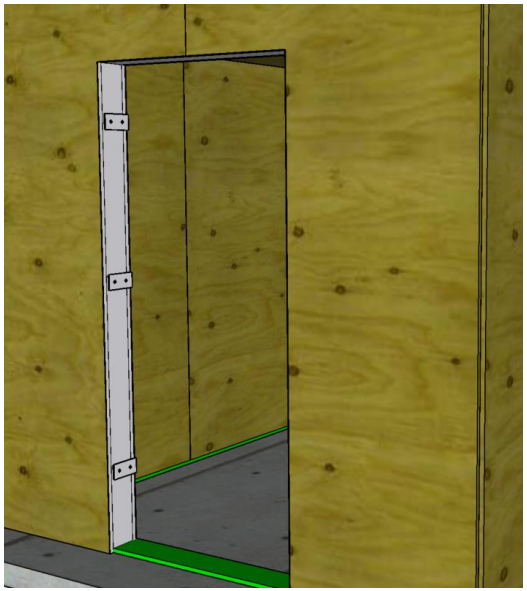


Top heavy angle installed over reinforcing sheet metal angle

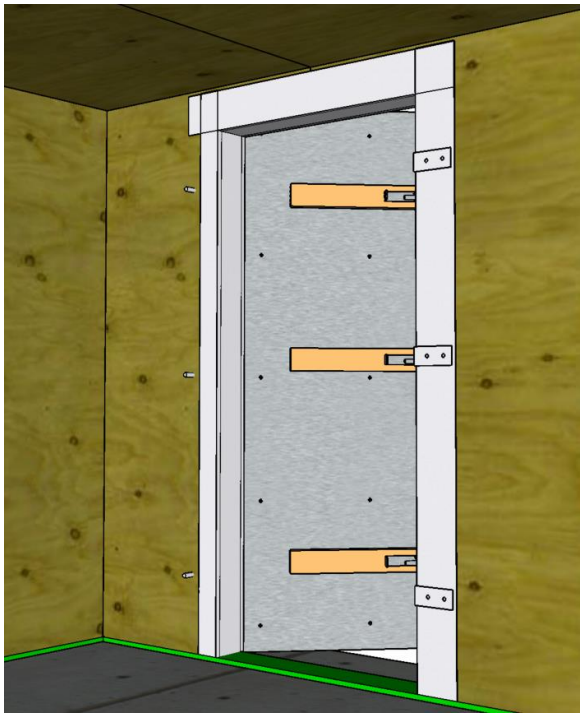
Use 3” long 3/8” dia. lag bolts to secure each heavy angle to the wall. Expand the slide bolt hole in each heavy angle so that the slide bolt fits smoothly.



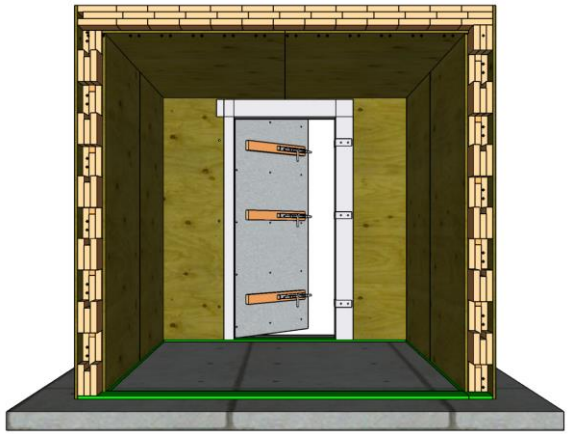
Slide bolt, heavy angle, reinforcing sheet metal angle

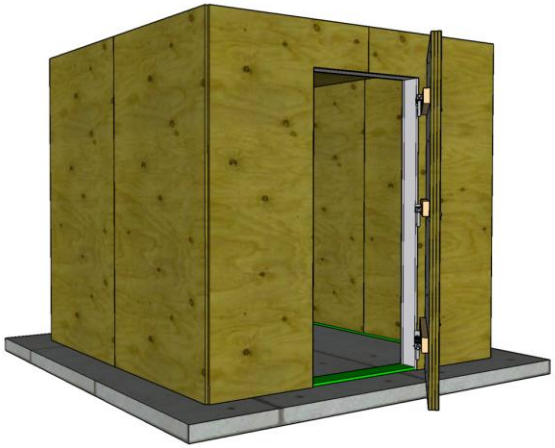


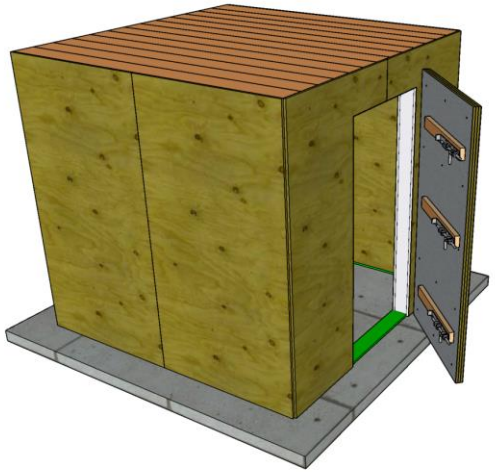
Heavy angles from shelter exterior



All door hardware installed







SECTION 7: PROVIDING VENTILATION

Natural ventilation is provided by 1” diameter holes drilled at the top and bottom of opposite walls. These ventilation holes have been Impact tested to assure that they do not compromise the integrity of the shelter wall. For test results, see:

Materials Needed In This Section:

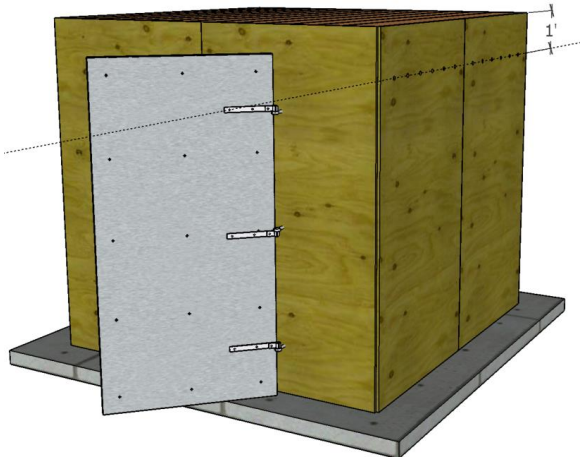
- 24 1” PVC pipe street elbows

Tools Needed For This Section:

- Drill
- 1” diameter auger drill bit

Natural cross-ventilation is provided by 24 holes drilled through the two walls adjacent to the entrance wall.

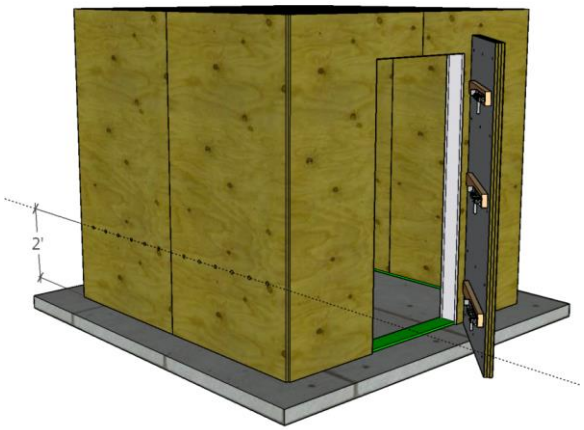
On one wall drill twelve 1” diameter holes 12” from the top of the exterior wall. The holes are spaced 7” o.c.



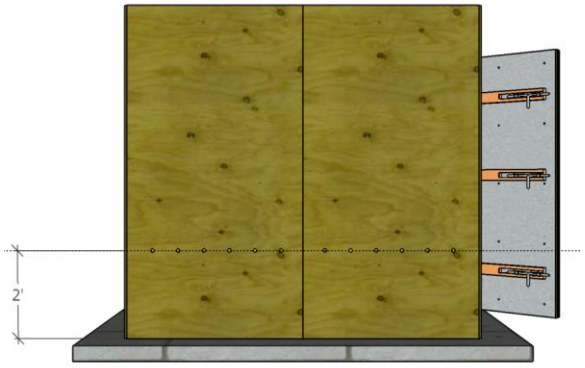
Location: top ventilation holes

Location: top ventilation holes

On the opposite wall drill twelve 1” diameter holes 24” from the base of the exterior wall. The holes are also spaced 7” o.c. It is not critical which wall has the holes high or low.

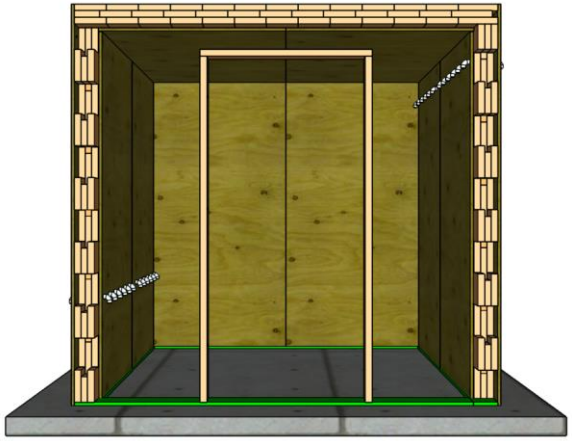


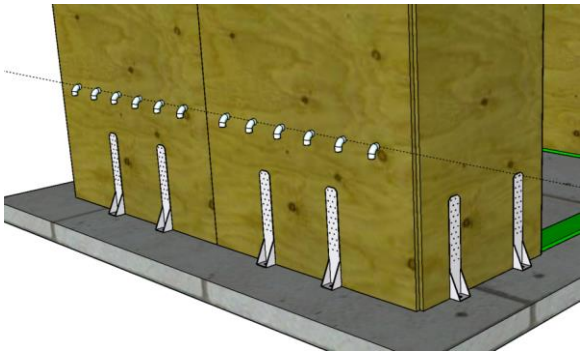
Location: bottom ventilation holes

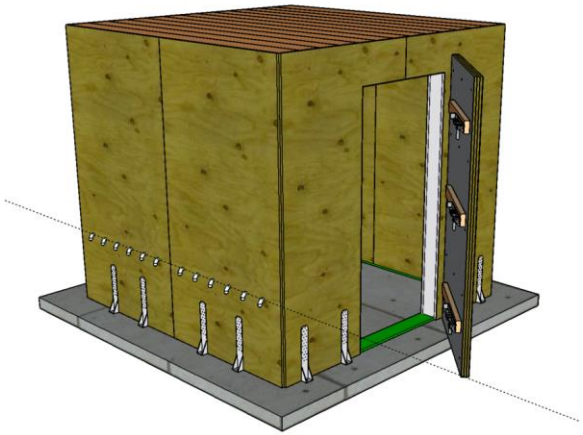


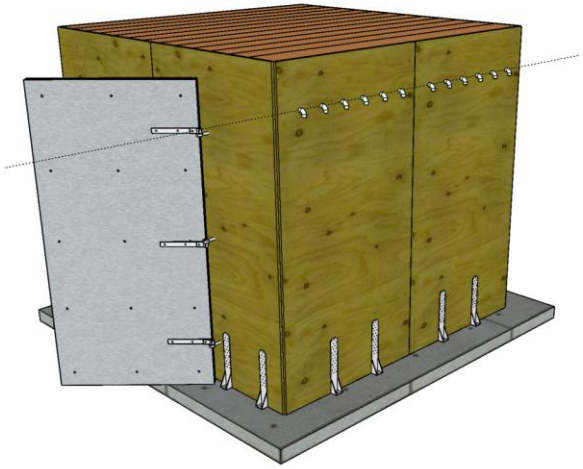
Location: bottom ventilation holes

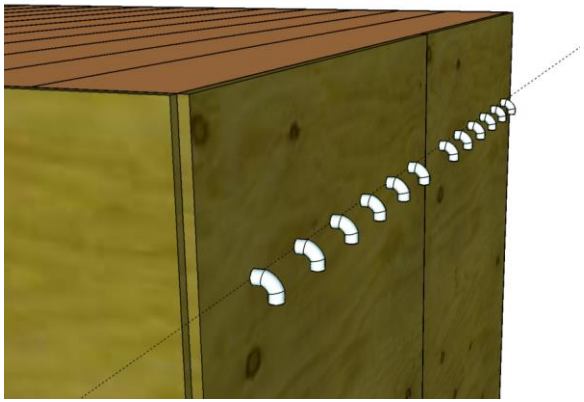
For added protection against windblown sand and other small debris, a PVC street elbow can be glued into both the interior and exterior ends of the holes. If pointed downward, these elbows will help deflect debris away from occupants. The ends of the holes may need to be enlarged to accommodate the elbow. Construction adhesive can be used to glue in the elbows.











SECTION 8: ANCHORING THE SHELTER

The tornado shelter must be anchored to a concrete slab in order to resist the uplift, overturning, and sliding forces caused by extreme winds. The slab must be a minimum of 4" thick and contain steel reinforcement. If properly installed, a 5/8" anchor will provide the 4000 lb load resistance required.

Materials Needed In This Section:

- 16 Simpson Strong Tie HTT5 tension ties
- Box of 16d framing nails, 3-1/4. long for tension ties
- 16 threaded 5/8" dia. anchor studs
- Concrete anchor epoxy

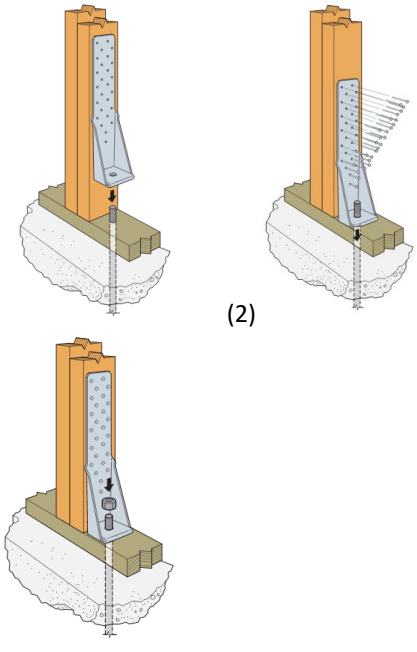
Tools Needed For This Section:

- Hammer drill
- 3/4" diameter hammer drill bit
- Threaded hole cleaning brush
- Socket wrench
- Hammer
- Epoxy caulking gun

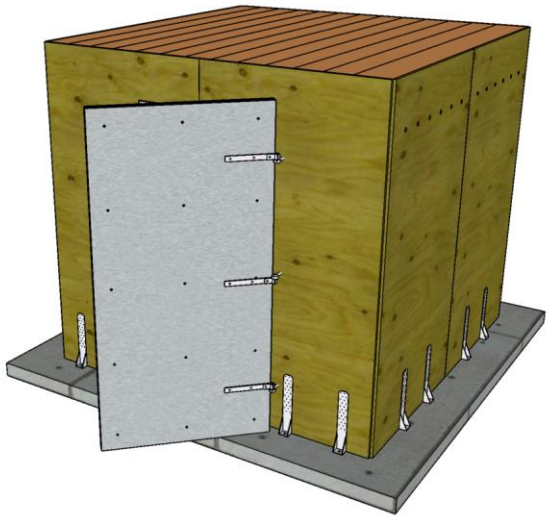
Manufacturers have specific instructions regarding the installation of concrete anchors. It is essential to follow these instructions carefully so that the shelter is properly anchored. See also FEMA Fact Sheet "Foundation and Anchoring Criteria for Shelters" (FEMA, Oct. 2015) as well as FEMA P-361 and FEMA P-320.

If slab thickness is uncertain, drill a hole in the slab to determine actual thickness.

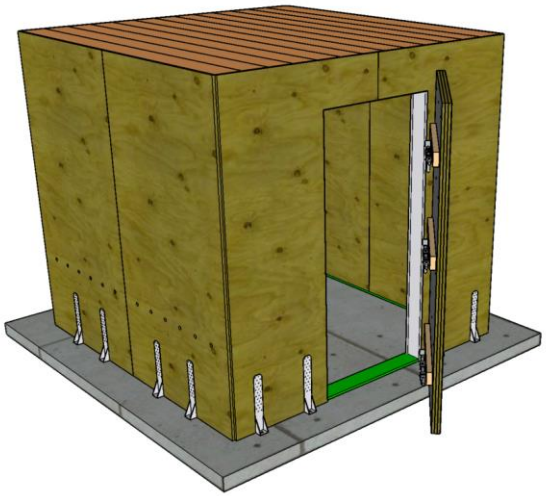
The basic procedure is outlined here, however anchor manufacturer's instructions must be carefully followed to assure anchor performance. Layout the hole locations using the hold-downs as a guide. Use the hammer drill and bit to drill sixteen holes around the exterior perimeter of the shelter corresponding to the locations given in the drawing below. Blow out the dust, then use the threaded brush to clean the interior of each hole and blow out again. Fill each hole partially full with anchor epoxy and insert a 5/8 dia." diameter threaded anchor. Assure that the hold down hole aligns with the threaded anchor that the hold down is tight to the wall. Let epoxy cure. Secure hold downs to wall with 16d nails and to the slab with bolts and washers.



Sequence: installing tension tie (source: www.strongtie.com)



Location: tension ties



Location: tensions ties