Residential Tornado Safe Room from Commodity Wood Products Design and Development

Robert H. Falk
James J. Bridwell
Abstract

In the United States, tornadoes cause significant damage and result in many injuries and deaths. Although the development and use of tornado safe rooms have helped decrease the human toll associated with these events, the cost of these structures is often too high for many that could benefit from their use. The development of a nonproprietary residential tornado safe room constructed from commodity wood building products, buildable by a local contractor or do-it-yourselfer, and adaptable to existing homes, could lower the cost of these structures and result in more widespread use. This report is an overview of the design and development of such a residential tornado safe room. This design was tested according to the requirements of the International Code Council Standard for the Design and Construction of Storm Shelters. It has a projected material cost of between $3,500 and $4,000, which is significantly less than a prefabricated room of similar size and built from other materials.

Keywords: tornado safe room, design, wood construction

February 2018


A limited number of free copies of this publication are available to the public from the Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53726-2398. This publication is also available online at www.fpl.fs.fed.us. Laboratory publications are sent to hundreds of libraries in the United States and elsewhere.

The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

The use of trade or firm names in this publication is for reader information and does not imply endorsement by the United States Department of Agriculture (USDA) of any product or service.
Residential Tornado Safe Room from Commodity Wood Products

Design and Development

Robert H. Falk, Research Engineer
James J. Bridwell, General Engineer
USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin

Introduction

A significant portion of the United States is susceptible to the dangerous winds of tornadoes (Fig. 1). Every year, these events cause injury, death, and billions of dollars of property damage (FEMA 2014). Improved weather forecasting, increased amount of warning time, and the development of reinforced shelters have helped decrease the human toll of these events.

The principal function of a tornado safe room is to protect occupants from high winds and debris generated by a tornado even if the structure that it is enclosed in is damaged or destroyed. Most commercially available tornado safe rooms are constructed of steel or concrete, materials typically requiring specialized professionals and equipment to construct. Wood products are nearly ubiquitous, require simple tools to size and connect, and are familiar to most building contractors. Contrary to children’s fables suggesting that wood is inferior to other building materials in high winds, wood and wood construction have strength enough to resist the forces of wind and earthquakes and also possess energy absorption characteristics superior to other common building materials.

Figure 1. Tornado activity in the United States from 1950 to 2013 (Source: Storm Prediction Center 2014).

Objective and Scope

The overall objective of this research was to develop a tornado safe room constructed from commodity wood products that meets established performance criteria for such structures. Several goals were pursued in the design of the wood tornado safe room: (1) as much as possible, materials should be available from local building material outlets and online sources, (2) the structure should be buildable by a local contractor or an advanced do-it-yourselfer, (3) retrofitting the room into an existing home should be possible, (4) costs should be kept down by minimizing the use of specialty materials and hardware.

Performance Criteria for Tornado Safe Rooms

The performance requirements for a residential tornado safe room have been standardized via ICC/NSSA-500 (ICC/NSSA 2014). This standard presents occupancy requirements, impact testing, wind pressure testing, ventilation, and other performance criteria for these structures. From an engineering standpoint, impact and wind pressure testing are the most challenging of these requirements. The results of the tests performed on the safe room described here are detailed in a companion report entitled “Residential Tornado Safe Room from Commodity Wood Products: Impact and Wind Pressure Testing” (Falk and others 2018).

Safe Room Design Considerations

Although nonproprietary wood safe room designs exist (FEMA 2014), they are typically based on a conventional nominal 2-in. stud wall design with added reinforcement, either in the form of steel plates or added infill masonry. The safe room design presented here is a departure from this convention and uses mass timber construction with solid wood walls and roof. Because commodity lumber is commonly sold in 8-ft lengths and wood sheathing materials...
are typically 4 by 8 ft in size, the room has been designed to be 8 by 8 ft in plan with a height of up to 8 ft. This size not only minimizes material waste but also makes this space suitable for other uses (for example, bathroom, utility room) when not needed in an emergency.

The design of this safe room was an iterative process in which a potential wall panel design was established on paper, built, and then impact tested to evaluate performance. The design was modified and retested until a suitable design evolved. Falk and others (2015) reports this wall and roof panel testing.

Wall and Roof Panels

Based on the wall and roof testing previously referenced, a final room design was established. The walls and roof of this safe room were constructed of stacked and interconnected nail-laminated lumber beams sheathed with plywood. Three 2 by 8s were nailed and glued together to form a beam with a tongue and groove configuration (Fig. 2). The beams were then stacked and interlocked in log cabin fashion to create the walls of the safe room (Fig. 3). Nominal 3/4-in. plywood sheathing was then nailed and glued to the walls and roof to further reinforce the room as well as to tie the walls and roof together (Fig. 4).

The use of 2 by 8s and plywood as the basic building blocks of this safe room allows easy transfer and construction into the basement of a home or inside a garage, allowing the room to be retrofitted into existing homes. In addition, the use of rows of interlocked lumber beams allows the room to be built with various ceiling heights, which makes the room adaptable to height-limited spaces, such as basements or garages with trussed roofs.

Safe Room Door

An important component of a tornado safe room is the entry door, and as with the tornado safe room itself, it must be designed and constructed to meet the requirements of ICC/NSSA-500 (ICC/NSSA 2014). Although many tornado safe room doors exist in the marketplace, they are usually constructed solely of steel. A study was conducted to determine if a tornado safe room door could be wholly or...
partially produced from commodity wood building products. This study followed the same iterative design process previously described for the safe room wall and roof panels (Falk and Bridwell 2016). The result was a door made from plywood and overlaid with 18-gauge (0.05-in.-thick) steel sheeting that was simple to construct and met the required impact resistance.

The door was constructed of three sheets of nominal 3/4-in. plywood overlaid on both faces with 18-gauge sheet steel (Fig. 5). This construction is detailed in Falk and Bridwell (2016). The door was hung with three 3/4-in. gate hinges, similar to that which might be found on a livestock gate. These hinges were chosen because of their low cost and adjustability in hanging an overlaid door (Fig. 6).

The door was latched from the inside using three cane bolts (Fig. 7). These bolts are normally used in a vertical orientation to secure a livestock gate. They were chosen because of their low cost, ease of installation, and simple operation.

Based on tests described in Falk and others (2018), 14-gauge (0.07-in.-thick) sheet metal angle was used to increase the impact resistance of the door frame (Figs. 8 and 9).

In addition, a Simpson Strong-Tie HL53 angle bracket (Simpson Strong-Tie Company, Inc., Pleasanton, California) was used to transfer the concentrated load of the cane bolt into the tornado safe room wall when the door was subjected to wind suction forces (Fig. 10). Figure 11 shows the three cane bolts in place that secure the door from the inside, and Figure 12 shows the door in the latched position.

Securing the Safe Room to the Foundation

Securing the safe room to the foundation is an important aspect of safe room design, and the tie-down connector, the anchor bolts securing the tie-down connector, and the concrete foundation must have adequate structural strength to resist the forces of the winds produced by a tornado.

The concrete foundation must have enough thickness, reinforcement, and surface area to resist anchor bolt pullout, foundation sliding, and room overturning. These design considerations are addressed in FEMA P-320 (FEMA 2014), FEMA P-361 (FEMA 2015), and ICC/NSSA (2014).
The tie-down used in the wood safe room described here was a Simpson Strong-Tie HTT5 (Fig. 13). The uplift and shear resistance of the tie-down used in this application was evaluated in Falk and others (2018).

**Other Design Considerations**

ICC/NSSA (2014) specifies other design considerations such as occupancy, ventilation, and fire resistance. Because the walls of this 8- by 8-ft safe room are 6 in. thick, the room has a usable floor area of 49 ft². For a residential safe room, 5 ft² per person are required. Therefore, this safe room would provide shelter for up to nine people. Ventilation is required and is based on the number of occupants. For a residential safe room, 2 in² are required for each occupant; therefore, 18 in² of ventilation are appropriate for this safe room. Although a 2-h fire rating is required for storm shelters, a residential safe room is exempt from this requirement. These considerations will be detailed in future design documents.

**Material Costs**

The Appendix indicates the material costs for the safe room discussed in this report as well as sources for these materials. As indicated in the Appendix, the cost of materials was about $3,600. Although this total was valid in 2016, this value should be considered an estimate because prices can vary. In addition, the costs listed do not include tax, shipping, or delivery costs, which also can vary by region.

**Conclusions**

The objective of this study was to develop a nonproprietary residential tornado safe room constructed from commodity wood building products, buildable by a local contractor or
do-it-yourselfer, and adaptable to existing homes. A low-cost design that meets the requirements of ICC/NSSA (2014) has been developed and has a projected material cost of between $3,500 and $4,000. The results of impact and wind pressure testing performed on this design can be found in a companion report (Falk and others 2018).

Literature Cited


Storm Prediction Center. 2014.
Appendix—Safe Room Material Costs

<table>
<thead>
<tr>
<th>Safe room material item</th>
<th>Quantity</th>
<th>Cost per item</th>
<th>Total cost</th>
<th>Source</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 by 8 lumber, 8-ft length</td>
<td>190</td>
<td>$6</td>
<td>$1,140</td>
<td>Big box</td>
<td>10 extra for warping and door jamb</td>
</tr>
<tr>
<td>1 by 6 treated sill, 8-ft length</td>
<td>4</td>
<td>$7</td>
<td>$28</td>
<td>Big box</td>
<td></td>
</tr>
<tr>
<td>Nominal 3/4-in. sheathing, 4 by 8 ft</td>
<td>21</td>
<td>$21</td>
<td>$441</td>
<td>Big box</td>
<td></td>
</tr>
<tr>
<td>16d nails (box of 5,000)</td>
<td>1</td>
<td>$55</td>
<td>$55</td>
<td>Big box</td>
<td>3-1/4 or 3-1/2 in. (longer is better)</td>
</tr>
<tr>
<td>Liquid nails (10-oz. case) (PPG Industries, Pittsburgh, PA)</td>
<td>10</td>
<td>$55</td>
<td>$550</td>
<td>Big box</td>
<td></td>
</tr>
<tr>
<td>8-in. screws</td>
<td>100</td>
<td>$65</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-in. screws</td>
<td>34</td>
<td>$50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Door jamb reinforcement angles (14 gauge)</td>
<td></td>
<td></td>
<td>$250</td>
<td></td>
<td>Obtained from local steel supplier. Assumes 4 by 8 steel sheet cut down to three angles needed. Cutting and bending cost included. Price may vary with location.</td>
</tr>
<tr>
<td>Door steel (18 gauge)</td>
<td>2</td>
<td>$61</td>
<td>$122</td>
<td>Local steel supplier</td>
<td>Obtained from local steel supplier. Assumes 4 by 8 steel sheet cut down to door size. Cutting cost included. Price may vary with location.</td>
</tr>
<tr>
<td>1/4-in. door bolts</td>
<td>1</td>
<td>$20</td>
<td>$20</td>
<td>Big box</td>
<td><a href="http://www.homedepot.com/p/National-Hardware-3-4-in-x-10-in-Bolt-Hook-293BC-3-4X10-Bolt-Hook/203616842">http://www.homedepot.com/p/National-Hardware-3-4-in-x-10-in-Bolt-Hook-293BC-3-4X10-Bolt-Hook/203616842</a></td>
</tr>
<tr>
<td>Tie-down</td>
<td>16</td>
<td>$25</td>
<td>$400</td>
<td>Simpson HTT5</td>
<td><a href="https://www.strongtie.com/holddownsandtensionties_coldformedsteelconstructon/s-ltt-s-dttandht">https://www.strongtie.com/holddownsandtensionties_coldformedsteelconstructon/s-ltt-s-dttandht</a> productgroup csf/s/ltt-s.dtt-</td>
</tr>
<tr>
<td>Door latch</td>
<td>3</td>
<td>$63</td>
<td>$189</td>
<td>5/8-in. cane bolt</td>
<td><a href="http://www.snugcottagehardware.com/Snug%20Product%20Pages/Latches%20for%20wood%20Traditional/5000%20Cane%20Bolts.html">http://www.snugcottagehardware.com/Snug%20Product%20Pages/Latches%20for%20wood%20Traditional/5000%20Cane%20Bolts.html</a></td>
</tr>
<tr>
<td>Miscellaneous bolts for door hinges and latch</td>
<td></td>
<td></td>
<td>$50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anchor bolt 5/8 in.</td>
<td>11</td>
<td>$30</td>
<td></td>
<td></td>
<td>See FEMA P-320 specifications (FEMA 2014)</td>
</tr>
<tr>
<td>Anchor bolt epoxy</td>
<td>2</td>
<td>$100</td>
<td></td>
<td></td>
<td>See FEMA P-320 specifications (FEMA 2014)</td>
</tr>
<tr>
<td>Total safe room cost</td>
<td></td>
<td></td>
<td>$3,604</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>