Taking Shelter from the Storm: Building a Safe Room
4 PDH / 4 CE Hours

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Continuing Education for Architects and Engineers
1. The severity of a tornado is categorized by the ______ scale:
   a. BC  
   b. EF  
   c. F  
   d. GT

2. Damage from a __________ tornado—roofs and some walls are torn from structures, some small buildings are destroyed, non-reinforced masonry buildings are destroyed, most trees in forest are uprooted:
   a. severe  
   b. incredible  
   c. moderate  
   d. considerable

3. Considering the Basis of Safe Room Design, extensive testing by Texas Tech University and other wind engineering research facilities has shown that walls, ceilings, and doors commonly used in building construction to meet minimum building code requirements for standard building construction ______ withstand the impact of missiles carried by extreme winds:
   a. can well  
   b. will usually  
   c. can often  
   d. cannot

4. Considering the Basis of Safe Room Design, most homes, even new ones constructed according to current building codes, do not provide adequate protection for occupants seeking life-safety protection from tornadoes.
   a. True  
   b. False

5. Designing a building, or portion of a building, to resist damage from more than one natural hazard requires different, sometimes competing, approaches.
   a. True  
   b. False

6. Regarding Safe Room Size, the minimum sizing requirement set forth in the ICC-500 for residential hurricane shelters is ___ square feet per occupant:
   a. 10  
   b. 15  
   c. 5  
   d. 7

7. With regards to Construction Materials, the materials your builder/contractor will need to build your safe room:
   a. are generally “special order”  
   b. should be available from building material suppliers in your community  
   c. are usually difficult to obtain  
   d. may not be allowed by local building codes

8. One of the most vulnerable parts of your safe room is the:
   a. floor  
   b. north wall  
   c. window  
   d. door

9. Many of these shelter products are designed and constructed as pre-manufactured units.
   a. True  
   b. False

10. Some SIPs have been designed such that they are capable of resisting the design wind and debris impact criteria of FEMA 320.
   a. True  
   b. False
Course Description:
This course material provides safe room designs that will show you how to design and construct a safe room for a home or small business. Design options include safe rooms located underneath, in the basement, in the garage, or in an interior room of a new home or small business. Other options also provide guidance on how to modify an existing home or small business to add a safe room in one of these areas. These safe rooms are designed to provide near-absolute protection for families or employees from the extreme winds expected during tornadoes and hurricanes and from flying debris, such as wood studs, that tornadoes and hurricanes usually create.

Learning Units:
4.0 LU/HSW

Learning Objective 1:
Upon completion of this course, the student will understand that “near absolute” protection means that, based on our current knowledge of tornadoes and hurricanes, the occupants of a safe room built according to this guidance will have a very high probability of being protected from injury or death.

Learning Objective 2:
The student will know how extreme winds can damage a building, will understand the basis of the safe room designs presented in this course, and will know how to best locate a safe room in a home or small business.

Learning Objective 3:
The student will have access to several sample safe room plans.

Learning Objective 4:
The student will have a better understanding of the approximate costs to add a safe room to an existing building as well as to include one in new construction.

An extensive list of individuals who have made significant contributions to this publication is available in the online version of this class.
INTRODUCTION

Every year, tornadoes, hurricanes, and other extreme windstorms injure and kill people, and cause millions of dollars worth of property damage in the United States. Even so, more and more people build homes in tornado- and hurricane-prone areas, possibly putting themselves into the path of such storms.

Having a safe room built for your home or small business can help provide “near-absolute protection” for you and your family or employees from injury or death caused by the dangerous forces of extreme winds. Near-absolute protection means that, based on our current knowledge of tornadoes and hurricanes, the occupants of a safe room built according to this guidance will have a very high probability of being protected from injury or death. Our knowledge of tornadoes and hurricanes is based on substantial meteorological records as well as extensive investigations of damage to buildings from extreme winds. It can also relieve some of the anxiety created by the threat of an oncoming tornado or hurricane. All information contained in this publication is applicable to safe rooms for use in homes as well as in small businesses.

Should you consider building a safe room in your home or small business to provide near-absolute protection for you, your family, or employees during a tornado or hurricane? The answer depends on your answers to many questions, including:

- Do you live in a high-risk area?
- How quickly can you reach safe shelter during extreme winds?
- What level of safety do you want to provide?
- What is the cost of a safe room?

This publication will help you answer these and other questions so you can decide how best to provide near-absolute protection for you and your family or employees. It includes the results of research that has been underway for more than 30 years, by Texas Tech University’s Wind Science and Engineering (WISE; formerly known as the Wind Engineering Research Center or WERC) Research Center and other wind engineering research facilities, on the effects of extreme winds on buildings.

This publication provides safe room designs that will show you and your builder/contractor how to construct a safe room for your home or small business. Design options include safe rooms located underneath, in the basement, in the garage, or in an interior room of a new home or small business. Other options also provide guidance on how to modify an existing home or small business to add a safe room in one of these areas. These safe rooms are designed to provide near-absolute protection for you, your family, or employees from the extreme winds expected during tornadoes and hurricanes and from flying debris, such as wood studs, that tornadoes and hurricanes usually create.

In August 2008, the International Code Council® (ICC®), with the support of the National Storm Shelter Association (NSSA), released a consensus standard on the design and construction of storm shelters. This standard, the ICC/NSSA Standard for the Design and Construction of Storm Shelters (ICC-500), codifies much of the extreme-wind shelter recommendations of the early editions of FEMA 320 and FEMA 361, Design and Construction Guidance for Community Safe Rooms (first edition, July 2000). FEMA 361 contains detailed guidance for the design and construction of community safe rooms, which also provide near-absolute protection, the level of protection provided in the residential safe rooms of this publication. The ICC-500 provides the minimum design and construction requirements for extreme-wind storm shelters and is expected to be incorporated into the 2009 International Building Code® (IBC®) and International Residential Code® (IRC®). It is important that those involved in the design, construction, and maintenance of storm shelters be knowledgeable of both FEMA guidance and ICC standards that pertain to sheltering from extreme winds.

The safe room designs presented in this publication meet or exceed all tornado and hurricane design
The National Association of Home Builders (NAHB) Research Center has evaluated these designs for construction methods, materials, and costs for the earlier editions of this publication. Engineers at Texas Tech University, engineering consultants, and FEMA have confirmed the design requirements for the expected forces from wind pressure and the impact of typical flying debris. When installation and foundation requirements are addressed by a local design professional, these designs will meet or exceed the design requirements set forth in the ICC-500 for residential and small community shelters (less than 16 persons) for both tornado or hurricane hazards. The safe rooms in this publication have been designed with life safety as the primary consideration.

**SECTION I | UNDERSTANDING THE HAZARDS**

Almost every state in the United States has been affected by extreme storms such as tornadoes and hurricanes. Virtually every state has been affected by a “considerable” tornado (see the terms in Figure I-1). All Atlantic and Gulf of Mexico coastal areas in the United States – including coastal areas of Puerto Rico and the U.S. Virgin Islands – and coastal areas of Hawaii have been affected by hurricanes. Even in states not normally considered to be susceptible to extreme windstorms, there are areas that experience dangerous extreme winds. These areas are typically near mountain ranges, and include the Pacific Northwest coast.

What Is a Tornado?

According to the American Meteorological Society’s Glossary of Meteorology, a tornado is “a violently rotating column of air, pendant from a cumuliform cloud or underneath a cumuliform cloud, and often (but not always) visible as a funnel cloud.” Tornadoes typically occur in the spring and summer months, but can occur at any time in any part of the country. Tornadoes are sometimes spawned by hurricanes. The severity of a tornado is categorized by the Enhanced Fujita Scale (EF Scale). As of February 2007, the EF Scale (see Figure I-1) was adopted by the National Oceanic and Atmospheric Administration (NOAA) to replace

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**TORNADO OCCURRENCE AND RESULTANT LOSSES ARE INCREASING**

In 1950, the National Weather Service (NWS) started keeping organized records of tornadoes occurring in the United States (U.S.). Since that time, 1953 was the deadliest year (519 deaths). The average in recent years has been 62 deaths per year. Deaths caused by tornadoes were 38, 67, and 81 for 2005, 2006, and 2007, respectively. As of May of this year, 110 deaths have been caused by tornadoes.

In addition to deaths, tornadoes cause injuries and devastating losses of personal property. Insurance claim losses from a single tornadic event of $1 billion and higher are becoming more frequent. So far in 2008, tornadoes have resulted in insured losses of more than $1 billion (almost $850 million of which from the mid-South outbreaks on February 5 and 6; in March, Atlanta and its surrounding counties were struck by a tornado that caused $349 million in losses).

Although hurricanes and earthquakes generally generate higher losses per event, since 1953, tornadoes (and related weather events) have caused an average of 57 percent of all U.S. insured catastrophic losses. In 2007, that number increased to 69 percent.

Source: A.M. Best, CNN

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**definition**

In this publication, the term **missiles** refers to debris and other objects picked up by the wind and moved with enough force to damage and even penetrate windows, doors, walls, and other parts of a building. In general, the stronger the wind, the larger and heavier the missiles it can carry and the greater the risk of severe damage or injury. But even small stones, branches, and other lighter missiles can easily break glass doors and windows.
Incredible:
Strong frame houses are lifted from foundations, reinforced concrete structures are damaged, automobile-sized missiles become airborne, trees are completely debarked.

Devastating:
Well-constructed houses are destroyed, some structures are lifted from foundations and blown some distance, cars are blown some distance, large debris becomes airborne.

Severe:
Roofs and some walls are torn from structures, some small buildings are destroyed, non-reinforced masonry buildings are destroyed, most trees in forest are uprooted.

Considerable:
Roof structures are damaged, mobile homes are destroyed, debris becomes airborne (missiles are generated), large trees are snapped or uprooted.

Moderate:
Roof surfaces are peeled off, windows are broken, some tree trunks are snapped, unanchored mobile homes are overturned, attached garages may be destroyed.

Light:
Chimneys are damaged, tree branches are broken, shallow-rooted trees are toppled.

Figure I-1. Typical tornado damage
What Is a Hurricane?

Hurricanes are categorized by the Saffir-Simpson scale (see Figure I-3). In the United States, 279 hurricanes were recorded to have made landfall between 1851 and 2006. Over one-third of these hurricanes (96) were classified as major hurricanes (designated Category 3 and higher on the Saffir-Simpson Hurricane Scale). Hurricanes have made landfall in Florida more than in any other state. The second most hurricane-affected state is Texas, but every state on the Gulf coast and bordering the Atlantic Ocean is susceptible to damage caused by hurricanes, as are U.S. island possessions and territories. Hurricanes between 1900 and 2006 resulted in 17,832 deaths.

In recent years, the U.S. territories of Puerto Rico, American Samoa, and Guam have been seriously affected by numerous tropical cyclones.

Do You Need a Safe Room?

On the basis of 60 years of tornado history and more than 150 years of hurricane history, the United States has been divided into four zones that geographically reflect the number and strength of extreme windstorms. Figure I-4 shows these four zones. Zone IV has experienced the most and the strongest tornado activity. Zone III has experienced significant tornado activity and includes coastal areas that are susceptible to hurricanes. The release of the ICC-500 has codified much of FEMA's guidance for safe room design and construction. However, there are additional details in the ICC-500 regarding hurricane shelters, including a new shelter design wind speed map that could be helpful to understanding your risk of extreme-wind events due to hurricanes. A safe room designed and constructed to the prescriptive designs included in this publication (and properly sited to address flood hazards) will meet or exceed the ICC-500 residential and small community shelter (less than 16 people) design criteria.

A safe room using the prescriptive designs of this publication should not be installed in a hurricane-prone area that may be inundated by storm surge from any hurricane, including Category 5 hurricanes.
the Fujita Scale (F Scale). The EF Scale is designed similar to the F Scale, but has been revised to have a greater number of Damage Indicators, which are used to characterize the degree of damage experienced by buildings during a tornado.

Not all parts of each state are at equal risk from tornadoes. For example, while Texas has the highest number of recorded tornadoes, the state’s least tornado-prone area (along the Gulf coast) has been hit by fewer tornadoes than northeastern Arkansas. Comparing the numbers of tornadoes recorded in different areas within a state can give you a better understanding of potential tornado activity in those areas. Figure I-2 shows the summary of recorded EF3, EF4, and EF5 tornadoes per 2,470 square miles in the United States and its possessions and territories. Between 1950 and 2006, tornadoes caused 5,506 deaths and 93,287 injuries.

What Is a Hurricane?

Hurricanes are categorized by the Saffir-Simpson scale (see Figure I-3).

In the United States, 279 hurricanes were recorded to have made landfall between 1851 and 2006. Over one-third of these hurricanes (96) were classified as major hurricanes (designated Category 3 and higher on the Saffir-Simpson Hurricane Scale). Hurricanes have made landfall in Florida more than in any other state. The second most hurricane-affected state is Texas, but every state on the Gulf coast and bordering the Atlantic Ocean is susceptible to damage caused by hurricanes, as are U.S. island possessions and territories. Hurricanes between 1900 and 2006 resulted in 17,832 deaths.

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On the basis of 60 years of tornado history and more than 150 years of hurricane history, the United States has been divided into four zones that geographically reflect the number and strength of extreme windstorms. Figure I-4 shows these four zones. Zone IV has experienced the most and the strongest tornado activity. Zone III has experienced significant tornado activity and includes coastal areas that are susceptible to hurricanes. The release of the ICC-500 has codified much of FEMA’s guidance for safe room design and construction. However, there are additional details in the ICC-500 regarding hurricane shelters, including a new shelter design wind speed map that could be helpful to understanding your risk of extreme-wind events due to hurricanes. A safe room designed and constructed to the prescriptive designs included in this publication (and properly sited to address flood hazards) will meet or exceed the ICC-500 residential and small community shelter (less than 16 people) design criteria.

A safe room using the prescriptive designs of this publication should not be installed in a hurricane-prone area that may be inundated by storm surge from any hurricane, including Category 5 hurricanes.
Figure I-3. Typical hurricane damage

**Catastrophic:**
Roof damage is considerable and widespread, window and door damage is severe, there are extensive glass failures, some complete buildings fail.

**Extreme:**
Extensive damage is done to roofs, windows, and doors; roof systems on small buildings completely fail; some curtain walls fail.

**Extensive:**
Large trees are toppled, some structural damage is done to roofs, mobile homes are destroyed, structural damage is done to small homes and utility buildings.

**Moderate:**
Some trees are toppled, some roof coverings are damaged, major damage is done to mobile homes.

**Minimal:**
Damage is done primarily to shrubbery and trees, unanchored mobile homes are damaged, some signs are damaged, no real damage is done to structures.
Further, it is best not to install residential or small community safe rooms in any area susceptible to flooding defined by the 500-year floodplain. However, in areas not prone to storm surge, a safe room may be installed within mapped floodplains only when the designs provided herein:

- Are accepted as meeting the safe room elevation flood criteria presented in the text box on pages 76 and 77
- Comply with all local floodplain ordinances
- Are coordinated with local emergency management

Your home or place of business is probably built in accordance with local building codes that consider the effects of minimum, “code-approved” design winds for your area. Building codes require that buildings be able to withstand a “design” wind event. In most tornado-prone regions, the building code design wind event is a wind event with 90 mph winds. For hurricane-prone areas, design wind events in the code range from 90 to 150 mph. A tornado or extreme hurricane can cause winds much greater than those on which local code requirements are based. Having a home built to “code” does not mean that your home can withstand wind from any event, no matter how extreme. The safe room designs in this publication provide a place to seek safe shelter during these extreme-wind events.

The worksheet on page 68 will help you determine your level of risk from these extreme events and will assist you in your consideration of a safe room. If you decide that you need a safe room, Section II will help you and your builder/contractor in planning your safe room. To learn more about the wind history for the area where you live, check with your local building official, meteorologist, emergency management official, or television weather reporter.

A safe room may be designed and constructed to meet all applicable FEMA criteria. However, use of the safe room during a hurricane may not be in compliance with mandatory evacuation orders of the local jurisdiction. FEMA recommends that all safe room occupants comply with local jurisdictional directions and orders during a hurricane event (which may include evacuation) even if they have constructed a safe room.

**definition**

In this publication, the term storm surge means an abnormal rise in sea level accompanying a hurricane or other intense storm, and whose height is the difference between the observed level of the sea surface and the level that would have occurred in the absence of the cyclone. Storm surge (see Figure I-5) is usually estimated by subtracting the normal or astronomic high tide from the observed storm tide.

**warning**

A safe room designed to protect you and your family or employees from a hurricane or tornado should not be built in an area expected to be flooded during a hurricane, thunderstorm, or other severe weather event. Residents of hazard-prone coastal areas should abide by the warnings of their local emergency services personnel and evacuate to safer ground. The protection from wind provided by safe rooms and shelters is quickly negated when people find themselves trapped and inundated by floodwaters.

If you do not know whether your home or small business is in a storm surge area or other area subject to flooding, check the community service section of your local phone book for storm surge evacuation information or ask your local emergency management or floodplain management official.
Figure I-4. Wind zones in the United States

WIND ZONES IN THE UNITED STATES*

ZONE I
130 mph

ZONE II
160 mph

ZONE III
200 mph

ZONE IV
250 mph

UNDERSTANDING THE HAZARDS

Number of Tornadoes per 2,470 Square Miles

- 0 – 1 Low Risk
- 2 – 4 Moderate Risk
- 5 – 10 Low Risk
- 11 – 15 High Risk
- > 15 High Risk

For example, if you live in Hattiesburg, MS, you would see that Hattiesburg is in an area shaded medium orange on the map on page 62. So according to the map key, the number of tornadoes per 2,470 square miles in the Hattiesburg area is 11-15.

To complete the worksheet on page 68, refer to the tornado occurrence and wind hazard maps for the northeastern United States. Revised hurricane shelter design wind speeds have been released in the ICC-500. For the purpose of the prescriptive solutions offered in this publication, the wind speeds given in Figure I-4 are used to calculate pressures and required resistances for residential safe rooms.

Hurricane-susceptible regions can be seen in Figure I-4, running from the southern tip of Texas to the Northeast. The color of the box tells you the level of your risk from extreme winds and helps you decide whether to build a safe room.

The box where the 11-15 row and the Zone IV column meet is shaded dark blue, which appears within the red-shaded area. On the map on page 66, Hattiesburg is in Wind Zone IV.

For example, if you live in Hattiesburg, MS, you would see that Hattiesburg is in an area shaded medium orange on the map on page 62. So according to the map key, the number of tornadoes per 2,470 square miles in the Hattiesburg area is 11-15.

For the purpose of the prescriptive solutions offered in this publication, the wind speeds given in Figure I-4 are used to calculate pressures and required resistances for residential safe rooms.
Homeowner’s Worksheet: Assessing Your Risk

To complete the worksheet on page 68, refer to the tornado occurrence and wind hazard maps for tornadoes and hurricanes on pages 62 and 66 (Figures I-2 and I-4, respectively). Using the map on page 62, note how many tornadoes were recorded per 2,470 square miles for the area where you live. Find the row on the worksheet that matches that number. Next, look at the map on page 66 and note the wind zone (I, II, III, or IV) in which you live. Find the matching column on the worksheet. Finally, find the box inside the worksheet that lines up with both the number of tornadoes per 2,470 square miles in your area and your wind zone. The color of that box tells you the level of your risk from extreme winds and helps you decide whether to build a safe room.

Hurricane-susceptible regions can be seen in Figure I-4, running from the southern tip of Texas to the Northeast. Revised hurricane shelter design wind speeds have been released in the ICC-500. For the purpose of the prescriptive solutions offered in this publication, the wind speeds given in Figure I-4 are used to calculate pressures and required resistances for residential safe rooms.

For example, if you live in Hattiesburg, MS, you would see that Hattiesburg is in an area shaded medium orange on the map on page 62. So according to the map key, the number of tornadoes per 2,470 square miles in the Hattiesburg area is 11-15.

On the map on page 66, Hattiesburg appears within the red-shaded area. The map key tells you that Hattiesburg is in Wind Zone IV.

The box where the 11-15 row and the Zone IV column meet is shaded dark blue, which shows that you live in an area of high risk. A safe room is the preferred method of wind protection in high-risk areas. Note that some areas of low or moderate risk, shown as pale blue or medium blue in the worksheet, are within the region of the United States that is subject to hurricanes (see Figure I-4). If you live in this hurricane-susceptible region, your risk is considered high, even though the worksheet indicates only a moderate or low risk.
Emergency Planning and Emergency Supply Kit

Whether or not you decide that you need a safe room in your home or small business, you can take two important steps to provide near-absolute protection for you, your family, or employees during a hurricane or tornado: prepare an emergency plan and put an emergency supply kit together. If you decide to build a safe room, your emergency plan should include notifying local emergency managers, first responders (local fire stations), and family members or others outside the immediate area that you have a safe room. This will allow emergency personnel to quickly free you if the exit from your safe room becomes blocked by debris. You should also prepare an emergency supply kit and either keep it in your safe room or be ready to bring it with you if you need to evacuate your home. Some of the items that the emergency supply kit should include are:

- An adequate supply of water for each person in your home or small business (1 gallon per person per day)
- Non-perishable foods that do not have to be prepared or cooked (if these include canned goods, remember to bring a manual can opener)
- Disposable eating utensils, plates, cups, paper towels, etc.
- Tools and supplies:
  - flashlight (one per person; do not bring candles or anything that lights with a flame)
  - battery-operated radio or television and NOAA\(^1\) weather radio
  - cellular phone or Citizen’s Band (CB) radio
  - extra batteries for the above tools
  - wrench (to turn off gas and water)
  - insect repellent and sunscreen
  - personal hygiene items such as hand wipes and toilet paper
- A first-aid kit, including necessary prescription medicines, bandages, and antibiotic ointment

\(^1\) The National Oceanic and Atmospheric Administration (NOAA) Weather Radio (NWR) is a nationwide network of radio stations broadcasting continuous weather information directly from a nearby National Weather Service (NWS) office. NWR broadcasts NWS warnings, watches, forecasts, and other hazard information 24 hours a day, as well as post-event information for all types of hazards, both natural and technological. NOAA Weather Radios are available at electronics stores across the country and range in cost from $25 up to $100 or more, depending on the quality of the receiver and number of features. The NWS does not endorse any particular make or model of receiver.

<table>
<thead>
<tr>
<th>TABLE I.1: Homeowner’s Worksheet</th>
<th>WIND ZONE (SEE FIGURE I-4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td>LOW RISK</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>MODERATE RISK</td>
<td>1 – 4</td>
</tr>
<tr>
<td>HIGH RISK</td>
<td>5 – 10</td>
</tr>
<tr>
<td>Safe room should be considered for protection from extreme winds.</td>
<td></td>
</tr>
<tr>
<td>Safe room is the preferred method of protection from extreme winds.</td>
<td></td>
</tr>
<tr>
<td>Safe room is the preferred method of protection from extreme winds if the home or small business is in a hurricane-susceptible region.</td>
<td></td>
</tr>
</tbody>
</table>
• Disposable eating utensils, plates, cups, paper towels, supply kit and either keep it in your safe room or be ready to bring it with you if you need to evacuate your home. Some of the items that the emergency supply kit should include are:

   • Extra change of clothing per person (store in plastic trash bags to keep clean and dry)
   • Appropriate outer wear (e.g., sunglasses, ponchos, jackets, gloves, headwear, boots, etc.)
   • Bedding materials such as pillows and blankets or sleeping bags
   • Special items for:
     • babies – formula, diapers, bottles, powdered milk
     • children – entertainment items such as books, games, or toys
     • adults – contact lenses and supplies, extra glasses, and a sufficient supply of prescription medications
     • pets – appropriate supplies such as water (1/2 gallon per day), food, leash, ID tag, carrying container, etc.
   • Additional items:
     • important documents such as insurance documents, a list of all your important contacts (e.g., family, doctors, insurance agents), banking information, leases/ mortgage, proof of occupancy (such as a utility bill), and a waterproof container in which to keep these documents
     • ABC² rated fire extinguisher
     • roofing tarps or plastic sheeting
     • roll of large heavy-duty trash bags and duct tape
     • money (cash)

You can get more information about emergency planning from American Red Cross (ARC) and FEMA publications, which you can obtain free of charge by calling FEMA at 1-800-480-2520, or by writing to FEMA, P.O. Box 2012, Jessup, MD 20794-2012. These publications include the following:

**Planning Documents:**

*Are You Ready? An In-depth Guide to Citizen Preparedness, FEMA IS-22*

*Emergency Preparedness Checklist, FEMA L-154 (ARC 4471)*

*Emergency Food and Water Supplies, ARC 5055*

*Your Family Disaster Supplies Kit, ARC 4463*

*Preparing for Disasters for People with Special Needs, FEMA 476 (ARC 4497)*

**Safe Room Documents:**

*Design and Construction Guidance for Community Safe Rooms, FEMA 361*

*Safe Room and Community Shelter Resource CD, FEMA 388 CD*

*Tornado Protection - Selecting Refuge Areas in Buildings, FEMA 431*


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2 ABC refers to fires originating from three types of sources: A - paper, wood, or fabric; B - gasoline or oil; or C - electrical.
Now that you better understand your risk from a tornado or hurricane, you can work with your builder/contractor to build a safe room to provide near-absolute protection for you, your family, or employees from these extreme windstorms. This section describes how extreme winds can damage a building, explains the basis of the safe room designs presented in this publication, and shows where you can build a safe room in your home or small business.

### Building Damage

Extreme winds can cause several kinds of damage to a building. To understand what happens when extreme winds strike, you must first understand that tornado and hurricane winds are not constant. Wind speeds, even in extreme-wind events, rapidly increase and decrease. An obstruction, such as a home, in the path of the wind causes the wind to change direction. This change in wind direction increases pressure on parts of the home. The combination of increased pressures and fluctuating wind speeds creates stress on the home that frequently causes connections between building components to fail.

For example, the roof covering, roof deck, or wall siding can be pulled off and the windows can be pushed into or suctioned out of a building. Figure II-1 shows how extreme winds can affect a building and helps explain why these winds cause buildings to fail. When wind is allowed to enter a building through a broken window, door, or roof section, that wind will act on the inside of a building much like air will act when forced into a balloon; it will push (or pull) on the walls and roof of the building from the inside. These forces within the building, added to the wind forces that are still acting on the outside of a building, often result in failure of the building because it was not designed to resist the forces acting on both the inside and the outside of the building. Buildings that fail under the effects of extreme winds often appear to have exploded, giving rise to the misconception that the damage is caused by unequal atmospheric or wind pressures inside and outside the building. This misconception has led to the myth that, during an extreme-wind event, the windows and doors in a building should be opened to equalize the pressure. In fact, opening a window or door allows wind to enter a building and increases the risk of building failure.

Damage can also be caused by flying debris (referred to as windborne missiles). If wind speeds are extreme enough, missiles can be thrown at a building with enough force to penetrate or perforate windows, walls, or the roof. For example, an object such as a 2” x 4” wood stud weighing 15 pounds, when carried by a 250-mph wind, can have a horizontal speed of 100 mph, which is enough force to penetrate or perforate most common building materials used in homes today. Even a reinforced
masonry wall, which typically has hollow cells between reinforced cells, will be perforated unless it has been designed and constructed to resist debris impact during extreme winds. Because missiles can severely damage and even perforate windows, walls, and roofs, they threaten not only buildings but the occupants as well.

**definition**

In this publication, missiles may be said to **penetrate** but not **perforate** the walls or roof of a safe room. For example, if a missile **penetrates** an exterior element of the safe room, this means the missile broke or damaged the exterior surface, but has not entered the safe room protected area. It is quite common for smaller missiles such as small stones, branches, and other lighter missiles to penetrate or imbed themselves into the exterior of the safe room and this is acceptable. However, the safe room walls, roof, and protected openings must not allow a missile to **perforate** these systems and allow the missile to enter into the safe room. When any portion of the safe room exterior is damaged such that a missile, or portion thereof, enters the protected area, the safe room exterior has been perforated and this is not acceptable.

**Basis of Safe Room Design**

The purpose of a safe room is to provide a space where you, your family, or employees can survive a tornado or hurricane with little or no injury. For tornado-prone areas, you should locate your safe room so that you can reach it as quickly as possibly from all parts of your home or business. In hurricane-prone areas, the safe room should not be built where it can be flooded during a hurricane. Your safe room should be readily accessible from all parts of your home or small business and should be free of clutter. To provide near-absolute protection for the occupants during extreme windstorms, the safe room must be adequately anchored to the home's foundation to resist overturning and uplift. The connections between all parts of the safe room must be strong enough to resist failure, and the walls, roof, and door must resist perforation by windborne missiles.

Extensive testing by Texas Tech University and other wind engineering research facilities has shown that walls, ceilings, and doors commonly used in building construction to meet minimum building code requirements for standard building construction cannot withstand the impact of missiles carried by extreme winds. The safe room designs in this publication account for these findings by specifying building materials and combinations of building materials that will resist perforation by missiles in extreme winds.

Most homes, even new ones constructed according to current building codes, do not provide adequate
protection for occupants seeking life-safety protection from tornadoes. Homes built to the modern building codes in hurricane-prone areas, such as windborne debris regions better resist wind forces and windborne debris impacts from hurricanes. However, a tornado or hurricane can cause wind and windborne debris loads on a home or small business that are much greater than those on which building code requirements are based. Only specially designed and constructed safe rooms, which are voluntarily built above the minimum code requirements of the IBC and IRC to the criteria of this publication, FEMA 361, or the ICC-500, offer life-safety occupant protection during a tornado or strong hurricane. The prescriptive designs provided in this publication provide near-absolute protection from winds and windborne debris associated with tornadoes or hurricanes.

The safe room designs provided in this publication are based on wind speeds that are rarely exceeded in the United States. Therefore, a safe room built according to these designs is expected to withstand the forces imposed on it by extreme winds without failing; this statement applies to both materials and connections used within the safe room. The intent of the designs is not to produce a safe room that will always remain completely undamaged, but rather a safe room that will enable its occupants to survive an extreme windstorm with minor or no injuries.

It is very important to note that predicting the exact strength of tornadoes and hurricanes is impossible. That is another reason why the safe room designs in this publication are based on extreme-wind speeds and why the primary consideration is life safety.

**note**

This publication provides FEMA safe room designs that meet or exceed the minimum shelter design requirements from the ICC-500 Storm Shelter Standard. The safe room designs in this publication are applicable for both tornado and hurricane hazards for the residential shelter and small community shelter (<16 occupants) design criteria identified in the ICC-500. The safe room design wind speed used is 250 mph and it has been designed as a “partially enclosed building” per ASCE 7 so as to meet the requirements of both residential and community safe rooms for tornado and hurricane hazards. Further, the missile resistance is based upon the 15-lb 2”x4” board missile traveling horizontally at 100 mph (again, the most restrictive criteria for both tornado and hurricane hazards). For additional design criteria and information for residential safe rooms, see the notes on the safe room plans in this publication and the design requirements for residential safe rooms in Chapter 3 of FEMA 361, *Design and Construction Guidance for Community Safe Rooms*.

Designing a building, or portion of a building, to resist damage from more than one natural hazard requires different, sometimes competing, approaches. For example, building a structure on an elevated foundation to raise it above expected flood levels can increase its vulnerability to wind and seismic damage. These design approaches need to be thoroughly considered. In flood-prone areas, careful attention should be given to the warning time, velocity, depth, and duration of floodwaters. These flooding characteristics can have a significant bearing on the design and possibly even the viability of a safe room. Your local building official or licensed professional engineer or architect can provide you with information about other natural hazards that affect your area and can also recommend appropriate designs.

**Safe Room Size**

The amount of floor area per person that your safe room must provide depends partly on the type of windstorm from which the safe room is intended to protect you. Tornadoes are not long-lasting storms, so if you are relying on your safe room only for tornado protection, you will not need to stay in the safe room for as long a time-frame as you would for a hurricane. As a result, comfort is not of great concern, and a safe room that provides at least 5 square feet of floor area per person (note that wheelchair and bedridden occupants will require more space) will be big enough. This allocation of space per occupant also meets the minimum sizing requirements set forth in the ICC-500 for residential and small community tornado shelters.

When the safe room is intended to provide near-absolute protection from storms such as hurricanes, which can last for 24 hours or more, the comfort of the occupants should be considered. For this type of

**note**

The safe room designs in this publication are applicable for any on-site construction. However, in a modular home, the safe room location would be limited to the basement or the below-ground module unless a separate foundation was designed and installed for the safe room. A modular home is a home constructed of modular units that have been built elsewhere, brought to the site, and installed on a permanent foundation.

**note**

Consult FEMA 361 or the ICC-500 for guidelines and requirements on how to identify the net usable floor space for a safe room design from the publication if it is to be used as a small community safe room. Hard fixtures (sinks, bathtubs, etc.) and furnishings reduce the square footage within a safe room that is available for protecting occupants.
safe room, the recommended amount of floor area per person (standing or seated, not wheelchair or bedridden) varies from 7 to 20 square feet, depending upon the classification of the safe room. The minimum sizing requirement set forth in the ICC-500 for residential hurricane shelters is 7 square feet per occupant, while for small community shelters 20 square feet per occupant is specified. Necessities, such as water and toilet facilities, should also be provided in the small community safe rooms to maintain compliance with the FEMA 361 criteria and ICC-500 requirements. The safe room designs in this guide may have a minimum floor area of 48 square feet and a wall length of 6 feet. A safe room of that size used for hurricane protection could accommodate up to six people in reasonable comfort while maintaining compliance with the FEMA 361 criteria and ICC-500 requirements. The maximum floor dimensions in the safe room designs provided in this guide are shown to be 14 feet by 14 feet square, providing 196 square feet of safe room space. This amount of space could provide safe room protection for nine occupants at the ICC-500 square footage requirements for a small community hurricane shelter. If you plan to build a safe room with any wall longer than 14 feet, or with a wall height greater than 8 feet, consult a licensed professional engineer or architect.

**Foundation Types**

Homes and other buildings vary in construction type as well as foundation type. Buildings constructed may have heavy walls systems, such as masonry or concrete, or they may have light walls systems constructed from wood framing, metal stud framing, or structural insulated panels (SIPs). Regardless of the structure above, the following types of foundations may be suitable for the installation of a safe room:

- **Basement**
- **Slab-on-grade**
- **Crawlspace or pile (however, prescriptive solutions for pile foundations are not provided in the drawings included in this publication)**

**Basement Foundation Applications**

A home on a basement foundation (see Figure II-2) is usually built on a foundation constructed of cast-in-place concrete or concrete masonry units (CMUs). Most concrete foundations are reinforced with steel bars or straps, but many CMU foundation walls have no steel reinforcement. The framing for the floor above the basement is supported by the exterior foundation walls and sometimes by a center beam.
In a new or existing home with a basement, the safe room should be built in the basement. You can build the safe room as an entirely separate structure with its own walls, or you can use one or more of the basement walls as walls of the safe room. If you use the existing basement walls, they will have to be specially reinforced. Typical reinforcement techniques used in residential basement walls will not provide sufficient protection from missiles and resistance to extreme-wind loads. In new construction, your builder/contractor can reinforce the walls near the safe room during the construction of your home. Reinforcing the basement walls of an existing home is not practical.

The likelihood of missiles entering the basement is lower than for above-ground areas; however, there is a significant chance that missiles or falling debris will enter the basement through an opening left when a window, a door, or the first floor above has been torn off by extreme winds. Therefore, your basement safe room must have its own reinforced ceiling; the basement ceiling (the first floor above) cannot be used as the ceiling of the safe room. The safe room designs provided have considered that large, heavy loading from debris may be experienced by the safe rooms when a surrounding structure may collapse during an extreme-wind event. The roof decks of these safe rooms are designed to limit the damage that may be induced from these debris sources. Although the building may collapse around the safe room, it is still appropriate to install the safe room in the basement.

The least expensive type of safe room that can be built in a basement is a lean-to safe room, which is built in the corner of the basement and uses two basement walls. The lean-to safe room uses the fewest materials, requires the least amount of labor, and can be built more quickly than other types of basement safe rooms (see drawings B-01 and B-02).

In general, it is easier to add a basement safe room during the construction of a new home than to retrofit the basement of an existing home. If you plan to add a basement safe room as a retrofitting project, keep the following points in mind:

- You must be able to clear out an area of the basement large enough for the safe room.
- Unless the exterior basement walls contain steel reinforcement as shown on the design drawings provided with this publication, these walls cannot be used as safe room walls since they are not reinforced to resist damage from missiles and uplift from extreme winds.
- Exterior basement walls that are used as safe room walls must not contain windows, doors, or other openings in the area providing protection.
- The safe room must be built with its own ceiling, so that the occupants will be protected from missiles and falling debris.

Slab-on-Grade Applications

A slab-on-grade home or commercial building (see Figure II-3) is built on a concrete slab that is installed on compacted or natural soil. The concrete may be reinforced with steel that helps prevent cracking and bending. If you are building a new slab-on-grade home and want to install a safe room (of any material or type), it is recommended that the slab or foundation beneath the safe room wall be reinforced and thicker to ensure proper support and resistance to all loads (gravity and wind loads). The thickened slab will act as a footing beneath the walls of the safe room to provide structural support. It will also help anchor the safe room so that it will stay in place during an extreme-wind event, even if the rest of the home is destroyed.

In an existing home, removing part of the slab and replacing it with a thickened section to support a safe room would involve extensive effort and disruption inside the home. Some safe room designs presented in the drawings will require a footing to be placed due to the weight of the safe room itself, but others may be secured to an existing slab provided it has reinforcing steel in the concrete. Therefore, building a safe room with concrete or concrete masonry walls in an existing slab-on-grade home may not be practical unless the existing slab can be shown to have reinforcement adequate to support the safe room. If reinforcement can be shown to be present, the designs provided in these plans may be retrofitted to certain reinforced slabs. Similarly, a wood-frame safe room may be constructed atop an existing, reinforced slab because its walls are not as heavy and do not require the support of a thickened slab; however, these lighter safe room designs are vulnerable to displacement by wind loads. A wood-frame safe room can be created from an existing room, such as a bathroom or closet, or built as a new room in an open area in the home, such as a garage. Whenever an existing slab is used as the foundation for a safe room, a structural engineer should evaluate the adequacy of the slab to resist the wind loads acting on the safe room.

You can also build a safe room as an addition to the outside of a slab-on-grade home. This type of safe room must not only have proper footings, but also a watertight roof. Because a safe room built as an outside addition will be more susceptible to the impact of missiles, it should not be built of wood framing alone. Instead, it should be built of concrete or concrete masonry. Access to this type of safe room can be provided through an existing window or door in an exterior wall of the home.

In general, it is easier to add a safe room during the construction of a new slab-on-grade home than to retrofit an existing slab-on-grade home. If you plan to add a safe room to a slab-on-grade home as a retrofitting project, keep the following points in mind:

- The walls of the safe room must be completely...
separate from the structure of the home. Keeping the walls separate makes it possible for the safe room to remain standing even if portions of the home around it are destroyed by extreme winds.

- If you are creating your safe room by modifying a bathroom, closet, or other interior room with wood-frame walls, the existing walls and ceiling must be retrofitted or replaced with walls and a ceiling resistant to the impact of windborne missiles and other effects of extreme winds. In most cases, this means removing the sheathing, such as drywall or plaster, on either the inside, outside, or both sides of the walls and ceiling. Where possible, it is recommended that the shelter be built as a “new room” within the existing room in order to isolate the shelter from the home structure.

- If you intend to build a safe room with concrete or concrete masonry walls, a section of your existing slab floor may have to be removed and replaced with a thicker slab. As noted above, if this is necessary it may mean the retrofit may not be practical in the existing home.

Crawlspace or Pile Applications

A home built on a crawlspace (see Figure II-4) usually has a floor constructed of wood framing. Along its perimeter, the floor is supported by the exterior foundation walls. The interior part of the floor is supported by beams that rest on a foundation wall or individual piers. Crawlspace foundation walls may be concrete, but are usually constructed from blocks of concrete masonry unit (CMU). They are often unreinforced and therefore provide little resistance to the stresses caused by extreme winds.

Building a safe room inside a home on a crawlspace foundation is more difficult than building a shelter inside a home on a basement or slab-on-grade foundation. The main reason is that the entire safe room, including its floor, must be separate from the framing of the home or the entire floor system and foundation of the home will be required to be constructed to support the extreme-wind loads acting on the safe room. In Figure II-4, a safe room is built inside the home or commercial building without using the floor system of the structure itself. In this option, the safe room has a separate concrete slab floor installed on top of earth fill and must be supported by steel reinforced concrete or CMU foundation walls. The floor system may be designed as open and elevated, but that design option is difficult to develop a prescriptive solution for and therefore is not provided in this publication. An alternative approach, which may be more economical, is to build an exterior safe room on a slab-on-grade foundation adjacent to an outside wall of the home and provide access through a door installed in that wall.

Ventilation in the area below the floor of the home is also an important issue. The wood-framed floor of a home on a crawlspace foundation is typically held 18 to 30 inches above the ground by the foundation walls for compliance with the building code. The space below the floor is designed to allow air to flow through so that the floor framing will not become too damp. It is important that the installation of the safe room not block this air flow.

In general, it is much easier to build a safe room inside a new crawlspace home than in an existing crawlspace home. If you plan to add a safe room to an existing crawlspace home as a retrofitting project, keep the following points in mind:

- The safe room must have a separate foundation. Building the foundation inside the home would
require cutting out a section of the existing floor and installing new foundation members, fill dirt, and a new slab – a complicated and expensive operation that is often not practical.

- A more practical and more economical approach would be to build an exterior safe room, made of concrete or concrete masonry, on a slab-on-grade foundation adjacent to an outside wall of the home, as described above.

**warning**

It is also important to remember that FEMA does not support placing safe rooms offering protection against extreme-wind events where floodwaters have the potential to endanger occupants within the safe room. Although the ICC-500 allows the placement of residential shelters in areas subject to flooding, FEMA safe room design criteria for residential safe rooms significantly limit the placement of safe rooms in Special Flood Hazard Areas (SFHAs). A residential safe room may only be sited in mapped SFHA where no wave action or high-velocity water flow is anticipated. Therefore, the installation of a safe room in a home supported by piles, piers, or columns should be scrutinized for its location with respect to flood hazards. With building connectors commercially available, it is extremely difficult to economically and structurally separate the safe room from the elevated floor framing and ensure that the safe room will withstand the forces of extreme winds.

If your safe room is located where coastal or riverine flooding may occur during hurricanes, it should not be occupied during a hurricane. Further, a residential safe room should not be located in an area subject to storm surge inundation. Although occupying such a safe room during a tornado may be acceptable, provided that the safe room is located where it will not be flooded by rains associated with other storm and tornado events, it should not be used during a hurricane. A residential safe room sited in the SFHA should meet the flood-specific FEMA safe room design criteria listed below. Consult your local building official or local National Flood Insurance Program (NFIP) representative to determine whether your home or small business, or a proposed stand-alone safe room site, is susceptible to coastal or riverine flooding. In any case, the installation of any safe room in a hurricane-prone area should be coordinated with local emergency management and law enforcement to ensure that its use during extreme-wind events is not a violation of any local or state evacuation plan.

Certain safe room designs provided in this publication may be elevated several feet above existing grade (see drawing sheets for specific details). However, even though the safe room floor may be elevated, it should be located outside of the following high-risk flood hazard areas:

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**Figure II-4. Cross-section: typical crawlspace foundation, with safe room**
1. The Coastal High Hazard Area (VE zones) or other areas known to be subject to high-velocity wave action; or

2. Areas seaward of the Limit of Moderate Wave Action (LiMWA) where mapped, also referred to as the Coastal A Zone in ASCE 24-05; or

3. Floodways; or

4. Areas subject to coastal storm surge inundation associated with a Category 5 hurricane (where applicable, these areas should be mapped areas studied by the U.S. Army Corps of Engineers (USACE), NOAA, or other qualified sources).

If it is not possible to install or place a residential safe room outside the SFHA, the residential safe room may be placed in an area that has been determined by detailed study to be in an A, shaded X, or unshaded X Zone, but still outside of the high hazard areas identified above. In the instances when a residential safe room is needed in these flood-prone areas, the top of the elevated floor of the safe room should be elevated to the highest of the elevations specified below (see the appropriate Flood Insurance Study (FIS) or Flood Insurance Rate Map (FIRM)):

1. The minimum elevation of the lowest floor required by the floodplain ordinance of the community (if such ordinance exists); or

2. Two feet above the base flood elevation (BFE); i.e., 2 feet above the flood elevation having a 1 percent annual chance of being equaled or exceeded in any given year (100-year event); or

3. The stillwater flood elevation associated with the 0.2 percent annual chance of being equaled or exceeded in any given year (500-year event).

**Residential Tornado Safe Room Exception:** Where a residential tornado safe room is located outside of the hurricane-prone region as identified on Figure 3-2 of FEMA 361, and the community participates in the NFIP, the safe room need only be elevated to the minimum lowest floor elevation identified by the floodplain ordinance of the community. Note, when installing a residential safe room in an area that has not been mapped or studied as part of a NFIP flood study (or equivalent flood study), the top of the safe room floor should be elevated such that it is 2 feet above the flood elevation corresponding to the highest recorded flood elevation in the area that has not been evaluated. Should no historical flood elevation data be available for the area, the elevation of the safe room floor should be set at the elevation identified by the local authority having jurisdiction.

In areas where Category 5 storm surges are not mapped, references in this publication to “Category 5” storm surge inundation areas should be taken to mean the area inundated by the highest storm surge category mapped.

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**New vs. Existing Homes or Buildings**

The safe room designs in this publication were developed primarily for use in new homes or buildings, but some can be used in existing buildings. When a new home is being built, the builder/contractor can construct walls, foundations, and other parts of the home as required to accommodate the safe room. Modifying the walls or foundation of an existing home as necessary for the construction of a safe room is more difficult. As a result, some of the safe room designs in this publication are not practical for existing homes. Constructing a safe room within your home or small business puts it as close as possible to your family and/or employees. A safe room may be installed during the initial construction of a home or retrofitted afterward. As long as the design and construction requirements and guidance are followed, the same level of near-absolute protection is provided by either type of safe room. The following sections discuss these issues further. Also, for this discussion, the term “retrofit” refers to the process of making changes to an existing building.

It is relatively easy and cost-effective to add a safe room when first building your home or small business. For example, when the home is constructed with exterior walls made from CMUs (also commonly known as “concrete block,” see Figure II-5), the near-absolute protection level in FEMA 320 can be achieved by slightly modifying the exterior walls at the safe room space with additional steel reinforcement and grout. The safe room is easily completed by adding interior walls constructed of reinforced CMU, a concrete roof deck over the safe room, and a special safe room door, as shown in Figure II-6.

Building a safe room in an existing home will typically cost 20 percent more than building the same safe room in a new home under construction. Because the safe room is being used for life safety and your home might be exposed to wind loads and debris impacts it was not designed to resist, an architect or engineer (A/E) should be consulted to address special structural requirements (even when using an A/E in such a project is not required by the local building department).
It is relatively easy and cost-effective to add a safe room when first building your home or small business. When a new home is being built, the design and construction requirements and guidance are followed, the same level of near-absolute protection is provided. Although basement and in-ground safe rooms are reinforced, vertically, with steel reinforcing bars from the foundation to the concrete roof deck, those wall sections must be built so that they will provide the highest level of protection against missiles and falling debris, and falling debris, and falling debris. This is an important alternative to be aware of if you are not able to install a safe room in your basement due to concerns related to flood hazards or naturally-high groundwater tables at your site. Researchers, emergency response personnel, and people cleaning up after tornadoes have often found an interior room of a home or small business still standing when all other above-ground parts of the structure of the building fail or be compromised during an extreme-wind event. Researchers, emergency response personnel, and people cleaning up after tornadoes have often found an interior room of a home or small business still standing when all other above-ground parts of the structure fail or be compromised during an extreme-wind event.

There are several possible locations in your home or small business for a safe room. Perhaps the most obvious location is a basement. Researchers, emergency response personnel, and people cleaning up after tornadoes have found an interior room of a home or small business still standing when all other above-ground parts of the structure fail or be compromised during an extreme-wind event. Researchers, emergency response personnel, and people cleaning up after tornadoes have found an interior room of a home or small business still standing when all other above-ground parts of the structure fail or be compromised during an extreme-wind event. Figure II-7 through II-9 are typical floor plans on which possible locations for safe rooms are shown. These plans are developed specifically for homes with safe rooms; they show how safe rooms can be added without changes to the layout of rooms. Figure II-5. CMUs were used for the exterior walls at this construction home under construction (New Smyrna Beach, Florida).

Figure II-6. View of an in-home safe room under construction. The CMU walls of this safe room are fully grouted and are reinforced, vertically, with steel reinforcing bars from the foundation to the concrete roof deck (New Smyrna Beach, Florida).

Figure II-7. CMUs were used for the exterior walls at this home under construction (New Smyrna Beach, Florida).
Safe Room Location

There are several possible locations in your home or small business for a safe room. Perhaps the most convenient and safest is below ground level in your basement. If your home or small business does not have a basement, you can install an in-ground safe room beneath a concrete slab-on-grade foundation or a concrete garage floor. Although basement and in-ground safe rooms provide the highest level of protection against missiles and falling debris because they may be shielded from direct forces of wind and debris, the above-ground designs provided in this publication are also capable of providing near-absolute protection. This is an important alternative to be aware of if you are not able to install a safe room in your basement due to concerns related to flood hazards or naturally-high groundwater tables at your site.

Another alternative location for your safe room is an interior room on the first floor of the home or small business. Researchers, emergency response personnel, and people cleaning up after tornadoes have often found an interior room of a home or small business still standing when all other above-ground parts of the home or small business have been destroyed. Closets, bathrooms, and small storage rooms offer the advantage of having a function other than providing occasional storm protection. Typically, these rooms have only one door and no windows, which makes them well-suited for conversion to a safe room. Bathrooms have the added advantage of including a water supply and toilet.

Regardless of where in your home or small business you build your safe room, the walls and ceiling of the safe room must be built so that they will provide near-absolute protection for you, your family, or employees from missiles and falling debris, and remain standing if your home or small business is severely damaged by extreme winds. If sections of your home’s or small business’ walls are used as safe room walls, those wall sections must be separated from the structure of the home or small business. This is to ensure the structural integrity of the safe room, should the rest of the structure fail or be compromised during an extreme-wind event.

Figures II-7 through II-9 are typical floor plans on which possible locations for safe rooms are shown with yellow highlighting. These are not floor plans developed specifically for homes with safe rooms; they show how safe rooms can be added without changes to the layout of rooms.
**Floor Plan 1: basement**

Possible safe room locations in a basement include the following:

- In a corner of the basement, preferably where the basement walls are below ground level
- In a bathroom, closet, or other interior room in the basement
- In a freestanding addition to the basement

A space that is to be used for a safe room must be kept free of clutter so that the safe room can be quickly and easily entered and so that the safe room occupants will not be injured by falling objects. For this reason, a bathroom is often a better choice for a safe room than a closet or other space used for storage. Remember, if the basement is below the level of storm surge or the level of flooding from any other source, it is not a suitable location for a safe room. In this situation, a possible alternative would be to build an exterior safe room, adjacent to your home, on a slab-on-grade above the flood level.

**Floor Plan 2: safe rooms on the primary level of a home or small business**

Possible safe room locations in a home on a slab-on-grade or crawlspace foundation include the following spaces on the first floor:

- Bathroom
- Closet
- Storage room
- Laundry room (provided the load-bearing wall between it and the garage, as shown in Figure II-8, can be properly separated from the structure of the home)
- Corner of the garage

Regardless of where the safe room is built, it must be equipped with a door that will resist the impact of windborne debris (missiles). Remember, if the first floor of the home or small business is in an area that is susceptible to storm surge from a Category 5 hurricane, it is not a suitable location for a residential safe room. Also, installation of safe rooms in SFHAs should only occur if the flood design criteria for FEMA safe rooms are met and approval has been provided by local jurisdictional authorities responsible for evacuating the area in the event of a hurricane and ensuring NFIP compliance. The prescriptive designs presented in this publication can only be elevated a few feet above existing grade and, therefore, may not comply with flood design criteria for residential safe rooms, which means the safe room designs presented in this publication should not be installed. In this situation, a possible alternative would be to build an exterior safe room on a slab-on-grade elevated on fill above the flood level.

**Figure II-8.**
Floor plan 2: home on a slab-on-grade or crawlspace foundation
**Floor Plan 3: below-grade safe rooms**

Possible locations for an in-ground safe room include the following:

- Below the slab in a closet or storage room
- Below the floor of the garage, in an area where cars will not be parked

Because of the difficulty of installing an in-ground safe room in an existing home, this type of safe room is practical only for new construction. Remember, if the first floor of the home is in an area subject to storm surge or below the level of flooding from any other source, it is not a suitable location for a safe room. In this situation, see the previous section for guidance on a possible alternative to build an exterior safe room on a slab-on-grade elevated on fill above the flood level.

![Figure II-9. Floor plan 3: in-ground (below-grade) safe rooms in a home on a slab-on-grade foundation](image)

**Floor Plan 4: multi-purpose safe rooms in a small business**

Small businesses can use prescriptive safe room designs for multi-purpose safe rooms (see Figure II-10). Using a 14-foot by 14-foot safe room, the area used for life-safety protection can also be adapted for a conference room or other purpose, provided the equipment and fixtures placed in the safe room can be removed quickly and efficiently. When placing safe rooms in buildings larger than typical residential structures, the layout should be designed so that the safe room is quickly accessible from most areas on the floor. If a larger safe room size is desired, design guidance in FEMA 361 can be used.

Tables II-1 and II-2 will help you decide what type of safe room is appropriate for your circumstances. Table II-1 applies to the construction of safe rooms in new homes or buildings. Table II-2 applies to retrofit situations, in which a safe room is being added to an existing home or building.
Figure II-10.
Floor Plan 4: multi-purpose safe rooms in a small business or public building
### Table II-1. Appropriate types of safe rooms for new homes and buildings

<table>
<thead>
<tr>
<th>Safe Room Considerations (New Homes or Buildings)</th>
<th>Appropriate Safe Room Type</th>
<th>Basement</th>
<th>In-Ground*</th>
<th>Above-Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>House or building located in a storm surge area</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>House or building located in a flood hazard area**</td>
<td>NA</td>
<td>NA</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>High water table</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Low cost</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Long-term safe room occupancy comfort</td>
<td></td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Least likely to be hit or impacted by windborne debris</td>
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</tbody>
</table>

### Table II-2. Appropriate types of safe rooms for existing homes and buildings

<table>
<thead>
<tr>
<th>Safe Room Considerations (Existing Homes or Buildings)</th>
<th>Appropriate Safe Room Type</th>
<th>Basement</th>
<th>In-Ground*</th>
<th>Above-Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>House or building located in a storm surge area</td>
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<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>House or building located in a flood hazard area**</td>
<td>NA</td>
<td>NA</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>High water table</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Low cost</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long-term safe room occupancy comfort</td>
<td></td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Least likely to be hit or impacted by windborne debris</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Easy retrofit</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of separating safe room from structural framing of house or building</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Minimal disruption to house or building</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of accessibility</td>
<td></td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

NA = Not Appropriate

* The in-ground safe rooms referred to in this publication are built below ground inside a home or building and therefore can be entered directly from within the home or building. Other types of in-ground safe rooms are available that are designed to be installed outside a home or building. Entering one of these exterior in-ground safe rooms would require leaving the home or building. This publication does not contain any designs or other information about exterior in-ground safe rooms.

** Per flood design criteria for FEMA safe rooms (see pages 76 and 77), elevation of a safe room is only permitted when specific flood design criteria have been met and when approved by the jurisdictional authority responsible for evacuations and NFIP compliance.

### Construction Materials

The materials your builder/contractor will need to build your safe room should be available from building material suppliers in your community. These materials have been carefully selected for their strength, durability, and/or ability to be readily combined in ways that enable them to withstand the forces of extreme winds and the impact of windborne missiles. Your builder/contractor should not substitute any other material for those specified in the designs.

One of the most vulnerable parts of your safe room is the door. The WISE Center at Texas Tech University tested the materials specified for doors in the safe room designs in this publication for their ability to carry wind loads and prevent perforation by missiles. The installation of the door is as important as the materials used in its construction. Please confirm with your builder/contractor that the door to your safe room can
be installed as shown in the design drawings included with this publication. A door specification has been provided in the plans if you cannot obtain a door that meets the debris impact testing requirements for a 15-lb 2x4 board member traveling horizontally at 100 mph (see ICC-500, Chapter 8 for the debris impact testing procedure to be used).

A complete list of the safe room construction materials, with their expected strengths or properties, is included in the safe room designs provided in this publication. Your builder/contractor should use it when buying the materials for your safe room.

There are other viable and appropriate shelters that have been designed and constructed to meet FEMA's design criteria for residential safe rooms that are not included in this publication. Since the first edition of FEMA 320 was released in 1998, many tornado events have occurred highlighting the importance of installing a safe room in homes or small businesses. Individuals and companies began designing shelters to provide alternatives to the prescriptive solutions presented here. As a result, a residential tornado and hurricane shelter industry has evolved.

Many of these shelter products are designed and constructed as pre-manufactured units. These pre-manufactured units are constructed from a variety of elements such as metal panels, fiberglass shells, Kevlar product systems, and many more. Others are shelters that use common building materials or are new innovations from the building industry such as structural insulated panels (SIPs). Because FEMA 320 was accepted as a "pre-standard" for the design and construction of shelters and safe rooms, many of these shelters have been designed to the FEMA criteria for residential safe rooms; that is, they are capable of resisting 250 mph winds (3-second gust) and the debris associated with such wind events (represented as a 15-lb 2x4 wood board traveling 100 mph).

It is important for prospective safe room owners to know that FEMA does not certify, approve, or license the design and construction of shelters to be called safe rooms. However, groups such as the National Storm Shelter Association (NSSA) have stepped forward to help regulate the residential shelter industry. Since the release of its Association Standard in April 2001 (NSSA Standard for the Design, Construction, and Performance of Storm Shelters), the NSSA has provided certifications for shelters that meet the FEMA 320 criteria in the marketplace. Further, various manufacturers have taken their designs to the National Designated Testing Laboratory (NDTL) to be certified to meet FEMA and NSSA criteria.

Additional information regarding pre-manufactured shelters is presented in the Consumer Guide in Section III of this publication. It is important to remember that, as with site-built safe rooms and shelters, pre-manufactured shelters should be attached to an appropriate foundation. A structural engineer should always be consulted to ensure that the prefabricated shelter is being installed on an appropriate and adequate foundation.

### II-3. Average costs for both 8-foot by 8-foot and 14-foot by 14-foot safe rooms in new homes or buildings

<table>
<thead>
<tr>
<th>Size</th>
<th>Safe Room Type</th>
<th>Applicable Drawing No.</th>
<th>Average Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>8-foot x 8-foot Safe Rooms</strong></td>
<td>Concrete Masonry Unit (CMU) Walls</td>
<td>AG-01,02,03</td>
<td>$8,200</td>
</tr>
<tr>
<td></td>
<td>Concrete Walls</td>
<td>AG-01,02,03</td>
<td>$8,100</td>
</tr>
<tr>
<td></td>
<td>Wood-Frame with CMU Infill</td>
<td>AG-05</td>
<td>$7,600</td>
</tr>
<tr>
<td></td>
<td>Wood-Frame with Plywood/Steel Sheathing</td>
<td>AG-06</td>
<td>$6,300</td>
</tr>
<tr>
<td></td>
<td>Insulating Concrete Form</td>
<td>AG-08,09</td>
<td>$8,300</td>
</tr>
<tr>
<td></td>
<td>Reinforced Concrete Box&lt;sup&gt;2&lt;/sup&gt;</td>
<td>IG-01</td>
<td>$7,000</td>
</tr>
<tr>
<td><strong>14-foot x 14-foot Safe Rooms</strong></td>
<td>CMU Walls</td>
<td>AG-01,02,03</td>
<td>$13,500</td>
</tr>
<tr>
<td></td>
<td>Concrete Walls</td>
<td>AG-01,02,03</td>
<td>$13,100</td>
</tr>
<tr>
<td></td>
<td>Wood-Frame with CMU Infill</td>
<td>AG-05</td>
<td>$13,600</td>
</tr>
<tr>
<td></td>
<td>Wood-Frame with Plywood/Steel Sheathing</td>
<td>AG-06</td>
<td>$11,400</td>
</tr>
<tr>
<td></td>
<td>Insulating Concrete Form</td>
<td>AG-08,09</td>
<td>$13,400</td>
</tr>
</tbody>
</table>

1 All safe room types shown in this table are above-ground (AG) types for slab-on-grade foundations. Safe rooms constructed in basements or on crawlspace will differ slightly in price based on the foundations used.

2 Below-ground safe room were estimated for a 5-foot by 5-foot by 8-foot (deep) safe room. The cost included a cast-in-place footing and safe room top, but the safe room walls were a pre-cast unit. The costs for these types of safe rooms are very dependent on site-specific soil conditions and the building materials used.

3 See drawings in this publication for specific materials used, sizes, and other values needed for estimating purposes.

4 Costs provided are budgetary cost estimates calculated to 2008 U.S. dollar values.
for shelters that meet the FEMA 320 criteria in the form of a quality verification process and seal program. Through independent testing and third party design reviews, participating members of the NSSA have received “seals” indicating that their shelters have been designed to meet the wind and debris impact protection criteria of FEMA 320. As a result, many pre-manufactured shelters have been verified and labeled with “seals” indicating that they comply with the FEMA 320 residential safe room design criteria. Therefore, when it can be verified that these pre-manufactured shelters are installed on a proper foundation, and are elevated and sited to meet the flood design criteria provided herein, these proprietary shelters can be viewed as an appropriate alternative to the designs presented in this publication.

FEMA supports the work of the NSSA to promote the design and construction of shelters that meet the near-absolute protection criteria set forth in this document. The efforts of NSSA allow individual or proprietary designs to be included in the market place and considered alongside the FEMA safe room designs as options for homeowners and business owners looking to provide protection from extreme-wind events that may impact their homes or buildings. For additional information on the NSSA and other shelter products that meet the FEMA criteria, see the Consumer Guide provided in Section III.

### Safe Room Cost

When designed and constructed per the specifications on the design plans, these safe rooms meet or exceed the design requirements for tornadoes and hurricanes as identified in the ICC-500 Storm Shelter Standard. Pre-fabricated shelters are also available for installation by a builder/contractor when first building your home, but are not explicitly addressed by this publication. The basic cost to design and construct a safe room during the construction of a new home starts at approximately $6,000, with larger, more refined, and more comfortable designs costing more than $15,000. The cost of your safe room will vary according to the following:

- The size of the safe room
- The location of the safe room
- The number of exterior home walls used in the construction of the safe room
- The type of door used
- The type of foundation on which your home is built
- Your location within the United States (because of regional variations in labor and material costs)
- Whether you are building a safe room into a new home or retrofitting an existing home

Table II-3 shows the average costs for building two types of safe rooms (above-ground [AG] and in-ground [IG]) in new homes on basement, slab-on-grade, and crawlspace foundations according to the design plans in this publication. These costs are for safe rooms with a floor area of 8 feet by 8 feet and 14 feet by 14 feet. The cost of retrofitting an existing home to add a safe room will vary with the size of the home and its construction type. In general, safe room costs for existing homes will be approximately 20 percent higher than those shown in Table II-3.

It is also interesting to note that the cost differential between constructing the combined tornado and hurricane safe rooms presented in this publication and those that may be constructed to meet the ICC-500 residential hurricane (only) safe room design criteria is not a significant cost savings. Construction cost comparisons for some of the common building materials used in the prescriptive designs of this publication were performed.

For the masonry and concrete safe rooms, wall and roof sections that were identified through testing as capable of resisting a test missile that had similar impact momentum as the ICC-500 design missile were selected. Because the ICC-500 is a new standard, very few tests have been performed for missile-resistant systems for the ICC-500 missile. Test results from Texas Tech University’s WISE Center, Florida A&M University, Florida State University, and the University of Florida were used to identify wall sections that had been tested. For these types of safe rooms, the costs to construct the ICC-500 residential hurricane safe room typically provided a cost savings of only 10 to 15 percent when compared to the cost to construct the FEMA 320 safe rooms presented in Table II-3. Proprietary safe rooms were not included in this cost comparison as no pre-manufactured shelters meeting the new ICC-500 requirements were able to be identified.

These findings, however, were not surprising when considering the common building materials used. As was the case when the First Edition of FEMA 320 was prepared, the safe room design for these small safe rooms is typically governed by the ability of the walls and doors to provide debris impact-resistance. When considering the factors that are involved (250 mph vs. 160 mph design wind speeds and debris impact-resistance for different weight and speed missiles), the net savings is measurable but not large as the reduction of materials from the design is typically limited to a reduction in reinforcing steel, connectors, or wall thickness. For both the masonry and concrete safe rooms, there was still a basic wall thickness that needed to be provided to resist both the debris impacts and the wind loads.
SECTION III | BUILDING YOUR SAFE ROOM

Your builder/contractor can use the design drawings provided in this guide to build a safe room for any of the wind zones shown on the map in Figure I-4. The design drawings provided include the details for building five types of safe rooms: concrete, concrete masonry, wood-frame, lean-to, and in-ground. Each of these alternatives is expected to perform equally well in resisting failures caused by extreme winds.

The materials and connections were chosen for their “ultimate strength,” which means that the materials are expected to resist the loads imposed on them until they or the connections between them fail. The intent of the designs is not to produce a safe room that will always remain completely undamaged, but rather a safe room that will enable its occupants to survive an extreme windstorm with little or no injuries. The safe room itself may need to be extensively repaired or completely replaced after an extreme-wind event.

The safe room size and materials specified in the drawings are based on principles and practices used by structural engineering professionals and the results of extensive testing for effects of missile impacts and wind pressures. Typical and maximum dimensions have been provided on the drawings. The safe rooms have been evaluated for and comply with the design criteria in FEMA 361 and the shelter standard requirements set forth in the ICC-500 for residential and small community shelters (shelters with less than 16 occupants). Before increasing the safe room size or using material types, sizes, or spacings other than those specified in the drawings, the changes should be reviewed by a licensed professional structural engineer.

The information in this section includes the following:

- Design drawings and details for safe rooms in basements, above the ground, and in the ground
- Designs for safe rooms installed on both slab-on-grade and crawlspace foundations
- General design notes and fastener and hardware schedules
- Materials lists with quantities and specifications

If you or your builder/contractor have questions about the design drawings in this guide, call the FEMA Building Sciences helpline at (866) 222-3580 or email saferoom@dhs.gov for technical guidance.

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Index of the Design Drawings

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<td>Basement Safe Room – Corner Location</td>
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</tr>
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<td>CMU/Concrete Sections Ceiling Alternatives</td>
</tr>
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<td>Ventilation Details</td>
</tr>
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<td>Wood-Frame Safe Room Plan – Plywood Sheathing with CMU Infill</td>
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<tr>
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<td>Materials Lists</td>
</tr>
</tbody>
</table>

* IG = In-ground, B = Basement, AG = Above-ground
How to Use the Drawings

- Drawings should not be scaled to determine dimensions.
- If there is a conflict between a dimension shown on the drawings and a scaled dimension, the dimension shown on the drawing should govern.
- If there is a conflict between the drawings and local codes, the local codes should govern as long as the life-safety protection provided by the safe room is not lessened. It is important to note, however, that the structural, wall, and roof systems should not be compromised because that would reduce the level of protection of the safe room. It is also important to note that these designs exceed most building code requirements.
- If there is a conflict among the general notes, specifications, and plans, the order of precedence is notes, then specifications, then plans.

Consumer Guide

While this guide presents FEMA’s guidance on the design and construction of residential safe rooms, FEMA does not test or certify materials or systems used in the construction of safe rooms. Vendor claims of compliance with FEMA and ICC criteria should be verified through independent testing or engineering analysis. The National Storm Shelter Association (NSSA) is a non-profit, industry association dedicated to the storm shelter industry. The NSSA “administers testing and engineering evaluation programs to be conducted by certified, independent entities for the purpose of issuing labels to qualified storm shelter producers.” In 2001, the NSSA prepared an association standard for the design and construction of storm shelters. The NSSA Association Standard will be superseded, and the new “Association Standard” will be the ICC-500 Storm Shelter Standard. The NSSA is one place a homeowner or prospective safe room owner can go to seek approved product listings (for safe rooms, shelters, or components) or to verify vendor claims of standards compliance for tornado and hurricane safe rooms.

The NSSA is the only non-profit organization with a quality verification process and seal program. This enables safe room consumers to consider the identity of safe room producers with labeled, quality-verified products; have an industry standard that establishes quality requirements; and be informed and educated on the storm shelter industry via seminars, web pages, and responses to inquiries through the NSSA. The standards to which NSSA holds its manufacturers are consistent with the level of protection provided by the ICC-500 design criteria and FEMA 320. Members of the NSSA that manufacture and construct residential safe rooms submit their designs to the NSSA for third party design reviews to ensure association support for compliance with FEMA 320 and continued respect for the storm shelter industry; it is recommended that all plans used for the construction of safe rooms or shelters be subject to a third party review for quality assurance purposes.

The NSSA website (http://www.nssa.cc) contains a wealth of information such as NSSA policies, evaluation procedures, grant programs, shelter news, and guidance on shelter construction, and industry links. The website also contains contact information for the following different member types:

- **Producer Members** – Those who manufacture or construct storm shelters and certify that shelters, designs, construction, and installation or installation instructions are in compliance with the NSSA standard
- **Installer Members** – Those responsible for compliance with installation instructions provided by producer members
- **Associate Members** – Those engaged in the storm shelter industry, but who do not have direct responsibility for storm shelter compliance with the NSSA standard (this includes suppliers and others engaged in the storm shelter industry)
- **Professional Members** – Design professionals who are capable of designing/analyzing shelters to confirm compliance with applicable standards and other professionals who support the mission of NSSA and also contribute to safety from extreme winds
- **Corporate Sponsors** – Corporate entities with business interests in the storm shelter industry who are willing to support the programs of the NSSA

It is recommended that consumers pursue safe rooms or shelters (manufactured, constructed, or installed) that are per the designs provided in this publication or are verified with a seal from NSSA to meet the FEMA criteria. The NSSA is one place that prospective safe room or shelter owners can look to for verification, certification, and compliance.

Safe Rooms Save Lives

The Oklahoma Safe Room Initiative and rebate program (http://www.gov.ok.gov/display_article.php?article_id=123&article_type=1) built 6,016 safe rooms after the 1999 tornado. There were no deaths during the 2003 tornado that impacted much of the same area also impacted in 1999; the success directly attributable to the availability and utilization of the safe rooms. The Oklahomans in “Tornado Alley” felt safe and protected knowing that their families had a safe place to go. As of March 2008, this and other FEMA grant programs have provided over $260,000,000 in federal funds towards the design and construction of nearly 20,000 residential and over 500 community safe rooms in 23 states and territories.
Below are just a few examples of how FEMA 320 safe rooms have saved the lives of people impacted by extreme-wind events. With proper installation, storm shelters and safe rooms serve as protection from injury or death caused by the dangerous forces of extreme winds. They can also relieve some of the anxiety created by the threat of an oncoming tornado or hurricane. The decision to build or purchase a safe room should include notifying local emergency managers and family members or others outside the immediate area. This will allow emergency personnel to quickly free the exit should it become blocked by debris. For additional information on these and other safe room “success stories,” see the FEMA websites listed below.

**Baxter County, Arkansas** – On February 5, 2008, when a tornado visited the town of Gassville, Arkansas, Jeanann Quattlebaum felt a certain calmness. Less than 10 months prior, she and her husband, Robert, had purchased a storm shelter. The Quattlebaums had been living in their subdivision for seven years. They purchased their home, which was not equipped with a safe room, from an area builder.

Arkansas is one of several states in “Tornado Alley,” a term used to describe a broad area of relatively high tornado occurrences in the central United States. The state ranks fourth, after Texas, Oklahoma, and Kansas, with tornadoes that are F3 and higher.

The Arkansas Residential Safe Room Program assists Arkansas homeowners who choose to install a shelter or safe room on their property. The program covers up to 50 percent of the cost and installation, not to exceed $1,000.00, for shelters or safe rooms built on or after January 21, 1999. The Quattlebaums’ storm shelter was purchased at a cost of $2,000.00. The circular concrete structure is 10 feet in diameter and stands 5 feet tall. It has the capacity to seat six to eight individuals. During the tornado event of February 5, 2008, it housed six as the tornado touched the lives of Gassville residents. The tornado left behind one fatality and damages to homes and property, which ranged from minimal to extensive.


**Oklahoma City, Oklahoma** – When Karen and her husband built their retirement home in 2002, they were determined to build a protective safe room equipped with the necessary amenities and materials in the event of a devastating tornado. Instead of building the room inside their home like most people, they decided to construct it 20 feet away from the house, and to build it large enough for their extended family.

“I believe my pets are part of my family,” Karen said, referring to her three dogs – two Airedales and a Blue Heeler – and bird – a Scarlet Macaw. “I wasn’t going to run three dogs through the house. Because of weather conditions, I couldn’t see running three dogs over the carpet.” Also, the house was intended to be their last and they wanted it to be a certain way. “It would have been too much structural change,” Karen said. “I didn’t want to change my basic plans of the house the floor plan I liked. I didn’t want to modify it to accommodate everyone.”

While the main house is mostly handicapped accessible, it still would have been difficult to construct a safe room inside the house and have someone in a wheelchair enter it without requiring assistance down the stairs. The safe room has a ramp, making it easily accessible for anyone confined to a wheelchair. “It is a retirement home for my husband and I and one of us could end up in a wheelchair someday, [whether] permanently or temporarily,” Karen said. “Based on Murphy’s Law, that’s when a tornado would hit. We just decided to have everything handicapped accessible.”

Karen and her husband based their safe room model on FEMA regulations and just added a few additional measures of their own. The room is a reinforced concrete structure with French drains. The front of the cellar faces north and wings are extended on the sides and top to hold back the clay. Four feet of earth also cover the roof of the cellar. Stucco, paint, and water sealer was applied to the concrete and a metal porch was built on top of hickory beams to prevent rain from pouring inside whenever the door was opened. No moisture is likely to leak into the cellar. Karen said she intended to build it that way because she strongly despises a “damp, musty basement.”

The project probably cost more than what it normally would have if they had built it inside their home and without all the added weather protection, but Karen was willing to make the sacrifice. She also wanted the room – measured at 10 by 12 feet – to be large enough for her, her husband, and their pets. “I just wanted to take FEMA’s requirements [design criteria] and enhance them,” she said. “I probably have exceeded their requirements … [so] yes, there was an added expense to have it bigger. But it really didn’t add that much. It was worth it to me. That was a personal call. Everybody has to make them.”


**Autauga County, Alabama** – After seeing the destruction of his parents’ home, an Autauga County firefighter decided that it is up to him to keep himself and his family safe from storms. Robert Van Valkenburg, 52, decided to look into building a tornado safe room for his home after his parents’ home was destroyed by a tornado spawned by Hurricane Andrew. “I grew up in that house and it was lost during Hurricane Andrew, so I take this stuff very seriously,” says Van Valkenburg. He adds, “When it impacts your family, and you see how it affects them, you take it
seriously and say ‘Well if it could happen to my mom and dad, it could happen to me.’

Van Valkenburg started the process of building his safe room in 2001. He called his local emergency manager and enrolled in the Alabama safe room program sponsored by FEMA and the Alabama Emergency Management Agency. Actual construction of the safe room took place over 8 months in 2002. FEMA paid 75 percent of the cost to build it, $3,500, through its Hazard Mitigation Grant Program (HMGPG). “My local emergency managers came out to look at the safe room while it was under construction and took pictures. I had to show an itemized break down of everything, and show the cost to substantiate what I paid for it. Then they gave me the money,” Van Valkenburg stated. He also spent more of his own money to add a second entry way to the room, in the event the other entry is blocked, a drainage system, and a generator in the back of his house that kicks in if there is a loss of power.

The safe room got its first test the following spring. Van Valkenburg, his wife, two children, and three dogs stayed in it when a storm system came through and a tornado touched down in the area. “We heard the sirens and went down there in the middle of the night,” says Van Valkenburg “I have my pager from the fire department, and when it goes off I know we have severe weather coming into Autauga County. If they say tornado warning we go there.” In 2004, his family used the shelter again, but for protection from two hurricanes. Twice during the summer, his family took shelter in their safe room during Hurricanes Ivan and Dennis.

The safe room is 11-by-12 feet and is below the ground under a new wing that Van Valkenburg built onto his house for his elderly father-in-law. It is built to be a natural extension of the house. “I knew because of my wife being claustrophobic, I had to design it where it looked like a room or she wouldn’t go into it,” he said. The room is made of reinforced concrete and has steel doors that lock from the inside. Van Valkenburg has also equipped it with a big, sturdy bed, battery powered televisions, water, non-perishable foods, a first aid kit, power tools and the negatives to all family photos. “We can come out of there and we can start life again,” said Van Valkenburg. “That’s what it is all about, coming out of the safe room and being able to live.”


Moore, Oklahoma – Don Staley and his family are no strangers to storms and tornados. Their first home was hit by a tornado in October 1998 and suffered minor damage, but was destroyed by another tornado on May 3, 1999. They rode out both storms inside the house. “It was such a frightening sound,” he said. “We decided we weren’t going to ride out another one inside the house.”

In December 2000, the Staleys’ new home was ready. Shortly after moving in, they had an aboveground safe room constructed on the back patio. The concrete room has 8-inch thick walls, an 18-inch thick ceiling, a 10-inch foundation, and a sliding entry door made of 12-gauge steel with 3/4-inch plywood on each side. The safe room is equipped with battery-powered lights and a battery-powered television.

When the warning sirens sounded on May 8, 2003, Don took shelter in the safe room along with his dog and two cats to ride out the storm feeling very protected and safe. “I was watching it on TV in there,” he recalled. “I could see it was coming my way and I could hear it coming. I could hear the roar. That’s a sound you never forget.”

When he emerged from the shelter, he found his house in shambles with the roof ripped off. Other houses on the street were also heavily damaged or destroyed. The Staleys used their safe room following the tornado to store and protect belongings they had salvaged. The Staleys’ home was among the more than 300 homes destroyed in the city that day. Whereas a severe tornado hit the city in May 1999 and claimed 44 lives, there were no deaths in the 2003 tornado. The absence of fatalities is being attributed to community preparedness, improved early warning systems, and the many safe rooms and shelters that have been built. Staley sums it all up, “The safe room saved my life, it came through with flying colors. It’s worth a million bucks to me.”


Lowndes County (MS) – North of Columbus, Mississippi is the community of Caledonia. Recently, that town has experienced a bit of growth; folks have moved in and built smaller homes to enjoy a more relaxed country atmosphere. And several United States Air Force retirees have settled there, following a tour of duty at Columbus AFB.

But there have been several storms in that area. In November 2002, a tornado struck and damaged homes and property there as well as other county locations. The State of Mississippi had already recognized the need for storm protection earlier and had instituted a tornado safety program, “A Safe Place to Go”. With this declaration, several storm shelter installations were funded by a FEMA Hazard Mitigation Grant. The Wayne Duncan family in Caledonia applied and were reimbursed according to FEMA/MEMA guidelines. An underground safe room was located just outside the carport in the backyard, providing welcome peace of mind.

About 2:00 pm, January 10, 2008, the storm roared across Columbus AFB and a tornado touched down in Caledonia, again. It nearly destroyed the local school,
causing damage to several homes. Mrs. Lena Duncan, with her daughter, son-in-law, and the grandbaby, ran from the house into the underground safe room and waited for the winds and rain to stop. The house was heavily damaged, but the family was safe in their shelter.

The Hazard Mitigation Grant Program (HMGP) remains in effect in Mississippi, following the Katrina declaration. Lowndes County is participating in this Grant. This summer, the Duncan family plan to relocate, down the road, in a new home. This new house will be built with a planned inclusion of a safe room, following the guidelines of FEMA 320. Still working in the Lowndes County Courthouse, Lena Duncan encourages anyone who asks about tornado safety to go talk with the Lowndes County Emergency Management officials about tornado preparedness and safety.

One final example discusses the program that funded several of the Oklahoma safe rooms mentioned above:

**Oklahoma City, Oklahoma** - On May 9, 2003, tornadoes swooped across Oklahoma City's "Tornado Alley." The tornadoes' path was virtually the same as the one that struck 4 years prior. Oklahoma has historically been subject to destructive and deadly tornadoes and high winds. After the 1999 tornado, 44 persons died, 800 were injured and over 6,000 homes were damaged or destroyed.

In order to make Oklahoma a safer place to live, the state launched a Safe Room Initiative Program. Oklahoma was the first state to promote and implement a Statewide residential safe room initiative to build safer communities. The safe room initiative was implemented by the State of Oklahoma with mitigation funds made available by FEMA through the HMGP. This program funded the building of 6,016 safe rooms across the state.

The three basic objectives to help ensure a successful program were public education, financial assistance, and quality control. First, the State of Oklahoma and FEMA kicked off an extensive Public Education Campaign that encompassed a wide range of outreach projects using public service announcements through radio, television, and print. Books, resources, and educational materials were distributed to the residents and communities, while speakers and meetings were used to reach the general public.

Next, the safe room had to be financially affordable to the people. Federal and State agencies developed a first-in-the-Nation safe room rebate program called “Oklahoma Can Survive” to help cover the cost of constructing safe rooms. A $2,000 rebate was offered to property owners for the building of a safe room [Editorial note: At the time of this program, FEMA estimated the safe room cost of an above-ground safe room was approximately $3,500.] The rebates were given in three phases. Phase 1 provided rebates to those people whose homes were destroyed or substantially damaged in the designated disaster area; Phase 2 provided rebates to people with damaged homes in the designated disaster area; and Phase 3 rebates were provided to anyone in the state who wanted a safe room.

Finally, minimal performance criteria guidelines were enforced for proper safe room construction. FEMA 320 was used as a construction guideline to provide all the information a contractor needed to build a safe room. FEMA then used performance criteria based on FEMA 320. An engineer was retained to assist the state in technical support, and help contractors and educating the general public about choosing a safe room construction contractor and helping homeowners with complaints against contractor performances.

AIA CES Course Number: AIAPDH117

Course Description:
This study examines the evolvement of U.S. housing construction during the 20th century. Of particular interest are changes in construction practices associated with the materials and methods used in home building that affect structural performance. The purpose is to benchmark housing structural characteristics (as implied by historic practice), to identify significant changes that have occurred, and to provide an objective resource for discussion and evaluation of structural design implications. Other related interests, such as construction quality, are also considered.

Learning Units:
3.0 LU/HSW

Learning Objective 1:
Upon completion of this course, the student will be aware of the recent history of home building with respect to relevant technical data on structural performance.

Learning Objective 2:
The student will understand that the process of improving current housing value should include periodic evaluation to confirm past successes and to consider the ramifications of past decisions.

Learning Objective 3:
The student will be able to use these findings to help foster future advancement in the interest of even better housing value.

Learning Objective 4:
The student will learn there have been many changes in materials and tools that require more precision in construction, resulting in a greater potential for error, particularly in connections. Accordingly, more attention should be given to connection details that balance structural needs with the intuition and capability of the tradesperson.
INTRODUCTION

Americans have greater access to better housing today than ever before. While modern housing may be considered to be better than in the past, the process of improving housing value should include periodic evaluation to confirm past successes, consider the ramifications of past decisions, and foster future advancement in the interest of even better housing value.

This paper examines the evolution of U.S. housing construction during the 20th century. Of particular interest are changes in construction practices associated with the materials and methods used in home building that affect structural performance. The purpose is to benchmark housing structural characteristics (as implied by historic practice), to identify significant changes that have occurred, and to provide an objective resource for discussion and evaluation of structural design implications. Other related interests, such as construction quality, are also considered.

Home building has always been rooted in practical applications of basic technology. Therefore, this study attempts to align the practical aspects of home building and its history with relevant technical data on structural performance. When available, statistics are cited with respect to housing styles, size, materials, and relevant structural aspects. Where reliable statistical data is unavailable, selected documents that define typical practices are used to arrive at reasonable historic profiles of housing construction and structural characteristics. To a limited degree, personal interviews of home builders with experience dating as far back as 1917 were conducted to compare with information found in the literature.

The study focuses on structural aspects of housing construction and breaks them into three periods of time: early 1900s, mid-1900s, and late 1900s. While it is recognized that change usually occurs slowly and that practices vary regionally, an attempt is made to typify relevant housing construction data and practices in each period. The following sections address:

• General Housing Characteristics,
• Design Loads,
• Foundation Construction,
• Wood-Frame Construction, and
• Construction Quality.

Additional information on thermal insulation materials and methods are reported in Appendix A as a matter of special interest.

1.0 GENERAL HOUSING CHARACTERISTICS

Based on U.S. Census data, the Builder Practices Survey, Housing at the Millennium: Facts, Figures, and Trends, and other sources (see Bibliography), a synopsis of American housing in the 20th century may be constructed for each of the following periods:

1.1 EARLY 1900s

The following characteristics describe a typical home and the housing market in 1900:

- **Population:** 76 million (40 percent urban, 60 percent rural)
- **Median family income:** $490
- **New home price:** average unknown\(^1\)
- **Type of purchase:** typically cash
- **Ownership rate:** 46 percent
- **Total housing units:** 16 million
- **Number of annual housing starts:** 189,000
  (65 percent single-family)
- **Average size (starts only):** less than 1,000 sq. ft.
- **Stories:** One to two stories
- **Bedrooms:** 2 to 3
- **Bathrooms:** 0 or 1

\(^1\) Based on Housing at the Millennium: Facts, Figures, and Trends, the average new home cost was less than $5,000. However, this estimate is potentially skewed in that many people could not afford a “house” of the nature considered in the study. Based on Sears, Roebuck, and Co. catalogue prices at the turn of the century, a typical house cost may have ranged from $1,000 to $2,000, including land.

The front elevation and floor plan of a typical home produced in 1900 is shown in Figure 1. Good examples of traditional housing styles and architectural plans in the early 1900s are found in catalogues produced by Sears, Roebuck and Co., a major producer of traditional American kit homes from about 1910 into the early 1930s (see Bibliography). Likewise, it should be recognized that a large portion of the public lived in rural areas that were not subject to municipal building codes, and housing needs were likely fulfilled in a variety of ways that may not be well documented in the popular literature on housing construction. For example, in Cotton Field’s No More it is stated that “more than half of the farmers lived in one-and two-room shacks that had not been whitewashed or painted for many years, if ever. Many of these houses had holes in the roof, wall, and floor.” Further, U.S. Census data for 1900 reports that the value of land and buildings per farm in eleven Southern states ranged from $600 to $2,000. By contrast, the values for Indiana and Kansas were $6,550 and $3,718, respectively. Thus, living conditions and housing varied widely in the early 1900s.
By the mid-1900s, the use of standardized products, materials, and methods of constructing homes had become fairly mature. In particular, lumber grading and sizes had become essentially uniform across the country. Much of the standardization in home building may be attributed to the Federal Housing Administration (current day Department of Housing and Urban Development) with its Minimum Property Requirements (MPRs) which were applied across the country following WWII, and which were eventually superceded by a first edition of the Minimum Property Standards (MPS) in 1958. At this point, the older “rules-of-thumb” were giving way to prescriptive construction requirements (e.g., span tables, construction specifications, etc.) that were based on practical as well as basic technical (engineering) criteria. Newer materials such as plywood sheathing were addressed as well as standard construction details. This document was, in the opinion of the author, one of the best organized, instructive, and comprehensive building standards developed in the United States.

The front elevation and floor plan of a typical home produced in 1950 is shown in Figure 2.
1.3 LATE 1900s

The following characteristics describe a typical home and the housing market in 2000:

- **Population**: 270 million (76 percent urban, 24 percent rural)
- **Median family income**: $45,000
- **New home price**: $200,000
- **Type of purchase**: 8 percent (many financing options)
- **Ownership rate**: 67 percent
- **Total housing units**: 107 million (approx. 50 percent single-family)
- **Number of housing starts**: 1.54 million (80 percent single-family)
- **Average size (starts only)**: 2,000 sq. ft. or more
- **Stories**: One story (48 percent); 1-1/2 or 2 story (49 percent)
- **Bedrooms**: 2 or less (12 percent); 3 (54 percent); 4 or more (34 percent)
- **Bathrooms**: 1-1/2 or less (7 percent); 2 (40 percent); 2-1/2+ (53 percent)
- **Garage**: 2 car (65 percent)

The front elevation and floor plan of a typical home produced in 2000 is shown in Figure 3.

By the late 1900s, detailed statistical data on new housing construction (such as collected by the U.S. Census and the NAHB Research Center’s *Builder Practices Survey*) had become readily available. Some basic housing construction statistics related to structural features of homes at this time are summarized in Table 1.

The species of framing lumber in the late 1900s generally include Douglas Fir, Hem-Fir, Spruce-Pine-Fir, and Southern Yellow Pine. Wall studs are typically...
The following characteristics describe a typical home and the housing market in 2000:

1. Late 1900s

The front elevation and floor plan of a typical home produced in 2000 is shown in Figure 3.

- Garage:
- Stories:
- Average size (starts only):
- Number of housing starts:
- Total housing units:
- Type of purchase:
- Population:


Table 2: Age Distribution of Existing U.S. Single-Family Homes (1995)

<table>
<thead>
<tr>
<th>Age of Home</th>
<th>Percentage of Housing Stock</th>
</tr>
</thead>
<tbody>
<tr>
<td>76 years or older</td>
<td>9</td>
</tr>
<tr>
<td>56 to 75 years old</td>
<td>11</td>
</tr>
<tr>
<td>25 to 55 years old</td>
<td>35</td>
</tr>
<tr>
<td>0 to 24 years</td>
<td>45</td>
</tr>
</tbody>
</table>

Table 3: Geographic Distribution of U.S. Single-Family Homes by Region (1995)

<table>
<thead>
<tr>
<th>Region</th>
<th>Percentage of Housing Stock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northeast</td>
<td>19</td>
</tr>
<tr>
<td>Midwest</td>
<td>24</td>
</tr>
<tr>
<td>South</td>
<td>37</td>
</tr>
<tr>
<td>West</td>
<td>20</td>
</tr>
</tbody>
</table>

Stud Grade lumber; roof and floor framing lumber is typically No. 1 or No. 2 grade when dimension lumber is used. Fasteners are typically pneumatic-driven 0.113 to 0.131 inch diameter nails or staples. Most homes are built following locally adopted and modified national model building codes offered by one of three private code development organizations. These codes include the Uniform Building Code, National Building Code, and Standard Building Code, as well as the One- and Two-Family Dwelling Code (OTFDC) developed by CABO, an umbrella for the three national model code organizations.

It is interesting to note that while the cost of housing increased 100-fold or more during the 20th century, family income increased by a factor of about 90. Thus, the cost of a home in 1900 was about 3 times the family income on average while the cost of a home in 2000 was about 4 times the family income on average. Despite this apparent change, the increased availability of private financing options for home purchasers has contributed to a nearly 50 percent increase in the home ownership rate during the past century.

Also of significance is the distribution of age and geographic location of single-family homes in the United States, as shown in Tables 2 and 3. Similar data for the earlier part of the 20th century was not found.

2.0 Design Loads

In the early 20th century, structural loads for housing design were not well codified or standardized. Houses and members were largely designed using “rules of thumb” which implicitly considered member strength, stiffness, and loading conditions. By 1923, the U.S. Department of Commerce had formed a Building Code Committee that began to standardize design loads to be used specifically for homes. These loads were later used to formulate various design recommendations such as span tables, footing sizes, and other construction specifications. Recommended live and dead loads published in 1928 are shown in Table 4.

It is interesting to note that the relationship of live load magnitude to influence area (tributary area) was recognized by the U.S. Department of Commerce at this early time in a rudimentary fashion:

“Although a live load of 40 pounds per square foot should be used in selecting all [individual] floor joists, such a load will not occur over a large floor area at the same time. The larger the area, the less chance there is of its being heavily loaded all over. In fact, the building Code Committee of the Department of Commerce, in 1923, after careful investigation, recommended that, in computing the load on girders carrying floors more than 200 square feet in area, a live load of 30 pounds per square foot be used.”

Table 4: Recommended Live and Dead Loads [U. S. Department of Commerce, 1928]

<table>
<thead>
<tr>
<th>Condition</th>
<th>Pounds Per Square Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Live load, all floors used for living purposes</td>
<td>40</td>
</tr>
<tr>
<td>Live load for attic (used for light storage only)</td>
<td>20</td>
</tr>
<tr>
<td>Dead weight for average double floor and joists, but without plaster</td>
<td>10</td>
</tr>
<tr>
<td>Dead weight of plaster ceiling, including joists on light unfloored attics</td>
<td>10</td>
</tr>
<tr>
<td>Roof of light construction, including both live and dead loads</td>
<td>10</td>
</tr>
<tr>
<td>Roof of medium construction with light slate or asbestos roofing, including both live and dead loads</td>
<td>30</td>
</tr>
<tr>
<td>Roof of heavy construction with heavy slate or tile roofing, including both live and dead loads</td>
<td>40</td>
</tr>
</tbody>
</table>
This practical consideration of influence area for dwelling design was subsequently lost in the development of building codes later in the 20th century. Most modern codes do allow a floor live load of 30 psf to be used for bedroom areas; however, this is a separate issue from that of influence area on design live loads.

At the turn of the century, cities that had comprehensive building laws generally specified dwelling floor live loads ranging from 40 to 70 psf. Specified roof loads ranged from 25 to 50 psf depending on the degree that dead, live, and snow loads were included in the values. Snow load reductions based on simple relations to roof slope were sometimes recognized. Wind loads, where specified, ranged from 10 to 30 psf with 20 psf being most common. However, wind loads did not find explicit consideration in housing design until later in the 1900s, even though they were noted throughout the century. For most of the 20th century, it appears that wind loads, when considered, usually used a simple uniform load to be applied to vertical and horizontal projected building surfaces.

In addition, there appears to have been considerable variation in how loads were applied and analyzed. For example, rafter selections were recommended by using horizontal joist span tables produced in the 1930s. Thus, it is unclear as to how various loads were factored into the design of roofs until later in the 20th century when span tables specifically for rafter design considered roof live, dead, and snow loads explicitly. In some cases the actual rafter sloped span was used and wind loads were accounted. However, a lack of standard procedure for analyzing sloped rafters has remained to this day.

By the mid-1900s, the National Bureau of Standards had produced a document titled Minimum Design Loads in Buildings and Other Structures (ASA A58.1-1955). In this document, the design floor live load for apartments and first floors of dwellings was set at 40 psf; second floors and habitable attics at 30 psf; and uninhabitable attics at 20 psf.

Throughout the later half of the 1900s, building codes varied in the requirements for building design loads. However, by the end of the century, the major model building codes began to standardize load requirements into a single format with uniform requirements, in most cases based on the American Society of Civil Engineer’s standard ASCE 7-98, Minimum Design Loads for Buildings and Other Structures (drawn from a later edition of the National Bureau of Standards document ASA A58.1-55).

### 3.0 FOUNDATION CONSTRUCTION

Foundation construction at the beginning of the 1900s differed significantly from that used by the end of the century. Residential foundations in the early 1900s rarely had separate spread footings; the first course of masonry was often laid directly on subgrade. The following relevant quote was found in Structural Analysis of Historic Buildings:

“Portland concrete and reinforced spread footings began to appear at about the turn of the century. They were obviously used sparingly at the beginning, as in the application of any new technology.”

When readily available, it is also found that many homes before 1900 used stone masonry for foundation walls or piers, with or without some type of mortar. Special consideration to foundations and soil support was only given to very unique structures or soil conditions. If engineered, building foundation bearing pressures were usually designed with “appropriate dead and live loads” at the beginning of the 20th century. Even then, the techniques were quite arbitrary and relied heavily on experience and judgment of the designer. Most building designs, at best, were based on a manual probing of the soil and reliance on local practice and/or past performance of nearby building foundations.

#### TABLE 5: PRESUMPTIVE SOIL BEARING VALUES BY TIME PERIOD (pounds per square foot)

<table>
<thead>
<tr>
<th>TIME PERIOD</th>
<th>SOIL DESCRIPTION</th>
<th>BEARING VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EARLY 1900s</strong></td>
<td>Soft/Wet Clay or Sand or Loam</td>
<td>2,000</td>
</tr>
<tr>
<td></td>
<td>Firm Earth</td>
<td>2,500 to 3,500</td>
</tr>
<tr>
<td></td>
<td>Ordinary Clay/Sand Mix and Sand</td>
<td>4,000</td>
</tr>
<tr>
<td></td>
<td>Hard Clay and Firm Course Sand</td>
<td>8,000</td>
</tr>
<tr>
<td></td>
<td>Firm Gravel/Sand Mix</td>
<td>12,000</td>
</tr>
<tr>
<td></td>
<td>Shale Rock</td>
<td>16,000</td>
</tr>
<tr>
<td></td>
<td>Hard Rock</td>
<td>40,000</td>
</tr>
<tr>
<td><strong>MID-1900s</strong></td>
<td>Soft Clay</td>
<td>2,000</td>
</tr>
<tr>
<td></td>
<td>Firm Clay and Sand/Clay Mix</td>
<td>4,000</td>
</tr>
<tr>
<td></td>
<td>Fine dry sand</td>
<td>6,000</td>
</tr>
<tr>
<td></td>
<td>Coarse Sand</td>
<td>8,000</td>
</tr>
<tr>
<td></td>
<td>Gravel</td>
<td>12,000</td>
</tr>
<tr>
<td></td>
<td>Soft Rock</td>
<td>16,000</td>
</tr>
<tr>
<td></td>
<td>Hard Rock</td>
<td>80,000</td>
</tr>
<tr>
<td><strong>LATE-1900s</strong></td>
<td>Clay, Sandy Clay, Silty Clay, and clayey silt</td>
<td>1,000</td>
</tr>
<tr>
<td></td>
<td>Sand, silty sand, clayey sand, silty gravel, and clayey gravel</td>
<td>1,500</td>
</tr>
<tr>
<td></td>
<td>Sandy gravel and/or gravel</td>
<td>2,000</td>
</tr>
<tr>
<td></td>
<td>Sedimentary and foliated rock</td>
<td>2,000</td>
</tr>
<tr>
<td></td>
<td>Massive crystalline bedrock</td>
<td>4,000</td>
</tr>
</tbody>
</table>
Typical presumptive (allowable, permissive, or safe) soil bearing values during the 20th century are shown in Table 5. It is noted that presumptive values decreased drastically (became more conservative) in the later half of the 20th century with no compelling reason identified in the literature.

By the mid-1900s and throughout the remainder of the century, the use of concrete footings and masonry (block) or concrete walls had become common practice. The introduction of separate spread footings is not well understood, as few documents used in this study spoke directly to this issue. Perhaps, newer wall construction methods and materials allowed the use of thinner foundation walls which brought about concern with bearing area on the foundation soil. Perhaps a greater concern or lower tolerance for settlement and cracking of foundation walls developed over time, as expectations for use of basements increased over the course of the century. Certainly, basement wall cracks are a major source of homeowner complaints or claims in modern homes; however, it does not appear that this was such a concern earlier in the century. Data on modern foundation construction types is reported in Table 1.

### 4.0 WOOD-FRAME CONSTRUCTION

Prior to the 1900s some significant changes in basic framing practices in the United States were set in motion. Up through most of the 19th century, homes were built following traditional timber construction known as braced framing adopted from England (see Figure 4). In this manner, homes used heavy squared timber frames and beams with diagonal bracing of 4x or larger timbers. Wood joinery methods were used for heavy connections rather than steel fasteners. Intermediate framing members of smaller dimension were used within the structural frame to provide for attachment of finish materials.

In the mid-1800s a new construction method, known as balloon framing, began to be used in the United States. This method used repetitive light framing members, generally 2x4s, made available by the proliferation of sawmills. By the start of the 20th century, balloon framing had practically replaced the traditional heavy braced framing technique. The balloon framing technique is illustrated in Figure 5. In some cases, vestiges of early practices such as the use of 4x corner posts, beams, and sill framing members existed well into the 20th century in combination with balloon framing. Balloon framing persisted until after World War II in some parts of the country.

Variations in application of the balloon framing method also recognized trade-offs between economy and performance. For example, Sears, Roebuck and Co., produced two types of pre-cut structural framing systems: one using the “honor-built” system and the other using the “standard-built” system. In advertising the “honor-built” system, the following features were highlighted:

- Rafters, 2x6 or 2x4 inches (larger where needed), 14-3/8 inches apart (16 inches on center).
- Double plates over doors and windows (as headers and trim nailing base).
- Double studdings at sides of doors and windows (as jamb support and trim nailing base).
- Three studs at corners.
- High grade horizontal wood sheathing boards, 13/16 inch thick with tarred felt overlay between sheathing and wood siding.
- Double floors with heavy building paper between the subfloor and finished floor.

![Figure 4. Braced Framing pre-1900.](image)
The “standard-built” construction was advertised (at the back of the 1928 Sears catalogue) as the “most house per dollar invested” for smaller homes of 1 to 1-1/2 stories. The largest home of this type had four rooms within a 24 feet by 36 feet plan. The

The following are key specifications of Sears’ “standard-built” homes:

- Rafters, 2x4 inches, 22-3/8 inches apart (24 inches on center); 2x4 ceiling joists at 16 inches on center (for interior finish).
- Single plates over doors and windows (no headers or trim nailing base).
- Single studdings at sides of doors and windows.
- Two studs at corners.
- No wood sheathing (only exterior wood siding of 1x6).
- No sub-floor (finish flooring applied direct to joists).
- Tarred felt under floors and siding.
- 2x8 inch joists placed 22-3/8 inches apart (24 inches on center), spans generally not exceeding 12 feet.
- Studdings, 2x4 inches, 14-3/8 inches apart (16 inches on center), double plate at top and single at bottom of wall; ceiling heights typically 8 feet-3 inches.
- Framing lumber for walls, floors, and roofs uses No. 1 Douglas Fir or Pacific Coast Hemlock (non-Sears standard construction is noted to use lower quality or No. 2 and No. 3 lumber and species such as Tamarak or White Pine).
- Common wire nails of sufficient quantity and variety of sizes.
- Cypress exterior trim.
- All outside paint, two coats.
- Sears also advertised cottage style or portable homes with 2x2 No. 1 yellow pine wall framing, 2x3 roof rafters, and post foundations. The largest size had three rooms with overall plan dimensions of 20 feet by 16 feet, plus a 5 foot covered porch. Sears noted that their “standard-built” homes incorporated some improvements over the common practice of that time, such as the use of three-stud corners and doubled 2x4 members at window and door openings for improved finish attachment. It is unknown how many homes of each type were sold by Sears, Roebuck and Co. But, the catalogues give clear evidence that at least two to three distinctly different levels of dwelling construction were recognized in the early 1900s as a matter of economy verses quality.

By the mid-1900s and during the housing “boom” following WWII, the preferred framing practice had evolved to platform framing, a further refinement of balloon framing. Platform framing is shown in Figure 6. This change was driven by economy and practicality.

Figure 5. Balloon Framing Technique in Early 1900s.
For example, balloon framing required the use of long wall framing members (studs) which were more expensive and less available. Also, balloon framing required fire blocking between wall framing at story levels to comply with modern building codes (initiated in the 1920s). In contrast, platform framing is inherently fire blocked by the use of horizontal wall plates at the top and bottom of each story. In addition, the balloon frame approach was essentially limited to “regular” two-story construction and did not readily allow for newer housing styles that featured story offsets (i.e., floor overhangs) and other “irregularities” in design. Finally, the platform framing technique provides a solid and safe work platform from which to stage construction for upper stories. Platform framing has dominated the housing market since the mid-1900s with a few refinements as follows:

- unnecessary use of bridging between studs and floor joists was eliminated;
- panel products have replaced the use of boards for wall, floor, and roof sheathing;
- wall sheathing no longer laps over the floor perimeter (except in some isolated high wind locales); and
- foundation sill members are anchored to the foundation.

Throughout the 20th century, 16 inch on center framing has remained the dominant choice. Interestingly, this practice has been associated with an early concern to provide adequate support for finish materials (i.e., exterior wood siding or sheathing and, particularly, interior lath and plaster finishes). On the other hand, spacing of roof framing members has largely increased from 16 inch on center (early to mid-1900s) to 24 inches on center in the late 1900s. This change is associated with the inception and later dominance of wood roof trusses in the second half of the 20th Century. However, 16 inch on center roof framing still finds limited use today, particularly in complicated roof designs that necessitate rafter framing.

It should be noted that 24 inch on center wall framing has been used throughout the 20th century in at least a small portion of housing construction for reasons of economy and, more recently, for its additional benefits of improved energy efficiency and resource conservation. Changes to panel forms of exterior and interior sheathing materials (including the use of plywood and OSB sheathing panels and gypsum wallboard, as opposed to boards or lath and plaster) have perhaps contributed to a greater use of 24 inch on center framing today than in the early 20th century. Still, 24 inch on center framing is generally used in less than 10 percent of wall area in modern residential construction annually.

Floor construction has also seen some use of alternate spacings such as 19.2 inch and 24 inch. In recent years, increased use of wider spacing for floor framing members may be associated with increased use of engineered wood products such as parallel chord wood trusses and wood I-joists.

Note: Platform framing in Figure 6 is representative of early platform framing. Platform framing in the mid-to late-1900s used panel products in lieu of board sheathing and bridging in floors and walls was eliminated.
4.1 WOOD MATERIALS

4.1.1 Size

Significant changes to sizes of dimension lumber used in balloon framing occurred in the early 1900s. At first, members where often rough sawn (or perhaps only surfaced on two sides) and available in actual (approximate) 2 inch thickness and depths of 4, 6, 8, 10, 12, and even 14 inches. Later, ostensibly to account for surfacing and shrinkage, finished lumber sizes were reduced to 1-3/4 inch thickness with actual depths of 1/4 inch scant of nominal for members up to 4-inch depth and 1/2-inch scant for members over 4-inch depth. Still later, the thickness was reduced to 1-5/8 inch (as in the Sears homes of 1928) and the depth was reduced to 3-5/8, 5-5/8, 7-1/2, 9-1/2, etc. Finally, in the mid-1900s, lumber dimensions were reduced to the standard sizes that are in use today. The nominal size vs. actual size in current use are as follows: 2x4 (1.5 in by 3.5 in), 2x6 (1.5 in by 5.5 inch), 2x8 (1.5 in by 7.25 in), 2x10 (1.5 in by 9.25 in), and 2x12 (1.5 in by 11.25 in).

4.1.2 Type/Species

Over the 20th century, supply and demand has dictated numerous changes in forestry and availability of wood materials in the United States. At the beginning of the 20th century, virgin growth lumber (also known as old growth) was commonly used. As resources of virgin growth lumber diminished, first in the east and then in the west, use of managed forests became more common and practically essential by the mid-to late-1900s. Wood species typically used for framing lumber in residential construction are shown in Table 6 by time period. As seen in the early 1900s many local species were used. However, Sears boasted in being able to ship the best available Douglas Fir and Pacific Coast Hemlock for their framing lumber. By the late 1900s, wood species were organized into 'species groups' each including several species with similar properties.

4.1.3 Structural Properties

For the purpose of this paper, structural quality deals with characteristics that affect the strength of lumber, not factors such as straightness (although there may be relevant correlation between tendency to warp and structural properties). The primary measures of structural quality are the grading methods used for lumber. However, density is perhaps the single most important parameter to consider, as it can be correlated to several structural properties including bending strength and connection capacity. Grading methods have evolved a great deal over the past century. Typical grades in each time period are shown in Table 7 below. As shown, the grade categories of lumber have increased with time. Modern home construction generally uses two or three grades of dimension lumber and three to four different species or species groups.

By the 1930s, lumber stress values for various species and grades had been used to develop prescriptive span tables for dwelling construction. No. 2 grade lumber was typically recommended for studs while No.1 grade was recommended for joist and rafter framing. The use of No. 2 grade lumber for joists was recognized as a “more economical construction.” But, a 2 inch deeper member was recommended for use with span tables based on No. 1 grade lumber. However, in the 1960s, many builders reported using construction grade lumber for floor joists.

Evidently, little analytical concern was placed on structural capacity prior to the 1900s except by way of practical experience, although limited discussions and test data related to structural properties of some commonly used wood species may be found in the
literature prior to 1900. However, because of the limited tests conducted, the experimenters often reported different structural property values and used different terminology in describing results. One of the better examples of wood engineering data was produced in 1913 by Carnegie Steel (Table 8) which used timber for the purpose of railroad trestle design. While a larger safety margin of about 5 was used for railroad design, a safety factor of 4 was typically recommended for general use where engineering was applied. The safety factors were typically applied to average ultimate strength values from limited testing to develop allowable or working stress design values.

As discussed later, many wood members for light building construction were probably sized or designed by intuitive “rules of thumb” passed down through years of experience. For example, there were no records found of engineering calculations or test data in the origins of balloon framing techniques in the mid-to late-1800s. However, this outcome is not to suggest that no structural consideration or verification testing was performed, since “proof testing” has historically been a common practice to validate new construction techniques. For example, modern roof trusses were developed using engineering tests and data in the mid-1900s. Proof testing of actual truss constructions (i.e., stacking weights on a trussed roof) was often done to verify performance to a skeptical audience. In essence, the concept of “seeing is believing” has played a significant role in the adoption of new construction technologies.

In summary, it appears that two methods of wood construction verification were emerging in the United States in the late 1800s and early 1900s. The first relied on experience with constructed systems for specific applications (i.e., balloon framing of buildings). The second and newer method relied on engineering analysis of special structures (i.e., railroad trestles) based on evaluation of stresses on individual members using quantified structural properties of various wood species. By the 1920s, allowable stresses for various species and two grades (No.1 and No.2) of structural timbers had been published (see Table 9). Later in the 1920s and 1930s, allowable stresses for structural lumber and timber for dry uses had been published (see Table 10). The following quotation from Light Frame House Construction describes the use of the data in Table 10 in the 1930s:

“In Table [10] is given a list of various softwoods used for building construction, with allowable unit working stresses for each species and grade. The species in the upper half of the list are manufactured in structural grades as shown. Definite working stresses have been assigned to all these grades by the manufacturers. For the species in the lower half of the table, structural grades are seldom manufactured as such. Nevertheless, timbers from these species, if carefully selected as to influence of defects, may be rated as ‘select structural,’ and timbers of lower grade as ‘common structural.’ The working stresses shown may then be applied.”

It is apparent that the application of grading standards was in its infancy in the 1930s. The common lumber grades (No. 1 and No. 2) were loosely defined in practice and may have varied substantially at the local level of supply. While published bending properties varied by grade and species, they did not differ much according to size of member. Similarly, modulus of elasticity values tended to vary by species, but not by grade.

Early tests of lumber density are not readily found in the available literature. Because of the lack of grading standards at that time, the lack of standard terminology, and the frequent use of locally grown and milled timber, it is difficult to determine the range of lumber densities typifying residential and other building construction earlier in the 1900s. However, in 1885 the data in Table 11 was reported.

By the 1930s, stress values for many popular wood species, and typically two grades each, were available from lumber grading agencies that followed grading standards. Through the mid-to late-1900s structural data on a wide variety of wood species grew rapidly. By the second half of the 20th century, grading rules and agencies were in full swing, and numerous design values were published in wood industry specifications such as the National Design Specification for Wood Construction and its supplement of wood design values. While dimension lumber dominated the housing market through most of the 20th century, the late 1990s saw a dramatic increase in the use of engineered wood members such as trusses, wood I-joists, and engineered wood panel products (see Table 1).
### TABLE 8: EARLY ENGINEERING DATA FOR STRUCTURAL TIMBERS (Carnegie Steel Co., 1913)

<table>
<thead>
<tr>
<th>Kind of Timber</th>
<th>Bending</th>
<th>Shearing</th>
<th>Compression</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Extreme Fiber Stress</td>
<td>Modulus of Elasticity</td>
<td>Parallel to the Grain</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>Working Stress</td>
<td>Average</td>
</tr>
<tr>
<td>Douglas fir</td>
<td>6,100</td>
<td>1,200</td>
<td>1,510,000</td>
</tr>
<tr>
<td>Longleaf pine</td>
<td>6,500</td>
<td>1,300</td>
<td>1,610,000</td>
</tr>
<tr>
<td>Shortleaf pine</td>
<td>5,600</td>
<td>1,100</td>
<td>1,480,000</td>
</tr>
<tr>
<td>White pine</td>
<td>4,400</td>
<td>900</td>
<td>1,130,000</td>
</tr>
<tr>
<td>Spruce</td>
<td>4,800</td>
<td>1,000</td>
<td>1,310,000</td>
</tr>
<tr>
<td>Norway pine</td>
<td>4,200</td>
<td>800</td>
<td>1,190,000</td>
</tr>
<tr>
<td>Tamarack</td>
<td>4,600</td>
<td>900</td>
<td>1,220,000</td>
</tr>
<tr>
<td>Western hemlock</td>
<td>5,800</td>
<td>1,100</td>
<td>1,480,000</td>
</tr>
<tr>
<td>Redwood</td>
<td>5,000</td>
<td>900</td>
<td>800,000</td>
</tr>
<tr>
<td>Bald Cypress</td>
<td>4,800</td>
<td>900</td>
<td>1,150,000</td>
</tr>
<tr>
<td>Red Cedar</td>
<td>4,200</td>
<td>800</td>
<td>800,000</td>
</tr>
<tr>
<td>White Oak</td>
<td>5,700</td>
<td>1,100</td>
<td>1,150,000</td>
</tr>
</tbody>
</table>

From Carnegie Steel Co. 1913, 310 (as reported in *Structural Analysis of Historic Buildings*)
<table>
<thead>
<tr>
<th>SPECIES</th>
<th>GRADE</th>
<th>Bending</th>
<th>Compression</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extreme Fiber</td>
<td>Horizontal Shear</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cedar, western red</td>
<td>1</td>
<td>900</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>600</td>
<td>53</td>
</tr>
<tr>
<td>Cedar, northern white</td>
<td>1</td>
<td>750</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>500</td>
<td>47</td>
</tr>
<tr>
<td>Chestnut</td>
<td>1</td>
<td>950</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>633</td>
<td>60</td>
</tr>
<tr>
<td>Cypress</td>
<td>1</td>
<td>1,300</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>867</td>
<td>67</td>
</tr>
<tr>
<td>Douglas fir</td>
<td>1</td>
<td>1,500</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1,000</td>
<td>60</td>
</tr>
<tr>
<td>Douglas fir (Rocky Mountain)</td>
<td>1</td>
<td>1,100</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>767</td>
<td>57</td>
</tr>
<tr>
<td>Fir, balsam</td>
<td>1</td>
<td>900</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>600</td>
<td>47</td>
</tr>
<tr>
<td>Gum, red</td>
<td>1</td>
<td>1,100</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>767</td>
<td>67</td>
</tr>
<tr>
<td>Hemlock, western</td>
<td>1</td>
<td>1,300</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>867</td>
<td>50</td>
</tr>
<tr>
<td>Hemlock, eastern</td>
<td>1</td>
<td>1,000</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>667</td>
<td>47</td>
</tr>
<tr>
<td>Larch, western</td>
<td>1</td>
<td>1,200</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>800</td>
<td>67</td>
</tr>
<tr>
<td>Maple, sugar or hard</td>
<td>1</td>
<td>1,500</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1,000</td>
<td>100</td>
</tr>
<tr>
<td>Maple, silver or soft</td>
<td>1</td>
<td>1,000</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>667</td>
<td>67</td>
</tr>
<tr>
<td>Oak, white or red</td>
<td>1</td>
<td>1,400</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>933</td>
<td>83</td>
</tr>
<tr>
<td>Pine, southern yellow</td>
<td>1</td>
<td>1,500</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1,000</td>
<td>70</td>
</tr>
<tr>
<td>Pine, eastern white, western white, and western yellow</td>
<td>1</td>
<td>900</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>600</td>
<td>57</td>
</tr>
<tr>
<td>Pine, Norway</td>
<td>1</td>
<td>1,100</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>733</td>
<td>57</td>
</tr>
<tr>
<td>Spruce, red, white, and Sitka</td>
<td>1</td>
<td>1,100</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>733</td>
<td>57</td>
</tr>
<tr>
<td>Spruce, Engelman</td>
<td>1</td>
<td>750</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>500</td>
<td>47</td>
</tr>
<tr>
<td>Tamarack, eastern</td>
<td>1</td>
<td>1,200</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>800</td>
<td>63</td>
</tr>
</tbody>
</table>

From Voss and Varney 1926, 8 (as reported in Structural Analysis of Historic Buildings without notation regarding safety margins and characteristic structural property data used to derive the working stress design values). Modulus of elasticity is assumed to represent an average characteristics, but does not differentiate between grades.
### TABLE 10: ALLOWABLE UNIT STRESSES FOR STRUCTURAL LUMBER AND TIMBER
(all sizes, dry locations) (HEW, 1931)

<table>
<thead>
<tr>
<th>SPECIES OF TIMBER</th>
<th>GRADE</th>
<th>ALLOWABLE UNIT STRESS (PSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Extreme Fiber in Bending</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Joist and Plank Sizes; 4 inches and less in thickness</td>
</tr>
<tr>
<td>Douglas fir, coast region</td>
<td>Dense superstructural</td>
<td>2,000</td>
</tr>
<tr>
<td></td>
<td>Superstructural and dense structural</td>
<td>1,800</td>
</tr>
<tr>
<td></td>
<td>Structural</td>
<td>1,600</td>
</tr>
<tr>
<td></td>
<td>Common structural</td>
<td>1,200</td>
</tr>
<tr>
<td>Douglas fir, inland empire</td>
<td>Dense superstructural</td>
<td>2,000</td>
</tr>
<tr>
<td></td>
<td>Dense structural</td>
<td>1,800</td>
</tr>
<tr>
<td></td>
<td>No.1 common dimension and timbers</td>
<td>1,135</td>
</tr>
<tr>
<td>Larch, western</td>
<td>No.1 common dimension and timbers</td>
<td>1,135</td>
</tr>
<tr>
<td>Pine, southern yellow</td>
<td>Extra dense select structural</td>
<td>2,300</td>
</tr>
<tr>
<td></td>
<td>Select structural</td>
<td>2,000</td>
</tr>
<tr>
<td></td>
<td>Extra dense heart</td>
<td>2,000</td>
</tr>
<tr>
<td></td>
<td>Dense heart</td>
<td>1,800</td>
</tr>
<tr>
<td></td>
<td>Structural square edge and sound</td>
<td>1,600</td>
</tr>
<tr>
<td>Redwood</td>
<td>Dense No. 1 common</td>
<td>1,200</td>
</tr>
<tr>
<td></td>
<td>Superstructural</td>
<td>2,133</td>
</tr>
<tr>
<td></td>
<td>Prime structural</td>
<td>1,707</td>
</tr>
<tr>
<td></td>
<td>Select structural</td>
<td>1,280</td>
</tr>
<tr>
<td></td>
<td>Heart structural</td>
<td>1,024</td>
</tr>
</tbody>
</table>

### WORKING STRESSES FOR STRUCTURAL LUMBER AND TIMBER
GRADED UNDER THE STRUCTURAL GRADE EXAMPLES OF THE AMERICAN LUMBER STANDARDS

<table>
<thead>
<tr>
<th>SPECIES OF TIMBER</th>
<th>GRADE</th>
<th>ALLOWABLE UNIT STRESS (PSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Extreme Fiber in Bending</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Joist and Plank Sizes; 4 inches and less in thickness</td>
</tr>
<tr>
<td>Cedar, Alaska</td>
<td>Select structural</td>
<td>1,100</td>
</tr>
<tr>
<td></td>
<td>Common structural</td>
<td>880</td>
</tr>
<tr>
<td>Cedar, northern and southern white</td>
<td>Select structural</td>
<td>750</td>
</tr>
<tr>
<td></td>
<td>Common structural</td>
<td>600</td>
</tr>
<tr>
<td>Cedar, Port Orford</td>
<td>Select structural</td>
<td>1,100</td>
</tr>
<tr>
<td></td>
<td>Common structural</td>
<td>880</td>
</tr>
<tr>
<td>Cedar, western red</td>
<td>Select structural</td>
<td>900</td>
</tr>
<tr>
<td></td>
<td>Common structural</td>
<td>720</td>
</tr>
<tr>
<td>Cypress, southern</td>
<td>Select structural</td>
<td>1,300</td>
</tr>
<tr>
<td></td>
<td>Common structural</td>
<td>1,040</td>
</tr>
<tr>
<td>Douglas fir, Rocky Mountain region</td>
<td>Select structural</td>
<td>1,100</td>
</tr>
<tr>
<td></td>
<td>Common structural</td>
<td>880</td>
</tr>
<tr>
<td>SPECIES OF TIMBER</td>
<td>GRADE</td>
<td>ALLOWABLE UNIT STRESS (PSI)</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>----------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extreme Fiber in Bending</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Joist and Plank sizes; 4 inches and less in thickness</td>
</tr>
<tr>
<td>Fir, balsam</td>
<td>Select structural</td>
<td>900</td>
</tr>
<tr>
<td></td>
<td>Common structural</td>
<td>720</td>
</tr>
<tr>
<td>Fir, golden, Noble, silver, white (commercial white)</td>
<td>Select structural</td>
<td>1,100</td>
</tr>
<tr>
<td></td>
<td>Common structural</td>
<td>880</td>
</tr>
<tr>
<td>Hemlock, eastern</td>
<td>Select structural</td>
<td>1,100</td>
</tr>
<tr>
<td></td>
<td>Common structural</td>
<td>880</td>
</tr>
<tr>
<td>Hemlock, west coast</td>
<td>Select structural</td>
<td>1,300</td>
</tr>
<tr>
<td></td>
<td>Common structural</td>
<td>1,040</td>
</tr>
<tr>
<td>Oak, commercial white and red</td>
<td>Select structural</td>
<td>1,400</td>
</tr>
<tr>
<td></td>
<td>Common structural</td>
<td>1,120</td>
</tr>
<tr>
<td>Pine, California, Idaho, and northern white, lodgepole, Pondosa, sugar</td>
<td>Select structural</td>
<td>900</td>
</tr>
<tr>
<td></td>
<td>Common structural</td>
<td>720</td>
</tr>
<tr>
<td>Pine, Norway</td>
<td>Select structural</td>
<td>1,100</td>
</tr>
<tr>
<td></td>
<td>Common structural</td>
<td>880</td>
</tr>
<tr>
<td>Spruce, Englemann</td>
<td>Select structural</td>
<td>750</td>
</tr>
<tr>
<td></td>
<td>Common structural</td>
<td>600</td>
</tr>
<tr>
<td>Spruce, red, white, Sitka</td>
<td>Select structural</td>
<td>1,100</td>
</tr>
<tr>
<td></td>
<td>Common structural</td>
<td>880</td>
</tr>
<tr>
<td>Tamarack, eastern</td>
<td>Select structural</td>
<td>1,200</td>
</tr>
<tr>
<td></td>
<td>Common structural</td>
<td>960</td>
</tr>
</tbody>
</table>

Note: The source document (HEW, 1931) did not indicate the margin of safety or characteristic structural property values used to derive the above working stress values. The table values were used to create joist, rafter, and girder span tables in the source document based on a stated extreme fiber working stress.
While difficult to quantify, the references used in the study indicate that a general decline in the structural quality of lumber has occurred. This reduction may be related to the increased use of managed growth lumber, which implies the use of younger, faster growing trees. Based on available reports of lumber density and species usage, it is the authors’ judgment that framing (dimension) lumber density has dropped from a typical range of 0.4 to 0.65 earlier in the 20th century to a range of 0.35 to 0.55 by the end of the 20th century – approximately a 10 percent reduction in lumber density. A similar change in the grade quality of lumber may also be inferred. This trend would affect member properties as well as connection properties that are discussed later. While these apparent changes are amply treated in wood engineering specifications and structural property data, the affect on conventional practices suggests the need for re-examination of rules of thumb that are still in use today, particularly with respect to system connections and system performance. On the other hand, it should be noted that many engineered wood products that use laminated veneers and similar methods to create entire members or parts of composite members tend to offset the apparent reduction in dimension lumber quality.

### 4.2 FLOOR FRAMING

In the early 1900s, floor joists were typically 2x8 with spans in the range of 12 feet to 14 feet spaced on 16 inch centers (though 24 inch on center placement was indicated for “economical floor construction” when a plaster ceiling was not supported by the joists). For spans of more than 14 feet, 2x10s were recommended when No. 1 grade lumber was used or 2x12 if No. 2 lumber was used. (It was generally recommended that joists be 2 inches deeper or 1 inch wider when lower grade material was used.) One early rule of thumb for sizing joists and beams from Audel’s states that “Joists longer than 12 times their width [depth] used without intermediate supports are apt to crack plastered ceilings.” Obviously, the concern here was with serviceability rather than safety. Rules of thumb for strength were not found in the reviewed literature, but some general guidelines have been passed down. For example, a span to depth ratio limit of 21 is commonly considered as a practical design limitation when beams or joists are laterally supported to prevent twisting. This rule of thumb would allow a 2x8 (1920s actual size 1-5/8” x 7-1/2”) to span about 13 feet.

By the 1930s, standardized lumber grades and stress values (see Table 10) were used to specify maximum spans based on engineering analysis of strength limits. A deflection limit of 1/360 of span was used to produce span tables for joists supporting plaster ceilings. Tables were also used to specify maximum horizontal spans.
for sloped roof rafters. Some examples of maximum spans are shown in Table 12.

By the mid-1900s and throughout the remainder of the century, building codes used span tables similar to Table 12; however, the 1/360 of span deflection limit was eventually applied to all floor joists with design loads of 30 psf or 40 psf. Separate tables were eventually created for the selection of roof rafters using different deflection limits (see Section 4.4). In modern codes, deflection limits—not strength limits—control most floor joist selections. The rationale associated with the elimination of the option to design a floor without a deflection limit when no interior finish was supported was to improve the “feel” of the floor (i.e., floor vibration or bounce) and also to minimize long-term deflection (creep). However, affordable homes well into the mid-1900s can be found with 2x8 floor joist at 16 inch centers spanning as much as 14 to 15 feet over unfinished space. Starting in the 1960s, 2x10 floor joists became as popular as 2x8 joists (both comprising a total of 75 percent of the practice and usually of a “construction” grade lumber). Engineered wood joists such as parallel chord wood trusses and I-joists came into use starting in the 1980s (see Table 1). Modern span tables and manufacturer data are readily available for engineered wood products. Because of differences in “feel” and because of greater spans (up to 20 feet and more), many engineered wood I-joist manufacturers recommend a deflection limit of 1/480 of the span.

4.3 WALL FRAMING

4.3.1 Studding

Over the 20th century, actual vs. nominal framing member sizes have decreased somewhat and wall framing methods have changed from balloon to platform frame. By far, the most common stud spacing throughout the 20th century was 16 inches on center; however, 24 inches on center has also been used primarily for single stories. In the early 1900s, it is clear that 16 inches on center framing was considered necessary for the support of lath and plaster interior finishes. While 2x4 studding is exclusively mentioned in the earlier parts of the century for typical dwelling construction, 2x6 studs are sometimes used in modern homes to allow for thicker wall cavity insulation (see Table 1). Because of their greater structural capacity and cost, 2x6 studs are sometimes spaced 24 inches on center where 2x4’s would be spaced 16 inches on center.

In the early 1900s, 2x4s spaced 16 inches on center were considered adequate for use in buildings up to three stories in height and for ceiling heights not exceeding 12 to 15 feet. This limit was related to the weak axis of the stud being braced by wall finishes and a maximum stud height to stud depth ratio of 50. For buildings over three stories in height, 2x6s or 3x4s were recommended in the lower stories. In modern codes with 2x4s of smaller standard dimension spaced 16 inches on center, building height is limited to two stories and the maximum 2x4 stud wall height is limited to 10 ft. For buildings over two stories in height, 2x6s or 3x4s are required for the lower stories. Preferred ceiling heights have also changed somewhat over time (see Table 1) which affects the selection of stud lengths.

4.3.2 Plates

While balloon framing generally used single plates at the top and bottom of walls, “standard” modern platform frame construction has adopted the use of double top plates (discussed earlier in Sears’ “standard-built” homes). However, single plates are still permitted, and are used occasionally, in modern affordable platform framed homes, specifically in non-load bearing walls or where loads are transferred directly down through studs.

4.3.3 Corners

Three stud corners have been typical throughout the 20th century. A 4x4 corner post was sometimes used in older homes as a hold-over from the 19th century braced frame construction. Two stud corners were also used and are still permitted.

4.3.4 Headers

In the early 1900s, headers were usually considered unnecessary above typical window and door openings because of the load distributing effects in the walls and floor members above the opening. Thus, only a single or double 2x4 flat-wise was used. Doubled 2x4 stud framing at window and door openings was considered as an enhancement to allow for better trim attachment and more sturdy support. Regarding headers in platform frame construction, the following 1923 quote was found in Audel’s:

“It [platform framing] made the formation of openings for windows and doors easier: a simple header (flat-wise 2x4) could be utilized because the platform above spreads loads from an upper floor or roof uniformly to the stud walls below.”

For framing above larger than normal doors and windows, truss framing using diagonal blocking with cripple studs was recommended, though extensive use of this recommended practice is doubtful. Framing requirements above window and door openings in the early 1900s are summarized in Table 13.

During the last half of the 1900s, built-up headers ranging in size up to two 2x12s for large openings
were provided in span tables in building codes based on various engineering assumptions and loading conditions with disregard for “load spreading” recognized earlier in the century. No clear reason (practical or technical) for this was found in the reviewed literature. It does appear that recognition of different header requirements in load bearing vs. non-load bearing conditions existed throughout the century, although confusion in the field often resulted in the use of headers in either case.

4.3.5 Bracing

Wall bracing includes not only the presence of designated bracing members, but also the contribution of various sheathing and finish materials applied to interior and exterior surfaces. In addition, housing style (i.e., amount and size of openings and plan configuration) can have significant effects on the amount and type of lateral bracing provided.

In the early 1900s, wall bracing followed one or more of the following reported practices:

◆ no bracing (relying solely on interior lath and plaster finish and exterior wood siding);

◆ 1x4 diagonal bracing (let-in or cut-in); or

◆ horizontal or diagonal board sheathing.

The following 1931 quote from *Wood Frame House Construction* explains the recommendation for wall bracing when no sheathing is used:

“Where sheathing is omitted, the wall should be braced, at each corner and beside each doorway, with let-in strips [1x4] running diagonally from the floor line above to the plate or sill below, and nailed strongly at the upper and lower ends as well as at each intervening stud…Drop siding is more suitable than bevel or common siding for direct application to studs without sheathing…While rabbeted siding serves to brace the building to some extent, it does not add sufficient strength to serve in lieu of other forms of bracing. For this reason the building should be braced, or the bracing effect needed should be supplied in some other way, as by wood lath and plaster, diagonal sheathing, or let-in bracing.”

Based on the above quote, it is apparent that interior finishes (wood lath and plaster) were considered as an adequate primary wall bracing mechanism in the 1930s and earlier. However, it was also recognized that other practices, such as the use of let-in braces or diagonal board sheathing provided enhanced bracing.

The Forest Products Laboratory conducted in-

<p>| TABLE 13: RECOMMENDED FRAMING ABOVE OPENINGS (HEW, 1931) |</p>
<table>
<thead>
<tr>
<th>OPENING WIDTH</th>
<th>RECOMMENDED HEADER FRAMING</th>
</tr>
</thead>
<tbody>
<tr>
<td>3’ or less</td>
<td>2-2x4 edge-wise in load bearing walls</td>
</tr>
<tr>
<td></td>
<td>1-2x4 flat-wise in non-load bearing walls</td>
</tr>
<tr>
<td>3’ to 6’</td>
<td>use a trussed header</td>
</tr>
<tr>
<td>greater than 6’</td>
<td>use a girder (built-up header)</td>
</tr>
</tbody>
</table>

plane shear tests in 1929 on various wall systems representative of the above practices. These tests were conducted to determine the effectiveness of different bracing because “no one knew the relative values of different methods.” The bracing tested ranged from horizontal sheathing of green lumber to wood lath and plaster without sheathing. Walls were either solid, framed with a single window opening, or framed with a window and door opening. The standard wall construction was designated as horizontal 1x6 board sheathing of seasoned lumber fastened to each stud with two 8d common wire nails (without interior lath and plaster finish). It was assigned a relative value of 100 percent (i.e., strength and stiffness factors of 1.0). Wall height and length dimensions included two conditions: 9 feet by 14 feet and 7 feet 4 inches by 12 feet. The walls were tested under sufficient vertical restraint (load) to prevent overturning from occurring. The test results for the various solid wall constructions are shown in Table 14; results for walls with openings are shown in Table 15. It is apparent that results varied substantially.

Interestingly, the “no bracing” condition (with lath and plaster only) provided 440 percent more shear capacity than the horizontal board sheathing without lath and plaster used as a comparative baseline. Diagonal board sheathing also provided significant racking strength for solid walls, but, when the diagonal boards were loaded in compression in walls with window and door openings, the shear capacity was less than that achieved with lath and plaster with the same window and door openings. Findings for walls with openings showed that any of the bracing methods that included a 1x4 brace, diagonal sheathing, or plaster and wood lath provided more shear capacity than for the solid wall with horizontal sheathing only.

With the introduction of 4x8 plywood sheathing panels in the mid-1900s, interest in wall bracing using wood sheathing panels was initiated. However, the standard affordable construction apparently remained with the use of 1x4 let-in braces and non-structural sheathing. Later, designated bracing was provided by wood structural panels (i.e., plywood) placed continuously or intermittently (i.e., at corners and at 25’ intervals along each wall). Also, a significant number of modern homes used proprietary wall bracing panels such as medium density fiber board, and others. By the end of the century, 7/16-inch-thick oriented strand board (OSB) was commonly used to
<table>
<thead>
<tr>
<th>SIZE OF PANEL</th>
<th>DESCRIPTION</th>
<th>LOAD (pounds)</th>
<th>STRENGTH FACTOR</th>
<th>STIFFNESS FACTOR</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>9' x 14'</td>
<td>8-inch horizontal sheathing, two 8d nails, no braces</td>
<td>2,588</td>
<td>1.0</td>
<td>1.0</td>
<td>No. 20 vibrated 50,000 cycles</td>
</tr>
<tr>
<td>7'-4&quot; x 12'</td>
<td>8-inch horizontal sheathing, two 8d nails, no braces</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7'-4&quot; x 12'</td>
<td>8-inch horizontal sheathing, two 8d nails, no braces</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9' x 14'</td>
<td>8-inch horizontal sheathing, two 8d nails, no braces</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9' x 14'</td>
<td>8-inch diagonal sheathing, two 8d nails, no braces, boards in tension</td>
<td>–</td>
<td>over 8</td>
<td>4.3</td>
<td>Test stopped at 20,000 lb load</td>
</tr>
<tr>
<td>7'-4&quot; x 12'</td>
<td>8-inch diagonal sheathing, two 8d nails, no braces, boards in tension</td>
<td>17,100</td>
<td>6.6</td>
<td>4.3</td>
<td>Test stopped at 20,000 lb load</td>
</tr>
<tr>
<td>9' x 14'</td>
<td>8-inch diagonal sheathing, two 8d nails, no braces, boards in tension</td>
<td>–</td>
<td>over 8</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>9' x 14'</td>
<td>8-inch diagonal sheathing, two 8d nails, no braces, boards in tension</td>
<td>20,100</td>
<td>7.8</td>
<td>7.3</td>
<td></td>
</tr>
<tr>
<td>9' x 14'</td>
<td>8-inch horizontal sheathing, two 8d nails, herringbone or bridge 2x4 braces</td>
<td>2,800</td>
<td>1.1</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>9' x 14'</td>
<td>8-inch horizontal sheathing, two 8d nails, cut-in 2x4 braces</td>
<td>3,700</td>
<td>1.4</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>9' x 14'</td>
<td>8-inch horizontal sheathing, two 8d nails, let-in 1x4 braces, first arrangement</td>
<td>9,250</td>
<td>3.6</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>9' x 14'</td>
<td>8-inch horizontal sheathing, two 8d nails, cut-in 2x4 braces, second arrangement</td>
<td>9,000</td>
<td>3.5</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td>9' x 14'</td>
<td>8-inch horizontal sheathing, three 8d nails, no braces</td>
<td>2,330</td>
<td>0.9</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>9' x 14'</td>
<td>8-inch horizontal sheathing, four 8d nails, no braces</td>
<td>3,550</td>
<td>1.4</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>9' x 14'</td>
<td>8-inch diagonal sheathing, three 8d nails, no braces, boards in tension</td>
<td>–</td>
<td>over 8</td>
<td>5.2</td>
<td>Test stopped at 20,000 lb load</td>
</tr>
<tr>
<td>9' x 14'</td>
<td>8-inch diagonal sheathing, four 8d nails, no braces</td>
<td>–</td>
<td>over 8</td>
<td>7.5</td>
<td>Test stopped at 20,000 lb load</td>
</tr>
<tr>
<td>9' x 14'</td>
<td>8-inch horizontal sheathing, two 10d nails, no braces</td>
<td>3,500</td>
<td>1.4</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>9' x 14'</td>
<td>8-inch horizontal sheathing, two 12d nails, no braces</td>
<td>2,800</td>
<td>1.1</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>9' x 14'</td>
<td>8-inch diagonal sheathing, two 10d nails, no braces, boards in tension</td>
<td>–</td>
<td>over 8</td>
<td>7.5</td>
<td>Test stopped at 20,000 lb load</td>
</tr>
<tr>
<td>9' x 14'</td>
<td>6-inch horizontal sheathing, two 8d nails, end and side matched, no braces</td>
<td>2,550</td>
<td>1.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>9' x 14'</td>
<td>Plaster on wood lath, no sheathing</td>
<td>11,400</td>
<td>4.4</td>
<td>7.2</td>
<td>First plaster crack at 10,600 lb</td>
</tr>
<tr>
<td>9' x 14'</td>
<td>Plaster on wood lath, 8-inch horizontal sheathing, two 8d nails, no braces</td>
<td>14,500</td>
<td>5.6</td>
<td>7.9</td>
<td>First plaster crack at 9,900 lb</td>
</tr>
<tr>
<td>9' x 14'</td>
<td>Plaster on wood lath, 8-inch diagonal sheathing, two 8d nails, no braces</td>
<td>20,300</td>
<td>7.8</td>
<td>9.2</td>
<td>First plaster crack at 12,200 lb</td>
</tr>
<tr>
<td>9' x 14'</td>
<td>Plaster on wood lath, studs and horizontal sheathing, green lumber then seasoned one month</td>
<td>12,700</td>
<td>4.9</td>
<td>6.0</td>
<td>First plaster crack at 8,200 lb</td>
</tr>
<tr>
<td>9' x 14'</td>
<td>8-inch horizontal green sheathing, two 8d nails, no braces, panel seasoned one month</td>
<td>1,700</td>
<td>0.7</td>
<td>0.5</td>
<td>Vibrated one million cycles</td>
</tr>
<tr>
<td>7'-4&quot; x 12'</td>
<td>8-inch horizontal green sheathing, two 8d nails, no braces, panel seasoned one month</td>
<td>1,800</td>
<td>0.7</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>9' x 14'</td>
<td>8-inch diagonal green sheathing, two 8d nails, no braces, panel seasoned one month</td>
<td>–</td>
<td>–</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>7'-4&quot; x 12'</td>
<td>8-inch diagonal green sheathing, two 8d nails, no braces, panel seasoned one month</td>
<td>–</td>
<td>–</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>9' x 14'</td>
<td>8-inch horizontal sheathing, two 8d nails, no braces, alt. sunshine and rain one month</td>
<td>2,175</td>
<td>0.8</td>
<td>0.7</td>
<td></td>
</tr>
</tbody>
</table>

Note: Panel frames consisted of 2x4 upper and lower plates, vertical studs spaced 16 inches, and triple end posts.
fully sheath exterior walls. Some statistics on the use of exterior sheathing/bracing are included in Table 1. Various sources of test data on shear resistance of wall materials are summarized in the Residential Structural Design Guide – 2000 Edition (HUD, 2000). Approximate ultimate shear values for various modern wall constructions based on research from the mid-to-late 1900s are shown in Table 16.

It is evident that the interior finish material, which is not considered explicitly as bracing, actually was the most significant determinant of bracing capacity in many homes built during the first half of the 20th century. During the mid-1900s the preference for interior finishes switched from wood lath and plaster to gypsum board, 2 foot wide gypsum “lath” that was finished with a skim coat of plaster. Soon thereafter, the preferred practice became gypsum wallboard using 4 foot wide panels with taped and finished joints. This practice has remained a standard through the end of the 20th century. It is noted that older lath and plaster interior finishes may provide up to 8 times more shear capacity than typical gypsum board wall finishes used in modern homes (i.e., 100 plf vs. 800 plf). However, all modern homes use either structural panel or let-in/metal braces in addition to support provided by interior finishes.

Since dwelling lateral (shear) capacity is to some degree dependent on interior finishes, it is important to consider changes in the average size of houses as depicted in Table 1, in amounts of interior wall relative to area, and in dead load (relative to seismic or wind design loads). Data on interior wall linear footage per story level as a function of square feet of floor area on a given story level are shown in Table 17. These data are based on a limited sample of house plans that are considered to be representative of a range of home styles constructed in each period. The decrease in the relative amounts of interior walls over the course of the past century is notable. While this trend tends to show a decrease in the amount of ancillary bracing provided by interior walls in newer homes, the lineal footage of exterior walls relative to floor area tend to increase in the newer homes. Thus, the overall bracing impact (considering the changes to interior and exterior walls) may be somewhat offset.
by these two countervailing trends. Uncertainty in the effects of increased irregularity in plan configuration of newer homes must also be considered relative to possible impact on resistance to lateral loads. However, one recent study of homes following the Northridge Earthquake seems to indicate that irregularities in wall line offsets cannot be directly associated with any noticeable trend in performance of single family homes (HUD, 1999). The data summarized in this section is provided to suggest the need for a more detailed and thorough evaluation of changes in bracing found in homes over the past century. Thus, the simple comparisons as suggested in this report are not absolute or complete treatments of this subject.

### 4.4 ROOF FRAMING

#### 4.4.1 Rafters

As noted earlier, roof rafters were typically 2x4 or 2x6 in the early 1900s. The horizontal span of rafters and the rules of thumb mentioned previously for joists were typically used for rafter members as well. For hip and valley rafters, the following rule of thumb from *Light Frame House Construction* was apparently in use in the early part of the 20th century:

- up to 12 foot horizontal span use a single hip rafter 2 inches deeper or 1 inch thicker than rafters; and
- over 12 foot horizontal span use a doubled rafter for the hip rafter.

Since engineering methods have failed to offer reasonably accurate explanations of the system effects related to hip or valley rafter design, similar rules of thumb are still in practice today (unless an engineered design is required). By the mid-1900s, rafter framing (and also floor joists) were commonly provided in engineered span tables using certain design assumptions and methods of analysis considering single elements and not systems. Newer span tables are based on updated lumber properties, but engineering assumptions similar to those used earlier in the century are found in all modern building codes for residential construction. During the mid-1900s, engineered wood roof trusses were introduced and by the late-1900s were used in a great majority of new homes (see Table 1).

#### 4.4.2 Roof Sheathing

In the early 1900s, roof sheathing of 1x6 or 1x8 boards, or minimum 1x3 furring (spaced sheathing) spaced according to weather exposure of wood shingles (up to 6 inches on center) was typical. A minimum of two 8d common wire nails were typically used to fasten random-length boards to each roof rafter. In the mid-1900s plywood roof sheathing entered the market and soon became the standard. By the late 1900s, most roofs were sheathed with some form of wood structural panel sheathing, primarily 7/16-inch-thick OSB (see Table 1); board sheathing methods had become practically extinct. Nailing requirements and types of fasteners changed to accommodate the panels and newer tools, such as pneumatic nail guns.

### TABLE 16: ULTIMATE SHEAR VALUES FOR TYPICAL MODERN WALL CONSTRUCTIONS

<table>
<thead>
<tr>
<th>Sheathing Type</th>
<th>Ultimate Shear Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1x4 Let-in brace</td>
<td>&gt;600 lbs/ea (tension), 2,000 lbs/ea (compression)</td>
</tr>
<tr>
<td>Metal T-brace (tension only)</td>
<td>1,400 lbs/ea</td>
</tr>
<tr>
<td>1/2” Gypsum Wall Board</td>
<td>100 plf</td>
</tr>
<tr>
<td>3/8” Plywood or 7/16” OSB</td>
<td>650 plf</td>
</tr>
<tr>
<td>Exterior 7/8” PC stucco and metal lath</td>
<td>500-750 plf, 750-1,580 plf</td>
</tr>
</tbody>
</table>

### TABLE 17: INTERIOR WALL AMOUNTS [lin. ft. as a percent of floor area of story]

<table>
<thead>
<tr>
<th>Wall Type</th>
<th>Older Homes (early 1900s)</th>
<th>Modern Homes (late 1900s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 story</td>
<td>9 percent ± 1 percent</td>
<td>1st floor of 1 to 2 story 4.3 percent ± 1 percent</td>
</tr>
<tr>
<td>1st floor of 2 story</td>
<td>6 percent ± 1 percent</td>
<td>2nd floor of 2 story 7.9 percent ± 1 percent</td>
</tr>
</tbody>
</table>
| 2nd floor of 2 story | 9 percent ± 1.5 percent | Notes:

1 Values based on a small sample of traditional house plans in Sears Catalogues (1910 – 1926) including affordable and more expensive construction of 1 and 2 stories.
2 Values based on a small sample of representative modern home plans (1990s) including economy and move-up construction (no luxury homes).
4.5 FASTENERS AND CONNECTIONS

Trends in the treatment of connections in housing during the 20th century provide important insights into changes in the structural characteristics of homes. This section reviews some of the changes in fastening practices and materials. Where found in the literature, data on structural characteristics of various fasteners or connections are summarized.

Wire nails have been the predominant fastener for wood framing connections throughout the 20th century. Up to the 20th century, the most common nails used were wrought iron or cut nails, which were preceded by the use of wooden pegs and special heavy timber connection details (i.e., wood joinery). Cut nails were quickly replaced by common wire nails in the earliest parts of the 20th century. However, it is worth noting that Audel's reports test data indicating that cut nails provide as much as 2 to 3 times the "holding capacity" of common wire nails of similar size. The tests were conducted with several repetitions and wood species, including hardwoods and soft woods and dense soft woods. It is presumed that the difference in withdrawal capacity can be explained by the wedging action created by the tapered shank of a cut nail. Cut nails continued to see infrequent use for some applications such as hardwood flooring, but eventually they became obsolete. In early framing practice, specifications often called for heavier loaded joints or thicker materials to be "securely spiked together." Spikes are similar to common wire nails, but are larger in diameter and greater in length than common wire nails. However, from the literature surveyed, it appears that for home building in the early 1900s, spikes may have considered to be 20d common wire nails. Rules of thumb for nail selection in the early 1900s are paraphrased as follows from Audel's:

"Use one penny size for each 1/8-inch of thickness for typical wood density. For softer wood use up to two penny-weights larger, and for harder/denser wood use one to two penny-weights smaller to prevent cracking of wood."

In the last half of the 1900s, box nails with a smaller shank diameter and a resin coating to increase holding were used to some unknown extent. By the late 1900s, pneumatic fasteners dominated the market. Various fastener sizes and types are addressed in the Residential Structural Design Guide – 2000 Edition (HUD, 2000) and other wood design or technology references.

Early requirements for nailing were as much a result of constructability considerations as for structural reason, and varied depending on a particular connection and its perceived role in the structural system. Often, the older requirements for connections used vague terms such as "spike securely" or "adequately nail." Perhaps this subjective approach was in realization that the fastening practice, material choices, and framing methods of the early 1900s were sufficiently conservative and simple as to not require exact specification. While connection requirements for modern residential wood framing can be found in building codes, no data is available that quantifies the variation in actual fastening techniques or practices used in the field. Observation tends to suggest that the variation is quite large. Very little technical data is available to explain the actual performance of various fastener and material choices found in modern home construction practice, particularly when considered at a system level (e.g., multiple joints and fasteners in a load path). Some studies of this nature are summarized in the Residential Structural Design Guide – 2000 Edition (HUD, 2000).

The following connection requirements or practices are excerpted and summarized from sources reviewed in this study. They are based on recommendations provided in various framing guidelines and early code documents and, therefore, may not represent actual field practice during the different time periods or in different locales.

4.5.1 Early 1900s

Sill to Foundation—Indicated as “desirable” to anchor sill to foundation (especially if high wind is possible); recommend 3/4 inch bolts extending 18 inches into concrete foundation wall with OG washer and nut. Recommendations for sill bolt spacing ranged from 6 feet to 12 feet on center. Evidently, anchoring was not a required or common practice for typical construction at the beginning of the 20th century.

Joist to Sill or Wall (depending on type of framing) —
(1) Balloon and braced framing: spike securely to side of studs (two near bottom and enough at top to hold in place during construction). (2) Platform framing: joists should be securely toe-nailed to plate with not less that 8d or 10d nails; box headers should be spiked securely into ends of joists with 20d nails (remember, the box header or band joist was treated as a continuous header above all openings in walls below).

Built-up Girders—Use 10d common wire nails at 12 inches on center top and bottom (staggered) to keep individual members from buckling separately or failing independently.

Joist Headers for Floor Openings—End nail through inside trimmer (if doubled trimmer joists) into end grain of each single or built-up header member with two 20d spikes for 2x6; 3 for 2x8 and 2x10; or 4 for 2x12 and 2x14.

Stud to Top and Bottom Plates—“Desirable” to end-nail using two 20d common wire nails.

Ribband to Stud—Let-in 1x6 into studs to support joists in balloon framing; secure ribband to each stud with two 8d common wire nails.

Rafter to Ceiling Joists or Collar Beams (cross ties)—
“Solidly nail” rafters to joists; connect a ceiling joist to every rafter if shallow slope roof or to every second or third rafter for steep roofs. Some old construction drawings suggest that 3 to 5 nails may have been used for this connection.

Rafters to Ridge Board—Toenail or end-nail rafter to ridge board; “not of great significance structurally,” but required to hold in place during construction.

Rafters to Wall Plate—Toe nailing was common practice; however, nail sizes and numbers were not shown or reported in any of the literature surveyed. Like foundation anchor bolts, it appears that anchoring of roofs was left to the realm of “accepted construction practice.”

Valley and Hip Rafter to Ridge—Provide “adequate fastening to ridge to prevent pulling apart.”

Sheathing Boards to Wall or Roof Framing—Two 8d common nails per board up to 1x8; three 8d common nails for greater than 1x8. In the early 1900s cut nails were still frequently used for this connection.

4.5.2 Late 1900s

The mid-1900s can be considered as a transition period in fastening technology. During this period, pneumatic fasteners began to be used (discussed below). Box nails were also used in place of common nails, but to an unknown degree. Other changes that affected fastener specification included the introduction of plywood sheathing, and the use of metal plate connected wood trusses in place of traditional rafter and joist framing. Special metal connectors, such as joist hangers, also came into use for certain connections or conditions.

By the late 1900s, pneumatic fasteners were used predominantly in the home building industry for framing purposes. The requirements for pneumatic fasteners (nails and staples) were provided in a code evaluation report (NER 272). However, connection schedules in codes still addressed primarily common wire nails. Thus, the connection requirements for specific fastener types in common use or approved for use are not consolidated. This condition may explain the variations in actual practice that may fall above or below the minimums implied by or explicitly defined in modern building codes.

5.0 CONSTRUCTION QUALITY

No reliable source of data was found regarding trends in construction quality over the course of the 20th century. However, it should be noted that complaints and concerns with shoddy construction in the references used in this study seem to indicate that it was just as much a concern at the beginning of the century as the end. Unfortunately, the significance of such concerns remain in the realm of anecdotal evidence, which serves to confirm that quality problems existed, but does not allow a quantitative assessment of the degree, frequency, or implications of such problems as related to structural performance in newer or older homes. It appears that the tradespeople of yesterday were just as subject to human error as they are today.

However, assuming no significant change in construction quality, certain changes in construction materials and methods may justify a greater concern in modern times on the basis that the techniques are less “forgiving” of mistakes or tolerances implicit to reasonable standards of workmanship. For example, modern framing members are somewhat smaller and require greater precision in fastener installation. Pneumatic fastening methods and panelized sheathing products tend to create situations where “blind” connections are made to underlying framing members without as close a control as inherent with hand-driven nails to secure boards. While such problems can be avoided with appropriate controls, newer materials and methods (including more varieties and options than in the past) do seem to place the burden of a greater standard of care on the tradesperson.

6.0 SUMMARY AND CONCLUSIONS

Significant changes to construction materials and methods have occurred over the past century that affect the economy and structural performance of homes. In some cases it appears that change has increased structural performance while, in other cases structural performance was reduced. It also appears that different levels of value (i.e., balancing of cost versus performance) have been applied throughout the century to meet varied housing needs or desires in the nation. As a result, minimums based on a compelling need for affordable housing have co-existed with “upgrades” used in homes sold to more affluent buyers. In such a manner, housing supply has served a diverse demand with needed flexibility in establishing an appropriate definition of value based on individual buyers or market segments.

Some significant changes to housing construction methods and materials discussed in this report are summarized as follows:

◆ Separate concrete spread footings, introduced in early 1900s, are found on nearly all homes by the end of the century. In fact, several enhancements to foundation construction have occurred over the past century.

◆ Framing method switched from balloon to platform frame technique.

◆ In 1900, lumber was ungraded and largely reliant on locally available species and “sorts”. Later, lumber grades were standardized and resources became more dependent on managed forests and fewer species.
◆ Lumber size was originally based on full dimensions (i.e., actual size of a 2x4 was 2 inches by 4 inches). During the 1900s, the sizes of “finished” dimension lumber were reduced in several stages to a standard thickness of 1.5 inches and standard widths of 3.5, 5.5, 7.25, 9.25, and 11.25 inches for nominal 2x4, 2x6, 2x8, 2x10, and 2x12 dimension lumber, respectively.

◆ At the end of the 20th century, engineered wood products quickly gained acceptance as alternatives to dimension lumber used primarily in sheathing, floor framing, and floor girder applications.

◆ A complete change from boards to engineered wood structural panels (i.e., OSB and plywood) happened relatively quickly early in the second half of the 20th century.

◆ Headers for windows and doors have seen significant change. At the beginning of the century structural headers, as such, were not normally used over openings; instead there was acknowledgement of system effects in distributing loads over wall openings. By the end of the 20th century, header requirements became more complicated requiring different tables to be considered under various conditions. For unspecified reasons, the earlier acknowledgment of system effects was abandoned. In addition, the apparent desire to simplify construction in the field has often resulted in the “worst-case” condition being applied to all headers in order to eliminate confusion.

◆ Wall bracing has apparently seen little change in effective capacity required by standardized testing of wall segments, though materials have changed during the course of the 20th century. Specific bracing requirements were implemented in the last half of the century. However, interior finishes have changed from lath and plaster to gypsum wallboard which has the effect of lowering the “reserve capacity” found in older homes relative to newer homes. Changes in house style, size, and design of interior space have also affected the “reserve capacity.” However, more recent trends toward total sheathing with structural material such as OSB can readily compensate for other “losses.”

◆ Fasteners changed, first from cut nails to common wire nails, then to pneumatic fasteners. Box or sinker nails were also used. However, little quantitative information is available to determine the functional or performance rationale for connections found in the historic practice or in building codes (not to suggest that data from various single fastener tests do not exist in large quantity). The withdrawal capacity of an 8d cut nail used at the beginning of the 20th century for sheathing was as much as 2 to 3 times more than a comparable 8d common wire nail according to early tests. The 8d common wire nail, in turn, provides greater withdrawal capacity when compared to most 8d (0.113 inch diameter) pneumatic nails commonly used at the end of the 20th century, but only when adhesive coatings on pneumatic nails are not considered. Thus, withdrawal capacity of nails for certain joints may have changed dramatically depending on the effectiveness of adhesives on newer coated nails. Changes in the shear capacity of certain joints, such as sheathing connections, also occurred as a result of the general reduction in nail diameters.

◆ Construction quality has been a concern through the 20th century with little evidence to suggest that any substantial change (good or bad) has occurred. However, there are some obvious changes in materials and tools that require more precision in construction; thus, there is a greater potential for error, particularly in connections. This problem is not helped by the numerous choices for fasteners (including staples, etc.) now on the market, and the lack of simplicity and uniformity in the regulations that govern connection requirements in modern construction practice.

7.0 RECOMMENDATIONS

The findings and conclusions of this study suggest that certain modern house construction practices should be carefully evaluated in view of changes in historic practice. Some specific recommendations include:

1. Re-evaluate, simplify, and prepare specific details for connections that balance structural needs with the intuition and capability of the tradesperson. For example, can two specific sizes of pneumatic nails be successfully used to specify all or most framing connections in a typical house?

2. Wall bracing practices should be re-assessed based on changes in the style, size, and interior finishes used in modern homes as compared to older homes (early 1900s).

3. Practices for header sizing and engineering analysis of homes in general should incorporate more efficient system-based design principles that were inherently understood in the design and framing practices in the early 1900s.

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APPENDIX A THERMAL INSULATION

Very little mention of any requirement for energy efficiency such as thermal insulation was found in the historical sources reviewed (see Bibliography). For example, no information on thermal insulation was found in the Sears catalogues, which were considered an exhaustive catalogue for building materials, although the use of tarred felt paper underneath flooring to prevent draftiness and under the siding for rot protection was mentioned.

Tarred paper was also recognized as an air barrier to prevent air leakage through walls in “poorly built” homes in a University of Wisconsin study in the early 1900s. This study reported various infiltration rates through frame walls and found that “air infiltration through frame wall construction, containing building paper or plaster properly applied, is negligibly small (0.1 to 0.3 cubic feet per hour with a 15 mph wind-induced pressure difference). It is also reported that the United States Bureau of Standards had conducted tests on the strength, rate of air penetration, and moisture proof properties of building papers. Asphalt impregnated papers were reported to weigh from 66 to 163 pounds per 1,000 square feet. It was noted that building paper “must be selected and put on much more carefully than is ordinarily done.”

One 1930s framing guide (HEW, 1931) encouraged the use of exterior board sub-sheathing for its structural bracing benefits and for comfort benefits in cold or hot climates since “wood is one of the best natural insulators.” In addition, one drawing of roof framing did indicate “insulation material” placed between ceiling joists, which may suggest the relative importance placed on insulation in roofs as compared to other locations. The same guide later describes air leakage and thermal conduction as primary sources of heat loss, and encourages the use of thermal insulation and weather striping of doors to save on the rising cost of coal as well as other sources of heating energy (fuel oil, electric, etc.), and percent reductions in air leakage were cited for practices such as weather stripping and tightly fitting doors.

The National Bureau of Standards (Journal of Research, Vol.6, No.3), reported fuel savings for combinations of weather-striped doors, insulation, and double (storm) windows. The savings were reported to range from 10 to 60 percent. The higher values were reported for use of 1-inch insulation (probably exterior wood sheathing) and double windows. It is noted that if tarred paper is not placed over sheathing (i.e., board sheathing is omitted) it is probably not worth installing because of air leakage between laps in the building paper. It is not clear that the function of moisture protection was considered reason enough to justify the use of building paper.

In general, energy efficiency did not become a serious consideration in home construction until later in the 1900s. The Minimum Property Standards (HUD, 1958) gave requirements for insulation based on a rudimentary calculation method. By the late 1900s, more sophisticated energy codes had been developed and relatively high levels of insulation were required in virtually every new home. The availability of materials to enhance energy efficiency also flourished (e.g., double glazed windows, various insulation types with high thermal resistivity, sealing and weather-stripping technologies, etc.). In addition to energy codes that addressed new construction, tax incentive programs were introduced in the 1970s to encourage insulation of older homes. In addition, credits were offered through energy efficient mortgage financing programs and demand-management programs offered by various utility companies.