Section II: Planning Your Shelter

Now that you better understand your risk from a tornado or hurricane, you can work with your builder/contractor to build a shelter to protect yourself and your family from these extreme windstorms. This section describes how extreme winds can damage a building, explains the basis of the shelter designs presented in this booklet, and shows where you can build a shelter in your house.

Building Damage

Extreme winds can cause several kinds of damage to a building. Figure II.1 shows how extreme winds affect a building and helps explain why these winds cause buildings to fail.

To understand what happens when extreme winds strike, you must first understand that tornado and hurricane winds are not constant. Wind speeds, even in these extreme wind events, rapidly increase and decrease. An obstruction, such as a house, in the path of the wind causes the wind to change direction. This change in wind direction increases pressure on parts of the house. The combination of increased pressures and fluctuating wind speeds creates stress on the house that frequently causes connections between building components to fail. For example, the roof or siding can be pulled off or the windows can be pushed in.

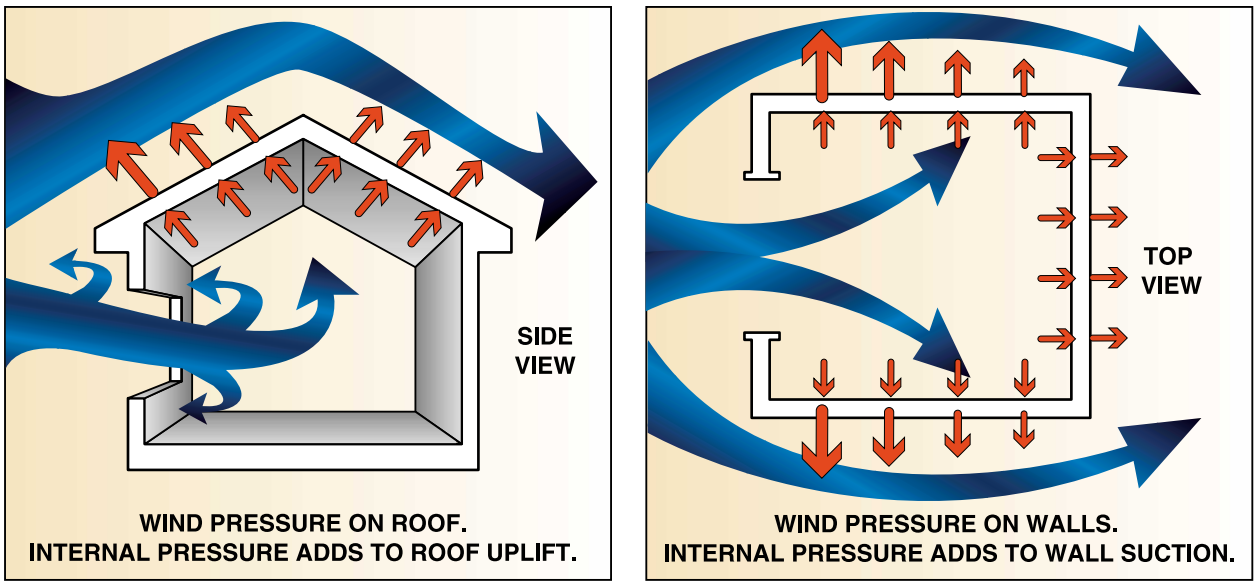


Figure II.1 Effect of extreme winds on building roof and walls

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 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 high enough, missiles can be thrown at a building with enough force to penetrate 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 and enough force to penetrate most common building materials used in houses today. Even a reinforced masonry wall will be penetrated unless it has been designed and constructed to resist debris impact during extreme winds. Because missiles can severely damage and even penetrate walls and roofs, they threaten not only buildings but the occupants as well.

Palm tree pierced by plywood missile, Hurricane Andrew

Basis of Shelter Design

The purpose of a shelter is to provide a space where you and your family can survive a tornado or hurricane with little or no injury. In hurricane-prone areas, the shelter cannot be built where it can be flooded during a hurricane. Your shelter should be readily accessible from all parts of your house, and it should be free of clutter. To protect the occupants during extreme windstorms, the shelter must be adequately anchored to the house foundation to resist overturning and uplift. The connections between all parts of the shelter must be strong enough to resist failure, and the walls, roof, and door must resist penetration 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 house construction cannot withstand the impact of missiles carried by

extreme winds. The shelter designs in this booklet account for these findings by specifying building materials and combinations of building materials that will resist penetration by missiles in extreme winds.

Missile (debris) launcher, Wind Engineering Research Center (WERC), Texas Tech University

The shelter designs, including both materials and connections, are based on wind speeds that are rarely exceeded in the United States. Therefore, a shelter built according to these designs is expected to withstand the forces imposed on it by extreme winds without failing. Those forces may cause cracks or other signs of stress in the materials or connections used in the shelter, and they may cause materials or connections to yield. However, the intent of the designs is not to produce a shelter that will always remain completely undamaged, but rather a shelter that will enable its occupants to survive an extreme windstorm with little or no injury.

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

Designing 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 floodprone areas, careful attention should be given to the warning time, velocity, depth, and duration of flood waters. These flooding characteristics can have a significant bearing on the design and possibly even the viability of a shelter. 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 recommend appropriate designs.

2" x 4" wood stud launched at 100 mph pierces unreinforced masonry wall, WERC, Texas Tech University

Shelter Size

The amount of floor area per person that your shelter must provide depends partly on the type of windstorm the shelter is intended to protect you from. Tornadoes are not long-lasting storms, so if you are relying on your shelter only for tornado protection, you will not need to stay in the shelter for a long time. As a result, comfort is not of great concern, and a shelter that provides about 5 square feet of floor area per person will be big enough.

When the shelter is intended to provide protection from storms such as hurricanes, which can last up to 12 hours, the comfort of the occupants should be considered. For this type of shelter, the recommended amount of floor area per person is about 10 square feet. Necessities, such as water and toilet facilities, should be provided. The shelter designs in this booklet are based on a maximum floor area of 64 square feet and a maximum wall length of 8 feet. A shelter of that size used for hurricane protection can accommodate up to six people in reasonable comfort. If you plan to build a shelter with any wall longer than 8 feet, consult a licensed professional engineer or architect.

NOTE

The shelter designs in this booklet are applicable for any on-site construction. However, in a modular house, the shelter location would be limited to the basement or the belowground module. A modular house is a house constructed of modular units that have been built elsewhere, brought to the site, and installed on a permanent foundation.

New vs. Existing Houses

The shelter designs in this booklet were developed primarily for use in new houses, but some can be used in existing houses. When a new house is being built, the builder/contractor can construct walls, foundations, and other parts of the house as required to accommodate the shelter. Modifying the walls or foundation of an existing house as necessary for the construction of a shelter is more difficult. As a result, some of the shelter designs in this booklet are not practical for existing houses. The following sections discuss this issue further.

In this booklet, the term “retrofit” refers to the process of making changes to an existing house.

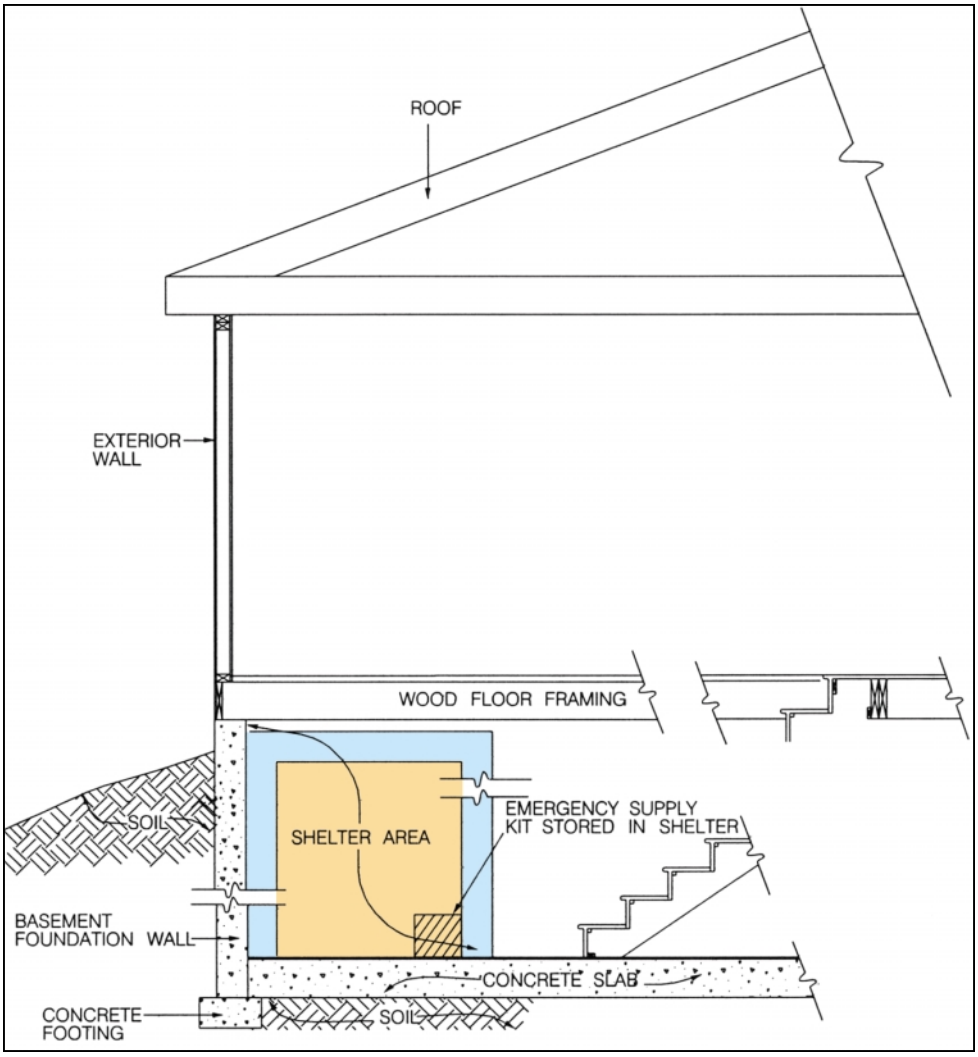
Foundation Types

Houses on the following types of foundations are suitable for the installation of a shelter:

- basement
- slab-on-grade
- crawlspace

A house on a basement foundation (see Figure II.2) is usually built on a foundation constructed of poured concrete or concrete masonry. Most concrete foundations are reinforced with steel bars or straps, but many concrete masonry 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.

Figure II.2
Cross-section: typical basement foundation, with shelter



In a new or existing house with a basement, the shelter should be built in the basement. You can build the shelter as an entirely separate structure with its own walls, or you can use one or more of the basement walls as walls of the shelter. If you use the basement walls, they will have to be specially reinforced. Typical reinforcement techniques used in residential basement walls will not provide sufficient protection from missiles. In new construction, your builder/contractor can reinforce the walls near the shelter during the construction of your house. Reinforcing the basement walls of an existing house 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 wind. Therefore, your basement shelter must have its own reinforced ceiling; the basement ceiling (the first floor above) cannot be used as the ceiling of the shelter.

The least expensive type of shelter that can be built in a basement is a lean-to shelter, which is built in the corner of the basement and uses two basement walls. The lean-to shelter uses the fewest materials, requires the least amount of labor, and can be built more quickly than other types of basement shelters.

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

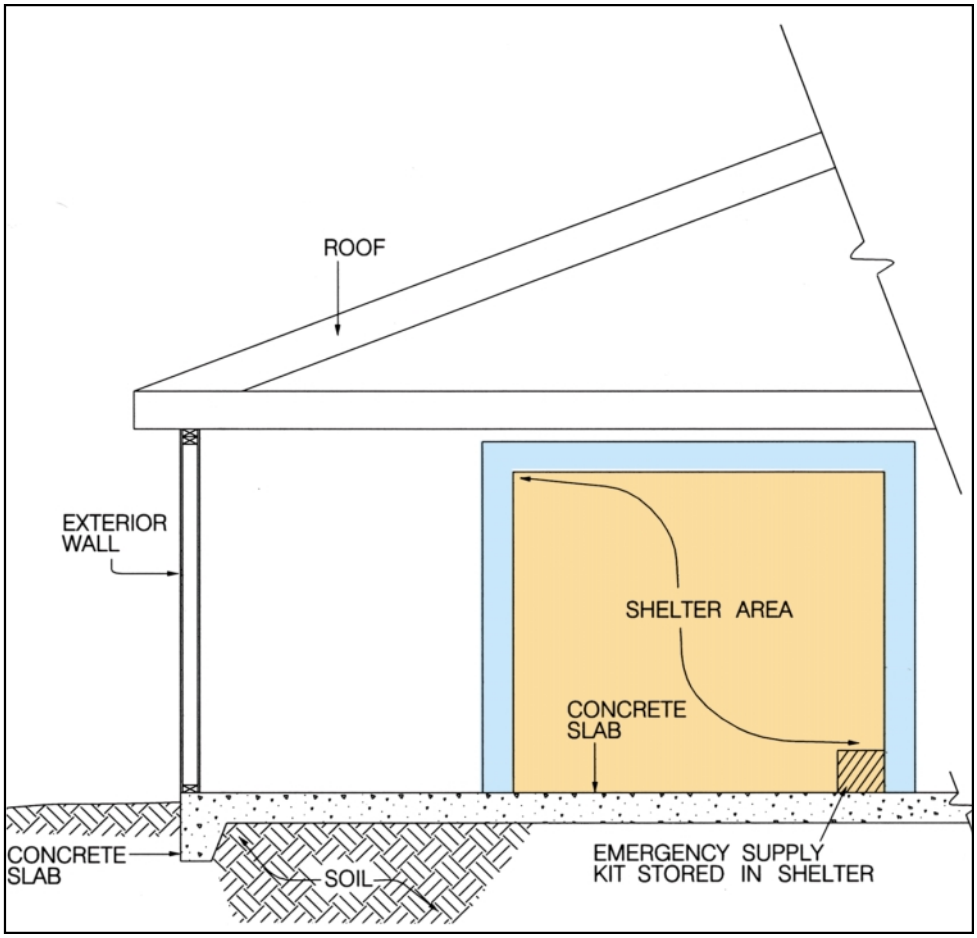
- You must be able to clear out an area of the basement large enough for the shelter.
- Unless the exterior basement walls contain steel reinforcement as shown on the design drawings provided with this booklet, these walls cannot be used as shelter walls since they are not reinforced to resist damage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

A slab-on-grade house (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 house and want to install a concrete or concrete masonry shelter, your builder/contractor must make the slab thicker where the shelter will be built. The thickened slab will act as a footing beneath the walls of the shelter to provide structural support. It will also help anchor the shelter so that it will stay in place during an extreme wind event, even if the rest of the house is destroyed.

In an existing house, removing part of the slab and replacing it with a thickened section would involve extensive effort and disruption inside the house. Therefore, building a shelter with concrete or concrete masonry walls in an existing slab-on-grade house is generally not practical. You can, however, build a wood-frame shelter, because its walls are not as heavy and do not require the support of a thickened slab. A wood-frame shelter 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 house, such as a garage.

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

Figure II.3
Cross-section: typical slab-on-grade foundation, with shelter

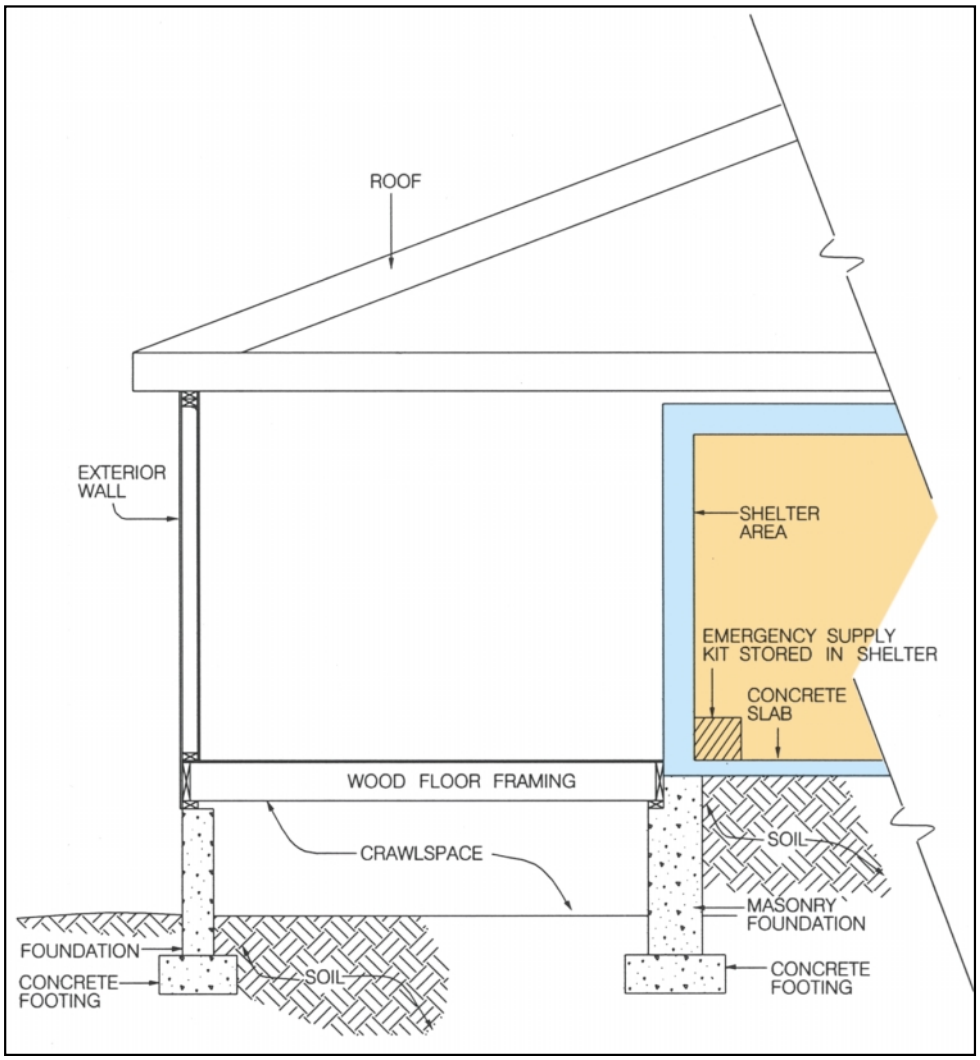


In general, it is easier to add a shelter during the construction of a new slab-on-grade house than to retrofit an existing slab-on-grade house. If you plan to add a shelter to a slab-on-grade house as a retrofitting project, keep the following points in mind:

- The walls of the shelter must be completely separate from the structure of the house. Keeping the walls separate makes it possible for the shelter to remain standing even if portions of the house around it are destroyed by extreme winds.
- If you are creating your shelter by modifying a bathroom, closet, or other interior room with wood-frame walls, the existing walls, including sheathing on either the inside or outside of the walls, such as drywall or plaster, must be removed and replaced with walls and a ceiling resistant to the impact of windborne missiles and other effects of extreme winds.
- If you intend to build a shelter with concrete or concrete masonry walls, a section of your existing slab floor will have to be removed and replaced with a thicker slab. As noted above, this is usually not practical in an existing house.

A house 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 of concrete masonry. Crawlspace foundation walls are often unreinforced and therefore provide little resistance to the stresses caused by extreme winds.

Figure II.4
Cross-section: typical crawlspace foundation, with shelter



Building a shelter inside a house on a crawlspace foundation is more difficult than building a shelter inside a house on a basement or slab-on-grade foundation. The main reason is that the entire shelter, including its floor, must be separate from the framing of the house. As shown in Figure II.4, a shelter built inside the house cannot use the floor of the house. The shelter must have a separate concrete slab floor installed on top of earth fill and must be supported by concrete or concrete masonry foundation walls. An alternative approach, which may be more economical, is to build an exterior shelter on a slab-on-grade adjacent to an outside wall of the house and provide access through a door installed in that wall.

Ventilation in the area below the floor of the house is also an important issue. The wood-framed floor of a house on a crawlspace foundation is typically held 18 to 30 inches above the ground by the foundation walls. 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 shelter not block this air flow.

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

- The shelter must have a separate foundation. Building the foundation inside the house 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 shelter, made of concrete or concrete masonry, on a slab-on-grade foundation adjacent to an outside wall of the house, as described above.

WARNING

You should not install a shelter in a house supported by piles, piers, or columns. With building connectors commercially available, there is no economical way to separate the shelter from the floor framing and ensure that the shelter will withstand the forces of extreme winds.

You may be tempted to build a shelter under a house on a pile, pier, or column foundation. However, if the house is in a storm surge area or other flood hazard area, the area under the house would be below the flood level. A shelter built in that area would trap its occupants in rising flood waters. See the warning on page 5 for more information.

Shelter Location

There are several possible locations in your house for a shelter. Perhaps the most convenient and safest is below ground level, in your basement. If your house does not have a basement, you can install an in-ground shelter beneath a concrete slab-on-grade foundation or a concrete garage floor. Basement shelters and in-ground shelters provide the highest level of protection against missiles and falling debris.

Another alternative shelter location is an interior room on the first floor of the house. Researchers, emergency response personnel, and people cleaning up after a tornado have often found an interior room of a house still standing when all other above ground parts of the house 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 shelter. Bathrooms have the added advantage of including a water supply and toilet.

Regardless of where in your house you build your shelter, the walls and ceiling of the shelter must be built so that they will protect you from missiles and falling debris, and so that they will remain standing if your house is severely damaged by extreme winds. If sections of your house walls are used as shelter walls, those sections must be separated from the structure of the house. This is true regardless of whether you use interior or exterior walls of the house.

Figures II.5 through II.7 are typical floor plans on which possible locations for shelters are shown with yellow highlighting. These are not floor plans developed specifically for houses with shelters. They show how shelters can be added without changes to the layout of rooms.

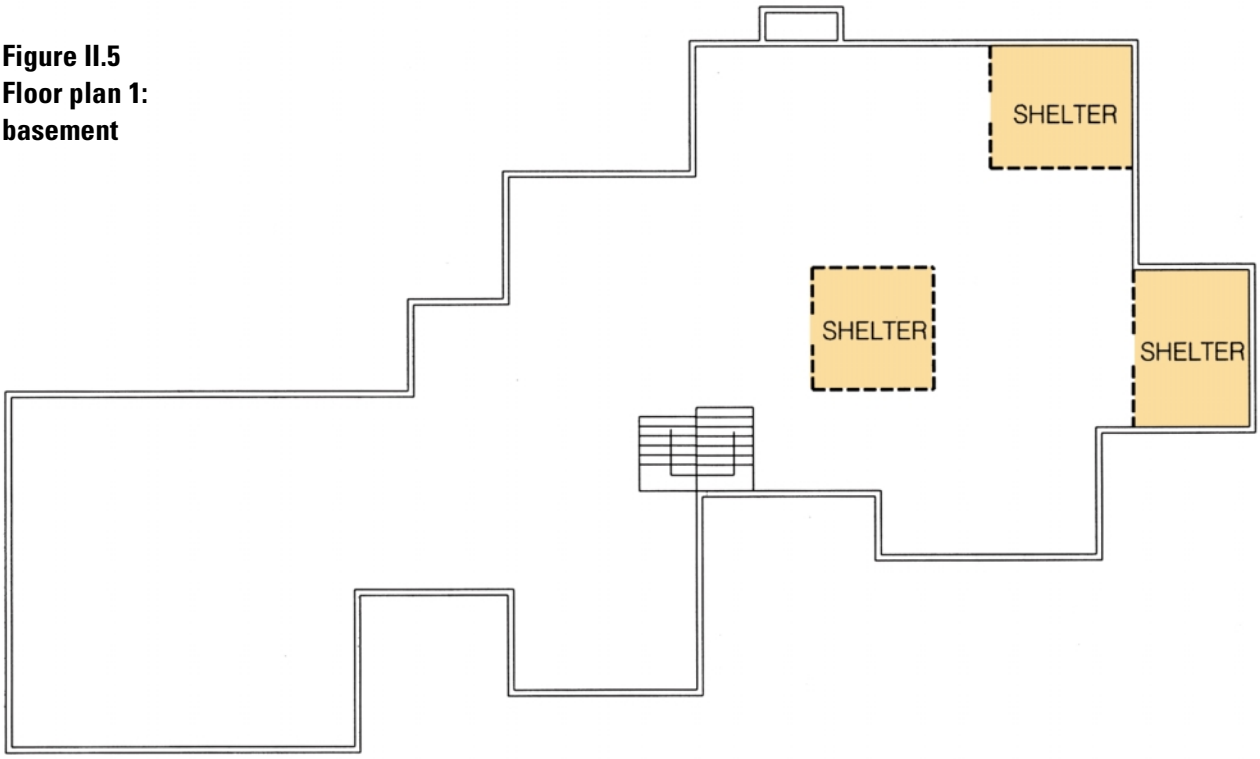
Floor Plan 1: basement

Possible shelter locations in a basement include the following:

- in a corner of the basement, preferably where the basement walls are below the level of the ground
- 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 shelter must be kept free of clutter so that the shelter can be quickly and easily entered and so that the shelter occupants will not be injured by falling objects. For this reason, a bathroom is often a better choice for a shelter 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 shelter. In this situation, a possible alternative would be to build an exterior shelter, adjacent to your house, on a slab-on-grade above the flood level.

Figure II.5
Floor plan 1: basement



Floor Plan 2: house on a slab-on-grade or crawlspace foundation

Possible shelter locations in a house 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.6, can be properly separated from the structure of the house)
- corner of the garage

Regardless of where the shelter is built, it must be equipped with a door that will resist the impact of missiles. Remember, if the first floor of the house is below the level of storm surge or the level of flooding from any other source, it is not a suitable location for a shelter. In this situation, a possible alternative would be to build an exterior shelter on a slab-on-grade elevated on fill above the flood level.

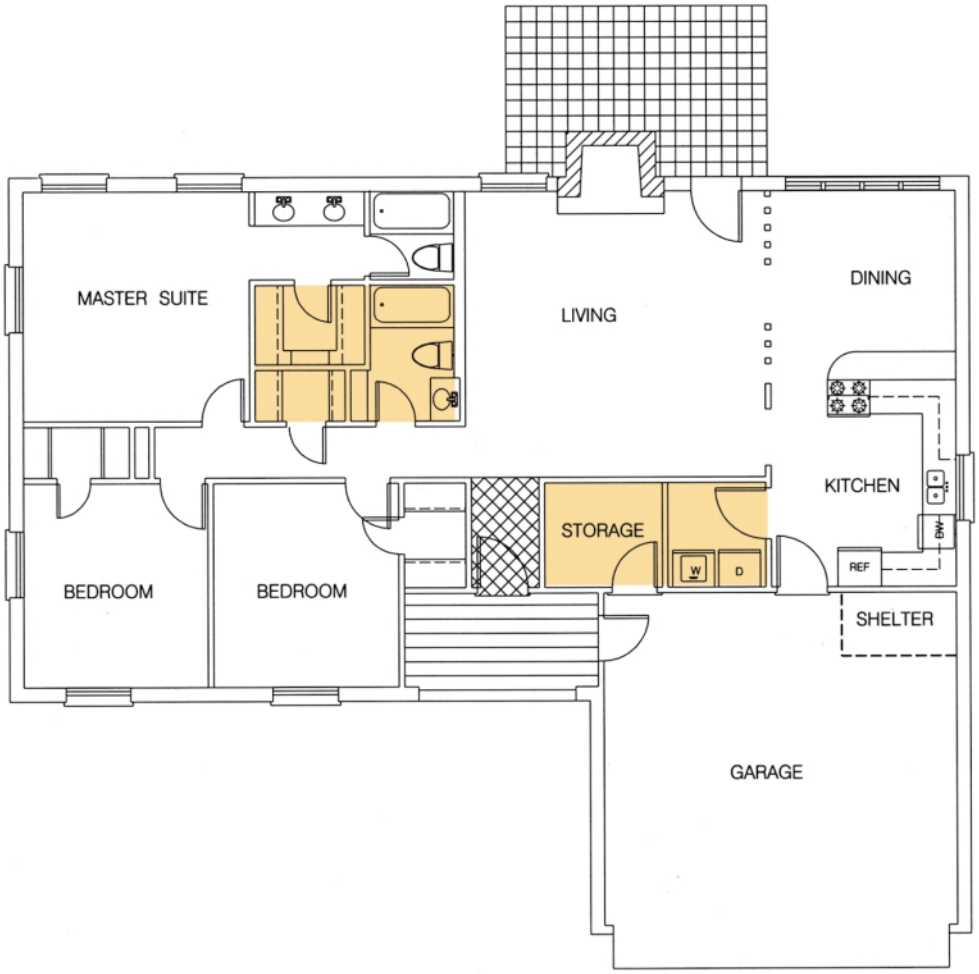


Figure II.6
Floor plan 2: house on slab-on-grade or crawlspace foundation

Floor Plan 3: house on a slab-on-grade foundation

Possible locations for an in-ground shelter 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 shelter in an existing house, this type of shelter is practical only for new construction. Remember, if the first floor of the house is below the level of storm surge or the level of flooding from any other source, it is not a suitable location for a shelter. In this situation, a possible alternative would be to build an exterior shelter on a slab-on-grade elevated on fill above the flood level.

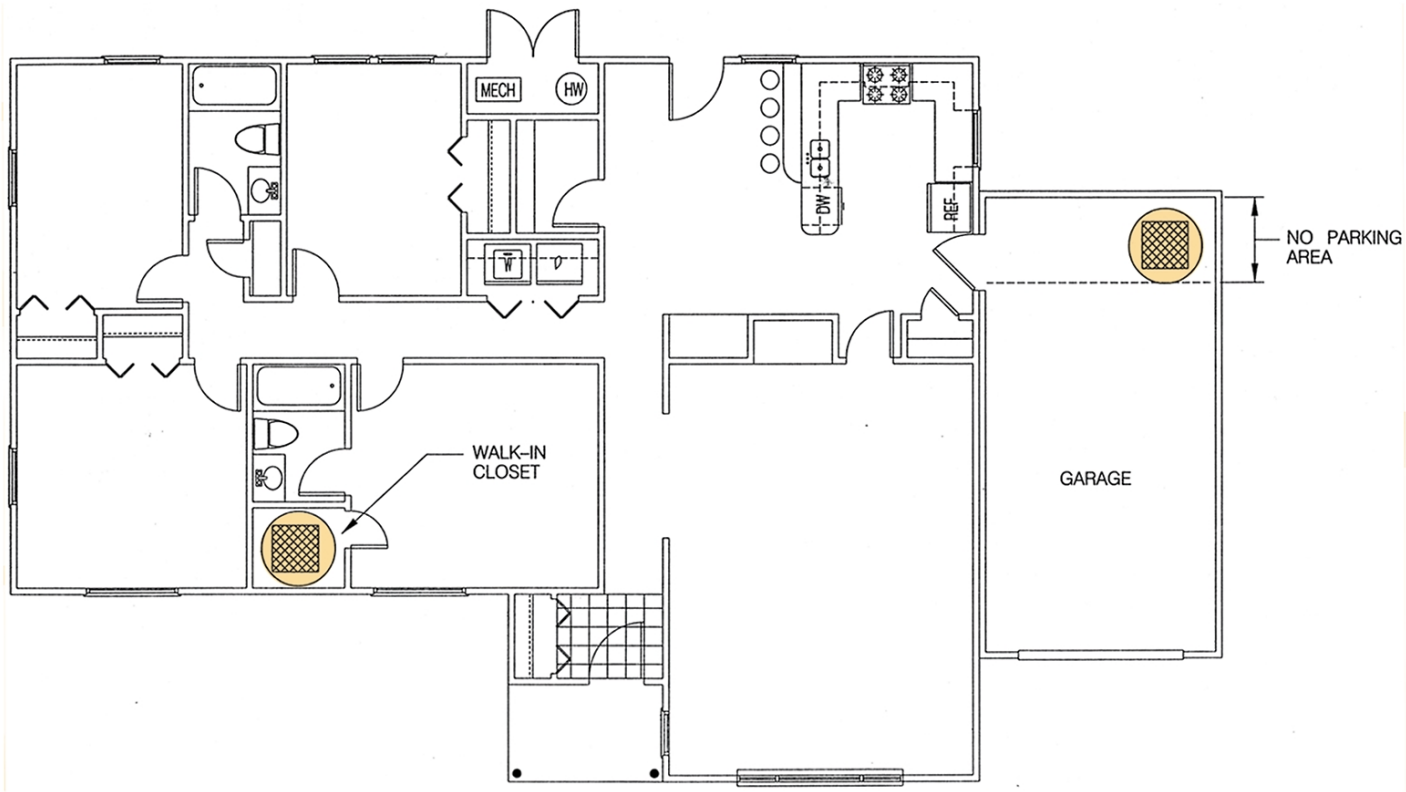


Figure II.7
Floor plan 3: house on slab-on-grade foundation

Tables II.1 and II.2 will help you decide what type of shelter is appropriate for your circumstances. Table II.1 applies to the construction of shelters in new houses. Table II.2 applies to retrofit situations, in which a shelter is being added to an existing house.

Table II.1
Appropriate types of shelters for new houses

	APPROPRIATE SHELTER TYPE		
SHELTER CONSIDERATIONS (NEW HOUSES)	BASEMENT	ABOVE-GROUND	IN-GROUND*
House located in storm surge area		✓	
House located in flood hazard area		✓	
High water table		✓	
Low cost	✓		✓
Long-term shelter occupancy	✓	✓	
Least likely to be hit by missiles			✓

Table II.2
Appropriate types of shelters for existing houses

	APPROPRIATE SHELTER TYPE		
SHELTER CONSIDERATIONS (EXISTING HOUSES)	BASEMENT	ABOVE-GROUND	IN-GROUND*
House located in storm surge area		✓	
House located in flood hazard area		✓	
High water table		✓	
Low cost	✓	✓	
Easiest retrofit	✓		
Long-term shelter occupancy	✓	✓	
Least likely to be hit by missiles			✓
Ease of separation from structural framing of house	✓		
Minimal disruption to house	✓		
Ease of accessibility		✓	

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

Construction Materials

The materials your builder/contractor will need to build your shelter 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 shelter is the door. The materials specified for doors in the shelter designs in this booklet were tested by the Wind Engineering Research Center at Texas Tech University for their ability to carry wind loads and prevent penetration 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 shelter can be installed as shown in the design drawings included with this booklet.

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

Shelter Cost

The cost of your shelter will vary according to the following:

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

Table II.3 shows the average costs for building three types of shelters – lean-to, aboveground (AG), and in-ground – in new houses on basement, slab-on-grade, and crawlspace foundations according to the design plans in this booklet. These costs are for shelters with a floor area of 8 feet by 8 feet.

Table II.3 Average cost for an 8-foot by 8-foot shelter in a new house

FOUNDATION TYPE	SHELTER TYPE[1]	AVERAGE COST
Basement	Lean-To	$3,000
	AG – Reinforced Masonry	$3,500
	AG – Wood-Frame w/Plywood & Steel Sheathing	$5,000
	AG – Wood-Frame w/Concrete Masonry Unit Infill	$4,500
	AG – Insulating Concrete Form	$3,200
	In-Ground	NA
Slab-on-Grade	Lean-To	NA
	AG – Reinforced Masonry	$3,500
	AG – Wood-Frame w/Plywood & Steel Sheathing	$4,500[2]
	AG – Wood-Frame w/Concrete Masonry Unit Infill	$4,000[2]
	AG – Insulating Concrete Form	$3,700
	In-Ground	$2,000
Crawlspace	Lean-To	NA
	AG – Reinforced Masonry	$4,500
	AG – Wood-Frame w/Plywood & Steel Sheathing	$6,000
	AG – Wood-Frame w//Concrete Masonry Unit Infill	$5,500
	AG – Insulating Concrete Form	$4,200
	In-Ground	NA

NA = shelter type not applicable for the foundation type shown

[1] AG = aboveground shelter (which can also be built in a basement)

[2] A first-floor, wood-framed interior room, such as a bathroom or closet, would be a normal part of a new house; therefore, the dollar amount shown is the additional cost for building the room as a shelter rather than as a standard interior room.

The cost of retrofitting an existing house to add a shelter will vary with the size of the house and its construction type. In general, shelter costs for existing houses will be approximately 20 percent higher than those shown in Table II.3.