

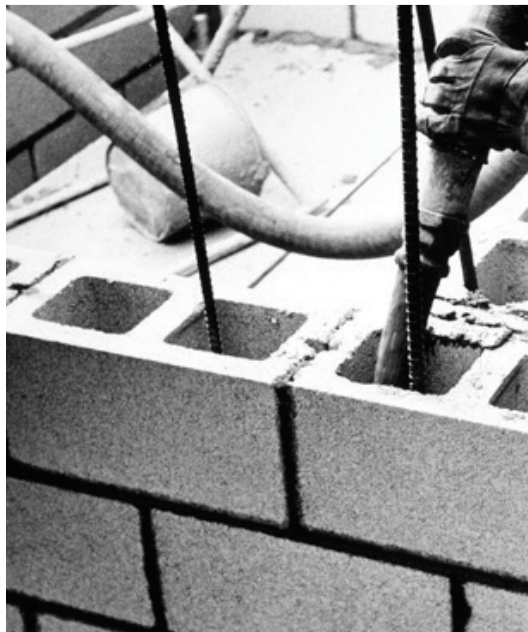


FLASH[®]
FEDERAL ALLIANCE FOR SAFE HOMES



Resilient Design Guide

CONCRETE CONSTRUCTION EDITION





The purpose of the *Resilient Design Guide – Concrete Edition* is to provide information regarding the effective use of above- and below-grade concrete wall systems, as well as concrete floor systems to illustrate cost-effective, robust practices for residential construction.

This information reflects leading practices combining the strength and durability of reinforced concrete and concrete masonry with conventional systems to provide the most practical, high-performing residential construction available.

Whether starter or custom, homes built to the specifications outlined in this guide will be more resistant to fire, flood, wind, and windborne debris than construction using wood or steel framing alone.

Throughout the guide, supplemental information describing the use of concrete products and systems offers additional insight into ways to enhance home safety and performance. Using the information in this guide will help home builders and design professionals provide families with not only more disaster-resilient homes, but enhanced peace of mind in the face of potential disasters.

This guide was developed during a charrette that brought together a cross section of concrete, building, and design professionals. The charrette allowed participants to integrate knowledge of subject matter experts in concrete systems, architecture, academics, engineering, products, and other building professionals with practical experience in building with concrete products. The group combined their knowledge and experience to develop an outline for this guide with the goal to provide not only an overview of the “why,” but the “how to” of residential concrete construction. The authors sincerely appreciate the many dedicated professionals that helped make this guide possible.



For more information, contact the Federal Alliance for Safe Homes (FLASH)[®] at (877) 221-SAFE or visit www.flash.org.



The nonprofit Federal Alliance for Safe Homes (FLASH)[®] is the country's leading consumer advocate for strengthening homes and safeguarding families from natural and manmade disasters. The FLASH mission is to promote life safety, property protection and resilience by empowering the families with knowledge and resources for strengthening homes and safeguarding families from disasters of all kinds.

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Founded in 1857, the AIA New York Chapter is the oldest and largest chapter of the American Institute of Architects. The Chapter's members include more than 5,000 practicing architects, allied professionals, students, and public members interested in architecture and design. The AIA New York Chapter is dedicated to three goals: design excellence, public outreach, and professional development.



America's Cement Manufacturers[™]

The Portland Cement Association (PCA), founded in 1916, is the premier policy, research, education, and market intelligence organization serving America's cement manufacturers. PCA members represent 92 percent of US cement production capacity and have facilities in all 50 states. The Association promotes safety, sustainability, and innovation in all aspects of construction, fosters continuous improvement in cement manufacturing and distribution, and generally promotes economic growth and sound infrastructure investment.

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Concrete Construction

Many U.S. households are located in areas that are affected by flooding, high wind (either hurricane or tornado), and wildfires. Designing homes in these areas to be strong and disaster-resilient can enhance occupant safety, and reduce costly repairs following catastrophic events. As an inherently strong and disaster-resilient material, concrete not only delivers benefits in the face of disaster, it provides additional benefits, such as energy efficiency, ordinary (vs. catastrophic) fire resistance, low maintenance, and eligibility for financial incentives like insurance discounts.

The new guide illustrates use of leading concrete construction practices and prescriptive recommendations to create a higher level of resiliency than is possible with conventional construction alone.

Building Codes

This guide is intended to provide designers and homebuilders with information about concrete construction while outlining options for enhanced resilience with affiliated costs and benefits. As building codes and practices vary throughout the U.S., users of this guide should become familiar with local building codes and keep in mind that a home can be made more resilient by building beyond the building code. This guide will not detail all minimum building code requirements, but will highlight beyond-code practices as well as other proven ways to increase resilience.

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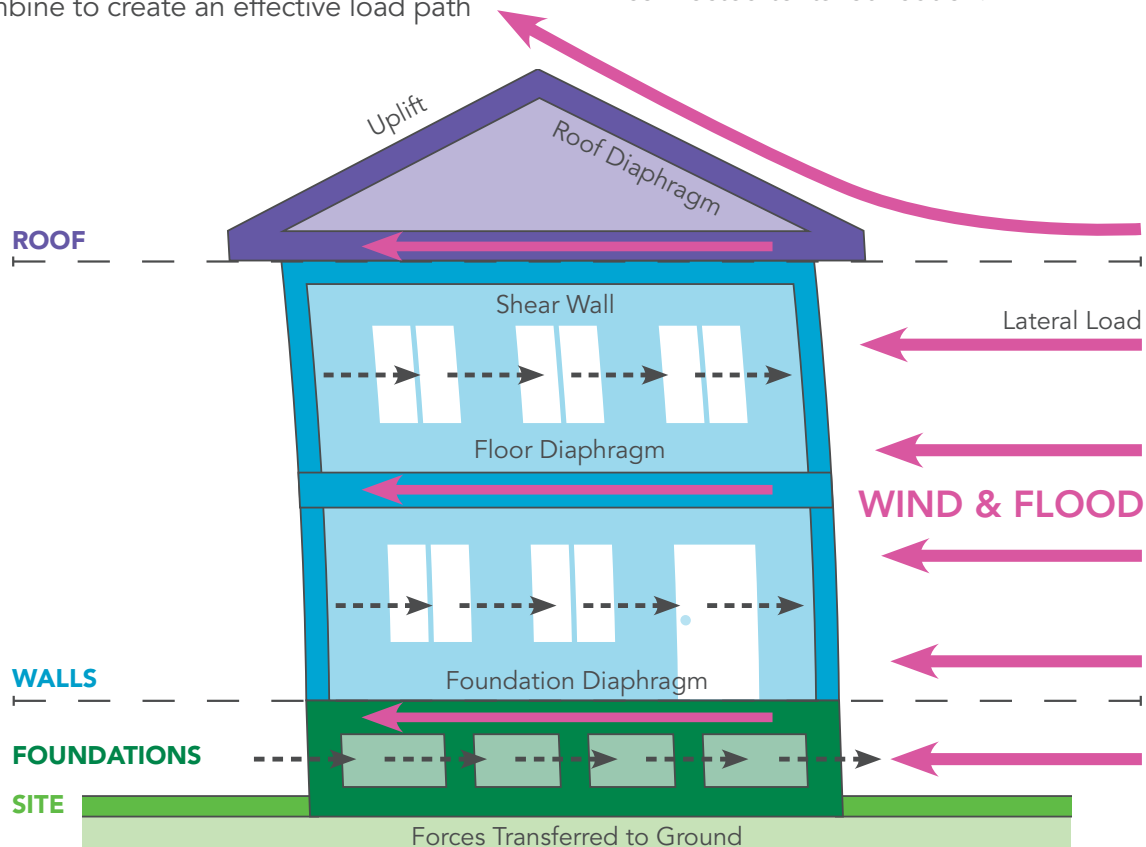
House as a Whole System

Typically, the primary force from wind or flooding is a lateral, or (sideways) force. For example, for a wind speed of 150 mph, the force of the wind pushing against the face of the wall is approximately 42 pounds per square foot. If this load were equated to a roof load, it would compare to the weight of three feet of snow pushing down on every square foot of roof.

Conventional residential construction is designed to transfer the vertical loads of a house from the roof to the foundation, and can be inadequate to resist high-wind and flood forces. Building exterior walls of houses with reinforced concrete and concrete masonry creates a much stronger and stiffer exterior shell, more capable of resisting vertical loads and lateral forces as well. Conventional roof decking and framing connected to these exterior walls with clips, straps, and/or anchor bolts securely fastened to the concrete, work together to provide additional support as stiff horizontal diaphragms. All of these systems combine to create an effective load path

carrying the forces acting on the house from the roof and walls down to the foundation of the home. They act together to resist the wind or flood loads attempting to lift up, push or pull the house sideways.

Additionally, winds and floods produce uplift forces that act dynamically to attempt to pull the components of a house apart. Reinforced concrete and concrete masonry systems provide the combined heavier weight and compressive strength of concrete and the tensile strength of steel reinforcement to hold the house down and connected to its foundation.



Roof

Walls

Foundation

Site



Construction Types Used in This Guide

Code Compliant Conventional Construction: Roof and Foundation Construction



Common house construction is typically strong enough for wind speeds less than 100 mph, and it does not account for flooding. Ordinary wind design roof construction and flood resilient foundation components are illustrated in this guide to give a baseline reference for minimum, code-compliant construction in many locations.


Higher Local Hazard Construction: Roof and Foundation Construction


Wind speeds above 100 mph and flowing flood waters require lateral strength from the roof to the foundation not provided by ordinary code compliant construction. Higher risk construction is illustrated in the pages of this guide to help explain how concrete wall systems can enhance performance to meet or exceed lateral and uplift load requirements for locations with higher potential hazard.

Resilient Construction: Roof, Above Grade Wall, Concrete Floor, and Foundation Construction

Houses can be made more resilient by designing for a higher lateral load because the safety factor will be increased, making house components more resistant to wind and flooding forces during storms, often significantly reducing potential for severe damage. Increased resilient concrete construction combining concrete walls and floors is illustrated in this guide with information regarding costs and expected benefits of making homes stronger and safer.

 These markers are used throughout the guide to indicate whether a building material is considered typical in higher local hazard construction or
 represents an "increased resilience" construction upgrade.

 This icon indicates the cost implication of different components from 1 to 5 with 1 (\$) representing baseline construction costs and 5 (\$\$\$\$\$) representing the most costly.

 This icon indicates the construction implication and/or difficulty level from 1 to 5 scale with 1 (🔨) representing baseline for ease of construction, need for specialized installation, and ability for skilled labor to complete the work. Five (5) (🔨🔨🔨🔨🔨) represents a requirement for highly specialized and skilled labor.

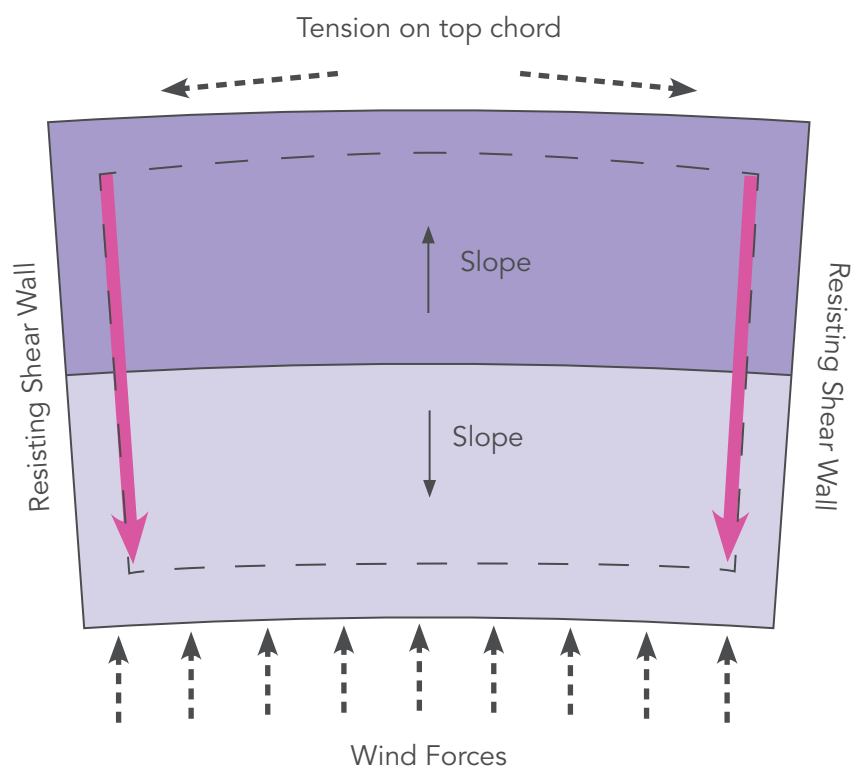
How a Roof Works

The roof is the primary structural element of the house, transferring the loads that act on the walls facing the wind, into the walls that are parallel to the wind. The main structural components of a roof assembly include:

1. Strong connection of the roof deck to roof framing, especially at the edges
2. Connection of the roof to concrete shear walls with anchored blocking and/or proper straps/clips

Roofs are highly exposed to wind and rain and need to be strong as an overall structural system, as well as watertight at any given area on the roof. A resilient roof has two durable layers of protection designed for high winds that include roof covering and underlayment.

OVERHEAD VIEW OF ROOF



Roof Components

COVERINGS

Coverings are the roof's first line of defense against wind and wind-driven rain. Common residential coverings include asphalt shingles, concrete/clay tiles over battens and metal panels.

UNDERLAYMENT

Underlayment is a secondary layer of roof covering designed to keep moisture from the decking. If a primary covering layer fails, properly installed underlayment will keep water from penetrating the roof and attic. Common underlayment includes 30 lb. felt or tar paper, self-adhesive membranes and membranes that are fully integrated into the decking.

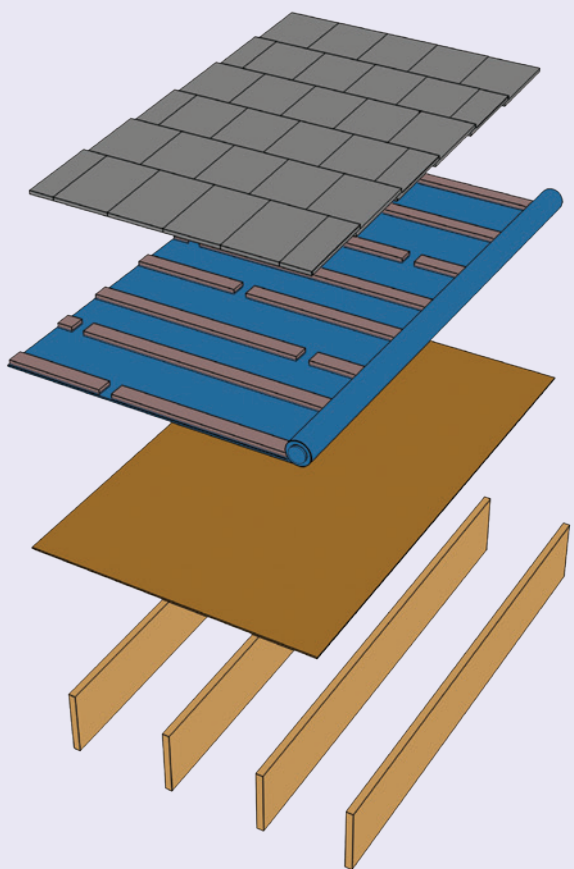
SHEATHING/DECKING

Sheathing/decking is a structural component of a roof typically made of plywood or oriented strand board (OSB) panels. Decking is fastened to the top of the roof framing and makes the framing rigid, so it can transfer loads to the exterior walls.

FRAMING

Framing is the primary structural element of a roof. In this guide, residential framing is limited to wood rafters and wood trusses. Roof framing should be tied to the walls as part of a load path from the roof to the foundation.

This guide depicts common residential framing materials currently used when building resilient concrete homes (wood rafters and wood trusses). Roof framing should be anchored to the walls as part of a continuous load path from the roof to the foundation. While beyond the scope of this publication, there are a number of all-concrete roof systems available including precast planks, insulating concrete deck forming systems, and conventional concrete forming for creation of increased resiliency of roof structures. See reference section at end of guide for more information on concrete roof systems.



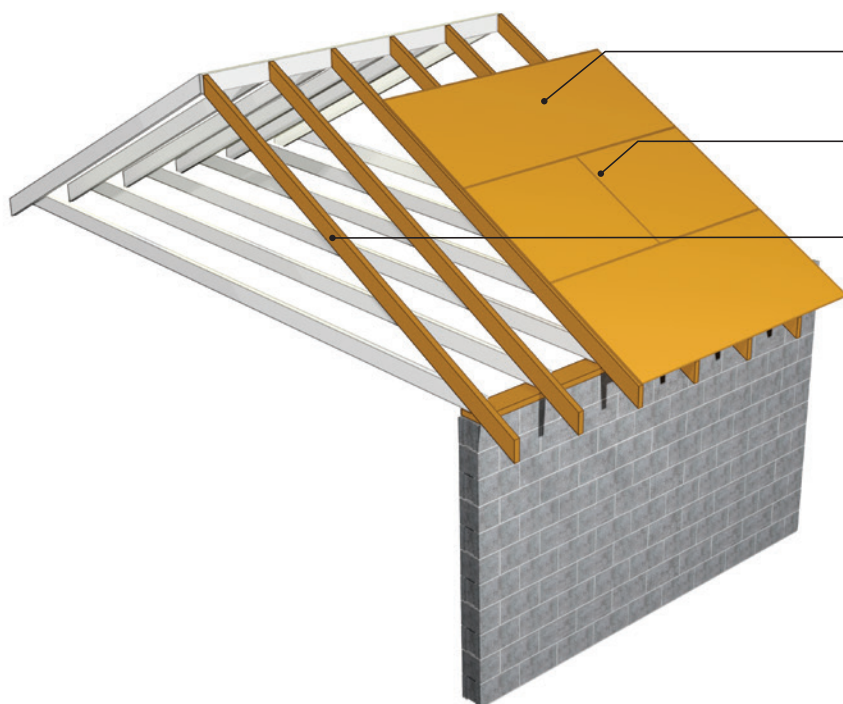
Roof Component Comparison

ROOF COMPONENTS	Code Compliant Conventional Construction	Higher Local Hazard Construction	Resilient Construction*
Decking – Thickness	1/2" plywood or OSB	5/8" plywood or OSB, full sheet at eaves, ridges; no sheet narrower than 24" anywhere on the roof and no sheet shorter than 48" at rake edge	5/8" plywood or OSB, no sheet narrower than 24" anywhere on the roof and no sheet shorter than 48" at rake edge
Decking – Fasteners	6d common nails	8d ring shank nails	8d ring shank nails
Decking – Nailing Schedule	6" O.C. at edge, 8" O.C. field	4" O.C. at edge, 6" O.C. field, panel edge "H" clip spaced between framing member attachment	4" O.C. at edge, 6" O.C. field, panel edge "H" clip spaced between framing member attachment
Sealed Roof Deck		Closed-cell spray polyurethane foam adhesive at underside of decking at all framing and joint attachments	Closed-cell spray polyurethane foam adhesive at underside of decking at all framing and joint attachments
Framing – Spacing	24" O.C.	24" O.C.	16" O.C.
Framing – Eave Blocking		2x eave blocking <i>(see structural detail, page 12)</i>	2x eave blocking <i>(see structural detail, page 13)</i>
Framing – Connection		Metal strap at every truss, Metal strap tie at ridge	Metal strap at every truss, Metal strap tie at ridge
Underlayment	30# felt paper	30# felt/tar paper, button cap fastener, 9" O.C. edge, 12" O.C. field or self-adhering polymer modified bitumen flashing membrane over entire deck or self-adhering polymer modified bitumen flashing tape on all decking panel joints	30# felt/tar paper, button cap fastener, 9" O.C. edge, 12" O.C. field or self-adhering polymer modified bitumen flashing membrane over entire deck or self-adhering polymer modified bitumen flashing tape on all decking panel joints
Covering – Type	Three tab shingle	High wind rated shingles or metal roof or metal panel/standing seam metal roof system or concrete & clay tile	High wind rated shingles or metal roof or metal panel/standing seam metal roof system or concrete & clay tile
Covering – Connection	4 corrosion resistant nails per shingle	6 corrosion resistant nails per shingle or manufacturer's instructions for increased wind loads	Per manufacturer's instructions for increased wind loads

*Solid reinforced concrete deck or precast planks can be substituted (in place of conventional decking) to create a continuous, wind resistant concrete shell. Consult ICF deck manufacturer, or precast concrete producer, or conventional concrete form manufacturer recommendations for details and connection requirements.

Code Compliant Conventional Construction

Typical Components



Decking

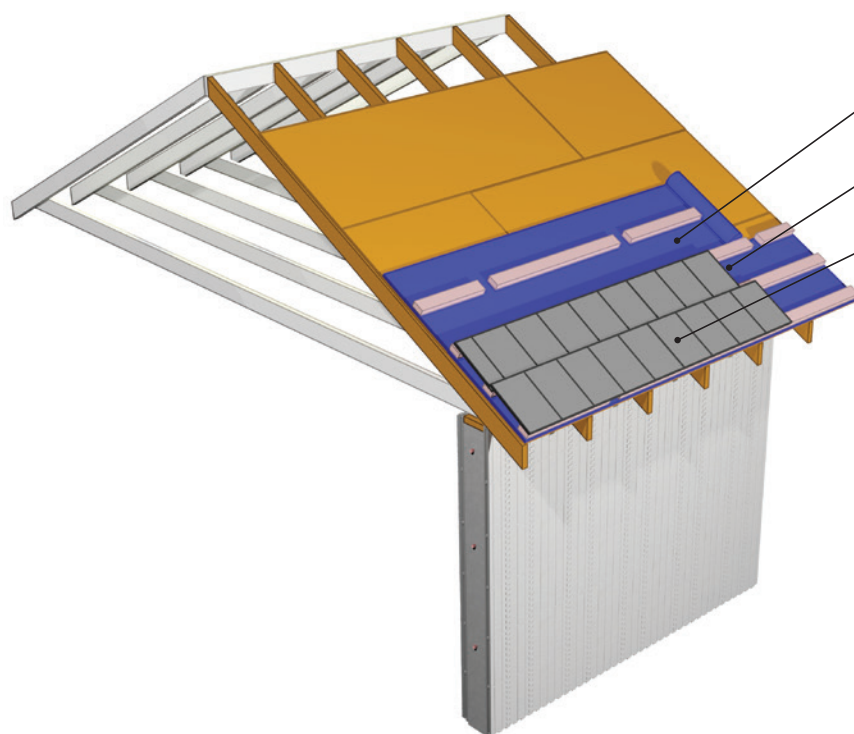
1/2" plywood/OSB

6d common nails 6" O.C.
edge 8" O.C. field

Framing

#2 grade 2x rafter & joist
framing 24" O.C. or 2x
engineered truss 24" O.C.

\$ 🛠️ Structure Detail



Underlayment

30# felt tar paper

Staple fastener

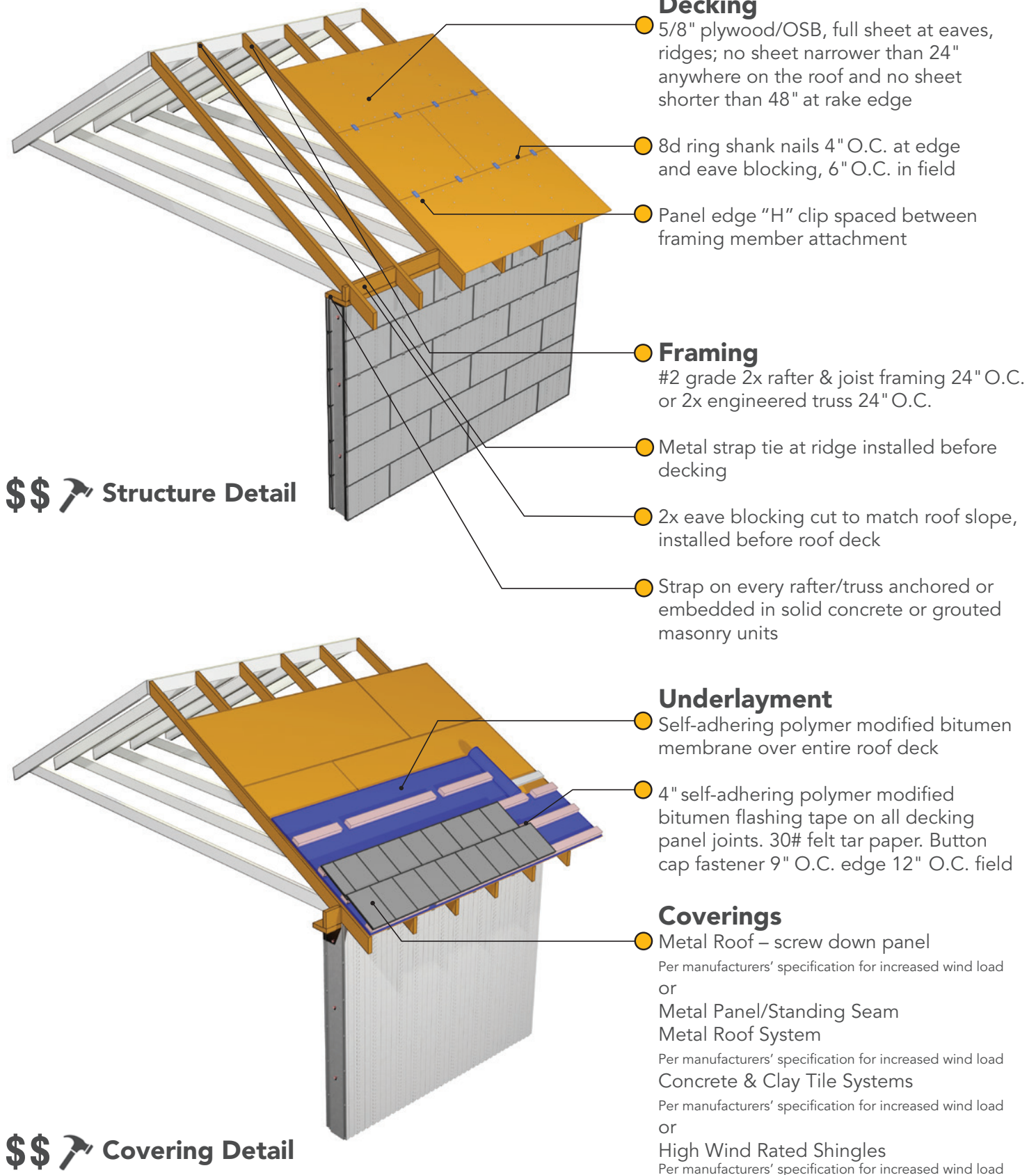
Coverings

Concrete tiles over
batten strips per
manufacturer's
recommendations

\$ 🛠️ Covering Detail

Higher Local Hazard Construction

Generally required by various high wind building codes

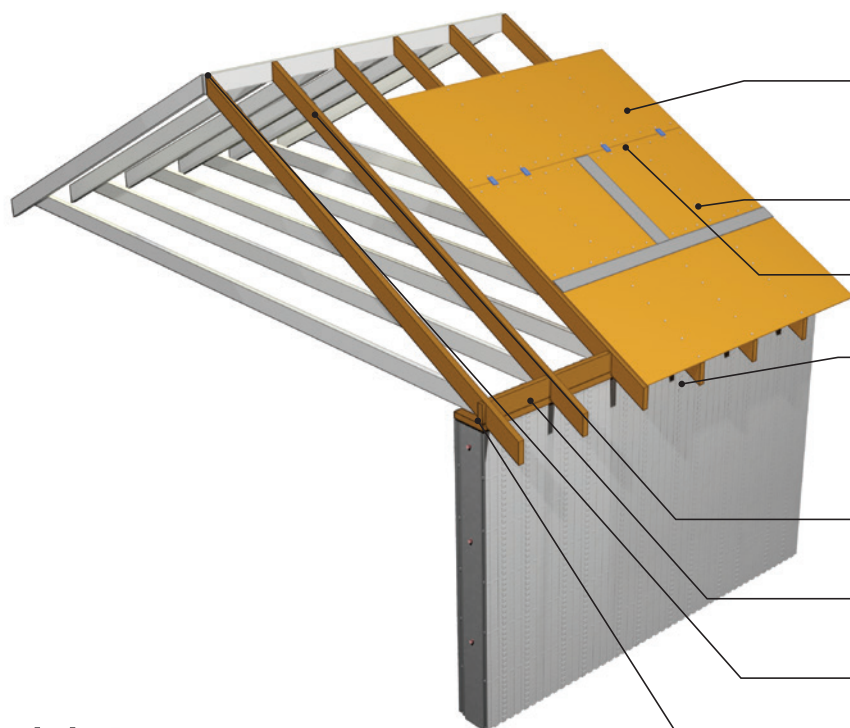


\$\$ 🛠️ Structure Detail

\$\$ 🛠️ Covering Detail

Resilient Construction

Reduces the damaging effects of a storm



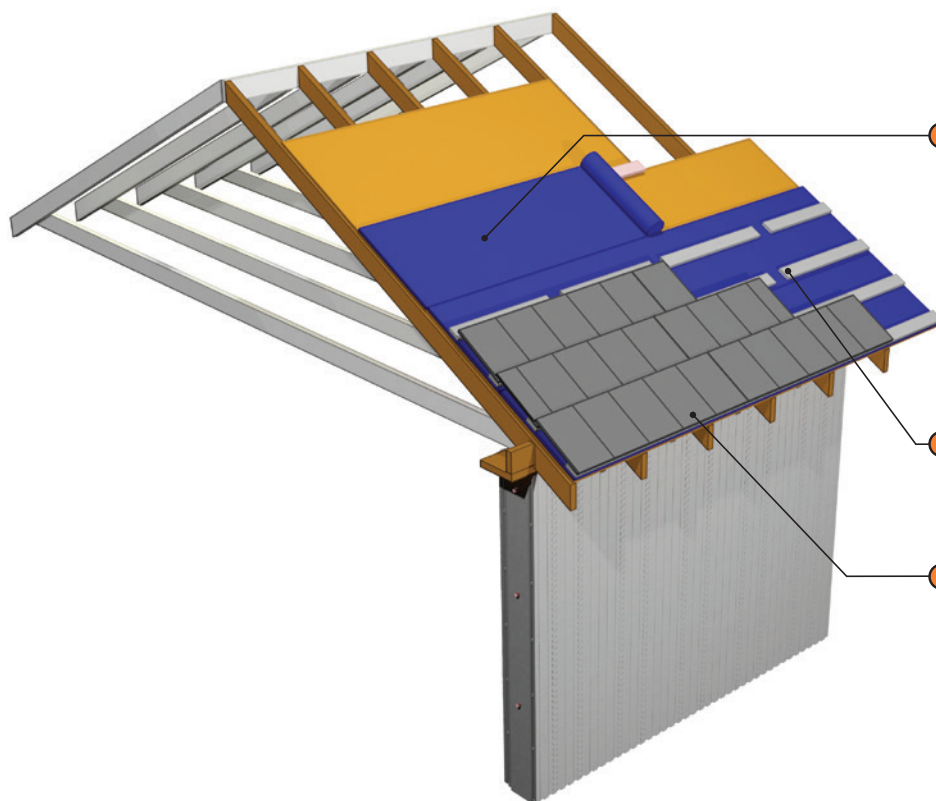
\$\$ 🛠️ Structure Detail

Decking

- 5/8" plywood/OSB, no sheet narrower than 24" anywhere on the roof and no sheet shorter than 48" at rake edge
- 8d ring shank nails 4" O.C. at edge and eave blocking, 6" O.C. field
- Panel edge "H" clip spaced between framing member attachment
- Closed-cell spray polyurethane foam adhesive at underside of decking at all framing and joints attachments

Framing

- #2 grade 2x rafter & joist framing 16" O.C. or 2x engineered truss 16" O.C.
- 2x eave blocking cut to match roof slope, installed before roof deck
- Metal strap tie at ridge installed before decking
- Strap on every rafter/truss anchored or embedded in solid concrete or grouted masonry units



\$\$\$ 🛠️🛠️🛠️🛠️ Covering Detail

Underlayment

- Self-adhering polymer modified bitumen membrane over entire roof deck or
Self-adhering polymer modified bitumen flashing tape on all decking panel joints. 30# felt tar paper. Button cap fastener 9" O.C. edge 12" O.C. field

Coverings

- On 1x4 wood (untreated) purlins fastened by 2 10d ring shank nails 12" O.C. into framing every other set
- Metal Roof – screw down panel
Per manufacturers' specification for increased wind load or
Metal Panel/Standing Seam Metal Roof System
Per manufacturers' specification for increased wind load
Concrete & Clay Tile Systems
Per manufacturers' specification for increased wind load or
High Wind Rated Shingles
Per manufacturers' specification for increased wind load

Supplemental Information – Roof

HAZARDS

Roofs are the most susceptible component of houses exposed to severe wind forces. Typically, wind damage to roofs is caused by uplift forces (vertical), suction and torsional forces (twisting), and horizontal pressures. Wind damage effects vary depending on the roof height, slope, siting and style. Steep roof systems generally fail at the ridge or along gable ends where wind forces are the highest. Low slope roofs typically fail at roof corners.

According to information documented by FEMA after major storms, the roof component damaged most often in high wind is the roof covering (shingle, tile, etc.). The second most common damage found is to sheathing (plywood or OSB decking). Roof covering failure usually follows use of the incorrect type of fasteners (e.g., nail too small or absence of mechanical attachment on concrete tiles, etc.). Sheathing damage

is more often the result of insufficient attachment (e.g. not enough nails in the nailing pattern).

Once the failures occur, they not only expose buildings to water penetration, but also generate windborne debris. When roof systems fail during a hurricane or other high wind events, the rest of the home is weakened and becomes vulnerable to significant, progressive damage.



credit: FEMA

Supplemental Information – Roof

RIDGES, VALLEYS AND ACCESSORIES

Roof ridges often experience covering loss in hurricanes or severe windstorms, and vented ridge caps should be properly fastened to ensure adequate resistance. Low profile ridge vents are a good choice as they are less vulnerable in high wind events. Roof valleys are vulnerable in severe weather because

they experience significant water flow that can lead to water infiltration. Special care should be taken to follow manufacturers' specifications to attach all roof elements, including accessories, equipment, solar panels and/or turbine roof vents.

UNDERLAYMENT AND COVERINGS

Underlayment should be securely fastened to roof decking independently of the roof covering fasteners. Staples are sometimes used to fasten underlayment materials such as felt/tar paper based on the assumption that fasteners used to apply roof shingles on top will secure the underlayment. Unfortunately, in a high wind zone, roofing materials are often lost and this leaves inadequately attached underlayment that cannot prevent water intrusion through deck joints or nail holes. Using a fastener such as

a button cap to secure the underlayment will help prevent water intrusion should the coverings fail. Peel-and-stick membrane products also offer superior protection when coverings are lost. Shingles are more wind resistant overall when installed using six versus four nails. Metal and concrete tile roof systems should always be attached using manufacturers' specifications for an increased wind load.

Supplemental Information – Roof

NAIL PATTERNS

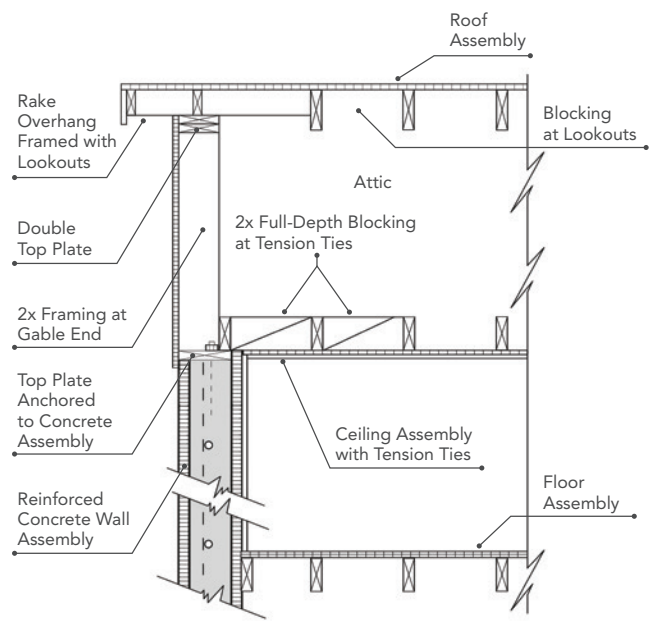
Nail patterns describe layout and spacing for a particular attachment of one component to

another. Choose the type, size and amount of nails to achieve high wind resilience.

GABLE END WALL

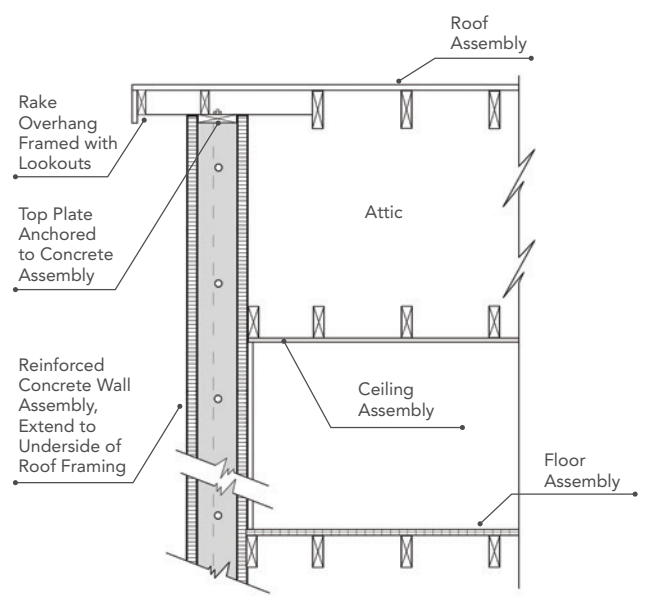
The rake is an overhang at the gable end wall that is particularly vulnerable to wind forces, so it should be adequately and properly attached to the rafters and top of the wall. It is critical to ensure the correct assembly of the edge of the roof framing, decking, underlayment, and coverings to withstand wind forces, as they meet at this

location. Additional lateral support for the walls and roof assembly is accomplished through connection of frame gable ends to supporting concrete exterior walls or extending the concrete or concrete masonry walls up into the gable ends and bracing the top of the wall to the underside of the roof framing.



Frame Gable End Wall Detail

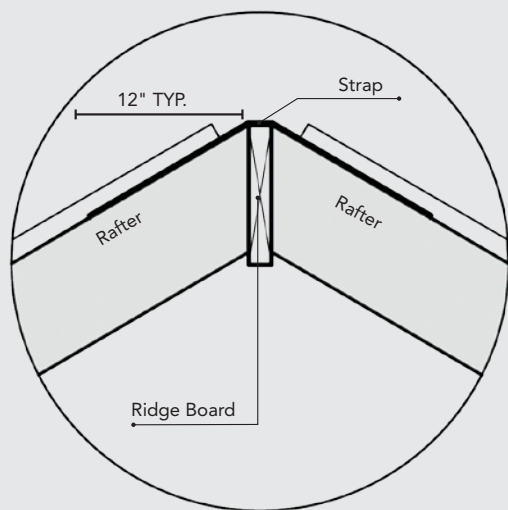
No Scale, See PCA 100 for Structural Details.



Concrete Gable End Wall Detail

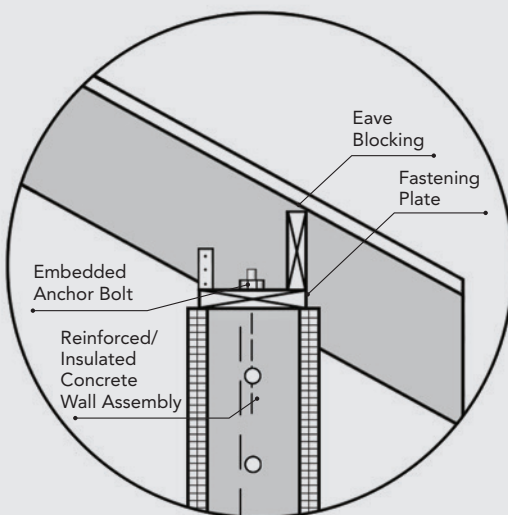
No Scale

Roof Connections



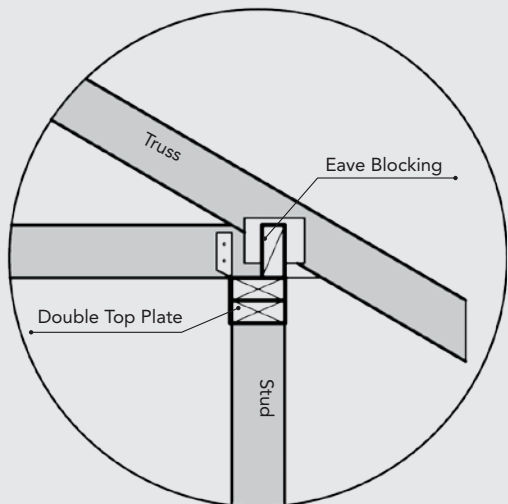
RAFTER AT RIDGE BOARD

Typical construction practices include cutting out a ridge vent in the roof decking to allow for air to flow freely from inside the attic. This free flow of air causes an unintended weakening of the roof diaphragm at a critical location, because the ridge board serves as a boundary of the roof diaphragm. When the decking is cut away for the vent, the decking is no longer connected between the rafters. Installing a strap or straps will strengthen the connection between rafters while still allowing for roof venting at the ridge.



RAFTER AT TOP OF WALL

Rafters attached to the top of a wall in a high wind zone should be fastened to the top plate of the wall with more than just fastening nails. The top plate is anchored to solid concrete or grouted masonry. Typically, metal connectors, straps, or clips are specified to hold down each rafter to the anchored top plate. Eave blocking between the rafters in high winds does more than keep the birds out of the attic; it helps tie the roof diaphragm to the walls and keeps the rafters from rolling due to lateral loads.



TRUSS AT TOP OF WALL

When a truss attaches to the top of the wall, it is similar to a rafter in the hold down connection. A metal strap or clip is specified to hold down the truss in the same way a rafter is held down, but the eave blocking detail is somewhat different. Most local building codes do not require full eave blocking when trusses are used for the roof structure; however, 2x4 blocks should be installed to help resist lateral loading.

How a Wall Works

Three types of wind forces act on walls—wind pressure perpendicular to the wall, lateral loads transferred from the roof to the foundation parallel to the wall, and uplift forces from the roof being lifted from the wall.

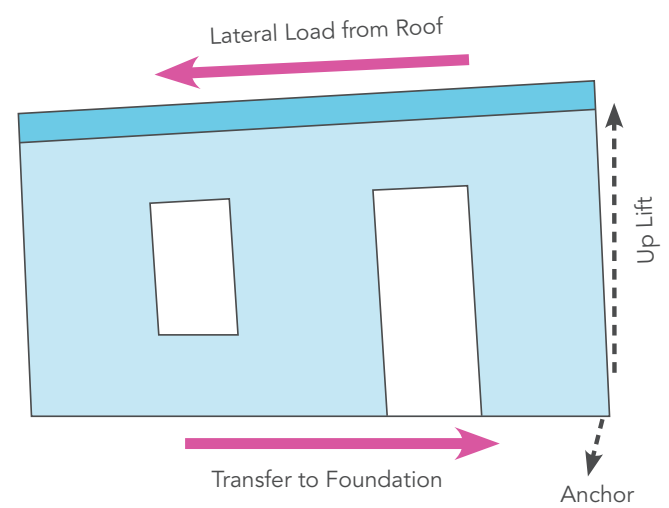
The **perpendicular wind force** acts as either positive or negative pressure and is greatest at the corners. The largest wind load is the **parallel lateral load**. This load comes from the roof diaphragm transferred to a shear wall. Concrete and concrete masonry is inherently strong in resisting compressive, or pushing forces, but relatively weak in tension, or pulling forces. A concrete shear wall includes steel reinforcement which is extremely strong in tension, so the resulting monolithic wall assembly resists combined forces far more effectively than conventional systems. Portland Cement Association studies have shown that 4" thick above-grade concrete wall assemblies have up to 4.2 times the capacity to carry vertical loads and up to 8.6 times the ability to resist horizontal loading than conventional 2x4 wood frame construction. Careful design of the attachment of roof and floor framing to these walls ensures a stronger, safer overall assembly.

For walls to function effectively as shear walls, careful consideration of the amount of solid wall area as well as placement of windows, doors, and utility openings must be considered to insure the wall has required total length of solid wall to provide adequate capacity to resist anticipated shear loading.

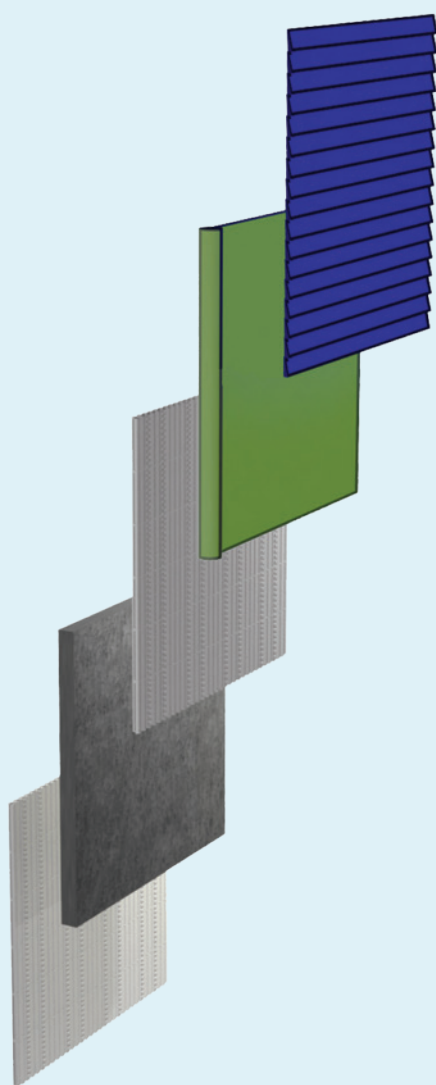
Reference materials or a structural engineer should be consulted. The end walls of long, narrow homes are often inadequate shear walls. In such cases, one or multiple interior partitions may have to be built as shear walls to provide the needed shear capacity.

Unlike conventional residential construction, the monolithic concrete wall assembly creates a more continuous, unbroken load path that allows the structure to better resist **uplift forces** to prevent the roof, wall, and foundation from separating under uplift and lateral loads. The heavier weight of the concrete walls further helps to resist uplift forces.

ELEVATION VIEW OF WALL



Wall Systems



WALL COVERING

Wall covering, also known as cladding, is the outermost layer of the assembly. Unlike roofs, wall cladding is not sealed from moisture. Instead, cladding protects the water barrier layer beneath from damage. All claddings can provide weather protection, but more durable concrete and masonry materials are preferred for resilient construction by providing better resistance and reduced damage from windborne debris. Common residential wall coverings include brick, fiber cement siding, stucco, vinyl, and wood.

HOUSE WRAP (Code Compliant Conventional Construction)

House wrap, also known as weather resistive barrier (WRB), has the unique ability to stop moisture from penetrating to the sheathing while still allowing water vapor within the wall to ventilate.

SOLID CONCRETE WALL ASSEMBLY

Use of concrete systems for above-grade walls eliminates the need for separate sheathing and framing components, reduces complexity, and simplifies the required labor. Finishes inside and out are solidly backed and more easily installed over continuous concrete or concrete masonry substrate, and this enhances structural integrity while greatly reducing gaps, seams, and potential for air infiltration.

INSULATION

Insulation runs continuously within concrete wall assemblies. There is no framing to create thermal shorts and undermine thermal effectiveness, or any requirements for additional layers of continuous insulation that could complicate installation of exterior finishes and/or window and door trim. Virtually all types of rigid insulations can be effectively incorporated into concrete wall assemblies, and polystyrene is the most prevalent. Some systems can incorporate field or factory-injected foams as well.

Wall Systems

TYPES OF CONCRETE WALL SYSTEMS

There are four major concrete wall systems that are commonly used for above-grade wall construction: concrete masonry, conventionally-formed, insulating concrete forms, and precast systems. In addition to resilience, all of these systems can provide the following general sustainability and energy efficiency advantages.

One of the most appealing attributes of above-grade concrete and concrete masonry walls is that they require less energy to heat and cool the building. Insulation, thermal mass, and low air infiltration all contribute to the energy savings. Further, large quantities of insulation can be easily incorporated into the concrete assemblies.

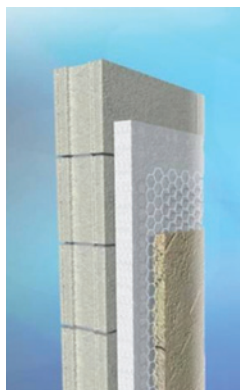
In addition to added insulation, the thermal mass properties of concrete construction enhance energy efficiency. Concrete holds heat from its surroundings and releases it slowly when temperatures moderate, functioning like a thermal storage battery. Incorporating lightweight aggregates, such as shale and clay, can also improve thermal efficiency.

Concrete walls typically have 10 to 30 percent better air tightness than comparable framed walls because the concrete envelope has fewer parts and pieces, and is nearly continuous with fewer joints. In addition to saving energy and costs associated with heating and cooling, concrete walls provide more consistent interior temperatures that provide increased occupant comfort.

Concrete systems are well suited to the use of recycled materials. For example, concrete can be mixed with supplementary cementitious materials like fly ash or slag to replace a portion of the traditional cement. Recycled aggregates like crushed concrete can also be used to reduce the need for virgin aggregate. Most steel used for reinforcement is recycled, and concrete components are typically sourced from local materials and shipped short distances to a project.

This combination of energy efficiency features and environmental benefits help projects earn credits toward certification under green rating systems like LEED®.

CONCRETE MASONRY SYSTEMS



Concrete masonry systems are familiar to most people because they are widely used, and have been for a very long time. Many types of low-rise buildings are made with these materials, from residential to educational to commercial and industrial. The tough exterior of exposed units provides a durable finish in demanding environments, and architects often prefer the aesthetic appeal of masonry to other finishes.

Concrete masonry units (CMU) are manufactured from very dry, stiff concrete mixtures that are placed into molds, vibrated, compacted, and demolded quickly. Units are stiff enough to hold their shape as they enter a curing chamber where they are kept moist and warm to allow the units to become hard and strong. Today's high-tech manufacturing processes ensure consistent, high quality CMU.

Once cured, the masonry is palletized and readied for shipping. Factories throughout the country manufacture concrete masonry units, reducing transportation distances and costs, adding to local economies and meeting sustainability criteria that requires close proximity and availability of construction materials.

ADVANTAGES

CMU has a wide range of beneficial attributes, and their relative importance may vary from one project to another. They are fire-resistant, durable and low maintenance. They last a long time, and can be easily reinforced to meet the needs of demanding, structural applications. CMU finishes are attractive, and do not require painting or other treatment. They do not contain volatile organic compounds (VOCs), or any other potentially off-gassing materials, however they do provide thermal mass to maintain uniform temperatures throughout the indoor space.

From a process perspective, an additional benefit of masonry is that it can be built without much space for construction staging. This is helpful and often essential on constricted sites or between buildings. And while it may be more labor intensive than other concrete construction options, the materials are readily available locally, eliminating costly time delays and the need for special orders.

Wall Systems

SIZES, COMPONENTS, CONFIGURATIONS, SYSTEMS

CMU are modular and held together with mortar. The most common size is a nominal 8-by-8-by-16- inches. Door and window openings are positioned to minimize cutting of units. Walls that contain one vertical layer of units are called single wythe. Two layers are double wythe. It is most common to build single- or double-wythe walls. When

wythes are separated by a continuous vertical space, the assembly is known as a cavity wall. Reinforcement is placed into horizontal and vertical cavities as needed, with grout placed around it. This helps walls to carry loads and resist other forces acting on them.

INSTALLATION, CONNECTIONS, FINISHES

Masonry requires little machinery for placement as it is laid by skilled masons typically equipped with only a trowel.

Masonry walls are tied together internally and connected to each other with reinforcement made from steel, and joint reinforcement may be used along mortar joints to prevent or control cracking in the wall. Anchors, plates, and other items that are common with other construction are used in masonry as well.

Finishes are often simplified when using masonry because it can be either sealed, painted, or left exposed. It can also be plastered to address aesthetic consideration, and to improve moisture resistance. In many cases, however, CMU is left exposed, and this is an option for both plain and architectural units.

BUILDING CODES

Model building codes like the International Building Code (IBC), International Residential Code (IRC) and others address masonry construction, including references to relevant standards.

Wall Systems

CONCRETE MASONRY WALL SYSTEMS

Category	Attributes
Performance	<ul style="list-style-type: none"> • Noncombustible • Integral insulation, thermal mass, and reduced air infiltration combine to reduce mechanical loads • Durable integral finishes eliminate need for additional site applied finishes • Traditional finishes can be easily installed • Thermal mass reduces mechanical loads • Reinforced and grouted cores for exceptional wind and debris impact resistance • Mass of walls provide exceptional acoustic performance • Insulation needs to be installed on inside or outside face, or within block cavities inside wall • Somewhat thicker wall assembly than conventional systems
Availability	<ul style="list-style-type: none"> • Readily available nationwide • Commonly used • Well understood throughout construction industry
Labor	<ul style="list-style-type: none"> • More specialized installation labor requirements • Design aids available
Sustainability and Energy	<ul style="list-style-type: none"> • Can contain recycled content • Mold, rot, mildew, and insect resistant

Wall Systems

CONVENTIONALLY FORMED CONCRETE



Cast-in-place (CIP) concrete walls are made with ready-mix concrete delivered from a local concrete producer, placed into removable forms that are erected on site. Historically, this has been one of the most common forms of building basement walls. The same below-grade techniques can be repeated with above-grade walls to form the first floor and upper levels of homes.

Early forays into this technology were done more than 100 years ago by Thomas Edison who saw the benefit of building homes with concrete well before it was widely understood. As technology developed, improvements in forming systems and insulation materials increased the ease and appeal of using removable forms for single-family construction.

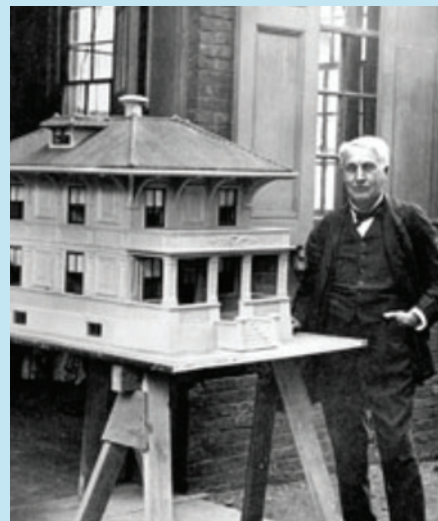
CIP systems are strong. Additionally, their inherent thermal mass, coupled with appropriate insulation, makes them very energy efficient. While CIP walls are usually thicker, traditional finishes can be applied to interior and exterior faces, so that the buildings look similar to frame construction.

HISTORY

The technology for casting concrete in removable forms dates back to the 1850's—the beginning of the reinforced concrete construction industry. Since that time, advancements in forming and placing technology, concrete mixtures, and insulation strategies have made construction of concrete homes using removable forms a well-accepted building technique.

ADVANTAGES

Cast-in-place provides benefits to builders and building owners alike.



Thomas Edison with model of a concrete house (circa 1910). Photo courtesy of U.S. Department of the Interior, National Park Service, Edison National Historic Site.

Wall Systems

OWNERS APPRECIATE:

- Strong walls
- Safety and disaster-resistance
- Mold, rot, mildew, and insect-resistance
- Sound-blocking ability
- Energy efficiency and cost savings (with an insulated system)

BUILDERS AND CONTRACTORS LIKE:

- Expand business to include more than basements
- Cost-effective and familiar building technology

COMPONENTS, INCLUDING INSULATION

The most common formwork materials for casting concrete in place are steel, aluminum, and wood. Many wood systems are custom manufactured and may be used only once or a few times. Steel and aluminum forming systems, on the other hand, are designed for multiple reuses, saving on costs. Metal panel forms are usually two to three feet wide and come in various heights to match the wall. Most common are eight and nine-foot-tall panels.

Cast-in-place (CIP) concrete is the second major component required for these systems. Although it is possible to batch concrete on site, ready mixed concrete is

widely available and is usually delivered by a ready mix supplier. By 2011, the average distance to most project sites from a ready mix plant was approximately 14 miles.

Combining concrete with steel reinforcement results in unsurpassed structural strength for residential and light commercial structures.

INSTALLATION, CONNECTIONS, FINISHES

Casting concrete in place involves a few distinct steps: placing formwork, placing reinforcement, incorporating insulation, and pouring concrete. Builders usually place forms at the corners first and then fill in between the corners. This helps with proper alignment of forms and, therefore, walls. After one side of the formwork is installed, steel reinforcement bars (rebar) can be installed individually or as a prefabricated cage.

Reinforcement in both directions maintains the wall strength. Vertically, bars are usually placed at one to four feet on center, and tied to dowels extending up from a footing or basement slab for structural integrity. Horizontally, bars are typically placed at about four-foot spacing in residential applications. Additional bars are placed at corners and around openings (doors, windows) to help control cracking and provide additional strength.

Insulation can be incorporated entirely within the concrete assembly or exposed on one

Wall Systems

face, and special components are available to hold the insulation in the desired location within the forms. Specially-engineered connectors can be used to interconnect the two wythes of concrete that separate a layer of insulation so they act together structurally. Alternatively, insulation can be installed on one or both sides of the wall after the concrete has been placed and formwork stripped. Foam is the most typical insulation used with either expanded polystyrene (EPS), or extruded polystyrene (XPS). XPS is stronger, but also costlier.

Once both form faces are tied together and braced and insulation has been installed, concrete is then placed in the forms via a chute extended directly from the concrete truck, a craned bucket, or concrete pump. Forms should always be filled at a steady, appropriate rate based on formwork manufacturer recommendations to prevent problems, including a breach or blowout. And, although blowouts are uncommon with metal and wood forms, misalignment can occur if they do.

For single-family residential construction, wall thicknesses will typically range from 4 to 12 inches. Uninsulated walls are typically 6 or 8 inches thick. Walls with insulation are generally thicker to accommodate the insulation while still maintaining adequate thickness of the structural portion of the assembly. For residential construction, insulated cast-in-place walls will generally add at least 6 inches to the overall thickness

of exterior walls compared to conventional construction.

Openings for doors and windows require bucks to surround the opening, to hold back the fresh concrete during placement, and provide suitable material for fastening window or door frames.

Floors and roofs can be concrete or wood, or light-gauge steel. Ledgers to support floor systems are anchored with bolts or brackets embedded into the concrete. For heavy steel floors, weld plates are installed inside the formwork so they become embedded in the fresh concrete. This provides an attachment for steel joists, trusses, or angle irons. Floors and roof systems can also be formed with conventional forming systems to create flat or ribbed decks that can span 12 to 16 feet.

Virtually any type of traditional applied finishes can be attached with furring strips. Wallboard remains the most common interior finish. Exterior finishes are much more varied, depend on customer preference, and can include siding, as well as traditional masonry.

Integral finishes cast into the face of the walls are a second popular option. Form liners attached to the exterior form face can impart any type of texture. The look and feel of masonry, siding, stucco, and stone can all be created as the wall is formed. Paint or stain often completes this treatment, leaving a finish that appears very much like real masonry, siding, stucco or stone.

Wall Systems

BUILDING CODES

Model building codes like the International Building Code (IBC), International Residential Code (IRC) and others address masonry construction, including references to relevant standards.

CONVENTIONALLY FORMED WALL SYSTEMS	
Category	Attributes
Performance	<ul style="list-style-type: none"> • Noncombustible • Integral insulation, thermal mass, and reduced air infiltration combine to reduce mechanical loads • Durable integral finishes eliminate need for additional site applied finishes/integral insulation • Thermal mass and reduced air infiltration combine to reduce mechanical loads • Solid monolithic reinforced concrete for exceptional wind and debris impact resistance • Formwork for floor and roof structures as well • Mass of walls provide exceptional acoustic performance • Somewhat thicker wall assembly than conventional systems
Availability	<ul style="list-style-type: none"> • Readily available nationwide • Commonly used and well understood
Labor	<ul style="list-style-type: none"> • Upfront investment in specialized formwork for above grade walls with architectural details • Forms must be stripped after concrete sets • Somewhat more specialized installation labor requirements • Design aids available for one and two family dwellings
Sustainability and Energy	<ul style="list-style-type: none"> • Can contain recycled content • Mold, rot, mildew, and insect resistant • Panelized construction with virtually no site waste

Wall Systems

INSULATING CONCRETE FORMS



Insulating concrete forms (ICFs) result in cast-in-place concrete walls that are sandwiched between two layers of insulation material. These systems are strong and energy efficient. Common applications for this method of construction are low- and mid-rise buildings, with property uses ranging from residential to commercial to industrial. Traditional finishes are applied to interior and exterior faces, so the buildings look similar to typical construction, although the walls are typically at least 6" thicker.

OVERVIEW AND HISTORY

The history of ICFs dates back to after World War II, when blocks of treated wood fibers held together by cement were used in Switzerland. In the 1940's and 1950's, chemical companies developed molded plastic foams, which by the 1960's allowed a Canadian inventor to develop a foam block that resembles today's typical ICFs. Europeans were developing similar products around the same time. In the 1980's and 1990's, some American companies began manufacturing the technology. The new companies developed variations and innovations to distinguish one system from another. Over time, some ICF manufacturers consolidated, leading to a smaller number of larger companies. The premium quality of ICF walls was particularly attractive to custom home clients. As word of ICFs grew and innovations reduced manufacturing and installation costs, builders began using the forms for mid-range priced homes. Some production builders now create entire developments using insulating concrete forms.

ADVANTAGES

Insulating concrete forms provide benefits to builders and building owners alike.

OWNERS APPRECIATE:

- Strong and durable walls
- Disaster resistance and safety
- Mold, rot, mildew, and insect resistance (below-grade can require termite protection)
- Improved reduction in noise penetration
- Overall temperature comfort
- Energy efficiency and cost savings

BUILDERS AND CONTRACTORS LIKE:

- Fast, easy construction
- Flexibility
- Lightweight for easy shipping and erection
- Compatibility with carpenter trades
- Ability to meet higher energy code mandates
- Less complicated construction

Wall Systems

SIZES, COMPONENTS, CONFIGURATIONS, SYSTEMS

Insulating concrete forms systems can vary in their design. The majority of systems available today create a flat, continuous concrete wall system, like a conventionally poured wall. There are a few systems available that create concrete walls of varying thickness or post and beam configurations. Whatever their differences, all major ICF systems are engineer-designed, code-accepted, and field-proven.

Today, the two layers of insulation that form the outside faces of the concrete are most often expanded polystyrene insulation, typically 2 to 2 ½-inches thick. These layers are held in place by regularly spaced ties that extend across the thickness of the wall while also providing continuous fastening strips for finish attachment just below the face of the insulation on both sides of the wall. They can be plastic or metal. Some are hinged to allow prefabricated forms to fold flatter for more efficient shipping. The joints between individual forms can feature interlocking teeth or a tongue and groove configuration molded into the forming material, or simple butt jointed seams.

Many manufacturers have developed units with universal interlocks that allow the forms to stack whether the form is flipped one way or the other. These “reversible” forms save time during placement and prevent improper alignment. Special units for corners, floors, and roof assemblies round out the product lines and improve

the engineering of the system and energy efficiency of the final construction. Some systems offer thicker layers of foam or other enhancements to the foam chemistry to enhance performance.

Individual ICF block sizes are typically on the order of 16 inches high by 48 inches long. They commonly form concrete wall thicknesses of 4-inches to 12-inches.

After finishes are applied inside and out, typical final wall thickness results in deeper window and door surrounds than what is used for traditional frame construction. Designers and homeowners like the character and implied strength that results from the deeper opening profile.

INSTALLATION, CONNECTIONS, FINISHES

Installation of insulating concrete form systems is similar to masonry construction. Builders typically start at the corners and place one course or layer at a time to build up the wall. Bracing is placed on one side of the wall as the forms are stacked, at roughly 6-foot intervals, to steady and align the forms, while often supporting a working platform for higher course assembly, rebar and concrete placement.

Once the forms are in place and braced and required reinforcement installed, concrete is usually pumped into the forms.

Wall Systems

Even with the bracing, forms need to be filled at an appropriate rate based on formwork manufacturer recommendation to prevent misalignment and blowouts, or breaches. However, blowouts are unlikely when manufacturer recommendations are followed. Reinforcement spacing similar to the description above for conventional formwork in both directions maintains the wall strength. Openings for doors and windows require bucks to surround the opening, contain the fresh concrete during placement, and provide suitable material for fastening window or door frames.

The ability to easily cut the foam insulation allows for fast installation of block outs, inserts, and utility sleeves as needed. Insulating concrete form systems are compatible with concrete floor and roof systems as well as conventional wood or steel framing. In smaller buildings, ledger assemblies for floor framing attachment mounted to the side of the formwork are common. In larger buildings or those for commercial uses, steel weld plates or bolt plates can be preinstalled within the formwork so they become embedded in the fresh concrete.

Finishes are usually screwed to the flat ends of metal or plastic ties embedded in the forming material. Finishes can alternately be furred out with furring strips. Almost any type of finish can be used with

these systems. Wallboard remains the most common interior finish and is the most typical means of meeting the code requirement for a 15-minute fire barrier over plastic foams surrounding living spaces. Any exterior finish that can be attached with screws can be easily accommodated over ICFs. For heavier finishes like cement plaster, consult manufacturer recommendations.

BUILDING CODES

As insulating concrete forms have increased in popularity, code approval has become much simpler. The International Residential Code (IRC) addresses the design requirements for detached one and two-family dwellings and townhouses of not more than three stories. For multi-family and commercial buildings, engineers and design professionals must follow the International Building Code (IBC) for structural design.

Wall Systems

INSULATING CONCRETE FORM WALL SYSTEMS

Category	Attributes
Performance	<ul style="list-style-type: none"> • Noncombustible • Integral insulation, thermal mass, and reduced air infiltration combine to reduce mechanical loads • Solid monolithic reinforced concrete for exceptional wind and debris impact resistance • Finishes readily installed to integral furring • Light weight forming that can be panelized and installed without need for crane • Mass of walls provide exceptional acoustic performance • Foam must be finished inside and out • Thicker wall assembly than conventional construction
Availability	<ul style="list-style-type: none"> • Readily available nationwide
Labor	<ul style="list-style-type: none"> • Local code may restrict use of rigid foam insulation below grade in areas designated "very heavy termite infestation" • Commonly used and well understood • Less specialized labor requirements • Design aids available for one- and two-family dwellings
Sustainability and Energy	<ul style="list-style-type: none"> • Can contain recycled content • Mold, rot, mildew resistant • Termiticide can be added to foam for insect resistance

Wall Systems

PRECAST CONCRETE SYSTEMS



Precast concrete is available in many shapes and sizes, including structural elements and unreinforced pieces. Panels are the most common members used in building construction, and may serve as structure or cladding or both. As structural-architectural panels, they provide a cost effective solution to building enclosures. Panels can be full- or half-sandwich or hollow core construction. Full-sandwich panels are popular because they provide two durable faces and allow a space between that is filled with insulation. The half-sandwich panels contain just one concrete face and

therefore require additional insulation and finishing after erection. Hollow core panels can be used for walls, but are especially well suited to floors. The hollow cores that extend the full length of the planks can be used for utility chases or sometimes as ducts for heating, ventilation, and air conditioning (HVAC).

ADVANTAGES

Concrete sandwich panels are highly engineered to provide rugged, durable surfaces for walls and can be used for floors, as well. They are manufactured in factory settings. Not only is this conducive to improved quality control, it's also possible to manufacture year-round in optimized indoor conditions.

By designing buildings to have one predominant panel size, panel manufacturing becomes a repetitive process and gains efficiency. Rigid insulation can often be incorporated as the panels are cast, but following a two-step casting process, the resulting void between panels can be injected with foam insulation.

The ability to quickly erect panels at the site is another advantage of precast. Once footings are prepared, panels can be placed

quickly to form the enclosure. This requires some lead time to order the panels, but is an advantage at the site. It also means that construction can be completed within a relatively small footprint and may allow building in weather that would negatively affect other types of construction. Solid, high-quality concrete construction built with an efficient use of labor makes for cost effective structures, particularly larger scale repetitive assemblies.

Precast, like all concrete construction, provides fire, rot, termite, and mold resistance. Exterior walls can withstand tornado-force winds. It is solid construction that protects occupants from weather and from natural disasters.

Wall Systems

SIZES

The casting process itself is not limited to any particular size, but there is a practical limit to their dimensions due to transportation and site erection requirements. When the pre-casting facility and site are located relatively close to each other, panels have been as long as 50 feet. Panels can be just about any size, as long as the trucks and streets can accommodate them and the equipment can place them.

Panel size should be suited to the building design. For instance, for a single-story structure, the panel may be eight to 10-feet tall, and 20 or 30 feet long. For a two-story building, the panel might be 15- to 20-feet tall. Again, as long as the panel can be trucked to the site without causing problems on roads or under bridge overpasses, the size is dictated by the building itself.

INSTALLATION, CONNECTIONS, AND FINISHES

Concrete weighs about 150 pounds per cubic foot, so precast items are heavy. For instance, a full-sandwich panel that is 10-by-20-feet by 8 inches thick (with a 3-inch void for insulation) weighs more than 6 tons. Cranes and other lifting equipment should be appropriately sized to handle the panels. Tight quality control of dimensions allows panels to be erected quickly at the site with only a minimum of field adjustments.

The precast is bolted to the footing or slab.

The panel must be braced, placed, leveled, and plumbed before the attachment is made. Generally, the brace remains in place until the panel is connected to neighboring panels which complete the structure and provide support. Hollow core panels are attached to vertical dowels extending up from the footing or slab and the core is grouted to create a column that ties the wall structurally to the base.

Connections between panels are made either by grout columns (hollow core slabs) or by bolting or welding plates cast with the concrete. Bolted joints should be finished by caulking with a sealant to seal the building enclosure and protect the steel connections from rusting.

Architectural finishes for precast are varied. Concrete can be integrally colored with mineral pigments. The range of colors is quite wide if white cement is used. One of the most common surface treatments is exposed aggregate, where steps are taken during panel manufacturing to remove some of the surface cement, exposing stones in the concrete mix. Exposed aggregate finishes are usually sealed to provide added resistance to water penetration. Alternately, panels may be cast with a form liner and painted with a masonry-type paint. This allows the simulation of many other finishes such as hand laid masonry (brick or stone). Some people prefer casting thin layers of actual brick or concrete units into the face of the panel. Still others prefer attaching the

Wall Systems

finish at the site to create either a cavity wall or a barrier wall.

Portland cement plaster is also a suitable finish for precast, and can be directly applied to panel faces.

Interior finishes may be given the same treatment as exterior faces, may receive a direct application of plaster or paint, or they can be finished with drywall for a more conventional appearance.

MANUFACTURING AND PHYSICAL PROPERTIES

Often, the production of panels is a highly automated process. Forms are built, openings laid out, reinforcement is placed, and perhaps even conduit is placed for mechanical or plumbing needs. Fresh concrete is deposited into these forms in a factory setting. This greatly improves the control over concrete mixing and temperature. Tight quality control is exercised at every step in the process, including adjustments to thickness and other dimensions for precise panel sizes.

Panels can be cast vertically or horizontally. Vertical casting is similar to cast-in-place concrete. The panels are cast in the same orientation which they will be placed in service. Horizontal casting is perhaps more common because it is easier and faster to lay out the panels, openings, and reinforcement, and cast the concrete. Following casting, panels are placed into curing chambers to develop strength and durability.

Casting beds create the panel faces. Horizontal casting also simplifies sandwich type fabricating. This allows for casting two separate panels—one interior, one exterior—so that a void is created between them. The void can then be filled with insulation to improve the panels' performance as part of a building envelope. This also permits quite a bit of flexibility for the aesthetics of each finished face.

BUILDING CODES

Panel manufacturers usually provide engineered, stamped plans for single-family residential homes they supply. They also provide a resource to answer questions from building departments. On larger buildings, it's common to custom engineer the building. The panel producer provides engineering data and specifications for their panels. Engineers then use this information in their designs.

Precast is designed following the International Building Code, which has provisions based on the Building Code Requirements for Reinforced Concrete.

Wall Systems

PRECAST CONCRETE WALL SYSTEMS	
Category	Attributes
Performance	<ul style="list-style-type: none"> • Noncombustible • Integral insulation, thermal mass, and reduced air infiltration combine to reduce mechanical loads • Durable integral finishes eliminate the need for additional site applied finishes • Elaborate architectural detailing possible • Integral insulation, thermal mass, and reduced air infiltration combine to reduce mechanical loads • Solid monolithic reinforced concrete for exceptional wind and debris impact resistance • Precast planks for floor and roof assemblies available as well • Mass of walls provide exceptional acoustic performance • Somewhat thicker wall assembly than conventional systems
Availability	<ul style="list-style-type: none"> • Readily available nationwide
Labor	<ul style="list-style-type: none"> • Panels require on site crane for placement • More specialized installation labor requirement • Commonly used and well understood • Fast site erection
Sustainability and Energy	<ul style="list-style-type: none"> • Mold, rot, mildew, and insect resistant • Panelized construction with virtually no site waste • Can contain recycled content

Supplemental Information – Walls

HAZARDS

Cladding/Coverings Loss

Siding of any type (wood, vinyl or fiber cement) can blow off a house and become damaging windborne debris. However, the solid concrete behind those finishes will continue to provide weather and impact protection.

Impact from Windborne Debris

Windborne debris impacts are difficult to anticipate; however, the concrete wall assembly will help protect occupants from flying debris.

Wind-Driven Water

A well attached weather resistive barrier can help to minimize moisture and water infiltration.

When cladding is lost, the concrete wall assemblies are far less vulnerable to wind-driven water while also providing a strong backing to help maintain the integrity of secondary weather barriers.

Openings & Penetrations

Door and window openings are commonly damaged by wind and wind-driven water. There are vital steps that make doors and windows wind resistant, including following specified installation instructions, using flashing, and deploying locking mechanisms.



credit: FEMA

HOUSE SHAPE

The shape of a house impacts how it handles lateral loads. For instance, a square house has the same load in every direction because the size of the ends and sides are uniform. Conversely, a long narrow house will

experience a much larger load on the long sides than on the short sides. Walls parallel to the lateral load need to be designed and built in a way that anticipates and handles this loading.

Supplemental Information – Walls

SHEAR WALLS

Shear walls are structural walls that resist lateral forces acting on a house, and reinforced concrete and concrete masonry function well as the primary components of a shear wall. In high wind zones, reinforced concrete exterior walls will provide more shear capacity than is typically required, eliminating the need for interior shear assemblies. Openings create weak points in shear walls and the shear wall strength is discounted for openings. Shear wall design

is based on the height and length of a wall, the number and size of openings and the calculated lateral loads based on the specific wind zone location of the home. The shear walls must be properly attached to the roof and floor structure in order to properly transfer the loads to the foundation.

EAVE BLOCKING

The method of eave blocking is a significant difference between typical construction and high wind zone construction. Typical eave blocking is commonly referred to as “bird blocking”. However, proper blocking between joists performs an essential function

as it transfers lateral loads from the roof deck to the shear walls. Eave blocking should be installed during framing before the roof decking is in place. Roof decking should be nailed to the blocking before underlayment is installed.

Supplemental Information – Walls

CLADDING AND COVERING

Brick Veneer

Brick veneer is popular as home cladding because it provides for low maintenance and windborne debris protection; however, it can be vulnerable to wind and wind-driven water in high wind areas. This is less of a problem with concrete walls. Because they are stiffer continuous assemblies, they reduce movement that can open veneer joints supported by conventional substrates. Common brick veneers are secured with masonry ties attached to the concrete or concrete masonry substrate; however, problems can occur when not enough ties are used, ties are not fastened securely or corrosion sets in. In high wind zones, ties should be spaced closer together and securely anchored. Also, using proper drainage and drying space will keep the ties and back side of the brick dry and less susceptible to moisture and corrosion.



Vinyl Siding

Vinyl siding is lightweight and susceptible to high wind damage. However, some manufacturers produce vinyl siding systems designed for high winds. Before using vinyl, ask local building suppliers for detailed product information and investigate the past product performance in your area.



Fiber Cement Siding

Fiber cement siding is popular as home cladding because it provides for low maintenance and windborne debris protection. Manufacturers provide for high wind by providing details for enhanced attachment with higher grade fasteners and closer placement. Roofing nails with larger heads are often specified in place of specialized "siding" nails. And, like masonry ties, fasteners should be securely anchored to the supporting concrete wall.



Supplemental Information – Walls

DESIGN PRESSURE (DP) RATINGS

Design Pressure (DP) ratings on windows should not be confused with impact ratings as they are based solely on the wind load the windows are designed to withstand. DP ratings and requirements vary by the home's wind zone location as well as window

location in the wall. For example, DP rating requirements in the middle of the wall where pressure is lower than those near the edges where pressure is greater. Refer to your local building authority to identify appropriate DP Ratings.

IMPACT WINDOWS

Impact-resistant windows are tested and rated with large and small missile impacts. Windows are required to remain intact after impact; however, glass breakage is allowed as long as the glass does not fall out of the window.

Large Missile

6' nine lb. 2x4 fired at 50 feet per second

Small Missile

30 pieces of roof gravel fired at 80 feet per second

When local building codes in high wind zones require impact-resistant windows, they often allow for product substitutions due to cost considerations.

SHUTTERS, PANELS, ETC.

Many products are available that can work in place of, or supplement the strength of, impact-resistant windows. Rated hurricane shutters decrease the chance of breaking glass.



Supplemental Information – Windows

INSTALLATION

Window installation is critical to window performance in the wall, so using the correct Design Pressure rating and impact resistance attributes will not matter if the installation is not correct. All window manufacturers specify the correct means of installation,

and high wind resilience can be achieved by following the manufacturers’ installation guidelines for increased wind load. Stiffer concrete wall assemblies help to reduce flexing of the window frames and joints, to better maintain weather tightness.

SELF-ADHERED FLASHING

Self-adhered flashing, commonly called “window tape,” is vital to securely seal window openings. Tape should be installed after the window is secured in place from the

bottom sections first and up to the top. Each section above should overlap the section below to create an effective drainage path.

Supplemental Information – Doors



Doors are weak parts of the wall and must be detailed correctly to keep wind and wind-driven rain out of the home. During a 130 mph wind (Category 4 hurricane), a typical 3' wide door will experience approximately 580 pounds of pressure. As with windows, the glass sections in doors are the most vulnerable. Door glass panels have their own Design Pressure and impact ratings although they are similar to windows ratings. Common areas where doors fail are outlined on the following pages.

Supplemental Information – Doors

DOOR TO JAMB AND FRAME

Latch

A common weak point is the latch and lock because high winds can concentrate large forces on that single point. Many new door models have three and five point latching as opposed to the traditional single point at the latch and handle, which creates a stronger door to door frame connection.

Hinges

The hinge side of the door is also a major concern. Door hinges need specific attachments to the door frame and door to ensure proper connection.

Jamb and Frame to Wall

If the door jamb and frame are not properly attached to the structure, the door system will fail. All door manufacturers provide detailed specifications on how to attach the system to the structure of the home. Stiffer concrete wall assemblies help to reduce flexing of the door frames and joints, to better maintain weather tightness and function.

FRENCH DOUBLE DOORS

Double doors often fail in high winds because they are weak where they come together, especially if they swing inward. Some units use a center post to create a stronger latch point; however, the post somewhat defeats the purpose of a double door configuration. More manufacturers are offering out-swinging double door models, and they are sometimes required by local building codes.



Supplemental Information – Doors

GARAGE DOORS

Like doors and windows, garage doors are a weak part of the wall, especially because most garages are designed to make the door opening as wide as possible. This wide opening requires a strong door frame that is commonly referred to as a “moment frame”. The wind load on a garage door is substantial. A typical 10'x10', single car garage door is subject to more than 6000 lbs. of pressure in 130 mph winds. Garage doors must be rated for pressures associated with the site design, wind speed, and exposure category. Garage doors are commonly made of thin sheet metal, fiberglass or similar materials so that they are lightweight for efficient lifting. As a result, they are vulnerable to damage by wind

forces and windborne debris. Glass panels in garage doors are not recommended because they introduce additional weakness and glass panel, wind-rated garage doors are expensive options for typical residential construction. Roll up doors are often connected at only a few critical points. The concentrated loads on the edges must be accounted for when attaching garage doors. Anchoring into concrete wall assemblies will enhance the overall performance of the garage door assembly. Thresholds poured into the concrete garage slab or installed onto the garage floor help keep out wind-driven water.

WIND-DRIVEN WATER

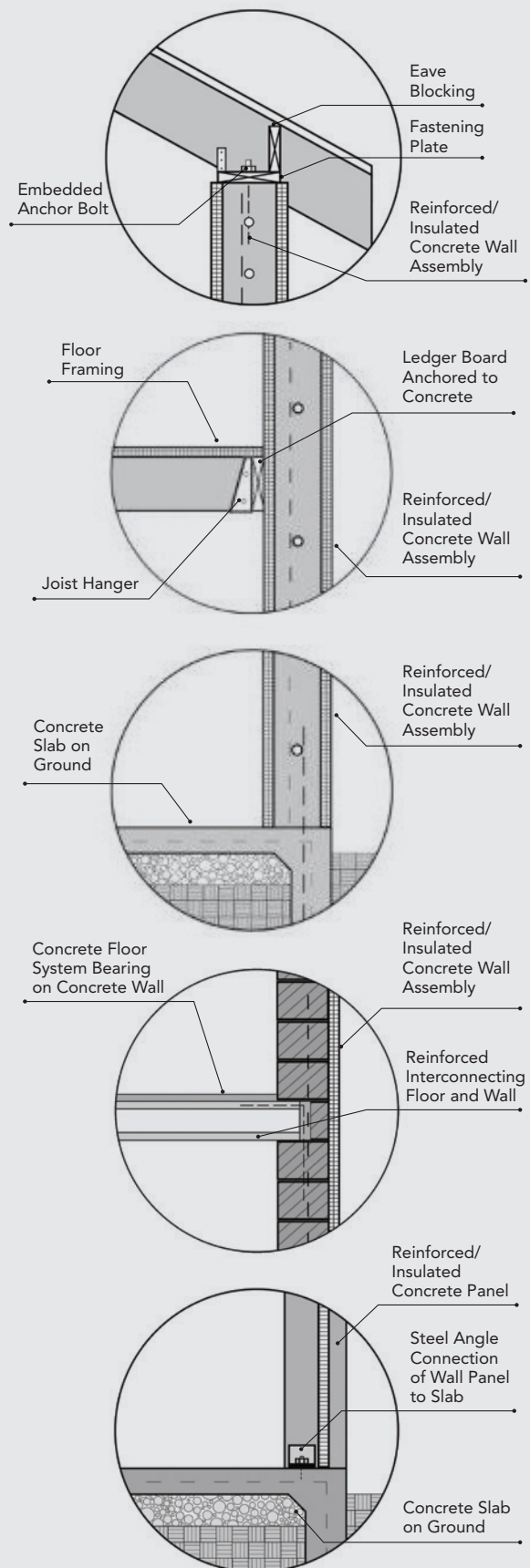
Seal

Doors should be properly flashed and sealed for both wind and wind-driven water. All four sides of the door should seal tight to the frame, and all four sides of the frame should be sealed tight to the structure. A combination of flashing and sealers such as caulking, foam and silicone should be used. Stiffer concrete wall surrounds will help to reduce flexing of the joints to better maintain weather tightness.

Thresholds

The threshold is the bottom of the door frame and provides transition from outside to inside. Thresholds can be particularly vulnerable to wind-driven water. Sealing the bottom of the threshold to the door frame is important and is often overlooked at the time of installation.

Wall Connections



TOP OF WALL

Wood roof framing is attached to a single 2x top plate, ripped to match the width dimension of the concrete wall. Anchor bolts with nuts and washers, number, spacing, and embedded depth into the concrete per code, secure the plate to the top of the concrete. Use pressure treated lumber or isolate the wood from contact with concrete with a sill sealer or membrane. Wind forces on the face of the reinforced concrete wall will not cause any lateral displacement of the top plate. Hold down straps wrapping over the top of the rafters hold the roof framing to the plate, preventing uplift.

WALL AT RAISED FLOOR – CONVENTIONAL FLOOR FRAMING

A continuous ledger board, depth to match the required depth of the floor framing, is secured to concrete with steel ledger board hangers, number, spacing, and embedded depth into the concrete per hardware manufacturer requirements. Floor joists, depth and spacing per code, are secured to the ledger board with joist hangers, sized to handle the anticipated applied loads.

WALL AT RAISED FLOOR – CONCRETE FLOOR SYSTEMS

Concrete wall assembly is built to the bearing height of the concrete floor assembly. Concrete floor assembly extends onto the concrete wall assembly, with reinforcement extended horizontally from the floor and turned down vertically into the concrete wall assembly.

WALL AT SLAB-ON-GRADE – CONCRETE MASONRY, CAST-IN-PLACE, OR PRECAST

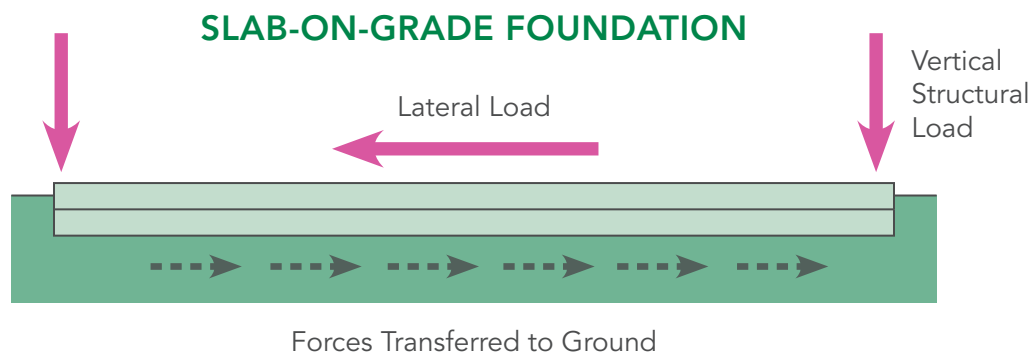
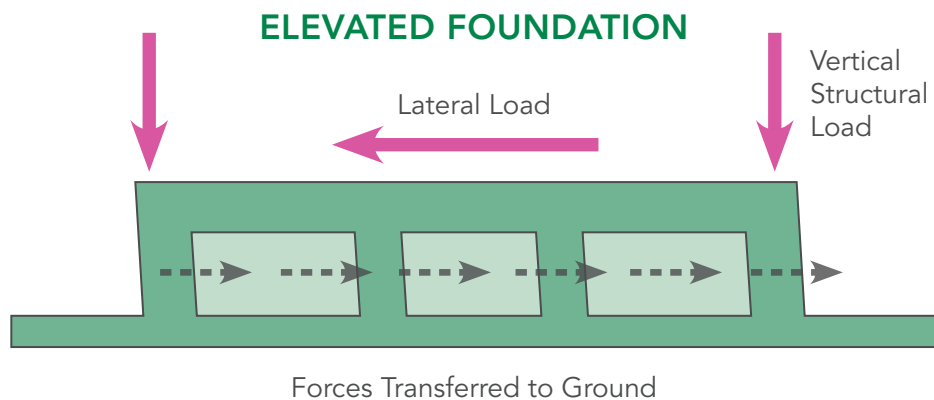
Vertical reinforcement, size, number, spacing, and embedded depth into the concrete per code requirements extend from slab into the concrete or concrete masonry wall assembly. Precast concrete panels bear on top of the slab, secured with steel angles. As an alternative (not shown), the concrete (cast-in-place or precast) or concrete masonry wall assembly can extend continuously from footing past the slab-on-grade location. Concrete slab is placed independent of the wall assembly providing a fully insulated slab edge. Local soil conditions dictate if additional reinforcement is needed to tie the edge of the slab to the side of the continuous wall assembly. Consult local building code for additional insulation requirements for slabs.

How Foundations Work

The primary structural role of the floor and foundation is to support the structure and transfer the lateral loads into the ground. The accumulated forces from high winds or flood waters are significant at foundations and the effects of such forces are increased in homes that are built on tall piers, a common practice in coastal flood zones. Elevated piers, which are built in the ground, or piles, which are driven into the ground, are generally eight or more feet deep depending on the soil capacity and should be designed by an engineer.

In a two-story home, the second floor deck is a stiff horizontal diaphragm that transfers the loads on the walls facing the wind to the wall parallel to the wind. Whether the foundation is a slab-on-grade or a framed floor, the

attachment of the walls to the floor is one of the most important structural details as this anchor condition transfers the lateral and uplift wind loads from the wall to the floor.



Foundation Components

SUBFLOOR

The subfloor is a horizontal diaphragm for either a ground floor or upper floor. As with the roof and wall sheathing, the strength of the plywood or OSB and the strength of the attachments are important. Floor decking is often glued and fastened to the floor framing.

FLOOR FRAMING

Floor framing is typically 2x10, 2x12 or engineered lumber. The size of the framing is determined by the spans and floor loads.

INSULATION

Insulation in raised floors should be tight to the underside of the decking unless another "air barrier" is created at a different location, e.g., the bottom of the framing members. Rigid insulation and spray foam insulation are recommended in high wind zones as these two types of applications deliver energy-efficiency, water resistance, and structural strength as opposed to batt and blown in insulation that only provide energy-efficiency.

SILL PLATES AND ANCHORS

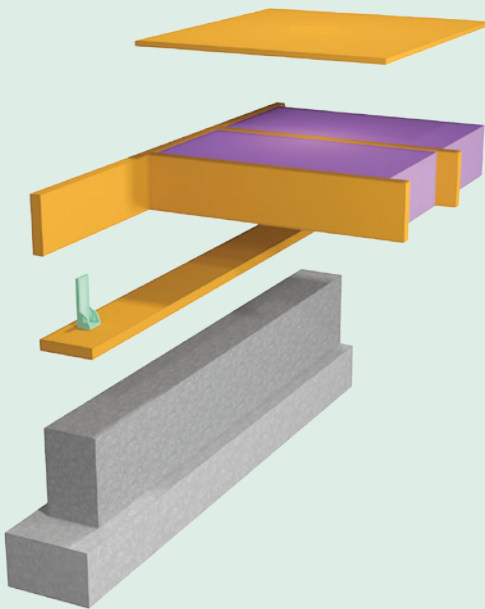
Sill plates are anchored to the foundation with anchor bolts cast into the foundation. The spacing and size of the anchor bolts are determined by the lateral loads.

CONCRETE FLOOR SYSTEMS

For greatest resilience substituting reinforced or precast decking, insulated as required, replaces subfloor framing, sill plates, and anchors. See pages 47-48.

FOUNDATIONS

Houses have various foundation systems. A slab-on-grade is the floor and the foundation when it is used. If the floor is elevated or has a crawl space, the foundation consists of a vertical member and a footing. The vertical member is either a stem wall or a pier, which is typically reinforced concrete block or cast-in-place concrete. The footing type depends upon the soil strength and whether the home is elevated. Typical footings are either spread footings under each pier, continuous spread footings for a stem wall or combined piers, or deep foundations such as concrete piers or driven piles.



Foundation Component Comparison

FOUNDATION COMPONENTS	Code Compliant Conventional Construction	Higher Local Hazard Construction	Resilient Construction
Raised Floor – Subfloor	3/4" tongue and groove (glued and nailed)	3/4" tongue and groove (glued and nailed)	
Raised Floor – Joists	2x (depth is span dependent on load)	2x (depth is span dependent load)	Precast concrete planks, or formed reinforced concrete slab
Raised Floor – Supporting Structure	2x double rim joist	2x double rim joist	Integral concrete beam or concrete beam supporting underside of planks or slab
Raised Floor – Foundation Connection	Sill plate with anchor bolts	Sill plate with anchor bolts, include hold down bolted through bottom plate into foundation	Steel reinforcement to connect concrete floor system to foundation
Raised Floor – Foundation	Reinforced concrete masonry or cast-in-place piers or continuous foundation wall designed by engineer to local code	Reinforced concrete masonry or cast-in-place piers or continuous foundation wall designed by engineer to local code	Reinforced concrete masonry or cast-in-place piers or continuous foundation wall designed by engineer to local code
Raised Floor – Footings	Reinforced concrete footings sized and designed by engineer based on local soil conditions	Reinforced concrete footings sized and designed by engineer based on local soil conditions	Reinforced concrete footings sized and designed by engineer based on local soil conditions
Raised Floor – Underside		Batt insulation covered with vapor barrier attached with button caps	Exposed concrete or fiber cement panels over ICF form foam
Slab-on-grade – Connection	Anchor bolts into bottom plate, 1/2" "J" bolts 48" O.C., plus 1 "J" bolt within 12" of corners	Vertical steel reinforcement dowels extending from foundation into concrete exterior wall supported above	Vertical steel reinforcement dowels extending from foundation into concrete exterior wall supported above
Slab-on-grade	Reinforced slab and grade beams sized and designed by engineer	Reinforced slab and grade beams sized and designed by engineer	Reinforced slab and grade beams sized and designed by engineer

Supplemental Information – Floors & Foundations

CONCRETE FLOOR SYSTEMS

Concrete floor systems have been popular for use in multi-family and commercial construction for a very long time. Today, similar systems derived from these larger scale projects are now available for use in one- and two-family dwellings. There are three types of concrete floor systems most

typically used in housing: precast planks, conventionally formed, and insulating concrete form floor systems. Composite steel joist and concrete or steel deck and concrete systems are also available, but they are beyond the scope of this publication.

PRECAST CONCRETE FLOOR PLANKS

Precast concrete floor planks are pre-ordered from a local precast producer, and typically cast offsite. They arrive at the site formed to length and already reinforced. Cranes set them into position, allowing for floor decks to be in place in only several hours. There is literally no site waste. These become particularly economical when combined with precast wall systems permitting floors and walls to be erected with one visit of a

crane. They can also be supported by other types of concrete wall systems. The planks can have hollow cores that can function as utility chases for some ductwork, plumbing, and electrical wiring. Finish coatings are typically installed directly to the underside of the planks, or final finishes are installed over furring strips secured to the bottom of the assembly.

CONVENTIONALLY FORMED CONCRETE FLOORS

Formwork similar to the removable forming used for wall construction can be assembled to allow for the construction of reinforced concrete floors. Very often the walls and floors are cast at the same time. Once the concrete has cured adequately to allow the floors to support themselves, the formwork and supporting shoring can be removed.

Again, there is minimal waste. The forms are designed to be used multiple times and are particularly economical on projects with a series of similar houses. Spans are determined by the thickness of the slab and reinforcement design. Electrical conduit can be installed to permit electrical systems to run within the slabs.

INSULATING CONCRETE FLOOR FORMING

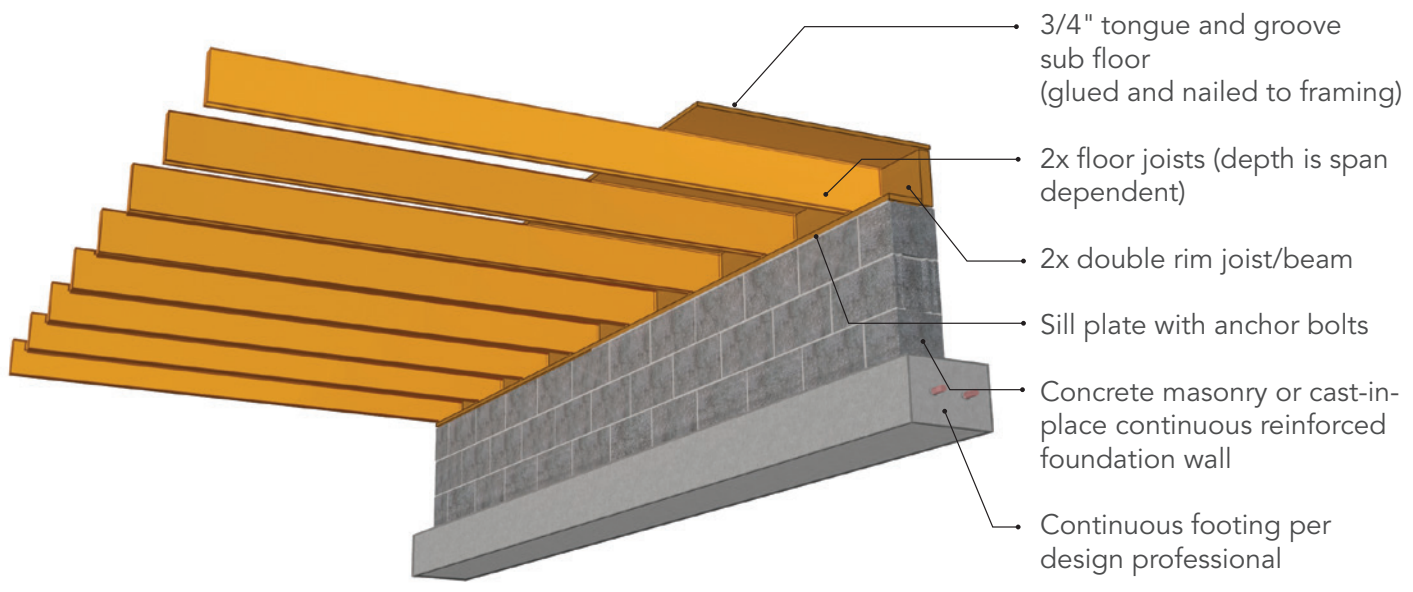
Like all other concrete floor systems, insulating concrete form, or ICF, floor forming systems can be supported by all of the popular concrete wall assembles. They feature polystyrene foam, designed to form up the underside of the concrete floor and remain in place after the pour, just like ICF wall systems. The systems typically have steel rails or channels that help support the forms during concrete placement. Shoring is installed to support the system when concrete is placed, and then removed when the floor can support itself. Finishes can typically be fastened to the integral support channels to complete the installation. Utilities can be cut into the foam after concrete is placed.

All concrete floor systems offer exceptional durability and fire resistance. They are also more dimensionally stable and are far less likely to be impacted by rot, rust, or insects. These systems provide thermal mass for improved energy efficiency which can be enhanced even more when combined with radiant heat systems. Concrete also provides a more effective sound barrier between floors. Longer spans than conventional framing allow for creation of more open spaces. All of these systems typically prefabricated or assembled with removable forms on site to greatly reduce site waste. Finally, from a resilience perspective, these assemblies create a strong and rigid diaphragm, transferring lateral loading extremely well.



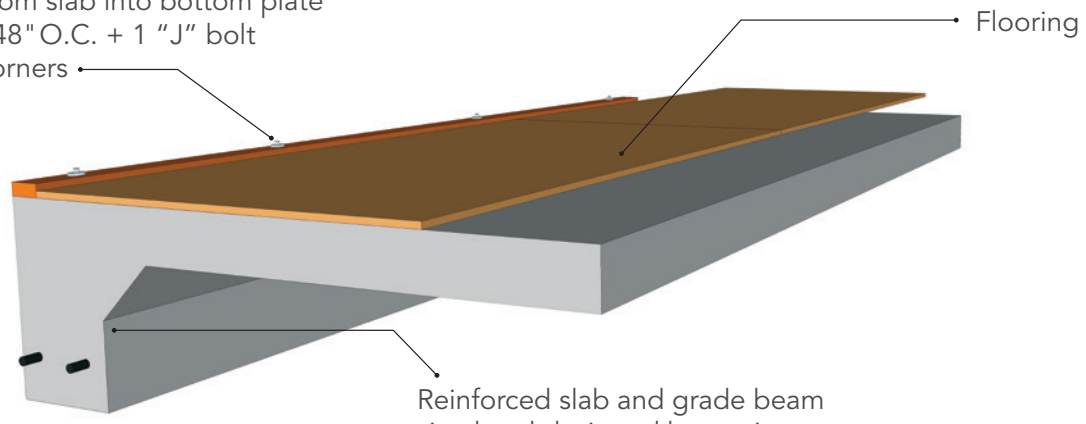
Code Compliant Conventional Construction

Typical Components



\$\$\$ 🛠️ Raised Floor

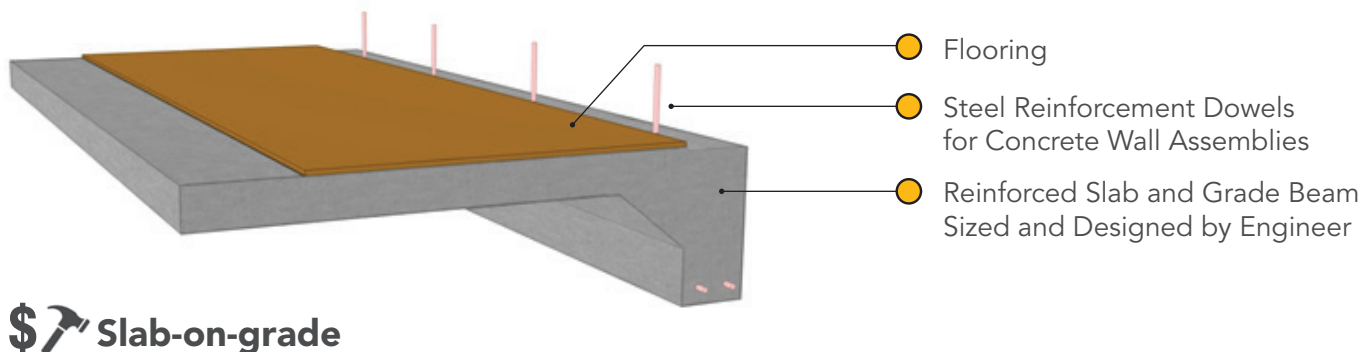
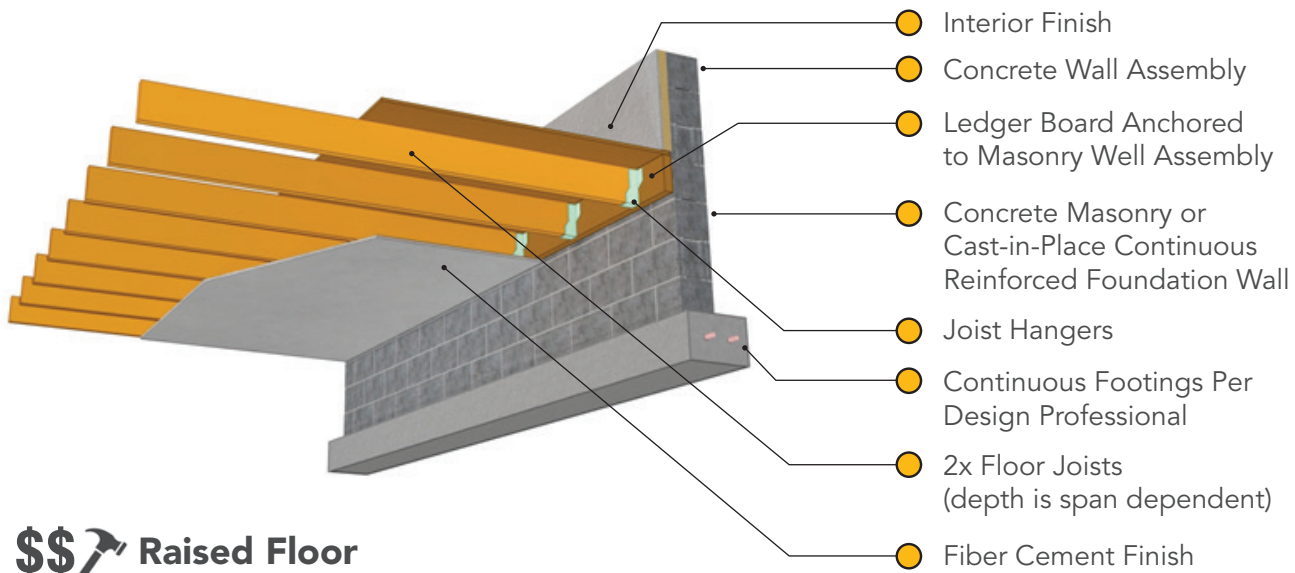
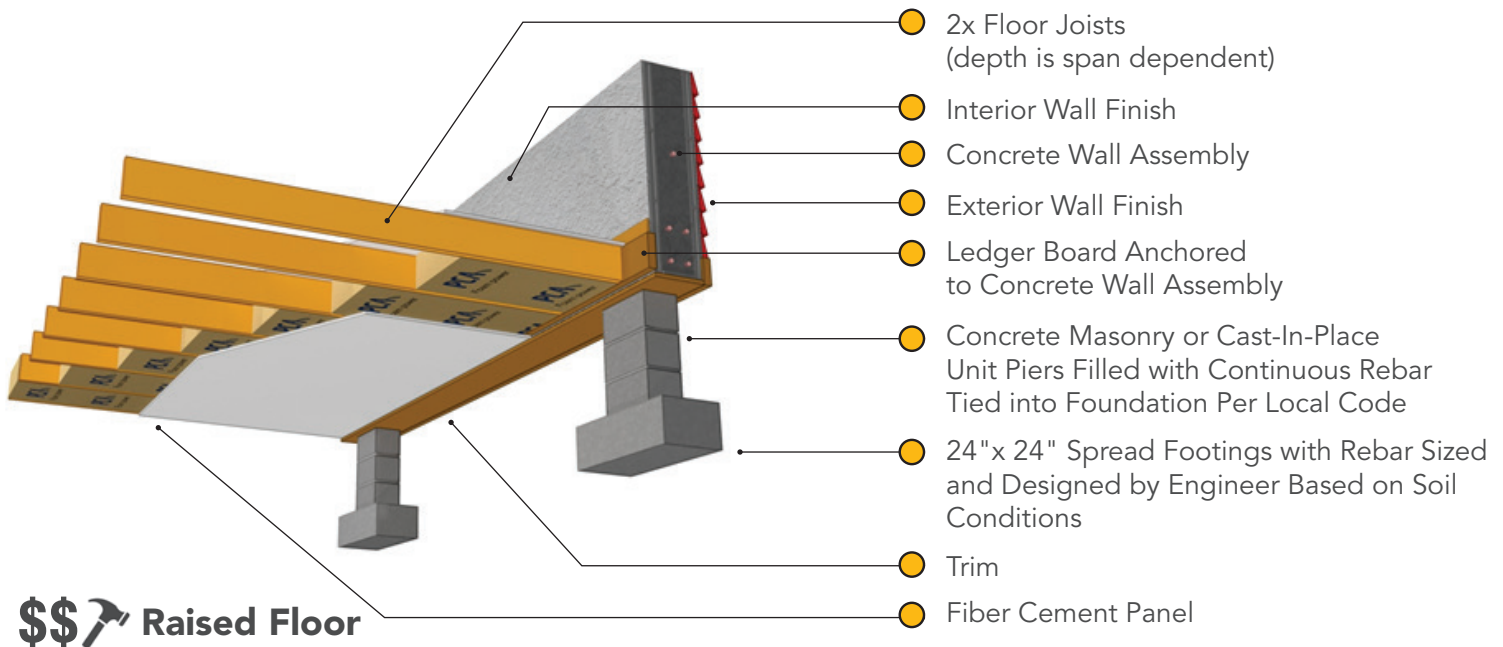
Anchor bolts from slab into bottom plate
 1/2" "J" bolts 48" O.C. + 1 "J" bolt within 12" of corners



\$ 🛠️ Slab-on-grade

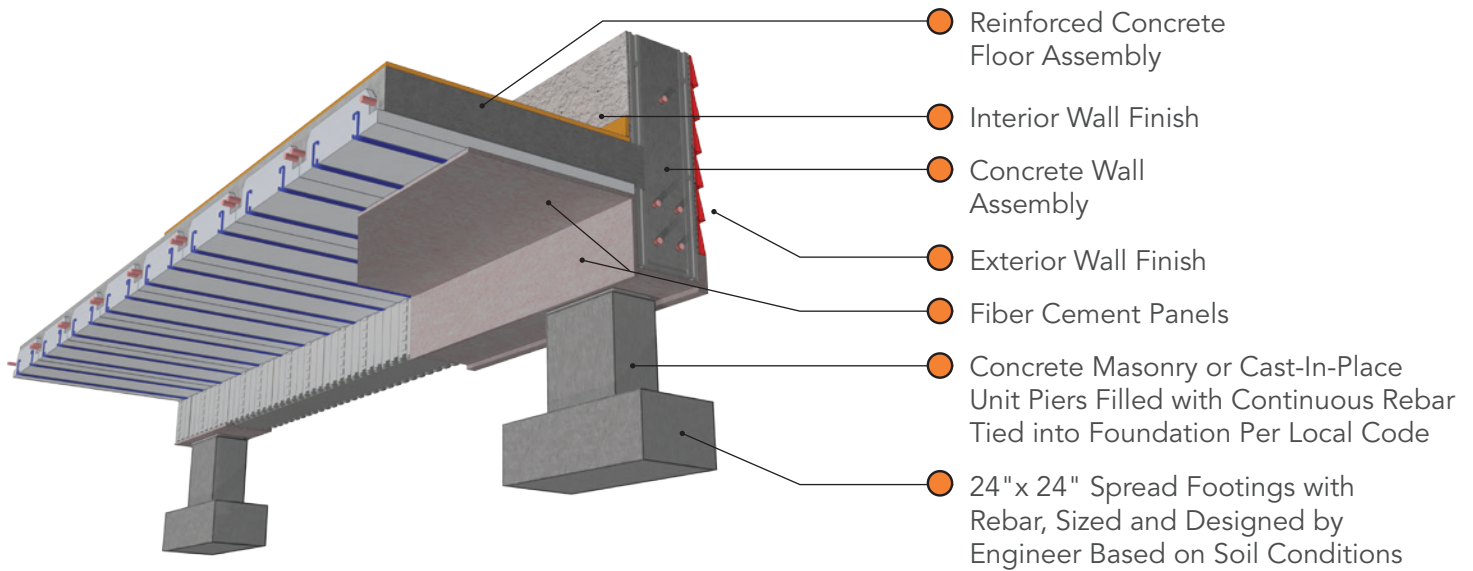
Higher Local Hazard Construction

Generally required by beyond-code programs

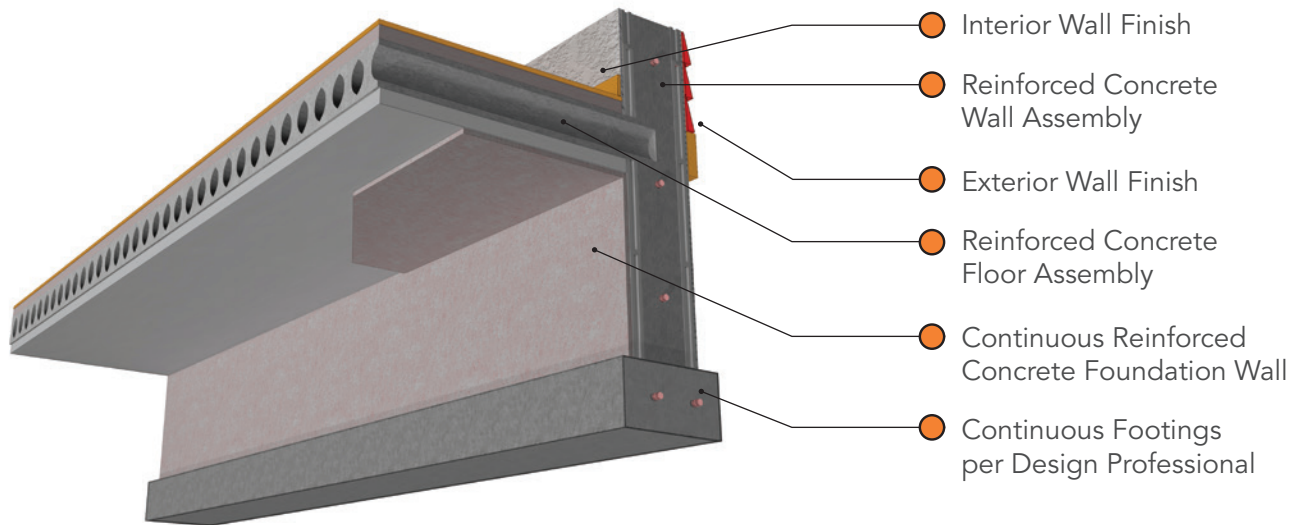


Resilient Construction

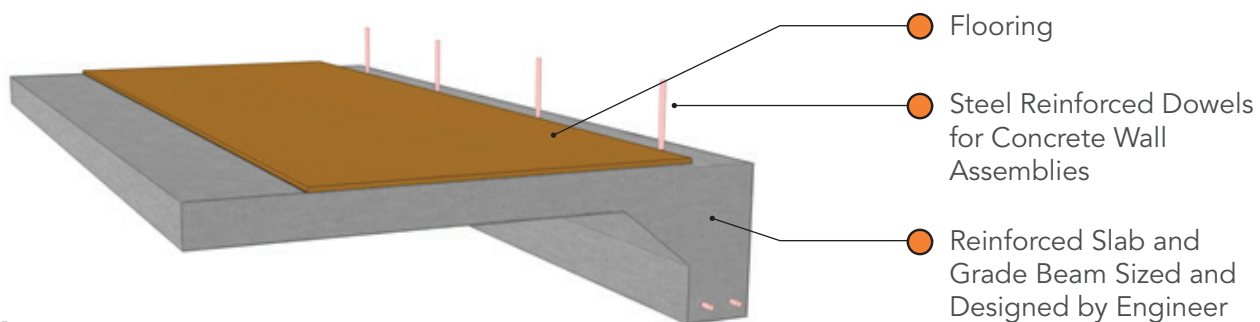
Reduces the damaging effects of a storm



\$\$\$ Raised Floor



\$\$\$ Raised Floor



\$ Slab-on-grade

Resilient Landscape

HAZARDS

Falling trees account for most of the major wind damage to houses in hurricanes. In storms like Hurricane Katrina with wind speed more than 120 mph, approximately 20% of the urban trees toppled. In Hurricane Andrew, 38% of the affected trees toppled. Beyond wind intensity, other storm factors influencing tree damage include:

- Amount and duration of rain
- Tree species, age and condition
- Soil characteristics

Even though it is not possible to build a home strong enough to withstand the impact of a



large tree, it is possible to plan and maintain landscapes that reduce the risk of trees falling on a home. Certain species are more vulnerable to wind damage such as various southern pine, pecan, red oak and water oak. Moreover, as every tree has an inherent life span, older trees of species with shorter life spans are most susceptible to storm damage.

LANDSCAPING

Trees benefit homeowners by beautifying the yard, attracting songbirds, providing protection from wind and noise and by shading the yard and home. However, falling trees and limbs are often the source of storm damage to homes. Three factors regarding trees should be considered: condition, location and species. Limbs on healthy trees that hang over the roof should be trimmed

back and any unhealthy or unstable trees should be removed.

In addition to trees, a resilient landscape takes into account manmade elements that might cause damage from wind such as fences, flag poles, lawn furniture and light fixtures. These elements, as well as building components such as gutters, downspouts and exterior air conditioning equipment, should be secured.

AUXILIARY STRUCTURES Gazebos, Pavilions, Pergolas

Outdoor covered structures are usually supported by horizontal beam members sitting on vertical columns which must be

correctly connected to the foundation to prevent uplift and wind damage.

RESILIENT HOME SYSTEMS Standby Generators

The most common result of wind storms is loss of electrical power due to trees and limbs falling on power lines. Ideally, electrical services are run underground as this reduces risk of power outages; and communities benefit from these types of efforts to invest in more resilient power infrastructure. For the individual homeowner, loss of electrical power is not only inconvenient in hot climates, but the lack of air conditioning allows mold growth inside the home. In cold locations, lack of heat can lead to frozen pipes and water damage. A resilient home is prepared for loss of power with good natural ventilation and a standby generator to provide power for a minimal amount of air conditioning and interior finishes that don't support mold growth.

Loss of electrical power in a neighborhood can also affect the water and sewage system. Sewage check valves and back flow preventers can be used on homes to guard against contamination from systems that might not operate normally after a disaster.

Placement Details

Install the generator set:

- Outdoors
- Near the incoming gas service
- Near the main electrical panel(s)
- On a flat, level mounting area

IMPORTANT PLACEMENT GUIDELINES

- The recommended distance from a structure is dependent on state and local codes.
- Locate the generator set so that the hot exhaust does not blow on plants or other combustible materials. No plants, shrubs, or other combustible materials are allowed within 1.2 m (4 ft.) of the exhaust end of the generator set.
- Do not install the generator set where exhaust gas could accumulate and seep inside or be drawn into a potentially occupied building. Furnace and other similar intakes must be at least 3 m (10 ft.) from the exhaust end of the generator set.
- Do not locate the generator set near patios, decks, play areas, or animal shelters.
- Do not install the composite mounting pad directly on grass, wood, or other combustible materials. Clear all combustible materials, including plants and shrubs, building materials, and lawn furniture, from an area at least 1.2 m (4 ft.) beyond the exhaust end of the generator.
- In flood hazard areas, locate the generator and its control systems above the highest expected flood level
- In high wind areas, the generator should be securely mounted to a concrete pad according to the mounting instructions in the installation manual.

Additional Information & Resources

Roof

Spray Foam

When applied to the underside of the roof deck, closed-cell spray polyurethane foam insulation has various characteristics to provide a sealed roof deck and secondary water barrier performance.

Properly applied spray foam can be considered as an impermeable insulation. Controlled air permeability helps to prevent and control bulk water entry which

create a sealed roof deck. Spray foam can also be considered a water/secondary resistive barrier and provides support against wind uplift and racking.

For resilient construction consider applying a 3" minimum full insulating layer between roof rafters/trusses.

For more information and product resources please visit:
www.flash.org/basf/rdghouse.pdf

Metal Roofing Options

For further information on the different types of metal roofing systems visit:

www.facilitiesnet.com/roofing/article/Metal-Roofs-Compare-the-Different-Systems--9806#

www.unioncorrugating.com/all_products.html

www.metalroofing.com/v2/content/metal-roofing/index.cfm?

www.metalroofing.com/v2/content/guide/types/

Walls

Connectors and Straps

For information how to choose metal connectors and fasteners, visit: www.strongtie.com

Alternate Construction Methods

This guide focuses on standard wood frame construction methods. For more information about alternative construction methods such as masonry, steel frame, factory-assembled or panelized construction systems, visit:

LTH Steel Structures

www.lthsteelstructures.com/building-types/steel-framing-kits-custom-homes

National Association of Home Builders

www.nahb.org

Manufacturers Home Institute

www.manufacturedhousing.org

Structural Insulated Panel Association

www.sips.org

Residential Advantage Building Systems

www.resadvan.com

Insulating Concrete Form Association (ICFA)

www.forms.org

National Concrete Masonry Association (NCMA)

www.ncma.org

Precast/Prestressed Concrete Institute (PCI)

www.pci.org

Additional Information & Resources

Floors and Foundation

Engineered Floor Framing Systems

For more information about engineered floor framing systems visit:

www.buildgp.com/engineered-lumber

Concrete and Rebar

For further information about concrete construction and to find out more about alternative construction methods using concrete please visit:

Portland Cement Association (PCA)
www.cement.org

Concrete Reinforcing Steel Institute
www.crsi.org

Site

Auxiliary Structures

These covered structures are usually supported by horizontal beam members sitting on vertical columns, which must be correctly connected to the foundation to prevent uplift and wind damage.

Standby Power Generation

For more information visit:
www.kohlergenerators.com

References

Home Builders Guide to Coastal Construction

Technical Fact Sheet Series

FEMA P-499 / December 2012

www.fema.gov/media-library/assets/documents/6131

Hurricane Katrina in the Gulf Coast:

Building Performance Observations, Recommendations, and Technical Guidance

Mitigation Assessment Team Report

FEMA 549 / July 2006

www.fema.gov/media-library/assets/documents/4069

PCA 100 - 2012

Prescriptive Design of Exterior Concrete Walls For One- and Two-Family Dwellings

EB 562 / January 2012

www.cement.org

Thank You

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