# PRESCRIPTIVE METHOD FOR INSULATING CONCRETE FORMS IN RESIDENTIAL CONSTRUCTION

**Second Edition (Revised)**

Prepared for

U.S. Department of Housing and Urban Development
Office of Policy Development and Research
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and

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# Foreword

In the past several years the U.S. Department of Housing and Urban Development (HUD) has focused on a variety of innovative building materials and systems for use in residential construction. HUD's efforts have addressed barriers to innovations and promoted education of home builders, home buyers, code officials, and design professionals. Key issues include building material or system limitations, advantages, availability, technical guidelines, and installed cost. Efforts on these issues have fostered the development, acceptance, and implementation of innovative construction technologies by the home building industry. Innovative design and construction approaches using wood, steel, and concrete materials have thus far been addressed as viable alternatives to conventional residential construction methods and materials.

Insulating Concrete Forms (ICFs) represent a category of building product that is receiving greater attention among builders. ICFs are hollow blocks, planks, or panels that can be constructed of rigid foam plastic insulation, a composite of cement and foam insulation, a composite of cement and wood chips, or other suitable insulation material that has the ability to act as forms for cast-in-place concrete walls. The forms typically remain in place after the concrete has cured, providing well-insulated construction. ICFs continue to gain popularity because they are competitive with light-frame construction and offer a strong, durable, and energy-efficient wall system for housing.

The first edition of the Prescriptive Method for Insulating Concrete Forms in Residential Construction represented the outcome of an initial effort to fulfill the need for prescriptive construction requirements and to improve the overall affordability of homes constructed with insulating concrete forms. The first edition also served as the source document for building code provisions in the International Residential Code (IRC).

The second edition expands on the first edition by adding provisions for Seismic Design Categories C and D (Seismic Zones 3 and 4). Wall construction requirements utilizing Grade 60 reinforcing steel and concrete mixes with selected compressive strengths are included. In addition, tables throughout the document have been simplified as a result of additional evaluation and user input.

We believe that providing this type of information to the home building industry promotes healthy competition, helps to define optimal use of our nation's natural resources, and enhances housing affordability.

Lawrence L. Thompson
General Deputy Assistant Secretary for
Policy Development and Research

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# Table of Contents

## PART II - COMMENTARY

**ERRATA: Cumulative updates and errata to this document can be found at www.cement.org/EB118.02**

# LIST OF TABLES

## PART I - PRESCRIPTIVE METHOD

## PART II - COMMENTARY



## APPENDIX A: ILLUSTRATIVE EXAMPLE

# LIST OF FIGURES

## PART I - PRESCRIPTIVE METHOD



## APPENDIX A: ILLUSTRATIVE EXAMPLE



## APPENDIX B: ENGINEERING TECHNICAL SUBSTANTIATION

# EXECUTIVE SUMMARY

The Prescriptive Method for Insulating Concrete Forms in Residential Construction was developed as a guideline for the construction of one- and two-family residential dwellings using insulating concrete form (ICF) systems. It provides a prescriptive method for the design, construction, and inspection of homes that take advantage of ICF technology. This document standardizes the minimum requirements for basic ICF systems and provides an identification system for the different types of ICFs. It specifically includes minimum wall thickness tables, reinforcement tables, lintel span tables, percentage of solid wall length, and connection requirements. The requirements are supplemented with appropriate construction details in an easy-to-read format. The provisions, including updated engineering calculations, are consistent with the latest U.S. building codes, engineering standards, and industry specifications.

This second edition includes improvements upon the previous edition in the following areas:

- Improved lintel reinforcement and span tables.
- Expanded provisions covering high seismic hazard areas, specifically Seismic Design Category D (Seismic Zones 3 and 4).
- Inclusion of conversions between fastest-mile wind speeds and newer 3-second gust wind speeds.
- Expanded provisions recognizing 3,000 psi and 4,000 psi concrete compressive strengths and Grade 60 steel reinforcement.
- New connection details.
- New table formatting for above-grade walls and required solid wall length to resist wind and seismic lateral loads.

This document is divided into two parts.

I. Prescriptive Method

The Prescriptive Method is a guideline to facilitate the use of ICF wall systems in the construction of one- and two-family dwellings. The provisions in this document were developed by applying accepted engineering practices and practical construction techniques; however, users of the document should verify its compliance with local building code requirements.

II. Commentary

The Commentary facilitates the use of the Prescriptive Method by providing the necessary background, supplemental information, and engineering data for the Prescriptive Method. The individual sections, figures, and tables are presented in the same sequence as in the Prescriptive Method.

Three appendices are also provided. Appendix A contains a design example illustrating the proper application of the Prescriptive Method for a typical home. Appendix B contains the engineering calculations used to generate the wall, lintel, percentage of solid wall length, and connection tables in the Prescriptive Method. Appendix C provides the conversion relationship between U.S. customary units and the International System (SI) units. A complete guide to the SI system and its use can be found in ASTM E 380 [1].

# PART I

# PRESCRIPTIVE METHOD

# INTRODUCTION

The Prescriptive Method is a guideline to facilitate the use of ICF wall systems in the construction of one- and two-family dwellings. By providing a prescriptive method for the construction of typical homes with ICF systems, the need for engineering can be eliminated in most applications. The provisions in this document were developed by applying accepted engineering practices and practical construction techniques. The provisions in this document comply with the loading requirements of the most recent U.S. model building codes at the time of publication. However, users of this document should verify compliance of the provisions with local building code requirements. The user is strongly encouraged to refer to Appendix A before applying the Prescriptive Method to a specific house design.

This document is not a regulatory instrument, although it is written for that purpose. The user should refer to applicable building code requirements when exceeding the limitations of this document, when requirements conflict with the building code, or when an engineered design is specified. This document is not intended to limit the appropriate use of concrete construction not specifically prescribed. This document is also not intended to restrict the use of sound judgement or engineering analysis of specific applications that may result in designs with improved performance and economy.

# 1.0 GENERAL

## 1.1 Purpose

This document provides prescriptive requirements for the use of insulating concrete form systems in the construction of residential structures. Included are definitions, limitations of applicability, below-grade and above-grade wall design tables, lintel tables, various construction and thermal guidelines, and other related information for home builders, building code officials, and design professionals.

## 1.2 Approach

The prescriptive requirements are based primarily on the Building Code Requirements for Structural Concrete (ACI 318-99) [2] and the Structural Design of Insulating Concrete Form Walls in Residential Construction [3] for member strength and reinforcement requirements. The requirements are also based on Minimum Design Loads for Buildings and Other Structures (ASCE 7-98) [4], the International Building Code [5], and the International Residential Code [6]. In addition, the requirements incorporate construction practices from the Guide to Residential Cast-in-Place Concrete Construction [7]. The engineering calculations that form the basis for this document are discussed in Appendix B, Engineering Technical Substantiation.

The provisions represent sound engineering and construction practice, taking into account the need for practical and affordable construction techniques for residential buildings. This document is not intended to restrict the use of sound judgment or exact engineering analysis of specific applications that may result in improved designs.

## 1.3 Scope

The provisions of the Prescriptive Method apply to the construction of detached one- and two-family homes, townhouses, and other attached single-family dwellings in compliance with the general limitations of Table 1.1. The limitations are intended to define the appropriate use of this document for most one- and two-family dwellings. An engineered design shall be required for houses built along the immediate, hurricane-prone coastline subjected to storm surge (i.e., beach front property) or in near-fault seismic hazard conditions (i.e., Seismic Design Category E). Intermixing of ICF systems with other construction materials in a single structure shall be in accordance with the applicable building code requirements for that material, the general limitations set forth in Table 1.1, and relevant provisions of this document. An engineered design shall be required for applications that do not meet the limitations of Table 1.1.

The provisions of the Prescriptive Method shall not apply to irregular structures or portions of structures in Seismic Design Categories C, D1, and D2. Only such irregular portions of structures shall be designed in accordance with accepted engineering practice to the extent such irregular features affect the performance of the structure. A portion of the building shall be considered to be irregular when one or more of the following conditions occur:

- When exterior shear wall lines are not in one plane vertically from the foundation to the uppermost story in which they are required.
- When a section of floor or roof is not laterally supported by shear walls on all edges.

- When an opening in the floor or roof exceeds the lesser of 12 ft (3.7 m) or 50 percent of the least floor dimension.
- When portions of a floor level are vertically offset.
- When shear walls (i.e., exterior ICF walls) do not occur in two perpendicular directions.
- When shear walls are constructed of dissimilar systems on any one-story level.

For townhouses in Seismic Design Category C and all buildings in Seismic Design Category D, the provisions of this section shall only apply to buildings meeting the following requirements.

1. Rectangular buildings with a maximum building aspect ratio of 2:1. The building aspect ratio shall be determined by dividing the longest dimension of the building by the shortest dimension of the building.
2. Walls are aligned vertically with the walls below.
3. Cantilever and setback construction shall not be permitted.
4. The weight of interior and exterior finishes applied to ICF walls shall not exceed 8 psf (0.38 kN/m2).
5. The gable portion of ICF walls shall be constructed of light-frame construction.

### 1.4 ICF System Limitations

There are three categories of ICF systems based on the resulting shape of the formed concrete wall. The shape of the concrete wall may be better understood by visualizing the form stripped away from the concrete, thereby exposing it to view as shown in Figure 1.1. The three categories of ICF wall types covered in this document are (1) flat, (2) waffle-grid, and (3) screen-grid.

The provisions of this document shall be used for concrete walls constructed with flat, waffle-grid, or screen-grid ICF systems as shown in Figure 1.1, defined in Section 1.5, and in accordance with the limitations of Section 2.0. Other systems, such as post-and-beam, shall be permitted with an approved design and in accordance with the manufacturer's recommendations.

## TABLE 1.1
## APPLICABILITY LIMITS

| ATTRIBUTE | MAXIMUM LIMITATION |
|---|---|
| **General** | |
| Number of Stories | 2 stories above grade plus a basement |
| Design Wind Speed | 150 mph (241 km/hr) 3-second gust (130 mph (209 km/hr) fastest-mile) |
| Ground Snow Load | 70 psf (3.4 kPa) |
| Seismic Design Category | A, B, C, D1, and D2 (Seismic Zones 0, 1, 2, 3, and 4) |
| **Foundations** | |
| Unbalanced Backfill Height | 9 feet (2.7 m) |
| Equivalent Fluid Density of Soil | 60 pcf (960 kg/m3) |
| Presumptive Soil Bearing Value | 2,000 psf (96 kPa) |
| **Walls** | |
| Unit Weight of Concrete | 150 pcf (23.6 kN/m3) |
| Wall Height (unsupported) | 10 feet (3 m) |
| **Floors** | |
| Floor Dead Load | 15 psf (0.72 kPa) |
| First-Floor Live Load | 40 psf (1.9 kPa) |
| Second-Floor Live Load (sleeping rooms) | 30 psf (1.4 kPa) |
| Floor Clear Span (unsupported) | 32 feet (9.8 m) |
| **Roofs** | |
| Maximum Roof Slope | 12:12 |
| Roof and Ceiling Dead Load | 15 psf (0.72 kPa) |
| Roof Live Load (ground snow load) | 70 psf (3.4 kPa) |
| Attic Live Load | 20 psf (0.96 kPa) |
| Roof Clear Span (unsupported) | 40 feet (12 m) |

For SI: 1 foot = 0.3048 m; 1 psf = 47.8804 Pa; 1 pcf = 157.0877 N/m3 = 16.0179 kg/m3; 1 mph = 1.6093 km/hr

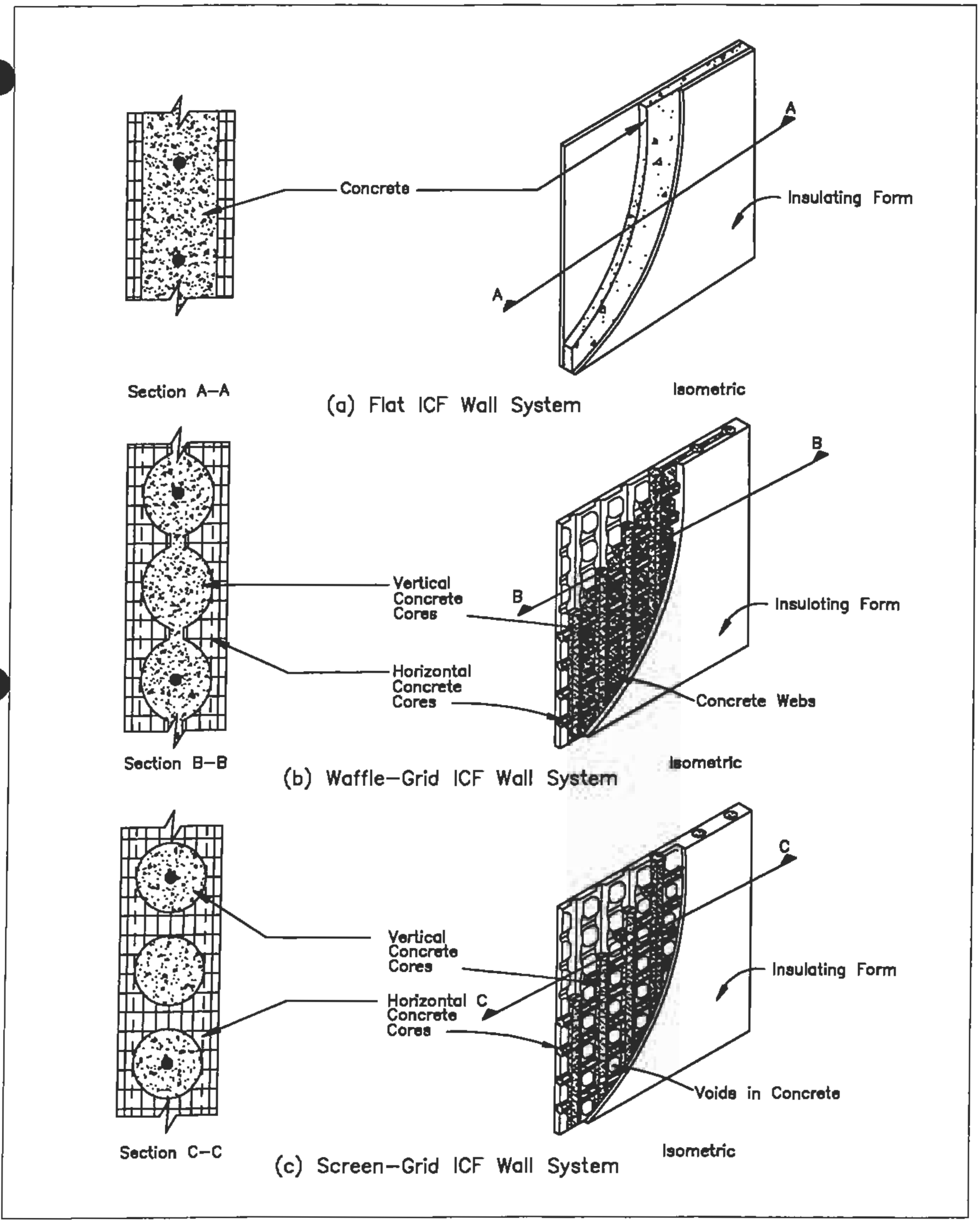



Figure 1.1 - ICF Wall Systems Covered by this Document

## 1.5 Definitions

*Accepted Engineering Practice:* An engineering approach that conforms with accepted principles, tests, technical standards, and sound judgment.

*Anchor Bolt:* A J-bolt or L-bolt, headed or threaded, used to connect a structural member of different material to a concrete member.

*Approved:* Acceptable to the building official or other authority having jurisdiction. A rational design by a competent design professional shall constitute grounds for approval.

*Attic:* The enclosed space between the ceiling joists of the top-most floor and the roof rafters of a building, not intended for occupancy but sometimes used for storage.

*Authority Having Jurisdiction:* The organization, political subdivision, office, or individual charged with the responsibility of administering and enforcing the provisions of applicable building codes.

*Backfill:* The soil that is placed adjacent to completed portions of a below-grade structure (i.e., basement) with suitable compaction and allowance for settlement.

*Basement:* That portion of a building that is partly or completely below grade and which may be used as habitable space.

*Bond Beam:* A continuous horizontal concrete element with steel reinforcement located in the exterior walls of a structure to tie the structure together and distribute loads.

*Buck:* A frame constructed of wood, plastic, vinyl, or other suitable material set in a concrete wall opening that provides a suitable surface for fastening a window or door frame.

*Building:* Any one- or two-family dwelling or portion thereof that is used for human habitation.

*Building Length:* The dimension of a building that is perpendicular to roof rafters, roof trusses, or floor joists (L).

*Building Width:* The dimension of a building that is parallel to roof rafters, roof trusses, or floor joists (W).

*Construction joint:* A joint or discontinuity resulting from concrete cast against concrete that has already set or cured.

*Compressive Strength:* The ability of concrete to resist a compressive load, usually measured in pounds per square inch (psi) or Mega Pascals (MPa). The compressive strength is based on compression tests of concrete cylinders that are moist-cured for 28 days in accordance with ASTM C 31 [8] and ASTM C 39 [9].

*Crawlspace:* A type of building foundation that uses a perimeter foundation wall to create an under floor space which is not habitable.

*Dead Load:* Forces resulting from the weight of walls, partitions, framing, floors, ceilings, roofs, and all other permanent construction entering into, and becoming part of, a building.

*Deflection:* Elastic movement of a loaded structural member or assembly (i.e., beam or wall).

*Design Professional:* An individual who is registered or licensed to practice their respective design profession as defined by the statutory requirements of the professional registration laws of the state or jurisdiction in which the project is to be constructed.

*Design (or Basic) Wind Speed:* Related to winds that are expected to be exceeded once every 50 years at a given site (i.e., 50-year return period). Wind speeds in this document are given in units of miles per hour (mph) by 3-second gust measurements in accordance with ASCE 7 [4].

*Dwelling:* Any building that contains one or two dwelling units.

*Eccentric Load:* A force imposed on a structural member at some point other than its center-line, such as the forces transmitted from the floor joists to wall through a ledger board connection.

*Enclosure Classifications:* Used for the purpose of determining internal wind pressure. Buildings are classified as partially enclosed or enclosed as defined in ASCE 7 [4].

*Equivalent Fluid Density:* The mass of a soil per unit volume treated as a fluid mass for the purpose of determining lateral design loads produced by the soil on an adjacent structure such as a basement wall. Refer to the Commentary for suggestions on relating equivalent fluid density to soil type.

*Exposure Categories:* Reflects the effect of the ground surface roughness on wind loads in accordance with ASCE 7 [4]. Exposure Category B includes urban and suburban areas, or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger. Exposure Category C includes open terrain with scattered obstructions having heights generally less than 30 ft (9.1 m) and shorelines in hurricane-prone regions. Exposure D includes open exposure to large bodies of water in non-hurricane-prone regions.

*Flame-Spread Rating:* The combustibility of a material that contributes to fire impact through flame spread over its surface; refer to ASTM E 84 [10].

*Flat Wall:* A solid concrete wall of uniform thickness produced by ICFs or other forming systems; refer to Figure 1.1.

*Floor Joist:* A horizontal structural framing member that supports floor loads.

*Footing:* A below-grade foundation component that transmits loads directly to the underlying earth.

*Form Tie:* The element of an ICF system that holds both sides of the form together. Form ties can be steel, solid plastic, foam plastic, a composite of cement and wood chips, a composite of cement and foam plastic, or other suitable material capable of resisting the loads created by wet concrete. Form ties remain permanently embedded in the concrete wall.

*Foundation:* The structural elements through which the load of a structure is transmitted directly to the earth.

*Foundation Wall:* The structural element of a foundation that resists lateral earth pressure, if any, and transmits the load of a structure to the earth; includes basement, stem, and crawlspace walls.

*Grade:* The finished ground level adjoining the building at all exterior walls.

*Grade Plane:* A reference plane representing the average of the finished ground level adjoining the building at all exterior walls.

*Ground Snow Load:* Measured load on the ground due to snow accumulation developed from a statistical analysis of weather records expected to be exceeded once every 50 years at a given site.

*Horizontal Reinforcement:* Steel reinforcement placed horizontally in concrete walls to provide resistance to temperature and shrinkage cracking. Horizontal reinforcement is required for additional strength around openings and in high loading conditions such as experienced in hurricanes and earthquakes.

*Insulating Concrete Forms (ICFs):* A concrete forming system using stay-in-place forms of foam plastic insulation, a composite of cement and foam insulation, a composite of cement and wood chips, or other insulating material for constructing cast-in-place concrete walls. Some systems are designed to have one or both faces of the form removed after construction.

*Interpolation:* A mathematical process used to compute an intermediate value of a quantity between two given values, assuming a linear relationship.

*Lap Splice:* Formed by extending reinforcement bars past each other a specified distance to permit the force in one bar to be transferred by bond stress through the concrete and into the second bar. Permitted when the length of one continuous reinforcement bar is not practical for placement.

*Lateral Load:* A horizontal force, created by earth, wind, or earthquake, acting on a structure or its components.

*Lateral Support:* A horizontal member providing stability to a column or wall across its smallest dimension. Walls designed in accordance with Section 5.0 provide lateral stability to the whole building when experiencing wind or earthquake events.

*Ledger:* A horizontal structural member fastened to a wall to serve as a connection point for other structural members, typically floor joists.

*Lintel:* A horizontal structural element of reinforced concrete located above an opening in a wall to support the construction above.

*Live Load:* Any gravity vertical load that is not permanently applied to a structure; typically transient and sustained gravity forces resulting from the weight of people and furnishings, respectively.

*Load-Bearing Value of Soil:* The allowable load per surface area of soil. It is usually expressed in pounds per square foot (psf) or Pascals (Pa).

*Post-and-Beam Wall:* A perforated concrete wall with widely spaced (greater than that required for screen-grid walls) vertical and horizontal concrete members (cores) with voids in the concrete between the cores created by the ICF form. The post-and-beam wall resembles a concrete frame rather than a monolithic concrete (i.e., flat, waffle-grid, or screen-grid) wall and requires a different engineering analysis per ACI 318 [2]; therefore, it is not addressed in this edition of the Prescriptive Method.

*Presumptive:* Formation of a judgment on probable grounds until further evidence is received.

*R-Value:* Coefficient of thermal resistance. A standard measure of the resistance that a material offers to the flow of heat; it is expressed as .

*Roof Snow Load:* Uniform load on the roof due to snow accumulation; typically 70 % to 80 % of the ground snow load in accordance with ASCE 7 [4].

*Screen-Grid Wall:* A perforated concrete wall with closely spaced vertical and horizontal concrete members (cores) with voids in the concrete between the members created by the ICF form; refer to Figure 1.1. It is also called an interrupted-grid wall or post-and-beam wall in other publications.

*Seismic Load:* The force exerted on a building structure resulting from seismic (earthquake) ground motions.

*Seismic Design Categories:* Designated seismic hazard levels associated with a particular level or range of seismic risk and associated seismic design parameters (i.e., spectral response acceleration and building importance). Seismic Design Categories A, B, C, D1, and D2 (Seismic Zones 0, 1, 2, 3, and 4) correspond to successively greater seismic design loads; refer to the IBC [5] and IRC [6].

*Sill Plate:* A horizontal member constructed of wood, vinyl, plastic, or other suitable material that is fastened to the top of a concrete wall, providing a suitable surface for fastening structural members constructed of different materials to the concrete wall.

*Slab-on-Grade:* A concrete floor, which is supported by, or rests on, the soil directly below.

*Slump:* A measure of consistency of freshly mixed concrete equal to the amount that a cone of uncured concrete sags below the mold height after the cone-shaped mold is removed in accordance with ASTM C 143 [11].

*Smoke-Development Rating:* The combustibility of a material that contributes to fire impact through life hazard and property damage by producing smoke and toxic gases; refer to ASTM E 84 [10].

*Span:* The clear horizontal or vertical distance between supports.

*Stem Wall:* A below-grade foundation wall of uniform thickness supported directly by the soil or on a footing. Wall thickness and height are determined as that which can adequately distribute the building loads safely to the earth and resist any lateral load.

*Stirrup:* Steel bars, wires, or welded wire fabric generally located perpendicular to horizontal reinforcement and extending across the depth of the member in concrete beams, lintels, or similar members subject to shear loads in excess of those permitted to be carried by the concrete alone.

*Story:* That portion of the building included between the upper surface of any floor and the upper surface of the floor next above, except that the top-most story shall be that habitable portion of a building included between the upper surface of the top-most floor and the ceiling or roof above.

*Story Above-Grade:* Any story with its finished floor surface entirely above grade except that a basement shall be considered as a story above-grade when the finished surface of the floor above the basement is (a) more than 6 feet (1.8 m) above the grade plane, (b) more than 6 feet (1.8 m) above the finished ground level for more than 50 % of the total building perimeter, or (c) more than 12 feet (3.7 m) above the finished ground level at any point.

*Structural Fill:* An approved, non-cohesive material such as crushed rock or gravel.

*Townhouse:* Single-family dwelling unit constructed in a row of attached units separated by fire walls at property lines and with open space on at least two sides.

*Unbalanced Backfill Height:* Typically the difference between the interior and exterior finish ground level. Where an interior concrete slab is provided, the unbalanced backfill height is the difference in height between the exterior ground level and the interior floor or slab surface of a basement or crawlspace.

*Unsupported Wall Height:* The maximum clear vertical distance between the ground level or finished floor and the finished ceiling or sill plate.

*Vapor Retarder:* A layer of material used to retard the transmission of water vapor through a building wall or floor.

*Vertical Reinforcement:* Steel reinforcement placed vertically in concrete walls to strengthen the wa[ll] against lateral forces and eccentric loads. In certain circumstances, vertical reinforcement is required for additional strength around openings.

*Waffle-Grid Wall:* A solid concrete wall with closely spaced vertical and horizontal concrete members (cores) with a concrete web between the members created by the ICF form; refer to Figure 1.1. The thicker vertical and horizontal concrete cores and the thinner concrete webs create the appearance of a breakfast waffle. It is also called an uninterrupted-grid wall in other publications.

*Web:* A concrete wall segment, a minimum of 2 inches (51 mm) thick, connecting the vertical and horizontal concrete members (cores) of a waffle-grid ICF wall or lintel member. Webs may contain form ties but are not reinforced (i.e., vertical or horizontal reinforcement or stirrups). Refer to Figure 1.1.

*Wind Load:* The force or pressure exerted on a building structure and its components resulting from wind. Wind loads are typically measured in pounds per square foot (psf) or Pascals (Pa).

*Yield Strength:* The ability of steel to withstand a tensile load, usually measured in pounds per square inch (psi) or Mega Pascals (MPa). It is the highest tensile load that a material can resist before permanent deformation occurs as measured by a tensile test in accordance with ASTM A 370 [12].

# 2.0 MATERIALS, SHAPES, AND STANDARD SIZES

## 2.1 Physical Dimensions

Concrete walls constructed with ICF systems in accordance with this document shall comply with the shapes and minimum concrete cross-sectional dimensions required in this section. ICF systems resulting in concrete walls not in compliance with this section shall be used in accordance with the manufacturer's recommendations and as approved.

### 2.1.1 Flat ICF Wall Systems

Flat ICF wall systems shall comply with Figure 2.1 and shall have a minimum concrete thickness of 5.5 inches (140 mm) for basement walls and 3.5 inches (89 mm) for above-grade walls.

### 2.1.2 Waffle-Grid ICF Wall Systems

Waffle-grid ICF wall systems shall have a minimum nominal concrete thickness of 6 inches (152 mm) for the horizontal and vertical concrete members (cores). The actual dimension of the cores and web shall comply with the dimensional requirements of Table 2.1 and Figure 2.2.

### 2.1.3 Screen-Grid ICF Wall System

Screen-grid ICF wall systems shall have a minimum nominal concrete thickness of 6 inches (152 mm) for the horizontal and vertical concrete members (cores). The actual dimensions of the cores shall comply with the dimensional requirements of Table 2.1 and Figure 2.3.

## 2.2 Concrete Materials

### 2.2.1 Concrete Mix

Ready-mixed concrete for ICF walls shall meet the requirements of ASTM C 94 [13]. Maximum slump shall not be greater than 6 inches (152 mm) as determined in accordance with ASTM C 143 [11]. Maximum aggregate size shall not be larger than 3/4 inch (19 mm).

> **Exception:** Maximum slump requirements may be exceeded for approved concrete mixtures resistant to segregation, meeting the concrete compressive strength requirements, and in accordance with the ICF manufacturer's recommendations.

### 2.2.2 Compressive Strength

The minimum specified compressive strength of concrete, fc', shall be 2,500 psi (17.2 MPa) at 28 days as determined in accordance with ASTM C 31 [8] and ASTM C 39 [9]. For Seismic Design Categories D1 and D2, the minimum compressive strength of concrete, fc', shall be 3,000 psi.

### 2.2.3 Reinforcing Steel

Reinforcing steel used in ICFs shall meet the requirements of ASTM A 615 [14], ASTM A 996 [15], or ASTM A 706 [16]. In Seismic Design Categories D1 and D2, reinforcing steel shall meet the requirements of ASTM A706 [16] for low-alloy steel. The minimum yield strength of the reinforcing steel shall be 40,000 psi (Grade 40) (300 MPa) except in Seismic Design Categories D1 and D2, where reinforcing steel shall have minimum yield strength of 60,000 psi (Grade 60) (414 MPa). Reinforcement shall be secured in the proper location in the forms with tie wire or other bar support system such that displacement will not occur during the concrete placement operation. Steel reinforcement shall have a minimum 3/4-inch (19-mm) concrete cover. Horizontal and vertical wall reinforcement shall not vary outside of the middle third of columns, horizontal and vertical cores, and flat walls for all wall sizes. Vertical and horizontal bars in basement walls shall be permitted to be placed no closer than 3/4-inch (19-mm) from the inside face of the wall.

Vertical and horizontal wall reinforcement required in Sections 3.0, 4.0, and 5.0 shall be the longest lengths practical. Where joints occur in vertical and horizontal wall reinforcement, a lap splice shall be provided in accordance with Figure 2.4. Lap splices shall be a minimum of $40d_b$ in length, where $d_b$ is the diameter of the smaller bar. The maximum gap between noncontact parallel bars at a lap splice shall not exceed $8d_b$, where $d_b$ is the diameter of the smaller bar.

## 2.3 Form Materials

Insulating concrete forms shall be constructed of rigid foam plastic meeting the requirements of ASTM C 578 [17], a composite of cement and foam insulation, a composite of cement and wood chips, or other approved material. Forms shall provide sufficient strength to contain concrete during the concrete placement operation. Flame-spread rating of ICF forms that remain in place shall be less than

**TABLE 2.1**
**REQUIREMENTS FOR ICF WALLS[1,2]**

| WALL TYPE and NOMINAL SIZE | MAXIMUM WALL WEIGHT[3] | MINIMUM WIDTH OF VERTICAL CORE inches (mm) | MINIMUM THICKNESS VERTICAL CORE inches (mm) | MAXIMUM SPACING OF OF VERTICAL CORES inches (mm) | MAXIMUM SPACING OF HORIZONTAL CORES inches (mm) | MINIMUM WEB THICKNESS inches (mm) |
|---|---|---|---|---|---|---|
| 3.5″ Flat | 44 | N/A | N/A | N/A | N/A | N/A |
| 5.5″ Flat | 69 | N/A | N/A | N/A | N/A | N/A |
| 7.5″ Flat | 94 | N/A | N/A | N/A | N/A | N/A |
| 9.5″ Flat | 119 | N/A | N/A | N/A | N/A | N/A |
| 6″ Waffle-Grid | 56 | 6.25 (159) | 5 (127) | 12 (305) | 16 (406) | 2 (51) |
| 8″ Waffle-Grid | 76 | 7 (178) | 7 (178) | 12 (305) | 16 (406) | 2 (51) |
| 6″ Screen-Grid | 53 | 5.5 (140) | 5.5 (140) | 12 (305) | 12 (305) | N/A |

For SI: 1 inch = 25.4 mm

[1] For width "W", thickness "T", spacing, and web thickness, refer to Figures 2.2 and 2.3.

[2] N/A indicates not applicable

[3] Wall weight is based on a unit weight of concrete of 150 pcf (23.6kN/m$^3$). The tabulated values do not include any allowance for interior and exterior finishes.

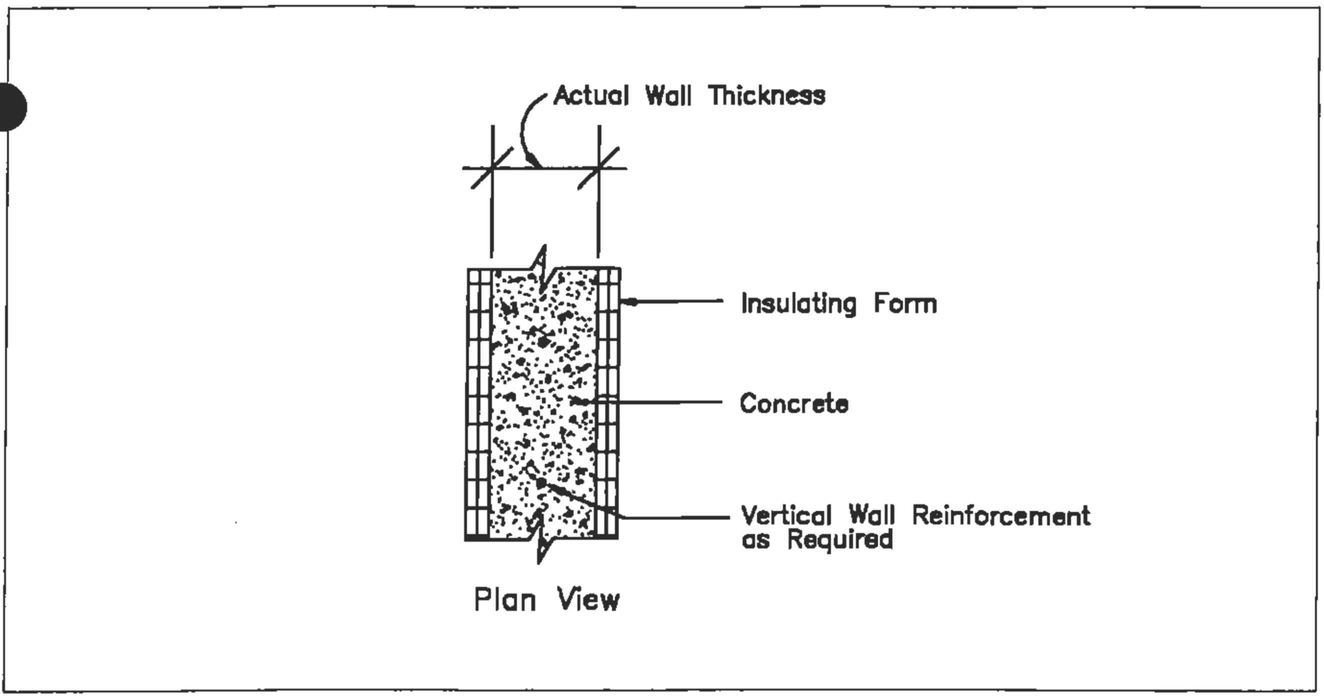



Figure 2.1 Flat ICF Wall System Requirements

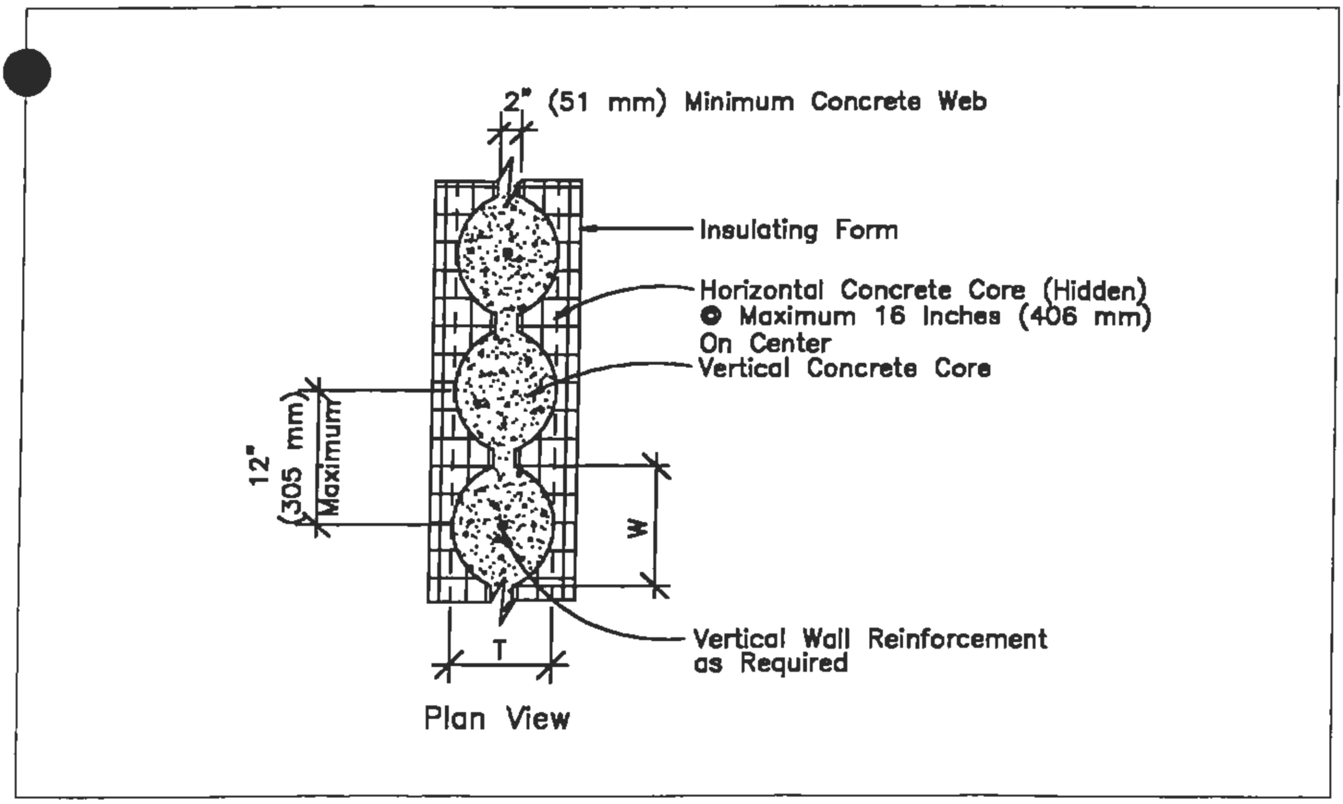



Figure 2.2 Waffle-Grid ICF Wall System Requirements

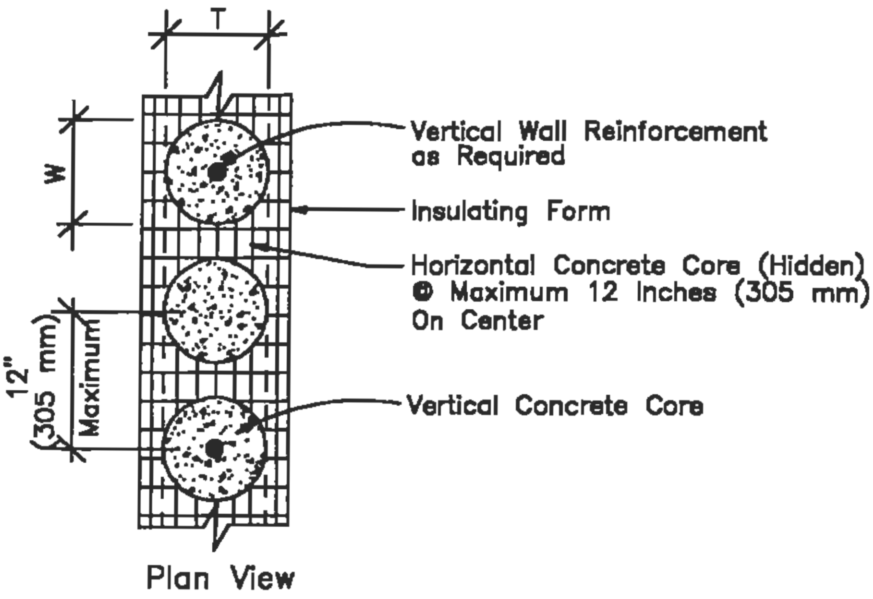



Figure 2.3 Screen-Grid ICF Wall System Requirements

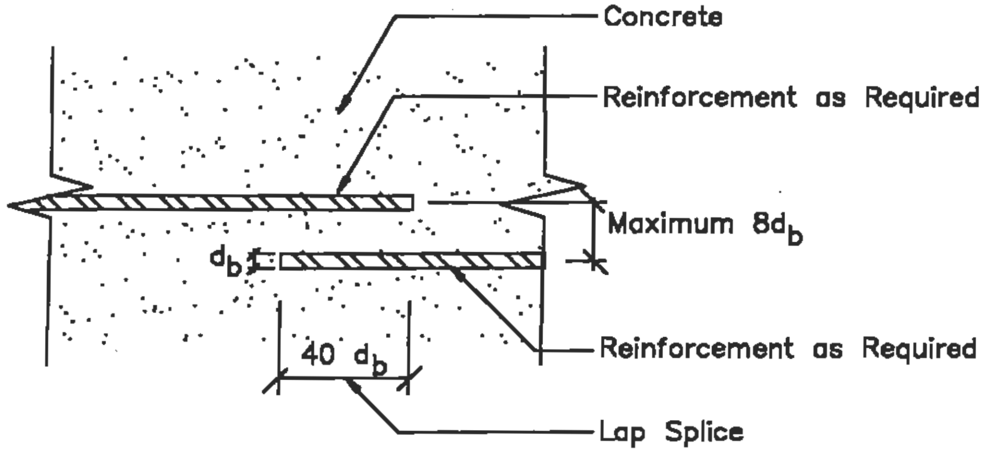



Figure 2.4 Lap Splice Requirements

# 3.0 FOUNDATIONS

## 3.1 Footings

All exterior ICF walls shall be supported on continuous concrete footings or other approved systems of sufficient design to safely transmit the loads imposed directly to the soil. Except when erected on solid rock or otherwise protected from frost, the footings shall extend below the frost line as specified in the local building code. Footings shall be permitted to be located at a depth above the frost line when protected from frost in accordance with the Design and Construction of Frost-Protected Shallow Foundations [18]. Minimum sizes for concrete footings shall be as set forth in Table 3.1. In no case shall exterior footings be less than 12 inches (305 mm) below grade. Footings shall be supported on undisturbed natural soil or approved structural fill. Footings shall be stepped where it is necessary to change the elevation of the top surface of the footings. Foundations erected on soils with a bearing value of less than 2,000 psf (96 kPa) shall be designed in accordance with accepted engineering practice.

## 3.2 ICF Foundation Wall Requirements

The minimum wall thickness shall be greater than or equal to the wall thickness of the wall story above. A minimum of one No. 4 bar shall extend across all construction joints at a spacing not to exceed 24 inches (610 mm) on center. Construction joint reinforcement shall have a minimum of 12 inches (305 mm) embedment on both sides of all construction joints.

> **Exception:** Vertical wall reinforcement required in accordance with this section is permitted to be used in lieu of construction joint reinforcement.

Vertical wall reinforcement required in this section and interrupted by wall openings shall be placed such that one vertical bar is located within 6 inches (152 mm) of each side of the opening. A minimum of one No. 4 vertical reinforcing bar shall be placed in each interior and exterior corner of exterior ICF walls. Horizontal wall reinforcement shall be required in the form of one No. 4 rebar within 12 inches (305 mm) from the top of the wall, one No. 4 rebar within 12 inches (305 mm) from the finish floor, and one No. 4 rebar near one-third points throughout the remainder of the wall.

### 3.2.1 ICF Walls with Slab-on-Grade

ICF stem walls and monolithic slabs-on-grade shall be constructed in accordance with Figure 3.1. Vertical and horizontal wall reinforcement shall be in accordance with Section 4.0 for the above- and below-grade portions of stem walls.

### 3.2.2 ICF Crawlspace Walls

ICF crawlspace walls shall be constructed in accordance with Figure 3.2 and shall be laterally supported at the top and bottom of the wall in accordance with Section 6.0. A minimum of one continuous horizontal No. 4 bar shall be placed within 12 inches (305 mm) of the top of the crawlspace wall. Vertical wall reinforcement shall be the greater of that required in Table 3.2 or, if supporting an ICF wall, that required in Section 4.0 for the wall above.

### 3.2.3 ICF Basement Walls

ICF basement walls shall be constructed in accordance with Figure 3.3 and shall be laterally supported at the top and bottom of the wall in accordance with Section 6.0. Horizontal wall reinforcement shall be provided in accordance with Table 3.3. Vertical wall reinforcement shall be provided in accordance with Tables 3.4 through 3.9.

### 3.2.4 Requirements for Seismic Design Categories C, D1, and D2

Concrete foundation walls supporting above-grade ICF walls in Seismic Design Category C shall be reinforced with minimum No. 5 rebar at 24 inches (610 mm) on center (both ways) or a lesser spacing if required by Tables 3.2 through 3.9.

Concrete foundation walls supporting above-grade ICF walls in Seismic Design Categories D1 and D2 shall be reinforced with minimum No. 5 rebar at a maximum spacing of 18 inches (457 mm) on center (both ways) or a lesser spacing if required by Tables 3.2 through 3.9, and the minimum concrete compressive strength shall be 3,000 psi (20.5 MPa). Vertical reinforcement shall be continuous with ICF above-grade wall vertical reinforcement. Alternatively, the reinforcement shall extend a minimum of $40d_b$ into the ICF above-grade wall, creating a lap-splice with the above-grade wall reinforcement or extend 24 inches (610 mm) terminating with a minimum 90º bend of 6 inches in length.

## 3.3 ICF Foundation Wall Coverings

### 3.3.1 Interior Covering

Rigid foam plastic on the interior of habitable spaces shall be covered with a minimum of 1/2-inch (13-mm) gypsum board or an approved finish material that provides a thermal barrier to limit the average temperature rise of the unexposed surface to no more than 250 degrees F (121 degrees C) after 15 minutes of fire exposure in accordance with ASTM E 119 [19].

The use of vapor retarders shall be in accordance with the authority having jurisdiction.

### 3.3.2 Exterior Covering

ICFs constructed of rigid foam plastics shall be protected from sunlight and physical damage by the application of an approved exterior covering. All ICFs shall be covered with approved materials installed to provide an adequate barrier against the weather. The use of vapor retarders and air barriers shall be in accordance with the authority having jurisdiction.

ICF foundation walls enclosing habitable or storage space shall be dampproofed from the top of the footing to the finished grade. In areas where a high water table or other severe soil-water conditions are known to exist, exterior ICF foundation walls enclosing habitable or storage space shall be waterproofed with a membrane extending from the top of the footing to the finished grade. Dampproofing and waterproofing materials for ICF forms shall be non-petroleum-based and compatible with the form. Dampproofing and waterproofing materials for forms other than foam insulation shall be compatible with the form material and shall be applied in accordance with the manufacturer's recommendations.

### 3.4 Termite Protection Requirements

Structures consisting of materials subject to termite attack (i.e., untreated wood) shall be protected against termite infestation in accordance with the local building code. When materials susceptible to termite attack are placed on or above ICF construction, the ICF foundation walls in areas subject to termite infestation shall be protected by approved chemical soil treatment, physical barriers (i.e., termite shields), borate-treated form material, or any combination of these methods in accordance with the local building code and acceptable practice.

TABLE 3.1
MINIMUM WIDTH OF ICF AND CONCRETE
FOOTINGS FOR ICF WALLS[1,2,3] (inches)

| MAXIMUM NUMBER OF STORIES[4] | MINIMUM LOAD-BEARING VALUE OF SOIL (psf) | | | | |
|---|---|---|---|---|---|
| | 2,000 | 2,500 | 3,000 | 3,500 | 4,000 |
| 5.5-Inch Flat, 6-Inch Waffle-Grid, or 6-Inch Screen-Grid ICF Wall Thickness[5] | | | | | |
| One Story[6] | 15 | 12 | 10 | 9 | 8 |
| Two Story[6] | 20 | 16 | 13 | 12 | 10 |
| 7.5-Inch Flat or 8-Inch Waffle-Grid, or 8-Inch Screen-Grid ICF Wall Thickness[5] | | | | | |
| One Story[7] | 18 | 14 | 12 | 10 | 8 |
| Two Story[7] | 24 | 19 | 16 | 14 | 12 |
| 9.5-Inch Flat ICF Wall Thickness[5] | | | | | |
| One Story | 20 | 16 | 13 | 11 | 10 |
| Two Story | 27 | 22 | 18 | 15 | 14 |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 psf = 47.8804 Pa

1 Minimum footing thickness shall be the greater of one-third of the footing width, 6 inches (152 mm), or 11 inches (279 mm) when a dowel is required in accordance with Section 6.0.

2 Footings shall have a width that allows for a nominal 2-inch (51-mm) projection from either face of the concrete in the wall to the edge of the footing.

3 Table values are based on 32 ft (9.8 m) building width (floor and roof clear span).

4 Basement walls shall not be considered as a story in determining footing widths.

5 Actual thickness is shown for flat walls while nominal thickness is given for waffle-gridand screen-grid walls. Refer to Section 2.0 for actual waffle-gridand screen-grid thickness and dimensions.

6 Applicable also for 7.5-inch (191-mm) thick or 9.5-inch (241-mm) thick flat ICF foundation wall supporting 3.5-inch (88.9-mm) thick flat ICF stories.

7 Applicable also for 9.5-inch (241-mm) thick flat ICF foundation wall story supporting 5.5-inch (140-mm) thick flat ICF stories.

## TABLE 3.2
## MINIMUM VERTICAL WALL REINFORCEMENT FOR ICF CRAWLSPACE WALLS [1,2,3,4,5,6]

| SHAPE OF CONCRETE WALLS | WALL THICKNESS[7] (inches) | MINIMUM VERTICAL REINFORCEMENT | | |
|---|---|---|---|---|
| | | MAXIMUM EQUIVALENT FLUID DENSITY 30 pcf | MAXIMUM EQUIVALENT FLUID DENSITY 45 pcf | MAXIMUM EQUIVALENT FLUID DENSITY 60 pcf |
| Flat | 3.5 [8] | #3@16"<br>#4@32"# | #3@18";<br>4@28"; #5@38" | #3@12";<br>#4@22"; #5@28" |
| | 5.5 | #3@24"<br>#4@48" | #3@24"<br>#4@48" | #3@24"<br>#4@48" |
| | 7.5 | N/R | N/R | N/R |
| Waffle-Grid | 6 | #3@24"<br>#4@48" | #3@24"<br>#4@48" | #3@12";<br>#4@24"; #5@36" |
| | 8 | N/R | N/R | N/R |
| Screen-Grid | 6 | #3@24"<br>#4@48" | #3@24"<br>#4@48" | #3@12";<br>#4@24"; #5@36" |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 pcf = 16.0179 kg/m$^3$

[1] Table values are based on reinforcing bars with a minimum yield strength of 40,000 psi (276 MPa) and concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa).
[2] N/R indicates no vertical wall reinforcement is required.
[3] Spacing of rebar shall be permitted to be multiplied by 1.5 when reinforcing steel with a minimum yield strength of 60,000 psi (414 MPa) is used. Reinforcement, when required, shall not be less than one #4 bar at 48 inches (1.2 m) on center.
[4] Applicable only to crawlspace walls 5 feet (1.5 m) or less in height with a maximum unbalanced backfill height of 4 feet (1.2 m).
[5] Interpolation shall not be permitted.
[6] Walls shall be laterally supported at the top before backfilling.
[7] Actual thickness is shown for flat walls while nominal thickness is given for waffle-gridand screen-grid walls. Refer to Section 2.0 for actual waffle-gridand screen-grid thickness and dimensions.
[8] Applicable only to one-story construction with floor bearing on top of crawlspace wall.

## TABLE 3.3
## MINIMUM HORIZONTAL WALL REINFORCEMENT FOR ICF BASEMENT WALLS

| MAXIMUM HEIGHT OF BASEMENT WALL FEET (METERS) | LOCATION OF HORIZONTAL REINFORCEMENT |
|---|---|
| 8 (2.4) | One No. 4 bar within 12 inches (305 mm) of the top of the wall story and one No. 4 bar near mid-height of the wall story |
| 9 (2.7) | One No. 4 bar within 12 inches (305 mm) of the top of the wall story and one No. 4 bar near third points in the wall story |
| 10 (3.0) | One No. 4 bar within 12 inches (305 mm) of the top of the wall story and one No. 4 bar near third points in the wall story |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 pcf = 16.0179 kg/m$^3$

[1] Horizontal reinforcement requirements are for reinforcing bars with a minimum yield strength from 40,000 psi (276 MPa) and concrete with a minimum concrete compressive strength 2,500 psi (17.2 MPa).

## TABLE 3.4
## MINIMUM VERTICAL WALL REINFORCEMENT FOR 5.5-inch- (140-mm-) THICK FLAT ICF BASEMENT WALLS [1,2,3,4,5]

| MAX. WALL HEIGHT (feet) | MAXIMUM UNBALANCED BACKFILL HEIGHT[6] (feet) | MINIMUM VERTICAL REINFORCEMENT | | |
|---|---|---|---|---|
| | | MAXIMUM EQUIVALENT FLUID DENSITY 30 pcf | MAXIMUM EQUIVALENT FLUID DENSITY 45 pcf | MAXIMUM EQUIVALENT FLUID DENSITY 60 pcf |
| 8 | 4 | #4@48" | #4@48" | #4@48" |
| | 5 | #4@48" | #3@12"; #4@22"; #5@32"; #6@40" | #3@8"; #4@14"; #5@20"; #6@26" |
| | 6 | #3@12"; #4@22"; #5@30"; #6@40" | #3@8"; #4@14"; #5@20"; #6@24" | #3@6"; #4@10"; #5@14"; #6@20" |
| | 7 | #3@8"; #4@14"; #5@22"; #6@26" | #3@5"; #4@10"; #5@14"; #6@18" | #3@4"; #4@6"; #5@10"; #6@14" |
| 9 | 4 | #4@48" | #4@48" | #4@48" |
| | 5 | #4@48" | #3@12"; #4@20"; #5@28"; #6@36" | #3@8"; #4@14"; #5@20"; #6@22" |
| | 6 | #3@10"; #4@20"; #5@28"; #6@34" | #3@6"; #4@12"; #5@18"; #6@20" | #4@8"; #5@14"; #6@16" |
| | 7 | #3@8"; #4@14"; #5@20"; #6@22" | #4@8"; #5@12"; #6@16" | #4@6"; #5@10"; #6@12" |
| | 8 | #3@6"; #4@10"; #5@14"; #6@16" | #4@6"; #5@10"; #6@12" | #4@4"; #5@6"; #6@8" |
| 10 | 4 | #4@48" | #4@48" | #4@48" |
| | 5 | #4@48" | #3@10"; #4@18"; #5@26"; #6@30" | #3@6"; #4@14"; #5@18"; #6@20" |
| | 6 | #3@10"; #4@18"; #5@24"; #6@30" | #3@6"; #4@12"; #5@16"; #6@18" | #3@4"; #4@8"; #5@12"; #6@14" |
| | 7 | #3@6"; #4@12"; #5@16"; #6@18" | #3@4"; #4@8"; #5@12" | #4@6"; #5@8"; #6@10" |
| | 8 | #3@4"; #4@8"; #5@12"; #6@14" | #4@6"; #5@8"; #6@12" | #4@4"; #5@6"; #6@8" |
| | 9 | #3@4"; #4@6"; #5@10"; #6@12" | #4@4"; #5@6"; #6@8" | #5@4"; #6@6" |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 pcf = 16.0179 kg/m$^3$

[1] Table values are based on reinforcing bars with a minimum yield strength of 40,000 psi (276 MPa) and concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa).

[2] Spacing of rebar shall be permitted to be multiplied by 1.5 when reinforcing steel with a minimum yield strength of 60,000 psi (414 MPa) is used. Reinforcement shall not be less than one #4 bar at 48 inches (1.2 m) on center.

[3] Deflection criterion is L/240, where L is the height of the basement wall in inches.

[4] Interpolation shall not be permitted.

[5] Walls shall be laterally supported at the top before backfilling.

[6] Refer to Section 1.0 for the definition of unbalanced backfill height.

## TABLE 3.5
## MINIMUM VERTICAL WALL REINFORCEMENT FOR 7.5-inch- (191-mm-) THICK FLAT ICF BASEMENT WALLS [1,2,3,4,5,6]

| MAX. WALL HEIGHT (feet) | MAXIMUM UNBALANCED BACKFILL HEIGHT[7] (feet) | MINIMUM VERTICAL REINFORCEMENT | | |
|---|---|---|---|---|
| | | MAXIMUM EQUIVALENT FLUID DENSITY 30 pcf | MAXIMUM EQUIVALENT FLUID DENSITY 45 pcf | MAXIMUM EQUIVALENT FLUID DENSITY 60 pcf |
| 8 | 4 | N/R | N/R | N/R |
| | 5 | N/R | N/R | N/R |
| | 6 | N/R | N/R | N/R |
| | 7 | N/R | #4@14"; #5@20"; #6@28" | #4@10"; #5@16"; #6@20" |
| 9 | 4 | N/R | N/R | N/R |
| | 5 | N/R | N/R | N/R |
| | 6 | N/R | N/R | #4@14"; #5@20"; #6@28" |
| | 7 | N/R | #4@12"; #5@18"; #6@26" | #4@8"; #5@14"; #6@18" |
| | 8 | #4@14"; #5@22"; #6@28" | #4@8"; #5@14"; #6@18" | #4@6"; #5@10"; #6@14" |
| 10 | 4 | N/R | N/R | N/R |
| | 5 | N/R | N/R | N/R |
| | 6 | N/R | N/R | #4@12"; #5@18"; #6@26" |
| | 7 | N/R | #4@12"; #5@18"; #6@24" | #4@8"; #5@12"; #6@18" |
| | 8 | #4@12"; #5@20"; #6@26" | #4@8"; #5@12"; #6@16" | #4@6"; #5@8"; #6@12" |
| | 9 | #4@10"; #5@14"; #6@20" | #4@6"; #5@10"; #6@12" | #4@4"; #5@6"; #6@10" |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 pcf = 16.0179 kg/m$^3$

1 Table values are based on reinforcing bars with a minimum yield strength of 40,000 psi (276 MPa) and concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa).

2 Spacing of rebar shall be permitted to be multiplied by 1.5 when reinforcing steel with a minimum yield strength of 60,000 psi (414 MPa) is used. Reinforcement, when required, shall not be less than one #4 bar at 48 inches (1.2 m) on center.

3 N/R indicates no reinforcement is required.

4 Deflection criterion is L/240, where L is the height of the basement wall in inches.

5 Interpolation shall not be permitted.

6 Walls shall be laterally supported at the top before backfilling.

7 Refer to Section 1.0 for the definition of unbalanced backfill height.

# TABLE 3.6
# MINIMUM VERTICAL WALL REINFORCEMENT FOR 9.5-inch- (241-mm-) THICK FLAT ICF BASEMENT WALLS [1,2,3,4,5,6]

| MAX. WALL HEIGHT (feet) | MAXIMUM UNBALANCED BACKFILL HEIGHT[7] (feet) | MINIMUM VERTICAL REINFORCEMENT | | |
|---|---|---|---|---|
| | | MAXIMUM EQUIVALENT FLUID DENSITY 30 pcf | MAXIMUM EQUIVALENT FLUID DENSITY 45 pcf | MAXIMUM EQUIVALENT FLUID DENSITY 60 pcf |
| 8 | 4 | N/R | N/R | N/R |
| | 5 | N/R | N/R | N/R |
| | 6 | N/R | N/R | N/R |
| | 7 | N/R | N/R | N/R |
| 9 | 4 | N/R | N/R | N/R |
| | 5 | N/R | N/R | N/R |
| | 6 | N/R | N/R | N/R |
| | 7 | N/R | N/R | #4@12"; #5@18"; #6@26" |
| | 8 | N/R | #4@12"; #5@18"; #6@26" | #4@8"; #5@14"; #6@18" |
| 10 | 4 | N/R | N/R | N/R |
| | 5 | N/R | N/R | N/R |
| | 6 | N/R | N/R | #4@18"; #5@26"; #6@36" |
| | 7 | N/R | N/R | #4@10"; #5@18"; #6@24" |
| | 8 | N/R | #4@12"; #5@16"; #6@24" | #4@8"; #5@12"; #6@16" |
| | 9 | N/R | #4@8"; #5@12"; #6@18" | #4@6"; #5@10"; #6@12" |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 pcf = 16.0179 kg/m$^3$

1 Table values are based on reinforcing bars with a minimum yield strength of 40,000 psi (276 MPa) and concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa).

2 Spacing of rebar shall be permitted to be multiplied by 1.5 when reinforcing steel with a minimum yield strength of 60,000 psi (414 MPa) is used. Reinforcement, when required, shall not be less than one #4 bar at 48 inches (1.2 m) on center.

3 N/R indicates no reinforcement is required.

4 Deflection criterion is L/240, where L is the height of the basement wall in inches.

5 Interpolation shall not be permitted.

6 Walls shall be laterally supported at the top before backfilling.

7 Refer to Section 1.0 for the definition of unbalanced backfill height.

## TABLE 3.7
## MINIMUM VERTICAL WALL REINFORCEMENT FOR 6-inch (152-mm) WAFFLE-GRID ICF BASEMENT WALLS[1,2,3,4,5]

| MAX. WALL HEIGHT (feet) | MAXIMUM UNBALANCED BACKFILL HEIGHT[6] (feet) | MINIMUM VERTICAL REINFORCEMENT | | |
|---|---|---|---|---|
| | | MAXIMUM EQUIVALENT FLUID DENSITY 30 pcf | MAXIMUM EQUIVALENT FLUID DENSITY 45 pcf | MAXIMUM EQUIVALENT FLUID DENSITY 60 pcf |
| 8 | 4 | #4@48" | #4@24"; #5@24" | #4@12" |
| | 5 | #4@12"; #5@24" | #4@12"; #5@12" | Design Required |
| | 6 | #4@12"; #5@12" | Design Required | Design Required |
| | 7 | Design Required | Design Required | Design Required |
| 9 | 4 | #4@48" | #4@12"; #5@24" | #3@12"; #4@12" |
| | 5 | #4@12" | #4@12"; #5@12" | Design Required |
| | 6 | #5@12"; #6@12" | Design Required | Design Required |
| | 7 | Design Required | Design Required | Design Required |
| | 8 | Design Required | Design Required | Design Required |
| 10 | 4 | #4@48" | #4@12"; #5@12"; | #5@12" #6@12" |
| | 5 | #3@12"; #4@12" | Design Required | Design Required |
| | 6 | Design Required | Design Required | Design Required |
| | 7 | Design Required | Design Required | Design Required |
| | 8 | Design Required | Design Required | Design Required |
| | 9 | Design Required | Design Required | Design Required |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 pcf = 16.0179 kg/m$^3$

1 Table values are based on reinforcing bars with a minimum yield strength of 40,000 psi (276 MPa) and concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa).

2 Spacing of rebar shall be permitted to be increased by 12 inches (305 mm) when reinforcing steel with a minimum yield strength of 60,000 psi (414 MPa) is used. Reinforcement shall not be less than one #4 bar at 48 inches (1.2 m) on center.

3 Deflection criterion is L/240, where L is the height of the basement wall in inches.

4 Interpolation shall not be permitted.

5 Walls shall be laterally supported at the top before backfilling.

6 Refer to Section 1.0 for the definition of unbalanced backfill height.

## TABLE 3.8
## MINIMUM VERTICAL WALL REINFORCEMENT FOR 8-inch (203-mm) WAFFLE-GRID ICF BASEMENT WALLS[1,2,3,4,5,6]

| MAX. WALL HEIGHT (feet) | MAXIMUM UNBALANCED BACKFILL HEIGHT[7] (feet) | MINIMUM VERTICAL REINFORCEMENT | | |
|---|---|---|---|---|
| | | MAXIMUM EQUIVALENT FLUID DENSITY 30 pcf | MAXIMUM EQUIVALENT FLUID DENSITY 45 pcf | MAXIMUM EQUIVALENT FLUID DENSITY 60 pcf |
| 8 | 4 | N/R | N/R | N/R |
| | 5 | N/R | #4@24"; #5@36" | #4@12"; #5@24" |
| | 6 | #4@24"; #5@36" | #4@12"; #5@24" | #4@12"; #5@12" |
| | 7 | #4@12"; #5@12"; #6@24" | #4@12"; #5@12" | #5@12"; #6@12" |
| 9 | 4 | N/R | N/R | N/R |
| | 5 | N/R | #4@12"; #5@24" | #4@12"; #5@24" |
| | 6 | #4@24"; #5@24" | #4@12"; #5@12" | #4@12"; #5@12" |
| | 7 | #4@12"; #5@24" | #5@12"; #6@12" | #5@12"; #6@12" |
| | 8 | #4@12"; #5@12"; | #5@12" #6@12" | Design Required |
| 10 | 4 | N/R | #4@24"; #5@24"; #6@36" | #3@12"; #4@12"; #5@24" |
| | 5 | N/R | #3@12"; #4@24"; #5@24"; #6@36" | #4@12"; #5@24" |
| | 6 | #4@12" #5@24" | #4@12"; #5@12" | #5@12"; #6@12" |
| | 7 | #4@12"; #5@12"; | #5@12" #6@12" | #6@12" |
| | 8 | #4@12"; #5@12" | #6@12" | Design Required |
| | 9 | #5@12"; #6@12" | Design Required | Design Required |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 pcf = 16.0179 kg/m$^3$

[1] Table values are based on reinforcing bars with a minimum yield strength of 40,000 psi (276 MPa) and concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa).

[2] Spacing of rebar shall be permitted to be increased by 12 inches (305 mm) when reinforcing steel with a minimum yield strength of 60,000 psi (414 MPa) is used. Reinforcement, when required, shall not be less than one #4 bar at 48 inches (1.2 m) on center.

[3] N/R indicates no reinforcement is required.

[4] Deflection criterion is L/240, where L is the height of the basement wall in inches.

[5] Interpolation shall not be permitted.

[6] Walls shall be laterally supported at the top before backfilling.

[7] Refer to Section 1.0 for the definition of unbalanced backfill height.

## TABLE 3.9
## MINIMUM VERTICAL WALL REINFORCEMENT FOR 6-inch (152-mm) SCREEN-GRID ICF BASEMENT WALLS[1,2,3,4,5]

| MAX. WALL HEIGHT (feet) | MAXIMUM UNBALANCED BACKFILL HEIGHT[6] (feet) | MINIMUM VERTICAL REINFORCEMENT | | |
|---|---|---|---|---|
| | | MAXIMUM EQUIVALENT FLUID DENSITY 30 pcf | MAXIMUM EQUIVALENT FLUID DENSITY 45 pcf | MAXIMUM EQUIVALENT FLUID DENSITY 60 pcf |
| 8 | 4 | #4@48" | #3@12"; #4@24"; #5@36" | #3@12"; #4@12"; #5@24" |
| | 5 | #3@12"; #4@24"; #5@24" | #3@12"; #4@12" | #4@12"; #5@12" |
| | 6 | #4@12"; #5@12"; | #5@12" #6@12" | Design Required |
| | 7 | Design Required | Design Required | Design Required |
| 9 | 4 | #4@48" | #3@12"; #4@24"; #5@24" | #3@12"; #4@12"; #5@12"; #6@24" |
| | 5 | #3@12"; #4@12"; #5@24" | #4@12"; #5@12" | Design Required |
| | 6 | #4@12"; #5@12" | Design Required | Design Required |
| | 7 | Design Required | Design Required | Design Required |
| | 8 | Design Required | Design Required | Design Required |
| 10 | 4 | #4@48" | #3@12"; #4@12"; #5@24"; #6@24" | #3@12"; #4@12" |
| | 5 | #3@12"; #4@12"; | #4@12" #5@12" | Design Required |
| | 6 | #4@12"; #5@12" | Design Required | Design Required |
| | 7 | Design Required | Design Required | Design Required |
| | 8 | Design Required | Design Required | Design Required |
| | 9 | Design Required | Design Required | Design Required |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 pcf = 16.0179 kg/$m^3$

1 Table values are based on reinforcing bars with a minimum yield strength of 40,000 psi (276 MPa) and concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa).

2 Spacing of rebar in shaded cells shall be permitted to be increased by 12 inches (305 mm) when reinforcing steel with a minimum yield strength of 60,000 psi (414 MPa) is used. Reinforcement shall not be less than one #4 bar at 48 inches (1.2 m) on center.

3 Deflection criterion is L/240, where L is the height of the basement wall in inches.

4 Interpolation shall not be permitted.

5 Walls shall be laterally supported at the top before backfilling.

6 Refer to Section 1.0 for the definition of unbalanced backfill height.

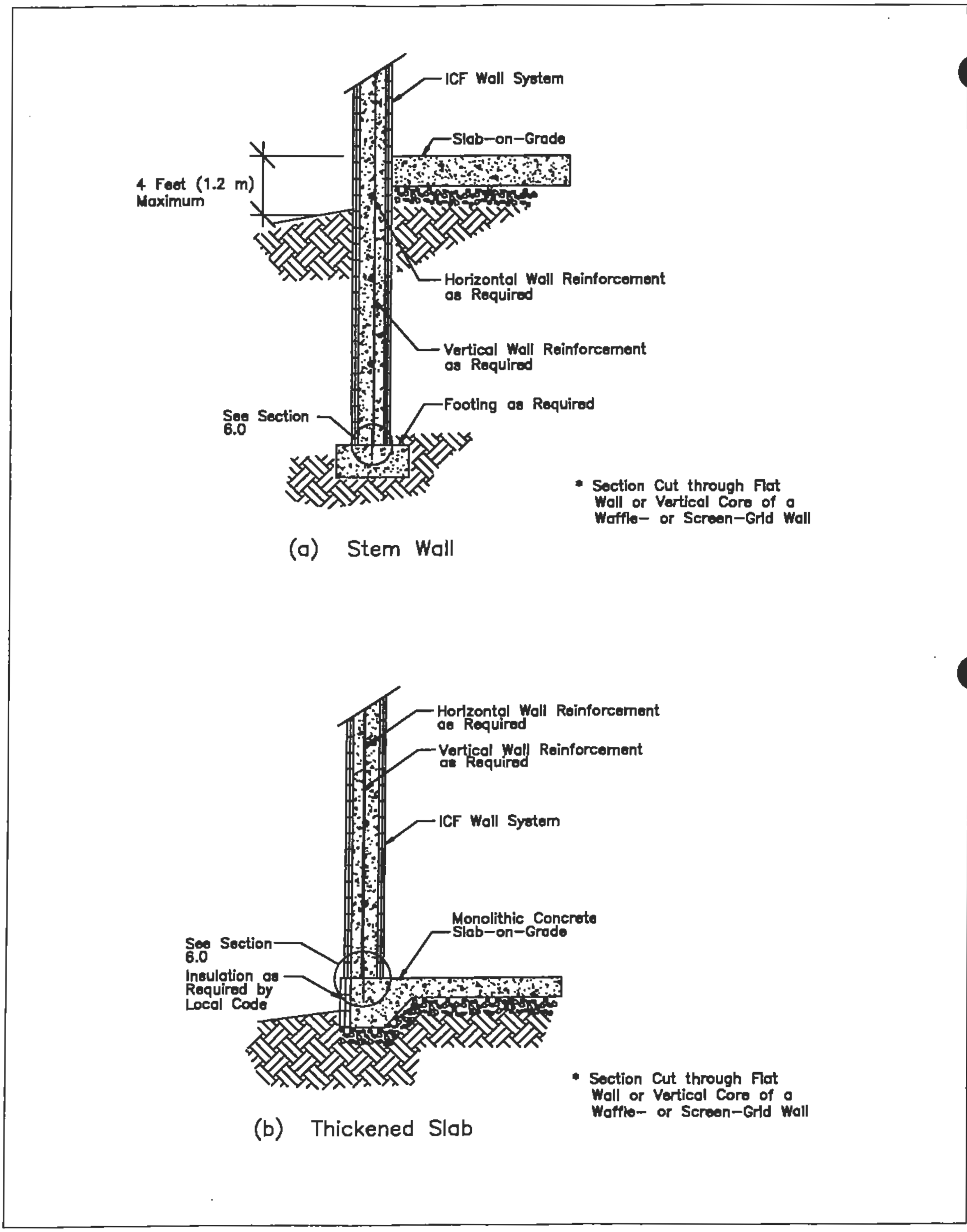
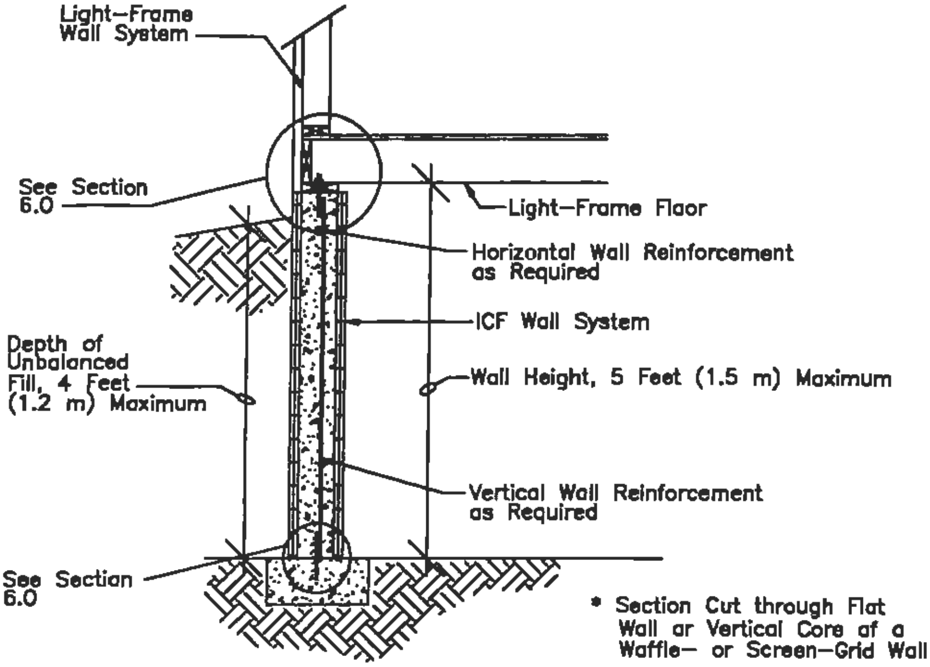
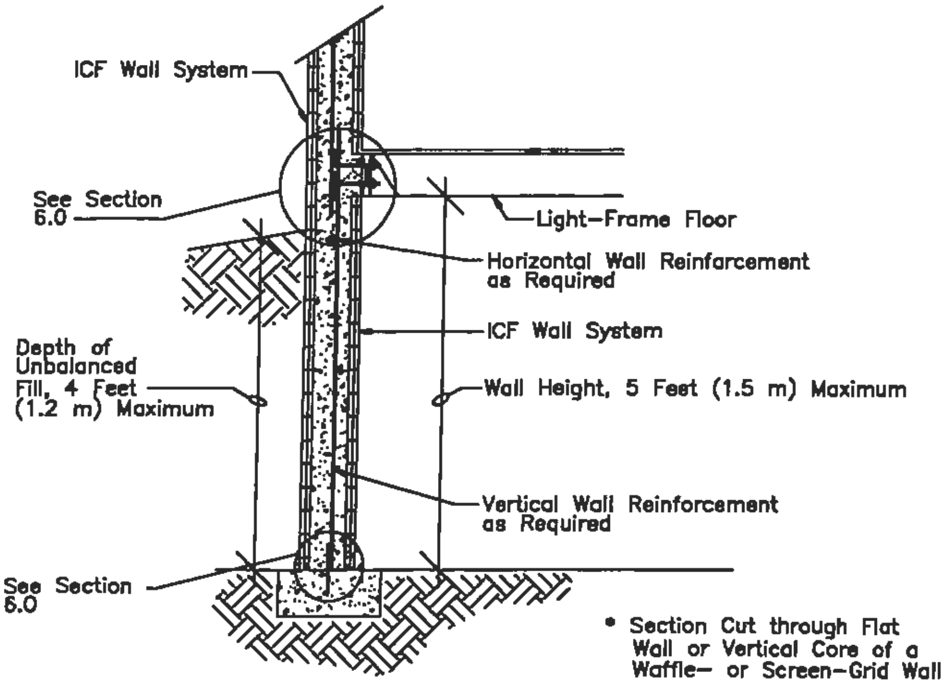



Figure 3.1 ICF Stem Wall and Monolithic Slab-on-Grade Construction




(a) Supporting Light–Frame Construction




(b) Supporting ICF Construction

Figure 3.2 ICF Crawlspace Wall Construction

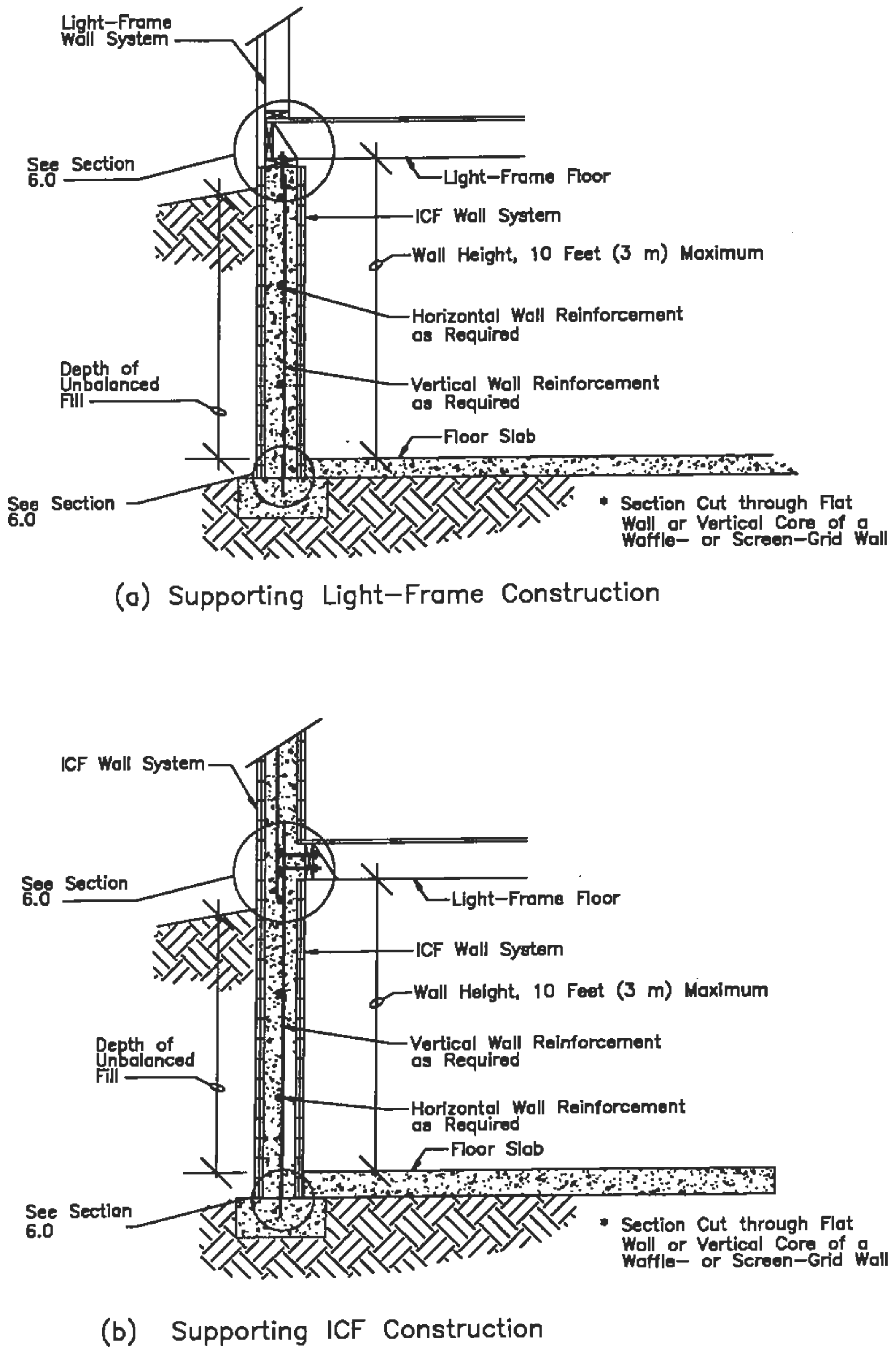



Figure 3.3 ICF Basement Wall Construction

# 4.0 ICF ABOVE-GRADE WALLS

## .1 ICF Above-Grade Wall Requirements

ICF above-grade walls shall be constructed in accordance with Figures 4.1, 4.2, or 4.3 and this section. The minimum length of ICF wall without openings, reinforcement around openings, and lintel requirements above wall openings shall be in accordance with Section 5.0. Lateral support for above-grade ICF walls shall be provided by the roof and floor framing systems in accordance with Section 6.0. The minimum wall thickness shall be greater than or equal to the wall thickness of the wall above.

Design wind pressures of Table 4.1 shall be used to determine the vertical wall reinforcement requirements in Tables 4.2, 4.3, and 4.4. The minimum vertical reinforcement shall be one No. 4 rebar (Grade 40) at 48 inches (1.2 m) on center and at all inside and outside corners of exterior ICF walls. Horizontal wall reinforcement shall be required in the form of one No. 4 rebar within 12 inches (305 mm) from the top of the wall, one No. 4 rebar within 12 inches (305 mm) from the finish floor, and one No. 4 rebar near one-third points throughout the remainder of the wall.

For townhouses in Seismic Design Category C, the minimum vertical and horizontal reinforcement shall be one No. 5 rebar at 24 inches (610 m) on center. For all buildings in Seismic Design Categories D1 and D2, the minimum vertical and horizontal reinforcement shall be one No. 5 rebar at a maximum spacing of 18 inches (457 mm) on center, and the minimum concrete compressive strength shall be 3,000 psi (20.5 MPa).

Above-grade ICF walls shall be supported on concrete foundations reinforced as required for the above-grade wall immediately above, or in accordance with Tables 3.2 through 3.9, whichever requires the greater reinforcement.

Vertical reinforcement shall be continuous from the bottom of the foundation wall to the roof. Lap splices, if required, shall comply with Section 2.2.3 and Figure 2.4. Where vertical reinforcement in the above-grade wall is not continuous with the foundation wall reinforcement, dowel bars with a size and spacing to match the vertical ICF wall reinforcement shall be embedded $40d_b$ into the foundation wall and shall be lap-spliced with the above-grade wall reinforcement. Alternatively, for No. 6 and larger bars, the portion of the bar embedded in the foundation wall shall be embedded 24 inches in the foundation wall and shall have a standard hook.

Where the free end of a reinforcing bar is required to have a standard hook, the hook shall be a 180-degree bend plus $4d_b$ extension but not less than 2-1/2 inches, or a 90-degree bend plus $12d_b$ extension.

For design wind pressure greater than 40 psf (1.9 kPa) or Seismic Design Category C or greater, all vertical wall reinforcement in the top-most ICF story shall be terminated with a 90 degree bend. The bend shall result in a minimum length of 6 inches (152 mm) parallel to the horizontal wall reinforcement and lie within 4 inches (102 mm) of the top surface of the ICF wall. Horizontal reinforcement shall be continuous around building corners using corner bars or by bending the bars. In either case, the minimum lap splice shall be 24 inches (610 mm). For townhouses in Seismic Design Category C and for all buildings in Seismic Design Categories D1 and D2, each end of all horizontal reinforcement shall terminate with a standard hook or lap splice.

**Exception:** In lieu of bending horizontal or vertical reinforcement, separate bent reinforcement bars shall be permitted provided that the minimum lap splice with vertical and horizontal wall reinforcement is not less than $40d_b$.

## 4.2 ICF Above-Grade Wall Coverings

### 4.2.1 Interior Covering

Rigid foam plastic on the interior of habitable spaces shall be covered with a minimum of 1/2-inch (13-mm) gypsum board or an approved finish material that provides a thermal barrier to limit the average temperature rise of the unexposed surface to no more than 250 degrees F (139 degrees C) after 15 minutes of fire exposure in accordance with ASTM E 119 [19]. The use of vapor retarders and air barriers shall be in accordance with the authority having jurisdiction.

### 4.2.2 Exterior Covering

ICFs constructed of rigid foam plastics shall be protected from sunlight and physical damage by the application of an approved exterior covering. All ICFs shall be covered with approved materials installed to provide a barrier against the weather. Use of air barriers and vapor retarders shall be in accordance with the authority having jurisdiction.

**TABLE 4.1**
**DESIGN WIND PRESSURE FOR USE WITH MINIMUM VERTICAL WALL REINFORCEMENT TABLES FOR ABOVE-GRADE WALLS[1]**

| WIND SPEED (mph) | DESIGN WIND PRESSURE (psf) | | | | | |
|---|---|---|---|---|---|---|
| | ENCLOSED[2] | | | PARTIALLY ENCLOSED[2] | | |
| | Exposure[3] | | | Exposure[3] | | |
| | B | C | D | B | C | D |
| 85 | 18 | 24 | 29 | 23 | 31 | 37 |
| 90 | 20 | 27 | 32 | 25 | 35 | 41 |
| 100 | 24 | 34 | 39 | 31 | 43 | 51 |
| 110 | 29 | 41 | 48 | 38 | 52 | 61 |
| 120 | 35 | 48 | 57 | 45 | 62 | 73 |
| 130 | 41 | 56 | 66 | 53 | 73 | 85[4] |
| 140 | 47 | 65 | 77 | 61 | 84[4] | 99[4] |
| 150 | 54 | 75 | 88[4] | 70 | 96[4] | 114[4] |

For SI: 1 psf = 0.0479 kN/m$^2$; 1 mph = 1.6093 km/hr

[1] This table is based on ASCE 7-98 components and cladding wind pressures using a mean roof height of 35 ft (10.7 m) and a tributary area of 10 ft$^2$ (0.9 m$^2$).

[2] Enclosure Classifications are as defined in Section 1.5.

[3] Exposure Categories are as defined in Section 1.5.

[4] For wind pressures greater than 80 psf (3.8 kN/m$^2$), design is required in accordance with accepted practice and approved manufacturer guidelines.

## TABLE 4.2
## MINIMUM VERTICAL WALL REINFORCEMENT FOR FLAT ICF ABOVE-GRADE WALLS [1,2,3]

| DESIGN WIND PRESSURE (TABLE 4.1) (psf) | MAXIMUM WALL HEIGHT PER STORY (feet) | MINIMUM VERTICAL REINFORCEMENT[4,5] | | | | | |
|---|---|---|---|---|---|---|---|
| | | SUPPORTING ROOF OR NON-LOAD-BEARING WALL | | SUPPORTING LIGHT-FRAME SECOND STORY AND ROOF | | SUPPORTING ICF SECOND STORY AND LIGHT-FRAME ROOF | |
| | | MINIMUM WALL THICKNESS (inches) | | | | | |
| | | 3.5 | 5.5 | 3.5 | 5.5 | 3.5 | 5.5 |
| 20 | 8 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 |
| | 9 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 |
| | 10 | #4@38 | #4@48 | #4@40 | #4@48 | #4@42 | #4@48 |
| 30 | 8 | #4@42 | #4@48 | #4@46 | #4@48 | #4@48 | #4@48 |
| | 9 | #4@32; #5@48 | #4@48 | #4@34; #5@48 | #4@48 | #4@34; #5@48 | #4@48 |
| | 10 | Design Required | #4@48 | Design Required | #4@48 | Design Required | #4@48 |
| 40 | 8 | #4@30; #5@48 | #4@48 | #4@30; #5@48 | #4@48 | #4@32; #5@48 | #4@48 |
| | 9 | Design Required | #4@42 | Design Required | #4@46 | Design Required | #4@48 |
| | 10 | Design Required | #4@32; #5@48 | Design Required | #4@34; #5@48 | Design Required | #4@38 |
| 50 | 8 | #4@20; #5@30 | #4@42 | #4@22; #5@34 | #4@46 | #4@24; #5@36 | #4@48 |
| | 9 | Design Required | #4@34; #5@48 | Design Required | #4@34; #5@48 | Design Required | #4@38 |
| | 10 | Design Required | #4@26; #5@38 | Design Required | #4@26; #5@38 | Design Required | #4@28; #5@46 |
| 60 | 8 | Design Required | #4@34; #5@48 | Design Required | #4@36 | Design Required | #4@40 |
| | 9 | Design Required | #4@26; #5@38 | Design Required | #4@28; #5@46 | Design Required | #4@34; #5@48 |
| | 10 | Design Required | #4@22; #5@34 | Design Required | #4@22; #5@34 | Design Required | #4@26; #5@38 |
| 70 | 8 | Design Required | #4@28; #5@46 | Design Required | #4@30; #5@48 | Design Required | #4@34; #5@48 |
| | 9 | Design Required | #4@22; #5@34 | Design Required | #4@22; #5@34 | Design Required | #4@24; #5@36 |
| | 10 | Design Required | #4@16; #5@26 | Design Required | #4@18; #5@28 | Design Required | #4@20; #5@30 |
| 80 | 8 | Design Required | #4@26; #5@38 | Design Required | #4@26; #5@38 | Design Required | #4@28; #5@46 |
| | 9 | Design Required | #4@20; #5@30 | Design Required | #4@20; #5@30 | Design Required | #4@21; #5@34 |
| | 10 | Design Required | #4@14; #5@24 | Design Required | #4@14; #5@24 | Design Required | #4@16; #5@26 |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 mph = 1.6093 km/hr

1 This table is based on reinforcing bars with a minimum yield strength of 40,000 psi (276 MPa) and concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa).

2 Deflection criterion is L/240, where L is the height of the wall story in inches.

3 Interpolation shall not be permitted.

4 Reinforcement spacing for 3.5 inch (88.9 mm) walls shall be permitted to be multiplied by 1.6 when reinforcing steel with a minimum yield strength of 60,000 psi (414 MPa) is used. Reinforcement shall not be less than one #4 bar at 48 inches (1.2 m) on center.

5 Reinforcement spacing for 5.5 inch (139.7 mm) walls shall be permitted to be multiplied by 1.5 when reinforcing steel with a minimum yield strength of 60,000 psi (414 MPa) is used. Reinforcement shall not be less than one #4 bar at 48 inches (1.2 m) on center.

6 A 3.5-inch wall shall not be permitted if wood ledgers are used to support floor or roof loads.

# TABLE 4.3
## MINIMUM VERTICAL WALL REINFORCEMENT FOR WAFFLE-GRID ICF ABOVE-GRADE WALLS [1,2,3]

| DESIGN WIND PRESSURE (TABLE 4.1) (psf) | MAXIMUM WALL HEIGHT PER STORY (feet) | MINIMUM VERTICAL REINFORCEMENT4 | | | | | |
|---|---|---|---|---|---|---|---|
| | | SUPPORTING ROOF OR NON-LOAD-BEARING WALL | | SUPPORTING LIGHT-FRAME SECOND STORY AND ROOF | | SUPPORTING ICF SECOND STORY AND LIGHT-FRAME ROOF | |
| | | MINIMUM WALL THICKNESS (inches) | | | | | |
| | | 6 | 8 | 6 | 8 | 6 | 8 |
| 20 | 8 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 |
| | 9 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 |
| | 10 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 |
| 30 | 8 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 |
| | 9 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 |
| | 10 | #4@36; #5@48 | #4@48 | #4@36; #5@48 | #4@48 | #4@36; #5@48 | #4@48 |
| 40 | 8 | #4@36; #5@48 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 |
| | 9 | #4@36; #5@48 | #4@48 | #4@36; #5@48 | #4@48 | #4@36; #5@48 | #4@48 |
| | 10 | #4@24; #5@36 | #4@36; #5@48 | #4@24; #5@36 | #4@48 | #4@24; #5@36 | #4@48 |
| 50 | 8 | #4@36; #5@48 | #4@48 | #4@36; #5@48 | #4@48 | #4@36; #5@48 | #4@48 |
| | 9 | #4@24; #5@36 | #4@36; #5@48 | #4@24; #5@36 | #4@48 | #4@24; #5@48 | #4@48 |
| | 10 | Design Required | #4@36; #5@48 | Design Required | #4@36; #5@48 | Design Required | #4@36; #5@48 |
| 60 | 8 | #4@24; #5@36 | #4@48 | #4@24; #5@36 | #4@48 | #4@24; #5@48 | #4@48 |
| | 9 | Design Required | #4@36; #5@48 | Design Required | #4@36; #5@48 | Design Required | #4@36; #5@48 |
| | 10 | Design Required | #4@24; #5@36 | Design Required | #4@24; #5@36 | Design Required | #4@24; #5@48 |
| 70 | 8 | #4@24; #5@36 | #4@36; #5@48 | #4@24; #5@36 | #4@36; #5@48 | #4@24; #5@36 | #4@48 |
| | 9 | Design Required | #4@24; #5@36 | Design Required | #4@24; #5@48 | Design Required | #4@24; #5@48 |
| | 10 | Design Required | #4@12; #5@36 | Design Required | #4@24; #5@36 | Design Required | #4@24; #5@36 |
| 80 | 8 | #4@12; #5@24 | #4@24; #5@48 | #4@12; #5@24 | #4@24; #5@48 | #4@12; #5@24 | #4@36; #5@48 |
| | 9 | Design Required | #4@24; #5@36 | Design Required | #4@24; #5@36 | Design Required | #4@24; #5@36 |
| | 10 | Design Required | #4@12; #5@24 | Design Required | #4@12; #5@24 | Design Required | #4@12; #5@24 |

For SI:1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 mph = 1.6093 km/hr

1 This table is based on reinforcing bars with a minimum yield strength of 40,000 psi (276 MPa) and concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa).
2 Deflection criterion is L/240, where L is the height of the wall story in inches.
3 Interpolation shall not be permitted.
4 Reinforcement spacing shall be permitted to be increased by 12 inches (305 mm) when reinforcing steel with a minimum yield strength of 60,000 psi (414 MPa) is used or #4 reinforcing bars shall be permitted to be substituted for #5 bars when reinforcing steel with a minimum yield strength of 60,000 psi (414 MPa) is used with the same spacing. Reinforcement shall not be less than one #4 bar at 48 inches (1.2 m) on center.

## TABLE 4.4
## MINIMUM VERTICAL WALL REINFORCEMENT FOR SCREEN-GRID ICF ABOVE-GRADE WALLS [1,2,3]

| DESIGN WIND PRESSURE (TABLE 4.1) (psf) | MAXIMUM WALL HEIGHT PER STORY (feet) | MINIMUM VERTICAL REINFORCEMENT[4] | | |
|---|---|---|---|---|
| | | SUPPORTING ROOF OR NON-LOAD-BEARING WALL | SUPPORTING LIGHT-FRAME SECOND STORY AND ROOF | SUPPORTING ICF SECOND STORY AND LIGHT-FRAME ROOF |
| | | MINIMUM WALL THICKNESS (inches) | | |
| | | 6 | 6 | 6 |
| 20 | 8 | #4@48 | #4@48 | #4@48 |
| | 9 | #4@48 | #4@48 | #4@48 |
| | 10 | #4@48 | #4@48 | #4@48 |
| 30 | 8 | #4@48 | #4@48 | #4@48 |
| | 9 | #4@48 | #4@48 | #4@48 |
| | 10 | #4@36; #5@48 | #4@48 | #4@48 |
| 40 | 8 | #4@48 | #4@48 | #4@48 |
| | 9 | #4@36; #5@48 | #4@36; #5@48 | #4@48 |
| | 10 | #4@24; #5@48 | #4@24; #5@48 | #4@24; #5@48 |
| 50 | 8 | #4@36; #5@48 | #4@36; #5@48 | #4@48 |
| | 9 | #4@24; #5@48 | #4@24; #5@48 | #4@24; #5@48 |
| | 10 | Design Required | Design Required | Design Required |
| 60 | 8 | #4@24; #5@48 | #4@24; #5@48 | #4@36; #5@48 |
| | 9 | #4@24; #5@36 | #4@24; #5@36 | #4@24; #5@36 |
| | 10 | Design Required | Design Required | Design Required |
| 70 | 8 | #4@24; #5@36 | #4@24; #5@36 | #4@24; #5@36 |
| | 9 | Design Required | Design Required | Design Required |
| | 10 | Design Required | Design Required | Design Required |
| 80 | 8 | #4@12; #5@36 | #4@24; #5@36 | #4@24; #5@36 |
| | 9 | Design Required | Design Required | Design Required |
| | 10 | Design Required | Design Required | Design Required |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 mph = 1.6093 km/hr

[1] This table is based on reinforcing bars with a minimum yield strength of 40,000 psi (276 MPa) and concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa).

[2] Deflection criterion is L/240, where L is the height of the wall story in inches.

[3] Interpolation shall not be permitted.

[4] Reinforcement spacing shall be permitted to be increased by 12 inches (305 mm) when reinforcing steel with a minimum yield strength of 60,000 psi (414 MPa) is used. Reinforcement shall not be less than one #4 bar at 48 inches (1.2 m) on center.

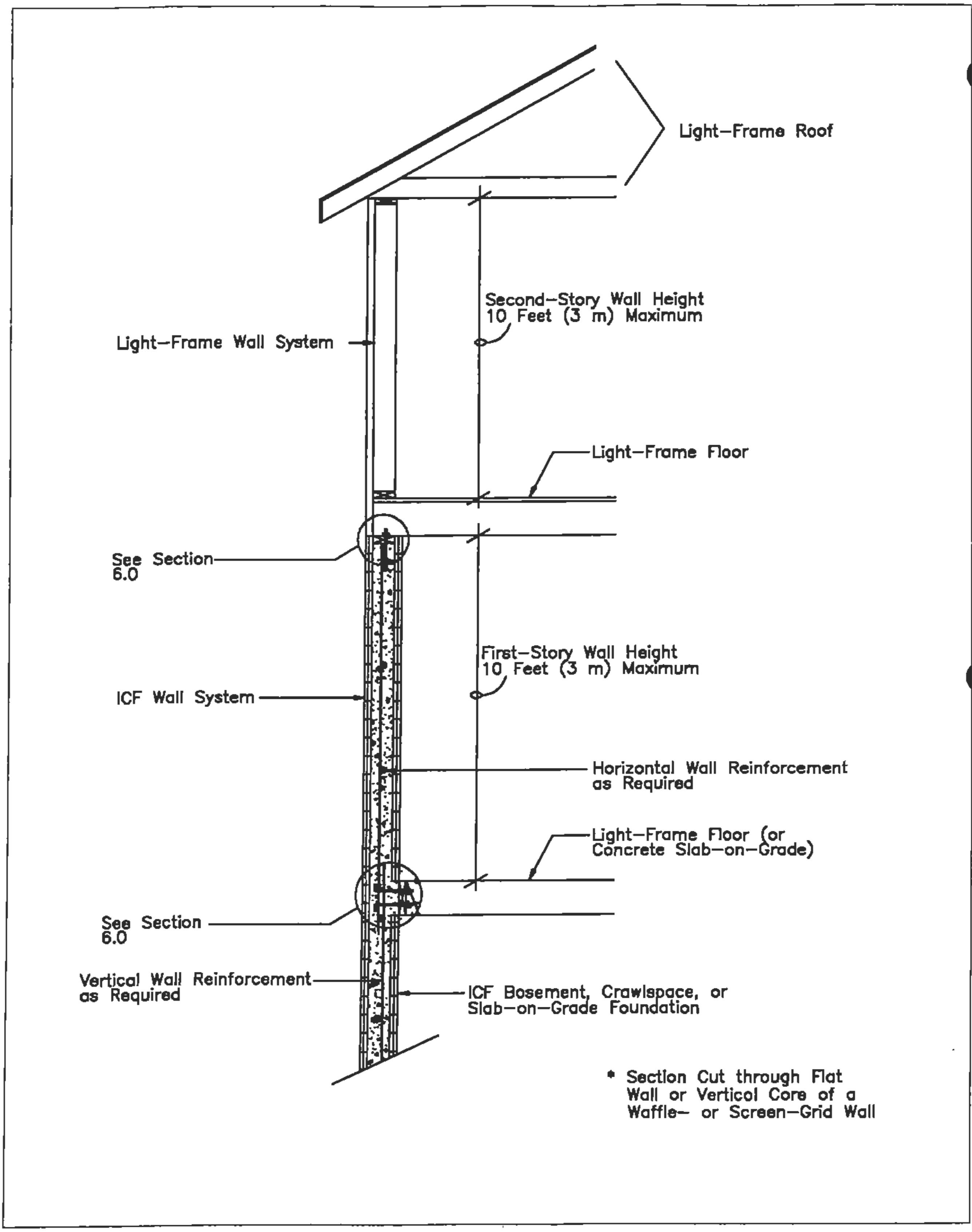



Figure 4.1 ICF Wall Supporting Light-Frame Roof

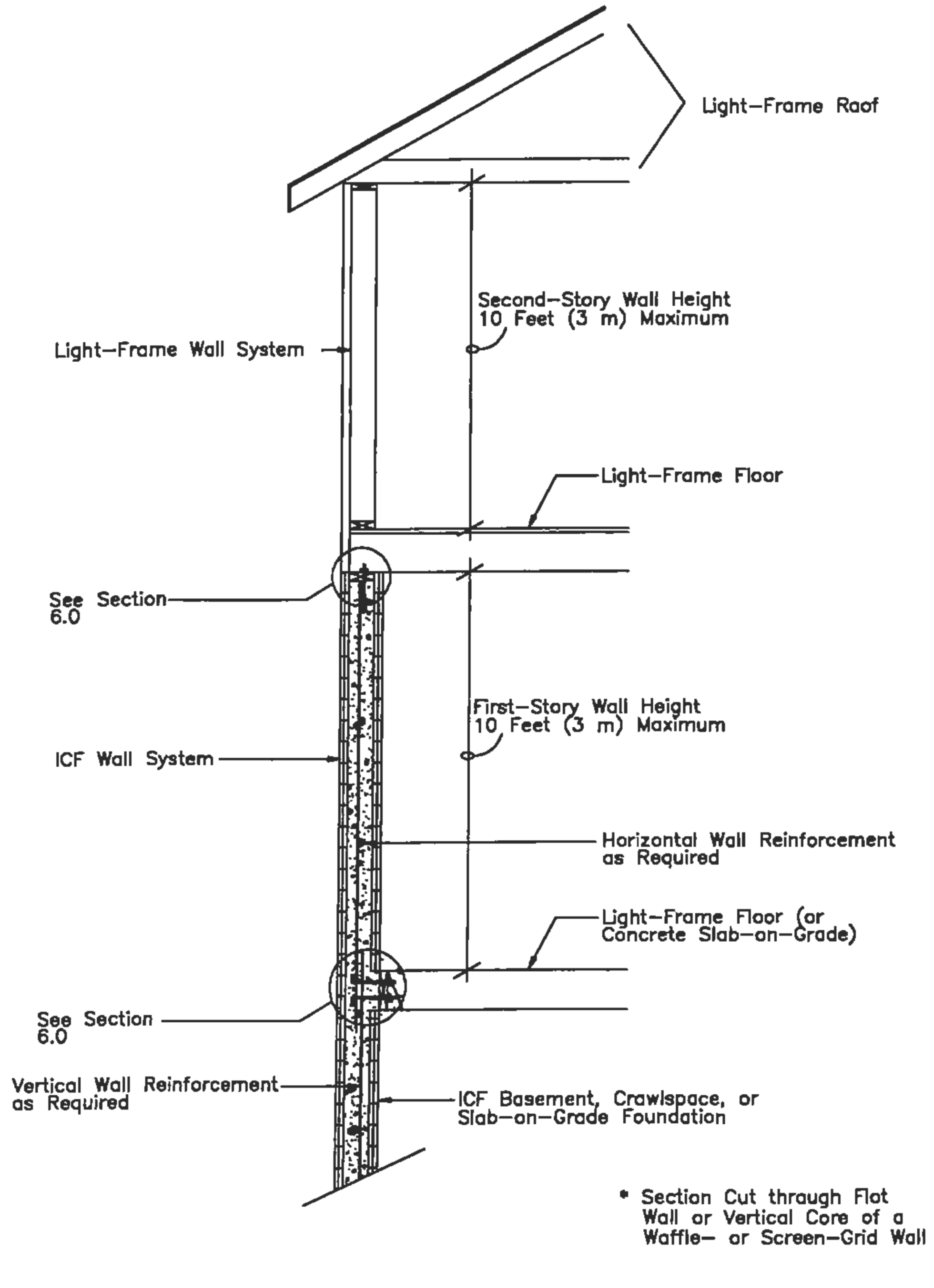



Figure 4.2 ICF Wall Supporting Light-Frame Second Story and Roof

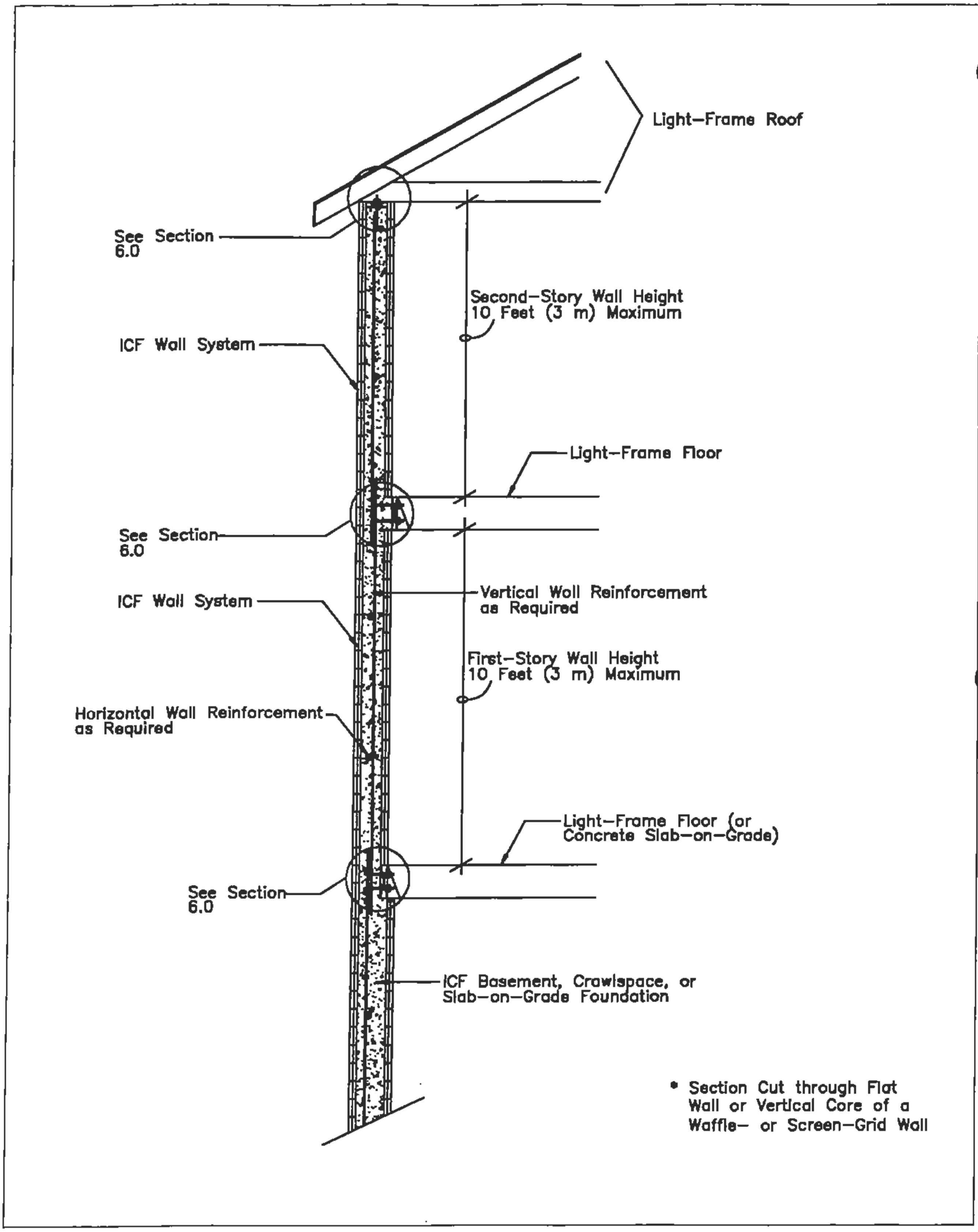



Figure 4.3 ICF Wall Supporting ICF Second Story and Light-Frame Roof

# 5.0 ICF WALL OPENING REQUIREMENTS

## 5.1 Minimum Length of ICF Wall without Openings

The wind velocity pressures of Table 5.1 shall be used to determine the minimum amount of solid wall length in accordance with Tables 5.2 through 5.4 and Figure 5.1. Table 5.5 shall be used to determine the minimum amount of solid wall length for Seismic Design Categories C, D1, and D2. The greater amount of solid wall length required by Tables 5.2 through 5.5 shall apply.

The amount of solid wall length shall include only those solid wall segments that are a minimum of 24 inches (610 mm) in length. The maximum allowable spacing of wall segments at least 24 inches (610 mm) in length shall be 18 feet (5.5 m) on center. A minimum length of 24 inches (610 mm) of solid wall segment, extending the full height of each wall story, shall occur at all interior and exterior corners of exterior walls.

For Seismic Design Categories D1 and D2, the amount of solid wall length shall include only those solid wall segments that are a minimum of 48 inches (1.2 mm) in length. A minimum length of 24 inches (610 mm) of solid wall segment, extending the full height of each wall story, shall occur at all interior and exterior corners of exterior walls. The minimum nominal wall thickness shall be 5.5 inches (140 mm) for all wall types.

## 5.2 Reinforcement around Openings

Openings in ICF walls shall be reinforced in accordance with Table 5.6 and Figure 5.2 in addition to the minimum wall reinforcement of Sections 3 and 4. Wall openings shall have a minimum depth of concrete over the length of the opening of 8 inches (203 mm) in flat and waffle-grid ICF walls and 12 inches (305 mm) in screen-grid ICF wall lintels. Wall openings in waffle-gridand screen-grid ICF walls shall be located such that no less than one-half of a vertical core occurs along each side of the opening.

**Exception:** Continuous horizontal wall reinforcement placed within 12 (305 mm) inches of the top of the wall story as required in Sections 3.0 and 4.0 is permitted to be used in lieu of top or bottom lintel reinforcement provided that the continuous horizontal wall reinforcement meets the location requirements specified in Figures 5.3, 5.4, and 5.5 and the size requirements specified in Tables 5.7 through 5.14.

All opening reinforcement placed horizontally above or below an opening shall extend a minimum of 24 inches (610 mm) beyond the limits of the opening. Where 24 inches (610 mm) cannot be obtained beyond the limit of the opening, the bar shall be bent 90 degrees in order to obtain a minimum 12-inch (305-mm) embedment.

## 5.3 Lintels

### 5.3.1 Load-Bearing ICF Wall Lintels

Lintels shall be provided in load-bearing walls over all openings greater than or equal to 2 feet (0.6 m) in width. Lintels without stirrup reinforcement shall be permitted for flat or waffle-grid ICF construction in load-bearing walls in accordance with Table 5.7. Lintels with stirrups for flat ICF walls shall be constructed in accordance with Figure 5.3 and Tables 5.8A and 5.8B. Lintels with stirrups for waffle-grid ICF walls shall be constructed in accordance with Figure 5.4 and Tables 5.9A and 5.9B. Lintels for screen-grid ICF walls shall be constructed in accordance with Figure 5.5 and Tables 5.10A and 5.10B. Lintel construction in accordance with Figure 5.3 and Tables 5.8A and 5.8B shall be permitted to be used with waffle-grid and screen-grid ICF wall construction. Lintels spanning between 12 feet – 3 inches (3.7 m) and 16 feet – 3 inches (5.0 m) shall be constructed in accordance with Table 5.11.

When required, No. 3 stirrups shall be installed in lintels at a maximum spacing of d/2 where d equals the depth of the lintel, D, less the bottom cover of the concrete as shown in Figures 5.3, 5.4, and 5.5. For flat and waffle-grid lintels, stirrups shall not be required in the middle portion of the span, A, in accordance with Figure 5.2 and Tables 5.12 and 5.13.

### 5.3.2 ICF Lintels Without Stirrups in Non Load-Bearing Walls

Lintels shall be provided in non-load-bearing walls over all openings greater than or equal to 2 feet (0.6 m) in length in accordance with Table 5.14. Stirrups shall not be required for lintels in gable end walls with spans less than or equal to those listed in Table 5.14.

**TABLE 5.1**
**WIND VELOCITY PRESSURE FOR DETERMINATION OF MINIMUM SOLID WALL LENGTH[1]**

| WIND SPEED (mph) | VELOCITY PRESSURE (psf) | | |
|---|---|---|---|
| | Exposure[2] | | |
| | B | C | D |
| 85 | 14 | 19 | 23 |
| 90 | 16 | 21 | 25 |
| 100 | 19 | 26 | 31 |
| 110 | 23 | 32 | 37 |
| 120 | 27 | 38 | 44 |
| 130 | 32 | 44 | 52 |
| 140 | 37 | 51 | 60 |
| 150 | 43 | 59 | 69[3] |

For SI: 1 psf = 0.0479 kN/m$^2$; 1 mph = 1.6093 km/hr

[1] Table values are based on ASCE 7-98 Figure 6-4 wind velocity pressures for low-rise buildings using a mean roof height of 35 ft (10.7 m).

[2] Exposure Categories are as defined in Section 1.5.

[3] Design is required in accordance with acceptable practice and approved manufacturer guide lines.

# TABLE 5.2A
# MINIMUM SOLID END WALL LENGTH REQUIREMENTS FOR FLAT ICF WALLS (WIND PERPENDICULAR TO RIDGE)[1,2,3,4,5]

| DESIGN VELOCITY PRESSURE (psf) | | | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 60 |
|---|---|---|---|---|---|---|---|---|---|---|
| WALL CATEGORY | BUILDING SIDE WALL LENGTH, L (feet) | ROOF SLOPE | MINIMUM SOLID WALL LENGTH ON BUILDING END WALL (feet) | | | | | | | |
| One-Story or Top Story of Two-Story | 16 | ≤ 1:12 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 |
| | | 5:12 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.25 | 4.50 |
| | | 7:12[4] | 4.00 | 4.25 | 4.25 | 4.50 | 4.75 | 4.75 | 5.00 | 5.50 |
| | | 12:12[4] | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 5.75 | 6.25 |
| | 24 | ≤ 1:12 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.25 | 4.50 |
| | | 5:12 | 4.00 | 4.00 | 4.00 | 4.25 | 4.25 | 4.50 | 4.50 | 4.75 |
| | | 7:12[4] | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 5.75 | 6.25 |
| | | 12:12[4] | 4.75 | 5.00 | 5.25 | 5.75 | 6.00 | 6.50 | 6.75 | 7.50 |
| | 32 | ≤ 1:12 | 4.00 | 4.00 | 4.00 | 4.00 | 4.25 | 4.25 | 4.50 | 4.75 |
| | | 5:12 | 4.00 | 4.00 | 4.25 | 4.50 | 4.50 | 4.75 | 5.00 | 5.25 |
| | | 7:12[4] | 4.50 | 5.00 | 5.25 | 5.50 | 6.00 | 6.25 | 6.50 | 7.25 |
| | | 12:12[4] | 5.00 | 5.50 | 6.00 | 6.50 | 7.00 | 7.25 | 7.75 | 8.75 |
| | 40 | ≤ 1:12 | 4.00 | 4.00 | 4.25 | 4.25 | 4.50 | 4.50 | 4.75 | 5.00 |
| | | 5:12 | 4.00 | 4.25 | 4.50 | 4.75 | 4.75 | 5.00 | 5.25 | 5.50 |
| | | 7:12[4] | 4.75 | 5.25 | 5.75 | 6.00 | 6.50 | 7.00 | 7.25 | 8.00 |
| | | 12:12[4] | 5.50 | 6.00 | 6.50 | 7.25 | 7.75 | 8.25 | 8.75 | 10.00 |
| | 50 | ≤ 1:12 | 4.00 | 4.25 | 4.25 | 4.50 | 4.75 | 4.75 | 5.00 | 5.50 |
| | | 5:12 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 5.75 | 6.00 |
| | | 7:12[4] | 5.25 | 5.75 | 6.25 | 6.75 | 7.25 | 7.75 | 8.25 | 9.25 |
| | | 12:12[4] | 6.00 | 6.75 | 7.50 | 8.00 | 8.75 | 9.50 | 10.25 | 11.50 |
| | 60 | ≤ 1:12 | 4.00 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.25 | 5.75 |
| | | 5:12 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 5.75 | 6.00 | 6.75 |
| | | 7:12[4] | 5.50 | 6.25 | 6.75 | 7.50 | 8.00 | 8.50 | 9.25 | 10.25 |
| | | 12:12[4] | 6.50 | 7.25 | 8.25 | 9.00 | 9.75 | 10.50 | 11.50 | 13.00 |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 psf = 0.0479 kN/$m^2$

1 Table values are based on reinforcing bars with a minimum yield strength of 40,000 psi (276 MPa) and concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa).

2 Table values are based on a 3.5 in (88.9 mm) thick flat wall. For a 5.5 in (139.7 mm) thick flat wall, multiply the table values by 0.9. The adjusted values shall not result in solid wall lengths less than 4 ft.

3 Table values are based on a maximum unsupported wall height of 10 ft (3.0 m).

4 Values are based on a 30 feet (9.1 m) building end wall width. For a 45 ft (13.7 m) building end wall and roof pitches greater than 7:12, multiply the table values by 1.2. For a 60 ft (18.3 m) building end wall and roof pitches greater than 7:12, multiply the table values by 1.4.

5 Linear interpolation shall be permitted.

## TABLE 5.2B
## MINIMUM SOLID END WALL LENGTH REQUIREMENTS FOR FLAT ICF WALLS (WIND PERPENDICULAR TO RIDGE)[1,2,3,4,5]

| DESIGN VELOCITY PRESSURE (psf) | | | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 60 |
|---|---|---|---|---|---|---|---|---|---|---|
| WALL CATEGORY | BUILDING SIDE WALL LENGTH, L (feet) | ROOF SLOPE | MINIMUM SOLID WALL LENGTH ON BUILDING END WALL (feet) | | | | | | | |
| First Story of Two-Story | 16 | ≤ 1:12 | 4.00 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.25 | 5.75 |
| | | 5:12 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 5.75 | 6.00 | 6.75 |
| | | 7:12[4] | 4.50 | 5.00 | 5.25 | 5.75 | 6.00 | 6.25 | 6.75 | 7.25 |
| | | 12:12[4] | 5.00 | 5.25 | 5.75 | 6.25 | 6.50 | 7.00 | 7.25 | 8.25 |
| | 24 | ≤ 1:12 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 5.75 | 6.00 | 6.75 |
| | | 5:12 | 4.75 | 5.25 | 5.50 | 6.00 | 6.25 | 6.75 | 7.00 | 7.75 |
| | | 7:12[4] | 5.25 | 5.75 | 6.25 | 6.75 | 7.00 | 7.50 | 8.00 | 9.00 |
| | | 12:12[4] | 5.50 | 6.25 | 6.75 | 7.25 | 8.00 | 8.50 | 9.00 | 10.25 |
| | 32 | ≤ 1:12 | 4.75 | 5.00 | 5.50 | 5.75 | 6.25 | 6.50 | 6.75 | 7.50 |
| | | 5:12 | 5.25 | 5.75 | 6.25 | 6.75 | 7.25 | 7.50 | 8.00 | 9.00 |
| | | 7:12[4] | 5.75 | 6.50 | 7.00 | 7.75 | 8.25 | 9.00 | 9.50 | 10.75 |
| | | 12:12[4] | 6.25 | 7.00 | 7.75 | 8.50 | 9.25 | 10.00 | 10.75 | 12.25 |
| | 40 | ≤ 1:12 | 5.00 | 5.50 | 5.75 | 6.25 | 6.75 | 7.25 | 7.50 | 8.50 |
| | | 5:12 | 5.50 | 6.25 | 6.75 | 7.25 | 8.00 | 8.50 | 9.00 | 10.25 |
| | | 7:12[4] | 6.25 | 7.00 | 7.75 | 8.75 | 9.50 | 10.25 | 11.00 | 12.50 |
| | | 12:12[4] | 7.00 | 8.00 | 8.75 | 9.75 | 10.75 | 11.50 | 12.50 | 14.25 |
| | 50 | ≤ 1:12 | 5.50 | 6.00 | 6.50 | 7.00 | 7.50 | 8.00 | 8.50 | 9.50 |
| | | 5:12 | 6.00 | 6.75 | 7.50 | 8.25 | 9.00 | 9.75 | 10.50 | 11.75 |
| | | 7:12[4] | 7.00 | 8.00 | 9.00 | 10.00 | 10.75 | 11.75 | 12.75 | 14.50 |
| | | 12:12[4] | 7.75 | 9.00 | 10.00 | 11.25 | 12.25 | 13.50 | 14.75 | 17.00 |
| | 60 | ≤ 1:12 | 5.75 | 6.50 | 7.00 | 7.50 | 8.25 | 8.75 | 9.50 | 10.75 |
| | | 5:12 | 6.75 | 7.50 | 8.25 | 9.25 | 10.00 | 10.75 | 11.75 | 13.25 |
| | | 7:12[4] | 7.75 | 9.00 | 10.00 | 11.00 | 12.25 | 13.25 | 14.50 | 16.75 |
| | | 12:12[4] | 8.75 | 10.00 | 11.50 | 12.75 | 14.00 | 15.50 | 16.75 | 19.50 |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 psf = 0.0479 kN/$m^2$

1 Table values are based on reinforcing bars with a minimum yield strength of 40,000 psi (276 MPa) and concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa).

2 Table values are based on a 3.5 in (88.9 mm) thick flat wall. For a 5.5 in (139.7 mm) thick flat wall, multiply the table values by 0.9. The adjusted values shall not result in solid wall lengths less than 4 ft.

3 Table values are based on a maximum unsupported wall height of 10 ft (3.0 m).

4 Values are based on a 30 feet (9.1 m) building end wall width. For a 45 ft (13.7 m) building end wall and roof pitches greater than 7:12, multiply the table values by 1.2. For a 60 ft (18.3 m) building end wall and roof pitches greater than 7:12, multiply the table values by 1.4.

5 Linear interpolation shall be permitted.

## TABLE 5.2C
## MINIMUM SOLID SIDE WALL LENGTH REQUIREMENTS FOR FLAT ICF WALLS (WIND PARALLEL TO RIDGE)[1,2,3,4,5]

| DESIGN VELOCITY PRESSURE (psf) | | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 60 |
|---|---|---|---|---|---|---|---|---|---|
| WALL CATEGORY | BUILDING END WALL WIDTH, W (feet) | MINIMUM SOLID WALL LENGTH ON BUILDING SIDE WALL (feet) | | | | | | | |
| One-Story or Top Story of Two-Story | 16 | 4.00 | 4.00 | 4.00 | 4.00 | 4.25 | 4.25 | 4.50 | 4.75 |
| | 24 | 4.00 | 4.25 | 4.50 | 4.75 | 4.75 | 5.00 | 5.25 | 5.50 |
| | 32 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 6.00 | 6.25 | 6.75 |
| | 40 | 5.00 | 5.50 | 5.75 | 6.25 | 6.75 | 7.00 | 7.50 | 8.25 |
| | 50 | 5.75 | 6.25 | 7.00 | 7.50 | 8.25 | 8.75 | 9.50 | 10.75 |
| | 60 | 6.50 | 7.50 | 8.25 | 9.25 | 10.00 | 10.75 | 11.75 | 13.25 |
| First Story of Two-Story | 16 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 5.75 | 6.50 |
| | 24 | 4.75 | 5.25 | 5.50 | 6.00 | 6.25 | 6.75 | 7.00 | 8.00 |
| | 32 | 5.50 | 6.00 | 6.50 | 7.00 | 7.50 | 8.00 | 8.75 | 9.75 |
| | 40 | 6.25 | 7.00 | 7.50 | 8.25 | 9.00 | 9.75 | 10.50 | 12.00 |
| | 50 | 7.25 | 8.25 | 9.25 | 10.25 | 11.25 | 12.25 | 13.25 | 15.25 |
| | 60 | 8.50 | 9.75 | 11.00 | 12.25 | 13.50 | 15.00 | 16.25 | 18.75 |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 psf = 0.0479 $kN/m^2$

[1] Table values are based on reinforcing bars with a minimum yield strength of 40,000 psi (276 MPa) and concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa).

[2] Table values are based on a 3.5 in (88.9 mm) thick flat wall. For a 5.5 in (139.7 mm) thick flat wall, multiply the table values by 0.9. The adjusted values may not result in solid wall lengths less than 4 ft.

[3] Table values are based on a maximum unsupported wall height of 10 ft (3.0 m).

[4] Table values are based on a maximum 12:12 roof pitch.

[5] Linear interpolation shall be permitted.

## TABLE 5.3A
## MINIMUM SOLID END WALL LENGTH REQUIREMENTS FOR WAFFLE-GRID ICF WALLS (WIND PERPENDICULAR TO RIDGE) 1,2,5,4,5

| DESIGN VELOCITY PRESSURE (psf) | | | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 60 |
|---|---|---|---|---|---|---|---|---|---|---|
| WALL CATEGORY | BUILDING SIDE WALL LENGTH, L (feet) | ROOF SLOPE | MINIMUM SOLID WALL LENGTH ON BUILDING END WALL (feet) | | | | | | | |
| One-Story or Top Story of Two-Story | 16 | ≤ 1:12 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.25 |
| | | 5:12 | 4.00 | 4.00 | 4.00 | 4.00 | 4.25 | 4.25 | 4.50 | 4.75 |
| | | 7:12[4] | 4.00 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 6.00 |
| | | 12:12[4] | 4.50 | 4.75 | 5.00 | 5.50 | 5.75 | 6.00 | 6.50 | 7.00 |
| | 24 | ≤ 1:12 | 4.00 | 4.00 | 4.00 | 4.00 | 4.25 | 4.25 | 4.50 | 4.75 |
| | | 5:12 | 4.00 | 4.00 | 4.25 | 4.25 | 4.50 | 4.75 | 4.75 | 5.25 |
| | | 7:12[4] | 4.50 | 4.75 | 5.25 | 5.50 | 5.75 | 6.25 | 6.50 | 7.25 |
| | | 12:12[4] | 5.00 | 5.50 | 6.00 | 6.50 | 7.00 | 7.50 | 7.75 | 8.75 |
| | 32 | ≤ 1:12 | 4.00 | 4.00 | 4.00 | 4.25 | 4.50 | 4.50 | 4.75 | 5.00 |
| | | 5:12 | 4.00 | 4.25 | 4.50 | 4.75 | 4.75 | 5.00 | 5.25 | 5.75 |
| | | 7:124 | 5.00 | 5.25 | 5.75 | 6.25 | 6.75 | 7.00 | 7.50 | 8.50 |
| | | 12:12[4] | 5.50 | 6.25 | 6.75 | 7.50 | 8.00 | 8.75 | 9.25 | 10.50 |
| | 40 | ≤ 1:12 | 4.00 | 4.00 | 4.25 | 4.50 | 4.75 | 5.00 | 5.00 | 5.50 |
| | | 5:12 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 5.75 | 6.25 |
| | | 7:12[4] | 5.25 | 5.75 | 6.25 | 7.00 | 7.50 | 8.00 | 8.50 | 9.50 |
| | | 12:12[4] | 6.25 | 7.00 | 7.75 | 8.50 | 9.25 | 10.00 | 10.75 | 12.25 |
| | 50 | ≤ 1:12 | 4.00 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 6.00 |
| | | 5:12 | 4.50 | 4.75 | 5.00 | 5.25 | 5.75 | 6.00 | 6.25 | 7.00 |
| | | 7:12[4] | 5.75 | 6.50 | 7.25 | 7.75 | 8.50 | 9.25 | 9.75 | 11.00 |
| | | 12:12[4] | 6.75 | 7.75 | 8.75 | 9.50 | 10.50 | 11.50 | 12.50 | 14.25 |
| | 60 | ≤ 1:12 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.75 | 6.00 | 6.50 |
| | | 5:12 | 4.75 | 5.25 | 5.50 | 5.75 | 6.25 | 6.50 | 7.00 | 7.75 |
| | | 7:12[4] | 6.25 | 7.25 | 8.00 | 8.75 | 9.50 | 10.25 | 11.00 | 12.75 |
| | | 12:12[4] | 7.50 | 8.75 | 9.75 | 10.75 | 12.00 | 13.00 | 14.25 | 16.25 |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 psf = 0.0479 kN/m$^2$

[1]Table values are based on reinforcing bars with a minimum yield strength of 40,000 psi (276 MPa) and concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa).

[2]Table values are based on a 6 in (152.4 mm) thick nominal waffle-grid wall. For a 8 in (203.2 mm) thick nominal waffle-grid wall, multiply the table values by 0.9.

[3]Table values are based on a maximum unsupported wall height of 10 ft (3.0 m).

[4]Table values are based on a 30 feet (9.1 m) building end wall width, W. For a 45 ft (13.7 m) building end wall and roof pitches greater than 7:12, multiply the table values by 1.2. For a 60 ft (18.3 m) building end wall and roof pitches greater than 7:12, multiply the table values by 1.4.

[5]Linear interpolation shall be permitted.

## TABLE 5.3B
## MINIMUM SOLID END WALL LENGTH REQUIREMENTS FOR WAFFLE-GRID ICF WALLS (WIND PERPENDICULAR TO RIDGE)[1,2,3,4,5]

| DESIGN VELOCITY PRESSURE (psf) | | | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 60 |
|---|---|---|---|---|---|---|---|---|---|---|
| WALL CATEGORY | BUILDING SIDE WALL LENGTH, L (feet) | ROOF SLOPE | MINIMUM SOLID WALL LENGTH ON BUILDING END WALL (feet) | | | | | | | |
| First Story of Two-Story | 16 | ≤ 1:12 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.75 | 6.00 | 6.50 |
| | | 5:12 | 4.75 | 5.00 | 5.50 | 5.75 | 6.25 | 6.50 | 7.00 | 7.75 |
| | | 7:12[4] | 5.00 | 5.50 | 5.75 | 6.25 | 6.75 | 7.25 | 7.75 | 8.50 |
| | | 12:12[4] | 5.25 | 6.00 | 6.50 | 7.00 | 7.50 | 8.00 | 8.75 | 9.75 |
| | 24 | ≤ 1:12 | 4.75 | 5.00 | 5.50 | 5.75 | 6.25 | 6.50 | 7.00 | 7.75 |
| | | 5:12 | 5.25 | 5.75 | 6.25 | 6.75 | 7.25 | 7.75 | 8.25 | 9.25 |
| | | 7:12[4] | 5.75 | 6.25 | 7.00 | 7.75 | 8.25 | 9.00 | 9.50 | 11.00 |
| | | 12:12[4] | 6.25 | 7.00 | 7.75 | 8.50 | 9.50 | 10.25 | 11.00 | 12.50 |
| | 32 | ≤ 1:12 | 5.00 | 5.50 | 6.00 | 6.50 | 7.00 | 7.50 | 8.00 | 9.00 |
| | | 5:12 | 5.75 | 6.50 | 7.00 | 7.75 | 8.25 | 9.00 | 9.75 | 11.00 |
| | | 7:12[4] | 6.50 | 7.25 | 8.25 | 9.00 | 9.75 | 10.75 | 11.50 | 13.25 |
| | | 12:12[4] | 7.25 | 8.25 | 9.25 | 10.25 | 11.25 | 12.25 | 13.25 | 15.25 |
| | 40 | ≤ 1:12 | 5.50 | 6.00 | 6.75 | 7.25 | 7.75 | 8.50 | 9.00 | 10.25 |
| | | 5:12 | 6.25 | 7.00 | 7.75 | 8.75 | 9.50 | 10.25 | 11.00 | 12.50 |
| | | 7:12[4] | 7.25 | 8.25 | 9.25 | 10.25 | 11.50 | 12.50 | 13.50 | 15.50 |
| | | 12:12[4] | 8.00 | 9.25 | 10.50 | 11.75 | 13.00 | 14.25 | 15.50 | 18.00 |
| | 50 | ≤ 1:12 | 6.00 | 6.75 | 7.50 | 8.00 | 8.75 | 9.50 | 10.25 | 11.75 |
| | | 5:12 | 7.00 | 8.00 | 9.00 | 9.75 | 10.75 | 11.75 | 12.75 | 14.75 |
| | | 7:12[4] | 8.25 | 9.50 | 10.75 | 12.00 | 13.25 | 14.50 | 15.75 | 18.50 |
| | | 12:12[4] | 9.25 | 10.75 | 12.25 | 13.75 | 15.50 | 17.00 | 18.50 | 21.50 |
| | 60 | ≤ 1:12 | 6.50 | 7.25 | 8.25 | 9.00 | 9.75 | 10.75 | 11.50 | 13.25 |
| | | 5:12 | 7.75 | 8.75 | 10.00 | 11.00 | 12.25 | 13.25 | 14.50 | 16.75 |
| | | 7:12[4] | 9.25 | 10.75 | 12.25 | 13.75 | 15.25 | 16.75 | 18.25 | 21.25 |
| | | 12:12[4] | 10.50 | 12.25 | 14.00 | 15.75 | 17.75 | 19.50 | 21.25 | 25.00 |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 psf = 0.0479 kN/m$^2$

1 Table values are based on reinforcing bars with a minimum yield strength of 40,000 psi (276 MPa) and concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa).

2 Table values are based on a 6 in (152.4 mm) thick nominal waffle-grid wall. For a 8 in (203.2 mm) thick nominal waffle-grid wall, multiply the table values by 0.9.

3 Table values are based on a maximum unsupported wall height of 10 ft (3.0 m).

4 Table values are based on a 30 feet (9.1 m) building end wall width, W. For a 45 ft (13.7 m) building end wall and roof pitches greater than 7:12, multiply the table values by 1.2. For a 60 ft (18.3 m) building end wall and roof pitches greater than 7:12, multiply the table values by 1.4.

5 Linear interpolation shall be permitted.

## TABLE 5.3C
## MINIMUM SOLID SIDE WALL LENGTH REQUIREMENTS FOR WAFFLE-GRID ICF WALLS (WIND PARALLEL TO RIDGE) [1,2,3,4,5]

| DESIGN VELOCITY PRESSURE (psf) | | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 60 |
|---|---|---|---|---|---|---|---|---|---|
| WALL CATEGORY | BUILDING END WALL WIDTH, W (feet) | MINIMUM SOLID WALL LENGTH ON BUILDING SIDE WALL (feet) | | | | | | | |
| One-Story or Top Story of Two-Story | 16 | 4.00 | 4.00 | 4.00 | 4.25 | 4.50 | 4.50 | 4.75 | 5.00 |
| | 24 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 5.75 | 6.25 |
| | 32 | 4.75 | 5.00 | 5.50 | 6.00 | 6.25 | 6.75 | 7.00 | 8.00 |
| | 40 | 5.50 | 6.00 | 6.50 | 7.00 | 7.75 | 8.25 | 8.75 | 10.00 |
| | 50 | 6.50 | 7.25 | 8.00 | 9.00 | 9.75 | 10.50 | 11.50 | 13.00 |
| | 60 | 7.75 | 8.75 | 10.00 | 11.00 | 12.25 | 13.25 | 14.50 | 16.75 |
| First Story of Two-Story | 16 | 4.50 | 5.00 | 5.25 | 5.50 | 6.00 | 6.25 | 6.75 | 7.25 |
| | 24 | 5.25 | 5.75 | 6.25 | 6.75 | 7.25 | 7.75 | 8.25 | 9.25 |
| | 32 | 6.00 | 6.75 | 7.50 | 8.25 | 9.00 | 9.75 | 10.25 | 11.75 |
| | 40 | 7.00 | 8.00 | 9.00 | 10.00 | 11.00 | 12.00 | 13.00 | 14.75 |
| | 50 | 8.50 | 9.75 | 11.25 | 12.50 | 13.75 | 15.25 | 16.50 | 19.25 |
| | 60 | 10.00 | 11.75 | 13.50 | 15.25 | 17.00 | 18.75 | 20.50 | 24.00 |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 psf = 0.0479 kN/m$^2$

[1] Table values are based on reinforcing bars with a minimum yield strength of 40,000 psi (276 MPa) and concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa).

[2] Table values are based on a 6 in (152.4 mm) thick nominal waffle-grid wall. For a 8 in (203.2 mm) thick nominal waffle-grid wall, multiply the table values by 0.9.

[3] Table values are based on a maximum unsupported wall height of 10 ft (3.0 m).

[4] Table values are based on a maximum 12:12 roof pitch.

[5] Linear interpolation shall be permitted.

# TABLE 5.4A
## MINIMUM SOLID END WALL LENGTH REQUIREMENTS FOR SCREEN-GRID ICF WALLS (WIND PERPENDICULAR TO RIDGE) [1,2,3,4,5]

| DESIGN VELOCITY PRESSURE (psf) | | | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 60 |
|---|---|---|---|---|---|---|---|---|---|---|
| WALL CATEGORY | BUILDING SIDE WALL LENGTH, L (feet) | ROOF SLOPE | MINIMUM SOLID WALL LENGTH ON BUILDING END WALL (feet) | | | | | | | |
| One-Story or Top Story of Two-Story | 16 | ≤ 1:12 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.25 |
| | | 5:12 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.25 | 4.25 | 4.50 |
| | | 7:12[4] | 4.00 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 6.00 |
| | | 12:12[4] | 4.25 | 4.75 | 5.00 | 5.50 | 5.75 | 6.00 | 6.50 | 7.00 |
| | 24 | ≤ 1:12 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.25 | 4.25 | 4.50 |
| | | 5:12 | 4.00 | 4.00 | 4.00 | 4.25 | 4.50 | 4.50 | 4.75 | 5.00 |
| | | 7:12[4] | 4.50 | 4.75 | 5.00 | 5.50 | 5.75 | 6.25 | 6.50 | 7.25 |
| | | 12:12[4] | 5.00 | 5.50 | 6.00 | 6.50 | 7.00 | 7.25 | 7.75 | 8.75 |
| | 32 | ≤ 1:12 | 4.00 | 4.00 | 4.00 | 4.25 | 4.25 | 4.50 | 4.75 | 5.00 |
| | | 5:12 | 4.00 | 4.00 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.75 |
| | | 7:12[4] | 4.75 | 5.25 | 5.75 | 6.25 | 6.50 | 7.00 | 7.50 | 8.50 |
| | | 12:12[4] | 5.50 | 6.25 | 6.75 | 7.50 | 8.00 | 8.75 | 9.25 | 10.50 |
| | 40 | ≤ 1:12 | 4.00 | 4.00 | 4.25 | 4.50 | 4.50 | 4.75 | 5.00 | 5.50 |
| | | 5:12 | 4.00 | 4.25 | 4.50 | 5.00 | 5.25 | 5.50 | 5.75 | 6.25 |
| | | 7:12[4] | 5.25 | 5.75 | 6.25 | 7.00 | 7.50 | 8.00 | 8.50 | 9.75 |
| | | 12:12[4] | 6.00 | 6.75 | 7.75 | 8.50 | 9.25 | 10.00 | 10.75 | 12.25 |
| | 50 | ≤ 1:12 | 4.00 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 6.00 |
| | | 5:12 | 4.25 | 4.75 | 5.00 | 5.25 | 5.50 | 6.00 | 6.25 | 7.00 |
| | | 7:12[4] | 5.75 | 6.50 | 7.00 | 7.75 | 8.50 | 9.25 | 9.75 | 11.25 |
| | | 12:12[4] | 6.75 | 7.75 | 8.75 | 9.75 | 10.75 | 11.50 | 12.50 | 14.50 |
| | 60 | ≤ 1:12 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 5.75 | 6.50 |
| | | 5:12 | 4.50 | 5.00 | 5.25 | 5.75 | 6.00 | 6.50 | 6.75 | 7.75 |
| | | 7:12[4] | 6.25 | 7.00 | 8.00 | 8.75 | 9.50 | 10.25 | 11.25 | 12.75 |
| | | 12:12[4] | 7.50 | 8.75 | 9.75 | 11.00 | 12.00 | 13.25 | 14.25 | 16.50 |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 psf = 0.0479 kN/$m^2$

[1] Table values are based on reinforcing bars with a minimum yield strength of 40,000 psi (276 MPa) and concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa).

[2] Table values are based on a 6 in (152.4 mm) thick nominal screen-grid wall.

[3] Table values are based on a maximum unsupported wall height of 10 ft (3.0 m).

[4] Table values are based on a 30 feet (9.1 m) building end wall width, W. For a 45 ft (13.7 m) building end wall and roof pitches greater than 7:12, multiply the table values by 1.2. For a 60 ft (18.3 m) building end wall and roof pitches greater than 7:12, multiply the table values by 1.4.

[5] Linear interpolation shall be permitted.

## TABLE 5.4B
## MINIMUM SOLID END WALL LENGTH REQUIREMENTS FOR SCREEN-GRID ICF WALLS (WIND PERPENDICULAR TO RIDGE)[1,2,3,4,5]

| DESIGN VELOCITY PRESSURE (psf) | | | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 60 |
|---|---|---|---|---|---|---|---|---|---|---|
| WALL CATEGORY | BUILDING SIDE WALL LENGTH, L (feet) | ROOF SLOPE | MINIMUM SOLID WALL LENGTH ON BUILDING END WALL (feet) | | | | | | | |
| First Story of Two-Story | 16 | ≤ 1:12 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 5.75 | 6.50 |
| | | 5:12 | 4.50 | 5.00 | 5.25 | 5.75 | 6.00 | 6.50 | 6.75 | 7.75 |
| | | 7:124 | 4.75 | 5.25 | 5.75 | 6.25 | 6.75 | 7.25 | 7.75 | 8.75 |
| | | 12:124 | 5.25 | 5.75 | 6.50 | 7.00 | 7.50 | 8.00 | 8.75 | 9.75 |
| | 24 | ≤ 1:12 | 4.50 | 5.00 | 5.25 | 5.75 | 6.25 | 6.50 | 7.00 | 7.75 |
| | | 5:12 | 5.00 | 5.75 | 6.25 | 6.75 | 7.25 | 7.75 | 8.25 | 9.25 |
| | | 7:124 | 5.75 | 6.25 | 7.00 | 7.75 | 8.25 | 9.00 | 9.75 | 11.00 |
| | | 12:124 | 6.25 | 7.00 | 7.75 | 8.50 | 9.50 | 10.25 | 11.00 | 12.75 |
| | 32 | ≤ 1:12 | 5.00 | 5.50 | 6.00 | 6.50 | 7.00 | 7.50 | 8.00 | 9.00 |
| | | 5:12 | 5.75 | 6.25 | 7.00 | 7.75 | 8.25 | 9.00 | 9.75 | 11.00 |
| | | 7:124 | 6.50 | 7.25 | 8.25 | 9.00 | 10.00 | 10.75 | 11.75 | 13.50 |
| | | 12:124 | 7.25 | 8.25 | 9.25 | 10.25 | 11.25 | 12.50 | 13.50 | 15.50 |
| | 40 | ≤ 1:12 | 5.50 | 6.00 | 6.50 | 7.25 | 7.75 | 8.50 | 9.00 | 10.25 |
| | | 5:12 | 6.25 | 7.00 | 7.75 | 8.75 | 9.50 | 10.25 | 11.00 | 12.75 |
| | | 7:124 | 7.25 | 8.25 | 9.25 | 10.50 | 11.50 | 12.50 | 13.75 | 15.75 |
| | | 12:124 | 8.00 | 9.50 | 10.75 | 12.00 | 13.25 | 14.50 | 15.75 | 18.25 |
| | 50 | ≤ 1:12 | 6.00 | 6.75 | 7.50 | 8.00 | 8.75 | 9.50 | 10.25 | 11.75 |
| | | 5:12 | 7.00 | 8.00 | 9.00 | 10.00 | 11.00 | 12.00 | 13.00 | 14.75 |
| | | 7:124 | 8.25 | 9.50 | 10.75 | 12.25 | 13.50 | 14.75 | 16.00 | 18.75 |
| | | 12:124 | 9.25 | 11.00 | 12.50 | 14.00 | 15.50 | 17.25 | 18.75 | 22.00 |
| | 60 | ≤ 1:12 | 6.50 | 7.25 | 8.25 | 9.00 | 10.00 | 10.75 | 11.75 | 13.25 |
| | | 5:12 | 7.75 | 8.75 | 10.00 | 11.25 | 12.25 | 13.50 | 14.75 | 17.00 |
| | | 7:124 | 9.25 | 10.75 | 12.25 | 14.00 | 15.50 | 17.00 | 18.50 | 21.75 |
| | | 12:124 | 10.50 | 12.25 | 14.25 | 16.25 | 18.00 | 20.00 | 21.75 | 25.50 |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 psf = 0.0479 kN/m$^2$

[1] Table values are based on reinforcing bars with a minimum yield strength of 40,000 psi (276 MPa) and concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa).

[2] Table values are based on a 6 in (152.4 mm) thick nominal screen-grid wall.

[3] Table values are based on a maximum unsupported wall height of 10 ft (3.0 m).

[4] Table values are based on a 30 feet (9.1 m) building end wall width, W. For a 45 ft (13.7 m) building end wall and roof pitches greater than 7:12, multiply the table values by 1.2. For a 60 ft (18.3 m) building end wall and roof pitches greater than 7:12, multiply the table values by 1.4.

[5] Linear interpolation shall be permitted.

# TABLE 5.4C
# MINIMUM SOLID SIDE WALL LENGTH REQUIREMENTS FOR SCREEN-GRID ICF WALLS (WIND PARALLEL TO RIDGE) [1,2,3,4,5]

| DESIGN VELOCITY PRESSURE (psf) | | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 60 |
|---|---|---|---|---|---|---|---|---|---|
| WALL CATEGORY | BUILDING END WALL WIDTH, W (feet) | MINIMUM SOLID WALL LENGTH ON BUILDING SIDE WALL (feet) | | | | | | | |
| One-Story or Top Story of Two-Story | 16 | 4.00 | 4.00 | 4.00 | 4.25 | 4.25 | 4.50 | 4.75 | 5.00 |
| | 24 | 4.00 | 4.25 | 4.50 | 5.00 | 5.25 | 5.50 | 5.75 | 6.25 |
| | 32 | 4.50 | 5.00 | 5.50 | 5.75 | 6.25 | 6.75 | 7.00 | 8.00 |
| | 40 | 5.25 | 6.00 | 6.50 | 7.00 | 7.75 | 8.25 | 8.75 | 10.00 |
| | 50 | 6.50 | 7.25 | 8.00 | 9.00 | 9.75 | 10.75 | 11.50 | 13.25 |
| | 60 | 7.75 | 8.75 | 10.00 | 11.25 | 12.25 | 13.50 | 14.50 | 17.00 |
| First Story of Two-Story | 16 | 4.50 | 4.75 | 5.25 | 5.50 | 5.75 | 6.25 | 6.50 | 7.25 |
| | 24 | 5.00 | 5.75 | 6.25 | 6.75 | 7.25 | 7.75 | 8.25 | 9.50 |
| | 32 | 6.00 | 6.75 | 7.50 | 8.25 | 9.00 | 9.75 | 10.50 | 12.00 |
| | 40 | 7.00 | 8.00 | 9.00 | 10.00 | 11.00 | 12.00 | 13.00 | 15.00 |
| | 50 | 8.50 | 9.75 | 11.25 | 12.50 | 14.00 | 15.25 | 16.75 | 19.50 |
| | 60 | 10.25 | 12.00 | 13.75 | 15.50 | 17.25 | 19.00 | 21.00 | 24.50 |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 psf = 0.0479 kN/m$^2$

1 Table values are based on reinforcing bars with a minimum yield strength of 40,000 psi (276 MPa) and concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa).

2 Table values are based on a 6 in (152.4 mm) thick nominal screen-grid wall.

3 Table values are based on a maximum unsupported wall height of 10 ft (3.0 m).

4 Table values are based on a maximum 12:12 roof pitch.

5 Linear interpolation shall be permitted.

## TABLE 5.5
## MINIMUM PERCENTAGE OF SOLID WALL LENGTH ALONG EXTERIOR WALL LINES FOR SEISMIC DESIGN CATEGORY C AND D[1,2]

| ICF WALL TYPE AND MINIMUM WALL THICKNESS (inches) | MINIMUM SOLID WALL LENGTH (percent) | | |
|---|---|---|---|
| | ONE-STORY OR TOP STORY OF TWO-STORY | WALL SUPPORTING LIGHT FRAME SECOND STORY AND ROOF | WALL SUPPORTING ICF SECOND STORY AND ROOF |
| Seismic Design Category C[3] | 20 percent | 25 percent | 35 percent |
| Seismic Design Category D1[4] | 25 percent | 30 percent | 40 percent |
| Seismic Design Category D2[4] | 30 percent | 35 percent | 45 percent |

For SI: 1 inch = 25.4 mm; 1 mph = 1.6093 km/hr

[1] Base percentages are applicable for maximum unsupported wall height of 10-feet (3.0-m), light-frame gable construction, all ICF wall types in Seismic Design Category C, and all ICF wall types with a nominal thickness greater than 5.5 inches (140 mm) for Seismic Design Category D1 and D2. These percentages assume that the maximum weight of the interior and exterior wall finishes applied to ICF walls do not exceed 8 psf (0.38 kN/m²).

[2] For all walls, the minimum required length of solid walls shall be based on the table percent value multiplied by the minimum dimension of a rectangle inscribing the overall building plan.

[3] Walls shall be reinforced with minimum No. 5 rebar (grade 40 or 60) spaced a maximum of 24 inches (609.6 mm) on center each way or No. 4 rebar (Grade 40 or 60) spaced at a maximum of 16 inches (406.4 mm) on center each way.

[4] Walls shall be constructed with a minimum concrete compressive strength of 3,000 psi (20.7 MPa) and reinforced with minimum #5 rebar (Grade 60, ASTM A706) spaced a maximum of 18 inches (457.2 mm) on center each way or No. 4 rebar (Grade 60 ASTM A706) spaced at a maximum of 12 inches (304.8 mm) on center each way.

## TABLE 5.6
## MINIMUM WALL OPENING REINFORCEMENT REQUIREMENTS IN ICF WALLS

| WALL TYPE AND OPENING WIDTH, L feet (m) | MINIMUM HORIZONTAL OPENING REINFORCEMENT | MINIMUM VERTICAL OPENING REINFORCEMENT |
|---|---|---|
| Flat, Waffle-, and Screen-Grid: L < 2 (0.61) | None Required | None Required |
| Flat, Waffle-, and Screen-Grid: L ≥ 2 (0.61) | Provide lintels in accordance with Section 5.3. Top and bottom lintel reinforcement shall extend a minimum of 24 inches (610 mm) beyond the limits of the opening.<br><br>Provide one No. 4 bar within of 12 inches (305 mm) from the bottom of the opening. Each No. 4 bar shall extend 24 inches (610 mm) beyond the limits of the opening. | In locations with wind speeds less than or equal to 110 mph (177 km/hr) or in Seismic Design Categories A and B, provide one No. 4 bar for the full height of the wall story within 12 inches (305 mm) of each side of the opening.<br><br>In locations with wind speeds greater than 110 mph (177 km/hr) or in Seismic Design Categories C, D1 and D2, provide two No. 4 bars or one No. 5 bar for the full height of the wall story within 12 inches (305 mm) of each side of the opening. |

## TABLE 5.7
## MAXIMUM ALLOWABLE CLEAR SPANS FOR ICF LINTELS WITHOUT STIRRUPS IN LOAD-BEARING WALLS[1,2,3,4,5,6,7] (NO. 4 OR NO. 5 BOTTOM BAR SIZE)

| MINIMUM LINTEL THICKNESS, T (inches) | MINIMUM LINTEL DEPTH, D (inches) | MAXIMUM CLEAR SPAN (feet – inches) | | | | | |
|---|---|---|---|---|---|---|---|
| | | SUPPORTING LIGHT-FRAME ROOF ONLY | | SUPPORTING LIGHT-FRAME SECOND STORY AND ROOF | | SUPPORTING ICF SECOND STORY AND LIGHT-FRAME ROOF[8] | |
| | | MAXIMUM GROUND SNOW LOAD (psf) | | | | | |
| | | 30 | 70 | 30 | 70 | 30 | 70 |
| **Flat ICF Lintel** | | | | | | | |
| 3.5 | 8 | 2-6 | 2-6 | 2-6 | 2-4 | 2-5 | 2-2 |
| | 12 | 4-2 | 4-2 | 4-1 | 3-10 | 3-10 | 3-7 |
| | 16 | 4-11 | 4-8 | 4-6 | 4-2 | 4-2 | 3-10 |
| | 20 | 6-3 | 5-3 | 4-11 | 4-6 | 4-6 | 4-3 |
| | 24 | 7-7 | 6-4 | 6-0 | 5-6 | 5-6 | 5-2 |
| 5.5 | 8 | 2-10 | 2-6 | 2-6 | 2-5 | 2-6 | 2-2 |
| | 12 | 4-6 | 4-4 | 4-3 | 3-11 | 3-10 | 3-7 |
| | 16 | 6-5 | 5-1 | 4-8 | 4-2 | 4-3 | 3-10 |
| | 20 | 8-2 | 6-6 | 6-0 | 5-4 | 5-5 | 5-0 |
| | 24 | 9-8 | 7-11 | 7-4 | 6-6 | 6-7 | 6-1 |
| 7.5 | 8 | 3-6 | 2-8 | 2-7 | 2-5 | 2-5 | 2-2 |
| | 12 | 5-9 | 4-5 | 4-4 | 4-0 | 3-10 | 3-7 |
| | 16 | 7-9 | 6-1 | 5-7 | 4-10 | 4-11 | 4-5 |
| | 20 | 8-8 | 7-2 | 6-8 | 5-11 | 6-0 | 5-5 |
| | 24 | 9-6 | 7-11 | 7-4 | 6-6 | 6-7 | 6-0 |
| 9.5 | 8 | 4-2 | 3-1 | 2-9 | 2-5 | 2-5 | 2-2 |
| | 12 | 6-7 | 5-1 | 4-7 | 3-11 | 4-0 | 3-7 |
| | 16 | 7-10 | 6-4 | 5-11 | 5-3 | 5-4 | 4-10 |
| | 20 | 8-7 | 7-2 | 6-8 | 5-11 | 6-0 | 5-5 |
| | 24 | 9-4 | 7-10 | 7-3 | 6-6 | 6-7 | 6-0 |
| **Waffle-Grid ICF Lintel** | | | | | | | |
| 6 or 8 | 8 | 2-6 | 2-6 | 2-6 | 2-4 | 2-4 | 2-2 |
| | 12 | 4-2 | 4-2 | 4-1 | 3-8 | 3-9 | 3-5 |
| | 16 | 5-9 | 5-8 | 5-7 | 5-1 | 5-2 | 4-8 |
| | 20 | 7-6 | 7-4 | 6-9 | 6-0 | 6-3 | 5-7 |
| | 24 | 9-2 | 8-1 | 7-6 | 6-7 | 6-10 | 6-2 |

For SI: 1 inch = 25.4 mm; 1 psf = 0.0479 kN/m$^2$; 1 ft = 0.3 m

[1]Table values are based on tensile reinforcement with a minimum yield strength of 40,000 psi (276 MPa), concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa), and a building width (floor and roof clear span) of 32 feet (9.8m).

[2]Deflection criterion is L/240, where L is the clear span of the lintel in inches.

[3]Linear interpolation shall be permitted between ground snow loads and between lintel depths.

[4]Lintel depth, D, shall be permitted to include the available height of ICF wall located directly above the lintel, provided that the increased lintel depth spans the entire length of the opening.

[5]Spans located in shaded cells shall be permitted to be multiplied by 1.05 when concrete with a minimum compressive strength of 3,000 psi (20.7 MPa) is used or by 1.1 when concrete with a minimum compressive strength of 4,000 psi (27.6 MPa) is used.

[6]Spans shall be permitted to be multiplied by 1.05 for a building width (floor and roof clear span) of 28 feet (8.5 m).

[7]Spans shall be permitted to be multiplied by 1.1 for a building width (floor and roof clear span) of 24 feet (7.3 m) or less.

[8] Supported ICF wall dead load varies based on wall thickness using 150 pcf (2403 kg/m3) concrete density

## TABLE 5.8A
## MAXIMUM ALLOWABLE CLEAR SPANS FOR FLAT ICF LINTELS WITH STIRRUPS IN LOAD-BEARING WALLS1,2,3,4,5,6,7 (NO. 4 BOTTOM BAR SIZE)

| MINIMUM LINTEL THICKNESS, T (inches) | MINIMUM LINTEL DEPTH, D (inches) | MAXIMUM CLEAR SPAN (feet – inches) | | | | | |
|---|---|---|---|---|---|---|---|
| | | SUPPORTING LIGHT-FRAME ROOF ONLY | | SUPPORTING LIGHT-FRAME SECOND STORY AND ROOF | | SUPPORTING ICF SECOND STORY AND LIGHT-FRAME ROOF[8] | |
| | | MAXIMUM GROUND SNOW LOAD (psf) | | | | | |
| | | 30 | 70 | 30 | 70 | 30 | 70 |
| 3.5 | 8 | 4-9 | 4-2 | 3-10 | 3-4 | 3-5 | 3-1 |
| | 12 | 6-8 | 5-5 | 5-0 | 4-5 | 4-6 | 4-0 |
| | 16 | 7-11 | 6-5 | 6-0 | 5-3 | 5-4 | 4-10 |
| | 20 | 8-11 | 7-4 | 6-9 | 6-0 | 6-1 | 5-6 |
| | 24 | 9-10 | 8-1 | 7-6 | 6-7 | 6-9 | 6-1 |
| 5.5 | 8 | 5-2 | 4-2 | 3-10 | 3-5 | 3-5 | 3-1 |
| | 12 | 6-8 | 5-5 | 5-0 | 4-5 | 4-6 | 4-1 |
| | 16 | 7-10 | 6-5 | 6-0 | 5-3 | 5-4 | 4-10 |
| | 20 | 8-10 | 7-3 | 6-9 | 6-0 | 6-1 | 5-6 |
| | 24 | 9-8 | 8-0 | 7-5 | 6-7 | 6-8 | 6-0 |
| 7.5 | 8 | 5-2 | 4-2 | 3-11 | 3-5 | 3-6 | 3-2 |
| | 12 | 6-7 | 5-5 | 5-0 | 4-5 | 4-6 | 4-1 |
| | 16 | 7-9 | 6-5 | 5-11 | 5-3 | 5-4 | 4-10 |
| | 20 | 8-8 | 7-2 | 6-8 | 5-11 | 6-0 | 5-5 |
| | 24 | 9-6 | 7-11 | 7-4 | 6-6 | 6-7 | 6-0 |
| 9.5 | 8 | 5-2 | 4-2 | 3-11 | 3-5 | 3-6 | 3-2 |
| | 12 | 6-7 | 5-5 | 5-0 | 4-5 | 4-6 | 4-1 |
| | 16 | 7-8 | 6-4 | 5-11 | 5-3 | 5-4 | 4-10 |
| | 20 | 8-7 | 7-2 | 6-8 | 5-11 | 6-0 | 5-5 |
| | 24 | 9-4 | 7-10 | 7-3 | 6-6 | 6-7 | 6-0 |

For SI: 1 inch = 25.4 mm; 1 psf = 0.0479 kN/m$^2$; 1 ft = 0.3 m

[1] Table values are based on concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa), reinforcing steel with a minimum yield strength of 40,000 psi (276 MPa), and a building width (floor and roof clear span) of 32 feet (9.8m).

[2] Deflection criterion is L/240, where L is the clear span of the lintel in inches.

[3] Linear interpolation is permitted between ground snow loads and between lintel depths.

[4] Lintel depth, D, is permitted to include the available height of ICF wall located directly above the lintel, provided that the increased lintel depth spans the entire length of the lintel.

[5] Spans located in shaded cells shall be permitted to be multiplied by 1.2 when reinforcing steel with a minimum yield strength of 60,000 psi (414 MPa) is used.

[6] Spans shall be permitted to be multiplied by 1.05 for a building width (floor and roof clear span) of 28 feet (8.5 m).

[7] Spans shall be permitted to be multiplied by 1.1 for a building width (floor and roof clear span) of 24 feet or less (7.3 m).

[8] Supported ICF wall dead load is 69 psf (3.3 kPa).

## TABLE 5.8B
## MAXIMUM ALLOWABLE CLEAR SPANS FOR FLAT ICF LINTELS WITH STIRRUPS IN LOAD-BEARING WALLS[1,2,3,4,5,6,7] (NO. 5 BOTTOM BAR SIZE)

| MINIMUM LINTEL THICKNESS, T (inches) | MINIMUM LINTEL DEPTH, D (inches) | MAXIMUM CLEAR SPAN (feet – inches) | | | | | |
|---|---|---|---|---|---|---|---|
| | | SUPPORTING LIGHT-FRAME ROOF ONLY | | SUPPORTING LIGHT-FRAME SECOND STORY AND ROOF | | SUPPORTING ICF SECOND STORY AND LIGHT-FRAME ROOF[8] | |
| | | MAXIMUM GROUND SNOW LOAD (psf) | | | | | |
| | | 30 | 70 | 30 | 70 | 30 | 70 |
| | 8 | 4-9 | 4-2 | 3-11 | 3-7 | 3-7 | 3-5 |
| | 12 | 7-2 | 6-3 | 5-11 | 5-5 | 5-5 | 5-0 |
| 3.5 | 16 | 9-6 | 8-0 | 7-4 | 6-6 | 6-7 | 5-11 |
| | 20 | 11-1 | 9-1 | 8-4 | 7-5 | 7-6 | 6-9 |
| | 24 | 12-2 | 10-0 | 9-3 | 8-2 | 8-4 | 7-6 |
| | 8 | 5-6 | 4-10 | 4-7 | 4-2 | 4-2 | 3-10 |
| | 12 | 8-3 | 6-9 | 6-3 | 5-6 | 5-7 | 5-0 |
| 5.5 | 16 | 9-9 | 8-0 | 7-5 | 6-6 | 6-7 | 6-0 |
| | 20 | 10-11 | 9-0 | 8-4 | 7-5 | 7-6 | 6-9 |
| | 24 | 12-0 | 9-11 | 9-3 | 8-2 | 8-3 | 7-6 |
| | 8 | 6-1 | 5-2 | 4-9 | 4-3 | 4-3 | 3-10 |
| | 12 | 8-2 | 6-9 | 6-3 | 5-6 | 5-7 | 5-0 |
| 7.5 | 16 | 9-7 | 7-11 | 7-4 | 6-6 | 6-7 | 6-0 |
| | 20 | 10-10 | 8-11 | 8-4 | 7-4 | 7-6 | 6-9 |
| | 24 | 11-10 | 9-10 | 9-2 | 8-1 | 8-3 | 7-5 |
| | 8 | 6-4 | 5-2 | 4-10 | 4-3 | 4-4 | 3-11 |
| | 12 | 8-2 | 6-8 | 6-2 | 5-6 | 5-7 | 5-0 |
| 9.5 | 16 | 9-6 | 7-11 | 7-4 | 6-6 | 6-7 | 5-11 |
| | 20 | 10-8 | 8-10 | 8-3 | 7-4 | 7-5 | 6-9 |
| | 24 | 11-7 | 9-9 | 9-0 | 8-1 | 8-2 | 7-5 |

For SI: 1 inch = 25.4 mm; 1 psf = 0.0479 $kN/m^2$; 1 ft = 0.3 m

1 Table values are based on concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa), reinforcing steel with a minimum yield strength of 40,000 psi (276 MPa), and a building width (floor and roof clear span) of 32 feet (9.8m).

2 Deflection criterion is L/240, where L is the clear span of the lintel in inches.

3 Linear interpolation is permitted between ground snow loads and between lintel depths.

4 Lintel depth, D, is permitted to include the available height of ICF wall located directly above the lintel, provided that the increased lintel depth spans the entire length of the lintel.

5 Spans located in shaded cells shall be permitted to be multiplied by 1.2 when reinforcing steel with a minimum yield strength of 60,000 psi (414 MPa) is used.

6 Spans shall be permitted to be multiplied by 1.05 for a building width (floor and roof clear span) of 28 feet (8.5 m).

7 Spans shall be permitted to be multiplied by 1.1 for a building width (floor and roof clear span) of 24 feet (7.3 m) or less.

8 Supported ICF wall dead load is 69 psf (3.3 kPa).

# TABLE 5.9A
# MAXIMUM ALLOWABLE CLEAR SPANS FOR WAFFLE-GRID ICF LINTELS WITH STIRRUPS IN LOAD-BEARING WALLS[1,2,3,4,5,6,7]
# (NO. 4 BOTTOM BAR SIZE)

| MINIMUM LINTEL THICKNESS, T[8] (inches) | MINIMUM LINTEL DEPTH, D (inches) | MAXIMUM CLEAR SPAN (feet – inches) | | | | | |
|---|---|---|---|---|---|---|---|
| | | SUPPORTING LIGHT-FRAME ROOF ONLY | | SUPPORTING LIGHT-FRAME SECOND STORY AND ROOF | | SUPPORTING ICF SECOND STORY AND LIGHT-FRAME ROOF[9] | |
| | | MAXIMUM GROUND SNOW LOAD (psf) | | | | | |
| | | 30 | 70 | 30 | 70 | 30 | 70 |
| 6 | 8 | 5-2 | 4-2 | 3-10 | 3-5 | 3-6 | 3-2 |
| | 12 | 6-8 | 5-5 | 5-0 | 4-5 | 4-7 | 4-2 |
| | 16 | 7-11 | 6-6 | 6-0 | 5-3 | 5-6 | 4-11 |
| | 20 | 8-11 | 7-4 | 6-9 | 6-0 | 6-3 | 5-7 |
| | 24 | 9-10 | 8-1 | 7-6 | 6-7 | 6-10 | 6-2 |
| 8 | 8 | 5-2 | 4-3 | 3-11 | 3-5 | 3-7 | 3-2 |
| | 12 | 6-8 | 5-5 | 5-1 | 4-5 | 4-8 | 4-2 |
| | 16 | 7-10 | 6-5 | 6-0 | 5-3 | 5-6 | 4-11 |
| | 20 | 8-10 | 7-3 | 6-9 | 6-0 | 6-2 | 5-7 |
| | 24 | 9-8 | 8-0 | 7-5 | 6-7 | 6-10 | 6-2 |

For SI: 1 inch = 25.4 mm; 1 psf = 0.0479 kN/m$^2$; 1 ft = 0.3 m

[1]Table values are based on concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa), reinforcing steel with a minimum yield strength of 40,000 psi (276 MPa), and a building width (floor and roof clear span) of 32 feet (9.8m).

[2] Deflection criterion is L/240, where L is the clear span of the lintel in inches.

[3] Linear interpolation is permitted between ground snow loads and between lintel depths.

[4] Lintel depth, D, is permitted to include the available height of ICF wall located directly above the lintel, provided that the increased lintel depth spans the entire length of the lintel.

[5] Spans located in shaded cells shall be permitted to be multiplied by 1.2 when reinforcing steel with a minimum yield strength of 60,000 psi (414 MPa) is used.

[6] Spans shall be permitted to be multiplied by 1.05 for a building width (floor and roof clear span) of 28 feet (8.5 m).

[7] Spans shall be permitted to be multiplied by 1.1 for a building width (floor and roof clear span) of 24 feet (7.3 m) or less.

[8] Lintel thickness corresponds to the nominal waffle-grid ICF wall thickness with a minimum web thickness of 2 inches (51 mm). For actual wall thickness, refer to section 2.0.

[9] Supported ICF wall dead load is 55 psf (2.6 kPa).

## TABLE 5.9B
## MAXIMUM ALLOWABLE CLEAR SPANS FOR WAFFLE-GRID ICF LINTELS WITH STIRRUPS IN LOAD-BEARING WALLS[1,2,3,4,5,6,7] (NO. 5 BOTTOM BAR SIZE)

| MINIMUM LINTEL THICKNESS, T[8] (inches) | MINIMUM LINTEL DEPTH, D (inches) | MAXIMUM CLEAR SPAN (feet – inches) | | | | | |
|---|---|---|---|---|---|---|---|
| | | SUPPORTING LIGHT-FRAME ROOF ONLY | | SUPPORTING LIGHT-FRAME SECOND STORY AND ROOF | | SUPPORTING ICF SECOND STORY AND LIGHT-FRAME ROOF[9] | |
| | | MAXIMUM GROUND SNOW LOAD (psf) | | | | | |
| | | 30 | 70 | 30 | 70 | 30 | 70 |
| 6 | 8 | 5-4 | 4-8 | 4-5 | 4-1 | 4-5 | 3-10 |
| | 12 | 8-0 | 6-9 | 6-3 | 5-6 | 6-3 | 5-1 |
| | 16 | 9-9 | 8-0 | 7-5 | 6-6 | 7-5 | 6-1 |
| | 20 | 11-0 | 9-1 | 8-5 | 7-6 | 8-5 | 6-11 |
| | 24 | 12-2 | 10-0 | 9-3 | 8-2 | 9-3 | 7-8 |
| 8 | 8 | 6-0 | 5-2 | 4-9 | 4-3 | 4-9 | 3-11 |
| | 12 | 8-3 | 6-9 | 6-3 | 5-6 | 6-3 | 5-2 |
| | 16 | 9-9 | 8-0 | 7-5 | 6-6 | 7-5 | 6-1 |
| | 20 | 10-11 | 9-0 | 8-4 | 7-5 | 8-4 | 6-11 |
| | 24 | 12-0 | 9-11 | 9-2 | 8-2 | 9-2 | 7-8 |

For SI: 1 inch = 25.4 mm; 1 psf = 0.0479 kN/m$^2$; 1 ft = 0.3 m

[1] Table values are based on concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa), reinforcing steel with a minimum yield strength of 40,000 psi (276 MPa), and a building width (floor and roof clear span) of 32 feet (9.8m).

[2] Deflection criterion is L/240, where L is the clear span of the lintel in inches.

[3] Linear interpolation is permitted between ground snow loads and between lintel depths.

[4] Lintel depth, D, is permitted to include the available height of ICF wall located directly above the lintel, provided that the increased lintel depth spans the entire length of the lintel.

[5] Spans located in shaded cells shall be permitted to be multiplied by 1.2 when reinforcing steel with a minimum yield strength of 60,000 psi (414 MPa) is used.

[6] Spans shall be permitted to be multiplied by 1.05 for a building width (floor and roof clear span) of 28 feet (8.5 m).

[7] Spans shall be permitted to be multiplied by 1.1 for a building width (floor and roof clear span) of 24 feet (7.3 m) or less.

[8] Lintel thickness corresponds to the nominal waffle-grid ICF wall thickness with a minimum web thickness of 2 inches (51 mm). For actual wall thickness, refer to section 2.0.

[9] Supported ICF wall dead load is 55 psf (2.6 kPa).

# TABLE 5.10A
# MAXIMUM ALLOWABLE CLEAR SPANS FOR SCREEN-GRID ICF LINTELS IN LOAD-BEARING WALLS[1,2,3,4,5,6,7,8] (NO. 4 BOTTOM BAR SIZE)

| MINIMUM LINTEL THICKNESS, T[9] (inches) | MINIMUM LINTEL DEPTH, D (inches) | MAXIMUM CLEAR SPAN (feet – inches) | | | | | |
|---|---|---|---|---|---|---|---|
| | | SUPPORTING LIGHT-FRAME ROOF ONLY | | SUPPORTING LIGHT-FRAME SECOND STORY AND ROOF | | SUPPORTING ICF SECOND STORY AND LIGHT-FRAME ROOF[10] | |
| | | MAXIMUM GROUND SNOW LOAD (psf) | | | | | |
| | | 30 | 70 | 30 | 70 | 30 | 70 |
| 6 | 12 | 3-7 | 2-10 | 2-5 | 2-0 | 2-0 | D/R |
| | 24 | 9-10 | 8-1 | 7-6 | 6-7 | 6-11 | 6-2 |

For SI:1 inch = 25.4 mm; 1 psf = 0.0479 kN/m$^2$; 1 ft = 0.3 m

[1] Table values are based on concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa), reinforcing steel with a minimum yield strength of 40,000 psi (276 MPa), and a building width (floor and roof clear span) of 32 feet (9.8m); D/R indicates design required.

[2] Stirups are not required for 12 in (304.8 mm) deep screen-grid lintels. Stirrups shall be required at a maximum spacing of 12 inches (304.8 mm) on center for 24 in (609.6 mm) deep screen-grid lintels.

[3] Deflection criterion is L/240, where L is the clear span of the lintel in inches.

[4] Linear interpolation is permitted between ground snow loads and between lintel depths.

[5] Spans located in shaded cells shall be permitted to be multiplied by 1.2 when reinforcing steel with a minimum yield strength of 60,000 psi (414 MPa) is used.

[6] Spans shall be permitted to be multiplied by 1.05 for a building width (floor and roof clear span) of 28 feet (8.5 m).

[7] Spans shall be permitted to be multiplied by 1.10 for a building width (floor and roof clear span) of 24 feet (7.3 m).

[8] Flat ICF lintels may be used in lieu of screen-grid lintels.

[9] Lintel thickness corresponds to the nominal screen-grid ICF wall thickness. For actual wall thickness, refer to section 2.0.

[10] Supported ICF wall dead load is 53 psf (2.5 kPa).

## TABLE 5.10B
## MAXIMUM ALLOWABLE CLEAR SPANS FOR SCREEN-GRID ICF LINTELS IN LOAD-BEARING WALLS1,2,3,4,5,6,7,8 (NO. 5 BOTTOM BAR SIZE)

| MINIMUM LINTEL THICKNESS, T[9] (inches) | MINIMUM LINTEL DEPTH, D (inches) | MAXIMUM CLEAR SPAN (feet – inches) | | | | | |
|---|---|---|---|---|---|---|---|
| | | SUPPORTING LIGHT-FRAME ROOF ONLY | | SUPPORTING LIGHT-FRAME SECOND STORY AND ROOF | | SUPPORTING ICF SECOND STORY AND LIGHT-FRAME ROOF [10] | |
| | | MAXIMUM GROUND SNOW LOAD (psf) | | | | | |
| | | 30 | 70 | 30 | 70 | 30 | 70 |
| 6 | 12 | 3-7 | 2-10 | 2-5 | 1-10 | 2-0 | D/R |
| | 24 | 12-2 | 10-0 | 9-3 | 8-3 | 8-7 | 7-8 |

For SI: 1 inch = 25.4 mm; 1 psf = 0.0479 kN/m$^2$; 1 ft = 0.3 m

[1] Table values are based on concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa), reinforcing steel with a minimum yield strength of 40,000 psi (276 MPa), and a building width (floor and roof clear span) of 32 feet (9.8m); D/R indicates design required.

[2] Stirups are not required for 12 in (304.8 mm) deep screen-grid lintels. Stirrups shall be required at a maximum spacing of 12 inches (304.8 mm) on center for 24 in (609.6 mm) deep screen-grid lintels.

[3] Deflection criterion is L/240, where L is the clear span of the lintel in inches.

[4] Linear interpolation is permitted between ground snow loads and between lintel depths. Lintel depth, D, is permitted to include the available height of any ICF wall located directly above the lintel, provided that the increased lintel depth spans the entire length of the lintel.

[5] Spans located in shaded cells shall be permitted to be multiplied by 1.2 when reinforcing steel with a minimum yield strength of 60,000 psi (414 MPa) is used.

[6] Spans shall be permitted to be multiplied by 1.05 for a building width (floor and roof clear span) of 28 feet (8.5 m).

[7] Spans shall be permitted to be multiplied by 1.10 for a building width (floor and roof clear span) of 24 feet (7.3 m).

[8] Flat ICF lintel may be used in lieu of screen-grid lintels.

[9] Lintel thickness corresponds to the nominal screen-grid ICF wall thickness. For actual wall thickness, refer to section 2.0.

[10] Supported ICF wall dead load is 53 psf (2.5 kPa).

## TABLE 5.11
## MINIMUM BOTTOM BAR ICF LINTEL REINFORCEMENT FOR LARGE CLEAR SPANS WITH STIRRUPS IN LOAD-BEARING WALLS[1,2,3,4,5]

| MINIMUM LINTEL THICKNESS, T[6] (inches) | MINIMUM LINTEL DEPTH, D (inches) | MINIMUM BOTTOM LINTEL REINFORCEMENT (quantity – size) | | | | | |
|---|---|---|---|---|---|---|---|
| | | SUPPORTING LIGHT-FRAME ROOF ONLY | | SUPPORTING LIGHT-FRAME SECOND STORY AND ROOF | | SUPPORTING ICF SECOND STORY AND LIGHT-FRAME ROOF[7] | |
| | | MAXIMUM GROUND SNOW LOAD (psf) | | | | | |
| | | 30 | 70 | 30 | 70 | 30 | 70 |
| **Flat ICF Lintel, 12 feet – 3 inches Maximum Clear Span** | | | | | | | |
| 3.5 | 24 | 1-#5 | D/R | D/R | D/R | D/R | D/R |
| 5.5 | 20 | 1-#6; 2-#4 | 2-#5 | D/R | D/R | D/R | D/R |
| | 24 | 1-#5 | 2-#5 | 2-#5 | 2-#6 | 2-#6 | D/R |
| 7.5 | 16 | 2-#5 | D/R | D/R | D/R | D/R | D/R |
| | 20 | 1-#6; 2-#4 | 2-#5 | 2-#6 | D/R | D/R | D/R |
| | 24 | 1-#6; 2-#4 | 2-#5 | 2-#5 | 2-#6 | 2-#6 | 2-#6 |
| 9.5 | 16 | 2-#5 | D/R | D/R | D/R | D/R | D/R |
| | 20 | 1-#6; 2-#4 | 2-#5 | 2-#6 | 2-#6 | 2-#6 | 2-#6 |
| | 24 | 1-#6; 2-#4 | 2-#5 | 2-#5 | 2-#6 | 2-#6 | 2-#6 |
| **Flat ICF Lintel, 16 feet – 3 inches Maximum Clear Span** | | | | | | | |
| 5.5 | 24 | 2-#5 | D/R | D/R | D/R | D/R | D/R |
| 7.5 | 24 | 2-#5 | D/R | D/R | D/R | D/R | D/R |
| 9.5 | 24 | 2-#5 | 2-#6 | 2-#6 | D/R | D/R | D/R |
| **Waffle-Grid ICF Lintel, 12 feet – 3 inches Maximum Clear Span** | | | | | | | |
| 6 | 20 | 1-#6; 2-#4 | D/R | D/R | D/R | D/R | D/R |
| | 24 | 1-#5 | 2-#5 | 2-#5 | 2-#6 | 2-#6 | D/R |
| 8 | 16 | 2-#5 | D/R | D/R | D/R | D/R | D/R |
| | 20 | 1-#6; 2-#4 | 2-#5 | 2-#6 | D/R | D/R | D/R |
| | 24 | 1-#5 | 2-#5 | 2-#5 | 2-#6 | 2-#6 | 2-#6 |
| **Screen-Grid ICF Lintel, 12 feet – 3 inches Maximum Clear Span** | | | | | | | |
| 6 | 24 | 1-#5 | D/R | D/R | D/R | D/R | D/R |

For SI: 1 inch = 25.4 mm; 1 psf = 0.0479 kN/$m^2$; 1 ft = 0.3 m

[1] Table values are based on concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa), reinforcing steel with a minimum yield strength of 40,000 psi (276 MPa), and a building width (floor and roof clear span) of 32 feet (9.8m).

[2] D/R indicates design is required.

[3] Deflection criterion is L/240, where L is the clear span of the lintel in inches.

[4] Linear interpolation is permitted between ground snow loads and between lintel depths. Lintel depth, D, is permitted to include the available height of ICF wall located directly above the lintel, provided that the increased lintel depth spans the entire length of the lintel.

[5] The required reinforcement(s) in the shaded cells shall be permitted to be reduced to the next smallest bar diameter when reinforcing steel with a minimum yield strength of 60,000 psi (414 MPa) is used.

[6] Actual thickness is shown for flat lintels while nominal thickness is given for waffle-grid and screen-grid lintels. Refer to Section 2.0 for actual wall thickness of waffle-grid and screen-grid ICF construction.

[7] Supported ICF wall dead load varies based on wall thickness using 150 pcf (2403 kg/$m^3$) concrete density.

## TABLE 5.12
## MIDDLE PORTION OF SPAN, A, WHERE STIRRUPS ARE NOT REQUIRED FOR FLAT ICF LINTELS[1,2,3,4,5,6,7]
## (NO. 4 or NO. 5 BOTTOM BAR SIZE)

| MINIMUM LINTEL THICKNESS, T (inches) | MINIMUM LINTEL DEPTH, D (inches) | MIDDLE SPAN NOT REQUIRING STIRRUPS (feet – inches) | | | | | |
|---|---|---|---|---|---|---|---|
| | | SUPPORTING LIGHT-FRAME ROOF ONLY | | SUPPORTING LIGHT-FRAME SECOND STORY AND ROOF | | SUPPORTING ICF SECOND STORY AND LIGHT-FRAME ROOF | |
| | | MAXIMUM GROUND SNOW LOAD (psf) | | | | | |
| | | 30 | 70 | 30 | 70 | 30 | 70 |
| 3.5 | 8 | 1-2 | 0-9 | 0-8 | 0-6 | 0-6 | 0-5 |
| | 12 | 1-11 | 1-3 | 1-1 | 0-10 | 0-10 | 0-8 |
| | 16 | 2-7 | 1-9 | 1-6 | 1-2 | 1-2 | 1-0 |
| | 20 | 3-3 | 2-3 | 1-11 | 1-6 | 1-6 | 1-3 |
| | 24 | 3-11 | 2-8 | 2-4 | 1-10 | 1-10 | 1-6 |
| 5.5 | 8 | 1-10 | 1-2 | 1-0 | 0-9 | 0-10 | 0-8 |
| | 12 | 3-0 | 2-0 | 1-8 | 1-4 | 1-4 | 1-1 |
| | 16 | 4-1 | 2-9 | 2-4 | 1-10 | 1-11 | 1-6 |
| | 20 | 5-3 | 3-6 | 3-0 | 2-4 | 2-5 | 2-0 |
| | 24 | 6-3 | 4-3 | 3-8 | 2-10 | 2-11 | 2-5 |
| 7.5 | 8 | 2-6 | 1-8 | 1-5 | 1-1 | 1-1 | 0-11 |
| | 12 | 4-1 | 2-9 | 2-4 | 1-10 | 1-10 | 1-6 |
| | 16 | 5-7 | 3-9 | 3-3 | 2-6 | 2-7 | 2-1 |
| | 20 | 7-1 | 4-10 | 4-1 | 3-3 | 3-4 | 2-9 |
| | 24 | 8-6 | 5-9 | 5-0 | 3-11 | 4-0 | 3-3 |
| 9.5 | 8 | 3-2 | 2-1 | 1-9 | 1-4 | 1-5 | 1-2 |
| | 12 | 5-2 | 3-5 | 2-11 | 2-3 | 2-4 | 1-11 |
| | 16 | 7-1 | 4-9 | 4-1 | 3-2 | 3-3 | 2-8 |
| | 20 | 9-0 | 6-1 | 5-3 | 4-1 | 4-2 | 3-5 |
| | 24 | 10-9 | 7-4 | 6-4 | 4-11 | 5-1 | 4-2 |

For SI: 1 inch = 25.4 mm; 1 psf = 0.0479 kN/m$^2$; 1 ft = 0.3 m

[1] This table is applicable to Tables 5.8A and 5.8B. The values are based on concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa), reinforcing steel with a minimum yield strength of 40,000 psi (276 MPa), and a building width (floor and roof clear span) of 32 feet (9.8m).

[2] Deflection criterion is L/240, where L is the clear span of the lintel in inches.

[3] Linear interpolation is permitted between ground snow loads and between lintel depths. Lintel depth, D, is permitted to include the available height of ICF wall located directly above the lintel, provided that the increased lintel depth spans the entire length of the lintel.

[4] The middle portion of the span, A, shall be permitted to be multiplied by 1.09 when concrete with a minimum compressive strength of 3,000 psi (20.7 MPa) is used.

[5] The middle portion of the span, A, shall be permitted to be multiplied by 1.26 when concrete with a minimum compressive strength of 4,000 psi (27.6 MPa) is used.

[6] The middle portion of the span, A, shall be permitted to be multiplied by 1.1 for a building width (floor and roof clear span) of 28 feet (8.5 m).

[7] The middle portion of the span, A, shall be permitted to be multiplied by 1.2 for a building width (floor and roof clear span) of 24 feet (7.3 m).

## TABLE 5.13
## MIDDLE PORTION OF SPAN, A, WHERE STIRRUPS ARE NOT REQUIRED FOR WAFFLE-GRID ICF LINTELS[1,2,3,4,5,6,7,8]
## (NO. 4 or NO. 5 BOTTOM BAR SIZE)

| MINIMUM LINTEL THICKNESS, T[9] (inches) | MINIMUM LINTEL DEPTH, D (inches) | MIDDLE SPAN NOT REQUIRING STIRRUP | | | | | |
|---|---|---|---|---|---|---|---|
| | | SUPPORTING LIGHT-FRAME ROOF ONLY | | SUPPORTING LIGHT-FRAME SECOND STORY AND ROOF | | SUPPORTING ICF SECOND STORY AND LIGHT-FRAME ROOF | |
| | | MAXIMUM GROUND SNOW LOAD (psf) | | | | | |
| | | 30 | 70 | 30 | 70 | 30 | 70 |
| 6 or 8 | 8 | 0-10 | 0-7 | 0-5 | 0-4 | 0-5 | 0-4 |
| | 12 | 1-5 | 0-11 | 0-9 | 0-7 | 0-8 | 0-6 |
| | 16 | 1-11 | 1-4 | 1-1 | 0-10 | 0-11 | 0-9 |
| | 20 | 2-6 | 1-8 | 1-5 | 1-1 | 1-2 | 0-11 |
| | 24 | 3-0 | 2-0 | 1-9 | 1-4 | 1-5 | 1-2 |

For SI: 1 inch = 25.4 mm; 1 psf = 0.0479 kN/m$^2$; 1 ft = 0.3 m

[1] This table is applicable to Tables 5.9A and B. The values are based on concrete with a minimum specified compressive strength of 2,500 psi (17.2 MPa), reinforcing steel with a minimum yield strength of 40,000 psi (276 MPa), and a building width (floor and roof clear span) of 32 feet (9.8m).

[2] Deflection criterion is L/240, where L is the clear span of the lintel in inches.

[3] Linear interpolation is permitted between ground snow loads and between lintel depths. Lintel depth, D, is permitted to include the available height of any ICF wall located directly above the lintel, provided that the increased lintel depth spans the entire length of the lintel.

[4] The middle portion of the span, A, shall be permitted to be multiplied by 1.09 when concrete with a minimum compressive strength of 3,000 psi (20.7 MPa) is used.

[5] The middle portion of the span, A, shall be permitted to be multiplied by 1.26 when concrete with a minimum compressive strength of 4,000 psi (27.6 MPa) is used.

[6] The middle portion of the span, A, shall be permitted to be multiplied by 1.1 for a building width of (floor and roof clear span) 28 feet (8.5 m).

[7] The middle portion of the span, A, shall be permitted to be multiplied by 1.2 for a building width of (floor and roof clear span) 24 feet (7.3 m).

[8] When required, stirrups shall be placed in each vertical core.

[9] Lintel thickness corresponds to the nominal waffle-grid ICF wall thickness with a minimum web thickness of 2 inches (51 mm). For actual wall thickness, refer to Section 2.0.

## TABLE 5.14
## MAXIMUM ALLOWABLE CLEAR SPANS FOR ICF LINTELS IN GABLE END (NON-LOAD-BEARING) WALLS WITHOUT STIRRUPS1,2 (NO. 4 BOTTOM BAR SIZE)

| MINIMUM LINTEL THICKNESS, T (inches) | MINIMUM LINTEL DEPTH, D (inches) | MAXIMUM CLEAR SPAN | |
|---|---|---|---|
| | | SUPPORTING LIGHT-FRAME GABLE END WALL (feet-inches) | SUPPORTING ICF SECOND STORY AND GABLE END WALL (feet-inches) |
| Flat ICF Lintel | | | |
| 3.5 | 8 | 11-1 | 3-1 |
| | 12 | 15-11 | 5-1 |
| | 16 | 16-3 | 6-11 |
| | 20 | 16-3 | 8-8 |
| | 22 | 16-3 | 10-5 |
| 5.5 | 8 | 16-3 | 4-4 |
| | 12 | 16-3 | 7-0 |
| | 16 | 16-3 | 9-7 |
| | 20 | 16-3 | 12-0 |
| | 22 | 16-3 | 14-3 |
| 7.5 | 8 | 16-3 | 5-6 |
| | 12 | 16-3 | 8-11 |
| | 16 | 16-3 | 12-2 |
| | 20 | 16-3 | 15-3 |
| | 22 | 16-3 | 16-3 |
| 9.5 | 8 | 16-3 | 6-9 |
| | 12 | 16-3 | 10-11 |
| | 16 | 16-3 | 14-10 |
| | 20 | 16-3 | 16-3 |
| | 22 | 16-3 | 16-3 |
| Waffle-Grid ICF Lintel | | | |
| 6 or 8 | 8 | 9-1 | 2-11 |
| | 12 | 13-4 | 4-10 |
| | 16 | 16-3 | 6-7 |
| | 20 | 16-3 | 8-4 |
| | 22 | 16-3 | 9-11 |
| Screen-Grid Lintel | | | |
| 6 | 12 | 5-8 | 4-1 |
| | 24 | 16-3 | 9-1 |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 psf = 47.8804 Pa

[1] Deflection criterion is L/240, where L is the clear span of the lintel in inches.

[2] Linear interpolation is permitted between lintel depths.

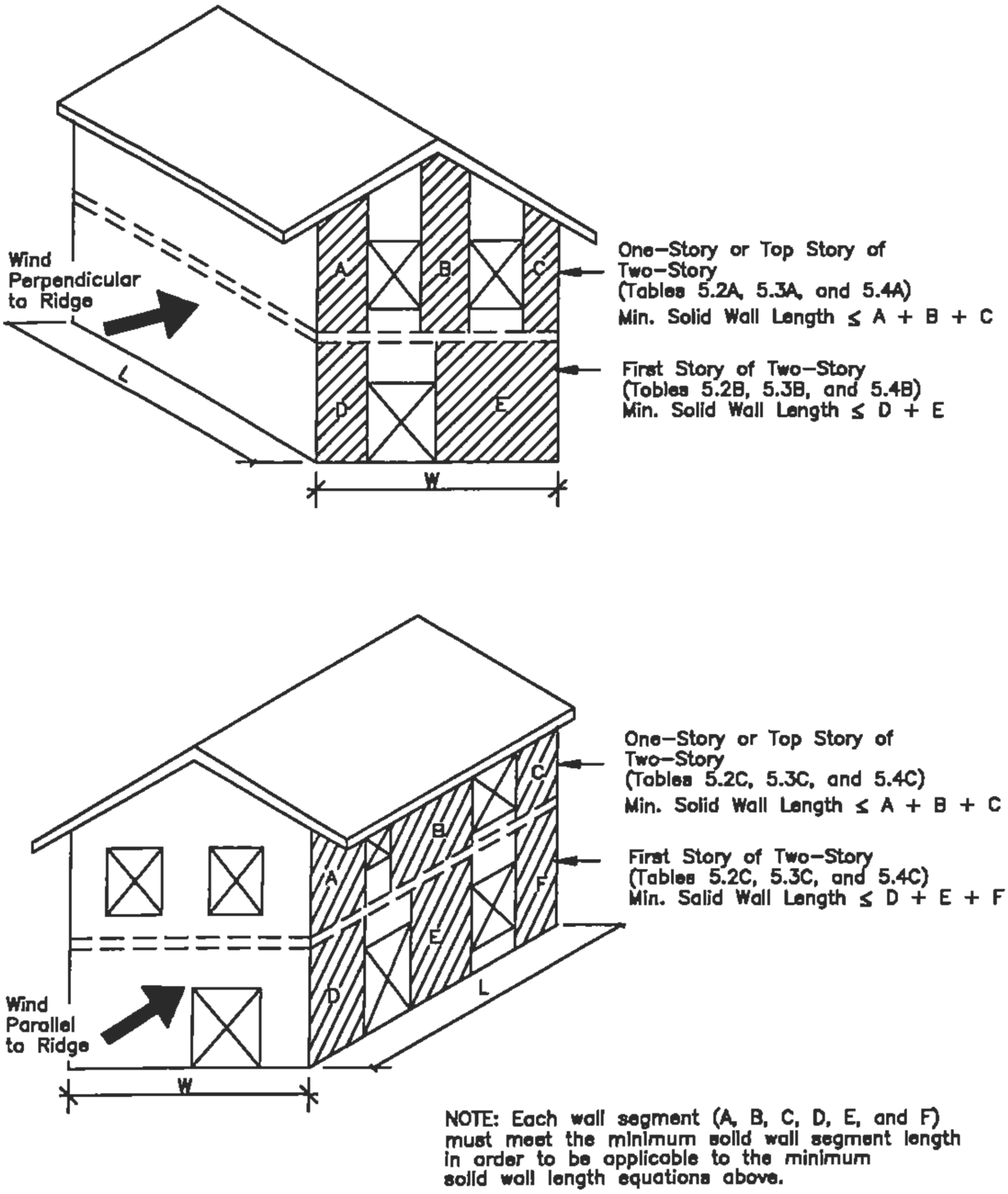



Figure 5.1 Variables for Use with Tables 5.2 through 5.4

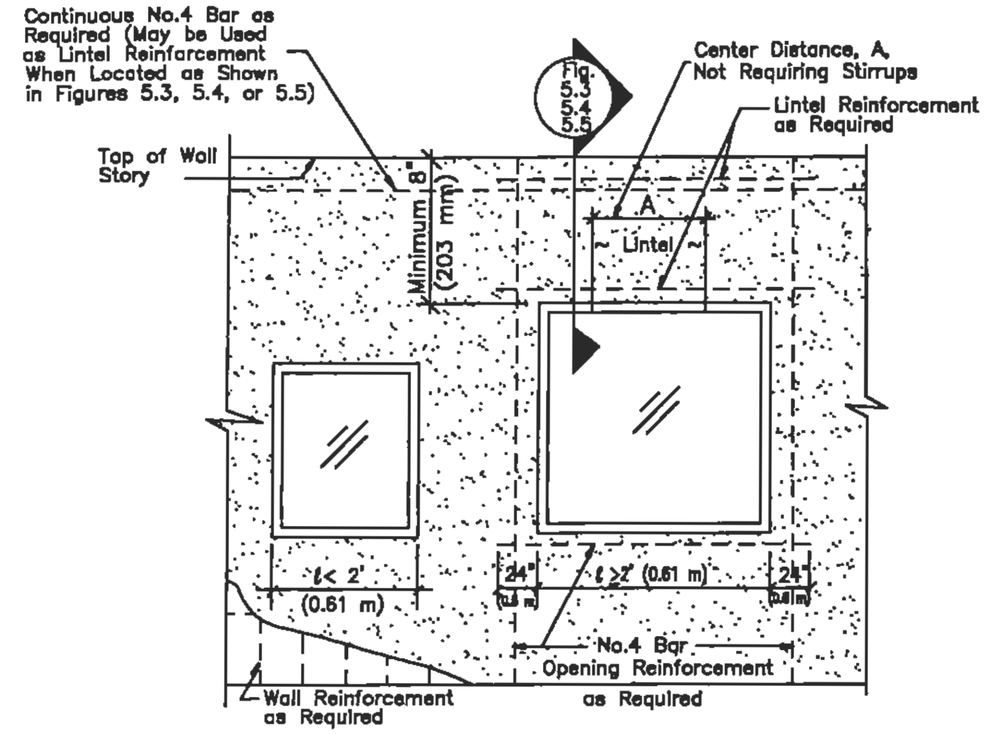



Figure 5.2 Reinforcement of Openings

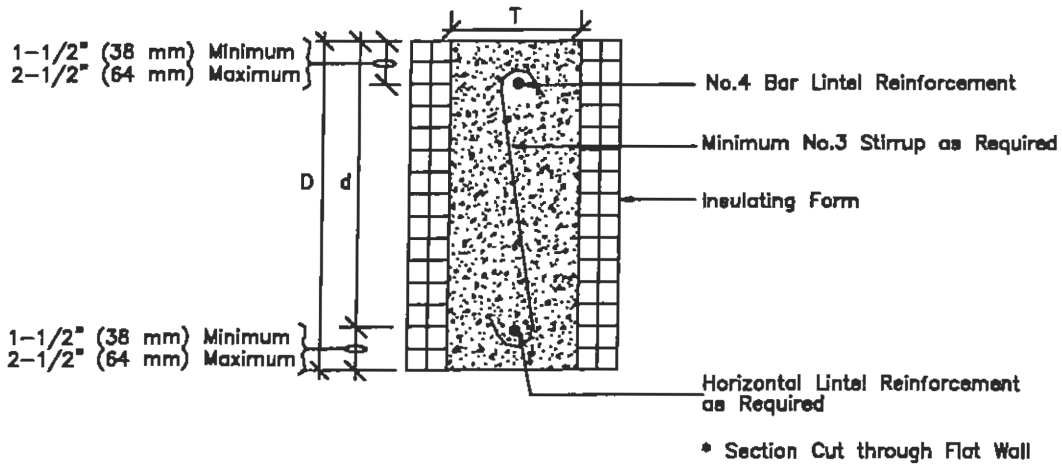
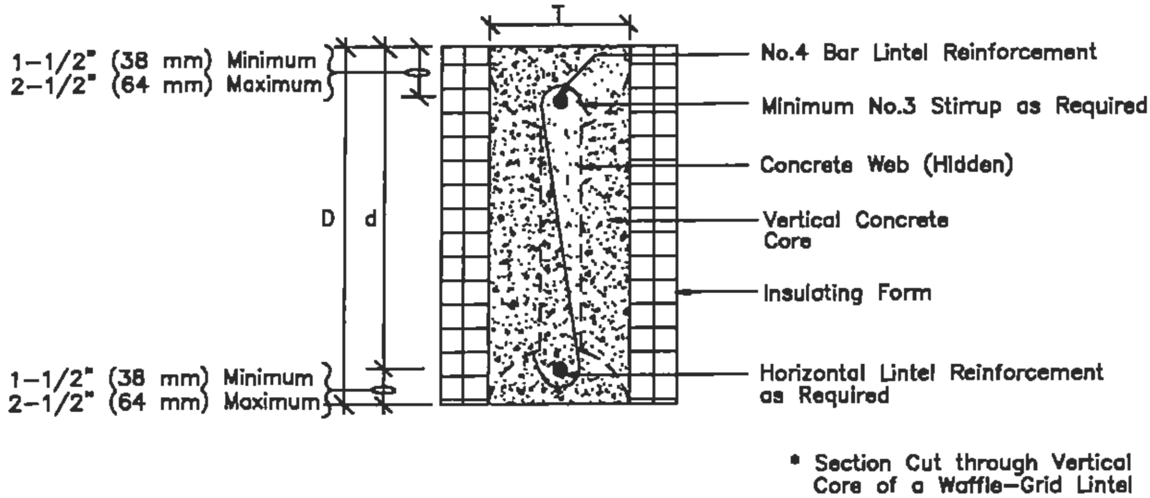
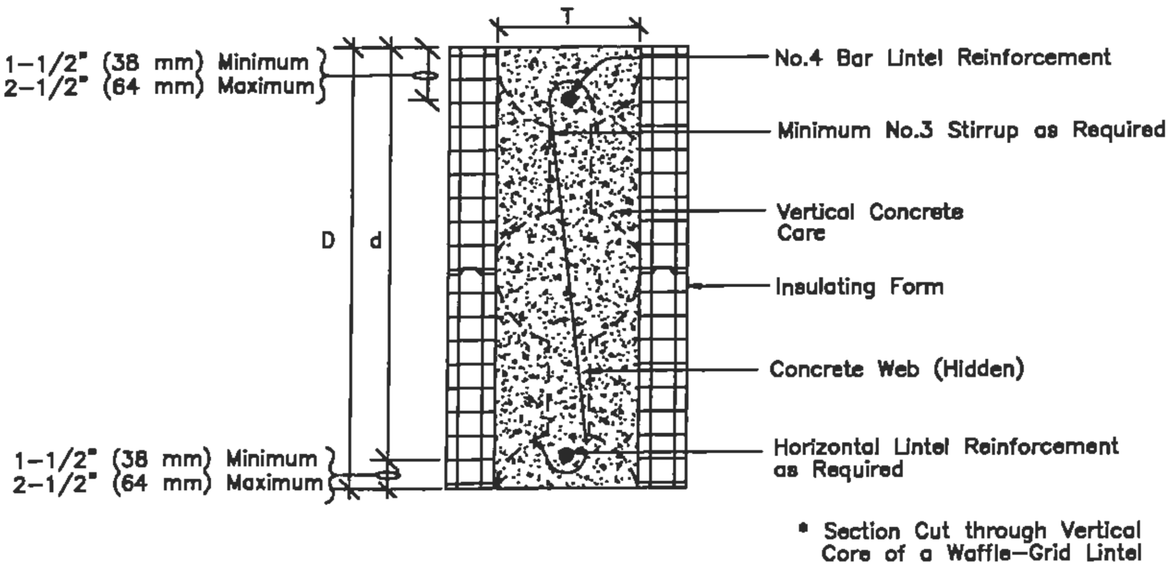



Figure 5.3 Flat ICF Lintel Construction

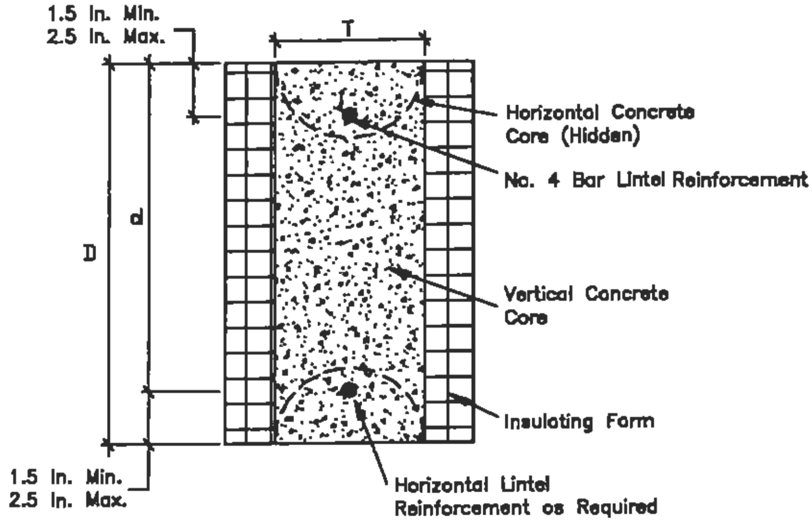



(a) Single Form Height

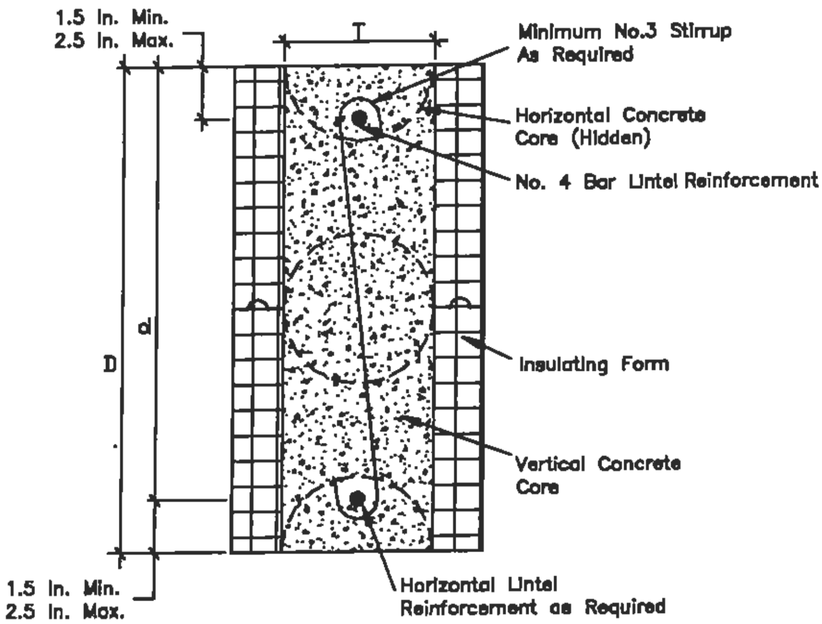



(b) Double Form Height

Figure 5.4 Waffle-Grid ICF Lintel Construction




(a) Single Form Height




(b) Double Form Height

Figure 5.5 Screen-Grid ICF Lintel Construction

# 6.0 ICF CONNECTION REQUIREMENTS

All ICF walls shall be connected to footings, floors, and roofs in accordance with this section. Requirements for installation of brick veneer and other finishes on exterior ICF walls and other construction details not covered in this section shall comply with the manufacturer's approved recommendations, applicable building code requirements, and accepted practice.

## 6.1 ICF Foundation Wall-to-Footing Connection

No vertical reinforcement (i.e., dowels) across the joint between the foundation wall and the footing is required when one of the following exists:

- The unbalanced backfill height does not exceed 4 feet (1.2 m).
- The interior floor slab is installed in accordance with Figure 3.3 before backfilling.
- Temporary bracing at the bottom of the foundation wall is erected before backfilling and remains in place during construction until an interior floor slab is installed in accordance with Figure 3.3 or the wall is backfilled on both sides (i.e., stem wall).

For foundation walls that do not meet one of the above requirements, vertical reinforcement (i.e., dowel) shall be installed across the joint between the foundation wall and the footing at 48 inches (1.2 m) on center in accordance with Figure 6.1. Vertical reinforcement (i.e., dowels) shall be provided for all foundation walls for buildings located in regions with 3-second gust design wind speeds greater than 130 mph (209 km/hr) or located in Seismic Design Categories D1 and D2 at 18 inches (457 mm) on center.

**Exception:** The foundation wall's vertical wall reinforcement, at intervals of 4 feet (1.2 m) on center, shall extend 8 inches (203 mm) into the footing in lieu of using a dowel as shown in Figure 6.1.

## 6.2 ICF Wall-to-Floor Connection

### 6.2.1 Floor on ICF Wall Connection (Top-Bearing Connection)

Floors bearing on ICF walls shall be constructed in accordance with Figure 6.2 or 6.3. The wood sill plate or floor system shall be anchored to the ICF wall with 1/2-inch- (13-mm-) diameter bolts placed at a maximum spacing of 6 feet (1.8 m) on center and not more than 12 inches (305 mm) from joints in the sill plate.

A maximum anchor bolt spacing of 4 feet (1.2 m) on center shall be required when the 3-second gust design wind speed is 110 mph (177 km/hr) or greater. Anchor bolts shall extend a minimum of 7 inches (178 mm) into the concrete and a minimum of 2 inches beyond horizontal reinforcement in the top of the wall. Also, additional anchorage mechanisms shall be installed connecting each joist to the sill plate. Light-frame construction shall be in accordance with the applicable building code.

In Seismic Design Category C, wood sill plates attached to ICF walls shall be anchored with Grade A 307, 3/8-inch (9.5 mm) diameter anchor bolts embedded a minimum of 7 inches (178 mm) and placed at a maximum spacing of 36 inches (914 mm) on center. In Seismic Design Category D1, wood sill plates attached to ICF walls shall be anchored with Grade A 307, 3/8-inch (9.5 mm) diameter anchor bolts embedded a minimum of 7 inches (178 mm) and placed at a maximum spacing of 24 inches (610 mm) on center. In Seismic Design Category D2, wood sill plates attached to ICF walls shall be anchored with Grade A 307, 3/8-inch (9.5 mm) diameter anchor bolts embedded a minimum of 7 inches (178 mm) and placed at a maximum spacing of 16 inches (406 mm) on center. The minimum edge distance from the edge of concrete to edge of anchor bolt shall be 2.5 inches (63.5 mm).

For townhouses in Seismic Design Category C, each floor joist perpendicular to an ICF wall shall be attached to the sill plate with an 18-gauge angle bracket using 3 – 8d common nails per leg in accordance with Figure 6.3. For all buildings in Seismic Design Category D1, each floor joist perpendicular to an ICF wall shall be attached to the sill plate with an 18-gauge angle bracket using 4 – 8d common nails per leg in accordance with Figure 6.3. For all buildings in Seismic Design Category D2, each floor joist perpendicular to an ICF wall shall be attached to the sill plate with an 18-gauge angle bracket using 6 – 8d common nails per leg in accordance with Figure 6.3.

For ICF walls parallel to floor framing in townhouses in Seismic Design Category C, full depth blocking shall be placed at 24 inches (610 mm) on center and shall be attached to the sill plate with an 18-gauge angle bracket using 5 – 8d common nails per leg. For ICF walls parallel to floor framing for all buildings in Seismic Design Category D1, full depth blocking shall be placed at 24 inches (610 mm) on center and shall be attached to the sill plate with an 18-gauge angle bracket using 6 – 8d common nails per leg. For ICF walls parallel to floor framing for all buildings in Seismic Design Category D2, full depth blocking shall be placed at 24 inches (610 mm) on center and shall be attached to the sill plate with an 18-gauge angle bracket using 9 – 8d common nails per leg.

### 6.2.2 Floor Ledger-ICF Wall Connection (Side-Bearing Connection)

Wood ledger boards shall be anchored to flat ICF walls having a minimum thickness of 5.5 inches (140 mm) thickness and to waffle-gridor screen-grid ICF walls having a minimum nominal thickness of 6 inches (152 mm) in accordance with Figure 6.4 or 6.5 and Table 6.1. Wood ledger boards shall be anchored to flat ICF walls having a minimum thickness of 3.5 inches (89 mm) in accordance with Figure 6.6 or 6.7 and Table 6.1. Minimum wall thickness shall be 5.5 inches (140 mm) in Seismic Design Category C, D1, and D2.

Additional anchorage mechanisms shall be installed at a maximum spacing of 6 feet (1.8 m) on center for Seismic Design Category C and 4 feet (1.2 m) on center for Seismic Design Categories D1and D2. The additional anchorage mechanisms shall be attached to the ICF wall reinforcement and joist, rafters, or blocking in accordance with Figures 6.4 through 6.9. The blocking shall be attached to floor or roof sheathing in accordance with sheathing panel edge fastener spacing. Such additional anchorage shall not be accomplished by the use of toe nails or nails subject to withdrawal nor shall such anchorage mechanisms induce tension stresses perpendicular to grain in ledgers or nailers. The capacity of such anchors shall result in connections capable of resisting the design values listed in Table 6.2. The additional anchorage shall be installed through an oversized hole in the ledger board that is 1/2 in (12.7 mm) larger than the anchorage mechanism diameter to prevent combined tension and shear in the mechanism.The diaphragm sheathing fasteners applied directly to a ledger shall not be considered effective in providing the additional anchorage required by this section.

Where the additional anchorage mechanisms consist of threaded rods with hex nuts or headed bolts complying with ASTM A307, Grade A or ASTM F1554, Grade 36, the design tensile strengths shown in Table 6.4 shall be equal to or greater than the product of the design values listed in Table 6.2 and the spacing of the bolts in feet. Anchor bolts shall be embedded as indicated in Table 6.4. Bolts with hooks shall not be used.

### 6.2.3 Floor and Roof diaphragm Construction in Seismic Design Categories D1and D2.

Edge spacing of fasteners in floor and roof sheathing shall be 4 inches (102 mm) on center for Seismic Design Category D1 and 3 inches (76 mm) on center for Seismic Design Category D1. In Seismic Design Categories D1 and D2, all sheathing edges shall be attached to framing or blocking. Minimum sheathing fastener size shall be 0.113 inch (2.8 mm) diameter with a minimum penetration of 1-3/8 inches (35 mm) into framing members supporting the sheathing. Minimum wood structural panel thickness shall be 7/16 inch (11 mm) for roof sheathing and 23/32 inch (18 mm) for floor sheathing. Vertical offsets in floor framing shall not be permitted.

## 6.3 ICF Wall-to-Roof Connection

Wood sill plates attaching roof framing to ICF walls shall be anchored to the ICF wall in accordance with Table 6.4 and Figure 6.8. Anchor bolts shall be located in the middle one-third of the flat ICF wall thickness or the middle one-third of the vertical core thickness of the waffle-grid and screen-grid ICF wall system and shall have a minimum embedment of 7 inches (178 mm). Roof framing attachment to wood sill plates shall be in accordance with the applicable building code.

In conditions where the 3-second gust design wind speed is 110 mph (177 km/hr) or greater, an approved uplift connector (i.e., strap or bracket) shall be used to attach roof assemblies to wood sill plates in accordance with the applicable building code. Embedment of strap connectors shall be in accordance with the strap connector manufacturer's approved recommendations.

In Seismic Design Category C, wood sill plates attaching roof framing to ICF walls shall be anchored with a Grade A 307, 3/8 inch (9.5 mm) diameter anchor bolt embedded a minimum of 7 inches (178 mm) and placed at a maximum spacing of 36 inches (914 mm) on center. Wood sill plates attaching roof framing to ICF walls shall be anchored with a minimum Grade A 307, 3/8 inch (9.5 mm) diameter anchor bolt embedded a minimum of 7 inches (178 mm) and placed at maximum spacing of 24 inches (609 mm) on center for Seismic Design Category D1 and a maximum spacing of 16 inches (406 mm) on center for Seismic Design Category D2. The minimum edge distance from the edge of concrete to edge of anchor bolt shall be 2.5 inches (63.5 mm).

In Seismic Design Category C, each rafter or truss shall be attached to the sill plate with an 18-gauge angle bracket using three 8d common nails per leg. For all buildings in Seismic Design Category D1, each rafter or truss shall be attached to the sill plate with an 18-gauge angle bracket using four 8d common nails per leg. For all buildings in Seismic Design Category D1, each rafter or truss shall be attached to the sill plate with an 18-gauge angle bracket using six 8d common nails per leg.

Where hipped roof construction is used without an attic floor, the following shall apply. For town-houses in Seismic Design Category C, each rafter shall be attached to the sill plate with an 18-gauge angle bracket using 3 – 8d common nails per leg in accordance with Figure 6.10. For all buildings in Seismic Design Category D1, each rafter shall be attached to the sill plate with an 18-gauge angle bracket using 4 – 8d common nails per leg in accordance with Figure 6.10. For all buildings in Seismic Design Category D2, each rafter shall be attached to the sill plate with an 18-gauge angle bracket using 6 – 8d common nails per leg in accordance with Figure 6.10.

## TABLE 6.1
## FLOOR LEDGER-ICF WALL CONNECTION (SIDE-BEARING CONNECTION) REQUIREMENTS[1,2,3]

| MAXIMUM FLOOR CLEAR SPAN[4] (feet) | MAXIMUM ANCHOR BOLT SPACING[5] (inches) | | | |
|---|---|---|---|---|
| | STAGGERED 1/2-INCH-DIAMETER ANCHOR BOLTS | STAGGERED 5/8-INCH-DIAMETER ANCHOR BOLTS | TWO 1/2-INCH-DIAMETER ANCHOR BOLTS[6] | TWO 5/8-INCH-DIAMETER ANCHOR BOLTS[6] |
| 8 | 18 | 20 | 36 | 40 |
| 10 | 16 | 18 | 32 | 36 |
| 12 | 14 | 18 | 28 | 36 |
| 14 | 12 | 16 | 24 | 32 |
| 16 | 10 | 14 | 20 | 28 |
| 18 | 9 | 13 | 18 | 26 |
| 20 | 8 | 11 | 16 | 22 |
| 22 | 7 | 10 | 14 | 20 |
| 24 | 7 | 9 | 14 | 18 |
| 26 | 6 | 9 | 12 | 18 |
| 28 | 6 | 8 | 12 | 16 |
| 30 | 5 | 8 | 10 | 16 |
| 32 | 5 | 7 | 10 | 14 |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm

1 Minimum ledger board nominal depth shall be 8 inches (203 mm). The actual thickness of the ledger board shall be a minimum of 1.5 inches (38 mm). Ledger board shall be minimum No. 2 Grade.

2 Minimum edge distance shall be 2 inches (51 mm) for 1/2-inch- (13-mm-) diameter anchor bolts and 2.5 inches (64 mm) for 5/8-inch- (16-mm-) diameter anchor bolts.

3 Interpolation is permitted between floor spans.

4 Floor span corresponds to the clear span of the floor structure (i.e., joists or trusses) spanning between load-bearing walls or beams.

5 Anchor bolts shall extend through the ledger to the center of the flat ICF wall thickness or the center of the horizontal or vertical core thickness of the waffle-grid or screen-grid ICF wall system.

6 Minimum vertical clear distance between bolts shall be 1.5 inches (38 mm) for 1/2-inch- (13-mm-) diameter anchor bolts and 2 inches (51 mm) for 5/8-inch- (16-mm-) diameter anchor bolts.

## TABLE 6.2
## DESIGN TENSILE STRENGTH OF HEADED BOLTS CAST IN CONCRETE[1]

| Diameter of Bolt - inches | Minimum Embedment Depth (inches) | Design Tensile Strength[2] (pounds) |
|---|---|---|
| 1/4 | 2 | 1040 |
| 3/8 with washer3 | 2-3/44 | 2540 |
| 1/2 with washer | 4 | 4630 |

1 Applicable to concrete of all strengths. See Notes (3) and (4)

2 Values are based on ASTM F1554, Grade 36 bolts. Where ASTM A307, Grade A headed bolts are used, the strength shall be increased by 1.034.

3 A hardened washer shall be installed at the nut embedded in the concrete or head of the bolt to increase the bearing area. The washer is not required where the concrete strength is 4000 psi or greater.

4 Embedment depth shall be permitted to be reduced 1/4-inch where 4000 psi concrete is used.

## TABLE 6.3
## MINIMUM DESIGN VALUES (plf) FOR FLOOR JOIST-TO-WALL ANCHORS REQUIRED IN SEISMIC DESIGN CATEGORIES C, D1, AND D2

| WALL TYPE | SEISMIC DESIGN CATEGORY | | |
|---|---|---|---|
| | C | D1 | D2 |
| Flat 3.5 | 193 | 320 | 450 |
| Flat 5.5 | 303 | 502 | 708 |
| Flat 7.5 | 413 | 685 | 965 |
| Flat 9.5 | 523 | 867 | 1,223 |
| Waffle 6 | 246 | 409 | 577 |
| Waffle 8 | 334 | 555 | 782 |
| Screen 6 | 233 | 387 | 546 |

For SI: 1plf = 14.59 N/m

1. Table values are based on IBC Equation 16-63 using a tributary wall height of 11 feet (3,353 mm). Table values may be reduced for tributary wall heights less than 11 feet (3.3 m) by multiplying the table values by X/11, where X is the tributary wall height.
2. Table values may be reduced by 30 percent to determine minimum allowable stress design values for anchors.

## TABLE 6.4
## TOP SILL PLATE-ICF WALL CONNECTION REQUIREMENTS

| MAXIMUM WIND SPEED (mph) | MAXIMUM ANCHOR BOLT SPACING 1/2-INCH-DIAMETER ANCHOR BOLT |
|---|---|
| 90 | 6′-0" |
| 100 | 6′-0" |
| 110 | 6′-0" |
| 120 | 4′-0" |
| 130 | 4′-0" |
| 140 | 2′-0" |
| 150 | 2′-0" |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 mph = 1.609344 km/hr

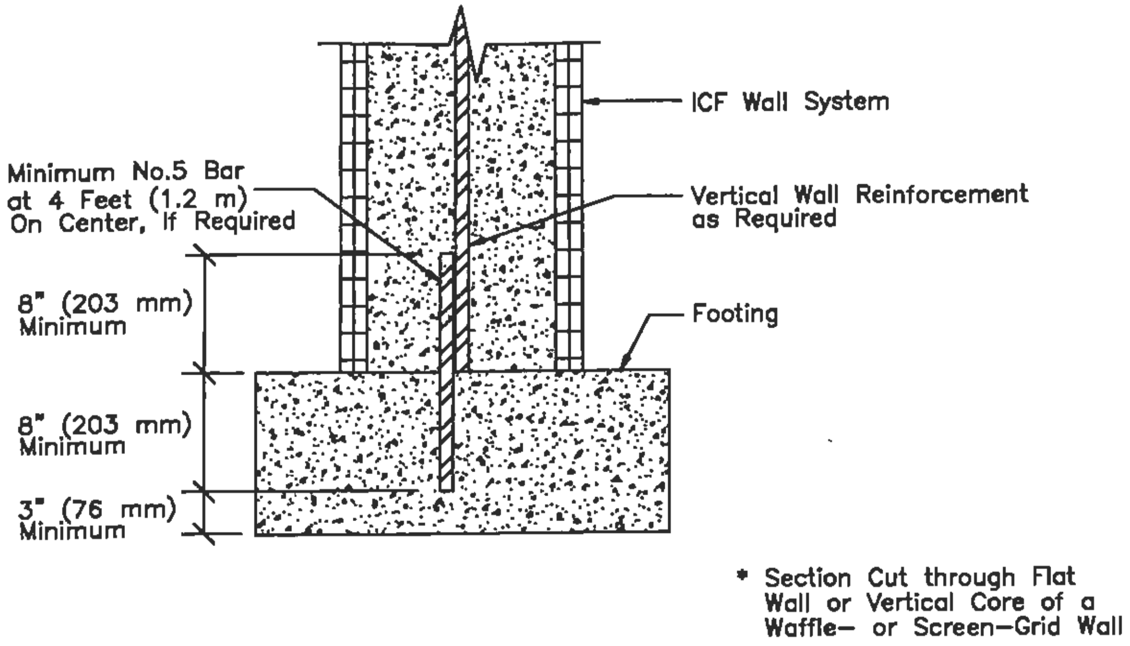



Figure 6.1 ICF Foundation Wall-to-Footing Connection

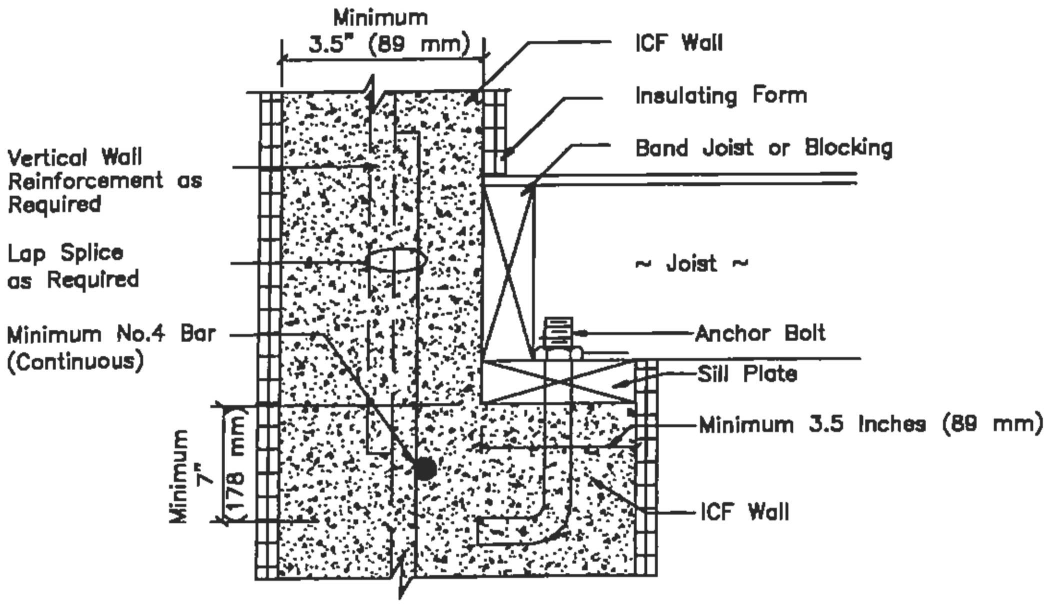



Figure 6.2 Floor on ICF Wall Connection (Top-Bearing Connection)

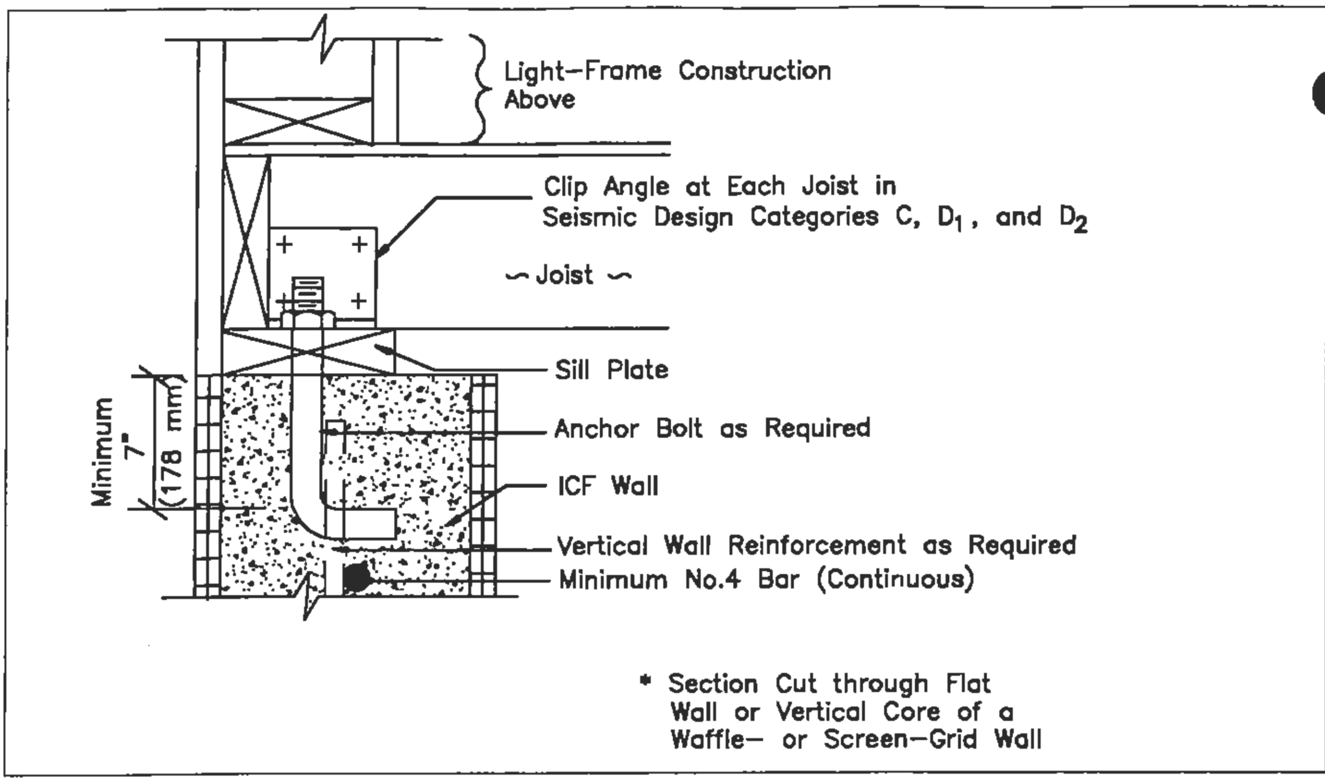



**Figure 6.3 Floor on ICF Wall Connection (Top-Bearing Connection)**
**(Not Permitted is Seismic Design Categories C, D1, or D2 Without Use of Out-of-Plane Wall Anchor in Accordance with Figure 6.5)**

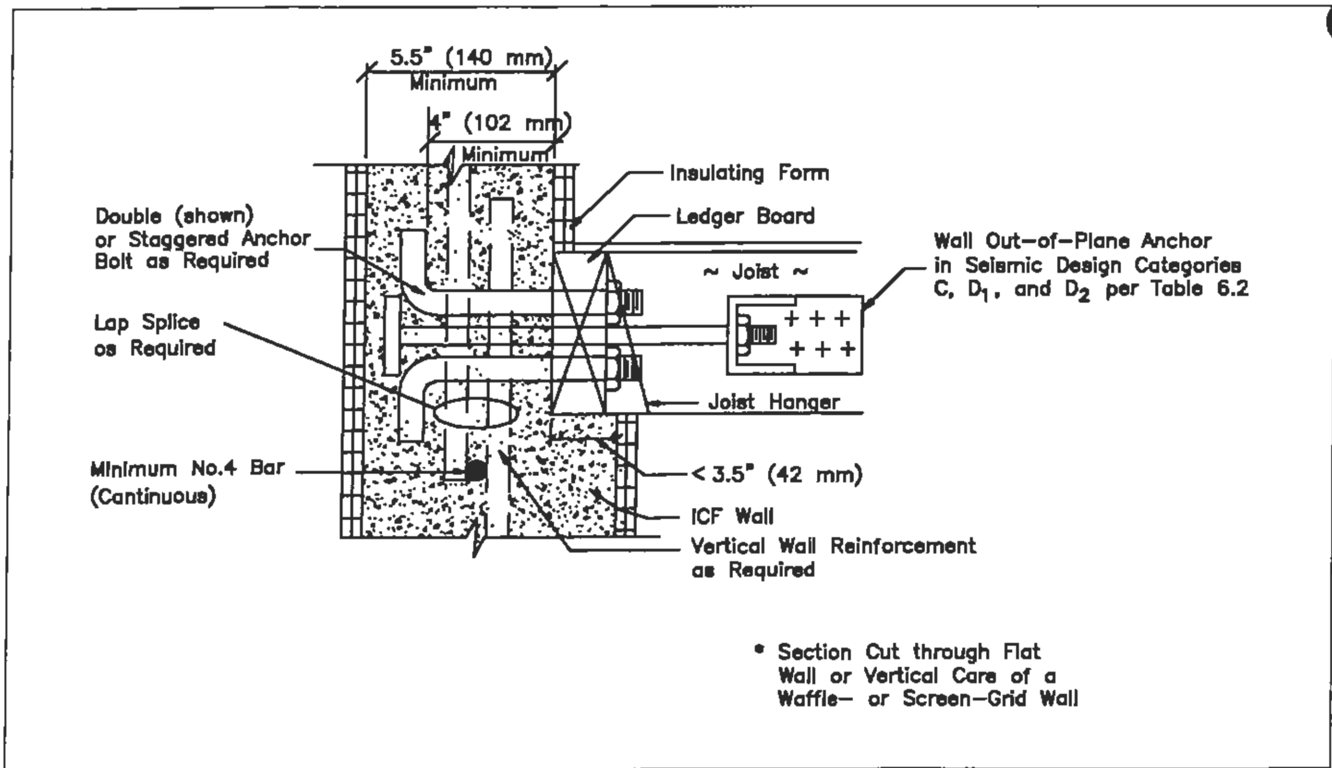



**Figure 6.4 Floor Ledger-ICF Wall Connection (Side-Bearing Connection)**

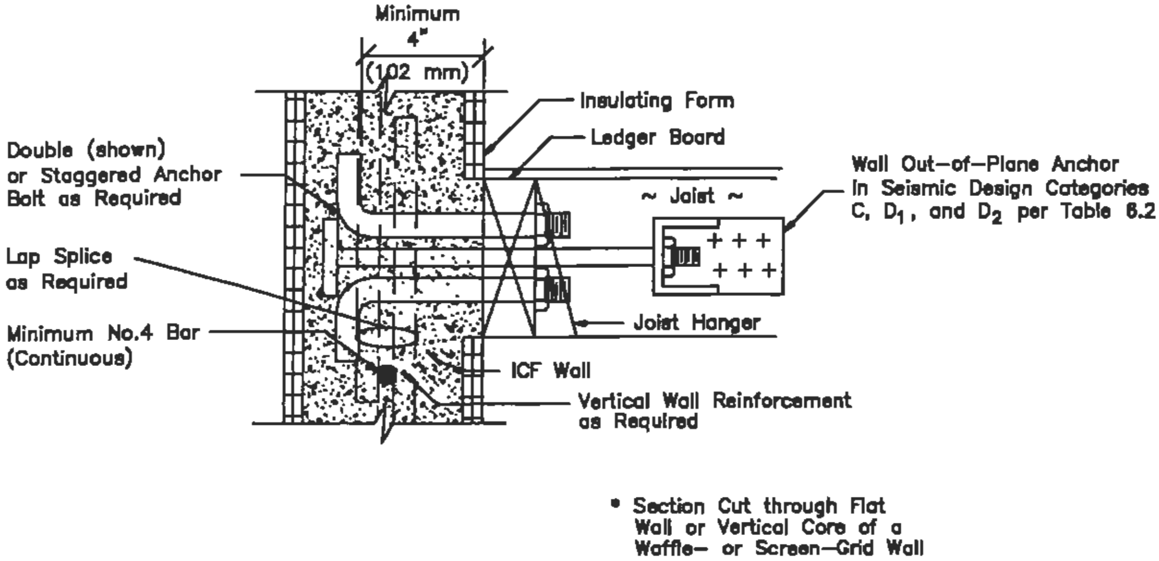



Figure 6.5 Floor Ledger-ICF Wall Connection (Side-Bearing Connection)

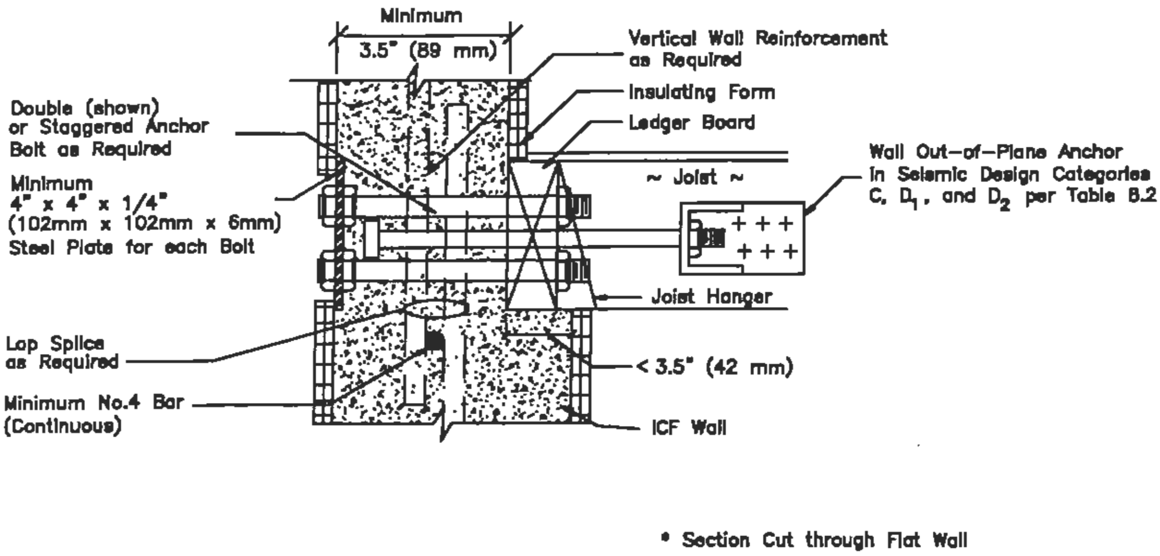



Figure 6.6 Floor Ledger-ICF Wall Connection (Through-Bolt Connection)

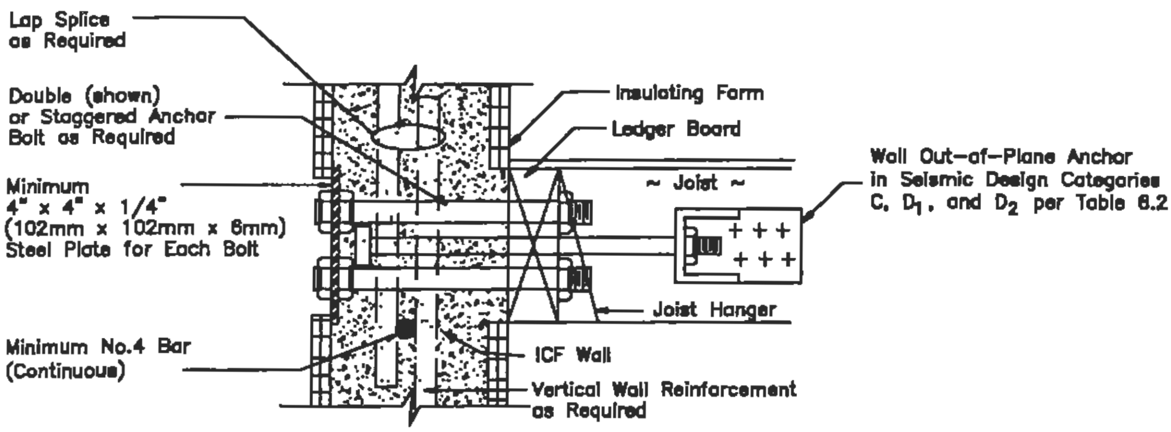



Figure 6.7 Floor Ledger-ICF Wall Connection (Through-Bolt Connection)

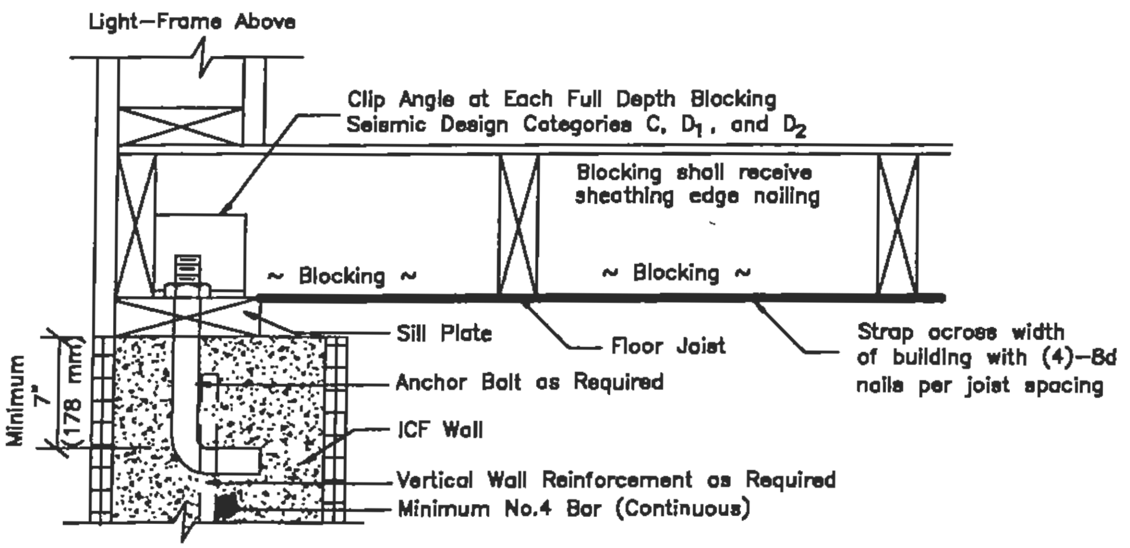



Figure 6.8 Anchorage Requirements for Townhouses in Seismic Design Category C and All Buildings in Seismic Design Category D for Floor Framing Parallel to Wall

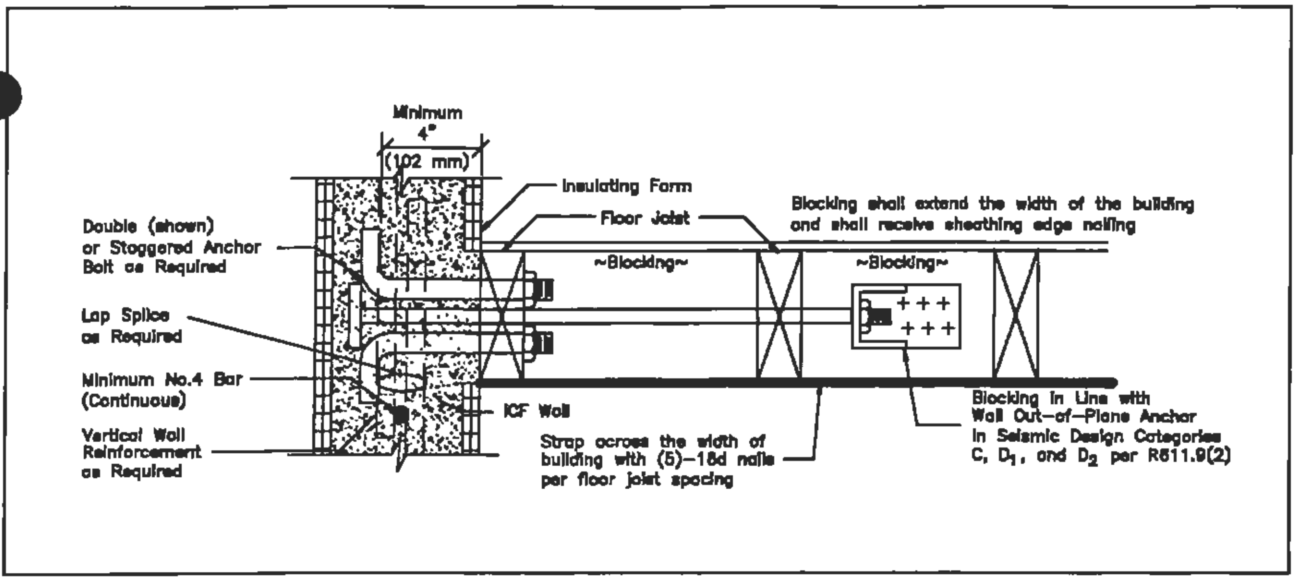



Figure 6.9 Anchorage Requirements for Townhouses in Seismic Design Category C and All Buildings in Seismic Design Category D for Floor Framing Parallel to Wall

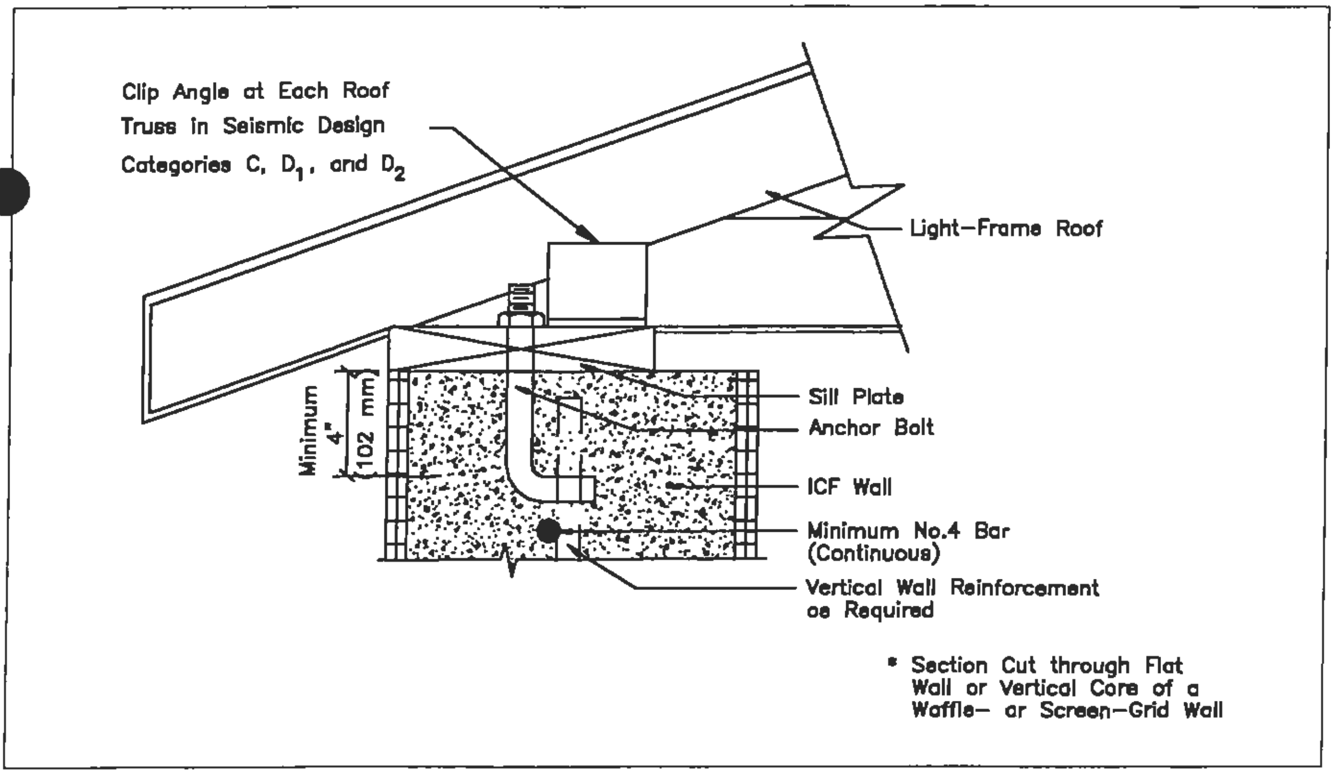



Figure 6.10 Top Wood Sill Plate-ICF Wall System Connection

# 7.0 UTILITIES

## 7.1 Plumbing Systems

Plumbing system installation shall comply with the applicable plumbing code.

## 7.2 HVAC Systems

HVAC system installation shall comply with the applicable mechanical code.

## 7.3 Electrical Systems

Electrical system installation shall comply with the National Electric Code.

# 8.0 CONSTRUCTION AND THERMAL GUIDELINES

## 8.1 Construction Guidelines

Before placing concrete, formwork shall be cleaned of debris and shall be free from frost. Concrete shall not be deposited into formwork containing snow, mud, or standing water or on or against any frozen material.

Before placing concrete, vertical and horizontal reinforcement shall be secured in place within the insulating concrete form as required in Section 2.0. Concrete placing methods and equipment shall be such that the concrete is conveyed and deposited at the specified slump, without segregation and without significantly changing any of the other specified qualities of the concrete.

An adequate method shall be followed to prevent freezing of concrete in cold weather during the placement and curing process. The insulating form shall be considered adequate protection against freezing when approved.

## 8.2 Thermal Guidelines

### 8.2.1 Energy Code Compliance

The insulation value (R-value) of all ICF wall systems shall meet or exceed the applicable provisions of the local energy code or the Model Energy Code [20].

### 8.2.2 Moisture

Form materials shall be protected against moisture intrusion through the use of approved exterior wall finishes in accordance with Sections 3.0 and 4.0.

### 8.2.3 Ventilation

The natural ventilation rate of ICF buildings shall not be less than that required by the local code or 0.35 ACH. When required, mechanical ventilation shall be provided to meet the minimum air exchange rate of 0.35 ACH in accordance with the Model Energy Code [20] or ASHRAE 62 [21].

## 9.0 REFERENCES


[1] ASTM E 380 *Standard Practice for Use of the International System of Units (SI) (the Modernized Metric System).* American Society for Testing and Materials (ASTM), West Conshohocken, Pennsylvania. 1992.

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[4] *Minimum Design Loads for Buildings and Other Structures* (ASCE 7-98). American Society of Civil Engineers, New York, New York. 1998.

[5] *International Building Code.* International Code Council (ICC). Falls Church, Virginia. 2000.

[6] *International Residential Code.* International Code Council (ICC). Falls Church, Virginia. 2000.

[7] *Guide to Residential Cast-in-Place Concrete Construction* (ACI 332R-84). American Concrete Institute, Detroit, Michigan. 1984.

[8] ASTM C 31/C 31M-96 *Standard Practice for Making and Curing Concrete Test Specimens in the Field.* American Society for Testing and Materials (ASTM), West Conshohocken, Pennsylvania. 1997.

[9] ASTM C 39-96 *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.* American Society for Testing and Materials (ASTM), West Conshohocken, Pennsylvania. 1996.

[10] ASTM E 84-96a *Standard Test Method for Surface Burning Characteristics of Building Materials.* American Society for Testing and Materials (ASTM), West Conshohocken, Pennsylvania. 1996.

[11] ASTM C 143-90a *Standard Test Method for Slump of Hydraulic Cement. American Society for Testing and Materials* (ASTM), West Conshohocken, Pennsylvania. 1978.

[12] ASTM A 370-96 *Standard Test Methods and Definitions for Mechanical Testing of Steel Products.* American Society for Testing and Materials (ASTM), West Conshohocken, Pennsylvania. 1996.

[13] ASTM C 94-96e1 *Standard Specification for Ready-Mixed Concrete. American Society for Testing and Materials* (ASTM), West Conshohocken, Pennsylvania. 1996.

[14] ASTM A615/A615 M-96a *Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement.* American Society for Testing and Materials (ASTM), West Conshohocken, Pennsylvania. 1996.

[15] ASTM A996/A996 M-01 *Standard Specification for Rail-Steel and Axle-Steel Deformed Bars for Concrete Reinforcement.* American Society for Testing and Materials (ASTM), West Conshohocken, Pennsylvania. 2001.

[16] ASTM A706/A706 M-96b *Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement*. American Society for Testing and Materials (ASTM), West Conshohocken, Pennsylvania. 1996.

[17] ASTM C 578-95 *Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation*. American Society for Testing and Materials (ASTM). West Conshohocken, Pennsylvania. 1995.

[18] *Design and Construction of Frost-Protected Shallow Foundations*. ASCE Standard 32-01, American Society of Civil Engineers, Reston, Virginia. 2001.

[19] ASTM E 119-95a *Standard Test Methods for Fire Tests of Building Construction and Materials*. American Society for Testing and Materials (ASTM), West Conshohocken, Pennsylvania. 1995.

[20] Model Energy Code. *The Council of American Building Officials* (CABO). Falls Church, Virginia. 1995.

[21] ASHRAE 62-1999 *Ventilation for Acceptable Indoor Air Quality*. American Society of Heating, Refrigerating, and Air-Conditioning Engineering, Inc., Atlanta, Georgia. 1999.

# PART II

# COMMENTARY

# INTRODUCTION

The Commentary is provided to facilitate the use of, and provide background information for, the Prescriptive Method. It also includes supplemental information and engineering data supporting the development of the Prescriptive Method. Individual sections, figures, and tables are presented in the same sequence found in the Prescriptive Method. For detailed engineering calculations, refer to Appendix B, Engineering Technical Substantiation.

Information is presented in both U.S. customary units and International System (SI). Reinforcement bar sizes are presented in U.S. customary units; refer to Appendix C for the corresponding reinforcement bar size in SI units.

# C1.0 GENERAL

## C1.1 Purpose

The goal of the *Prescriptive Method* is to present prescriptive criteria (i.e., tables, figures, guidelines) for the construction of one- and two-story dwellings with insulating concrete forms. Before development of the First Edition of this document, no "generic" prescriptive standards were available to builders and code officials for the purpose of constructing concrete homes with insulating concrete forms without the added expense of a design professional and the other costs associated with using a "nonstandard" material for residential construction.

The *Prescriptive Method* presents minimum requirements for basic residential construction using insulating concrete forms. The requirements are consistent with the safety levels contained in the current U.S. building codes governing residential construction.

The *Prescriptive Method* is not applicable to all possible conditions of use and is subject to the applicability limits set forth in Table 1.1 of the *Prescriptive Method*. The applicability limits should be carefully understood as they define important constraints on the use of the *Prescriptive Method*. This document is not intended to restrict the use of either sound judgment or exact engineering analysis of specific applications that may result in improved designs and economy.

## C1.2 Approach

The requirements, figures, and tables provided in the *Prescriptive Method* are based primarily on the *Building Code Requirements for Structural Concrete* [C1] and the *Structural Design of Insulating Concrete Form Walls in Residential Construction* [C2], and the pertinent requirements of the *Minimum Design Loads for Buildings and Other Structures* [C3], the *International Residential Code* [C4], and the *International Building Code* [C5]. Construction practices from the *Guide to Residential Cast-in-Place Concrete Construction* [C6] have also been used. Engineering decisions requiring interpretations or judgments in applying the above references are documented in this *Commentary* and in Appendix B.

## C1.3 Scope

It is unrealistic to develop an easy-to-use document that provides prescriptive requirements for all types and styles of ICF construction. Therefore, the *Prescriptive Method* is limited in its applicability to typical one- and two-family dwellings. The requirements set forth in the *Prescriptive Method* apply only to the construction of ICF houses that meet the limits set forth in Table 1.1 of the *Prescriptive Method*. The applicability limits are necessary for defining reasonable boundaries to the conditions that must be considered in developing prescriptive construction requirements. The *Prescriptive Method*, however, does not limit the application of alternative methods or materials through engineering design by a design professional.

The basic applicability limits are based on industry convention and experience. Detailed applicability limits were documented in the process of developing prescriptive design requirements for various elements of the structure. In some cases, engineering sensitivity analyses were performed to help define appropriate limits.

The applicability limits strike a reasonable balance among engineering theory, available test data, and proven field practices for typical residential construction applications. They are intended to prevent misapplication while addressing a reasonably large percentage of new housing conditions. Special consideration is directed toward the following items related to the applicability limits.

*Building Geometry*

The provisions in the *Prescriptive Method* apply to detached one- or two-family dwellings, townhouses, and other attached single-family dwellings not more than two stories in height above grade. Application to homes with complex architectural configurations is subject to careful interpretation and sound judgment by the user and design support may be required.

*Site Conditions*

Snow loads are typically given in a ground snow load map such as that provided in ASCE 7 [C3] or by local practice. The 0 to 70 psf (0 to 3.4 kPa) ground snow load used in the *Prescriptive Method* covers approximately 90 % of the United States, which includes the majority of the houses that are expected to use this document. In areas with higher ground snow loads, this document cannot be used and a design professional should be consulted.

All areas of the United States fall within the 85 to 150 mph (137 to 241 km/hr) range of 3-second gust design wind speeds [C3][C4][C5]. Houses built along the immediate, hurricane-prone coastline subjected to storm surge (i.e., beach-front property) cannot be designed with this document and a design professional should be consulted. The National Flood Insurance Program (NFIP) requirements, administered by the Federal Emergency Management Agency (FEMA), should also be employed for structures located in coastal high-hazard zones as locally applicable.

Buildings constructed in accordance with the *Prescriptive Method* are limited to sites designated as Seismic Design Categories A, B, C, D1, and D2 [C4][C5].

Soil borings are rarely required for residential construction except where there are known risks or a history of problems (i.e., organic deposits, landfills, expansive soils) associated with building in certain areas. The presumptive soil-bearing value of 2,000 psf (96 kPa) is based on typical soil conditions in the United States except in areas of high risk or where local experience or geotechnical investigation proves otherwise.

*Loads*

Loads and load combinations requiring calculations to analyze the structural components and assemblies of a home are presented in Appendix B, *Engineering Technical Substantiation.*

If relying on either older fastest-mile wind speed maps or older design provisions based on fastest-mile wind speeds, the designer should convert the wind speeds in accordance with Table C1.1 for use with the tables in the *Prescriptive Method.*

TABLE C1.1
WIND SPEED CONVERSIONS

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Fastest Mile (mph) | 70 | 75 | 80 | 90 | 100 | 110 | 120 | 130 |
| 3-second Gust (mph) | 85 | 90 | 100 | 110 | 120 | 130 | 140 | 150 |

## C1.4 ICF System Limitations

All ICF systems are typically categorized with respect to the form itself and the resulting shape of the formed concrete wall. There are three types of ICF forms: panel, plank, and block. The differences among the ICF form types are their size and attachment requirements.

There are also three categories of ICF systems based on the resulting shape of the formed concrete wall. From a structural design standpoint, it is only the shape of the concrete inside the form, not the type of ICF form, that is of importance. The shape of the concrete wall may be better understood by visualizing the form stripped away from the concrete, thereby exposing it to view. The three categories of ICF wall forms are flat, grid, and post-and-beam. The grid wall type is further categorized into waffle-grid and screen-grid wall systems. These classifications are provided solely to ensure that the design tables in this document are applied to the ICF wall systems as the authors intended.

The post-and-beam ICF wall system is not included in this document because it requires a different engineering analysis. It is analyzed as a concrete frame rather than as a monolithic concrete (i.e., flat, waffle-grid, or screen-grid) wall construction in accordance with ACI 318 [C1]. Post-and-beam systems may be analyzed in the future to provide a prescriptive method to facilitate their use.

## C1.5 Definitions

The definitions in the *Prescriptive Method* are provided because certain terms are likely to be unfamiliar to the home building trade. Additional definitions that warrant technical explanation are defined below.

***Permeance:*** The permeability of a porous material; a measure of the ability of moisture to migrate through a material.

***Superplasticizer:*** A substance added to concrete mix that improves workability at very low water-cement ratios to produce high, early-strength concrete. Also referred to as high-range, water-reducing admixtures.

# C2.0 MATERIALS, SHAPES, AND STANDARD SIZES

## C2.1 Physical Dimensions

Due to industry variations related to the dimensions of ICFs, dimensions were standardized (i.e., thickness, width, spacing) to allow for the development of the *Prescriptive Method*. This prescriptive approach may result in a conservative design for ICFs where thickness and width are greater than the minimum allowable or the spacing of vertical cores is less than the maximum allowable. Consult a design professional if a more economical design is desired.

### C2.1.1 Flat ICF Wall Systems

***Wall Thickness:*** The actual wall thickness of flat ICF wall systems is limited to 3.5 inches (89 mm), 5.5 inches (140 mm), 7.5 inches (191 mm), or 9.5 inches (241 mm) in order to accommodate systems currently available. ICF flat wall manufacturers whose products have a wall thickness different than those listed above shall use the tables in the Prescriptive Method for the nearest available wall thickness that does not exceed the actual wall thickness.

### C2.1.2 Waffle-Grid ICF Wall Systems

***Core Thickness and Width:*** The vertical and horizontal core thickness and width are limited per Table 2.1 in the *Prescriptive Method* in order to accommodate ICF waffle-grid wall systems currently available. Variation among the ICF waffle-grid manufacturers is minimal; therefore, the tables in the *Prescriptive Method* should produce economical designs for buildings meeting the applicability limits of Table 1.1 in the *Prescriptive Method*. ICF waffle-grid manufacturers that offer concrete cross sections larger than those required in Table 2.1 of the *Prescriptive Method* shall use the tables for the nominal size that has the nearest available core thickness not exceeding the actual wall thickness. Although Figure 2.2 in the *Prescriptive Method* shows the ICF waffle-grid vertical core shape as elliptical, the shape of the vertical core may be round, square, or rectangular provided that the minimum dimensions in Table 2.1 are met.

***Core Spacing:*** The vertical and horizontal core spacing is limited per Table 2.1 of the *Prescriptive Method* in order to accommodate the ICF waffle-grid wall systems currently available. Variation in the products offered by the ICF waffle-grid manufacturers is minimal; therefore, the tables in the Prescriptive Method should produce economical designs for buildings meeting the applicability limits of Table 1.1 in the *Prescriptive Method.*

***Web Thickness:*** The minimum web thickness of 2 inches (51 mm) is based on ICF waffle-grid systems currently available. Variation in the products offered by the ICF waffle-grid manufacturers is minimal; therefore, the tables in the *Prescriptive Method* should produce economical designs for buildings meeting the applicability limits of Table 1.1 in the *Prescriptive Method*.

### C2.1.3 Screen-Grid ICF Wall System

***Core Thickness and Width:*** The vertical and horizontal core thickness and width are limited per Table 2.1 in the Prescriptive Method in order to accommodate ICF screen-grid wall systems currently available. ICF screen-grid manufacturers that offer concrete cross sections larger than those required in Table 2.1 shall use the tables for the nominal size that has the nearest available core thickness not exceeding the actual wall thickness. Although Figure 2.3 of the *Prescriptive Method* shows the ICF screen-grid vertical core shape as round, the shape of the vertical core may be square, rectangular, elliptical, or other shape provided that the minimum dimensions in Table 2.1 are met.

***Core Spacing:*** The vertical and horizontal core spacing is limited per Table 2.1 of the *Prescriptive Method* in order to accommodate the large number of ICF screen-grid wall systems currently available. Due to a lack of test data to suggest otherwise, the maximum allowable horizontal and vertical core spacing is a value agreed on by the steering committee members. The core spacing is the main requirement differentiating an ICF screen-grid system from an ICF post-and-beam system. Future testing is required to determine the maximum allowable core spacing without adversely affecting the wall system's ability to act as a wall rather than as a frame.

## C2.2 Concrete Materials

### C2.2.1 Concrete Mix

The maximum slump and aggregate size requirements are based on current ICF practice. Considerations included in the prescribed maximums are ease of placement, ability to fill cavities thoroughly, and limiting the pressures exerted on the form by wet concrete.

Concrete for walls less than 8 inches (203 mm) thick is typically placed in the forms by using a 2-inch- (51-mm-) to 4-inch- (102-mm-) diameter boom or line pump; aggregates larger than the maximums prescribed may clog the line. To determine the most effective mix, the industry is planning to conduct experiments that vary slump and aggregate size, and use admixtures (i.e., superplasticizers). The research may not produce an industry wide standard due to the variety of available form material densities and ICF types; therefore, an exception for higher allowable slumps is provided in the *Prescriptive Method.*

### C2.2.2 Compressive Strength

The minimum concrete compressive strength of 2,500 psi is based on the minimum current ICF practice, which corresponds to minimum compressive strength permitted by building codes. This edition of the *Prescriptive Method* provides adjustment factors in the footnotes of tables that recognize the benefits of using higher strength concrete. For Seismic Design Categories D1 and D2, a minimum concrete compressive strength of 3,000 psi is required [C1][C5].

It is believed that concrete cured in ICFs produce higher strengths than conventional concrete construction because the formwork creates a "moist cure" environment for the concrete; however, the concrete compressive strength specified herein is based on cylinder tests cured outside the ICF in accordance with ASTM C31 [C7] and ASTM C 39 [C8].

### C2.2.3 Reinforcing Steel

***Materials:*** The *Prescriptive Method* applies to reinforcing steel with a minimum yield strength of 40 ksi (300 MPa). In certain instances, this prescriptive approach results in a conservative design for ICFs where reinforcement with a greater yield strength is used. This edition of the *Prescriptive Method* provides adjustment factors in the footnotes of tables that recognize the benefits of using Grade 60 (420 MPa) reinforcing steel. Low-alloy reinforcing steel is required in Seismic Design Categories D1 and D2 for improved ductility [C1][C5].

*Placement:* The *Prescriptive Method* requires vertical and horizontal wall reinforcement to be placed in the middle third of the wall thickness. The requirements for vertical and horizontal wall reinforcement placement are based on current construction practice for a large number of ICF manufacturers. They provide deviations from the center of the wall on which the calculations are based for reinforcement lap splices and intersections of horizontal and vertical wall reinforcement.

A few ICF manufacturers produce a groove or loop in the form tie allowing for easier reinforcement placement. These manufacturers may locate the groove or loop closer to the interior or exterior face of the wall to reap the maximum benefit from the steel reinforcement; the location depends on the wall's loading conditions and is reflected in the exception for basement walls as well as in the middle-third requirement for above-grade walls.
Lap splices are provided to transfer forces from one bar to another where continuous reinforcement is not practical. Lap splices are typically necessary at the top of basement and first story walls, between wall stories, at building corners, and for continuous horizontal wall reinforcement. The lap splice requirements are based on ACI 318 [C1].

## C2.3 Form Materials

The materials listed in the *Prescriptive Method* are based on currently available ICFs. From a structural standpoint, the material can be anything that has sufficient strength to contain the concrete during pouring and curing. From a thermal standpoint, the form material should provide the R-value required by the local building code; however, the required R-value could be met by installing additional insulation to the exterior of the form, provided that it does not reduce the minimum concrete dimensions as specified in Section 2.0. From a life-safety standpoint, the form material can be anything that meets the criteria for flame-spread and smoke development. The *Prescriptive Method* addresses other concerns (i.e., water vapor transmission, termite resistance) that must be considered when using materials other than those specifically listed here. This section is not intended to exclude the use of either a current or future material provided that the requirements of this document are met.

# C3.0 FOUNDATIONS

## C3.1 Footings

The loads imposed on the footings do not vary from those of conventional concrete construction; however, the *Prescriptive Method* provides a table for minimum footing widths with ICF construction. ICF footing forms are currently available and may be used if they meet the minimum footing dimensions required in Table 3.1 in the *Prescriptive Method*. Table 3.1 is similar to the requirements in the IRC [C4] for 8-inch- (203-mm-) solid or fully grouted masonry. The minimum footing width values are based on a 28-foot- (8.5-m-) wide building.

Minimum footing widths are based on the maximum loading conditions found in Table 1.1 of the Prescriptive Method, a minimum footing depth of 12 inches (305 mm) below grade, unsupported wall story heights up to 10 feet (3 m), and the assumption that all stories are the same thickness and are constructed of ICFs unless otherwise noted.

The values in Table 3.1 of the *Prescriptive Method* for a one-story ICF structure account for one ICF story above-grade. The values in Table 3.1 for a two-story ICF structure account for two ICF stories above-grade. The values in the table account for an ICF basement wall in all cases.

Footnote 1 to Table 3.1 in the *Prescriptive Method* provides guidance for sizing an unreinforced footing based on rule of thumb. This requirement may be relaxed when a professional designs the footing. Soil borings are rarely required for residential construction except where there are known risks or a history of problems (i.e., organic deposits, landfills, expansive soils) associated with building in certain areas. For an approximate relationship between soil type and load-bearing value, refer to Table C3.1.

## C3.2 ICF Foundation Wall Requirements

The *Prescriptive Method* provides reinforcement tables for foundation walls constructed within the applicability limits of Table 1.1 in the *Prescriptive Method*. The maximum design conditions are Seismic Design Category D2, ground snow load of 70 psf (3.4 kPa), and equivalent fluid density of 60 pcf (960 kg/m$^3$). The *Prescriptive Method* provides the minimum required vertical and horizontal wall reinforcement for various equivalent fluid densities, wall heights, and unbalanced backfill heights. Vertical wall reinforcement tables are limited to foundation walls (non-load-bearing) with unsupported wall heights up to 10 feet (3 m).

Residential construction makes widespread use of 8-foot (2.4-m) walls; however, ICF homes are often constructed with higher ceilings. Walls are grouped into three categories as follows:

- walls with soil backfill having a maximum 30 pcf (481 kg/m$^3$) equivalent fluid density;
- walls with soil backfill having a maximum 45 pcf (721 kg/m$^3$) equivalent fluid density;
- walls with soil backfill having a maximum 60 pcf (960 kg/m$^3$) equivalent fluid density.

The following design assumptions were used to analyze the walls:

- Walls support either one or two stories above. The load case considered in the development of the second edition of the *Prescriptive Method* is conservative in that no dead, live, or other gravity loads are considered which would increase the moment capacity, even with considerable eccentricity of axial load toward the outside face of the foundation wall. This method is consistent with the development of the plain concrete and reinforced concrete ICF foundation wall provisions in the *International Residential Code* [C4].

- Walls are simply supported at the top and bottom of each story.
- Walls contain no openings.
- Bracing is provided for the wall by the floors above and floor slabs below.
- Roof slopes range from 0:12 to 12:12.
- Deflection criterion is the height of the wall, in inches, divided by 240.

Deflection limits are primarily established with regard to serviceability concerns. The intent is to prevent excessive deflection, which may result in cracking of finishes. For walls, most codes generally agree that L/240 represents an acceptable serviceability limit for deflection. For walls with flexible finishes, less stringent deflection limits may be used. The reader is referred to Appendix B, *Engineering Technical Substantiaton,* for an example calculation for a foundation wall. In cases where the calculations required no vertical wall reinforcement, a minimum wall reinforcement of one vertical No. 4 bar at 48 inches (1.2 m) on center is a recommended practice to account for temperature, shrinkage, potential honeycombing, voids, or construction errors.

Minimum horizontal wall reinforcement is based on recommendations in *Design Criteria for Insulating Concrete Form Wall Systems* [C10]. The minimum allows for temperature, shrinkage, potential honeycombing, voids, or construction errors.

### C3.2.1 ICF Walls with Slab-on-Grade

ICF stem wall thickness and height are determined as those which can distribute the building loads safely to the earth. The stem wall thickness should be greater than or equal to the thickness of the above-grade wall it supports. Given that stem walls are relatively short and are backfilled on both sides, lateral earth loads induce a small bending moment in the walls; accordingly, lateral bracing should not be required before backfilling.

### C3.2.2 ICF Crawlspace Walls

Table 3.2 in the *Prescriptive Method* applies to crawlspace walls 5 feet (1.5 m) or less in height with a maximum unbalanced backfill height of 4 feet (1.2 m). These values were derived from the *Structural Design of Insulating Concrete Form Walls in Residential Construction* [C2]. Loading conditions were based on a maximum 32-foot- (9.8-m-) wide building with the lightest practical gravity loads experienced in residential construction (i.e., a zero dead load as described previously). The values for minimum vertical wall reinforcement are based on the controlling loading condition. For detailed engineering calculations, refer to Appendix B, *Engineering Technical Substantiation.*

Soil borings are rarely required for residential construction except where there are known risks or a history of problems (i.e., organic deposits, landfills, expansive soils) associated with building in certain areas. Refer to Table C3.2 for an approximate relationship between soil classifications and equivalent fluid density [C3].

Backfilling should not occur without lateral support at the top of the wall from either the first floor structure or temporary bracing unless the backfill height is less than one-half the crawlspace wall height. This requirement ensures that the backfill does not cause the wall to overturn. Concrete walls can withstand the higher lateral load created from the backfill when the top of the wall is braced and axial loads are present on the wall. Typically, providing lateral bracing at the top of the wall until the structure above is in place is sufficient. Moreover, backfilling should not occur before seven days after the concrete pour; waiting seven days typically allows the concrete to reach sufficient strength.

### C3.2.3 ICF Basement Walls

Tables 3.3 through 3.9 in the *Prescriptive Method* pertain to basement walls. The values were derived from the *Structural Design of Insulating Concrete Form Walls in Residential Construction* [C2]. Loading conditions were based on lightest possible gravity loads experienced in residential construction (i.e., a zero dead load as described previously). The values for minimum vertical wall reinforcement are based on the controlling loading condition. For detailed engineering calculations, refer to the Appendix B, *Engineering Technical Substantiation.*

Soil borings are rarely required for residential construction except where there are known risks or a history of problems (i.e., organic deposits, landfills, expansive soils) associated with building in certain areas. Refer to Table C3.2 for an approximate relationship between soil classifications and equivalent fluid density.

Backfilling should not occur without lateral support at the top of the wall from either the first floor structure or temporary bracing unless the unbalanced backfill height is less than one-half the basement wall height. This requirement ensures that the backfill does not cause the wall to overturn. Concrete walls can withstand the higher lateral loads created from the backfill when the top of the wall is braced and axial loads are present on the wall. Typically, providing lateral bracing at the top of the wall until the structure above is in place is sufficient. Moreover, backfilling should not occur before seven days after the concrete pour; waiting seven days typically allows the concrete to reach sufficient strength.

## C3.3 ICF Foundation Wall Coverings

The requirements for interior covering of habitable spaces are based on current building codes and are self-explanatory.

It is generally accepted that a monolithic concrete wall is a solid wall through which water and air cannot readily flow; however, there is a possibility that the concrete wall may have honeycombs, voids, or hairline cracks through which water may enter. Voids between ICF blocks are inherent in current screen-grid ICF walls and will allow ground water to enter the structure. As a result, a moisture barrier on the exterior face of all ICF below-grade walls is generally required and should be considered good practice. Due to the variety of materials on the market, waterproofing and dampproofing materials are typically specified by the ICF manufacturer. The limitation in the *Prescriptive Method* regarding non-petroleum-based materials reflects the concern that many ICFs are usually manufactured of rigid foam plastic, which is generally incompatible with petroleum-based materials.

A vapor retarder may be required on the interior face of the ICF wall in some cases. Test results have shown a potential exists for condensation occurring on the interior face of above-grade ICFs with a permeance as little as 0.5 perms in colder climates. Few problems have been reported when the exterior wall finishes are properly designed and constructed to prevent water intrusion. The reader is referred to *Mitigation of Moisture in Insulating Concrete Form Wall Systems* [C11] for more information on the testing and suggested construction recommendations.

## C3.4 Termite Protection Requirements

Termites need wood (cellulose) and moisture to survive. Rigid foam plastic provides termites with no nutrition but can provide access to the wood structural elements. Recently, some building codes have prohibited rigid foam plastics for near- or below-grade use in heavy termite infestation areas. Code officials and termite treaters fear that foam insulation provides a "hidden pathway." Local building code requirements, a local pest control company, and the ICF manufacturer should be consulted regarding this concern to determine if additional protection is necessary. A brief list of some possible termite control measures follow.

- Rely on soil treatment as a primary defense against termites. Periodic retreatment and inspection should be carried forth by the homeowner or termite treatment company.
- Install termite shields.
- Provide a 6-inch- (152-mm-) high clearance above finish grade around the perimeter of the structure where the foam has been removed to allow visual detection of termites.
- The use of borate-treated ICF forms will kill insects that ingest them, and testing of borate-treated EPS foam shows that it reduces tunneling compared to untreated EPS.

**TABLE C3.1**
**LOAD-BEARING SOIL CLASSIFICATION**

| MINIMUM LOAD-BEARING VALUE psf (kPa) | SOIL DESCRIPTION |
|---|---|
| 2,000 (96) | Clay, sandy clay, silty clay, and clayey silt |
| 3,000 (144) | Sand, silty sand, clayey sand, silty gravel, and clayey gravel |
| 4,000 (192) | Sandy gravel and medium-stiff clay |
| > 4,000 (192) | Stiff clay, gravel, sand, sedimentary rock, and crystalline bedrock |

**TABLE C3.2**
**EQUIVALENT FLUID DENSITY SOIL CLASSIFICATION**

| MAXIMUM EQUIVALENT FLUID DENSITY pcf (kg/m$^3$) | UCS1 CLASSIFICATION | SOIL DESCRIPTION |
|---|---|---|
| 30 (481) | GW, GP, SW, SP, GM | Well-drained, cohesionless soils such as clean (few or no fines) sand and gravels |
| 45 (721) | GC, SM | Well-drained, cohesionless soils such as sand and gravels containing silt or clay |
| 60 (961) | SC, MH, CL, CH, ML-CL | Well-drained, inorganic silts and clays that are broken up into small pieces |

[1] UCS - Uniform Soil Classification system

# C4.0 ICF ABOVE-GRADE WALLS

## C4.1 ICF Above-Grade Wall Requirements

The *Prescriptive Method* provides reinforcement tables for walls constructed above-grade within the applicability limits of Table 1.1 in the *Prescriptive Method*. The maximum design conditions are Seismic Design Category D2, ground snow load of 70 psf (3.4 kPa), and a design wind pressure of 80 psf (3.8 kPa). The Prescriptive Method provides the minimum required vertical and horizontal wall reinforcement for different design wind pressures and wall heights. Vertical wall reinforcement tables are limited to one- and two-story buildings for non-load-bearing and load-bearing walls laterally unsupported up to 10 feet (3 m).

Residential construction makes widespread use of 8-foot (2.4-m) walls; however, ICF homes are often constructed with higher ceilings. Walls are grouped into three categories as follows:

- walls for one-story or the second floor of a two-story building (supporting a roof only);
- walls for the first story of a two-story building where the second story is light-frame construction (supporting light-frame second story and roof); and
- walls for the first story of a two-story building where the second story is ICF construction (supporting ICF second story and roof).

The following design assumptions were made in analyzing the walls:

- Walls are simply supported at each floor and roof providing lateral support.
- Walls contain no openings.
- Lateral support is provided for the wall by the floors, slab-on-grade, and roof.
- Roof slopes range from 0:12 to 12:12.
- Deflection criterion is the laterally unsupported height of the wall, in inches, divided by 240.
- The minimum possible axial load is considered for each case.
- Wind loads were calculated in accordance with ASCE 7 [C3] using components and cladding coefficients, interior zone, and mean roof height of 35 feet (11 m).

Deflection limits are primarily established with regard to serviceability concerns. The intent is to prevent excessive deflection, which may result in cracking of finishes. For walls, most codes generally agree that L/240 represents an acceptable serviceability limit for deflection. For walls with flexible finishes, less stringent deflection limits may be used. The reader is referred to Appendix B, *Engineering Technical Substantiaton,* for an example calculation for an above-grade wall. In cases where the calculations required no vertical wall reinforcement, the following minimum wall reinforcement is required.

A minimum of one vertical No. 4 bar at 48 inches (1.2 m) on center is required for all above-grade wall applications. This requirement establishes a minimum "good practice" in ICF construction and provides for crack control, continuity, and a "safety factor" for conditions where concrete consolidation cannot be verified due to the stay-in-place formwork. In addition, structural testing was conducted at the NAHB Research Center, Inc. to determine the in-plane shear resistance of concrete walls cast with ICFs [C9]. All test specimens had one No. 4 vertical bar at 48 inches on center. Upon review of the data, this requirement allows the in-plane shear analysis to be calculated as reinforced concrete instead of plain structural concrete. This allows for lower minimum solid wall lengths for wind and seismic design. This minimum reinforcement allows all shear walls to be analyzed identically and provides consistency in all table values. Details on the analysis approach are found in Appendix B.

Minimum horizontal wall reinforcement is based on recommendations in *Design Criteria for Insulating Concrete Form Wall Systems* [C10]. The minimum allows for temperature, shrinkage, or potential construction errors.

The more stringent requirement that vertical wall reinforcement be terminated with a bend or hook in high wind areas is based on current standards for conventional masonry construction. The requirement has proven very effective in masonry construction in conditions with wind speeds 110 mph (177 km/hr) or greater. The bend or hook provides additional tensile strength in the concrete wall to resist the large roof uplift loads in high wind areas. A similar detailing requirement is used in high seismic conditions as required in ACI 318 [C1].

## C4.2 ICF Above-Grade Wall Coverings

The requirements for interior covering of habitable spaces are based on current building codes and are self-explanatory.

It is generally accepted that a monolithic concrete wall is a solid wall through which water and air cannot readily flow; however, there is a possibility that the concrete wall may have honeycombs, voids, or hairline cracks through which water may enter. Voids between ICF blocks are inherent in current screen-grid ICF walls and may allow water to enter the structure. As a result, a moisture barrier on the exterior face of the ICF wall is generally required and should be considered good practice.

A vapor retarder may also be required on the interior face of the ICF wall in some cases. Test results have shown a potential exists for condensation occurring on the interior face of above-grade ICFs with a permeance as little as 0.5 perms in colder climates. Few problems have been reported when the exterior wall finishes are properly designed and constructed to prevent water intrusion. The reader is referred to *Mitigation of Moisture in Insulating Concrete Form Wall Systems* [C11] for more information on the testing and suggested construction recommendations.

# C5.0 ICF WALL OPENING REQUIREMENTS

## C5.1 Minimum Length of ICF Wall without Openings

The tables in Sections 3.0 and 4.0 are based on ICF walls without door or window openings. This simplified approach rarely arises in residential construction since walls generally contain windows and doors to meet functional needs. The amount of openings affects the lateral (racking) strength of the building parallel to the wall, particularly for wind and seismic loading conditions. The *Prescriptive Method* provides recommendations for the amount and placement location of additional reinforcement required around openings. It also addresses the minimum amount of solid wall required to resist in-plane shear loads from wind and seismic forces.

The values for the minimum solid wall length along exterior wall lines listed in Tables 5.2 to 5.5 of the *Prescriptive Method* were calculated using the main wind force resisting wind loads and seismic loads in accordance with ASCE 7 [C3] and the IBC [C5]. The ICF solid wall amounts were checked using resistance models for buildings with differing dimensions.

A shear model following the methods outlined in UBC Chapter 21 regarding shear walls was used [C12]. This method linearly varies the resistance of a wall segment from a cantilevered beam model at an aspect ratio (height-to-width) greater than 4.0 to a solid shear wall for all segments less than 2.0. The *Prescriptive Method* requires all walls to have a minimum 2 foot (0.6 m) solid wall segment adjacent to all corners. Therefore, the flexural capacity of the 2 foot (0.6 m) elements at the corners of the walls was first determined. This value was then subtracted from the required design load for the wall line, resulting in the design load required by the remainder of the wall. The amount of solid wall required to resist the remaining load was determined using shear elements. Refer to Appendix B for detailed calculations.

For Seismic Design Categories D1 and D2, all walls are required to have a minimum 4 foot (1.2 m) solid wall segment adjacent to all corners. In addition, all wall segments in the wall line are required to have minimum 4 foot (1.2 m) solid wall segments in order to be included in the total wall length. This requirement is based on tested performance [C9].

## C5.2 Reinforcement around Openings

The requirements for number and placement of reinforcement around openings in the Prescriptive Method are based on ACI [C1] and IBC [C5]. Per ACI [C1], the designer is required to provide two No. 5 bars on each side of all window and door openings; this is considered impractical for residential ICF construction. The IBC [C5] has clauses modifying this requirement to one No. 4 bar, provided that the vertical bars span continuously from support to support and that horizontal bars extend a minimum of 24 inches (610 mm) beyond the opening. The requirement for two No. 4 bars or one No. 5 bar in locations with 3-second gust design wind speeds greater than 110 mph (177 km/hr) is provided to resist uplift loads.

## C5.3 Lintels

### C5.3.1 Load-Bearing ICF Wall Lintels

Lintels are horizontal members used to transfer wall, floor, roof, and attic dead and live loads around openings in walls. Lintels are divided into three categories as follows:

- lintels in a one-story building or in the second story of a two-story building (supporting a roof only);
- lintels in the first story of a two-story building where the second story is light-frame construction (supporting light-frame second story and roof); and
- lintels in the first story of a two-story building where the second story is ICF construction (supporting ICF second story and roof).

The following design assumptions were made in analyzing the lintels:

- Lintels have fixed end restraints since the walls and lintels are cast monolithically.
- A vertical core occurs at each end of the lintel for proper bearing.
- Lateral resistance is provided for the lintel by the floor or roof system above.
- Roof slopes range from 0:12 to 12:12.
- Deflection criterion is the clear span of the lintel, in inches, divided by 240.
- Ceilings, roofs, attics, and floors span the full width of the house (assume no interior load-bearing walls or beams).
- Floor and roof clear span is maximum 32 feet (9.8 m).
- Roof snow loads were calculated by multiplying the ground snow load by 0.7. Therefore, the roof snow load was taken as $P = 0.7P_g$, where $P_g$ is the ground snow load in pounds per square foot.
- Loads experienced by the lintel are uniform loads and do not take into account any arching action that might occur because opening locations above the lintel cannot be determined for all cases.
- Shear reinforcement in the form of No. 3 stirrups are provided based on ACI [C1] and lintel test results; refer to *Lintel Testing for Reduced Shear Reinforcement in Insulating Concrete Form Systems* [C13] and *Testing and Design of Lintels Using Insulating Concrete Forms* [C14].

All live and dead loads from the roof, attic, floor, wall above, and lintel itself were taken into account in the calculations using the ACI 318 [C1] load combination, $U = 1.4D + 1.7L$. Adjustment factors are provided for clear spans of 28 feet (8.5 m) and 24 feet (7.3 m). Typically, the full dead load and a percentage of the live load are considered in lintel analysis where information regarding opening placement in the story is known. The area of load combinations or lintels, particularly when multiple transient live loads from various areas of the building are considered, must be refined to produce more economical and rational designs.

The calculations are based on the lintel occurring in an above-grade wall with a floor live load of 30 psf (1.4 kPa). Due to the conservative nature of the lintel load analysis, the tables may be used for lintels located in foundation walls where the maximum floor live load is 40 psf (1.9 kPa) and additional wall dead loads from the story above are present.

Deflection limits are established primarily with regard to serviceability concerns. The intent is to prevent excessive deflection that may result in cracking of finishes. Windows and doors are also sensitive to damage caused by excessive lintel deflection; therefore, a conservative deflection limit of L/480 for service dead loads and sustained live loads is often suggested. This limit is very conservative when the installation of the window and door components is properly detailed. Accounting for the conservative lintel load analysis discussed above, L/240 for full service dead and live loads was used. The lintel section is assumed cracked and a stiffness factor of $0.1E_cI_g$ is used in accordance with test results and recommendations made in *Design Criteria for Insulating Concrete Form Wall Systems* [C10].

Additional tables are provided in the second edition of the *Prescriptive Method* to provide additional options for lintels. Many of the new tables are based on the design methodologies outlined in the research report entitled Testing and *Design of Lintels Using Insulating Concrete Forms* [C14]. The reader is referred to Appendix B, *Engineering Technical Substantiaton*, for example calculations of lintels in bearing walls.

Because the maximum allowable lintel spans seldom account for garage door openings in homes with a story above using a single No. 4 or No. 5 bottom bar for lintel reinforcement, requirements are provided for larger wall openings such as those commonly used for one- and two-car garage doors.

### C5.3.2 ICF Non Load-Bearing Wall Lintels

Lintels are horizontal members used to transfer wall dead loads around openings in non load-bearing walls. Lintels are divided into two categories as follows:

- lintels in a one-story building or the second story of a two-story building and where the gable end wall is light-frame construction (supporting light-frame gable end wall); and
- lintels in the first story of a two-story building where the second story is ICF construction (supporting ICF second-story gable end wall).

The following design assumptions were made in analyzing the lintels:

- Lintels have fixed end restraints since the walls and lintels are cast monolithically.
- A vertical core occurs at each end of the lintel for proper bearing.
- Lateral resistance is provided for the lintel by the floor or roof system above.
- Deflection criterion is the clear span of the lintel, in inches, divided by 240.
- Lintels support only dead loads from the wall above.

Loads experienced by the lintel are uniform loads and do not take into account any arching action that might occur above the lintel within a height equal to the lintel clear span because opening locations above the lintel cannot be determined for all cases. Lintel dead weight and the dead load of the wall above were taken into account in the calculations using ACI 318 [C1] load combination, $U = 1.4D + 1.7L$. This analysis is conservative because arching action is not accounted for above the lintel within a height equal to the lintel clear span since wall opening locations above the lintel cannot be determined for all cases. The calculations are based on the lintel occurring in an above-grade wall. Due to the conservative nature of the lintel load analysis, the tables may be used for foundation walls where additional wall dead loads from the story above may be present.

Deflection limits are established primarily with regard to serviceability concerns. The intent is to prevent excessive deflection that may result in cracking of finishes. Windows and doors are also sensitive to damage caused by lintel deflection; therefore, a conservative deflection limit of L/480 for service dead loads and sustained live loads is often suggested. This limit is very conservative when the installation of window and door components is properly detailed. Accounting for the conservative lintel load analysis discussed above, L/240 for full service dead and full service live loads was used.

The lintel section is assumed cracked and a stiffness factor of $0.1E_cI_g$ is used in accordance with test results and recommendations made in *Design Criteria for ICF Wall Systems* [C10]. The reader is referred to Appendix B, Engineering Technical Substantiaton, for an example calculation of a non-load-bearing lintel.

# C6.0 ICF CONNECTION REQUIREMENTS

## C6.1 ICF Foundation Wall-to-Footing Connection

The requirements of the *Prescriptive Method* are based on typical residential construction practice for light-frame construction. Due to the heavier axial loads of ICF construction, frictional resistance at the footing-ICF wall interface is higher and provides a greater factor of safety than in light-frame residential construction except for Seismic Design Categories D1 and D2 where dowels are required.

## C6.2 ICF Wall-to-Floor Connection

### C6.2.1 Floor on ICF Wall Connection (Top-Bearing Connection)

The requirements of the *Prescriptive Method* are based on typical residential construction and the IRC [C4] for foundations constructed of concrete or masonry units. In high wind and high seismic conditions, connections are analyzed and detailed in accordance with ACI [C1] and the IBC [C5].

### C6.2.2 Floor Ledger-ICF Wall Connection (Side-Bearing Connection)

The requirements of the *Prescriptive Method* are based on the *Structural Design of Insulating Concrete Form Walls in Residential Construction* [C2]. Although other materials, such as cold-formed metal framing and concrete plank systems, may be used for the construction of floors in ICF construction, the majority of current ICF residential construction uses wood floor framing. Consult the manufacturer for proper connection details when using floor systems constructed of other materials. Consult a design professional when constructing buildings with floor systems which exceed the limits set forth in Table 1.1 of the *Prescriptive Method*. In high wind and high seismic conditions, connections are analyzed and detailed in accordance with ACI [C1] and the IBC [C5].

## C6.3 ICF Wall-to-Roof Connection

The requirements of the *Prescriptive Method* are based on typical residential construction and the IRC [C4] for walls constructed of concrete or masonry units. In high wind and high seismic conditions, connections are analyzed and detailed in accordance with ACI [C1] and the IBC [C5].

# C7.0 UTILITIES

## C7.1 Plumbing Systems

Due to the different ICF materials available, the reader is advised to refer to the local building code for guidance.

Typical construction practice with ICFs made of rigid plastic foam calls for cutting a chase into the foam for small pipes. Almost all ICFs made of rigid plastic foam will accommodate up to a 1-inch- (25-mm-) diameter pipe and some may accommodate up to a 2-inch- (51-mm-) diameter pipe. The pipes are typically fastened to the concrete with plastic or metal ties or concrete nails. The foam is then replaced with adhesive foam installed over the pipe. Larger pipes are typically installed on the inside face of the wall with a chase constructed around the pipe to conceal it; alternatively, pipes are routed through interior light-frame walls.

## C7.2 HVAC Systems

Due to the different ICF materials available, the reader is advised to refer to the local building code for guidance.

ICF walls are considered to have high R-values and low air infiltration rates; therefore HVAC equipment may be sized smaller than in typical light-frame construction. Refer to *Sizing Air-Conditioning and Heating Equipment for Residential Buildings with ICF Walls* [C15].

## C7.3 Electrical Systems

Due to the different ICF materials available, the reader is advised to refer to the local building code and the ICF manufacturer for guidance.

# C8.0 CONSTRUCTION AND THERMAL GUIDELINES

The construction and thermal guidelines are provided to supplement the requirements of the *Prescriptive Method* and are considered good construction practices. These guidelines should not be considered comprehensive. Manufacturer's catalogs, recommendations, and other technical literature should also be consulted. Refer to *Guidelines for Using the CABO Model Energy Code with Insulating Concrete Forms* [C16].

Proper fasteners and tools are essential to any trade. Tables C8.1 and C8.2 provide a list of fasteners and tools that are commonly used in residential ICF construction. Adhesives used on foam forms shall be compatible with the form material.

**TABLE C8.1**
**TYPICAL FASTENERS FOR USE WITH ICFs**

| FASTENER TYPE | USE/APPLICATION |
|---|---|
| Galvanized nails, ringed nails, and drywall screws | Attaching items to furring strips or form fastening surfaces |
| Adhesives | Attaching items to form for light- and medium-duty connections such as gypsum wallboard and base trim |
| Anchor bolts or steel straps | Attaching structural items to concrete core for medium- and heavy-duty connections such as floor ledger board and sill plate |
| Duplex nails | Attaching items to concrete core for medium-duty connections |
| Concrete nails or screw anchors | Attaching items to concrete core for medium-duty connections such as interior light-frame partitions to exterior ICF walls |

## TABLE C8.2
## RECOMMENDED TOOLS FOR ICF CONSTRUCTION

| TOOL | USE/ APPLICATION | APPLICABLE FORM MATERIAL |
|---|---|---|
| **CUTTING** | | |
| Drywall saw | Small, straight, or curved cuts and holes | Foam |
| Keyhole saw | Precise holes for utility penetrations | All |
| PVC or miter saw | Small, straight cuts and for shaving edges of forms | Foam |
| Rasp or coarse sandpaper | Shaving edges of forms; removing small high spots after concrete pour | Foam |
| Hand saw | Fast, straight cuts | All |
| Circular saw | Fast, precise cuts; ensure proper blade is used | All |
| Reciprocating saw | Fast cuts, good for utility cuts, ensure proper blade is used | All |
| Thermal cutter | Fast, very precise cuts; removing large bulges in wall after concrete pour | Foam |
| Utility knife | Small, straight, or curved cuts and holes | Foam |
| Router | Fast, precise utility cuts; use with 1/2-inch drive for deep cutting | Foam |
| Hot knife | Fast, very precise utility cuts | Foam |
| **MISCELLANEOUS** | | |
| Mason's trowel | Leveling concrete after pour; striking excess concrete from form after pour | All |
| | Applying thin mortar bed to forms | Composite |
| Wood glue, construction adhesive, or adhesive foam | Gluing forms together at joints | Foam |
| Cutter-bender | Cutting and bending steel reinforcement to required lengths and shapes | All |
| Small-gauge wire or precut tie wire or wire spool | Tying horizontal and vertical reinforcement together | All |
| Nylon tape | Reinforcing seams before concrete is poured | Foam |
| Nylon twine | Tying horizontal and vertical reinforcement together | All |
| Chalk line | Plumbing walls and foundation | All |
| Tin snips | Cutting metal form ties | Foam |
| **MOVING/PLACING** | | |
| Forklift, manual lift, or boom or crane truck | Carrying large units or crates of units and setting them in place | All |
| Chute | Placing concrete in forms for below-grade pours | All |
| Line pump | Placing concrete in forms; use with a 2-inch hose | All |
| Boom pump | Placing concrete in forms; use with two "S" couplings and reduce the hose to a 2-inch diameter | All |

## C9.0 REFERENCES

[C1] *Building Code Requirements for Structural Concrete* (ACI 318-99), American Concrete Institute, Detroit, Michigan, 1999.

[C2] *Structural Design of Insulating Concrete Form Walls in Residential Construction*, Portland Cement Association, Skokie, Illinois, 1998.

[C3] *Minimum Design Loads for Buildings and Other Structures* (ASCE 7-98), American Society of Civil Engineers, New York, New York, 1998.

[C4] *International Residential Code*, International Code Council (ICC), Falls Church, Virginia, 2000.

[C5] *International Building Code*, International Code Council (ICC), Falls Church, Virginia, 2000.

[C6] *Guide to Residential Cast-in-Place Concrete Construction* (ACI 322R-84), American Concrete Institute, Detroit, Michigan, 1984.

[C7] ASTM C 31/C 31M-96 *Standard Practice for Making and Curing Concrete Test Specimens in the Field*, American Society for Testing and Materials (ASTM), West Conshohocken, Pennsylvania, 1997.

[C8] ASTM C 39-96 *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*, American Society for Testing and Materials (ASTM), West Conshohocken, Pennsylvania, 1996.

[C9] *In-Plane Shear Resistance of Insulating Concrete Form Walls, Prepared for the U.S. Department of Housing and Urban Development*, Portland Cement Association, and the National Association of Home Builders by the NAHB Research Center, Inc., Upper Marlboro, Maryland, 2001.

[C10] *Design Criteria for Insulating Concrete Form Wall Systems*, (RP 116), Prepared for the Portland Cement Association by Construction Technology Laboratories, Inc., Skokie, Illinois, 1996.

[C11] *Mitigation of Moisture in Insulating Concrete Form Wall Systems*, Prepared for the Portland Cement Association by Construction Technology Laboratories, Inc., Skokie, Illinois, 1998.

[C12] *Uniform Building Code*, International Conference of Building Officials. Whittier, California, 1997.

[C13] *Lintel Testing for Reduced Shear Reinforcement in Insulating Concrete Form Systems*, Prepared for the U.S. Department of Housing and Urban Development, Portland Cement Association, and the National Association of Home Builders by NAHB Research Center, Inc., Upper Marlboro, Maryland, 1998.

[C14] *Testing and Design of Lintels Using Insulating Concrete Forms*, Prepared for the U.S. Department of Housing and Urban Development, Portland Cement Association, and the National Association of Home Builders by the NAHB Research Center, Inc., Upper Marlboro, Maryland, 2000.

[C15] *Sizing Air-Conditioning and Heating Equipment for Residential Buildings with ICF Walls, (No. 2159)*, Prepared for the Portland Cement Association by Construction Technology Laboratories, Inc., Skokie, Illinois, 1998.

[C16] *Guidelines for Using the CABO Model Energy Code with Insulating Concrete Forms (No. 2150)*, Prepared for the Portland Cement Association by Construction Technology Laboratories, Inc., Skokie, Illinois, 1998.

# APPENDIX A

# ILLUSTRATIVE EXAMPLE

## Purpose

Appendix A contains a design example illustrating the proper application of the different standards and specifications in the *Prescriptive Method.* It provides a step-by-step procedure on how to apply the requirements of the *Prescriptive Method* when designing a home. A typical residential building is used to demonstrate the application of insulating concrete form construction requirements.

Information is presented in both U.S. customary units and International System (SI) units. Reinforcement bar sizes are presented in U.S. customary units; refer to Appendix C for the corresponding reinforcement bar size in SI units.

## Building Design Criteria

The example building has the following characteristics:

| | |
|---|---|
| Building type: | Two-story house (above an unfinished basement) with a center load-bearing beam supporting the first floor and a center load-bearing wall supporting the second floor. Roof trusses bear on exterior walls only. |
| Building site: | Enclosed building sited in Exposure B |
| Building width: | 30 feet (9.1 m) perpendicular to ridge |
| Building length: | 60 feet (18.3 m) parallel to ridge |
| Maximum unbalanced backfill height: | 6 feet (1.8 m) |
| Soil-bearing capacity: | 2,500 psf (120 kPa) |
| Basement wall height: | 8 feet (2.4 m) |
| First story wall height: | 9 feet (2.7 m) |
| Second story wall height: | 8 feet (2.4 m) |
| Basement wall ICF type: | 6-inch- (152-mm-) thick flat ICF concrete wall |
| First-story wall ICF type: | 4.5-inch- (114-mm-) thick flat ICF concrete wall |
| Second-story wall ICF type: | 4.5-inch- (114-mm-) thick flat ICF concrete wall |
| Floor joists: | Wood joists spaced at 24 inches (610 mm) on center |
| Roof framing: | Wood trusses spaced at 24 inches (610 mm) on center |
| Roof slope: | 8:12 |

The following design criteria are applicable to the example home:

| Ground Snow Load psf (kPa) | 3-Second Gust Wind Speed (mph) mph (km/hr) | Seismic Design Category | First-Floor Live Load psf (kPa) | Second-Floor Live Load psf (kPa) | Floor Dead Load psf (kPa) | Equivalent Fluid Density pcf (kg/m$^3$) | Soil-Bearing Capacity psf (kPa) |
|---|---|---|---|---|---|---|---|
| 50 (2.4) | 110 (177) | B | 40 (1.9) | 30 (1.4) | 10 (0.5) | 30 (481) | 2,500 (120) |

Building elevations are shown in Figure A1.1 on the next page.

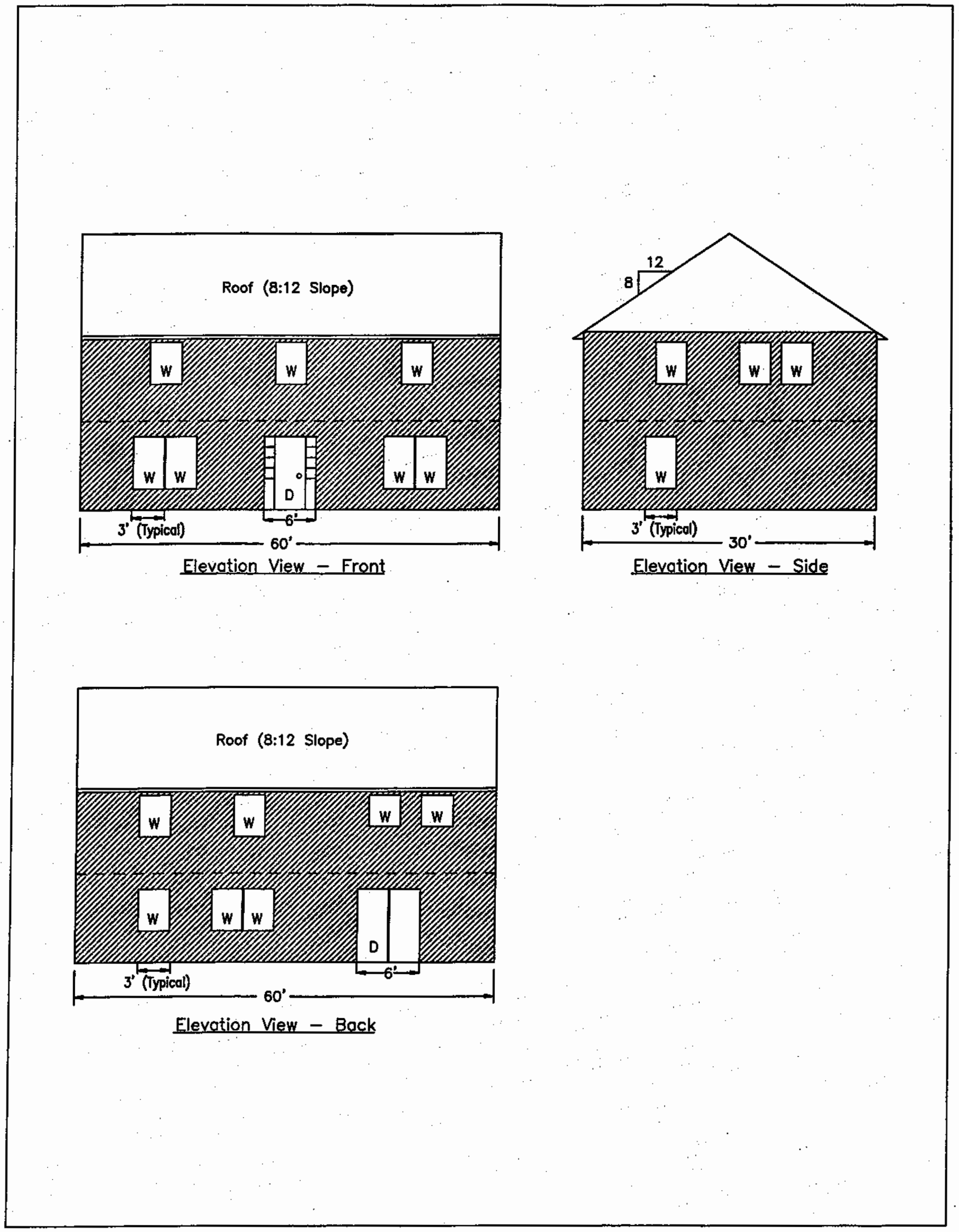



Figure A1.1 Building Elevations

## Building Design Requirements Summary

The list below summarizes the requirements that result from applying the *Prescriptive Method* to the given building. A detailed description of the process is given in the following sections. Connection requirements are not highlighted in this Appendix since adequate details and tables are provided in the *Prescriptive Method.* The omission of detailed connection requirements from this Appendix is not, however, intended to diminish the importance of proper anchoring. The user should devote substantial efforts to connection requirements, which cannot be adequately conveyed in one building example.

**TABLE A1.1**
**SUMMARY OF ILLUSTRATIVE EXAMPLE CALCULATIONS FOR EXTERIOR WALLS**

| Framing Description | Type | Thickness/ Size | Vertical Reinforcement Requirement | | Horizontal Reinforcement Requirement[1] | Reference |
|---|---|---|---|---|---|---|
| Footings | Concrete | 16 inches by 6 inches | Grade 40 | N/A | N/A | Section 2.0<br>Section 3.0<br>Table 3.1 |
| | | | Grade 60 | N/A | | |
| Basement Walls | Flat ICF | 6 inches thick | Grade 40 | #3@12", #4@22", #5@30", or #6@40" | One No. 4 bar within 12 inches of the top of the wall story and one No. 4 bar near mid-height of the wall story | Section 2.0<br>Section 3.0<br>Table 3.3<br>Table 3.4 |
| | | | Grade 60 | #3@18", #4@33", #5@45", or #6@60" | | |
| First-Story Walls | Flat ICF | 4.5 inches thick | Grade 40 | #4@34" or #5@48" | One No. 4 bar within 12 inches of the top of the wall story and one No. 4 bar near third points of the wall story | Section 2.0<br>Section 4.0<br>Table 4.1<br>Table 4.2 |
| | | | Grade 60 | #4@48" | | |
| Second-Story Walls | Flat ICF | 4.5 inches thick | Grade 40 | #4@42" | One No. 4 bar within 12 inches of the top of the wall story and one No. 4 bar near third points of the wall story | Section 2.0<br>Section 4.0<br>Table 4.1<br>Table 4.2 |
| | | | Grade 60 | #4@48" | | |
| First-Story Solid Wall Length | Flat ICF | 4.5 inches thick | 30' End Wall requires 8.7 feet of solid wall length<br>60' Side Wall requires 5.6 feet of solid wall length | | | Section 5.0<br>Table 5.2B<br>Table 5.2C |
| Second-Story Solid Wall Length | Flat ICF | 4.5 inches thick | 30' End Wall requires 6.2 feet of solid wall length<br>60' Side Wall requires 4.8 feet of solid wall length | | | Section 5.0<br>Table 5.2B<br>Table 5.2C |

FOR SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm

[1]The minimum horizontal reinforcement requirements are for both Grade 40 and Grade 60 reinforcement.

TABLE A1.2
SUMMARY OF ILLUSTRATIVE EXAMPLE CALCULATIONS
FOR LINTELS

| Framing Description | Type | Thickness/ Size | Stirrup/Shear Reinforcement Requirement | | Horizontal Reinforcement Requirement | Reference |
|---|---|---|---|---|---|---|
| | | | Concrete | Requirements | | |
| First-Story 6-foot Lintel[1] | Flat ICF | 24 inches deep by 4.5 inches thick | 2,500 psi | No. 3 Stirrups @ 11" except for middle 1' – 8" of span | Minimum Grade 40 - No. 4 Reinforcing bar | Section 5.3 Tables 5.6, 5.7, 5.8A & 5.12 |
| | | | 3,000 psi | No. 3 Stirrups @ 11" except for middle 1' – 9" of span | | |
| | | | 4,000 psi | No. 3 Stirrups @ 11" except for middle 2' – 1" of span | | |
| First-Story 3-foot Lintel | Flat ICF | 24 inches deep by 4.5 inches thick | 2,500 psi<br>3,000 psi<br>4,000 psi | Stirrups are not required | Minimum Grade 40 - No. 4 Reinforcing bar | Section 5.3 Tables 5.6, 5.7, 5.8A & 5.12 |
| Second-Story 3-foot Lintel | Flat ICF | 12 inches deep by 4.5 inches thick | 2,500 psi<br>3,000 psi<br>4,000 psi | Stirrups are not required | Minimum Grade 40 - No. 4 Reinforcing bar | Section 5.3 Tables 5.6, 5.7, 5.8A & 5.12 |

FOR SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm

## Footings

The design house is 30 feet (9.1 m) wide, the soil-bearing capacity is 2,500 psf (120 kPa), and the thickness of the basement wall is 6 inches (152 mm). The basement is supporting two ICF stories above. The minimum footing size for these conditions is established from Table 3.1 of the *Prescriptive Method* as 16 inches (406 mm) wide by 6 inches (152 mm) thick. The footings require a minimum concrete compressive strength of 2,500 psi (17 MPa).

TABLE 3.1
MINIMUM WIDTH OF ICF AND CONCRETE
FOOTINGS FOR ICF WALLS[1,2,3]
(excerpt from the *Prescriptive Method*)

| Maximum Number of Stories[4] | Minimum Load-Bearing Value of Soil (psf) | | | | |
|---|---|---|---|---|---|
| | 2,000 | 2,500 | 3,000 | 3,500 | 4,000 |
| 5.5-Inch Flat, 6-Inch Waffle-Grid, or 6-Inch Screen-Grid ICF Wall Thickness[5] | | | | | |
| One Story[6] | 15 | 12 | 10 | 9 | 8 |
| Two Story[6] | 20 | 16 | 13 | 12 | 10 |

## ICF Basement Walls

The building is 30 feet (9.1 m) wide and is subject to lateral soil pressure with an equivalent fluid density of 30 pcf (481 kg/m$^3$). It has a maximum unbalanced backfill height of 6 feet (1.8 m), and its basement wall is 8 feet (2.4 m) in height. The minimum horizontal wall reinforcement in accordance with Table 3.3 of the *Prescriptive Method* is one No. 4 bar within 12 inches (305 mm) of the top of the wall story and one No. 4 bar near mid-height of the wall story. The ICF basement walls are assumed to be laterally supported at the top of the wall by the floor joists as required in Section 3.0 of the *Prescriptive Method.* In addition, using Table 3.4 of the *Prescriptive Method*, the basement walls require minimum vertical wall reinforcement of one No. 3 bar, one No. 4 bar, one No. 5 bar, or one No. 6 bar spaced at 12 inches (305 mm), 22 inches (559 mm), 30 inches (762 mm), and 40 inches (1.0 m) on center, respectively, for Grade 40 reinforcement. However, if Grade 60 reinforcement is used, basement walls require a minimum vertical reinforcement of one No. 3 bar, one No. 4 bar, one No. 5 bar, or one No. 6 bar spaced at 18 inches (457 mm), 33 inches (838 mm), 45 inches (1.1 m), or 60 inches (1.5 m) on center, respectively.

Basement walls require a minimum compressive strength of concrete of 2,500 psi (17.2 MPa). An increased minimum concrete compressive strength of 3,000 psi (20.6 MPa) or 4,000 psi (27.6 MPa) does not affect the reinforcement requirements for ICF basement walls.

**TABLE 3.3**
**MINIMUM HORIZONTAL WALL REINFORCEMENT FOR ICF BASEMENT WALLS**
**(excerpt from the *Prescriptive Method*)**

| Maximum Height of Basement Wall feet (meters) | Location of Horizontal Reinforcement |
|---|---|
| 8 (2.4) | One No. 4 bar within 12 inches (305 mm) of the top of the wall story and one No. 4 bar near mid-height of the wall story |
| 9 (2.7) | One No. 4 bar within 12 inches (305 mm) of the top of the wall story and one No. 4 bar near third points in the wall story |

**TABLE 3.4**
**MINIMUM VERTICAL WALL REINFORCEMENT FOR 5.5-INCH- (140-MM-)THICK FLAT ICF BASEMENT WALLS [1,2,3]**
**(excerpt from the *Prescriptive Method*)**

| MAX. WALL HEIGHT (feet) | MAXIMUM UNBALANCED BACKFILL HEIGHT[4] (feet) | MINIMUM VERTICAL REINFORCEMENT | | |
|---|---|---|---|---|
| | | MAXIMUM EQUIVALENT FLUID DENSITY 30 pcf | MAXIMUM EQUIVALENT FLUID DENSITY 45 pcf | MAXIMUM EQUIVALENT FLUID DENSITY 60 pcf |
| 8 | 4 | #4@48" | #4@48" | #4@48" |
| | 5 | #4@48" | #3@12"; #4@22"; #5@32"; #6@40" | #3@8"; #4@14"; #5@20"; #6@26" |
| | 6 | #3@12"; #4@22"; #5@30"; #6@40" | #3@8"; #4@14"; #5@20"; #6@24" | #3@6"; #4@10"; #5@14"; #6@20" |

## ICF First-Story Walls

The building is 30 feet (9.1 m) wide and is subject to a 3-second gust wind speed of 110 mph (177 km/hr) and a ground snow load of 50 psf (2.4 kPa). The building is enclosed and sited in Exposure Category B. The first-story walls are 9 feet (2.7 m) in height. In accordance with Table 4.1 of the *Prescriptive Method*, the wind pressure used to design the minimum vertical reinforcement requirements for the above grade walls is 29 psf (1.4 kN/m$^2$). Since interpolation is not permitted in Table 4.2 a wind pressure of 30 psf (1.5 kN/m$^2$) must be used. Using Table 4.2 of the *Prescriptive Method*, we find that 4.5-inch- (114-mm-) thick first-story flat ICF walls supporting an ICF second story and light-frame roof requires a minimum of one vertical No. 4 or one No. 5 bar spaced at 34 inches (863 mm) and 48 inches (1.2 m) respectively on center for Grade 40 reinforcement or one vertical No. 4 bar spaced 48 inches (1.2 m) on center for Grade 60 reinforcement. Section 4.1 requires horizontal wall reinforcement in the form of one No. 4 rebar within 12 inches (305 mm) from the top of the wall, one No. 4 rebar within 12 inches (305 mm) from the finish floor, and one No. 4 rebar near one-third points throughout the remainder of the wall.

The first-story walls also require a minimum compressive strength of concrete of 2,500 psi (17.2 MPa). An increased minimum concrete compressive strength of 3,000 psi (20.6 MPa) or 4,000 psi (27.6 MPa) does not affect the reinforcement requirements for ICF first-story walls.

**TABLE 4.1**
**DESIGN WIND PRESSURE FOR USE WITH MINIMUM VERTICAL WALL REINFORCEMENT TABLES FOR ABOVE GRADE WALLS[1]**
**(excerpt from the *Prescriptive Method*)**

| WIND Speed (mph) | DESIGN WIND PRESSURE (PSF) | | | | | |
|---|---|---|---|---|---|---|
| | Enclosed[2] | | | PARTIALLY ENCLOSED[2] | | |
| | Exposure[3] | | | Exposure[3] | | |
| | B | C | D | B | C | D |
| 85 | 18 | 24 | 29 | 23 | 31 | 37 |
| 90 | 20 | 27 | 32 | 25 | 35 | 41 |
| 100 | 24 | 34 | 39 | 31 | 43 | 51 |
| 110 | 29 | 41 | 48 | 38 | 52 | 61 |

**TABLE 4.2**
**MINIMUM VERTICAL WALL REINFORCEMENT FOR FLAT ICF ABOVE-GRADE WALLS [1,2,3,4]**
**(excerpt from the *Prescriptive Method*)**

| Design Wind Pressure (Table 4.1) | Maximum Wall Height per Story | Minimum Vertical Reinforcement[4,5] | | | | | |
|---|---|---|---|---|---|---|---|
| | | Supporting Roof or Non-Load Bearing Wall | | Supporting Light-Frame Second Story and Roof | | Supporting ICF Second Story and Light-Frame Roof | |
| | | Minimum Wall Thickness (inches) | | | | | |
| (psf) | (feet) | 3.5 | 5.5 | 3.5 | 5.5 | 3.5 | 5.5 |
| 20 | 8 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 |
| | 9 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 |
| | 10 | #4@38 | #4@48 | #4@40 | #4@48 | #4@42 | #4@48 |
| 30 | 8 | #4@42 | #4@48 | #4@46 | #4@48 | #4@48 | #4@48 |
| | 9 | #4@32; #5@48 | #4@48 | #4@34; #5@48 | #4@48 | #4@34; #5@48 | #4@48 |

## ICF Second-Story Walls

Applying the same design wind pressure to the second-story walls as for the first-story walls, second-story walls require a minimum vertical wall reinforcement of one No. 4 bar spaced at 42 inches (1.0 m) on center for Grade 40 reinforcement or one No.4 bar spaced 48 inches (1.2 m) on center for Grade 60 reinforcement for flat walls with a thickness of 4.5 inches (114 mm) supporting a light-frame roof in accordance with Table 4.2. Section 4.1 requires horizontal wall reinforcement in the form of one No. 4 rebar within 12 inches (305 mm) from the top of the wall, one No. 4 rebar within 12 inches (305 mm) from the finish floor, and one No. 4 rebar near one-third points throughout the remainder of the wall.

The second-story walls also require a minimum compressive strength of concrete of 2,500 psi (17.2 MPa). An increased minimum concrete compressive strength of 3,000 psi (20.6 MPa) or 4,000 psi (27.6 MPa) does not affect the reinforcement requirements for ICF walls.

**TABLE 4.2**
**MINIMUM VERTICAL WALL REINFORCEMENT**
**FOR FLAT ICF ABOVE-GRADE WALLS [1,2,3,4]**
**(excerpt from the *Prescriptive Method*)**

| Design Wind Pressure (Table 4.1) | Maximum Wall Height per Story | Minimum Vertical Reinforcement[5,6] | | | | | |
|---|---|---|---|---|---|---|---|
| | | Supporting Roof or Non-Load Bearing Wall | | Supporting Light-Frame Second Story and Roof | | Supporting ICF Second Story and Light-Frame Roof | |
| | | Minimum Wall Thickness (inches) | | | | | |
| (psf) | (feet) | 3.5 | 5.5 | 3.5 | 5.5 | 3.5 | 5.5 |
| 20 | 8 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 |
| | 9 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 |
| | 10 | #4@38 | #4@48 | #4@40 | #4@48 | #4@42 | #4@48 |
| 30 | 8 | #4@42 | #4@48 | #4@46 | #4@48 | #4@48 | #4@48 |
| | 9 | #4@32; #5@48 | #4@48 | #4@34; #5@48 | #4@48 | #4@34; #5@48 | #4@48 |

## Minimum Length of ICF Wall without Openings

To determine the minimum percentage of solid wall length required for the example house, Section 5.0, Table 5.1, Table 5.2A, Table 5.2B, and Table 5.2C of the *Prescriptive Method* are used. The design house is a two-story home, 30 feet (9.1 m) wide by 60 feet (18.3 m) long. It has a roof slope of 8:12 and is located in an Exposure B 110 mph (177 km/hr) wind area and Seismic Design Category B. Each above-grade wall story is 4.5 inches (114 mm) thick.

In accordance with Table 5.1 of the *Prescriptive Method*, the velocity pressure used to design the minimum length of ICF without openings for the above grade walls is 23 psf (1.1 kN/m$^2$).

**TABLE 5.1**
**VELOCITY PRESSURE FOR DETERMINATION OF MINIMUM SOLID WALL LENGTH[1]**
**(excerpt from the *Prescriptive Method*)**

| Wind Speed (mph) | VELOCITY PRESSURE (PSF) Exposure[2] | | |
|---|---|---|---|
| | B | C | D |
| 85 | 14 | 19 | 23 |
| 90 | 16 | 21 | 25 |
| 100 | 19 | 26 | 31 |
| 110 | 23 | 32 | 37 |

FIRST-STORY WALLS

End Wall Design

Wind

The minimum length of solid end wall is based on the wind velocity pressure from Table 5.1, the building side wall length, and the roof slope. Interpolation is required to obtain the accurate amount of solid end wall length required from Table 5.2B.

For the 7:12 roof pitch and 23 psf (1.1 kN/m$^2$), interpolating between 9.0 feet (25 psf) and 7.75 feet (20 psf) results in 5 equal increments of 0.25 feet; (9.0 ft – 7.75 ft)/5 = 0.25 ft. Thus, 9.0 feet (25 psf) minus 2 x 0.25 ft (2 psf) results in *8.5 feet* for 23 psf (1.1 kN/m$^2$).

For the 12:12 roof pitch and 23 psf (1.1 kN/m$^2$), interpolating between 10.0 feet (25 psf) and 8.75 feet (20 psf) results in 5 equal increments of 0.25 feet; (10.0 ft – 8.75 ft)/5 = 0.25 ft. Thus, 10.0 feet (25 psf) minus 2 x 0.25 ft (2 psf) results in *9.5 feet* for 23 psf (1.1 kN/m$^2$).

For 8:12 roof pitch, interpolating between 8.5 ft (7:12) and 9.5 ft (12:12) results in 5 equal increments of 0.2 feet; (9.5 ft – 8.5 ft)/5 = 0.2 ft. Thus, 8.5 feet (7:12) plus 0.2 feet indicates that the minimum solid wall length required is *8.7 feet* for the 8:12 roof pitch.

However, a conservative value from the 12:12 roof pitch and 25 psf velocity pressure resulting in a minimum solid wall length of 10 feet (3.0 m) may be used without interpolating.

**TABLE 5.2B**
**MINIMUM SOLID END WALL LENGTH REQUIREMENTS FOR FLAT ICF WALLS (WIND PERPENDICULAR TO RIDGE)[1,2,3,4,5]**
**(excerpt from the *Prescriptive Method*)**

| Design Velocity Pressure (psf) | | | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 60 |
|---|---|---|---|---|---|---|---|---|---|---|
| Wall Category | Building Side Wall Length, L (feet) | Roof Slope | Minimum Solid Wall Length on Building End Wall, W (feet) | | | | | | | |
| First Story of Two-Story | 16 | ≤ 1:12 | 4.00 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.25 | 5.75 |
| | | 5:12 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 5.75 | 6.00 | 6.75 |
| | | 7:12 | 4.50 | 5.00 | 5.25 | 5.75 | 6.00 | 6.25 | 6.75 | 7.25 |
| | | 12:12 | 5.00 | 5.25 | 5.75 | 6.25 | 6.50 | 7.00 | 7.25 | 8.25 |
| | 24 | ≤ 1:12 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 5.75 | 6.00 | 6.75 |
| | | 5:12 | 4.75 | 5.25 | 5.50 | 6.00 | 6.25 | 6.75 | 7.00 | 7.75 |
| | | 7:12 | 5.25 | 5.75 | 6.25 | 6.75 | 7.00 | 7.50 | 8.00 | 9.00 |
| | | 12:12 | 5.50 | 6.25 | 6.75 | 7.25 | 8.00 | 8.50 | 9.00 | 10.25 |
| | 32 | ≤ 1:12 | 4.75 | 5.00 | 5.50 | 5.75 | 6.25 | 6.50 | 6.75 | 7.50 |
| | | 5:12 | 5.25 | 5.75 | 6.25 | 6.75 | 7.25 | 7.50 | 8.00 | 9.00 |
| | | 7:12 | 5.75 | 6.50 | 7.00 | 7.75 | 8.25 | 9.00 | 9.50 | 10.75 |
| | | 12:12 | 6.25 | 7.00 | 7.75 | 8.50 | 9.25 | 10.00 | 10.75 | 12.25 |
| | 40 | ≤ 1:12 | 5.00 | 5.50 | 5.75 | 6.25 | 6.75 | 7.25 | 7.50 | 8.50 |
| | | 5:12 | 5.50 | 6.25 | 6.75 | 7.25 | 8.00 | 8.50 | 9.00 | 10.25 |
| | | 7:12 | 6.25 | 7.00 | 7.75 | 8.75 | 9.50 | 10.25 | 11.00 | 12.50 |
| | | 12:12 | 7.00 | 8.00 | 8.75 | 9.75 | 10.75 | 11.50 | 12.50 | 14.25 |
| | 50 | ≤ 1:12 | 5.50 | 6.00 | 6.50 | 7.00 | 7.50 | 8.00 | 8.50 | 9.50 |
| | | 5:12 | 6.00 | 6.75 | 7.50 | 8.25 | 9.00 | 9.75 | 10.50 | 11.75 |
| | | 7:12 | 7.00 | 8.00 | 9.00 | 10.00 | 10.75 | 11.75 | 12.75 | 14.50 |
| | | 12:12 | 7.75 | 9.00 | 10.00 | 11.25 | 12.25 | 13.50 | 14.75 | 17.00 |
| | 60 | ≤ 1:12 | 5.75 | 6.50 | 7.00 | 7.50 | 8.25 | 8.75 | 9.50 | 10.75 |
| | | 5:12 | 6.75 | 7.50 | 8.25 | 9.25 | 10.00 | 10.75 | 11.75 | 13.25 |
| | | 7:12 | 7.75 | 9.00 | 10.00 | 11.00 | 12.25 | 13.25 | 14.50 | 16.75 |
| | | 12:12 | 8.75 | 10.00 | 11.50 | 12.75 | 14.00 | 15.50 | 16.75 | 19.50 |

## Side Wall Design

### Wind

The minimum length of solid side wall length is based on the wind velocity pressure from Table 5.1 and the building end wall length. Interpolation between the velocity pressure and building end wall length is required to obtain the accurate amount of solid end wall length required from Table 5.2C.

For the 24 ft building end wall length and 23 psf (1.1 kN/m$^2$), interpolating between 5.25 feet (25 psf) and 4.75 feet (20 psf) results in 5 equal increments of 0.1 feet; (5.25 ft – 4.75 ft)/5 = 0.1 ft. Thus, 5.25 feet (25 psf) minus 2 x 0.1 ft (2 psf) results in *5.05 feet.*

For the 32 ft building end wall length and 23 psf (1.1 kN/m$^2$), interpolating between 6.0 feet (25 psf) and 5.5 feet (20 psf) results in 5 equal increments of 0.1 feet; (6 ft – 5.5 ft)/5 = 0.1 ft. Thus, 6.0 feet (25 psf) minus 2 x 0.1 ft (2 psf) results in *5.8 feet.*

For 30 ft building end wall width, interpolating between 5.05 ft (24 ft end wall) and 5.8 ft (32 ft end wall) results in 4 approximate increments of 0.188 feet; (5.8 ft – 5.05 ft)/4 = 0.188 ft. Thus, 5.05 feet (30 ft end wall) plus 3 x 0.188 ft (6 ft end wall length) indicates that the minimum solid wall length required is *5.6 feet*.

However, a conservative value from the 32ft end wall length and 25 psf velocity pressure resulting in a minimum solid wall length of 6.0 feet (1.8 m) may be used without interpolating.

**TABLE 5.2C**
**MINIMUM SOLID SIDE WALL LENGTH**
**REQUIREMENTS FOR FLAT ICF WALLS**
**(WIND PARALLEL TO RIDGE)[1,2,3,4,5]**
**(excerpt from the *Prescriptive Method*)**

| Design Velocity Pressure (psf) | | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 60 |
|---|---|---|---|---|---|---|---|---|---|
| Wall Category | Building End Wall Width, W (feet) | Minimum Solid Wall Length on Building Side Wall, L (feet) | | | | | | | |
| One-Story or Top Story of Two-Story | 16 | 4.00 | 4.00 | 4.00 | 4.00 | 4.25 | 4.25 | 4.50 | 4.75 |
| | 24 | 4.00 | 4.25 | 4.50 | 4.75 | 4.75 | 5.00 | 5.25 | 5.50 |
| | 32 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 6.00 | 6.25 | 6.75 |
| | 40 | 5.00 | 5.50 | 5.75 | 6.25 | 6.75 | 7.00 | 7.50 | 8.25 |
| | 50 | 5.75 | 6.25 | 7.00 | 7.50 | 8.25 | 8.75 | 9.50 | 10.75 |
| | 60 | 6.50 | 7.50 | 8.25 | 9.25 | 10.00 | 10.75 | 11.75 | 13.25 |
| First Story of Two-Story | 16 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 5.75 | 6.50 |
| | 24 | 4.75 | 5.25 | 5.50 | 6.00 | 6.25 | 6.75 | 7.00 | 8.00 |
| | 32 | 5.50 | 6.00 | 6.50 | 7.00 | 7.50 | 8.00 | 8.75 | 9.75 |
| | 40 | 6.25 | 7.00 | 7.50 | 8.25 | 9.00 | 9.75 | 10.50 | 12.00 |
| | 50 | 7.25 | 8.25 | 9.25 | 10.25 | 11.25 | 12.25 | 13.25 | 15.25 |
| | 60 | 8.50 | 9.75 | 11.00 | 12.25 | 13.50 | 15.00 | 16.25 | 18.75 |

The above values are based on concrete with a minimum compressive strength of 2,500 psi (17.2 MPa). Due to the combination of shear and flexural elements in the design of the minimum solid wall length no adjustment factors are available if concrete with a minimum compressive strength of 3,000 psi (20.6 MPa) or 4,000 psi (27.6 MPa) is used.

Remember that Section 5.0 requires a minimum length of 24 inches (610 mm) of solid wall segment, extending the full height of each wall story, at all corners of exterior walls and that 2-foot (610-mm) wall segments shall not exceed the maximum allowable spacing of 18 feet (5.5 m) on center.

## SECOND-STORY WALLS

### End Wall Design

#### Wind

The minimum length of solid end wall is based on the wind velocity pressure from Table 5.1, the building side wall length, and the roof slope.

Interpolation is required to obtain the accurate amount of solid end wall length required from Table 5.2A.

For the 7:12 roof pitch and 23 psf (1.1 kN/m$^2$), interpolating between 6.25 feet (25 psf) and 5.5 feet (20 psf) results in 5 equal increments of 0.15 feet; (6.25 ft – 5.5 ft)/5 = 0.15 ft. Thus, 6.25 feet (25 psf) minus 2 x 0.15 ft (2 psf) results in *5.95 feet.*

For the 12:12 roof pitch and 23 psf (1.1 kN/m$^2$), interpolating between 7.25 feet (25 psf) and 6.5 feet (20 psf) results in 5 equal increments of 6.5 feet; (7.25 ft – 6.5 ft)/5 = 0.15 ft. Thus, 7.25 feet (25 psf) minus 2 x 0.15 ft (2 psf) results in *6.95 feet.*

For 8:12 roof pitch, interpolating between 5.95 ft (7:12) and 6.95 ft (12:12) results in 5 equal increments of 0.2 feet; (6.95 ft – 5.95 ft)/5 = 0.2 ft. Thus, 5.95 feet (7:12) plus 0.2 feet indicates that the minimum solid wall length required is *6.15 feet*.

However, a conservative value from the 12:12 roof pitch and 25 psf velocity pressure resulting in a minimum solid wall length of 7.25 feet (2.2 m) may be used without interpolating.

**TABLE 5.2A**
**MINIMUM SOLID END WALL LENGTH**
**REQUIREMENTS FOR FLAT ICF WALLS**
**(WIND PERPENDICULAR TO RIDGE)[1,2,3,4,5]**
**(excerpt from the *Prescriptive Method*)**

| Design Velocity Pressure (psf) | | | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 60 |
|---|---|---|---|---|---|---|---|---|---|---|
| Wall Category | Building Side Wall Length, L (feet) | Roof Slope | Minimum Solid Wall Length on Building End Wall, W (feet) | | | | | | | |
| One-Story or Top Story of Two-Story | 16 | ≤ 1:12 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 |
| | | 5:12 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.25 | 4.50 |
| | | 7:12 | 4.00 | 4.25 | 4.25 | 4.50 | 4.75 | 4.75 | 5.00 | 5.50 |
| | | 12:12 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 5.75 | 6.25 |
| | 24 | ≤ 1:12 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.25 | 4.50 |
| | | 5:12 | 4.00 | 4.00 | 4.00 | 4.25 | 4.25 | 4.50 | 4.50 | 4.75 |
| | | 7:12 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 5.75 | 6.25 |
| | | 12:12 | 4.75 | 5.00 | 5.25 | 5.75 | 6.00 | 6.50 | 6.75 | 7.50 |
| | 32 | ≤ 1:12 | 4.00 | 4.00 | 4.00 | 4.00 | 4.25 | 4.25 | 4.50 | 4.75 |
| | | 5:12 | 4.00 | 4.00 | 4.25 | 4.50 | 4.50 | 4.75 | 5.00 | 5.25 |
| | | 7:12 | 4.50 | 5.00 | 5.25 | 5.50 | 6.00 | 6.25 | 6.50 | 7.25 |
| | | 12:12 | 5.00 | 5.50 | 6.00 | 6.50 | 7.00 | 7.25 | 7.75 | 8.75 |
| | 40 | ≤ 1:12 | 4.00 | 4.00 | 4.25 | 4.25 | 4.50 | 4.50 | 4.75 | 5.00 |
| | | 5:12 | 4.00 | 4.25 | 4.50 | 4.75 | 4.75 | 5.00 | 5.25 | 5.50 |
| | | 7:12 | 4.75 | 5.25 | 5.75 | 6.00 | 6.50 | 7.00 | 7.25 | 8.00 |
| | | 12:12 | 5.50 | 6.00 | 6.50 | 7.25 | 7.75 | 8.25 | 8.75 | 10.00 |
| | 50 | ≤ 1:12 | 4.00 | 4.25 | 4.25 | 4.50 | 4.75 | 4.75 | 5.00 | 5.50 |
| | | 5:12 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 5.75 | 6.00 |
| | | 7:12 | 5.25 | 5.75 | 6.25 | 6.75 | 7.25 | 7.75 | 8.25 | 9.25 |
| | | 12:12 | 6.00 | 6.75 | 7.50 | 8.00 | 8.75 | 9.50 | 10.25 | 11.50 |
| | 60 | ≤ 1:12 | 4.00 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.25 | 5.75 |
| | | 5:12 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 5.75 | 6.00 | 6.75 |
| | | 7:12 | 5.50 | 6.25 | 6.75 | 7.50 | 8.00 | 8.50 | 9.25 | 10.25 |
| | | 12:12 | 6.50 | 7.25 | 8.25 | 9.00 | 9.75 | 10.50 | 11.50 | 13.00 |

## Side Wall Design

### Wind

The minimum length of solid side wall length is based on the wind velocity pressure from Table 5.1 and the building end wall length.

Interpolation is required to obtain the accurate amount of solid wall length required from Table 5.2C. However, since the values used to interpolate for the required minimum length of solid wall are almost equal, the conservative value from the 32 ft end wall length and 25 psf velocity pressure is used resulting in a minimum solid wall length of 4.75 feet (1.4 m)

**TABLE 5.2C**
**MINIMUM SOLID SIDE WALL LENGTH**
**REQUIREMENTS FOR FLAT ICF WALLS**
**(WIND PARALLEL TO RIDGE)[1,2,3,4,5]**
**(excerpt from the *Prescriptive Method*)**

| Design Velocity Pressure (psf) | | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 60 |
|---|---|---|---|---|---|---|---|---|---|
| Wall Category | Building End Wall Width, W (feet) | Minimum Solid Wall Length on Building Side Wall, L (feet) | | | | | | | |
| One-Story or Top Story of Two-Story | 16 | 4.00 | 4.00 | 4.00 | 4.00 | 4.25 | 4.25 | 4.50 | 4.75 |
| | 24 | 4.00 | 4.25 | 4.50 | 4.75 | 4.75 | 5.00 | 5.25 | 5.50 |
| | 32 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 6.00 | 6.25 | 6.75 |
| | 40 | 5.00 | 5.50 | 5.75 | 6.25 | 6.75 | 7.00 | 7.50 | 8.25 |
| | 50 | 5.75 | 6.25 | 7.00 | 7.50 | 8.25 | 8.75 | 9.50 | 10.75 |
| | 60 | 6.50 | 7.50 | 8.25 | 9.25 | 10.00 | 10.75 | 11.75 | 13.25 |
| First Story of Two-Story | 16 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 5.75 | 6.50 |
| | 24 | 4.75 | 5.25 | 5.50 | 6.00 | 6.25 | 6.75 | 7.00 | 8.00 |
| | 32 | 5.50 | 6.00 | 6.50 | 7.00 | 7.50 | 8.00 | 8.75 | 9.75 |
| | 40 | 6.25 | 7.00 | 7.50 | 8.25 | 9.00 | 9.75 | 10.50 | 12.00 |
| | 50 | 7.25 | 8.25 | 9.25 | 10.25 | 11.25 | 12.25 | 13.25 | 15.25 |
| | 60 | 8.50 | 9.75 | 11.00 | 12.25 | 13.50 | 15.00 | 16.25 | 18.75 |

The above values are based on concrete with a minimum compressive strength of 2,500 psi (17.2 MPa). Due to the combination of shear and flexural elements in the design of the minimum solid wall length no adjustment factors are available if concrete with a minimum compressive strength of 3,000 psi (20.6 MPa) or 4,000 psi (27.6 MPa) is used.

Remember that Section 5.0 requires a minimum length of 24 inches (610 mm) of solid wall segment, extending the full height of each wall story, at all corners of exterior walls and that 2-foot (610-mm) minimum wall segments shall not exceed the maximum allowable spacing of 18 feet (5.5 m) on center.

## Wall Openings and Lintels

In this example, there are two opening sizes: 6-foot- (1.8-m-) wide openings for the entrance doorway, sliding door, and double windows in the first story and 3-foot- (0.9-m-) wide openings throughout the remainder of the building. Tables 5.6, 5.7, 5.8A, and 5.12 of the *Prescriptive Method* are used in this exercise to determine the lintel type and reinforcement requirements. For the 6-foot- (1.8-m-) and 3-foot- (0.9-m-) wide openings, Table 5.12 of the *Prescriptive Method* requires a lintel over the opening in accordance with Section 5.0.

The 6-foot (1.8 m) wide openings are located in the first-story load-bearing walls of the building. First-story walls were previously stated as 4.5 inch (114 mm) thick flat ICF walls. The building is 30 feet (9.1 m) wide and subject to a ground snow load of 50 psf (2.4 kPa). Since the lintels are located in the first-story wall, they support one ICF story and a roof and ceiling.

Table 5.7 of the *Prescriptive Method* should be consulted first to determine if lintels without stirrups/shear reinforcement are permitted. Table 5.7 illustrates that a 3.5 inch (88.9 mm) lintel thickness and 24 inch (610 mm) lintel depth supporting an ICF story above without stirrups allows for:

30 psf (1.5 kPa) ⇒ lintel span = 5' – 6" (1.7 m)
70 psf (3.4 kPa) ⇒ lintel span = 5' – 2" (1.6 m)

By interpolation, for the design snow load of 50 psf (2.4 kPa) the allowable lintel span without stirrups is 5' – 4" (1.6 m). This span may be increased by multiplying by the following adjustment factors in the footnote of Table 5.7:

2,500 psi (17.2 MPa) Compressive Strength Concrete ⇒ No Adjustment Factor
3,000 psi (20.7 MPa) Compressive Strength Concrete ⇒ Adjustment Factor = 1.05
4,000 psi (27.6 MPa) Compressive Strength Concrete ⇒ Adjustment Factor = 1.10

The allowable span for the specified lintel without stirrups are as follows:

2,500 psi (17.2 MPa) Compressive Strength Concrete ⇒ 5' – 4"(1.00) = 5' – 4" (1.6 m)
3,000 psi (20.7 MPa) Compressive Strength Concrete ⇒ 5' – 4"(1.05) = 5' – 7" (1.7 m)
4,000 psi (27.6 MPa) Compressive Strength Concrete ⇒ 5' – 4"(1.10) = 5' – 10" (1.8 m)

Therefore, lintels with stirrups are required for the 6-foot (1.8 m) openings regardless of concrete compressive strength used.

Consult Table 5.8A of the *Prescriptive Method* to determine the allowable span for the specified lintel. Table 5.8A of the *Prescriptive Method* illustrates that a 4.5-inch (114-mm) lintel thickness and 24-inch (610-mm) lintel depth will suffice since the lintel's maximum allowed span is 6'-1" (1.9 m) for a design snow load of 70 psf (3.4 kPa).

Determine the center portion of the span, A, where stirrups are not required by using Table 5.12 of the *Prescriptive Method*. Using interpolation, Table 5.12 of the *Prescriptive Method* illustrates that a 4.5-inch (114-mm) lintel thickness and 24-inch (610-mm) lintel depth subjected to a 50 psf (2.4 kPa) snow load is required to have stirrups for all but the center 1'–8" (0.5 m) of the span. The footnotes of Table 5.12 of the *Prescriptive Method* allows the center portion of the span (A) where stirrups are not required to be multiplied by 1.09 for 3,000 psi (20.7 MPa) and 1.26 for 4,000 psi (27.6 MPa) compressive strength concrete. The adjustment factors produce the following center portion of the span where stirrups are not required:

2,500 psi (17.2 MPa) Compressive Strength Concrete ⇒ 1' – 8"(1.00) = 1' – 8" (0.5 m)
3,000 psi (20.7 MPa) Compressive Strength Concrete ⇒ 1' – 8"(1.09) = 1' – 9" (0.5 m)
4,000 psi (27.6 MPa) Compressive Strength Concrete ⇒ 1' – 8"(1.26) = 2' – 1" (0.6 m)

When required, No. 3 stirrups shall be spaced no more than 11 inches (279 mm). In addition, Table 5.6 of the *Prescriptive Method* requires a minimum vertical reinforcement of one No. 4 bar within 12 inches (305 mm) of each side of the 6-foot- (1.8-m-) wide opening for the full height of the wall in conditions where wind speeds are 110 mph (177 km/hr) or less.

The 3-foot (0.9 m) wide openings are located throughout the remainder of the building. First-story and second-story walls were previously stated as 3.5 inch (88.9 mm) thick flat ICF walls. The building is 28 feet (8.5 m) wide and subject to a ground snow load of 50 psf (2.4 kPa).

Table 5.7 of the *Prescriptive Method* should be consulted first to determine if lintels without stirrups are permitted for the 3-foot (0.9 m) first-story lintels. Table 5.7 illustrates that a 4.5 inch (114 mm) lintel thickness and 24 inch (610 mm) lintel depth supporting one ICF story and a roof and ceiling without stirrups allows for:

30 psf (1.5 kPa) ⇒ lintel span = 5' – 6" (1.7 m)
70 psf (3.4 kPa) ⇒ lintel span = 5' – 2" (1.6 m)

By interpolation, for the design snow load of 50 psf (2.4 kPa) the allowable lintel span without stirrups is 5' – 4" (1.6 m). Since the allowable span is greater than the required 3-foot (0.9 m) span length, the applicable building width and concrete compressive strength adjustments need not be applied.

Table 5.7 of the *Prescriptive Method* should be consulted first to determine if lintels without stirrups/shear reinforcement are permitted for the 3-foot (0.9 m) second-story lintels. Table 5.7 illustrates that a 4.5 inch (114 mm) lintel thickness and 12 inch (305 mm) lintel depth supporting a light-frame roof and ceiling without stirrups allows for:

30 psf (1.5 kPa) ⇒ lintel span = 4' – 2" (1.3 m)
70 psf (3.4 kPa) ⇒ lintel span = 4' – 2" (1.3 m)

Since the listed span is greater than the required 3-foot (0.9 m) span length, the applicable building width and concrete compressive strength adjustments need not be applied. Since the opening width is only 3 feet (0.9 m), vertical reinforcement on each side of the opening is not required by Table 5.6.

**TABLE 5.6**
**MINIMUM WALL OPENING REINFORCEMENT REQUIREMENTS IN ICF WALLS**
**(excerpt from the *Prescriptive Method*)**

| WALL TYPE AND OPENING WIDTH, L feet (m) | MINIMUM HORIZONTAL OPENING REINFORCEMENT | MINIMUM VERTICAL OPENING REINFORCEMENT |
|---|---|---|
| Flat, Waffle-, and Screen-Grid: L < 2 (0.61) | None Required | None Required |
| Flat, Waffle-, and Screen-Grid: L ≥ 2 (0.61) | Provide lintels in accordance with Section 5.3. Top and bottom lintel reinforcement shall extend a minimum of 24 inches (610 mm) beyond the limits of the opening.<br><br>Provide one No. 4 bar within of 12 inches (305 mm) from the bottom of the opening. Each No. 4 bar shall extend 24 inches (610 mm) beyond the limits of the opening. | In locations with wind speeds less than or equal to 110 mph (177 km/hr) or in Seismic Design Categories A and B, provide one No. 4 bar for the full height of the wall story within 12 inches (305 mm) of each side of the opening.<br><br>In locations with wind speeds greater than 110 mph (177 km/hr) or in Seismic Design Categories C, $D_1$, and $D_2$ provide two No. 4 bars or one No. 5 bar for the full height of the wall story within 12 inches (305 mm) of each side of the opening. |

## TABLE 5.7
## MAXIMUM ALLOWABLE CLEAR SPANS FOR ICF LINTELS WITHOUT STIRRUPS IN LOAD-BEARING WALLS[1,2,3,4,5,6,7] NO. 4 OR NO. 5 BOTTOM BAR SIZE
(excerpt from the *Prescriptive Method*)

| Minimum Lintel Thickness, T (inches) | Minimum Lintel Depth, D (inches) | Maximum Clear Span (feet – inches) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Supporting Light-Frame Roof Only | | Supporting Light-Frame Second Story and Roof | | Supporting ICF Second Story and Light-Frame Roof[8] | |
| | | Maximum Ground Snow Load (psf) | | | | | |
| | | 30 | 70 | 30 | 70 | 30 | 70 |
| **Flat ICF Lintel** | | | | | | | |
| 3.5 | 8 | 2-6 | 2-6 | 2-6 | 2-4 | 2-5 | 2-2 |
| | 12 | **4-2** | **4-2** | 4-1 | 3-10 | 3-10 | 3-7 |
| | 16 | 4-11 | 4-8 | 4-6 | 4-2 | 4-2 | 3-10 |
| | 20 | 6-3 | 5-3 | 4-11 | 4-6 | 4-6 | 4-3 |
| | 24 | 7-7 | 6-4 | 6-0 | 5-6 | **5-6** | **5-2** |
| 5.5 | 8 | 2-10 | 2-6 | 2-6 | 2-6 | 2-6 | 2-6 |
| | 12 | 4-8 | 3-8 | 3-4 | 3-0 | 3-0 | 2-9 |
| | 16 | 6-5 | 5-1 | 4-8 | 4-2 | 4-3 | 3-10 |

## TABLE 5.8A
## MAXIMUM ALLOWABLE CLEAR SPANS FOR FLAT ICF LINTELS WITH STIRRUPS IN LOAD-BEARING WALLS[1,2,3,4,5,6,7] (NO. 4 BOTTOM BAR SIZE)
(excerpt from the *Prescriptive Method*)

| Minimum Lintel Thickness, T (inches) | Minimum Lintel Depth, D (inches) | Maximum Clear Span (feet – inches) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Supporting Light-Frame Roof Only | | Supporting Light-Frame Second Story and Roof | | Supporting ICF Second Story and Light-Frame Roof[8] | |
| | | Maximum Ground Snow Load (psf) | | | | | |
| | | 30 | 70 | 30 | 70 | 30 | 70 |
| 3.5 | 8 | 4-9 | 4-2 | 3-10 | 3-4 | 3-5 | 3-1 |
| | 12 | 6-8 | 5-5 | 5-0 | 4-5 | 4-6 | 4-0 |
| | 16 | 7-11 | 6-5 | 6-0 | 5-3 | 5-4 | 4-10 |
| | 20 | 8-11 | 7-4 | 6-9 | 6-0 | 6-1 | 5-6 |
| | 24 | 9-10 | 8-1 | 7-6 | 6-7 | 6-9 | 6-1 |
| 5.5 | 8 | 5-2 | 4-2 | 3-10 | 3-5 | 3-5 | 3-1 |
| | 12 | 6-8 | 5-5 | 5-0 | 4-5 | 4-6 | 4-1 |
| | 16 | 7-10 | 6-5 | 6-0 | 5-3 | 5-4 | 4-10 |

**TABLE 5.12**
**MIDDLE PORTION OF SPAN, *A*, WHERE STIRRUPS ARE NOT REQUIRED FOR FLAT ICF LINTELS[1,2,3,4,5,6,7]**
**NO. 4 or NO. 5 BOTTOM BAR SIZE**
**(excerpt from the *Prescriptive Method*)**

| Minimum Lintel Thickness, T (inches) | Minimum Lintel Depth, D (inches) | Maximum Center Distance, A (feet – inches) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Supporting Light-Frame Roof Only | | Supporting Light-Frame Second Story and Roof | | Supporting ICF Second Story and Light-Frame Roof [7] | |
| | | Maximum Ground Snow Load (psf) | | | | | |
| | | 30 | 70 | 30 | 70 | 30 | 70 |
| 3.5 | 8 | 1-2 | 0-9 | 0-8 | 0-6 | 0-6 | 0-5 |
| | 12 | 1-11 | 1-3 | 1-1 | 0-10 | 0-10 | 0-8 |
| | 16 | 2-7 | 1-9 | 1-6 | 1-2 | 1-2 | 1-0 |
| | 20 | 3-3 | 2-3 | 1-11 | 1-6 | 1-6 | 1-3 |
| | 24 | 3-11 | 2-8 | 2-4 | 1-10 | 1-10 | 1-6 |
| 5.5 | 8 | 1-10 | 1-2 | 1-0 | 0-9 | 0-10 | 0-8 |
| | 12 | 3-0 | 2-0 | 1-8 | 1-4 | 1-4 | 1-1 |
| | 16 | 4-1 | 2-9 | 2-4 | 1-10 | 1-11 | 1-6 |

## ICF Foundation Wall-to-Footing Connection

Section 6.0 of the *Prescriptive Method* does not require dowels to be installed across the ICF wall-footing interface because the interior floor slab will be poured before backfilling and installed in accordance with Figure 3.3 of the *Prescriptive Method.*

## ICF Basement Wall-to-Floor Connection

The design house is 28 feet (8.5 m) wide and has wood floor joists spaced at 24 inches (610 mm) on center. A wood ledger is used to support the floor joists; refer to Section 6.0. A 2-inch (51-mm) nominal wood ledger and 1/2-inch (13-mm) anchor bolts will be used. Assuming that a load-bearing beam is placed beneath the floor at mid-span, the resulting floor clear span is approximately 14 feet (4.3 m). Table 6.1 of the *Prescriptive Method* requires a minimum staggered 1/2-inch- (13-mm-) diameter anchor bolt spaced at 12 inches (305 mm) on center. Alternatively, two 1/2-inch- (13-mm-) diameter anchor bolts spaced at 24 inches (610 mm) on center, staggered 5/8-inch- (15.8-mm-) diameter anchor bolt spaced at 16 inches (406 mm) on center, or two 5/8-inch- (15.8-mm-) diameter anchor bolts spaced at 32 inches (813 mm) on center may also be used.

**TABLE 6.1**
**FLOOR LEDGER-ICF WALL CONNECTION (SIDE-BEARING CONNECTION) REQUIREMENTS[1,2,3]**
**(excerpt from the *Prescriptive Method*)**

| Maximum Floor Clear Span[4] (feet) | Maximum Anchor Bolt Spacing[5] (inches) | | | |
|---|---|---|---|---|
| | Staggered 1/2-Inch-Diameter Anchor Bolts | Staggered 5/8-Inch-Diameter Anchor Bolts | Two 1/2-Inch-Diameter Anchor Bolts[6] | Two 5/8-Inch-Diameter Anchor Bolts[6] |
| 8 | 18 | 20 | 36 | 40 |
| 10 | 16 | 18 | 32 | 36 |
| 12 | 14 | 18 | 28 | 36 |
| 14 | 12 | 16 | 24 | 32 |

## ICF Wall-To-Roof Connection

Section 6.0, Table 6.3, and Figure 6.8 of the *Prescriptive Method* are used to determine the top of the ICF wall-to-roof connection requirements. It is assumed that the design house has wood trusses in lieu of wood rafters and is located in a 110 mph (177 km/hr) wind area. Table 6.3 of the *Prescriptive Method* requires a minimum of a 1/2-inch (13-mm) anchor bolt spaced at 6 feet (1.8 m) on center. Section 6.3 requires an approved uplift strap to attach the roof to the wood sill plates in accordance with the applicable building code.

**TABLE 6.4**
**TOP SILL PLATE-ICF WALL CONNECTION REQUIREMENTS**
**(excerpt from the *Prescriptive Method*)**

| MAXIMUM WIND SPEED (mph) | MAXIMUM ANCHOR BOLT SPACING 1/2-INCH-DIAMETER ANCHOR BOLT |
|---|---|
| 90 | 6'-0" |
| 100 | 6'-0" |
| 110 | 6'-0" |

# APPENDIX B

# ENGINEERING TECHNICAL SUBSTANTIATION

## INTRODUCTION

The *Engineering Technical Substantiation* is provided as a supplemental information package to document the basis for the development of the *Prescriptive Method.* Structural calculations illustrate the method for determining the reinforcement requirements for the walls and lintels; supplemental equations and reference standards substantiate the examples. The example calculations are not intended to be inclusive of all design considerations for a given application but rather are intended to illustrate the derivation of the requirements in the *Prescriptive Method.*

Information is presented in both U.S. customary units and International System (SI) units except for reinforcement bar sizes which are only presented in U.S. customary units. Refer to Appendix C for the corresponding reinforcement bar size in SI units.

## B1.0 GENERAL

### B1.1 Load Calculations

***Roof Loads***

Roof snow loads were calculated using ASCE 7 [B1], multiplying the ground snow load by 0.7. Therefore, the roof snow load was taken as $P = 0.7P_g$, where $P_g$ is the ground snow load in pounds per square foot. Off-balance snow loads were not considered since heavier gravity loads improve the performance of concrete walls used in residential construction. Also, this approach has proven successful based on past performance and experience in residential construction when building and roof spans are relatively small.

***Wind Loads***

Wind loads were based on 3-second gust wind speeds ranging from 90 to 150 mph (145 to 241 km/hr). Wind pressures were calculated in accordance with ASCE 7 [B1] by using components and cladding coefficients for partially-enclosed and enclosed buildings, interior zone, and a mean roof height of 35 feet (10.7 m). Component and cladding wind loads are used to determine out-of-plane bending and out-of-plane shear in the walls. Main wind force resisting system (MWFRS) loads were also determined in accordance with ASCE 7 [B1]. The distribution of lateral wind loads to components or assemblies comprising the MWFRS was achieved by a standard tributary area method. Wind forces on all windward and leeward surfaces were considered when determining MWFRS loads. Example wind calculations are presented in Section 4 and 5 of the *Technical Substantiation.*

***Seismic Loads***

Seismic loads were determined in accordance with the International Building Code [B7].

## B1.2 ICF Foundation Wall Design Approach

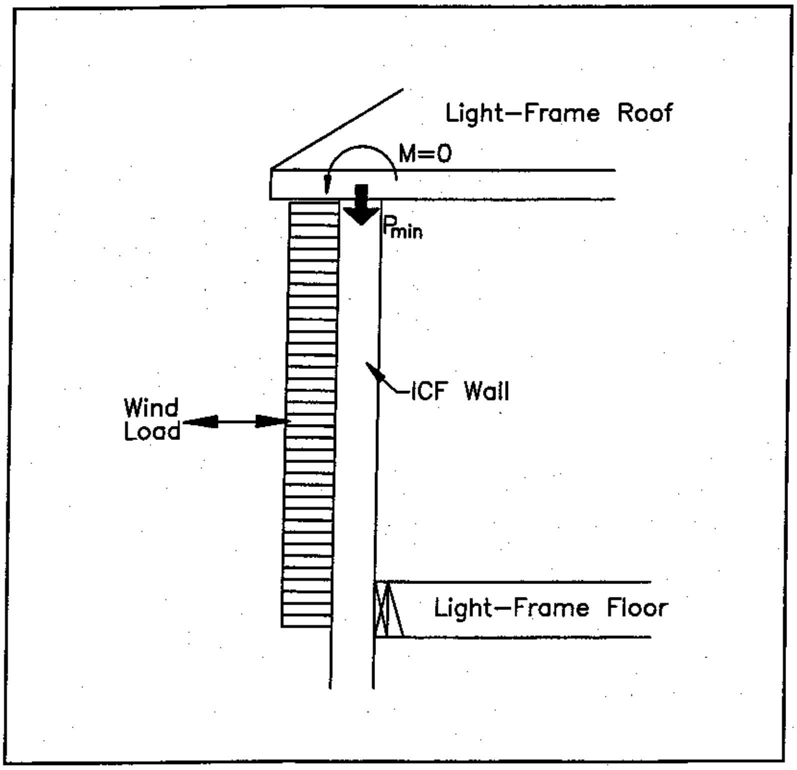
Four different construction cases were investigated to cover a range of residential construction possibilities for the development of the first edition of the *Prescriptive Method.* As expected, the controlling load case was that which induced the lowest practical axial load on the foundation wall in combination with maximum design bending or lateral load. Therefore, a single construction case was investigated in the development of the second edition.

The load case considered in the development of the second edition of the *Prescriptive Method* is conservative in that the no dead, live or gravity loads are considered which would increase the moment capacity, even with considerable eccentricity of axial load toward the outside face of the foundation wall. This method is consistent with the development of the plain concrete and reinforced concrete foundation wall provisions in the *International Residential Code* [B2].

The foundation wall height, unbalanced backfill height, and earth load vary. The vertical wall reinforcements listed in the minimum vertical wall reinforcement tables for basement walls of the *Prescriptive Method* are the results from calculations based on the above construction case and ACI [B3] Load Combinations.

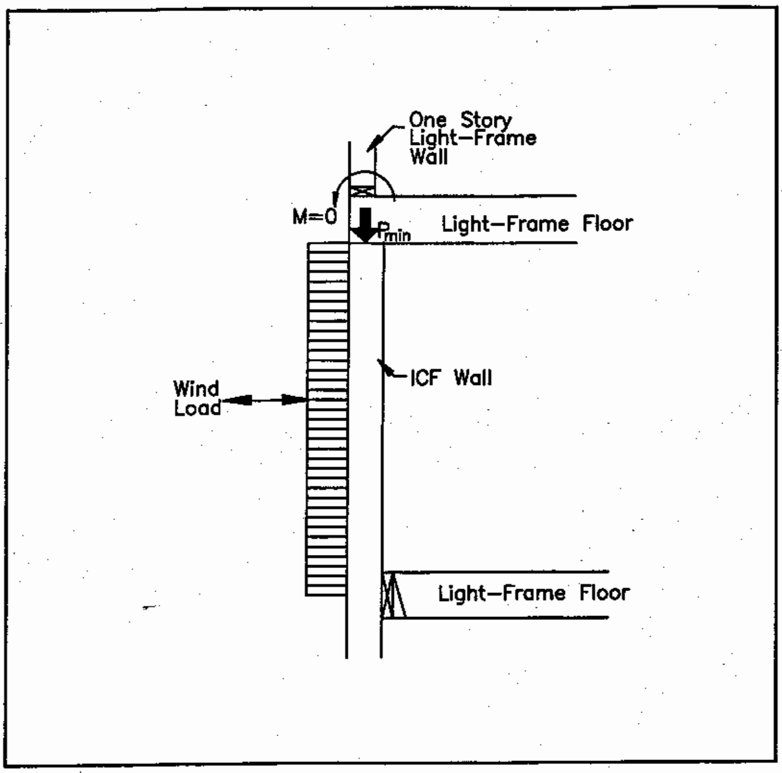
## B1.3 ICF Above-Grade Wall Design Approach

For above-grade wall construction, three different construction cases were investigated to cover the range of construction possibilities. The three construction cases are described below.



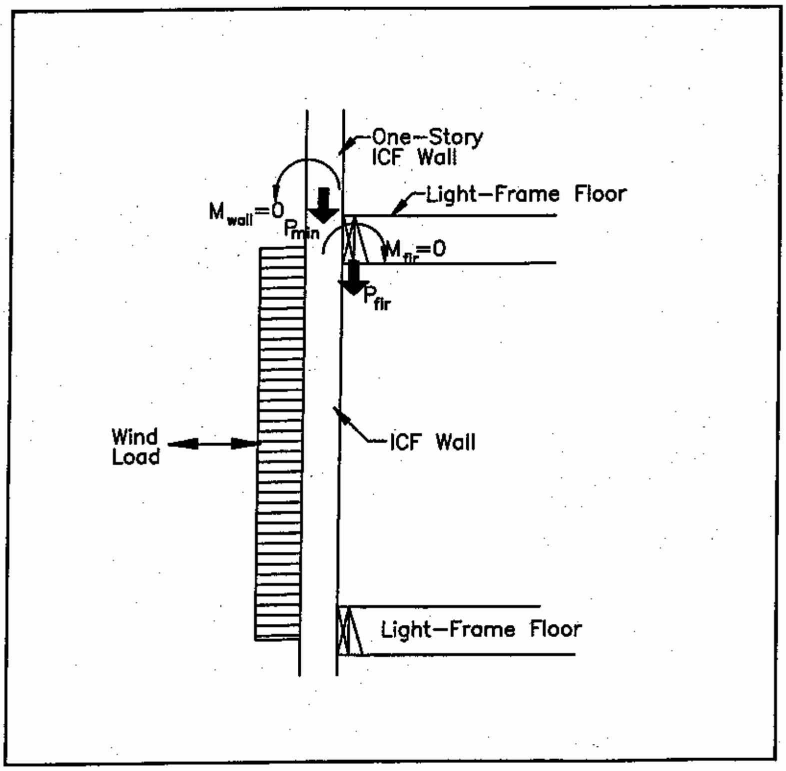

**Supporting Light-Frame Roof Only**

- Smallest axial design load with light-frame construction due to dead loads
- Assume gable end wall
- Wind loads vary from 20 psf to 80 psf (0.96 kPa to 3.83 kPa)
- No eccentricity, assume roof trusses bearing directly on the wall.




**Supporting One-Story Light-Frame Construction and Roof**

- Smallest axial design load with light-frame construction due to dead loads
- No eccentricity; assume direct floor bearing on first-story wall
- Wind loads vary from 20 psf to 80 psf (0.96 kPa to 3.83 kPa)




**Supporting One-Story ICF Construction and Light-Frame Roof**

- Smallest axial design load with ICF construction due to dead loads
- No wall eccentricity; assume ICF wall thickness for second-story wall is equal to ICF wall thickness for first-story wall
- Wind loads vary from 20 psf to 80 psf (0.96 kPa to 3.83 kPa)
- No floor eccentricity

The following values were used to design the above-grade walls; refer to Figure B1.1. The story wall height and wind load vary. The vertical wall reinforcements listed in the minimum vertical wall reinforcement tables in the *Prescriptive Method* are the results of calculations based on the applicable construction case (B1 through B3) and ACI [B3] Load Combinations.

| BUILDING GEOMETRY | Units | ABOVE-GRADE CONSTRUCTION CASE | | |
|---|---|---|---|---|
| | | B1 | B2 | B3 |
| Maximum Building Plan Dimension | feet (m) | 60 (18) | 60 (18) | 60 (18) |
| Roof Slope | ---- | 0:12 | 12:12 | 12:12 |
| Roof Tributary Area | feet (m) | Gable End | 2 (0.6) | 2 (0.6) |
| First-Floor Tributary Area | feet (m) | N/A | N/A | N/A |
| Second-Floor Tributary Area | feet (m) | N/A | 2 (0.6) | 2 (0.6) |
| First-Story Wall Height | feet (m) | Vary | Vary | Vary |
| Second-Story Wall Height | feet (m) | N/A | 8 (2.4) | 8 (2.4) |
| First-Story Wall Thickness | inches (mm) | Vary | Vary | Vary |
| Second-Story Wall Thickness | inches (mm) | N/A | 3.5 (88.9) light-frame | 3.5 (88.9) ICF |
| Foundation Wall Thickness | psf (kPa) | N/A | N/A | N/A |
| **DEAD LOADS** | | | | |
| First Floor | psf (kPa) | N/A | N/A | N/A |
| Second Floor | psf (kPa) | N/A | 10 (0.48) | 10 (0.48) |
| Roof and Ceiling | psf (kPa) | 0 | 10 (0.48) | 10 (0.48) |
| First-Story Wall | psf (kPa) | Vary | Vary | Vary |
| Second-Story Wall | psf (kPa) | N/A | 8 (0.39) | 44 (2.1) |
| Foundation Wall | psf (kPa) | N/A | N/A | N/A |
| **LIVE LOADS** | | | | |
| First Floor | psf (kPa) | N/A | N/A | N/A |
| Second Floor | psf (kPa) | N/A | 0 | 0 |
| Roof (ground snow) | psf (kPa) | 0 | 0 | 0 |
| Attic | psf (kPa) | 0 | 0 | 0 |
| **SEISMIC DESIGN CATEGORY** | ---- | A - $D_2$ | A - $D_2$ | A - $D_2$ |

**Figure B1.1 Above-Grade Wall Loading Conditions and Building Geometry**

## B1.4 ICF Lintel Design Criteria

The moment and shear capacities were determined in accordance with ACI [B3]. The following design assumptions were used:

| | | | |
|---|---|---|---|
| *Second-Floor Live Load* | = | 30 *psf* | [1.4 *kPa*] |
| *Attic Live Load* | = | 20 *psf* | [0.96 *kPa*] |
| *Roof Dead Load* | = | 15 *psf* | [0.72 *kPa*] |
| *Roof and Floor Clear Span* | = | 32 *ft* | [9.8 *m*] |
| *ICF Wall Dead Load* | = | 69 *psf* | [3.3 *kPa*] |
| *Deflection Criterion* | = | *L*/240 | |

*No. 4 and No. 5 bars are used for tensile reinforcement. All steel has a minimum tensile strength of 40,000 psi (300 MPa). All concrete has a minimum compressive strength, $f'_c$, of 2,500 psi (17.2 MPa).*

## B1.5 Ledger Board Connection Design Criteria

The following design assumptions were used:

| | | | |
|---|---|---|---|
| *Floor Live Load* | = | 40 *psf* | [1.9 *kPa*] |
| *Floor Dead Load* | = | 15 *psf* | [0.72 *kPa*] |
| *Wind Load* | = | 80 *psf* | [3.8 *kPa*] |
| *Wall Height above and below Connection* | = | 10 *feet* | [3 *m*] |
| *Floor Joist Spacing* | = | 2 *feet* | [0.61 *m*] |

# B2.0 PROPERTIES

## B2.1 Material Properties

### B2.1.1 Steel Reinforcement and Concrete

Assume the following minimums.

$F_y = 40{,}000$ *psi for steel reinforcement* [300 *MPa*]
$f_c' = 2{,}500$ *psi for concrete* [17 *MPa*]

Assume the following maximums.

$F_y = 60{,}000$ *psi for steel reinforcement* [414 *MPa*]
$f_c' = 4{,}000$ *psi for concrete* [28 *MPa*]

### B2.1.2 Ledger Board

Assume a 1.5-inch x 7.25-inch (38-mm x 184-mm), No. 2 Grade Hem-Fir with the following allowable design properties determined in accordance with the *National Design Specification for Wood Construction (NDS)* [B4].

$F_b = 850$ *psi* [5.9 *MPa*]
$F_b' = 850$ *psi* (1.15) (1.6) (1.0)
= 1,564 *psi modified for flat use, wind load duration, and size* [10.8 *MPa*]
$F_b' = 850$ *psi* (1.0)(1.0)
= 850 *psi modified for live load duration and size* [5.9 *MPa*]
$F_{c\perp} = 405$ *psi* [2.8 *MPa*]
$F_{c\perp}' = 405$ *psi* (1.25) = 506 *psi modified for small bearing area* [3.5 *MPa*]
$F_v = 75$ *psi* [0.52 *MPa*]
$F_v' = (75$ *psi*$)$ (2) = 150 *psi modified for no splits* [1.03 *MPa*]
$S_{xx} = 13.14$ $in^3$ [215 $dm^3$]
$S_{yy} = 2.72$ $in^3$ [44.6 $dm^3$]
$h = 7.25$ *inch* [184 *mm*]
$b = 1.5$ *inch* [38 *mm*]

### B2.1.3 Ledger Board Bolts

Assume A36 steel with the following design properties determined in accordance with the *Manual of Steel Construction Allowable Stress Design* [B5].

$F_t = 19{,}100$ *psi* [132 *MPa*]
$F_y = 36{,}000$ *psi* [248 *MPa*]
$F_v = 9{,}860$ *psi threads included in shear plane* [68 *MPa*]

## B2.2 Section Properties of Concrete

Due to the variety of available dimensions, a minimum equivalent rectangular section with the dimensions listed in Figure B2.1 is used to generate minimum reinforcement tables in the *Prescriptive Method* for use with as many ICF products as reasonably possible without adversely impacting design economy or practicality.

| ICF Wall Type | Nominal Thickness inches (mm) | Minimum Equivalent Thickness inches (mm) | Minimum Equivalent Width inches (mm) | Vertical Core Spacing inches (mm) |
|---|---|---|---|---|
| Flat | 3.5 (89) | 3.5 (89) | 12 (305) | N/A |
| | 5.5 (140) | 5.5 (140) | 12 (305) | N/A |
| | 7.5 (191) | 7.5 (191) | 12 (305) | N/A |
| | 9.5 (241) | 9.5 (241) | 12 (305) | N/A |
| Waffle-Grid | 6 (152) | 5.0 (127) | 6.25 (159) | 12 (305) |
| | 8 (203) | 7.0 (178) | 7.0 (178) | 12 (305) |
| Screen-Grid | 6 (152) | 5.5 (140) | 5.5 (140) | 12 (305) |

**Figure B2.1 Equivalent Rectangular Section Dimensions**

## B3.0 ICF FOUNDATION WALL DESIGN EXAMPLES AND ENGINEERING CALCULATIONS

The following engineering calculations are provided as supplemental information to illustrate the means and methods of analysis followed in developing the requirements included in the *Prescriptive Method.* Structural calculations specifically illustrate the method for calculating the reinforcement requirements and adjustment factors used within the tables. The example calculations are not intended to be inclusive of all design considerations for a given application, but rather are intended to illustrate the derivation of the tables in the *Prescriptive Method.*

### B3.1 5.5-Inch- (140-mm-) Thick Flat ICF Basement Wall

For the purposes of illustration, a flat ICF foundation wall is selected from Table 3.4 of the *Prescriptive Method* for foundation walls constructed in soil with an equivalent fluid density of 30 pcf (481 $kg/m^3$). The foundation wall is 9 feet (2.7 m) high and has 5 feet (1.5 m) of unbalanced backfill. Table 3.4 shows that the foundation wall is required to have a minimum of one No. 4 bar at 48 inches (1.2 m) on center for vertical wall reinforcement. Calculate the capacity and check the adequacy of the 5.5-inch- (140-mm-) thick flat ICF foundation wall.

Using the material properties in Section 2.0 compute the amount of vertical wall reinforcement required. The load case considered is conservative in that no dead, live or gravity loads are considered which would increase the capacity. The controlling condition is when the axial load is minimized and the moment is maximized, therefore, only the dead load for the foundation wall itself is considered. The following example summarizes the nominal and factored loads calculated.

<u>*Dead Loads on Foundation Wall*</u>

| | | |
|---|---|---|
| *First Floor* | 0 *plf* | [0 *N/m*] |
| *Roof and Ceiling* | 0 *plf* | [0 *N/m*] |
| *First-Story Wood Wall* | 0 *plf* | [0 *N/m*] |
| *Foundation ICF Wall* | $0.5(9.0\,ft)(5.5in/12in/ft)(150\,pcf) = 309\,plf$ *@ mid-height* | [4.5 *N/m*] |

<u>*Live Loads on Foundation Wall*</u>

| | | |
|---|---|---|
| *First Floor* | 0 *plf* | [0 *N/m*] |
| *Roof and Ceiling* | 0 *plf* | [0 *N/m*] |
| *First-Story Wood Wall* | 0 *plf* | [0 *N/m*] |

<u>*Foundation Wall Moments*</u>

| | | |
|---|---|---|
| *Dead Load*$_{@top}$ | 0 *in-lb/lf* | [0 *N-m/m*] |
| *Live Load*$_{@top}$ | 0 *in-lb/lf* | [0 *N-m/m*] |

$$Moment_{@midht} \quad -\frac{(30pcf)(5ft)(4.5ft)^2}{2}+\frac{(30pcf)(4.5ft)^3}{6}+306plf(4.5ft)=312ft-lb/lf \qquad [1.39\ kN\text{-}m/m]$$

$$Moment_{@x} \quad -\frac{(30pcf)(5ft)(2.85ft)^2}{2}+\frac{(30pcf)(2.85ft)^3}{6}+306plf(2.85ft)=377ft-lb/lf \qquad [1.68\ kN\text{-}m/m]$$

*x = 2.85 feet (0.87 m) location of the maximum moment; a simply supported beam model is used.*

Parallel Shear

*The unbalanced backfill height is greater than 4 feet (1.2 m). Assume all basement walls in the building have 5 feet (1.5 m) of unbalanced backfill height. Parallel shear is neglected as common practice since the foundation walls are generally restrained by the soil lateral pressure on all sides and opening areas in foundation walls are generally low.*

Perpendicular Shear

*Refer to Section 7.0 for variable definitions.*

$$V_{top}=\frac{ql^3}{6L}=\frac{(30pcf)(5ft)^3}{6(9ft)}=69plf \qquad [1.0\ kN/m]$$

$$V_{bottom}=\frac{ql^2}{2}-V_{top}=\frac{(30pcf)(5ft)^2}{2}-69plf=306plf \qquad [4.2\ kN/m]$$

$$V_{midht}=qlx-\frac{qx^2}{2}-V_{bottom}=(30pcf)(5ft)(4.5ft)-\frac{(30pcf)(4.5ft)^2}{2}-306plf=66plf \qquad [0.96\ kN/m]$$

## Load Combinations

The following load combinations are from ACI 318 Chapter 9 [B3]:

(1) U = 1.4D + 1.7 L
(2) U = 1.4D + 1.7 L + 1.7 H
(3) U = 0.9D + 1.3 W
(4) U = 0.9D + 1.7 H

All foundation design cases are controlled by load combination number (4) since it produces the smallest possible axial load and maximum bending load.

## Check Perpendicular Shear

The critical factored perpendicular shear load, $V_u$, experienced by the foundation wall occurs at the bottom of the wall story due to ACI 318 Load Combination (4).

$$V_u=1.7(306plf)=520plf \qquad [7.1\ kN/m]$$

$$\phi V_n=0.65\left(\frac{4}{3}\right)\sqrt{f'_c}\,b_w h=0.65\left(\frac{4}{3}\right)\sqrt{2{,}500\,psi}(12\,in)(5.5\,in)=2{,}860\,plf \qquad [41.7\ kN/m]$$

$$V_u \le \phi V_n \quad OK$$

Check Compression and Tension

$M_u = 1.7(377\ ft\text{-}lb/lf)(12\ in/ft) = 7{,}690\ in\text{-}lb/ft$ [2.9 *kN-m/m*]

$P_u = 0.9(423\ plf) = 381 plf$ [5.3 *kN/m*]

Determine Points for the Interaction Diagrams

Interaction Diagram for Plain Structural Concrete

Point 1 – Pure Compression

$$P_o = 0.60 f'_c\left[1-\left(\frac{h}{32t}\right)^2\right]A_c = 0.6(2{,}500psi)\left[1-\left(\frac{9ft(12in/ft)}{32(5.5in)}\right)^2\right](5.5in)(12in) = 61{,}722lbf$$ [275 *kN*]

$\phi P_n = 0.65(61{,}722) = 40{,}119lbf$ [178 *kN*]

$\phi M_n = 0$

Point 2 – Pure Bending

$$\phi M_n = \phi 5\sqrt{f'_c}S = 0.65(5)\sqrt{2{,}500psi}\left(\frac{(12in)(5.5in)^2}{6}\right) = 9{,}831lb - in$$ [1.1 *kN-m*]

$\phi P_u = 0$

Point 3 – Balanced Condition

The balanced condition represents the dividing point between compression controls and tension controls regions of the strength interaction diagram. According to ACI 22.5.3 [B3] plain structural concrete members subject to combined axial load and bending shall be proportioned such that on the compression face:

$$P_u/\phi P_n + M_u/\phi(0.85)(f'_c)S \le 1$$

and on the tension face:

$$M_u/S - P_u/A_g \le 5\phi\sqrt{f'_c}$$

Hence,

$$M_u = \frac{\phi P_n + 5\phi\sqrt{f'_c}A_c}{\left(\frac{A_c}{S} + \frac{\phi P_n}{\phi(0.85)(f'_c)(S)}\right)}$$

$$= \frac{40{,}119lb + 5(0.65)\sqrt{2{,}500psi}(5.5in)(12in)}{\left(\frac{(5.5in)(12in)}{(12in)(5.5in)^2/6} + \frac{40{,}119lb}{(0.65)(0.85)(2{,}500psi)\frac{(12in)(5.5in)^2}{6}}\right)} = 32{,}364lb-in \quad [3.64\ kN\text{-}m]$$

$$P_u = \frac{M_u}{S}A_c - 5\phi\sqrt{f'_c}A_c = \frac{32{,}364lb-in(5.5in)(12in)}{(12in)(5.5in)^2/6} - 5(0.65)\sqrt{2{,}500psi}(5.5in)(12in) = 24{,}581lbf \quad [109\ kN]$$

The hand calculations above were consolidated into spreadsheet form and factored according to ACI 318 [B3]. The factored moments were also magnified according to ACI 318 Section 10.12 [B3] for structurally reinforced concrete walls (see Section B4 of the *Technical Substantiation* for an example of magnified moments). With the factored axial loads and maximum factored moments, multiple reinforcement schedules were plotted on a factored $P_u$-$M_u$ interaction diagram.

Figure B3.1 shows the factored loads for the 5.5-inch (140 mm) thick plain ICF wall in this example (see plotted point for "30 pcf"). It also contains the plain structural concrete curve. The requirements of the foundation wall system are moment controlled and thereby lie on the lowest portion of the curve. For determining the requirements, a "zoom-in" on the moment controlled region of the diagram is shown in Figure B3.2.

Figure B3.2 indicates that the required strength for the 5.5-inch- (140-mm-) thick flat basement wall that is 9 feet (2.7 m) high and has 5 feet (1.5 m) of unbalanced backfill in soil with an equivalent fluid density of 30 pcf (481 kg/m$^3$) is satisfied by specifying the wall to meet plain structural concrete requirements.

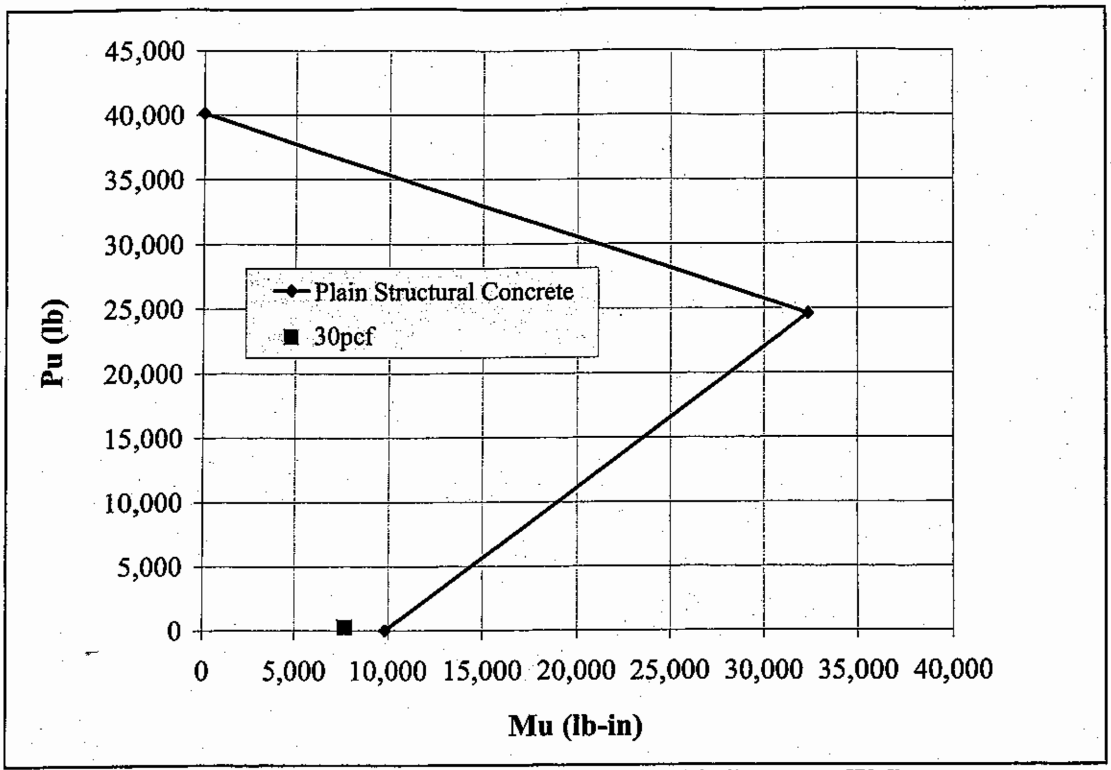



**Figure B3.1 $P_u$-$M_u$ Diagram for the 5.5 in Basement Wall**

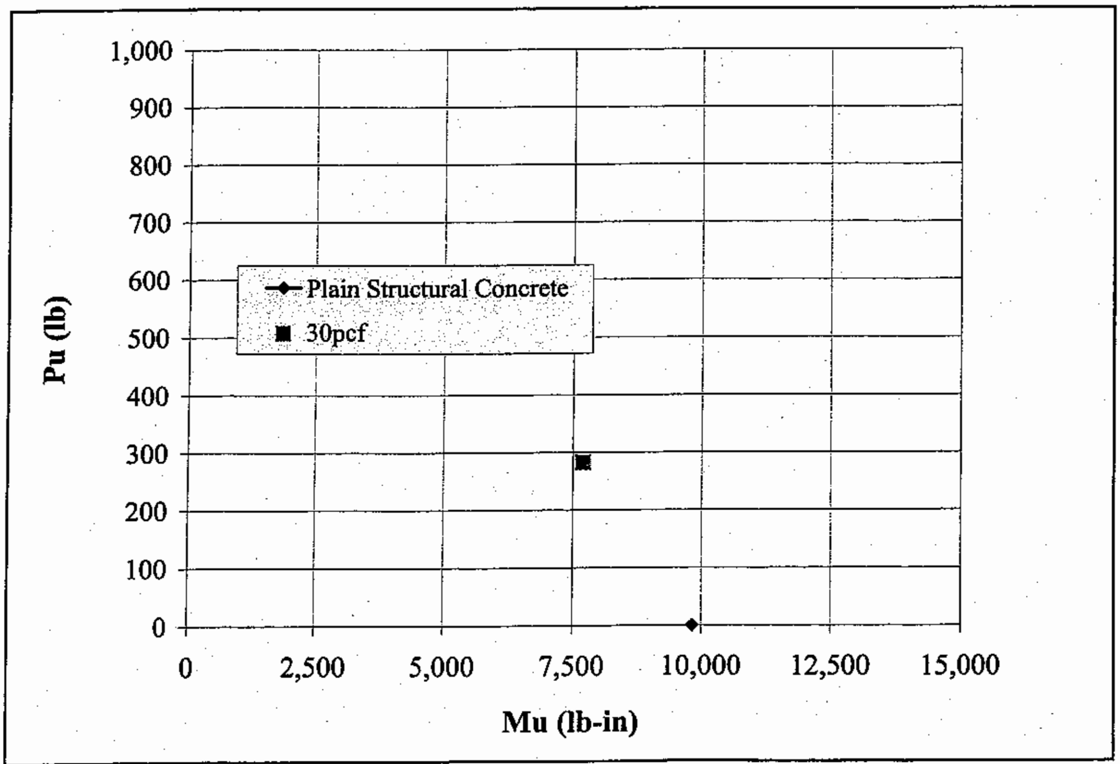



**Figure B3.2 Zoom of $P_u$-$M_u$ Diagram for the 5.5 in Basement Walls**

Check Deflection

For below-grade walls, a deflection limit of *L/240* for service live loads is used. To calculate wall deflection, effective section properties, $E_cI_g$, of the uncracked concrete section are used. For simplicity, when calculating the maximum deflection, assume the earth load acts on the entire wall height.

$$\Delta_{maximum} = \frac{0.01304(0.5)ql^5}{E_cI_g} = \frac{0.01304(0.5)(30\,pcf)(1\,ft)(9\,ft)^5}{(2{,}850{,}000\,psi)\left(\frac{(12in)(5.5\,in)^3}{12}\right)}\left(\frac{1{,}728in^3}{ft^3}\right) = 0.042in \qquad [1.07\ mm]$$

$$\Delta_{allowable} = \frac{L}{240} = \frac{(9\,ft)\left(\frac{12\,in}{ft}\right)}{240} = 0.45\,in \qquad [11\ mm]$$

$$\Delta_{actual} \le \Delta_{allowable} \qquad OK$$

Determine Reinforcement

Although the wall is acceptable as a structural plain concrete wall in this case, a nominal amount of reinforcement is specified for the 5.5 inch (140 mm) thick below grade walls. Tests [B6] have shown that horizontal and vertical wall reinforcement spacing limited to 48 inches (1.2 m) on center results in reliable performance for ICFs; therefore, one Grade 40 (276 MPa) or Grade 60 (414 MPa), No. 4 bar at 48 inches (1.2 m) on center is specified for minimum vertical wall reinforcement. One No. 4 bar at 48 inches (1.2 m) on center is similarly specified as a minimum horizontal wall reinforcement. At least one continuous horizontal reinforcing bar should be placed within the top 12 inches (305 mm) of the wall story.

This procedure was repeated based on all possible construction permutations included in Chapter 3 of the *Prescriptive Method* including 60 ksi (414 MPa) reinforcing steel, 3,000 psi (20.7 MPa) concrete, and 4,000 psi (27.6 MPa) concrete. However, when reinforced concrete was required by first analyzing plain concrete $P_u$–$M_u$ curves, a similar set of $P_u$–$M_u$ curves was created to determine minimum amounts of reinforcement required. These analyses yielded the allowable 50-percent spacing increase when 60 ksi (414 MPa) reinforcing steel is used. However, there was no appreciable benefit in using higher strength concrete for this application.

**TABLE 3.4**
**MINIMUM VERTICAL WALL REINFORCEMENT FOR**
**5.5-INCH- (140-MM-) THICK FLAT ICF BASEMENT WALLS [1,2,3,4,5]**
**(excerpt from the *Prescriptive Method*)**

| Max. Height of Basement Wall (feet) | Maximum Unbalanced Backfill Height[6] (feet) | Minimum Vertical Reinforcement | | |
|---|---|---|---|---|
| | | Maximum Equivalent Fluid Density 30 pcf | Maximum Equivalent Fluid Density 45 pcf | Maximum Equivalent Fluid Density 60 pcf |
| 8 | 4 | #4@48" | #4@48" | #4@48" |
| | 5 | #4@48" | #3@12"; #4@22"; #5@32"; #6@40" | #3@8"; #4@14"; #5@20"; #6@26" |
| | 6 | #3@12"; #4@22"; #5@30"; #6@40" | #3@8"; #4@14"; #5@20"; #6@24" | #3@6"; #4@10"; #5@14"; #6@20" |
| | 7 | #3@8"; #4@14"; #5@22"; #6@26" | #3@5"; #4@10"; #5@14"; #6@18" | #3@4"; #4@6"; #5@10"; #6@14" |
| 9 | 4 | #4@48" | #3@32"; #4@48" | #4@48" |
| | 5 | #4@48" | #3@12"; #4@20"; #5@28"; #6@36" | #3@8"; #4@14"; #5@20"; #6@22" |
| | 6 | #3@10"; #4@20"; #5@28"; #6@34" | #3@6"; #4@12"; #5@18"; #6@20" | #4@8"; #5@14"; #6@16" |
| | 7 | #3@8"; #4@14"; #5@20"; #6@22" | #4@8"; #5@12"; #6@16" | #4@6"; #5@10"; #6@12" |
| | 8 | #3@6"; #4@10"; #5@14"; #6@16" | #4@6"; #5@10"; #6@12" | #4@4"; #5@6"; #6@8" |

# B4.0 ICF ABOVE-GRADE WALL DESIGN EXAMPLES AND ENGINEERING CALCULATIONS

The following engineering calculations are provided as supplemental information to illustrate the means and methods used in the development of the requirements included in the *Prescriptive Method*. Example calculations are used to illustrate the method of determining reinforcement requirements and adjustment factors used within the tables. The example calculations are not intended to be inclusive of all design considerations, but rather are intended to clearly illustrate the derivation of values in the *Prescriptive Method*.

## B4.1 Calculating Wind Pressures

An enclosed building sited where wind speeds are 100 mph (161 km/hr) in Exposure Category B is considered. Table 4.1 shows that the above-grade wall design wind pressure is 24 psf (1.15 kPa). This wind pressure is used to select the appropriate vertical reinforcement requirements for out-of-plane bending for the various ICF systems at the stated conditions for this example. The following calculations show how the design wind pressures in Table 4.1 are calculated for the example building conditions using ASCE 7 [B1]. A mean roof height of 35 ft (10.7 m) was used for all table values.

### B4.1.1 Determine the Velocity Pressure

$$q_h = 0.00256 K_z K_{zt} K_d V^2 I = (0.00256)(0.73)(1.0)(1.0)(100 mph)^2 (1.00) = 18.69 psf$$

Note: A $K_d$ factor of 1.0 is used for concrete design in accordance with the International Building Code, Section 1605.2.1 [7].

### B4.1.2 Determine the Net External and Internal Pressure Coefficient

$$\sum \left( GC_p - GC_{pi} \right) = (-1.1 - 0.18) = -1.28$$

Note: $GC_p$ is based on Zone 4 values. Negative pressure creates the worst-case load magnitude. A $GC_{pi}$ value of –0.55 is used to determine pressures for partially enclosed buildings in lieu of –0.18 above.

### B4.1.3 Determine the Design Wind Pressure

$$p = q_h \sum \left( GC_p - GC_{pi} \right) = (18.69 psf)(-1.28) = -23.9 psf$$

## B4.2 Out-of-Plane Seismic Loads

According to the *International Building Code* [B7], bearing walls and shear walls shall be designed for an out-of-plane force that is the greater of 10 percent of the wall weight or the quantity given by

$$F_p = 0.40 I_E S_{DS} W_w$$

where:

$I_E$ = Occupancy importance factor (1.00 for residential construction)
$S_{DS}$ = The short period site design spectral response acceleration coefficient
$W_w$ = The weight of the wall

Figure B4.1 summarizes the out-of-plane seismic loads for Seismic Design Categories C, $D_1$, and $D_2$. Since the out-of-plane seismic loads for Seismic Design Category C are less than the lowest design wind pressure (20 psf) in Tables 4.2 through Table 4.4 of the *Prescriptive Method*, wind governs the design in all cases. By inspecting Tables 4.2 to 4.5 of the Prescriptive Method at the out-of-plane seismic load for Seismic Design Categories $D_1$ and $D_2$, it is clear that the minimum vertical reinforcement requirement of one No. 5 bar at 18 inches (457 mm) on center provides more than adequate out of plane bending resistance for Seismic Design Categories $D_1$ and $D_2$.

| Wall Type | Weight (psf) | Seismic Design Category C | | Seismic Design Category $D_1$ | | Seismic Design Category $D_2$ | |
|---|---|---|---|---|---|---|---|
| | | $S_{DS}$ | $F_p$ (psf) | $S_{DS}$ | $F_p$ (psf) | $S_{DS}$ | $F_p$ (psf) |
| 3.5-in Flat | 43.75 | 0.5g | 8.8 | 0.83g | 14.5 | 1.17g | 20.5 |
| 5.5-in Flat | 68.75 | 0.5g | 13.8 | 0.83g | 22.8 | 1.17g | 32.2 |
| 6-in Waffle | 56.00 | 0.5g | 11.2 | 0.83g | 18.6 | 1.17g | 26.2 |
| 8-in Waffle | 76.00 | 0.5g | 15.2 | 0.83g | 25.2 | 1.17g | 35.6 |
| 6-in Screen | 53.00 | 0.5g | 10.6 | 0.83g | 17.6 | 1.17g | 24.8 |

**Figure B4.1**
**Out-of-Plane Seismic Loads for Seismic Design Category C, $D_1$, and $D_2$**

### B4.3 6-Inch- (152-mm-) Thick Waffle-Grid ICF Above-Grade Wall

A waffle-grid ICF above-grade wall is selected from Table 4.3 of the *Prescriptive Method* for above-grade walls constructed in an area where the design wind pressure is 30 psf (1.44 kPa). The above-grade wall is 9 feet (2.7 m) high and supports a light-frame roof only. Table 4.3 shows that the above-grade wall requires one #4 bar at 48 in (1.2 m) on center. Table 4.5 shows that the above-grade wall requires horizontal reinforcement in the form of one No. 4 bar at third points in the wall story and one No. 4 bar within 12 inches (305 mm) of the top of the wall story. Calculate the capacity and check the adequacy of the 6-inch- (152-mm-) thick waffle-grid ICF above-grade wall.

Using the values in Figure B1.1 and the material properties in Section 2.0, the amount of vertical wall reinforcement required was determined as follows.

The wall moments are calculated by multiplying the axial load by the assumed eccentricities of the roof, wall above, and floor as applicable. The controlling condition is when the gravity load is minimized and the moment is maximized.

*Dead Loads*

| | | |
|---|---|---|
| *Roof and Ceiling* | 0 *plf* | [0 *kN/m*] |
| *First-Story ICF Wall* | 0.5(9.0 *ft*)(55 *psf*) = 248 *plf* @ *mid-height* | [3.6 *kN/m*] |

*Live Loads*

| | | |
|---|---|---|
| *Roof and Ceiling* | 0 *plf* | [0 *kN/m*] |
| *Attic* | 0 *plf* | [0 *kN/m*] |

*First-Story Wall Moments*

| | | |
|---|---|---|
| *Dead Load* $_{@top}$ | 0 *in-lb/lf* | [0 *N-m/m*] |
| *Live Load* $_{@top}$ | 0 *in-lb/lf* | [0 *N-m/m*] |
| *Wind Load* $_{@midht}$ | $\frac{30psf(9ft)^2(1ft)}{8} = 303.8 ft-lb/lf = 3{,}645 in-lb/lf$ | [1.3 *kN-m/m*] |

*Parallel Shear*

*Refer to Section 5.0 for parallel shear calculations.*

Perpendicular Shear

*Refer to Section 7.0 for variable definitions.*

$$V_u = \frac{ql}{2} = \frac{(30psf)(9ft)}{2} = 135plf\left(\frac{ft}{1 vertical core}\right) = 135\, lb/post$$ [433 *kN/post*]

Load Combinations

The following ACI 318 and IBC Load Combinations were used for design purposes [B3] [B7]:

(1) U = 1.4D + 1.7L
(2) U = 0.75 (1.4D + 1.7L + 1.7W)
(3) U = 1.05D + 1.28L + 1.0E
(4) U = 0.9D + 1.3W
(5) U = 0.9D + 1.0E

All out-of-plane bending design cases were controlled by load combination (4) for wind loads and load combination (5) for earthquake loads.

The hand calculations above were consolidated into spreadsheet form and factored following ACI 318 [B3] and IBC [B7] guidelines. The factored moments were also magnified following the requirements found in ACI 318 section 10.12 [B3]. The maximum moment in the wall was determined at the mid-point of the wall. With the maximum factored axial loads and maximum factored moments the construction cases were plotted on a factored $P_u$-$M_u$ curve constructed following conventional reinforced concrete practices and ACI recommended resistance factors. The following sections provide example calculations and an example $P_u$-$M_u$ curve.

Check Perpendicular Shear

The critical factored perpendicular shear load, $V_u$, experienced by the first-story wall occurs at the bottom of the wall story due to ACI [B3] Load Combination (4). Consider a reinforced section.

$V_u = (1.3)(135\,lb/post) = 176\,lb/post$ [0.78 *kN/post*]

$\phi V_n = 0.85(2)\sqrt{f'_c}bh = 0.85(2)\sqrt{2{,}500\,psi}(6.25in)(5in) = 2{,}656\,lb/post$ [11.8 *kN/post*]

$V_u \le \phi V_n \quad OK$

Check Compression and Tension

The critical maximum moment, $M_u$, experienced by the first-story wall occurs at mid-height due to ACI [B3] Load Combination (4). The corresponding total factored axial load, $P_u$, is also taken at mid height of the first story-wall based on ACI [B3] Load Combination (4).

$M_u = (1.3)(3{,}645\,in-lb/ft)(ft/post) = 4{,}739\,in-lb/post$ [0.54 *kN-m/post*]

$P_u = (0.9)(248\,plf) = 223\,plf = 223\,lb/post$ [1.0 *kN/post*]

Determine Magnified Moment

With one exception, the equations below are taken from ACI 10.12 [B3]. The equation for *EI*, as listed in ACI 10.12.3 [B3], is applicable to wall sections that contain a double layer of reinforcement. Given that ICFs contain only one layer of reinforcement, the equation for *EI* noted below is used instead [B8].

$M_u = (1.3)(3{,}645\,in-lb/lf) = 4{,}739\,in-lb/post$ [0.54 *kN-m/post*]

$P_u = (0.9)(248\,plf) = 223\,plf = 223\,lb/post$ [1.0 *kN/post*]

$E_c = 57{,}000\sqrt{f_c'} = 57{,}000\sqrt{2{,}500\,psi} = 2{,}850{,}000\,psi$ [19.7 *GPa*]

From ACI Section 10.12.3 [B3], assume $\beta_d = 0.6$, therefore;

$$EI = 0.25E_cI_g = 0.25(2{,}850{,}000\,psi)\left(\frac{(6.25in)(5in)^3}{12}\right) = 46{,}386{,}718\,psi$$ [320 *GPa*]

$$M_{2,min} = P_u(0.6 + 0.03h) = 223lb(0.6 + 0.03(5in)) = 167.3in - lb$$ [18.9 *N-m*]

$C_m = 1.0$ *for members with transverse loads between supports*

$$P_c = \frac{\pi^2 EI}{(kl_u)^2} = \frac{\pi^2(46{,}386{,}718\,psi)}{[(1.0)(9ft)^2][(12in/ft)^2]} = 39{,}211lb$$ [174 *kN*]

$$\delta_{ns} = \frac{C_m}{1-\left(\frac{P_u}{0.75P_c}\right)} \ge 1.0 = \frac{1.0}{1-\left(\frac{223lb}{0.75(39{,}211lb)}\right)} = 1.008$$

$$M_{ns} = \delta_{ns}M_u = 1.008(4{,}739in - lb) = 4{,}777in - lb$$ [0.53 *kN-m*]

Determine Points for the Interaction Diagrams

Interaction Diagram for one No. 4 bar spaced 48 in (1.2 m) on center

Point 1 – Pure Compression

$$P_o = 0.85 f'_c (A_{concrete} - A_s) + f_y A_s$$

$$= 0.85(2{,}500psi)(6.25in(5in) - 0.2in^2(12in/48in)) + 40{,}000psi(0.2in^2)(12in/48in) = 68{,}300lbf \quad [967\ kN/m]$$

$$P_{n\max} = 0.8P_o = 0.8(68{,}300lbf) = 54{,}640lbf \quad [774\ kN/m]$$

$$P_u = \phi\ P_{n\max} = 0.7(54{,}640lbf) = 38{,}248lbf \quad [542\ kN/m]$$

$$\phi\ M_n = 0$$

Point 2 – Balanced Condition

The balanced condition represents the dividing point between compression controls and tension controls regions of the strength interaction diagram. It is defined by the simultaneous occurrence of a strain of 0.003 in the extreme fiber of the concrete and the strain $\varepsilon_y = f_y/E_s$ on the tension steel.

Distance to the neutral axis:

$$x_b = \frac{87{,}000d}{f_y + 87{,}000} = \frac{87{,}000(5in/2)}{40{,}000psi + 87{,}000} = 1.71in \quad [43.4\ mm]$$

Compression force:

$$C_c = 0.85 f'_c \beta\ x_b b = 0.85(2{,}500psi)(0.85)(1.71in)(6.25in) = 19{,}304lb \quad [85.9\ kN]$$

Tension force:

$$T = A_s f_y = (0.2in^2)(12in/48in)(40{,}000psi) = 2{,}000lb \quad [8.9\ kN]$$

Factored Balanced Axial Load:

$$\phi\ P_b = \phi(C_c - T) = 0.7(19{,}304lb - 2{,}000lb) = 12{,}113lb \quad [53.9\ kN]$$

Factored Balanced Moment:

$$\phi M_b = \phi C_c\left(d - \frac{\beta\ x_b}{2}\right) = 0.7(19{,}304lb)\left(\frac{5in}{2} - \frac{0.85(1.71in)}{2}\right) = 23{,}962lb - in \quad [2.7\ kN\text{-}m]$$

Point 3 – Pure Bending

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{(0.2in^2)(12in/48in)(40{,}000psi)}{0.85(2{,}500psi)(6.25in)} = 0.15in \qquad [3.8\ mm]$$

$$\phi M_n = \phi A_s f_y \left(d - \frac{a}{2}\right) = 0.9(0.2in^2)(12in/48in)(40{,}000psi)\left(\frac{5in}{2} - \frac{0.15in}{2}\right) = 4{,}365lb - in \qquad [482\ N\text{-}m]$$

$$\phi P_u = 0$$

Additional points were determined in the compression controls region (between Point 1 and Point 2) and the tension controls region (between Point 2 and Point 3) to populate the interaction diagrams. This procedure was duplicated for numerous reinforcement schedules to obtain the most efficient design possible.

Determine Reinforcement

Plot the magnified moment and the corresponding total factored axial load on the interaction diagram for a 6-inch (152-mm) thick waffle-grid wall. This diagram was constructed for each possible configuration using a range of reinforcement ratios that extend below the ACI minimum. Figure B4.2 is a close up of the lowest portion of the curve since the requirements of the wall system for out-of-plane bending are in the tension controlled region. It should be noted that increasing the gravity load in this region of the $P_u$-$M_u$ will increase the wall strength against transverse loads.

The interaction diagrams shown are based on 2,500 psi (17.2 MPa) concrete, 40,000 psi (276 MPa) reinforcing steel, and the reinforcing steel being centered in the wall cross section. This procedure was repeated for all possible permutations including 3,000 psi (20.6 MPa) concrete, 4,000 psi (27.6 MPa) concrete, and 60,000 psi (414 MPa) reinforcing steel to determine the relationship between the differing material properties.

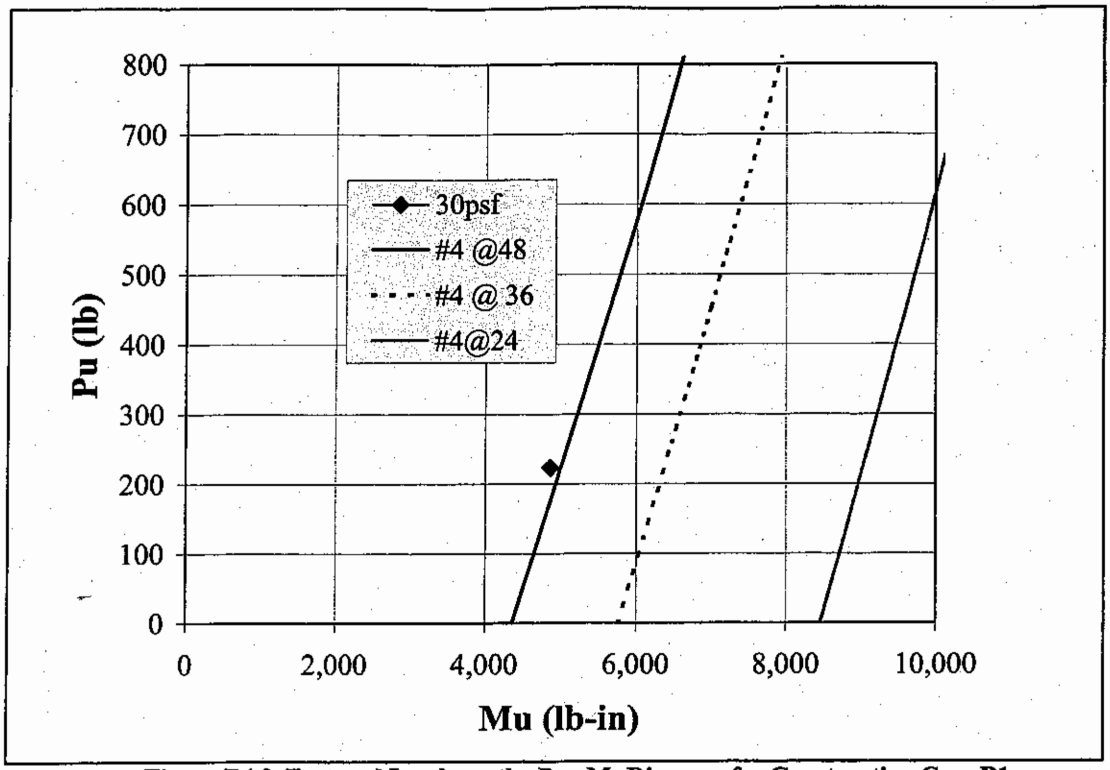



**Figure B4.2 Factored Loads on the $P_u - M_u$ Diagram for Construction Case B1**

Check Deflection

For above-grade walls, a deflection limit of *L/240* for total service loads is used. To calculate wall deflection at service load levels, effective section properties of the assumed cracked concrete section are based on $0.1E_cI_g$.

Assume a gypsum board interior finish exposed to view. The deflection calculations below are based on wind loads. Refer to Section 7.0 for the maximum deflection equation.

$$\Delta_{actual} = \frac{5(30psf)(1ft)(9ft)^4\left(\frac{1{,}728in^3}{ft^3}\right)}{(0.1)(384)(2{,}850{,}000psi)\left(\frac{(6.25in)(5in)^3}{12}\right)} = 0.24in \qquad [6.1\ mm]$$

$$\Delta_{allowable} = \frac{(9ft)\left(\frac{12in}{ft}\right)}{240} = 0.45in \qquad [11.4\ mm]$$

$\Delta_{actual} < \Delta_{allowable}$ *OK*

### 4.3.1 Construction Case Summary

From Table 4.3 of the *Prescriptive Method*, we obtain one vertical Grade 40 (300 MPa), No. 4 bar at 48 inches (1.2 m) on center, and from Section 4.5 one horizontal No. 4 bar near third points in the wall story. Note that in Seismic Design Categories $D_1$ and $D_2$ the minimum vertical and horizontal reinforcement shall be one No. 5 rebar at a maximum spacing of 18 inches (457 mm) on center and the minimum concrete compressive strength shall be 3,000 psi (20.5 MPa) [B3] [B7].

**TABLE 4.3**
**MINIMUM VERTICAL WALL REINFORCEMENT**
**FOR WAFFLE-GRID ICF ABOVE-GRADE WALLS [1,2,3,4]**
**(excerpt from the *Prescriptive Method*)**

| Design Wind Pressure (Table 4.1) | Maximum Wall Height per Story | Minimum Vertical Reinforcement[5] | | | | | |
|---|---|---|---|---|---|---|---|
| | | Supporting Light-Frame Roof Only | | Supporting Light-Frame Second Story and Roof | | Supporting ICF Second Story and Light-Frame Roof | |
| | | Minimum Wall Thickness (inches) | | | | | |
| (psf) | (feet) | 6 | 8 | 6 | 8 | 6 | 8 |
| 20 | 8 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 |
| | 9 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 |
| | 10 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 |
| 30 | 8 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 |
| | 9 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 | #4@48 |
| | 10 | #4@36; #5@48 | #4@48 | #4@36; #5@48 | #4@48 | #4@36; #5@48 | #4@48 |

# B5.0 ICF WALL OPENING DESIGN EXAMPLES AND ENGINEERING CALCULATIONS

## B5.1 Calculating In-Plane Shear Due to Wind

For illustration of the design methods used, a building sited in Exposure C where wind speeds are 90 mph (145 km/hr) is selected from Table 5.1 of the *Prescriptive Method* for above-grade walls. Table 5.1 shows that the design velocity pressure is 21 psf (1.0 kPa). This velocity pressure is used to select the minimum solid wall length requirements for in-plane shear for the various ICF systems. The following calculations determine the velocity pressure using the main wind force resisting systems for a building sited in Exposure C where the wind speeds are 90 mph (145 km/hr). A mean roof height of 35 ft (10.7 m) was used for all cases.

For the purpose of illustrating the determination of building lateral loads or in-plane shear wall loads due to winds, consider a one-story house with a 6:12 roof pitch for determining the shear loads on the building. Consider a building plan of 40ft (12.2 m) – perpendicular to ridge (end wall length) – by 60ft (18.3 m) – parallel to ridge (side wall length). Lateral wind loads are assigned to the exterior wall lines by the tributary area method. Torsion is not considered since the horizontal diaphragm is considered flexible in comparison with the concrete shear walls in using the more conservative tributary area load distribution method. Therefore, only Case A is considered in Figure 6-4 of ASCE 7-98 [B1] as is typical for residential design practice.

### B5.1.1 Determine the Velocity Pressure

$$q_h = 0.00256 K_z K_{zt} K_d V^2 I = (0.00256)(1.01)(1.0)(1.0)(90mph)^2(1.00) = 20.94 psf \quad [998.8\ Pa]$$

The value above corresponds to the value of 21 psf (1.0 kN/m$^2$) in the *Prescriptive Method* (Table 5.1).

Note: A $K_d$ factor of 1.0 is used for concrete design in accordance with the *International Building Code*, Section 1605.2.1 [B7].

### B5.1.2 Determine the In-Plane Shear Load

Using Figure 6-4 from ASCE 7-98 [B1].

a: Smaller of 10 percent of least building plan dimension (0.1*40ft =4ft) or 0.4*height of the building (0.4*35ft=14ft), but not less than 4% of least horizontal dimension (0.04(40ft) = 1.6 ft) or 3ft (0.9m).

Therefore a = 4ft [1.2 m]

For 6:12 roof pitch, the roof angle = $\tan^{-1}(6/12)$ = 26.6 degrees. Determine the external pressure coefficient through interpolation of Table 6-4 of ASCE 7-98 [B1]. The results of interpolation are shown below.

| Pitch | θ | Zones | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 1E | 2E | 3E | 4E |
| 6:12 | 26.6 | 0.550 | -0.099 | -0.447 | -0.391 | 0.728 | -0.190 | -0.585 | -0.535 |
| 0:12 | 0.0 | 0.400 | X | X | -0.290 | 0.610 | X | X | -0.430 |

Source: ASCE 7-98 Table 6-4 [B1]

#### B5.1.2.1 Wind Perpendicular to Ridge (building orientation of 0 degrees)

Determine Net External Pressure Coefficients * Surface Area

Walls

$$\sum(GC_{pf}) * Surface\ Area$$
$$= 0.5[10ft[0.550(22ft) + 0.728(8ft)] - 10ft[-0.391(22ft) - 0.535(8ft)]]$$
$$= 154.03ft^2$$

Roof

$$\sum(GC_{pf}) * Surface\ Area$$
$$= \left(\frac{20ft}{\cos 26.6}\right)(-0.099(22ft) - 0.190(8ft) + 0.447(22ft) + 0.585(8ft))\sin 26.6$$
$$= 108.32ft^2$$

Since the contribution from the roof is positive, it is included. This is true for all roof slopes greater than approximately 5:12 in accordance with Figure 6-4 of ASCE 7-98 [B1].

Determine Wind Load (40 ft End Wall)

$$V_{parallel} = q_h \sum(GC_{pf}) x\, Surface\, Area = (20.94psf)(154.03ft^2 + 108.32ft^2) = 5{,}494lb \qquad [24.4\ kN]$$

$$V_u = 1.3(5{,}494lb) = 7{,}142lb \qquad [31.7\ kN]$$

#### B5.1.2.2 Wind Parallel to Ridge (building orientation rotated 90 degrees)

Determine Net External Pressure Coefficients *x* Surface Area

Walls

$$\sum(GC_{pf}) * Surface\ Area$$
$$= 0.5[10ft[0.400(12ft) + 0.610(8ft)] - 10ft[-0.290(12ft) - 0.430(8ft)]] \qquad [7.7\ m^2]$$
$$= 83.0ft^2$$

Gable end portion of wall. Use roof slope equal to zero to determine coefficients.

$$\sum(GC_{pf}) * Surface\ Area$$

$$= \frac{1}{2}\left(\frac{6}{12}\right)(8ft)(8ft)(0.610+0.430) + \left(\frac{6}{12}\right)(8ft)(12ft)(0.400+0.290)$$

$$+ \frac{1}{2}\left(\frac{6}{12}\right)(12ft)(12ft)(0.400+0.290)$$

$$= 74.6ft^2$$

Total external pressure coefficients weighted by tributary surface area:

$$=83.0ft^2 + 74.6ft^2 = 157.6ft^2 \quad [14.6\ m^2]$$

Determine Wind Load (60 ft Side Wall)

$$V_{parallel} = q_h \sum(GC_{pf}) = (20.94psf)(157.6ft^2) = 3{,}300lb \quad [14.7\ kN]$$

$$V_u^- = 1.3(3{,}300lb) = 4{,}290lb \quad [19.1\ kN]$$

### B5.2 Minimum Length of Solid Wall Along Exterior 6-Inch- (152-mm-) Thick Waffle-Grid ICF Above-Grade Wall

A waffle-grid ICF above-grade wall is selected from Table 5.3A of the *Prescriptive Method* for above-grade walls. The building is constructed in an area where the wind speeds equate to a velocity pressure of 21 psf (1.0 kPa) in Table 5.1 and is located in Seismic Design Category B. The above-grade wall is 9 feet (2.7 m) high and supports a light-frame roof only. Consider a building where the side wall length (parallel to ridge) is 60 ft (18.3 m) and the building end wall length (perpendicular to ridge) is 40 ft (9.1 m). Assume the building has a 6:12 roof slope. Through interpolation, Table 5.3A of the *Prescriptive Method* shows that a minimum length of solid wall of 5.7 ft (1.7 m) is required. Calculate the capacity and check the adequacy of the 6-inch- (152-mm-) thick waffle-grid ICF load-bearing above-grade wall for parallel shear.

The tables in Sections 3.0 and 4.0 are based on ICF walls without door or window openings. This simplified approach rarely arises in residential construction since walls generally contain windows and doors. The amount of openings affects the lateral (racking) strength of the building, particularly for wind and seismic loading conditions. The *Prescriptive Method* provides recommendations for the amount and placement location of additional reinforcement required around openings. It also addresses the minimum amount of solid wall required to resist racking loads from wind and moderate seismic forces.

The values for the minimum required length of solid wall along exterior wall lines listed in Table 5.2 through Table 5.4 of the *Prescriptive Method* were calculated using the main wind force resisting wind loads in accordance with ASCE 7 [B1]. The ICF walls were checked using resistance models for multiple building dimensions.

A shear model following the methods outlined in the *Uniform Building Code* (UBC) regarding shear wall design was used. This method linearly varies the resistance of a wall from a cantilevered beam model at an aspect ratio (height over width) of 4 to a solid shear wall for all segments greater than 2. All walls are required to have a minimum 2 ft solid wall adjacent to all corners. This methodology was also confirmed in the research conducted at the NAHB Research Center, Inc. entitled *In-Plane Shear Resistance of Insulating Concrete Form Walls* [B9].

Therefore, for conservative analysis purposes, the two foot corner elements were considered flexural elements and included their resistance in determining the shear wall capacity. The amount of solid wall required includes the contribution of minimum 2ft (0.6 m) corners plus additional length of solid wall to meet the design wind or seismic load.

### B5.2.1 ASCE 7 Wind Loads

The in-plane shear loads were determined previously in Section 5.1 of the Technical Substantiation.

$$V_u = 1.3(5{,}494lb) = 7{,}142lb \qquad [31.8\text{ kN}]$$

### B5.2.2 Concrete Resistance

Shear Elements

$$\phi V_c = \phi 2\sqrt{f'_c}\,hbx = 0.85(2)\sqrt{2{,}500psi}(5in)(6.25in/ft)x = (2{,}656lb/ft)x \qquad [1.9\text{ kN/m}]x$$

Flexural Elements (Corners)

Calculate the depth of the compressive stress block.

$$a = \frac{A_s f_y}{0.85 f'_c h} = \frac{(0.20in^2)(40ksi)}{(0.85)(2.5ksi)(6.25in)} = 0.60in \qquad [19.1\text{ mm}]$$

Calculate the nominal moment strength.

$$M_n = A_s f_y\left(d - \frac{a}{2}\right) = (0.20in^2)(40ksi)\left(24in - 4in - \frac{0.6in}{2}\right)(1000lb/kip) = 157{,}600in-lb \qquad [17.7\text{ MN}-\text{m}]$$

Calculate the factored shear force from the bending moment:

$$\phi V_m = \phi M_u / h = (0.9)(157{,}600in-lb)/(9ft)(12in/ft) = 1{,}313lb \qquad [5.8\text{ kN}]$$

Determine Required Wall Length

The total shear in the wall line is resisted by the 2 corners and "x" length of shear panels.

$$V_u \leq 2(\phi V_m) + x(\phi V_c)$$

$$x = \frac{V_u - 2(\phi V_m)}{\phi V_c} = \frac{7{,}142 lb/ft - 2(1{,}313 lb)}{2{,}656 lb/ft} = 1.7 ft \qquad [0.5\ m]$$

Total wall length = 2 ft corner + 2 ft corner + 1.7 ft = 5.7 ft as shown in Table 5.3A through interpolation of the highlighted values.

The required minimum solid wall lengths were determined in this manner and are listed in Table 5.2 through 5.4.

**TABLE 5.3A**
**MINIMUM SOLID END WALL LENGTH**
**REQUIREMENTS FOR WAFFLE-GRID ICF WALLS**
**FOR WIND PERPENDICULAR TO RIDGE [1,2,5,4,5]**
**(excerpt from the *Prescriptive Method*)**

| Design Velocity Pressure (psf) | | | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 60 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Wall Category** | **Building Side Wall Length, L (feet)** | **Roof Slope** | **Minimum Solid Wall Length on Building End Wall** | | | | | | | |
| One Story/ Top Story of Two Story | 16 | ≤ 1:12 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.25 |
| | | 5:12 | 4.00 | 4.00 | 4.00 | 4.00 | 4.25 | 4.25 | 4.50 | 4.75 |
| | | 7:12 | 4.00 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 6.00 |
| | | 12:12 | 4.50 | 4.75 | 5.00 | 5.50 | 5.75 | 6.00 | 6.50 | 7.00 |
| | 24 | ≤ 1:12 | 4.00 | 4.00 | 4.00 | 4.00 | 4.25 | 4.25 | 4.50 | 4.75 |
| | | 5:12 | 4.00 | 4.00 | 4.25 | 4.25 | 4.50 | 4.75 | 4.75 | 5.25 |
| | | 7:12 | 4.50 | 4.75 | 5.25 | 5.50 | 5.75 | 6.25 | 6.50 | 7.25 |
| | | 12:12 | 5.00 | 5.50 | 6.00 | 6.50 | 7.00 | 7.50 | 7.75 | 8.75 |
| | 32 | ≤ 1:12 | 4.00 | 4.00 | 4.00 | 4.25 | 4.50 | 4.50 | 4.75 | 5.00 |
| | | 5:12 | 4.00 | 4.25 | 4.50 | 4.75 | 4.75 | 5.00 | 5.25 | 5.75 |
| | | 7:12 | 5.00 | 5.25 | 5.75 | 6.25 | 6.75 | 7.00 | 7.50 | 8.50 |
| | | 12:12 | 5.50 | 6.25 | 6.75 | 7.50 | 8.00 | 8.75 | 9.25 | 10.50 |
| | 40 | ≤ 1:12 | 4.00 | 4.00 | 4.25 | 4.50 | 4.75 | 5.00 | 5.00 | 5.50 |
| | | 5:12 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 5.75 | 6.25 |
| | | 7:12 | 5.25 | 5.75 | 6.25 | 7.00 | 7.50 | 8.00 | 8.50 | 9.50 |
| | | 12:12 | 6.25 | 7.00 | 7.75 | 8.50 | 9.25 | 10.00 | 10.75 | 12.25 |
| | 50 | ≤ 1:12 | 4.00 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.50 | 6.00 |
| | | 5:12 | 4.50 | 4.75 | 5.00 | 5.25 | 5.75 | 6.00 | 6.25 | 7.00 |
| | | 7:12 | 5.75 | 6.50 | 7.25 | 7.75 | 8.50 | 9.25 | 9.75 | 11.00 |
| | | 12:12 | 6.75 | 7.75 | 8.75 | 9.50 | 10.50 | 11.50 | 12.50 | 14.25 |
| | 60 | ≤ 1:12 | 4.25 | 4.50 | 4.75 | 5.00 | 5.25 | 5.75 | 6.00 | 6.50 |
| | | 5:12 | 4.75 | 5.25 | 5.50 | 5.75 | 6.25 | 6.50 | 7.00 | 7.75 |
| | | 7:12 | 6.25 | 7.25 | 8.00 | 8.75 | 9.50 | 10.25 | 11.00 | 12.75 |

## B5.3 Minimum Percentage of Solid Wall Length Along Exterior Above-Grade Walls for Seismic Design Categories C, $D_1$, and $D_2$

The amount of openings in a wall affects the lateral or in-plane shear (racking) strength of the building, particularly for wind and seismic loading conditions. The *Prescriptive Method* provides recommendations for the amount and placement location of additional reinforcement required around openings. It also addresses the minimum amount of solid wall required to safely resist racking loads from wind and seismic forces. In addition, minimum amounts of solid wall as a percentage of wall length were increased above calculated amounts to ensure that walls behaved as cantilevered structural concrete walls rather than a moment frame. This conservative adjustment, in part, is a result of in-plane shear tests of ICF walls with varying opening amounts [B9].

The values for the base percentage of solid wall length along exterior wall lines listed in Table 5.5 of the *Prescriptive Method* were calculated using seismic load provisions in accordance with the IBC [B7]. The ICF walls were checked using three resistance models for a 2:1 length-to-width building aspect ratio (the higher load for endwalls was used as the basis of loading for all walls). Each model considered a 15 psf (0.7 kPa) roof dead load, 10 psf (0.5 kPa) floor dead load, 10 psf (0.5 kPa) interior wall dead load, a 70 psf (3.3 kPa) ground snow load, and the weight of the ICF walls. Multiple models were used to bound the range of plausible designs due to the uncertainty of the performance of building under high seismic loads. The minimum reinforcement requirement for Seismic Design Categories C, $D_1$, and $D_2$ were used as required in ACI 318 Chapter 21 [B3] and the IBC [B7] for ordinary reinforced concrete shear walls (Seismic Design Category C) and special reinforced concrete shear walls (Seismic Design Categories $D_1$ and $D_2$).

Model 1

Model 1 considered the walls in Seismic Design Category C as ordinary reinforced concrete with a Response Modification Coefficient (R) of 4.5 and the walls in Seismic Design Category $D_1$ and $D_2$ as special reinforced concrete with a Response Modification Coefficient (R) of 5.5. The resistance of the walls were considered to have two-2 ft (0.6 m) wide flexural controlled elements at the corners of the building and a shear controlled element (minimum 4 ft length) somewhere along the wall line of interest.

Model 2

Model 2 considered the walls in Seismic Design Category C as ordinary reinforced concrete with a Response Modification Coefficient (R) of 4.5 and the walls in Seismic Design Category $D_1$ and $D_2$ as special reinforced concrete with a Response Modification Coefficient (R) of 5.5. The resistance of the walls were considered to be provided only by 2 ft (0.6 m) wide by 8 ft (2.4 m) tall flexural controlled elements (cantilevers) along the wall line.

Model 3

Model 3 considered a near elastic design using a Response Modification Coefficient (R) of 2.5 Seismic Design Categories C, $D_1$, and $D_2$ (even though the walls are reinforced as required for ordinary or special reinforced concrete walls). The resistance of the walls were considered to have shear controlled elements along the wall line.

All models considered a minimum concrete compressive strength of 2,500 psi (17.3 MPa) for Seismic Design Category C and 3,000 psi (20.7 MPa) for Seismic Design Category $D_1$ and $D_2$. A strength reduction factor for shear of 0.60 was used for Seismic Design Categories $D_1$ and $D_2$ in accordance with ACI 318 Section 9.3.4 [B3]. Figure B5.3.1 summarizes the loads on the building and Figure B5.3.2 summarizes the required percentages from each model. The models were used to bound the design of percent solid wall length for different levels of conservatism. The amount of reinforcement remains the same for each model and is in compliance with the provisions of ACI 318 – Chapter 21 for Special Reinforced Concrete Walls [B3]. The same resistance calculations were used to determine the required resistance of the wall line as those described in Section B5.2.2.

| Wall Type | Wall Supporting Light Frame Roof Only | | | Wall Supporting Light Frame Second Story and Light Frame Roof | | | Wall Supporting ICF Second Story and Light Frame Roof | | |
|---|---|---|---|---|---|---|---|---|---|
| | Model 1 | Model 2 | Model 3 | Model 1 | Model 2 | Model 3 | Model 1 | Model 2 | Model 3 |
| **Seismic Design Category C** | | | | | | | | | |
| Flat, 3.5 | 4,439 | 4,439 | 7,990 | 7,302 | 7,302 | 13,144 | 10,250 | 10,250 | 18,450 |
| Flat, 5.5 | 5,485 | 5,485 | 9,873 | 8,294 | 8,294 | 14,929 | 13,400 | 13,400 | 24,120 |
| Flat, 7.5 | 6,575 | 6,575 | 11,835 | 9,225 | 9,225 | 16,605 | 16,660 | 16,660 | 29,988 |
| Waffle, 6 | 4,952 | 4,952 | 8,914 | 7,687 | 7,687 | 13,837 | 11,788 | 11,788 | 21,218 |
| Waffle, 8 | 5,806 | 5,806 | 10,451 | 8,584 | 8,584 | 15,451 | 14,352 | 14,352 | 25,834 |
| Screen, 6 | 4,824 | 4,824 | 8,683 | 7,558 | 7,558 | 13,604 | 11,405 | 11,405 | 20,529 |
| **Seismic Design Category $D_1$** | | | | | | | | | |
| Flat, 3.5 | 6,102 | 6,102 | 13,424 | 10,037 | 10,037 | 22,081 | 14,090 | 14,090 | 30,998 |
| Flat, 5.5 | 7,570 | 7,570 | 16,654 | 11,447 | 11,447 | 25,183 | 18,495 | 18,495 | 40,689 |
| Flat, 7.5 | 9,039 | 9,039 | 19,886 | 12,680 | 12,680 | 27,896 | 22,900 | 22,900 | 50,380 |
| Waffle, 6 | 6,807 | 6,807 | 14,975 | 10,565 | 10,565 | 23,243 | 16,204 | 16,204 | 35,649 |
| Waffle, 8 | 7,981 | 7,981 | 17,558 | 11,799 | 11,799 | 25,958 | 19,729 | 19,729 | 43,404 |
| Screen, 6 | 6,631 | 6,631 | 14,588 | 10,389 | 10,389 | 22,856 | 15,676 | 15,676 | 34,487 |
| **Seismic Design Category $D_2$** | | | | | | | | | |
| Flat, 3.5 | 8,543 | 8,543 | 18,795 | 14,052 | 14,052 | 30,914 | 19,726 | 19,726 | 43,397 |
| Flat, 5.5 | 10,599 | 10,599 | 23,318 | 16,026 | 16,026 | 35,257 | 25,893 | 25,893 | 56,965 |
| Flat, 7.5 | 12,654 | 12,654 | 27,839 | 17,752 | 17,752 | 39,054 | 32,060 | 32,060 | 70,532 |
| Waffle, 6 | 9,530 | 9,530 | 20,966 | 14,792 | 14,792 | 32,542 | 22,686 | 22,686 | 49,909 |
| Waffle, 8 | 11,174 | 11,174 | 24,583 | 16,519 | 16,519 | 36,342 | 27,620 | 27,620 | 60,764 |
| Screen, 6 | 9,283 | 9,283 | 20,423 | 14,545 | 14,545 | 31,999 | 21,946 | 21,946 | 48,281 |

**Figure B5.3.1 In-Plane Seismic Loads for Seismic Design Categories C, $D_1$, and $D_2$ for the Models Investigated**

| Wall Type | Wall Supporting Light Frame Roof Only | | | Wall Supporting Light Frame Second Story and Light Frame Roof | | | Wall Supporting ICF Second Story and Light Frame Roof | | |
|---|---|---|---|---|---|---|---|---|---|
| | Model 1 | Model 2 | Model 3 | Model 1 | Model 2 | Model 3 | Model 1 | Model 2 | Model 3 |
| **Seismic Design Category C** | | | | | | | | | |
| Flat, 3.5 | 1.3% | 9.6% | 7% | 4.0% | 15.9% | 12% | 6.7% | 22.3% | 17% |
| Flat, 5.5 | 1.4% | 11.8% | 6% | 3.1% | 17.8% | 9% | 6.1% | 28.8% | 14% |
| Flat, 7.5 | 1.5% | 14.1% | 5% | 2.7% | 19.8% | 7% | 5.9% | 35.7% | 13% |
| Waffle, 6 | 2.9% | 12.5% | 11% | 6.3% | 19.4% | 17% | 11.5% | 29.8% | 27% |
| Waffle, 8 | 2.5% | 14.6% | 8% | 4.7% | 21.6% | 12% | 9.4% | 36.1% | 21% |
| Screen, 6 | 2.4% | 11.0% | 11% | 6.0% | 17.2% | 18% | 11.0% | 25.9% | 27% |
| **Seismic Design Category $D_1$** | | | | | | | | | |
| Flat, 3.5 | 3.7% | 13.3% | 16% | 8.4% | 21.8% | 27% | 13.3% | 30.6% | 37% |
| Flat, 5.5 | 3.4% | 16.3% | 13% | 6.4% | 24.6% | 19% | 11.8% | 39.8% | 31% |
| Flat, 7.5 | 3.3% | 19.4% | 11% | 5.4% | 27.2% | 16% | 11.2% | 49.1% | 28% |
| Waffle, 6 | 6.8% | 17.2% | 24% | 12.9% | 26.7% | 38% | 22.0% | 40.9% | 58% |
| Waffle, 8 | 5.5% | 20.1% | 18% | 9.5% | 29.7% | 27% | 17.7% | 49.6% | 45% |
| Screen, 6 | 6.2% | 15.1% | 24% | 12.5% | 23.6% | 38% | 21.4% | 35.6% | 58% |
| **Seismic Design Category $D_2$** | | | | | | | | | |
| Flat, 3.5 | 6.6% | 18.6% | 23% | 13.3% | 30.5% | 37% | 20.1% | 42.8% | 52% |
| Flat, 5.5 | 5.8% | 22.8% | 18% | 9.9% | 34.5% | 27% | 17.5% | 55.7% | 44% |
| Flat, 7.5 | 5.4% | 27.1% | 16% | 8.2% | 38.0% | 22% | 16.3% | 68.7% | 40% |
| Waffle, 6 | 11.2% | 24.1% | 34% | 19.7% | 37.3% | 53% | 32.5% | 57.3% | 81% |
| Waffle, 8 | 8.8% | 28.1% | 25% | 14.4% | 41.5% | 38% | 25.8% | 69.4% | 63% |
| Screen, 6 | 10.6% | 21.1% | 34% | 19.5% | 33.0% | 54% | 31.9% | 49.8% | 81% |

**Figure B5.3.2 Minimum Required Percentages of Solid Wall Length for Seismic Design Categories C, $D_1$, and $D_2$ for the Models Investigated**

The values in Figure B5.3.2 were examined for each wall type, model and Seismic Design Category. The wall type has little affect on the percentage of solid wall length required. Although the resistance increases as the thickness of the walls increase, so does the weight and therefore seismic load on the wall line. Therefore, a single minimum percentage was chosen for each category regardless of wall type. The percentage solid wall length found in the *Prescriptive Method* Table 5.5 also factors in the results of full-scale ICF wall tests with openings [B9]. This testing indicates unfavorable failure modes related to cracks that initiated at corners of openings for walls with small percentages of solid wall length. Therefore, the simplified values in Table 5.5 were generally chosen to be conservative relative to the testing and analysis to ensure adequate strength and ductility and to prevent moment frame behavior of walls intended to behave as cantilevered structural concrete walls. In addition, the added requirement of a minimum shear wall segment length of 4 feet was applied to buildings in Seismic Design Categories $D_1$ and $D_2$.

## B5.4 ICF Lintel Design Examples and Engineering Calculations

The following engineering calculations are provided as supplemental information to illustrate the means and methods for the development of the tables included in the *Prescriptive Method*. Structural calculations illustrate the method for calculating the reinforcement requirements and adjustment factors used within the tables. The example calculations are not intended to be inclusive of all design considerations for a given application, but rather are intended to illustrate the derivation of the tables in the *Prescriptive Method*.

### B5.4.1 Flat ICF Lintel Design without Stirrups in a Load-Bearing ICF Wall

A flat ICF lintel is selected from Table 5.7 of the *Prescriptive Method* for lintels supporting a light frame second floor and a light-frame roof and subjected to a 30 psf (1.4 kPa) ground snow load. The lintel's nominal thickness is 5.5 inches (140 mm), with a depth of 20 inches (508 mm). A building with a 32 ft (9.8 m) floor and roof clear span is considered. Table 5.7 shows that the lintel without stirrups and a minimum No. 4 bar has a maximum clear span of 6'-0" (1.8 m). Calculate the capacity and check the adequacy of the 5.5-inch x 20-inch (140-mm x 508-mm) flat ICF lintel.

#### B5.4.1.1 Maximum Allowable Span Due to Bending Moment

$$M_u = \phi M_n$$

$$\phi M_n = \phi A_s f_y \left(d - \frac{a}{2}\right)$$

$$\phi = 0.9 \ \textit{(strength reduction factor)}$$

Calculate the reinforcement ratio for one No. 4 bottom bar.

$$\rho = \frac{A_s}{A_c} = \frac{0.20 in^2}{(5.5 in)(18 in)} = 0.0020$$

$$\rho_b = \frac{0.85 f'_c \beta_1}{f_y}\left(\frac{87{,}000}{f_y + 87{,}000}\right) = \frac{0.85(2{,}500\,psi)(0.85)}{40{,}000\,psi}\left(\frac{87{,}000}{40{,}000\,psi + 87{,}000}\right) = 0.0309$$

$$\rho_{max} = 0.75\rho_b = 0.75(0.0309) = 0.0232$$

$$\rho_{min} = 0.0012$$

$$Since\ \rho_{max} \ge \rho_b \ge \rho_{min}\ OK.$$

Calculate the depth of the compressive stress block.

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{(0.20 in^2)(40 ksi)}{(0.85)(2.5 ksi)(5.5 in)} = 0.62\,in \qquad [15.7\ mm]$$

Calculate the nominal moment strength.

$$M_n = A_s f_y\left(d - \frac{a}{2}\right) = (0.2 in^2)(40 ksi)\left(18 in - \frac{0.62 in}{2}\right) = 142 in - kip \qquad [15.9\ kN\text{-}m/m]$$

Calculate the factored bending moment.

$$M_u = \phi M_n = (0.9)(142 in - kip)/12 = 10.7 ft - kip$$ [14.4 *kN-m*]

Calculate the load on the lintel.

| | | | |
|---|---|---|---|
| *Live Loads* | | | |
| | *Snow* = (0.7)(30 *psf*) | = 21 *psf* | [1.01 *kPa*] |
| | *Floor* | = 30 *psf* | [1.44 *kPa*] |
| | *Attic* | = 20 *psf* | [0.96 *kPa*] |
| | *Total Live* | = 71 *psf* | [3.40 *kPa*] |
| *Dead Loads* | *Roof* | = 15 *psf* | [0.72 *kPa*] |
| | *Floor* | = 10 *psf* | [0.48 *kPa*] |
| | *Total Dead* | = 25 *psf* | [1.20 *kPa*] |
| | *Wall* | = 80 *plf* | [1.16 *kPa*] |

*Factored Load* = ((71 *psf*)(1.7) + (25 *psf*)(1.4))(32 *ft*)/(1000)(2) + (80 *plf*)(1.4)/(1000)+ (5.5 in)(20 in)(0.150 kcf)(1.4)/(144$in^2/ft^2$) =2.76 *klf* [40.6 *kN/m*]

Calculate the allowable span. Since the lintel is monolithic with the wall both ends are considered fixed.

$$M = \frac{wl^2}{12} \Rightarrow l = \sqrt{\frac{12M}{w}} = \sqrt{\frac{(12)(10.6 ft - kip)}{2.76 klf}} = 6.78 ft = 6' - 9"$$ [2.1 *m*]

### B5.4.1.2 Maximum Allowable Span Due to Shear

$V_u = \phi V_n$

$V_n = V_c + V_s$

$V_s = 0$ since there are no stirrups present

$\phi = 0.85$ *(strength reduction factor)*

Calculate the load on the lintel (see calculations in Section B5.4.1.1)

*Factored Load* = 2.76 *klf* [40.6 *kN/m*]

Determine shear strength of the concrete. The following design recommendations summarized in the report entitled *Testing and Design of Lintels Using Insulating Concrete Forms* [B11] were used in the lintel shear calculations throughout the *Prescriptive Method.*

Flat ICF Lintels

(1) Require a minimum amount of tensile reinforcing steel, $A_{s,min}$, determined by the lesser of:

- $A_{s,min} = 0.2\ \text{in}^2$ [129.0 mm²]
- $A_{s,\min} = \dfrac{3\sqrt{f'_c}\,b_w d}{f_y} \geq \dfrac{200 b_w d}{f_y}$ ACI Equation 10-3

(2) If the area of tensile reinforcing steel, $A_s$, is greater than the minimum calculated using ACI 318 Equation 10-3 and the beam has a span-to-depth ratio ($l_n/D$) of less than 5, calculate the shear capacity using the deep beam provisions, ACI 318 Equation 11-29. Use ACI Equations 11-3 or 11-5 to determine the shear capacity for all other scenarios.

(3) Use shear reinforcement (stirrups) as required by *ACI 318-99*. The study [B11] was unable to draw conclusive recommendations regarding any change to limits for shear reinforcement requirements, particularly when shear reinforcement is necessary in longer span members.

Waffle-Grid ICF Lintels

(1) Require a minimum amount of tensile reinforcing steel, $A_{s,min}$, determined by the lesser of:

- $A_{s,min} = 0.2\ \text{in}^2$ [129.0 mm²]
- $A_{s,\min} = \dfrac{3\sqrt{f'_c}\,b_w d}{f_y} \geq \dfrac{200 b_w d}{f_y}$ ACI Equation 10-3

(2) If the beam has a span-to-depth ratio ($l_n/D$) of less than 5, calculate the shear capacity using the deep beam provisions, ACI 318 Equation 11-29, with an effective web thickness of 3.2 in (81.3 mm).

If the beam has a span-to-depth ratio ($l_n/D$) of greater than 5, calculate the shear capacity with an effective web thickness of 2.6 in (66.0 mm) using ACI 318 Equation 11-3 or an effective web thickness of 2.0 in (50.8 mm) in ACI Equation 11-5.

(3) Use shear reinforcement (stirrups) as required by *ACI 318-99*. The study [B11] was unable to draw conclusive recommendations regarding any change to limits for shear reinforcement requirements, particularly when shear reinforcement is necessary in longer span members.

Screen-Grid ICF Lintels

(1) Require a minimum amount of tensile reinforcing steel, $A_{s,min}$, determined by the lesser of:

- $A_{s,min} = 0.2\ in^2$ [129.0 mm²]
- $A_{s,\min} = \frac{3\sqrt{f'_c}b_w d}{f_y} \geq \frac{200 b_w d}{f_y}$ ACI Equation 10-3

(2) If the beam has a span-to-depth ratio ($l_n/D$) of less than 5, calculate the shear capacity using the deep beam provisions, ACI 318 Equation 11-29, with an effective web thickness of 2.0 in (81.3 mm) for lintels with depths 24 in (609.6 mm) or greater, and an effective web thickness of 0.9 in (22.9 mm) for lintels with depths less than 24 in (609.6 mm).

If the beam has a span-to-depth ratio ($l_n/D$) of greater than 5, calculate the shear capacity with an effective web thickness of 2.2 in (55.8 mm) using ACI 318 Equation 11-3 or ACI Equation 11-5.

According to the above design methodology two scenarios should be checked:

Scenario 1: The span-to-depth ratio ($l_n/D$) is greater than or equal to 5 (not a deep beam according to ACI 318) or the amount of tensile reinforcement ($A_{s,min}$) is less than:

$$A_{s,\min} < MAX\left(\frac{3\sqrt{f'_c}b_w d}{f_y}, \frac{200 b_w d}{f_y}\right) \quad \text{ACI Equation 10-3}$$

Scenario 2: The span-to-depth ratio ($l_n/D$) is less than 5 (deep beam according to ACI) and the amount of tensile reinforcement ($A_{s,min}$) is greater than or equal to:

$$A_{s,\min} \geq MAX\left(\frac{3\sqrt{f'_c}b_w d}{f_y}, \frac{200 b_w d}{f_y}\right) \quad \text{ACI Equation 10-3}$$

If the area of tensile reinforcing steel, $A_s$, is greater than the minimum calculated using ACI 318 Equation 10-3 and the beam has a span-to-depth ratio ($l_n/D$) of less than 5 (Scenario 2), calculate the shear capacity using the deep beam provisions, ACI 318 Equation 11-29. Use ACI Equations 11-3 or 11-5 to determine the shear capacity for all other scenarios [B10].

Check the area of steel.

$A_s = 0.2\ in^2$ [1.3 $cm^2$]

$$\frac{3\sqrt{f'_c}b_w d}{f_y} = \frac{3\sqrt{2{,}500psi}(5.5in)(18in)}{40{,}000psi} = 0.371in^2 \qquad [2.4\ cm^2]$$

$$\frac{200b_w d}{f_y} = \frac{200(5.5in)(18in)}{40{,}000psi} = 0.495in^2 \qquad [3.2\ cm^2]$$

Since $A_{s,min} < 0.495$ in$^2$ analyze using Scenario 1.

Use ACI Equation 11-3 to determine shear capacity of the section.

$$V_c = 2\sqrt{f'_c}b_w d = 2\sqrt{2{,}500psi}(5.5in)(18in) = 9.9kips \qquad [44.0\ kN]$$

$$\frac{1}{2}\phi V_c = (0.85)(9.9kip)/2 = 4.2kips \qquad [18.8\ kN]$$

Determine the maximum shear force.

$$V_u = \frac{wl}{2} = \frac{(2.76klf)l}{2} = (1.38klf)l$$

Determine the critical shear force.

$$Critical\ V_u = \frac{wl}{2} - wd = (1.38klf)l - (2.76klf)(18in)/(12in/ft) = (1.38klf)l - 4.14k$$

Solve for the span.

$$\frac{1}{2}\phi V_c = Critical\ V_u \Rightarrow 4.2kips = (1.38klf)l - 4.1kips \Rightarrow l = 6.01ft = 6'\text{–}00'' \qquad [1.83m]$$

### B5.4.1.3 Maximum Allowable Span Due to Deflection

Calculate the load on the lintel.

| | | | |
|---|---|---|---|
| *Live Loads* | | | |
| | *Snow* = (0.7)(30 *psf*) | = 21 *psf* | [1.01 *kPa*] |
| | *Floor* | = 30 *psf* | [1.44 *kPa*] |
| | *Attic* | = 20 *psf* | [0.96 *kPa*] |
| | *Total Live* | = 71 *psf* | [3.40 *kPa*] |
| *Dead Loads* | *Roof* | = 15 *psf* | [0.72 *kPa*] |
| | *Floor* | = 10 *psf* | [0.48 *kPa*] |
| | *Total Dead* | = 25 *psf* | [1.20 *kPa*] |
| | *Wall* | = 80 *plf* | [1.16 *kPa*] |

*Unfactored load (used in deflection calculations)*

$$=(71\ psf + 25\ psf)(32\ ft)/(2) + (5.5\ in)(20\ in)(150\ pcf)/(144in^2/ft^2) = 1{,}651plf \qquad [24.0\ kN/m]$$

Deflection limit of lintel

$$\Delta = \frac{l}{240}$$

Deflection of lintel

$$\Delta = \frac{wl^4}{(0.1)384EI}$$

Calculate moment of inertia, *I*.

$$I = \frac{bh^3}{12} = \frac{5.5(20)^3}{12} = 3{,}667in^4$$ [$1.52 \times 10^5\ cm^4$]

Calculate the allowable span.

$$\frac{l}{240} = \frac{wl^4}{(0.1)384EI} \Rightarrow l = \sqrt[3]{\frac{(0.1)384EI}{240w}} =$$

$$= \sqrt[3]{\frac{(0.1)(384)(3{,}122{,}000psi)(3{,}667in^4)}{(240)(1{,}651plf)(144in^2)}} = 19.75ft = 19'\text{–}9"$$

**B5.4.1.4 Governing Design**

A 5.5-inch x 20-inch (140-mm x 508-mm) flat ICF lintel in a load-bearing wall with one No. 4 or one No. 5 bottom bar may span a maximum of 6'-0" (1.8 m) due to shear limitations with no stirrups required. From Table 5.7 of the *Prescriptive Method* we also obtain a maximum clear span of 6'-0" (1.8 m).

**TABLE 5.7**
**MAXIMUM ALLOWABLE CLEAR SPANS FOR**
**ICF LINTELS WITHOUT STIRRUPS IN LOAD-BEARING WALLS[1,2,3,4,5,6]**
**NO. 4 OR NO. 5 BOTTOM BAR SIZE**
**(excerpt from the *Prescriptive Method*)**

| Minimum Lintel Thickness, T (inches) | Minimum Lintel Depth, D (inches) | Maximum Clear Span (feet – inches) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Supporting Light-Frame Roof Only | | Supporting Light-Frame Second Story and Roof | | Supporting ICF Second Story and Light-Frame Roof [7] | |
| | | Maximum Ground Snow Load (psf) | | | | | |
| | | 30 | 70 | 30 | 70 | 30 | 70 |
| Flat ICF Lintel | | | | | | | |
| 3.5 | 8 | 2-6 | 2-6 | 2-6 | 2-4 | 2-5 | 2-2 |
| | 12 | 4-2 | 4-2 | 4-1 | 3-10 | 3-10 | 3-7 |
| | 16 | 4-11 | 4-8 | 4-6 | 4-2 | 4-2 | 3-10 |
| | 20 | 6-3 | 5-3 | 4-11 | 4-6 | 4-6 | 4-3 |
| | 24 | 7-7 | 6-4 | 6-0 | 5-6 | 5-6 | 5-2 |
| 5.5 | 8 | 2-10 | 2-6 | 2-6 | 2-6 | 2-6 | 2-6 |
| | 12 | 4-8 | 3-8 | 3-4 | 3-0 | 3-0 | 2-9 |
| | 16 | 6-5 | 5-1 | 4-8 | 4-2 | 4-3 | 3-10 |
| | 20 | 8-2 | 6-6 | 6-0 | 5-4 | 5-5 | 5-0 |
| | 24 | 9-8 | 7-11 | 7-4 | 6-6 | 6-7 | 6-1 |

## B5.4.2 Waffle-Grid ICF Lintel Design with Stirrups in a Load-Bearing ICF Wall

A waffle-grid ICF lintel is selected from existing Table 5.9B of the *Prescriptive Method* for lintels supporting light-frame roofs and subjected to a 70 psf (3.3 kPa) ground snow load. The lintel's nominal thickness is 6 inches (152.4 mm), with a depth of 20 inches (508 mm). Table 5.9B shows that the lintel has a maximum clear span of 9' – 1" (2.8 m). Calculate the capacity for the 6-inch x 20-inch (152.4-mm x 508 mm) waffle-grid ICF lintel assuming a 32 ft (9.8 m) building width.

### B5.4.2.1 Maximum Allowable Span Due to Bending Moment

$$M_u = \phi M_n$$

$$\phi M_n = \phi A_s f_y \left(d - \frac{a}{2}\right)$$

$\phi = 0.9$ *(strength reduction factor)*

Calculate the depth of the compressive stress block.

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{(0.31 in^2)(40 ksi)}{(0.85)(2.5 ksi)(5 in)} = 1.17 in$$ [29.7 *mm*]

Calculate the nominal moment strength.

$$M_n = A_s f_y \left( d - \frac{a}{2} \right) = (0.31 in^2)(40\ ksi)\left( 18 in - \frac{1.17 in}{2} \right) = 216 in - kip$$ [24.4 *mm*]

Calculate the factored bending moment.

$$M_u = \phi M_n = (0.9)(216 in - kip)/12 = 16.2\ ft - kip$$ [22 *kN-m*]

Calculate the load on the lintel.

| | | | |
|---|---|---|---|
| *Live Loads* | | | |
| | *Snow* = (0.7)(70 *psf*) | = 49 *psf* | [2.3 *kPa*] |
| | *Attic* | = 20 *psf* | [0.96 *kPa*] |
| | *Total Live* | = 69 *psf* | [3.4 *kPa*] |
| *Dead Loads* | *Roof* | = 15 *psf* | [0.72 *kPa*] |
| | *Total Dead* | = 15 *psf* | [0.72 *kPa*] |

*Factored Load* = ((69 *psf*)(1.7) + (15 *psf*)(1.4))(32 *ft*)/(1000)(2) + (20 *in*/16 *in*)(0.500 $ft^2$)(0.150 kcf)(1.4) =2.34 *klf* [34 *kN/m*]

*Note: 0.50 sf (0.05 $m^2$) of concrete fills one linear foot of waffle-grid form.*

Calculate the allowable span. Since the lintel is monolithic with the wall both ends are considered fixed.

$$M = \frac{wl^2}{12} \Rightarrow l = \sqrt{\frac{12M}{w}} = \sqrt{\frac{(12)(16.2 ft - kip)}{2.34 klf}} = 9.11 ft = 9'-1''$$

## B5.4.2.2 Maximum Allowable Span Due to Deflection

Calculate the load on the lintel.

| | | | |
|---|---|---|---|
| *Live Loads* | | | |
| | *Snow* = (0.7)(70 *psf*) | = 49 *psf* | [2.3 *kPa*] |
| | *Attic* | = 20 *psf* | [0.96 *kPa*] |
| | *Total Live* | = 69 *psf* | [3.4 *kPa*] |
| *Dead Loads* | *Roof* | = 15 *psf* | [0.72 *kPa*] |
| | *Total Dead* | = 15 *psf* | [0.72 *kPa*] |

*Unfactored load (used in deflection calculations)*

$=(69\ psf + 15\ psf)(32\ ft)/(2) + (20\ in/16\ in)(0.50\ sf)(150\ pcf) = 1{,}438\ plf$ [20.9 $kN/m$]

Deflection limit of lintel.

$$\Delta = \frac{l}{240}$$

Deflection of lintel

$$\Delta = \frac{wl^4}{(0.1)384EI}$$

Calculate moment of inertia, $I$.

Calculate $\bar{y}$ from bottom of lintel

$$\bar{y} = \frac{\sum A_i \bar{y}_i}{\sum A_i} = \frac{(5\,in)(4\,in)(18\,in) + (2\,in)(13\,in)(9.5\,in) + (5\,in)(3\,in)(1.5\,in)}{(5\,in)(4\,in) + (2\,in)(13\,in) + (5\,in)(3\,in)} = 10.32\,in$$

Calculate $I$.

$$I = \sum\left(\frac{b_i h_i^3}{12} + Ad^2\right) = \left(\begin{array}{l} \frac{(5\,in)(4\,in)^3}{12} + (5\,in)(4\,in)(7.7\,in)^2 \\ + \frac{(2\,in)(13\,in)^3}{12} + (2\,in)(13\,in)(0.82\,in)^2 \\ + \frac{(5\,in)(3\,in)^3}{12} + (5\,in)(3\,in)(8.82\,in)^2 \end{array}\right) = 2{,}768\,in^4$$ [1.15 x $10^5$ $cm^4$]

Calculate the allowable span.

$$\frac{l}{240} = \frac{wl^4}{(0.1)384EI} \Rightarrow l = \sqrt[3]{\frac{(0.1)384EI}{5(240)w}} =$$

$$= \sqrt[3]{\frac{(0.1)(384)(3{,}122{,}000\,psi)(2{,}768\,in^4)}{(240)(1{,}438\,plf)(144\,in^2)}} = 18.8\,ft = 18'\text{–}9"$$

*Since* 18'–8"> 9'–1", *bending moment governs span.*

### B5.4.2.3 Increased Span Length for 60ksi Reinforcing Steel

$$M_u = \phi M_n$$

$$\phi M_n = \phi A_s f_y \left(d - \frac{a}{2}\right)$$

$\phi = 0.9$ *(strength reduction factor)*

Calculate the depth of the compressive stress block.

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{(0.31 in^2)(60 ksi)}{(0.85)(2.5 ksi)(5 in)} = 1.75 in$$ [44.4 *mm*]

Calculate the nominal moment strength.

$$M_n = A_s f_y \left(d - \frac{a}{2}\right) = (0.31 in^2)(60 ksi)\left(18 in - \frac{1.75 in}{2}\right) = 318.5 in - kip$$ [36.0 *kN-m*]

Calculate the factored bending moment.

$$M_u = \phi M_n = (0.9)(318.5 in - kip)/12 = 23.9 ft - kip$$ [32.5 *kN-m*]

Calculate the load on the lintel.

| | | | |
|---|---|---|---|
| *Live Loads* | | | |
| | *Snow* = (0.7)(70 *psf*) | = 49 *psf* | [2.3 *kPa*] |
| | *Attic* | = 20 *psf* | [0.96 *kPa*] |
| | *Total Live* | = 69 *psf* | [3.4 *kPa*] |
| *Dead Loads* | *Roof* | = 15 *psf* | [0.72 *kPa*] |
| | *Total Dead* | = 15 *psf* | [0.72 *kPa*] |

*Factored Load* = ((69 *psf*)(1.7) + (15 *psf*)(1.4))(32 *ft*)/(1000)(2) + (20 *in*/16 *in*)(0.500 $ft^2$)(0.150 kcf)(1.4) =2.34 *klf* [34 *kN/m*]

*Note: 0.50 sf (0.05 $m^2$) of concrete fills one linear foot of waffle-grid form.*

Calculate the allowable span. Since the lintel is monolithic with the wall both ends are considered fixed.

$$M = \frac{wl^2}{12} \Rightarrow l = \sqrt{\frac{12M}{w}} = \sqrt{\frac{(12)(23.9 ft - kip)}{2.34 klf}} = 11.1 ft = 11'\text{-}1"$$

*Since* 18'-8"> 11'-1", *bending moment governs span.*

Determine percentage increase of 60ksi reinforcing steel vs. 40ksi reinforcing steel.

Percentage Increase $= \frac{11.08 - 9.08}{9.08}(100) = 22.0\% > 20\%$ allowed from Table 5.9B of the *Prescriptive Method.*

### B5.4.2.4 Determine Stirrup Requirements

$V_u = \phi V_n$

$V_n = V_c + V_s$

$\phi = 0.85$ *(strength reduction factor)*

Determine the maximum shear force on the lintel.

$$V_u = \frac{wl}{2} = \frac{(2.34klf)(9.08ft)}{2} = 10.6kips \qquad [47.1\ kN]$$

$$Critical\ V_u = V_u - wd = 10.6kips - (2.34k/ft)(18in)/(12in/ft) = 7.09kips \qquad [31.5\ kN]$$

Determine if lintel meets deep beam requirements.

$\frac{l_n}{d} = \frac{(9.08ft)(12)}{18} = 6.05 > 5$ therefore, according to the above design recommendations analyze using ACI Equation 11-3.

Determine if stirrups are required. An effective web width of 2.6 inches (66.0 mm) is suggested according to the above design recommendation for the 6-in waffle-grid [B10].

$$V_c = 2\sqrt{f_c'}b_w d = 2\sqrt{2{,}500psi}(2.6in)(18in) = 4.68kips \qquad [20.8\ kN]$$

$$\frac{1}{2}\phi V_c = (0.85)(4.68kip)/2 = 1.99kips \qquad [8.8\ kN]$$

*Since 7.09 kips > 1.99 kips, stirrups are required.*

Check required spacing of No. 3 vertical stirrup ($A_v = 0.22$ in$^2$ (142 mm$^2$)).

$$Required\ s = \frac{A_v f_y d}{V_u} = \frac{(0.22in^2)(40ksi)(18in)}{(7.09kip - 4.68kip)} = 65.7in \qquad [1.7\ m]$$

Maximum allowable spacing is $\frac{d}{2} = \frac{18in}{2} = 9in$

*Since 9 in < 65.7 in., the maximum allowable spacing governs*

Determine the middle portion of the span, A, where stirrups are not required.

$$A = span - 2\left(\frac{V_u - \frac{1}{2}\phi V_c}{w}\right) = 9.08ft - 2\left(\frac{10.6kips - 1.99kips}{2.34kip/ft}\right) = 1.72ft = 1ft - 8in \qquad [0.5\ m]$$

### B5.4.2.5 Governing Design

A 6-inch x 20-inch (152-mm x 508-mm) waffle-grid ICF lintel in a load-bearing wall with one No. 5 Grade 40 bottom bar may span a maximum of 9'-1" (2.8 m) due to bending limitations. However, if a No. 5 Grade 60 bottom bar is used a maximum span of 1.2(9'-1") = 10.9 ft = 10'-8" (3.3 m) is permitted according to the footnote in Table 5.9B of the *Prescriptive Method.* Stirrups are required in the lintel except for the middle portion of the span equaling 1'-8" (0.5 m). Table 5.13 of the Prescriptive Method also requires stirrups except for the middle portion of the span equaling 1'-8" (0.5 m).

**TABLE 5.9B**
**MAXIMUM ALLOWABLE CLEAR SPANS FOR**
**WAFFLE-GRID ICF LINTELS IN LOAD-BEARING WALLS[1,2,3,4,5,6,7]**
**NO. 5 BOTTOM BAR SIZE**
**(excerpt from the *Prescriptive Method*)**

| Minimum Lintel Thickness, T[8] (inches) | Minimum Lintel Depth, D (inches) | Maximum Clear Span (feet – inches) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Supporting Light-Frame Roof Only | | Supporting Light-Frame Second Story and Roof | | Supporting ICF Second Story and Light-Frame Roof[8] | |
| | | Maximum Ground Snow Load (psf) | | | | | |
| | | 30 | 70 | 30 | 70 | 30 | 70 |
| 6 | 8 | 5-4 | 4-8 | 4-5 | 4-1 | 4-5 | 3-10 |
| | 12 | 8-0 | 6-9 | 6-3 | 5-6 | 6-3 | 5-1 |
| | 16 | 9-9 | 8-0 | 7-5 | 6-6 | 7-5 | 6-1 |
| | 20 | 11-0 | **9-1** | 8-5 | 7-5 | 8-5 | 6-11 |
| | 24 | 12-2 | 10-0 | 9-3 | 8-2 | 9-3 | 7-8 |

**TABLE 5.13**
**MIDDLE PORTION OF SPAN (A) WHERE STIRRUPS ARE NOT REQUIRED FOR WAFFLE-GRID ICF LINTELS[1,2,3,4,5,6,7,8]**
**NO. 4 or NO. 5 BOTTOM BAR SIZE**
**(excerpt from the *Prescriptive Method*)**

| Minimum Lintel Thickness, T[9] (inches) | Minimum Lintel Depth, D (inches) | Maximum Center Distance, A (feet – inches) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Supporting Light-Frame Roof Only | | Supporting Light-Frame Second Story and Roof | | Supporting ICF Second Story and Light-Frame Roof[10] | |
| | | Maximum Ground Snow Load (psf) | | | | | |
| | | 30 | 70 | 30 | 70 | 30 | 70 |
| 6 or 8 | 8 | 0-10 | 0-7 | 0-5 | 0-4 | 0-5 | 0-4 |
| | 12 | 1-5 | 0-11 | 0-9 | 0-7 | 0-8 | 0-6 |
| | 16 | 1-11 | 1-4 | 1-1 | 0-10 | 0-11 | 0-9 |
| | 20 | 2-6 | 1-8 | 1-5 | 1-1 | 1-2 | 0-11 |
| | 24 | 3-0 | 2-0 | 1-9 | 1-4 | 1-5 | 1-2 |

### 5.4.3 Screen-Grid ICF Lintel Design in a Load-Bearing ICF Wall

A screen-grid ICF lintel is selected from Table 5.10A of the *Prescriptive Method* for lintels supporting an ICF second story and a light-frame roof and subjected to a 30 psf (1.4 kPa) ground snow load. The lintel's nominal thickness is 6 inches (152 mm), with a depth of 24 inches (610 mm). Table 5.10A shows that the lintel has a maximum clear span of 6'-11" (2.1 m). Calculate the bending capacity and deflection limit for the 6-inch x 24-in (152-mm x 610-mm) screen-grid ICF lintel. Assume a 32 ft (9.8 m) building width.

#### B5.4.3.1 Maximum Allowable Span Due to Bending Moment

$$M_u = \phi M_n$$

$$\phi M_n = \phi A_s f_y \left(d - \frac{a}{2}\right)$$

$\phi = 0.9$ *(strength reduction factor)*

Calculate the depth of the compressive stress block.

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{(0.20in^2)(40ksi)}{(0.85)(2.5ksi)(5.5in)} = 0.68in \qquad [17.3\ mm]$$

Calculate the nominal moment strength.

$$M_n = A_s f_y \left(d - \frac{a}{2}\right) = (0.20in^2)(40ksi)\left(22in - \frac{0.68in}{2}\right) = 173.3in - kip \qquad [19.5\ kN\text{-}m]$$

Calculate the factored bending moment.

$$M_u = \phi M_n = (0.9)(173.3 in-kip)/12 = 13.0 ft-kip$$ [17.7 *kN-m*]

Calculate the load on the lintel.

| | | | |
|---|---|---|---|
| *Live Loads* | | | |
| | *Snow* = (0.7)(30 *psf*) | = 21 *psf* | [1.00 *kPa*] |
| | *Attic* | = 20 *psf* | [0.96 *kPa*] |
| | *Floor* | = 30 *psf* | [1.44 *kPa*] |
| | *Total Live* | = 71 *psf* | [3.41 *kPa*] |
| *Dead Loads* | *Roof* | = 15 *psf* | [0.72 *kPa*] |
| | *Floor* | = 10 *psf* | [0.48 *kPa*] |
| | *Total Dead* | = 25 *psf* | [1.20 *kPa*] |
| | Wall | = (53 *psf*)(8 *ft*) = 424 *plf* | [6.2 *kN/m*] |

*Factored Load* = ((71 *psf*)(1.7) + (25 *psf*)(1.4))(32 *ft*)/(1000)(2) + (0.424 klf)(1.4) + (24 *in*/12 *in*)(0.053 *ksf*)(1.4) = 3.23 *klf* [47.0 *kN/m*]

*Note: 0.053 ksf is the weight of the concrete for screen-grid lintels.*

Calculate the allowable span; assume both ends are fixed.

$$M = \frac{wl^2}{12} \Rightarrow l = \sqrt{\frac{12M}{w}} = \sqrt{\frac{(12)(13.0 ft-kip)}{3.23 klf}} = 6.95 ft = 6'\text{-}11"$$ [2.1 *m*]

## B5.4.3.2 Maximum Allowable Span Due to Deflection

Calculate the load on the lintel.

| | | | |
|---|---|---|---|
| *Live Loads* | | | |
| | *Snow* = (0.7)(30 *psf*) | = 21 *psf* | [1.00 *kPa*] |
| | *Attic* | = 20 *psf* | [0.96 *kPa*] |
| | *Floor* | = 30 *psf* | [1.44 *kPa*] |
| | *Total Live* | = 71 *psf* | [3.41 *kPa*] |
| *Dead Loads* | *Roof* | = 15 *psf* | [0.72 *kPa*] |
| | *Floor* | = 10 *psf* | [0.48 *kPa*] |
| | *Total Dead* | = 25 *psf* | [1.20 *kPa*] |
| | Wall | = (53 *psf*)(8 *ft*) = 424 *plf* | [6.2 *kN/m*] |

*Factored Load* = ((71 *psf*)(1.7) + (25 *psf*)(1.4))(32 *ft*)/(1000)(2) + (0.424 klf)(1.4) + (24 *in*/12 *in*)(0.053 *ksf*)(1.4) = 3.23 *klf* [47.0 *kN/m*]

*Unfactored load (used in deflection calculations)*

=(71 *psf* + 25 *psf*)(32 *ft*)/(2) + (424 *plf*) + (24 *in*/12 *in*)(53 *psf*) = 2,066 *plf* [6.9 *kN/m*]

Deflection limit of lintel.

$$\Delta = \frac{l}{240}$$

Deflection of lintel.

$$\Delta = \frac{wl^4}{(0.1)384EI}$$

Calculate moment of inertia, *I*.

Calculate $\bar{y}$ from bottom of lintel.

$$\bar{y} = \frac{\sum A_i \bar{y}_i}{\sum A_i} = \frac{(5in)(2.5in)(22.75in) + (5in)(5in)(12.0in) + (5in)(2.5in)(1.25in)}{(5in)(2.5in) + (5in)(5in) + (5in)(2.5in)} = 12.00in \qquad [305\ mm]$$

Calculate $I$.

$$I = \sum\left(\frac{b_i h_i^3}{12} + Ad^2\right) = \left(\begin{array}{l} \frac{(5in)(2.5in)^3}{12} + (5in)(2.5in)(10.75in)^2 \\ + \frac{(5in)(5in)^3}{12} \\ + \frac{(5in)(2.5in)^3}{12} + (5in)(2.5in)(10.75in)^2 \end{array}\right) = 2{,}954.2in^4 \qquad [1.23 \times 10^5\ mm4]$$

Calculate the allowable span.

$$\frac{l}{240} = \frac{wl^4}{(0.1)384EI} \Rightarrow l = \sqrt[3]{\frac{(0.1)384EI}{(240)w}} =$$

$$= \sqrt[3]{\frac{(0.1)(384)(3{,}122{,}000psi)(2{,}954.2in^4)}{(240)(2{,}066plf)(144in^2)}} = 17.0ft = 17'\text{-}0"$$

*Since* 17'–0"> 6'–11", *bending moment governs span.*

### B5.4.3.3 Increased Span Length for 60ksi Reinforcing Steel

$$M_u = \phi M_n$$

$$\phi M_n = \phi A_s f_y\left(d - \frac{a}{2}\right)$$

$\phi = 0.9$ *(strength reduction factor)*

Calculate the depth of the compressive stress block.

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{(0.20 in^2)(60 ksi)}{(0.85)(2.5 ksi)(5.5 in)} = 1.03 in$$ [26.2 *mm*]

Calculate the nominal moment strength.

$$M_n = A_s f_y \left( d - \frac{a}{2} \right) = (0.20 in^2)(60 ksi)\left( 22 in - \frac{1.03 in}{2} \right) = 257.8 in - kip$$ [29.1 *kN-m*]

Calculate the factored bending moment.

$$M_u = \phi M_n = (0.9)(257.8 in - kip)/12 = 19.3 ft - in$$ [26.2 *kN-m*]

Calculate the load on the lintel.

| | | | |
|---|---|---|---|
| *Live Loads* | | | |
| | *Snow* = (0.7)(30 *psf*) | = 21 *psf* | [1.00 *kPa*] |
| | *Attic* | = 20 *psf* | [0.96 *kPa*] |
| | *Floor* | = 30 *psf* | [1.44 *kPa*] |
| | *Total Live* | = 71 *psf* | [3.41 *kPa*] |
| *Dead Loads* | *Roof* | = 15 *psf* | [0.72 *kPa*] |
| | *Floor* | = 10 *psf* | [0.48 *kPa*] |
| | *Total Dead* | = 25 *psf* | [1.20 *kPa*] |
| | Wall | = (53 *psf*)(8 *ft*) = 424 *plf* | [6.2 *kN/m*] |

*Factored Load* = ((71 *psf*)(1.7) + (25 *psf*)(1.4))(32 *ft*)/(1000)(2) + (0.424 klf)(1.4) + (24 *in*/12 *in*)(0.053 *ksf*)(1.4) = 3.23 *klf* [47.0 *kN/m*]

Calculate the allowable span; assume both ends are fixed.

$$M = \frac{wl^2}{12} \Rightarrow l = \sqrt{\frac{12M}{w}} = \sqrt{\frac{(12)(19.3 ft - kip)}{3.23 klf}} = 8.5 ft = 8'\text{–}6"$$

*Since* 17'–0"> 8'–6", *bending moment governs span for 60 ksi steel.*

Determine percentage increase of 60 ksi reinforcing steel vs. 40 ksi reinforcing steel.

Percentage Increase $= \frac{8.50 - 6.92}{6.92}(100) = 22.8\% > 20\%$ allowed from Table 5.10A of the *Prescriptive Method.*

### 5.4.4 Flat ICF Lintel Design in a Non Load-Bearing ICF Wall Without Stirrups

A flat ICF lintel in a non load-bearing wall is selected from Table 5.14 of the *Prescriptive Method* for lintels supporting an ICF second story. The lintel thickness is 5.5 inches (140 mm), with a depth of 12 inches (305 mm). Table 5.14 shows the lintel to have a maximum clear span of 7 feet (2.1 m). Calculate the capacity and check the adequacy of the 5.5-inch x 12-inch (140-mm x 305-mm) flat concrete lintel in a non load-bearing ICF wall.

#### B5.4.4.1 Maximum Allowable Span Due to Bending Moment

$$M_u = \phi M_n$$

$$\phi M_n = \phi A_s f_y \left(d - \frac{a}{2}\right)$$

$\phi = 0.9$ *(strength reduction factor)*

Calculate the reinforcement ratio for one No. 4 bar horizontal tensile steel.

$$\rho = \frac{A_s}{bd} = \frac{0.2 in^2}{(5.5in)(10in)} = 0.0036$$

$$\rho_b = \frac{0.85 f'_c \beta_1}{f_y}\left(\frac{87{,}000}{f_y + 87{,}000}\right) = \frac{0.85(2{,}500 psi)(0.85)}{40{,}000 psi}\left(\frac{87{,}000}{40{,}000 psi + 87{,}000}\right) = 0.0309$$

$$\rho_{max} = 0.75\rho_b = 0.75(0.0309) = 0.0232$$

$$\rho_{min} = 0.0012$$

*Since* $\rho_{max} \geq \rho_b \geq \rho_{min}$ *OK*

Calculate the depth of the compressive stress block.

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{(0.2\,in^2)(40\,ksi)}{(0.85)(2.5\,ksi)(5.5\,in)} = 0.684\,in \qquad [15.9\ mm]$$

Calculate the nominal moment strength.

$$M_n = A_s f_y \left(d - \frac{a}{2}\right) = (0.20\,in^2)(40\,ksi)\left(10\,in - \frac{0.684\,in}{2}\right) = 77.3\,in - kip \qquad [8.8\ kN\text{-}m]$$

Calculate the factored bending moment.

$$M_u = \phi M_n = (0.9)(77.3\,in - kip)/12 = 5.8\,ft - kip \qquad [7.9\ kN\text{-}m]$$

Calculate the load on the lintel.

| | | | |
|---|---|---|---|
| *Dead Loads* | *ICF Wall Above* | = 69 *psf* | [3.3 *kPa*] |
| | *Total Dead* | = 69 *psf* | [3.3 *kPa*] |

*Factored Load* = 1.4 ((0.69 *ksf*)(8 *ft*) + (5.5 *in*)(12 *in*)(0.150 *kcf*)/(144 $in^2$)) = 0.87 *klf* [12.7 *kN/m*]

Calculate the allowable span; assume both ends are fixed.

$$M = \frac{wl^2}{12} \Rightarrow l = \sqrt{\frac{12M}{w}} = \sqrt{\frac{(12)(5.8\ ft-kip)}{0.87\ klf}} = 8.9\ ft = 8'-11'' \qquad [2.7\ m]$$

## B5.4.4.2 Maximum Allowable Span Due to Shear

$$V_u = \phi V_n$$
$$V_n = V_c + V_s$$
$V_s = 0$ since there are no stirrups present

$\phi = 0.85$ *(strength reduction factor)*

Calculate the load on the lintel (see calculations in Section 5.4.4.1)

*Factored Load* $= 0.87\ klf$ [12.7 *kN/m*]

Check the area of steel.

$$A_s = 0.2\ in^2 \qquad [1.3\ cm^2]$$

$$\frac{3\sqrt{f'_c}b_w d}{f_y} = \frac{3\sqrt{2{,}500psi}(5.5in)(10in)}{40{,}000psi} = 0.206 in^2 \qquad [1.3\ cm^2]$$

$$\frac{200 b_w d}{f_y} = \frac{200(5.5in)(10in)}{40{,}000psi} = 0.275 in^2 \qquad [1.8\ cm^2]$$

Since $A_{s,min} < 0.495$ in$^2$ analyze using Scenario 1 outlined in Section 5.4.1.2 of the *Technical Substantiation.*

Use ACI Equation 11-3 to determine shear capacity of the section.

$$V_c = 2\sqrt{f'_c}b_w d = 2\sqrt{2{,}500psi}(5.5in)(10in) = 5.5kips \qquad [24.5\ kN]$$

$$\frac{1}{2}\phi V_C = (0.85)(5.5kip)/2 = 2.34kips \qquad [10.2\ kN]$$

Determine the maximum shear force.

$$V_u = \frac{wl}{2} = \frac{(0.87\ klf)l}{2} = (0.435klf)l$$

Determine the critical shear force.

$$Critical\ V_u = \frac{wl}{2} - wd = (0.435klf)l - (0.87klf)(10in)/(12in/ft) = (0.435klf)l - 0.725k$$

Solve for the span.

$$\frac{1}{2}\phi V_c = Critical\, V_u \Rightarrow 2.34kips = (0.435klf)l - 0.725kips \Rightarrow l = 7.04ft = 7'\text{–}00$$ [2.1 m]

### B5.4.4.3 Maximum Allowable Span Due to Deflection

Calculate the load on the lintel.

| | | | |
|---|---|---|---|
| *Dead Load* | *ICF Wall Above* | = 69 *psf* | [3.3 *kPa*] |
| | *Total Dead* | = 69 *psf* | [3.3 *kPa*] |

*Unfactored Load (used in deflection calculations)*

$$=(69\,psf)(8\,ft) + (5.5\,in)(12\,in)(150\,pcf)/144\,in^2 = 621\,plf$$ [9.1 *kN/m*]

Deflection limit of lintel

$$\Delta = \frac{l}{240}$$

Deflection of lintel

$$\Delta = \frac{wl^4}{(0.1)384EI}$$

Calculate the allowable span.

$$\frac{l}{240} = \frac{wl^4}{(0.1)384EI} \Rightarrow l = \sqrt[3]{\frac{(0.1)384EI}{(240)w}}$$

$$= \sqrt[3]{\frac{(0.1)(384)(3{,}122{,}000psi)\left(\frac{1}{12}(5.5in)(12in)^3\right)}{(240)(621plf)(144in^2)}} = 16.4ft = 16'\text{–}4"$$ [5.0 *m*]

### B5.4.4.4 Governing Design

A 5.5-inch x 12-inch (140-mm x 305-mm) flat ICF lintel in a non load-bearing wall supporting an ICF gable end wall with one No. 4 bar may span a maximum of 7'-0" (2.1 m) due to shear and does not require stirrups. From Table 5.14 of the *Prescriptive Method* we obtain a maximum clear span of 7 feet (2.1 m). The values in Table 5.14 have been adjusted to simplify the table for all ICF wall types.

**TABLE 5.14**
**MAXIMUM ALLOWABLE CLEAR SPANS FOR**
**ICF LINTELS IN GABLE END (NON-LOAD-BEARING) WALLS WITHOUT STIRRUPS[1,2,3]**
**NO. 4 BOTTOM BAR SIZE**
**(excerpt from the *Prescriptive Method*)**

| Minimum Lintel Thickness, T (inches) | Minimum Lintel Depth, D (inches) | Maximum Clear Span: Supporting Light-Frame Gable End Wall (feet) | Maximum Clear Span: Supporting ICF Second Story Gable End Wall[4] (feet) |
|---|---|---|---|
| **Flat ICF Lintel** | | | |
| 3.5 | 8 | 11-1 | [redacted] |
| | 12 | 15-11 | [redacted] |
| | 16 | 16-3 | [redacted] |
| | 20 | 16-3 | [redacted] |
| | 22 | 16-3 | [redacted] |
| 5.5 | 8 | 16-3 | [redacted] |
| | 12 | 16-3 | [redacted] |
| | 16 | 16-3 | 9-7 |
| | 20 | 16-3 | 12-0 |
| | 22 | 16-3 | 14-3 |

# B6.0 LEDGER BOARD CONNECTION DESIGN EXAMPLES AND ENGINEERING CALCULATIONS

The following engineering calculations are based on the application of several recognized engineering standards and specifications.

## B6.1 Ledger Board-Waffle ICF Connection Design

A wood 1.5-inch x 7.25-inch (38-mm x 184-mm) ledger board is attached to a 6-inch (152-mm) waffle-grid wall. Assume a 4-inch- (102-mm-) diameter hole is cut into the form around each bolt and that the bolt length extends to the center of the ICF wall thickness. Assume a 5/8-inch (19-mm) bolt diameter of A36 steel is used with a 1 3/8-inch- (35-mm-) diameter washer. The floor joists are 2 feet (0.61 m) on center and have a clear span of 22 feet (6.7 m). Wood member and connection design is in accordance with *NDS* [B4].

### B6.1.1 Calculate Loads

Nominal Service Load

$V = Dead\ Load + Live\ Load$

$V = (0.5)(22\ ft)((40\ psf + 15\ psf)) = 605\ plf$ [8.8 *kN/m*]

Factored Load

$V_u = 1.4\ Dead\ Load + 1.7\ Live\ Load$

$V_u = (0.5)(22\ ft)(1.4(15\ psf) + 1.7(40\ psf)) = 979\ plf$ [14.3 *kN/m*]

### B6.1.2 Determine Maximum Bolt Spacing Due to Shear-Friction in Concrete

$$V_n = A_{bolt} F_y \mu \leq \begin{Bmatrix} 0.2 f'_c A_{concrete} \\ 800 A_{concrete} \end{Bmatrix}$$

$$V_n = \frac{\pi (1.375\ in)^2}{4}(36{,}000\ psi)(0.6) = 32{,}074\ lb \qquad [143\ kN]$$

$$V_{n,max} = 0.2(2{,}500\ psi)\left(\frac{\pi (4\ in)^2}{4}\right) = 6{,}283\ lb \quad \longleftarrow \quad GOVERNS \qquad [28\ kN]$$

$$V_{n,max} = 800\left(\frac{\pi (4\ in)^2}{4}\right) = 10{,}053\ lb \qquad [44.7\ kN]$$

$$V_u \leq \phi V_n \quad OK$$

$$x = \frac{\phi V_n \mu}{V_u}$$

$$x = \frac{(0.85)(6{,}283\ lb)(12\ in/ft)(0.6)}{(979\ plf)} = 39.3\ in \qquad [998\ mm]$$

### B6.1.3 Determine Maximum Bolt Spacing Due to Tension in Concrete (Anchorage Capacity)

$$\phi V_c = \phi\,(4)(A_v)\sqrt{f_c^{'}}$$

$$V_u \leq \phi V_c \quad OK$$

$$x = \frac{\phi V_c}{0.75\left(\frac{V_u}{0.6} + 1.7(wind\ load)(wall\ height)\right)}$$

$$x = \frac{\phi\,4\left(\pi(2.5\ in)^2\right)\sqrt{2{,}500\ psi}(12\ inch/ft)}{0.75\left(\frac{979\ plf}{0.6} + 1.7(40\ psf)(10\ ft)\right)} = 23.1\ in \qquad [587\ mm]$$

### B6.1.4 Determine Maximum Bolt Spacing Due to Tension in Bolt Due to Shear-Friction and Wind Suction Pressure

$$T = 0.75\left(\frac{V_u}{0.6} + 1.7(wind\ load)(wall\ height)\right)(bolt\ spacing)$$

$$f_t = \frac{T}{A_{bolt}}$$

$$f_t \leq F_t$$

$$x = \frac{F_t A_b (12\ inches/ft)}{0.75\left(\frac{V_u}{0.6} + 1.7(wind\ load)(wall\ height)\right)}$$

$$x = \frac{(19{,}100\ psi)\left(0.306\ in^2\right)(12\ inches/ft)}{0.75\left(\frac{979\ plf}{0.6} + 1.7(40\ psf)(10\ ft)\right)} = 40.5\ in \qquad [1.03\ m]$$

### B6.1.5 Determine Maximum Bolt Spacing Due to Bolted Wood Connection to Concrete

$$Z_{actual} \leq Z_{allowable}$$

$$Z_{actual} = V(bolt\ spacing)$$

$$Z_{allowable} = 520\ lb/bolt$$

$$x = \frac{(12\ inches/ft)(520\ lb/bolt)}{605\ plf} = 10.3\ in \qquad [262\ mm]$$

### B6.1.6 Determine Maximum Bolt Spacing Due to Bending About Strong Axis in Ledger Board

$$f_b = \frac{M}{S_{xx}}$$

$$M = \frac{PL(bolt\ spacing)}{4}$$

$$f_b \le F_b$$

$$x = \frac{4F_b S_{xx}}{V}$$

$$x = \frac{4(850\ psi)(13.14\ in^3)(12\ in/ft)}{605\ plf(2\ ft\ joist\ spacing)} = 443.1\ in$$ [11.3 *m*]

### B6.1.7 Determine Maximum Bolt Spacing Due to Bending About Weak Axis in Ledger Board Due to Wind Suction Pressure

$$f_b = \frac{M}{S_{yy}}$$

$$M = \frac{w(bolt\ spacing)^2}{8}$$

$$f_b \le F_b$$

$$x = \sqrt{\frac{8F_b' S_{yy}}{(wind\ load)(wall\ height)}}$$

$$x = (12\ in/ft)\sqrt{\frac{8(1{,}564\ psi)(2.72\ in^3)}{(40\ psf)(10\ ft)}} = 110.7\ in$$ [2.8 *m*]

### B6.1.8 Determine Maximum Bolt Spacing Due to Allowable Bearing at Washer Due to Weak Axis Bending

$$f_{c\perp} = \frac{T}{A_{washer}}$$

$$M = \frac{w(bolt\ spacing)^2}{8}$$

$$f_{c\perp} \le F_{c\perp}$$

$$x = \frac{F_{c\perp}'(A_{washer})}{(wind\ load)(wall\ height)}$$

$$A_{washer} = \pi\left(\frac{1.375\ in}{2}\right)^2 - \pi\left(\frac{0.625\ in}{2}\right)^2 = 1.18\ in^2$$ [761 *mm*²]

$$x = \frac{(506\ psi)(1.18\ in^2)(12\ in/ft)}{(40\ psf)(10\ ft)} = 17.9\ in$$ [455 *mm*]

Note: Bolts are required to be staggered or placed in pairs in the top and bottom edges of the ledger to minimize cross-grain tension forces on the ledger. Therefore, cross-grain tension failure modes are addressed in this detailing requirement. In high seismic conditions, additional anchorage is also required.

### B6.1.9 Minimum Bolt Spacings and Edge Distance as Defined by *NDS* [B4].

| | | | |
|---|---|---|---|
| Minimum bolt spacing | $3d_b$ | $3(0.625\,in) = 1.9\ inches$ | $[48\ mm]$ |
| Minimum edge distance | $4d_b$ | $4(0.625\,in) = 2.5\ inches$ | $[64\ mm]$ |
| Minimum distance between bolts in a row | $3d_b$ | $3(0.625\,in) = 1.9\ inches$ | $[48\ mm]$ |
| Minimum end distance | $12\ in$ | | $[305\ mm]$ |
| Minimum distance between rows of bolts | $3d_b$ | $3(0.625\,in) = 1.9\ inches$ | $[48\ mm]$ |

### B6.1.10 Governing Design

A wood 1.5-inch x 7.25-inch (38-mm x 183-mm) ledger board attached to a 6-inch (152-mm) waffle-grid wall with 5/8-inch-(19-mm) diameter bolts and 1 3/8-inch (35-mm) washers for floor joists that span 22 feet (6.7 m) require a maximum spacing of 10.3 inches (262 mm) on center as governed by shear in the bolted connection of the wood ledger to concrete. From Table 6.1 of the *Prescriptive Method*, we also obtain a maximum bolt spacing of 10 inches (254 mm) on center for a staggered 5/8-inch-(15.9-mm-) diameter bolted connection or 20 inches (508 mm) on center for a double-bolted connection. Bolt patterns are very important to good practice with wood construction.

**TABLE 6.1**
**FLOOR LEDGER-ICF WALL CONNECTION (SIDE-BEARING CONNECTION) REQUIREMENTS[1,2,3]**
**(excerpt from the *Prescriptive Method*)**

| Maximum Floor Clear Span4 (feet) | Maximum Anchor Bolt Spacing[5] (inches) | | | |
|---|---|---|---|---|
| | Staggered 1/2-Inch-Diameter Anchor Bolts | Staggered 5/8-Inch-Diameter Anchor Bolts | Two 1/2-Inch-Diameter Anchor Bolts[6] | Two 5/8-Inch-Diameter Anchor Bolts[6] |
| 8 | 18 | 20 | 36 | 40 |
| 10 | 16 | 18 | 32 | 36 |
| 12 | 14 | 18 | 28 | 36 |
| 14 | 12 | 16 | 24 | 32 |
| 16 | 10 | 14 | 20 | 28 |
| 18 | 9 | 13 | 18 | 26 |
| 20 | 8 | 11 | 16 | 22 |
| 22 | 7 | 10 | 14 | 20 |
| 24 | 7 | 9 | 14 | 18 |
| 26 | 6 | 9 | 12 | 18 |
| 28 | 6 | 8 | 12 | 16 |
| 30 | 5 | 8 | 10 | 16 |
| 32 | 5 | 7 | 10 | 14 |

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm

## B6.2 Additional Requirements for Seismic Design Category C, $D_1$, and $D_2$

### B6.2.1 Out-of-Plane Anchorage Requirements for Seismic Design Category C, $D_1$, and $D_2$

Determine the additional anchorage requirements for connecting the ledgers and joists to a 5.5-in (140-mm) flat ICF wall in Seismic Design Category $D_1$. Anchorage shall not be accomplished by the use of toe-nails or nails subject to withdrawal nor shall such anchorage mechanisms induce tension stresses perpendicular to grain in ledgers or nailers. The required design value of such anchors are listed in Table 6.2.

The out-of-plane seismic load that must be transferred from the wall to floor connection was determined from *International Building Code* Section 1620.2.1 Equation 16-64 [B7]:

$F_p = 0.80 I_E S_{DS} w_w$ where,

$F_p$ = the out-of-plane seismic force
$I_E$ = occupancy importance factor (Table 1604.5 of the *IBC*)
$S_{DS}$ = the short period site design spectral response acceleration coefficient (Table 301.2.2.1.1 of the IRC)
$w_w$ = the weight of the wall

Therefore, the out-of-plane seismic load induced from the 5.5-in (140-mm) flat ICF wall in Seismic Design Category $D_1$ is:

$$F_p = 0.80 I_E S_{DS} w_w = 0.80(1.0)(0.83)(5.5in)(150pcf)(11ft)(1ft/12in) = 502plf \quad [734\ N/m]$$

**TABLE 6.2**
**MINIMUM DESIGN VALUES (plf) FOR FLOOR JOIST-TO-WALL ANCHORS REQUIRED IN SEISMIC DESIGN CATEGORIES C, $D_1$, AND $D_2$**
**(excerpt from the *Prescriptive Method*)**

| WALL TYPE | SEISMIC DESIGN CATEGORY | | |
|---|---|---|---|
| | C | $D_1$ | $D_2$ |
| Flat 3.5 | 193 | 320 | 450 |
| Flat 5.5 | 303 | 502 | 708 |
| Flat 7.5 | 413 | 685 | 965 |
| Flat 9.5 | 523 | 867 | 1,223 |
| Waffle 6 | 246 | 409 | 577 |

### B2.2.2 Top Bearing Anchorage Requirements for Seismic Design Category C, $D_1$, and $D_2$

Determine the anchorage requirements for connecting the wood sill plates to a flat ICF wall in Seismic Design Category $D_2$. According to the IBC, the attachment that the anchor is connecting to the structure shall be designed such that the attachment will undergo ductile yielding at a load level corresponding to anchor forces no greater than the design strength of the anchor specified. In short, this provision prevents concrete breakout as a possible failure mode due to the sudden nature of this type of failure. The required design value of such anchors are the values listed in Table 6.2 divided by 2.

Determine the design shear strength of an A307, 3/8-inch (9.5 mm) diameter anchor bolt embedded 7 inches (178 mm) in the concrete.

Steel strength of the anchor in shear:

$$0.75\phi V_s = 0.75\phi 0.6(A_{se})(f_{ut}) = (0.75)(0.75)(0.6)(0.078in^2)(60{,}000psi) = 1{,}580lb$$

Concrete breakout strength of anchor in shear:

$$0.75\phi V_{cb} = 0.75\phi\left(\frac{A_v}{A_{v_o}}\right)\Psi_6\Psi_7 V_b \quad \text{where,}$$

$$\Psi_6 = 1.0$$

$$\Psi_7 = 1.0$$

$$V_b = 7\left[\frac{l}{d_o}\right]^{0.2}\sqrt{d_o}\sqrt{f'_c}c_1^{1.5} = 7\left[\frac{7in}{0.375in}\right]^{0.2}\sqrt{0.375in}\sqrt{3{,}000psi}\left(\frac{5.5in}{2} - 0.375in\right)^{1.5} = 1{,}543lb$$

$$0.75\phi V_{cb} = (0.75)(0.75)(1.0)(1.0)(1.0)(1{,}543lb) = 868lb$$

Determine the 5-percent offset dowel bearing strength using the general dowel equations for calculating lateral connection values. Upon investigating the seven failure modes, failure mode $III_s$ (Side Member Bearing and Dowel Yielding in the Main Member) perpendicular-to-grain governs the general dowel equation yield mode. The following method outlines the yield mode $III_s$ calculation using a Specific Gravity of 0.42 and 0.70 for the wall framing and the concrete, respectively.

$$P = \frac{-B + \sqrt{B^2 - 4AC}}{2A} \quad \text{where,}$$

$$A = \frac{D^{0.5}}{4D(6{,}100)G_s^{1.45}} + \frac{D^{0.5}}{2D(6{,}100)G_m^{1.45}} = \frac{(0.375in)^{0.5}}{4(0.375in)(6{,}100)(0.42)^{1.45}} + \frac{(0.375in)^{0.5}}{2(0.375in)(6{,}100)(0.70)^{1.45}} = 0.000460$$

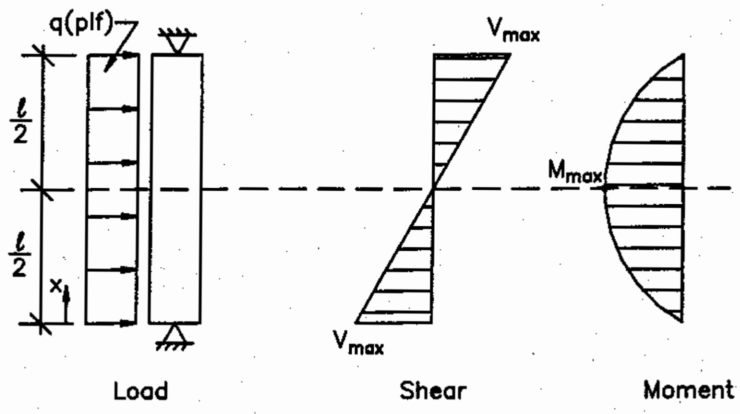
$$B = \frac{l_s}{2} + g = \frac{1.5in}{2} + 0 = 0.75$$

$$C = -\frac{4(6{,}100)(G_s)^{1.45}(D)(l_s)^2}{4(D)^{0.5}} - \frac{(F_b)(D_m)^3}{6} = -\frac{(6{,}100)(0.42)^{1.45}(0.375in)(1.5in)^2}{4(0.375)^{0.5}} - \frac{(45{,}000psi)(0.375in)^3}{6} = -992.7$$

$$P = \frac{-0.75 + \sqrt{0.75^2 - 4(0.000460)(-992.7)}}{2(0.75)} = 865lb$$

Since $865lb < 868lb$, yielding of the attachment governs the design per the requirements in the IBC. Therefore, the spacing required for the 3/8-inch anchor bolt in Seismic Design Category $D_2$ is equal to $(1{,}223lb/ft)(12in/ft)/(865lb) = 17in$, which is greater than the required 16in spacing.

## B7.0 TYPICAL BEAM LOADING CONDITIONS




$V_{max} ? \frac{ql}{2}$

$V_x ? q\left(\frac{l}{2} / x\right)$

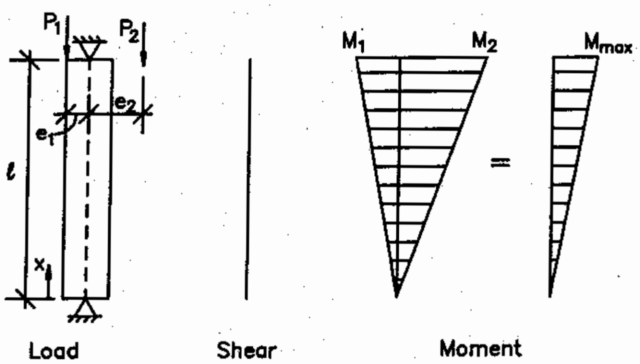
$M_{max} ? \frac{ql^2}{8}$

$M_x ? \frac{qx}{2}(l / x)$

$F_{max@center} ? \frac{5ql^4}{384EI}$

$F_x ? \frac{qx}{24EI}(l^3 / 2lx^2 - x^3)$

Figure B7.1 Uniform Load, Simple Span




$V_{max} ? V_x ? 0$

$M_{max} ? |M_2| / |M_1|$ where $|M_2| @ |M_1|$

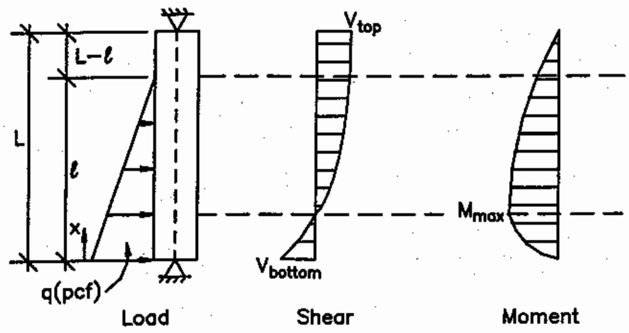
$M_{max} ? |M_1| / |M_2|$ where $|M_1| @ |M_2|$

$M_2 ? P_2e_2$

$M_1 ? P_1e_1$

$M_x ? M_{max}\left(\frac{x}{l}\right)$

Figure B7.2 Eccentric Point Loads, Simple Span




$$V_{top} ? \frac{q l^3}{6L}$$

$$V_{bottom} ? \frac{q l^2}{2} / \frac{q l^3}{6L}$$

$$V_x ? q l x / \frac{q x^2}{2}{}^{b} / V_{bottom} \quad \text{where } x > l$$

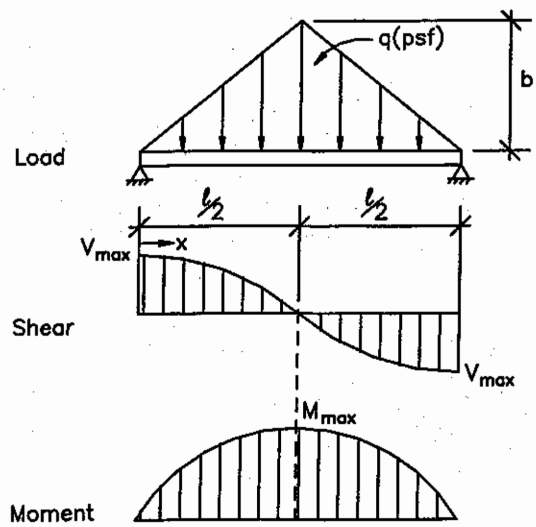
$$V_x \quad V_{top} \quad \text{where } x \quad l$$

$$M_x ? / \frac{q l x^2}{2} - \frac{q x^3}{{}^{b}6} \quad V_{bottom} x \quad \text{where } x > l$$

$$M_x ? \frac{q l^3}{6L} * L / x + \quad \text{where } x \, t \, l$$

$$x_{@ M_{max}} ? \frac{q l / \sqrt{q^2 l^2 / 2 q V_{bottom}}}{q}$$

**Figure B7.3 Partial Triangular Load, Simple Span**




$$V_{max} ? \frac{1}{4} b q l$$

$$V_x ? \frac{bq}{4l} * l^2 / 4x^2 + \quad \text{where } x > \frac{l}{2}$$

$$M_{max} ? \frac{1}{12} b q l^2$$

$$M_x ? \frac{b q l x}{2} \left( \frac{1}{2} / \frac{2x^2}{3l^2} \right) \quad \text{where } x > \frac{l}{2}$$

$$F_{max @ center} ? \frac{b q l^4}{120EI}$$

$$F_x ? \frac{bqx}{960EIl} * 5l^2 / 4x^2 +^2 \quad \text{where } x > \frac{l}{2}$$

**Figure B7.4 Load Uniformly Increasing to Center, Simple Span**

## B8.0 REFERENCES

[B1] *Minimum Design Loads for Buildings and Other Structures* (ASCE 7-98). American Society of Civil Engineers, New York, New York. 1998.

[B2] *International Residential Code.* International Code Council (ICC), Falls Church, Virginia. 2000.

[B3] *Building Code Requirements for Structural Concrete* (ACI 318-99). American Concrete Institute, Detroit, Michigan. 1999.

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[B5] *Manual of Steel Construction Allowable Stress Design, Ninth Edition.* American Institute of Steel Construction. Chicago, Illinois. 1989.

[B6] *Design Criteria for Insulating Concrete Form Wall Systems,* (RP116). Prepared for the Portland Cement Association by Construction Technology Laboratories, Inc., Skokie, Illinois. 1996.

[B7] *International Building Code.* International Code Council (ICC). Falls Church, Virginia. 2000.

[B8] *Structural Design of Insulating Concrete Form Walls in Residential Construction.* Portland Cement Association, Skokie, Illinois. 1998.

[B9] *In-Plane Shear Resistance of Insulating Concrete Form Walls.* Prepared for the U.S. Department of Housing and Urban Development, Portland Cement Association, and the National Association of Home Builders by the NAHB Research Center, Inc., Upper Marlboro, Maryland. 2001.

[B10] *Lintel Testing for Reduced Shear Reinforcement in Insulating Concrete Form Systems.* Prepared for the U.S. Department of Housing and Urban Development, Portland Cement Association, and the National Association of Home Builders by the NAHB Research Center, Inc., Upper Marlboro, Maryland. 1998.

[B11] *Testing and Design of Lintels Using Insulating Concrete Forms.* Prepared for the U.S. Department of Housing and Urban Development, Portland Cement Association, and the National Association of Home Builders by the NAHB Research Center, Inc., Upper Marlboro, Maryland. 2000.

# APPENDIX C

# METRIC CONVERSION FACTORS

The following list provides the conversion relationship between U.S. customary units and the International System (SI) units. A complete guide to the SI system and its use can be found in ASTM E 380, *Metric Practice*.

## Length

| To convert from | to | Multiply by |
|---|---|---|
| inch (in) | meter (m) | 2.540 000 E-02 |
| foot (ft) | meter (m) | 3.048 000 E-01 |
| yard (yd) | meter (m) | 9.144 000 E-01 |
| mile (mi) | meter (m) | 1.609 344 E+03 |

## Area

| To convert from | to | Multiply by |
|---|---|---|
| square foot ($ft^2$ or sf) | square meter ($m^2$) | 9.290 304 E-02 |
| square inch ($in^2$) | square meter ($m^2$) | 6.451 600 E-04 |
| square yard ($yd^2$) | square meter ($m^2$) | 8.361 274 E-01 |
| square mile ($mi^2$) | square meter ($m^2$) | 2.589 988 E+06 |

## Force per Unit Area (stress or pressure)

| To convert from | to | Multiply by |
|---|---|---|
| kip per sq. inch (ksi) | Pascal (Pa) | 6.894 757 E+06 |
| pound per sq. foot (psf) | Pascal (Pa) | 4.788 026 E+01 |

One Pascal equals 1,000 Newton per square meter.
One kip equals 1,000 pound.

## Volume

| To convert from | to | Multiply by |
|---|---|---|
| cubic inch ($in^3$) | cubic meter ($m^3$) | 1.638 706 E-05 |
| cubic foot ($ft^3$) | cubic meter ($m^3$) | 2.831 685 E-02 |
| cubic yard ($yd^3$) | cubic meter ($m^3$) | 7.645 549 E-01 |
| gallon (gal) Can. liquid | cubic meter ($m^3$) | 4.546 090 E-03 |
| gallon (gal) U.S. liquid | cubic meter ($m^3$) | 3.785 412 E-03 |
| fluid ounce (fl. oz.) U.S. liquid | cubic meter ($m^3$) | 2.957 353 E-05 |

One U.S. gallon equals 0.8327 Canadian gallon.
One liter equals 0.001 cubic meter.

## Force

| To convert from | to | Multiply by |
|---|---|---|
| kip (1,000 lb) | Newton (N) | 4.448 222 E+03 |
| pound (lb) | Newton (N) | 4.448 222 E+00 |
| ton (2,000 lb) | Newton (N) | 8.896 444 E+03 |

## Force per Unit Length

| To convert from | to | Multiply by |
|---|---|---|
| kip per linear foot (plf) | Newton per meter (N/m) | 1.459 390 E-02 |
| pound per linear foot (plf) | Newton per meter (N/m) | 1.459 390 E+01 |

## Mass

| To convert from | to | Multiply by |
|---|---|---|
| pound (lb), avoirdupois | kilogram (kg) | 4.535 924 E-01 |
| ton (2,000 lb) | kilogram (kg) | 9.071 847 E+02 |
| slug | kilogram (kg) | 1.459 390 E+01 |

## Mass per Unit Length

| To convert from | to | Multiply by |
|---|---|---|
| kip per linear foot (plf) | kilogram per meter | 1.488 164 E-03 |
| pound-per linear foot (plf) | kilogram per meter | 1.488 164 E+00 |

## Moment

| To convert from | to | Multiply by |
|---|---|---|
| foot-pound (ft-lb) | Newton-meter (N-m) | 1.355 818 E+06 |

## Mass per Unit Volume (Density)

| To convert from | to | Multiply by |
|---|---|---|
| pound per cubic foot (pcf) | kilogram per cubic meter (kg/m$^3$) | 1.601 846 E+01 |
| pound per cubic yard (lb/yd$^3$) | kilogram per cubic meter (kg/m$^3$) | 5.932 764 E-01 |

## Velocity

| To convert from | to | Multiply by |
|---|---|---|
| miles per hour (mph) | kilometer per hour (km/hr) | 1.609 344 E+00 |
| miles per hour (mph) | meter per second (m/s) | 4.470 400 E-01 |

## Temperature

| To convert from | to | Equation |
|---|---|---|
| degrees Fahrenheit (°F) | degrees Celsius (°C) | $T_c=(T_f-32)/1.8$ |
| degrees Fahrenheit (°F) | Kelvin (K) | $T_K=(T_f+459.67)/1.8$ |
| Kelvin (K) | degrees Celsius (°C) | $T_c=(T_K-273.15)$ |

The prefixes and symbols below are commonly used to form names and symbols of the decimal multiples of the SI units.

| Multiplication Factor | Prefix | Symbol | Multiplication Factor | Prefix | Symbol |
|---|---|---|---|---|---|
| 1,000,000,000 = $10^9$ | giga | G | 0.01 = $10^{-2}$ | centi | c |
| 1,000,000 = $10^6$ | mega | M | 0.001 = $10^{-3}$ | milli | m |
| 1,000 = $10^3$ | kilo | k | 0.000001 = $10^{-6}$ | micro | µ |
| | | | 0.000000001 = $10^{-9}$ | nano | n |

## Reinforcement Bar Data

| Inch-Pound | Metric |
|---|---|
| No. 3 | No. 10 |
| No. 4 | No. 13 |
| No. 5 | No. 16 |
| No. 6 | No. 19 |
| No. 7 | No. 22 |
| No. 8 | No. 25 |
| Grade 40 | Grade 300 |
| Grade 60 | Grade 420 |