

IN-LB

Inch-Pound Units

SI

International System of Units

Insulating Concrete Form Design and Construction— Report

Reported by ACI Committee 560

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Insulating Concrete Form Design and Construction—Report

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Insulating Concrete Form Design and Construction—Report

Reported by ACI Committee 560

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Insulating concrete forms (ICFs) are leave-in-place forms typically produced in block or panel shapes of expanded polystyrene (EPS). They provide additional components, such as insulation and a substrate for interior and exterior finish attachment, for a wall or floor system. The most widely used ICFs are block shapes, which are stacked in an interlocking fashion to create stable formwork for creation of reinforced concrete walls. Due to the variability of these manufactured form systems, this report does not attempt to address every ICF type, but provides a commentary on those systems most prevalent in the market, and insight, as well as additional information, relative to their use in design and construction. The report focuses on ICFs for walls.

Keywords: bracing system; crossties; expanded polystyrene; formwork configurations; formwork materials; insulating concrete forms; polypropylene; polyurethane; screen grid; wall design; wall systems; web.

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APPENDIX REFERENCES, p. 49**CHAPTER 1—INTRODUCTION AND SCOPE****1.1—Introduction**

This report is a comprehensive introduction to the design and construction of reinforced concrete structures with insulating concrete forms (ICFs). ICFs are stay-in-place concrete forms that create vertical elements such as walls, columns, and pilasters, and horizontal elements such as floors and roofs. This report focuses on ICFs for walls.

ICFs that result in reinforced concrete walls are of varying dimensions and manufactured in blocks, planks, panels, and other shapes. They are made of plastic foam or a blended combination of other types of material such as cement, foam, and wood fiber. The most common ICFs used for wall construction typically provide two layers of low-absorptive foam plastic insulation held together with a system of cross-ties. The cross-ties are also typically configured to allow for direct attachment of internal and external finishes to the ICF. Reinforcing steel can be installed within the hollow portion of the form, followed by concrete placed to create a reinforced concrete wall. Figures 1.1a through 1.1c are examples of ICFs used for wall construction.

There are many manufacturers of ICFs. An ICF manufacturer's form design is proprietary, so each has specific characteristics and limitations. While individual ICFs perform similarly, they are not generally interchangeable. Most major ICF manufacturers have their own proprietary training programs supporting residential and commercial construction. Insulating concrete forms are typically lightweight so they are easy to handle and place. Concrete placement when using ICFs is completed by skilled craft construction crews who are trained and experienced with concrete placement and consolidation per [ACI 301](#).

In spite of their simplicity, ICFs are based on extensive research and continue to evolve with changes in technology. Because there are many proprietary systems, and building codes do not offer general guidance about ICF construction, this report provides background information that is useful for designing and building ICF structures. This report also supplements proprietary information available from indi-

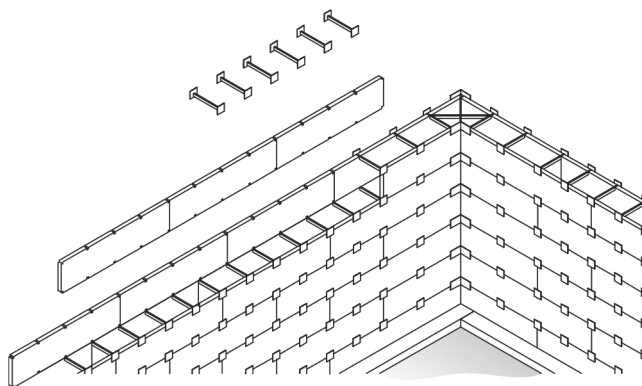


Fig. 1.1a—Panel and tile construct-in-place ICF system.

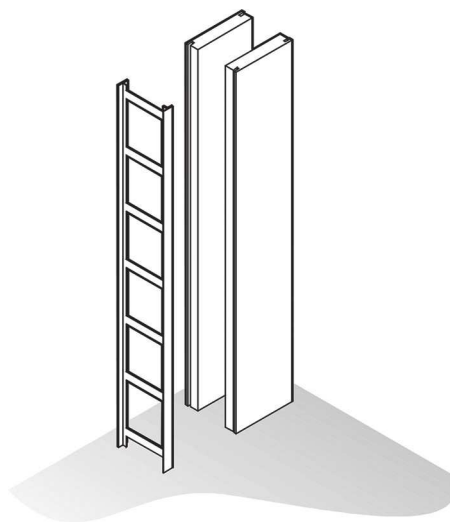


Fig. 1.1b—Vertical ladder and panel ICF system (ladder for interconnection).

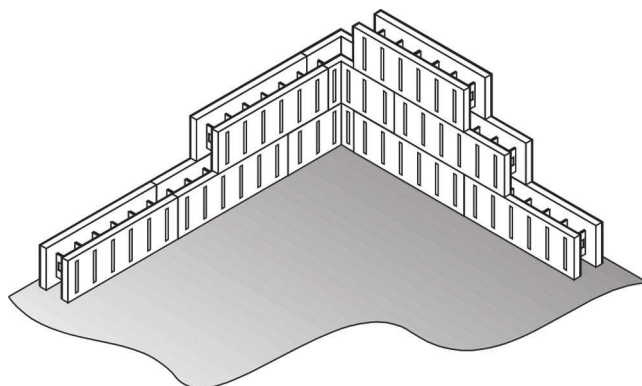


Fig. 1.1c—Block-type ICF system.

vidual manufacturers with general information applying to most ICFs. In addition to informing designers and builders, this report is useful to building officials and other professionals who work with ICFs.

Originally evolved in Switzerland near the end of World War II, the earliest versions of ICFs were made from treated wood fibers and portland cement. In the late 1940s and 50s, plastic foams were developed, and in the 1960s the concepts of combining plastic foams and ICFs together

resulted in the creation of contemporary ICFs. In the 1980s and 90s, numerous companies and products emerged. Growth in the number of ICF manufacturers led to the creation of the Insulating Concrete Form Association (ICFA) in the mid-1990s with a primary goal to advance the industry.

Insulating concrete forms initially entered the residential marketplace through their use in foundations and basements. They expanded into above-grade walls, often in more-expensive, large-scale homes. However, as more manufacturers entered the market and ICFs became more readily available with a larger installer base, they gained increased acceptance in all residential construction. ICFs increased almost sixfold in market share between 1996 and 2006 in the residential construction market for both below-grade and above-grade walls (Lyman 2007). With residential applications historically accounting for a large percentage of the ICF market, commercial ICF projects continued to grow in market share and magnitude of project scope and complexity. Increased use of ICFs throughout the United States for residential and commercial construction has led to the need for more detailed guidance and documentation.

Product innovation continues, with additional differentiating features among ICF manufacturers, including crosstie material type, crosstie geometric configuration to facilitate reinforcing bar positioning, crosstie configuration for finish attachment, form shape, and interlocking mechanisms. Some manufacturers offer compatible insulated horizontal ICFs—for example, floors and roofs—providing a total cast-in-place concrete building envelope.

1.2—Scope

As noted previously, there are many proprietary ICF systems, and building codes do not offer general guidance about ICF construction. This report provides background information that is useful for designing and building ICF structures. It also supplements proprietary information available from individual manufacturers with general information applying to most ICFs. This report is also useful to building officials and other professionals who may work with ICFs.

Construction in the United States has undergone several important changes in the past century. With these changes have come codes and standards to assist owners, building officials, designers, and contractors in constructing quality structures that are durable and sustainable, with more emphasis on energy efficiency. Quality-of-life issues are also being addressed, either through codes or other building criteria, notably the development of green building rating systems and programs promoting greater energy efficiency and sustainability (USGBC 2010). Occupant health, safety, and general well-being—for example, resilient construction—are also being identified as important factors in building construction practices, integrating entire building envelopes into a cohesive system. This ultimately is moving today's industry toward more sustainable structures that are longer-lasting and resilient enough to reduce rebuilding, thereby reducing energy consumption.

Research on ICFs is addressed in detail throughout this document. Manufacturers should provide specific, detailed

information about their proprietary products and tests demonstrating performance of the ICF in meeting the intent of applicable building codes. Whether this information is available as an evaluation service report or some other technical report, it should allow a licensed design professional to determine whether an ICF is appropriate for a particular application.

CHAPTER 2—DEFINITIONS

ACI provides a comprehensive list of definitions through an online resource, “ACI Concrete Terminology,” <https://www.concrete.org/store/productdetail.aspx?ItemID=CT13>. Definitions provided herein complement that resource.

crossties—connectors, typically of plastic or metal, that join two opposite faces of insulating concrete forms.

expanded polystyrene—type of foamed plastic formed by the expansion of polystyrene resin beads in a molding process; when formed into planks or boards, sometimes referred to by the slang term “bead board”.

foamed plastic—plastic expanded chemically, mechanically, or thermally to form a lightweight, closed-cell structure; usually expanded or extruded to make a lightweight insulating material that can be formed into any shape, including panels or blocks.

insulating concrete form—stay-in-place concrete forming system usually composed of foamed plastic and associated crossties or webs; the form has particular insulating characteristics as well as usually serving a structural purpose for attachment of interior and exterior finishes.

polypropylene—thermoplastic polymer material commonly used as crossties in insulating concrete forms.

seismic design category—classification assigned to a structure based on its risk category and severity of the design earthquake ground motion at the site.

web—connection between two opposite faces of an insulating concrete form block, usually made from the same material as the insulating concrete form itself, such as expanded polystyrene, without a crosstie.

CHAPTER 3—INSULATING CONCRETE FORM SYSTEMS

3.1—Flat-wall

Flat-wall insulating concrete form (ICF) systems are the most commonly used in wall construction today. They result in a solid, flat reinforced concrete wall sandwiched between two faces of low-absorptive, foam plastic insulating material, commonly referred to as expanded polystyrene (EPS). The form faces are typically interconnected by polypropylene crossties that are subsequently encapsulated in the reinforced concrete. Figure 3.1a illustrates a typical block-type ICF. Figure 3.1b illustrates the typical isometric and cross section view of the form and the resulting concrete core.

3.2—Additional ICF systems

Three additional insulated concrete form (ICF) systems, typically referred to as waffle, screen, and post-and-beam, also create a reinforced concrete wall. They are commonly referred to as nonflat systems. Figure 3.2a illustrates a

waffle system with a concrete core that varies in thickness yet maintains a minimum thickness throughout. A screen system (Fig. 3.2b) and a post-and-beam system (Fig. 3.2c) more aptly resemble a grid-type reinforced concrete structure where there are distinct horizontal and vertical members

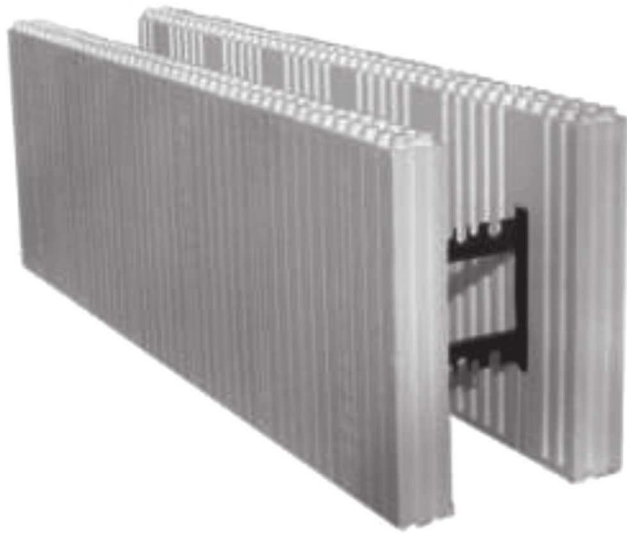


Fig. 3.1a—Block-type ICF.

with intermittent voids filled by the ICF material. The use of nonflat systems is limited by a lack of appropriate design guidance. Chapters 5 and 6 provide information and construction guidance to the licensed design professional applying ACI 318 standards to any ICF system, which can result in a reinforced concrete core of any geometry, including the dimensions and spacing of elements. It is important to note that with any ICF, minimum dimensions need to be provided for the concrete core to accommodate the reinforcing bars. For example, reinforcing bar ties for compression members require minimum overall dimensions to accommodate the minimum bend radius and clear cover requirements.

ICF wall construction, depending on the system type, often results in an energy-efficient wall with two insulation layers. The insulation, which is typically more than 2 in. (50 mm) per side, can be varied in thickness and type to provide the desired insulating value. The forms are filled with concrete and, due to the wall's thermal mass, energy consumption is reduced. Thermal mass is a property that enables building materials to absorb, store, and later release significant amounts of heat. Buildings constructed of concrete have a unique energy-saving advantage because of their inherent thermal mass. These materials absorb energy slowly and hold it for much longer periods of time than do less-massive materials. In essence, the form and concrete mass acts like

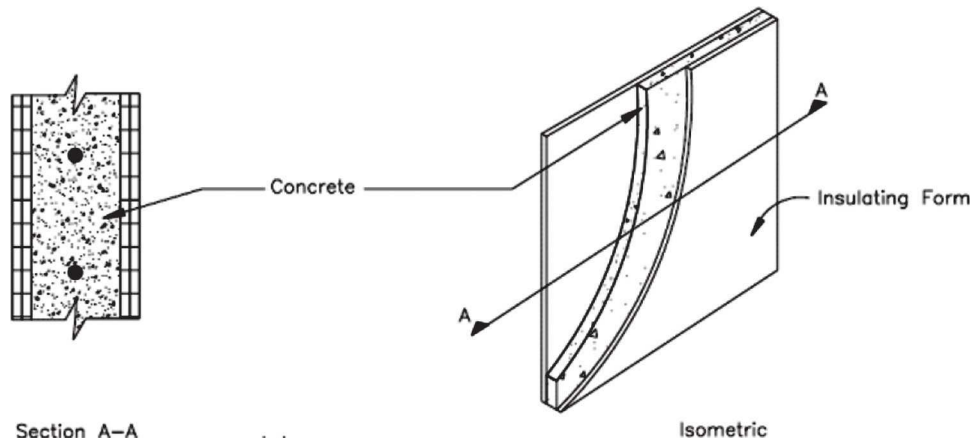


Fig. 3.1b—Flat wall ICF wall system and plan view Section A-A.

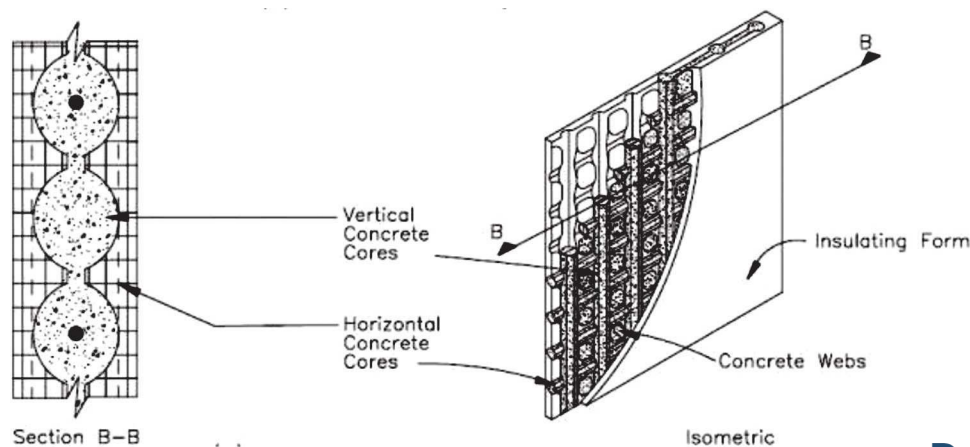


Fig. 3.2a—Waffle grid ICF wall system and plan view Section B-B.

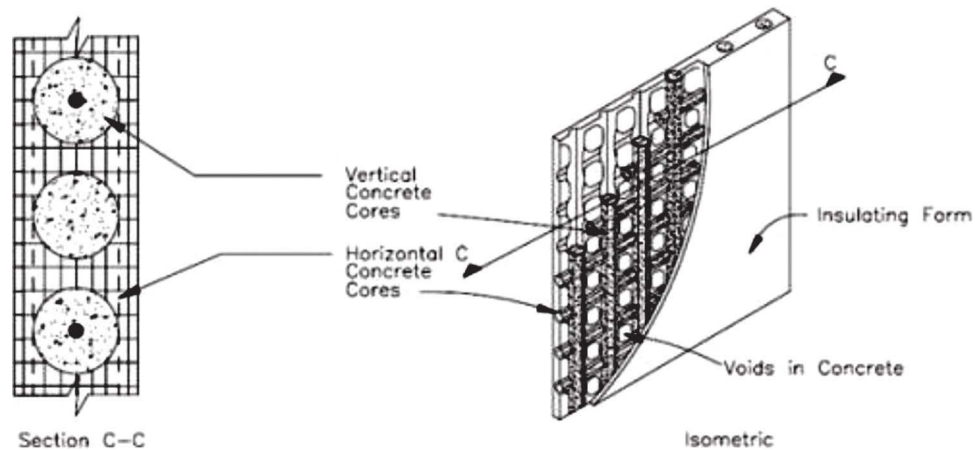


Fig. 3.2b—Screen grid ICF wall system and plan view Section C-C.

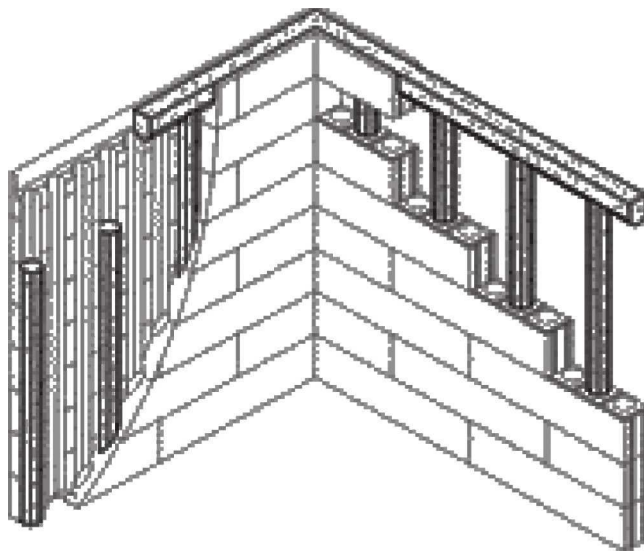


Fig. 3.2c—Post-and-beam ICF wall system.

a battery that stores heat or cold, so temperatures stay more consistent in the building's interior. The combined concrete wall, with a layer of insulating material on each side, also creates an envelope less prone to cracks and openings, which reduces migration of conditioned air to the outside and unconditioned air to the inside. ICF wall systems also have excellent acoustic characteristics that result in low sound transmission for greater interior comfort from exterior noises. From a builder's perspective, the forms also reduce the escape of moisture from the concrete due to their low absorptivity, thus assisting in the curing process.

CHAPTER 4—MATERIALS

Concrete used in insulated concrete form (ICF) construction should be proportioned to provide the specified compressive strength complying with structural requirements while providing sufficient flowability. A wide range of cementitious materials can achieve the desired mixture properties. Note that the ICF system and reinforcement could significantly affect concrete flow and consolidation and, therefore,

should be reviewed and considered by the producer and contractor when proportioning the concrete mixture.

4.1—Concrete mixture

4.1.1 Cementitious materials—Cementitious materials used in insulated concrete form (ICF) construction should conform to [ASTM C150/C150M](#), [C595/C595M](#), or [C1157/C1157M](#). Supplementary cementitious materials such as fly ash, slag cement, and silica fume can also be used in addition to portland cement. They should meet the requirements of [ASTM C618](#), [C989/C989M](#), and [C1240](#), respectively. A wide range of cements and combinations of cementitious materials can achieve the desired mixture properties. Unlike forms for ordinary cast-in-place concrete, which are removed after concrete has cured sufficiently, ICF forms stay in place. As a result, a larger proportion of supplementary cementitious materials could potentially be used to replace portland cement in the ICF concrete mixtures without concerns for developing early strength due to the need to remove forms as soon as possible. The shape of the open space created by the ICF and configuration/placement of reinforcement can affect concrete flow and consolidation. Placement characteristics should be considered in mixture proportions by the concrete producer and contractor.

4.1.2 Aggregate materials—Aggregates should conform to [ASTM C33/C33M](#) (normalweight), or [ASTM C330/C330M](#) (lightweight). Coarse aggregate size may need to be reduced to a 3/4 in. (19.0 mm) maximum aggregate size due to the size and configuration of the ICFs and the quantity and spacing of reinforcing bars.

4.1.3 Chemical admixtures—Water-reducing admixtures should meet the requirements of [ASTM C494/C494M](#). Low-, mid-, or high-range water-reducing admixtures may be used, depending on the water-cementitious materials ratio (w/cm). Retarding admixtures should conform to ASTM C494/C494M Type B (retarding) or Type D (water-reducing and retarding) and are used to stabilize and control cement hydration. They are especially useful in hot-weather applications. Retarding admixtures can act as lubricants to help discharge concrete from a mixer and improve handling and in-place performance characteristics. Accelerators such as

calcium chloride conforming to **ASTM D98** and nonchloride accelerators conforming to ASTM C494/C494M Type C or E may be used. **ACI 212.3R** should be used for guidance in the use of accelerators. Cement hydration stabilizers have been used as an aid in extending the working time of the mixture along with viscosity-modifying admixtures to enhance workability; these advantages can be applied and implemented during production and placement of ICF concrete. When combining several admixtures in any concrete mixture, trial batches should be made to identify potential admixture incompatibility and verify that desired fresh and hardened properties are consistently achievable. Air-entraining admixtures should meet the requirements of **ASTM C260/C260M**.

4.1.4 Mixture design—Concrete used for ICF construction should be proportioned to provide a specified strength complying with building code requirements. Proportions should be determined according to **ACI 211.1**. Concrete mixtures for ICF construction should incorporate an optimized combination of locally available materials that consistently produce concrete with the required workability and finishability properties during placement. The concrete mixture should be selected for appropriate workability and aggregate sizes based on form geometry and reinforcement spacing. Concrete should not segregate or have excessive bleed water during placement and consolidation. Concrete should be batched and delivered with uniform proportions and consistency. The implementation of quality-control procedures provides for consistent mixture production, delivery, and placement.

4.1.5 Self-consolidating concrete—Self-consolidating concrete (SCC) is a highly flowable, specially designed, nonsegregating concrete that is fluid enough to fill the formwork and encapsulate the reinforcement without mechanical consolidation. These properties represent constructability advantages for ICFs and many other concrete applications. SCC should be produced in accordance with **ACI 237R**. A typical SCC mixture design will differ from a conventional concrete mixture with the addition of:

- a) High-range water reducers
- b) Viscosity-modifying admixtures
- c) Smaller aggregates and optimized gradation

Note that a potential increase in form pressures associated with the selected SCC should be checked against the ICF manufacturer's data relative to allowable form pressures.

4.2—Reinforcing materials overview

4.2.1 Steel reinforcing bars—Steel reinforcing bars are deformed steel bars conforming to one of the following ASTM specifications, as required by the project specifications:

- a) **ASTM A615/A615M**
- b) **ASTM A706/A706M**
- c) **ASTM A955/A955M**
- d) **ASTM A996/A996M**
- e) **ASTM A1035/A1035M**

4.2.2 Fiber reinforcing—The use of fiber reinforcement with ICFs should be consistent with current guidance provided by ACI Committee 544 technical documents, which address the use of fiber-reinforced concrete. Generally, in

structural members such as walls, beams, and columns, where continuous tensile reinforcement is required for safety and structural integrity, the total absence of reinforcing bars is not recommended. **ACI 318** does not recognize the use of fiber-reinforced concrete in building design. Therefore, ICF wall design should follow reinforced concrete design consistent with ACI 318. Fiber reinforcement case studies show that use of fiber reinforcement can replace all reinforcing bars, but the reliability of such an approach would require strict, rigid quality-control measures during placement and subsequent load testing to verify performance (**Pinkerton et al. 2013**).

CHAPTER 5—INSULATING CONCRETE FORMS

5.1—Formwork material

Insulated concrete form (ICF) product manufacturers can produce forms composed of several material types and shapes. The form panel materials can range from foam plastic to different types of composite materials. Forms typically specified and employed in the construction marketplace are made from expanded polystyrene (EPS) with polypropylene crossties. EPS is commonly referred to as foam plastic material. ICF systems made of other composite materials, such as cementitious/foam plastic blends, are available in the marketplace. Because performance characteristics associated with those systems are not as well defined by industry standards and building codes, they go beyond the scope of this document and, therefore, are not addressed. Instead, the remainder of this report will address ICF systems that use foam plastic material as the form panel.

5.2—Formwork configurations

Manufacturers produce insulated concrete forms (ICFs) in several sizes and geometric configurations, although there are no industry standards regarding these. There are manufacturers who produce flat wall ICFs that are similar in size and geometry. The sizes of ICFs directly influence the width or depth of the overall dimensional envelope of the structure.

5.2.1 Block systems—Block systems typically are made in sizes to cast 4 to 12 in. (100 to 300 mm) thick concrete walls in 2 in. (50 mm) increments. Form heights range from 12 to 24 in. (300 to 600 mm), with the most common being 16 in. (400 mm). Typically, form crossties are embedded into the form panel material at the time of manufacturing and spaced at 6 or 8 in. (150 or 200 mm) on center. The material and design of the crosstie (for example, how it interlocks with the expanded polystyrene [EPS] panels and its geometry across the width of the form) is specific to each ICF manufacturer.

Each ICF manufacturer's brand has its own complement of forms. The common form types for each size are straight forms and 90-degree corners. Manufacturers can produce additional form configurations/units such as 45-degree corners; adjustable corners; radius forms; and corbel forms such as a brick ledge, taper-top forms, transition forms, and T-block forms. These types of atypical units may only be available in limited sizes. Refer to Fig. 5.2.1a through 5.2.1d for examples of the previously described

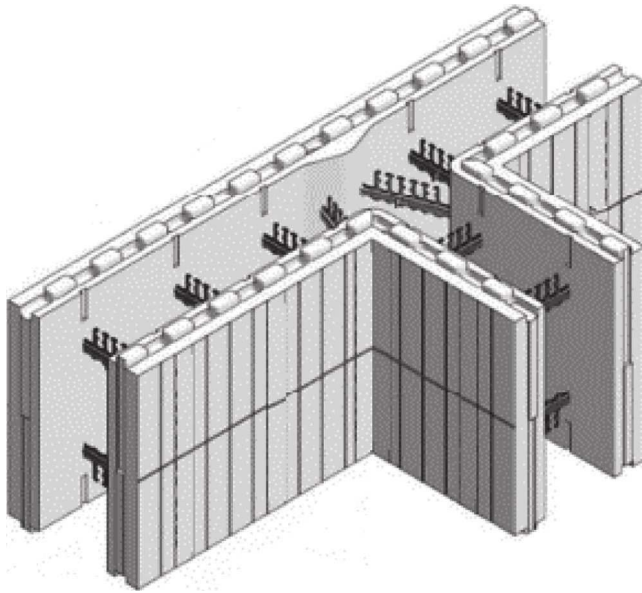


Fig. 5.2.1a—Example of T-block.

5.2.2 Panel systems—Panel ICF systems are similar to block systems, but differ because the panels and cross-ties are packaged separately, shipped to the jobsite, and are field assembled. The cross-ties can be a multi-piece system with a portion of the cross-tie embedded in the foam plastic and another part for joining form panels. There could also be a separate piece that is inserted into the foam plastic panels at the time of construction. Figure 5.2.2 illustrates one type of panel ICF system.

5.2.3 Hinged systems—Some ICF systems have hinged cross-ties. These systems are shipped to the jobsite flat and unfolded on-site prior to assembling the wall forms in their specific locations. Figure 5.2.3 illustrates one type of a hinged block system. Similarly, panel systems with hinged cross-ties can also be assembled at the jobsite.

5.2.4 Plank systems—With plank systems, boards of foam plastic are shipped to the jobsite and assembled into concrete wall forms with proprietary form-tie components. Plank systems can be oriented horizontally or vertically. Although plank systems are similar to panel systems, planks are typically not as wide as panels and may be longer and thinner. Connections between the panels are made at the edges of the planks. A panel system could have connections within the field of the panel in addition to its edges. An example of a vertical plank system is provided in Fig. 5.2.4.

5.3—Insulating concrete form components

Stay-in-place insulating concrete forms (ICFs) are generally composed of foam plastic insulation panels and cross-ties. Understanding these two common components of most ICFs is beneficial for a basic knowledge of ICFs.

5.3.1 Insulation panels—Two ICF panels contain the concrete in the form and serve as insulation for the finished wall. Typically, these panels are several inches (centimeters) thick and consist of expanded polystyrene (EPS). Some systems are made from extruded polystyrene (XPS) and others from rigid insulation materials. With flat wall ICF systems,



Fig. 5.2.1b—Example of 45-degree corner block.

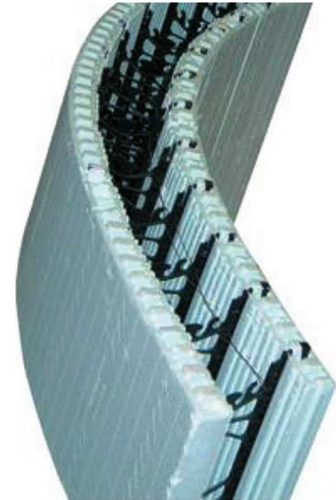


Fig. 5.2.1c—Example of radius form block.

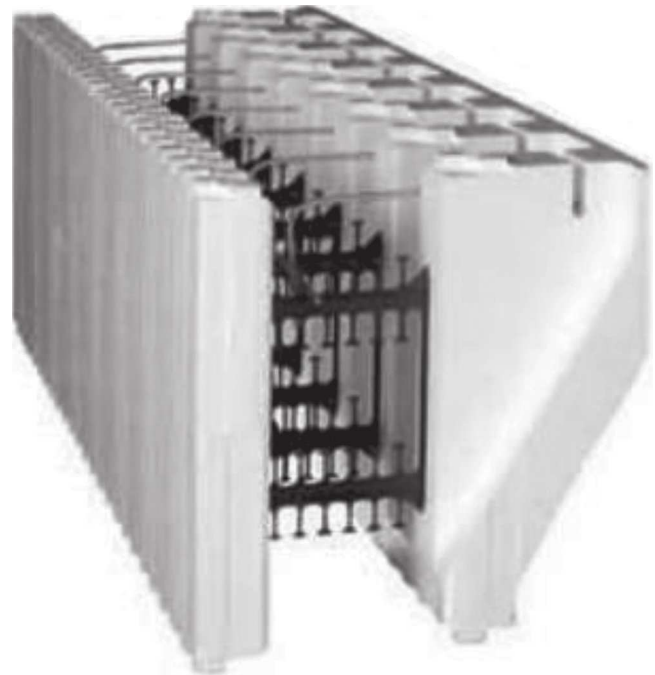


Fig. 5.2.1d—Example of the corbel form (brick ledge).

the panels are flat on both their inside and outside faces. With nonflat ICF systems, the EPS is molded in nonflat shapes. Thermal resistivity (R value) of the insulation is dependent

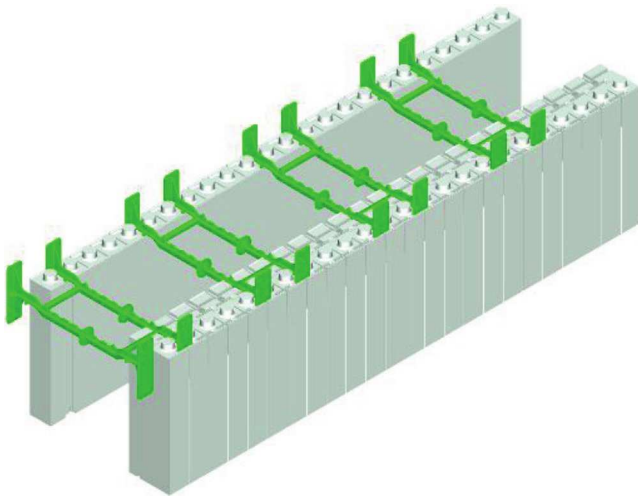


Fig. 5.2.2—Example of a panel ICF system.

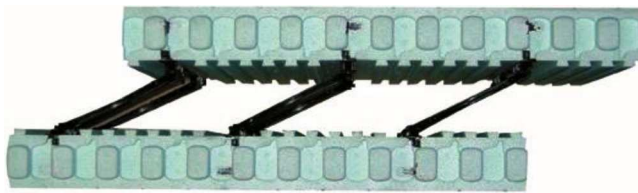


Fig. 5.2.3—Example of a hinged block ICF.

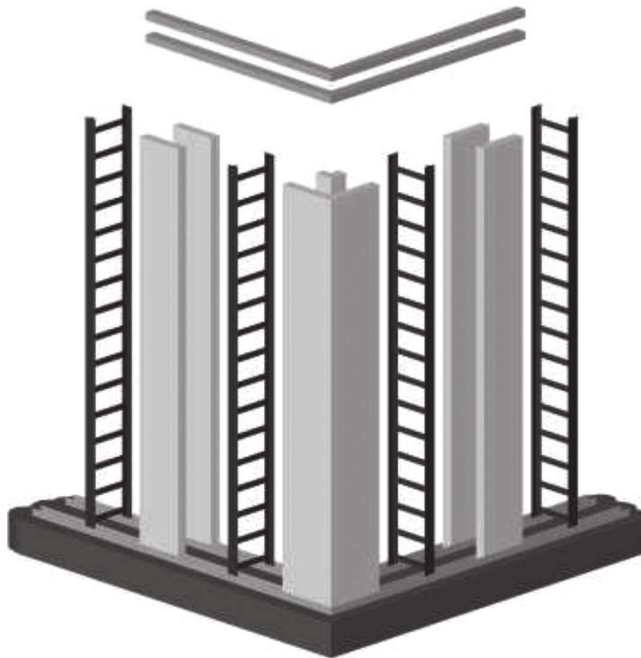


Fig. 5.2.4—Example of a plank ICF system.

on the material density. EPS ICF panels typically possess R -values of approximately 4 or 5 per 1 in. (25 mm) of EPS panel thickness. [ASTM C578](#) and [ASTM C1303/C1303M](#) are used to characterize the thermal properties of EPS.

5.3.2 Crossties—Although crossties are typically injection-molded polypropylene parts, some systems use other plastic resins, and others galvanized steel. One-piece crossties are molded into the EPS panels and multi-piece cross-



EPS panel partially removed to expose embedded one piece cross tie and cross tie flange (cross tie flange used as a furring strip for attachment of cladding).

Fig. 5.3.2—Cutaway view of typical ICF block-type system.

ties, used in field-assembled ICF systems (sometimes referred to as knock-down ICF systems), and have one portion molded into the EPS panels and another into the parts molded in the panels. Plank systems use a different tie system, one that bridges across the cavity at the edges of the insulation planks. The crossties also serve to hold reinforcing steel in place inside the cavity with various support points for reinforcing steel molded into the crossties, or to serve as a support to which the reinforcing steel can be tied. Most ties have a furring strip on each end to which interior wall finishes and exterior cladding can be attached once the concrete has been placed in the wall. Figure 5.3.2 illustrates a typical cross section of a block-type ICF system showing the panel and crosstie. In some screen grid ICF systems, the insulation, which is continuous through the wall at regular intervals, serves as the connection between faces. These systems do not have a separate crosstie.

5.4—Material performance requirements

5.4.1 Foam plastic—The International Building Code ([IBC-2012](#)), International Residential Code ([IRC-2012](#)), and [ASTM E2634](#) state that foam plastic must meet the material properties of [ASTM C578](#) for the type of foam plastic as specified by the insulated concrete form (ICF) manufacturer, which is typically Type II. Foam plastic is interesting because of its short-term structural application as formwork panels, and its compressive, tensile, and flexural strength properties that are critical parameters in withstanding the pressure of freshly placed concrete.

Additionally, when tested in accordance with [ASTM E84](#), the flame spread index of the foam plastic must be 75 or less as a general requirement, and must be 25 or lower when the ICFs are used in noncombustible construction. In addition, per [ASTM E84](#), the smoke developed index must not be more than 450.

5.4.2 Crossties—[ASTM E2634](#) specifies that crossties must have adequate tensile strength to resist a formwork

load of 675 lb/ft² (32 kN/m²). Typically, crossties are made of injection-molded polypropylene plastic. ASTM E2634 also specifies that plastic must have the following:

- a) Shear strength tested in accordance with **ASTM D732** to a minimum value determined by the geometric design of the crosstie
- b) Minimum ignition temperature of 662°F (350°C) when tested in accordance with **ASTM D1929**
- c) Rate of burn that satisfies the minimum requirements of the CC2 classification as defined and tested in accordance with **ASTM D635**
- d) Fastener strength determined by testing in accordance with the modified **ASTM D1761** test method, and then reduced by the safety factor specified in **ASTM E2634**

5.4.3 System performance—In accordance with ASTM E2634, the ICF system should be able to resist lateral forces of 675 lb/ft² (32 kN/m²). The value was developed based on over 15 years of field experience in North America and Europe, and following research conducted at McMaster University, Hamilton, ON, Canada.

5.5—Bracing and scaffolding

Insulating concrete form systems require bracing and scaffolding during construction. Typically, the bracing and scaffold system used during stacking of insulated concrete forms (ICFs) keeps the forms in position and gives workers access to the top courses of the wall. The bracing system also plumbs the wall before concrete placement and replumbs after concrete placement. The scaffolding provides workers access for placing and consolidating concrete. Bracing and scaffolding should remain in place until lateral support, such as a floor diaphragm, has been installed and the concrete has cured sufficiently to support construction loads. Additional discussion related to bracing systems is included in **Chapter 7**.

5.6—Miscellaneous

5.6.1 Third-party inspections: compliance with the intent of the building code—Third-party inspection of insulated concrete form (ICF) manufacturing plants is usually required by evaluation services issuing evaluation reports that confirm overall compliance with specified building codes and the ICF manufacturer's quality protocols. Third-party inspections are usually conducted on a quarterly basis. ASTM E2634 for flat wall ICFs contains a requirement for third-party inspections. In general, the foam plastic material delivered to project construction sites is required to possess third-party certification per **IBC-2012** and **IRC-2012**, although this requirement has not been applied specifically to ICFs.

5.6.2 Labeling—Building codes that include ICF design, the evaluation reports, and ASTM E2634 all specify labeling requirements. At a minimum, each package of ICFs must be labeled with the brand name, manufacturer's name, product listing, any and all building code approvals the system has, and a system that identifies time and place of manufacture.

CHAPTER 6—DESIGN AND ACI 318 APPLICATION

6.1—General

The structural design of the insulated concrete form (ICF) concrete core can be addressed in a number of distinct approaches, including:

- a) Prescriptive design
- b) Rational, engineering design
- c) Rational, engineering design approach validated by testing

The prescriptive design approach is currently restricted to residential structures. There are three methods available, documented by the International Residential Code (**IRC-2012**), Portland Cement Association (**PCA 100**), and **ACI 332**. The prescriptive methods all contain specific restrictions on the overall structure; for example, geometry and the seismic design category, as well as geometric limitations on the concrete core created by the ICF. Restrictions and limitations inherently limit the type of ICF that can be specified by the licensed design professional and used for the construction of a structure. When the licensed design professional desires the use of an ICF on a nonresidential project, or a residential situation where the prescriptive restrictions will be violated, the principles of **ACI 318** and generally accepted engineering practice should be used.

The ACI 318 design methodology used for the concrete core is necessarily dependent on the final configuration of the concrete core. The concrete core created by the ICF is typically characterized by one of the following ICF wall systems:

- a) Flat (Fig. 3.1b)
- b) Waffle grid (Fig. 3.2a)
- c) Screen grid (Fig. 3.2b)
- d) Post-and-beam (Fig. 3.2c)

Although the classification and associated design of a flat ICF wall system is relatively straightforward, the other three (waffle grid, screen grid, and post-and-beam) should be handled differently from a design/analysis perspective. Determining if a grid type of ICF wall system or a post-and-beam structurally behaves similarly to a flat wall with a number of holes (screen grid ICF wall systems) or as a concrete frame (post-and-beam ICF wall systems) requires evaluation by a licensed design professional. Application of ACI 318 to any ICF wall system should be based on generally accepted engineering practices documented by design calculations. Some ICF wall systems, due to their geometry and overall composition, can be more difficult to quantify by design calculations, and confirmatory structural testing may be required.

Another unique characteristic of most ICFs is the out-of-plane load path of the wall. For example, the load path for the transfer of a leeward wall's wind load (suction) from the point of load application to the wall's concrete core, is typically accomplished via the ICF's crossties. The crosstie of most forms is a monolithic assembly that also provides a furring strip embedded within the form material. Exterior or interior cladding elements—for example, brick veneer ties and gypsum board—are then fastened to the furring strips. Figure 6.1 illustrates an example of the crosstie element and

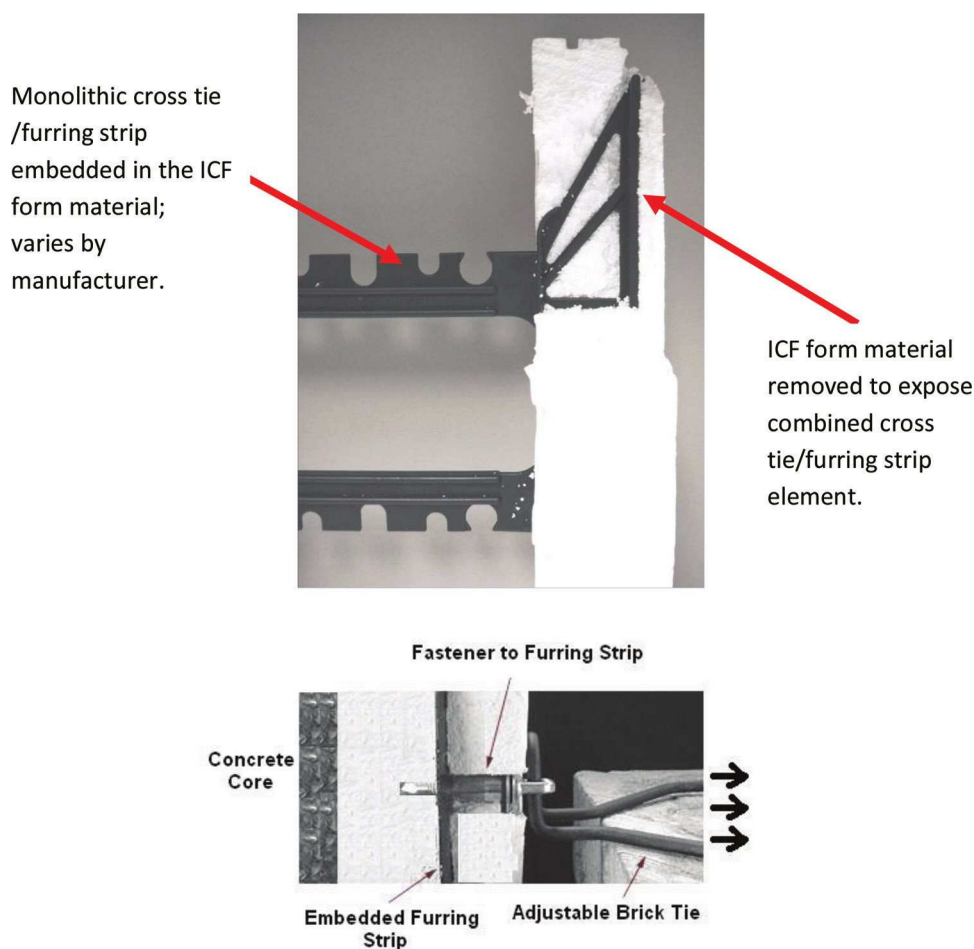


Fig. 6.1—Typical out-of-plane load path for flat wall ICF system.

the load path from a brick veneer to the concrete core. The ICF manufacturer's product literature should provide allowable loads for the crosstie elements. Additionally, this literature should provide allowable pullout loads for different fasteners into the crosstie elements. Manufacturers provide this information because the crosstie element may be a material—for example, polypropylene—that lacks standardized structural properties and is typically not analyzed or frequently used by the licensed design professional. Brick veneer ties that are fastened to crossties will exert both a tension and compression force to the crosstie via the screw attachment point.

Alternatively, out-of-plane wall load could also be directly applied to the insulation panel, which in turn transmits the load in bearing to the concrete core. Examples are windward wall pressure where an exterior finish material is directly applied to the ICF—for example, exterior insulated finish system. In the case of below-grade walls, soil presses directly against the ICF form, which typically is protected by a below-grade moisture barrier material.

6.2—Flat wall ICF systems: application of ACI 318

Design of the concrete core created by flat insulated concrete form (ICF) wall systems is no different than the design of traditional cast-in-place concrete wall systems

with removable forms. The International Residential Code (IRC-2012) and Portland Cement Association (PCA 100) place geometric constraints on the concrete core of flat wall ICF systems to use prescriptive design tables that allow designers to select the required reinforcing steel. These limitations are in addition to the overall structure limitations associated with the prescriptive method as applicable to residential construction. If the prescriptive limitations are too restrictive for a residential design under IRC-2012, or when the concrete design is per the International Building Code (IBC-2012), the licensed design professional should apply the provisions of ACI 318 to design the flat wall ICF system.

An important consideration unique to flat wall ICF systems is the number and size of crossties. Most ICFs contain a greater number of crossties than traditional removable forms. The spacing and clear cover of both vertical and horizontal reinforcement will be dictated to some degree by the locations of the form crossties. Due to numerous crossties, any locations where massing of reinforcing steel is necessary such as boundary elements of special structural walls or jambs, the reinforcing steel and crossties can create restrictions obstructing concrete placement. Additionally, the detailing of reinforcement around wall openings may require the reinforcing bars to be oriented relative to the form face. This type of bar orientation may be

problematic due to the spacing and size of the ICF's cross-ties. The licensed design professional should consider these unique characteristics and refer to the ICF manufacturer's literature during the design process to detail the reinforced concrete core, while considering the constraints created by form geometry and crossties.

6.3—Waffle grid ICF wall systems: application of ACI 318

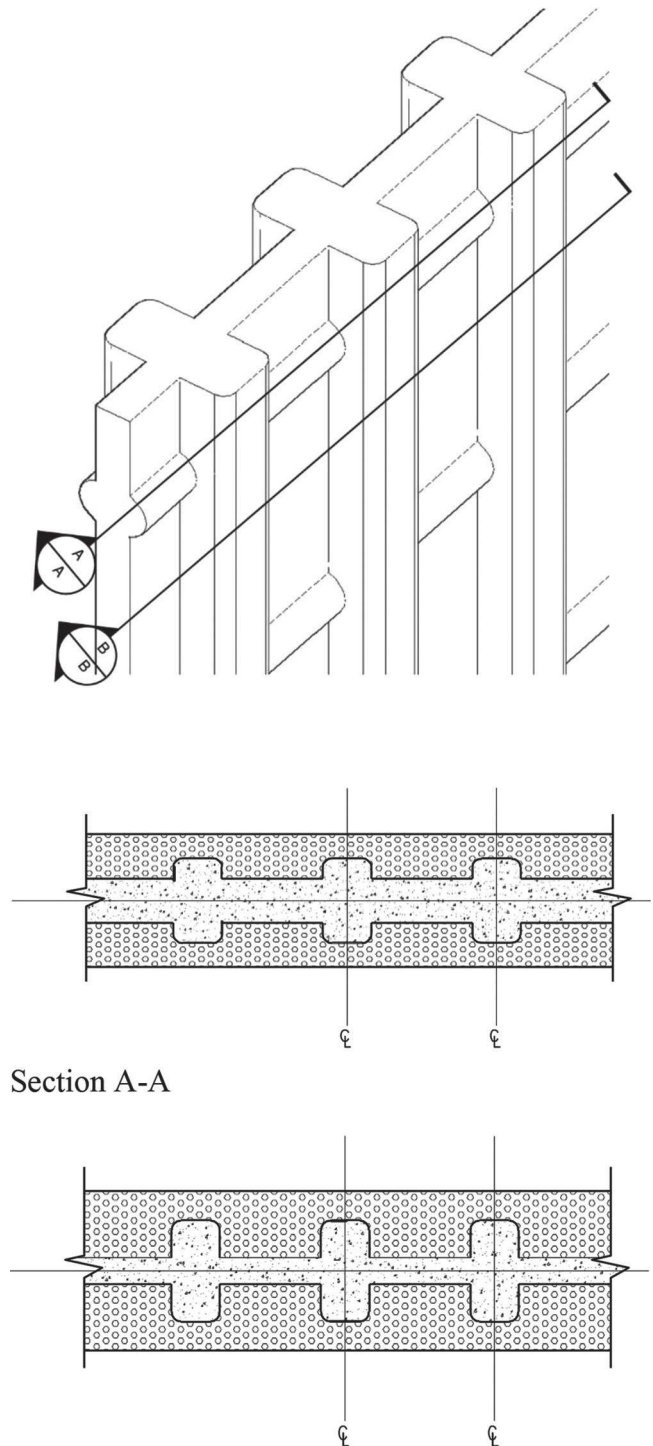
As noted previously, a waffle grid insulated concrete form (ICF) characteristically consists of closely spaced vertical and horizontal concrete members (cores) and a monolithic concrete web that is maintained throughout the wall plane. The thickness of the concrete web that is maintained will vary among ICF manufacturers. Currently, both the **IRC-2012** and **PCA 100** place geometric constraints on the concrete core of waffle grid ICF wall systems. These limits allow designers to use prescriptive design tables to select the required reinforcing steel. These limits are in addition to the overall structural limits associated with the prescriptive method used in residential construction. When prescriptive limits cannot be met for residential construction, or when the concrete design is per the **IBC-2012**, the licensed design professional should use **ACI 318** to design a waffle grid ICF wall system.

The concrete core design method for a waffle grid ICF wall system can be approached similarly to the design of flat concrete walls. ACI 318 allows walls to be designed as a column, by the simplified method, and to analyze slender walls by the alternative method.

Because the simplified method is limited to walls of solid rectangular cross section and the slender wall approach requires the wall to be of constant cross section, waffle grid ICF wall systems should be designed as columns. It is important to note that with any ICF, minimum dimensions need to be provided for the concrete core to accommodate the reinforcing bars. For example, reinforcing bar ties for compression members require minimum overall dimensions to accommodate the minimum bend radius and clear cover requirements. Application of ACI 318 for these systems is best addressed by reviewing the design method applied for each type of loading condition.

6.3.1 Wall design for axial loading and flexure—The design of a waffle grid wall system to resist axial and flexural loads begins with understanding how the applied loads are distributed to the wall's discrete elements, referred to as vertical and horizontal cores. Figure 6.3.1 illustrates an isometric view of a generic waffle grid wall system. The two horizontal sections illustrate the cross section geometry at an elevation between the horizontal cores (B-B) as well as at the elevation of a horizontal core (A-A).

Axial load can be transferred to the wall in a concentric or eccentric manner, depending on the connection details. Where a concentrated load is applied concentrically to the concrete core (for example, a roof truss or joist bearing on the top of the concrete wall), the licensed design professional can generally assume a load distribution consistent with ACI 318 guidance (ACI 318-14 Section 11.2.3), provided the mono-



Section B-B

Fig. 6.3.1—Waffle grid isometric view and plan sections (A-A, B-B).

lithic concrete web is of sufficient thickness. Current guidance restricts the horizontal length of wall considered as effective in resisting each concentrated load as the smaller of:

- Center-to-center distance between concentrated loads
- Bearing width + (4×) wall thickness

Inherent in this ACI 318 guidance is the assumption of a wall cross section of uniform thickness. ACI 318 does permit a different distribution of a concentrated load if the

validity of the distribution can be demonstrated by analysis (ACI 318-14 Section 11.2.3.1).

The ability of a thin web of a waffle grid ICF wall system to adequately distribute axial or combined bending and axial load conditions from the thinner sections of the wall to the reinforced vertical cores would require the demonstrated analysis. Thin may be considered less than minimum dimensions for walls as defined in 11.3.1.1 of **ACI 318-14**. In place of a detailed analysis or investigation of load distribution, the concentrated loads could be aligned with the vertical cores. The alignment of concentrated loads with the vertical cores logically facilitates a straightforward design and is used most frequently by licensed design professionals.

Where an eccentric concentrated load is applied to the wall, such as a ledger bolted to the side of the concrete wall, both axial load and bending moment are induced to the waffle grid ICF wall system. Most of these systems possess a monolithic concrete web of minimal thickness that usually is ill-suited to receive the connection hardware, such as post-installed anchors and embeds, unless the ICF is modified. At times, a horizontal strip of the form will be removed to allow the concrete to extend out to the interior face of the form. The increased concrete thickness in this horizontal band provides a more robust area to attach connection hardware, such as ledgers and embeds. Another option is to locate the connection hardware at the same elevation as the horizontal cores of a waffle grid wall system. Both approaches, however, result in a situation where connection hardware is attached to a horizontal core, which could lie between vertical cores. The induced moment and axial load need to be transmitted to the vertical cores where they are resisted as part of the normal load path for axial and flexural loads. An eccentric connection induces shear, bending, and torsion into the horizontal core, which then induces axial, shear, and flexural loads to the vertical cores. Analysis of this load path should consider spacing and geometry of the horizontal and vertical cores, which although challenging, is possible. Alternately, transfer the eccentric, concentrated loads directly to the vertical cores (for example, the connection hardware is mounted at the vertical cores). This approach, which provides a more direct load path, is more likely to be employed by most licensed design professionals.

Following the recommendations discussed previously, where a concentric or eccentric axial load is directly applied to the vertical core, the design of a vertical core can be performed consistent with a column as outlined by ACI 318. The vertical core is designed similar to a 1 ft (300 mm) wide strip of wall subject to axial load or combined flexure and axial load. Additionally, the minimum reinforcement associated with walls required by ACI 318 should be met. Due to their varying cross section, waffle grid ICF walls will typically be unable to comply with the minimum reinforcement requirement to place two layers of reinforcement, should the wall be more than 10 in. (250 mm) thick.

For most waffle grid ICF wall systems, the out-of-plane load on the wall, from point of application to the resisting concrete core, is similar to that of flat wall ICF systems. As with flat wall ICF systems, the ICF manufacturer's product

literature typically provides allowable loads that can be applied to the crosstie elements. The unique difference with waffle grid ICF wall systems is that when out-of-plane loads are applied directly to the ICF, the horizontal cores and the thin monolithic concrete web should transmit this load to the vertical cores, assuming the wall spans vertically. As the spacing of horizontal and vertical cores increases, the load path becomes more complex. The licensed design professional should consider the load path and the manner in which the out-of-plane wall loads are distributed and resisted by the various elements, such as the monolithic web, horizontal cores, and vertical cores of the overall concrete core.

6.3.2 Wall design for out-of-plane shear and in-plane shear loading—Out-of-plane shear resistance can be calculated by methods typically employed to transfer forces at the base of a wall, such as shear friction by reinforcement and dowels. In-plane shear resistance can be calculated by methods used for ordinary reinforced concrete structural walls, assuming the single layer of vertical reinforcement being used lies in the same vertical plane, which extends down the length of the wall. An example is the centerline of the vertical reinforcement in the cores is coincident with the centerline of the monolithic web of the waffle grid ICF wall system. The lack of ability of a waffle grid ICF wall system to incorporate detailing provisions associated with special structural walls in areas of moderate or high seismicity, and the challenge of interpreting and applying those provisions to these wall systems, make them less desirable from a design perspective.

6.4—Screen grid and post-and-beam ICF wall systems: application of ACI 318

6.4.1 Screen grid ICF wall systems: application of ACI 318—As noted previously, the concrete core of a screen grid insulated concrete form (ICF) wall system consists of closely spaced vertical and horizontal concrete members (cores) with the form material filling the voids between concrete members. As with ICF waffle systems, both the International Residential Code (**IRC-2012**) and **PCA 100** places geometric constraints on the concrete core of screen grid ICF wall systems to use prescriptive design tables allowing designers to select the required reinforcing steel. These limitations are in addition to the overall structure limitations associated with the prescriptive method as applicable to residential construction. When the prescriptive limitations cannot be met for residential construction, or when the concrete design is in accordance with **IBC-2012**, the licensed design professional should apply the wall or beam/column provisions of ACI 318 to design the screen grid ICF wall system.

The application of ACI 318 for axial loading and out-of-plane loading (flexure) for these systems is identical to the process for waffle grid ICF wall systems. Again, it is important to note that with any ICF minimum dimensions need to be provided for the concrete core to accommodate the reinforcing bars. For example, reinforcing bar ties for compression members require minimum overall dimensions to accommodate the minimum bend radius and clear distance. Considerations related to load distribution and transfer of

forces among the vertical and horizontal cores are no different between waffle grid and screen grid ICFs; however, the ability of the form to distribute the out-of-plane load to the concrete core is unique. Where the load is applied directly to the insulation panels, the insulation panel needs to perform in a structural manner to transmit the load to the concrete core; it should span between the horizontal and vertical cores. Examples are windward wall pressure when an exterior finish material is directly applied to the ICF (for example, exterior insulated finish system) or in the case of below-grade walls where soil presses directly against the ICF form. The ICF manufacturer should address this facet of the form's performance because most licensed design professionals are not equipped to evaluate the structural performance of expanded polystyrene (EPS) or other foam plastic materials.

In-plane and out-of-plane shear resistance can be calculated by methods typically employed by transferring shear forces at the base of columns, considering the vertical cores as small columns. As with waffle grid ICF wall systems, the inability of a screen grid ICF wall system to incorporate detailing provisions associated with special structural walls in areas of moderate or high seismicity, as well as the challenge of interpreting and applying those provisions to these wall systems, make them less desirable from a design perspective.

6.4.2 Post-and-beam ICF wall systems: application of ACI 318—A clear delineation between a post-and-beam ICF wall system and a screen grid ICF wall system is currently not defined by any association or consensus-based standard writing body. The combination of core spacing, vertically and horizontally, and core sizes dramatically affects the structural behavior of the system. As noted previously, exactly when the system moves from wall-like behavior to frame-like behavior is currently left to the judgement of the licensed design professional. The experience and knowledge of the licensed design professional with ICF wall systems is paramount to their successful structural performance. If a post-and-beam system mimics the structural behavior of a concrete frame, the applicable beam/column provisions of **ACI 318** would apply. Due to the usual size restrictions of wall forms, however, traditional column/beam reinforcing and detailing is not likely possible with post-and-beam ICFs. Application of ACI 318 to these systems is difficult, and in regions of moderate to high seismicity, where additional detailing is required, these wall systems should be avoided.

6.5—Other design resources for ICF wall systems

The two consensus standards for insulated concrete forms (ICFs) are **ASTM E2634** and **PCA 100**. The licensed design professional should use these documents where applicable when specifying and designing ICF wall systems. The Portland Cement Association (PCA) has a history of ICF-related research and publications (**Gajda et al. 2000**; **Gajda and VanGeem 2001**), addressing the interrelationship of the concrete core/insulated form in the performance of the wall envelope. For example, considerations such as flashing and vapor barriers have been investigated (**Gajda et al. 2000**; **Gajda and VanGeem 2001**).

In addition, there are organizations that perform technical evaluations of building products, components, methods, and materials that directly address code compliance. The evaluation's technical reports are useful to regulatory agencies, licensed design professionals, and building-product manufacturers. Agencies use these evaluation reports to help determine code compliance and enforce building regulations; designers use reports as verification of information provided on the ICFs and that intended uses satisfy code requirements; and manufacturers typically use reports as evidence that their products meet code requirements and warrant approval from local jurisdictions. This is especially important when the products are new and innovative. Several evaluation agencies provide this type of service to ICF manufacturers. Evaluation agencies should be approved by the authorities having jurisdiction (AHJ). **ISO/IEC 17065** often forms the basis of the AHJ approval. Published documents that contain content relevant to ICF wall systems including acceptance criteria (AC) are **ICC-ES AC345**, **ICC-ES AC15**, and **ICC-ES AC353**.

Acceptance criteria are developed by the International Code Council-Evaluation Service (ICC-ES) technical staff in consultation with the report applicant, who is typically the manufacturer, and with input from interested parties. The criteria are usually the subject of open public hearings of the ICC-ES Evaluation Committee (made up of code officials) and are approved by the ICC-ES Evaluation Committee after issues raised during the hearings are resolved.

ICC-ES AC15 offers minimal guidance in applying ACI 318 to ICF wall systems. ICC-ES AC15 provides more definitive guidance related to when engineering analysis, in accordance with ACI 318, is acceptable and when qualification testing should be conducted to confirm the engineering analysis. Qualification testing is denoted as being necessary for screen grid and post-and-beam ICF wall systems. In addition, if the ICF wall system is a portion of the lateral-force-resisting system in **IBC-2012** Seismic Design Categories C, D, E or F, dynamically loaded in-plane shear tests (cyclic shear tests) are necessary and one should reference **ACI ITG-5.1** as the reference test protocol.

The licensed design professional is not mandated to follow any of the aforementioned acceptance criteria, but should be aware of their existence and all other industry entities related to ICF wall system design and acceptance. In addition, local code officials and regulatory agencies may require such reports (such as those published by ICC-ES) to base the decision of code compliance or on other information.

CHAPTER 7—CONSTRUCTION

7.1—Planning the construction process

Because the majority of insulated concrete form (ICF) wall systems are modular in nature, planning is essential to an efficient construction project. The following steps provide guidance for planning a successful ICF project. They are written for a block-type ICF wall system. Other systems will require modification. Builders should follow specific recommendations provided by the ICF manufacturer. Before

the start of construction, the following information should be confirmed or clarified, with written descriptions, illustrations, or both, and made available to the builder:

- a) Concrete walls thickness
- b) Backfill depth, if the project involves foundation walls
- c) Project drawings showing the wall heights, and all rough opening sizes, including windows and doors
- d) Specified or scheduled reinforcing steel
- e) Number of courses needed to achieve the specified wall heights
- f) The bottom and top elevations of all openings

Before the ICFs are delivered to the project site, the following tasks should be completed:

- a) Lay out and construct the footings according to the project specifications and confirm the specified elevations have been achieved. An elevation tolerance of $\pm 1/4$ in. (5 mm) is recommended to mitigate problems with levelness of the ICF system (7.2).
- b) Create clear delivery access for ICF forms, for ready mixed concrete, for concrete pump trucks, and a location for equipment cleanout.
- c) Create a staging and storage area for the ICFs; if the ICF system requires field assembly, such as a knock-down system, additional space is required for assembly.
- d) Create an area for storage of reinforcing steel and ICF bracing.
- e) Create a plan for bracing and reinforcing steel to be delivered at a similar time as the ICF.

Builders should ensure they have the following before they begin:

- a) Plans and construction drawings
- b) Reinforcing steel design and schedule, including lintel design
- c) Approved concrete mixture for proper consolidation and flowability during placement
- d) Specified dimensions and the top and bottom elevations of all window and door openings
- e) Buck material (7.4.3) and temporary bracing for the window and door openings, to be installed during concrete placement
- f) ICF bracing/alignment/scaffolding system, including specified screws, for ICFs and reinforcing steel
- g) Scaffold planks and guard rails

7.2—Foundation/multiple level considerations

The builder should check that the footing is level and within a tolerance of $\pm 1/4$ in. (5 mm). Should footing elevation be out of tolerance, shimming and scribing of the first course of insulated concrete forms (ICFs) can achieve level coursing of the forms. The builder should also check that the footings are square and compliant with specified dimensions. The footing should be clean and free of any debris. Chalk lines should be placed on the footing, marking the outside dimensions of the ICF walls in addition to marks indicating the location of any openings in the wall system.

When constructing multiple-story ICF walls, there are two items that should be planned for and addressed:

- a) The interlocking patterns on the tops of ICF panels, at the top of wall elevation, at each concrete placement should

be covered to be protect the interlocking patterns from becoming filled with concrete during concrete placement.

- b) Reinforcing steel placement should allow for splices at floor-to-floor construction joints.

7.3—Reinforcing steel placement considerations

In most block-, hinged-, and panel-type systems, horizontal reinforcement is generally held in place by cross-ties and installed with each insulated concrete form (ICF) course as it is placed. Most ICF manufacturers recommend horizontal reinforcing steel be placed in alternate horizontal locations within the forms. Alternating placement location allows the vertical reinforcing steel to be lowered into position between the alternating horizontal reinforcing steel. Vertical reinforcement is typically placed after the completion of blocks comprising a typical story height. Placement of the vertical reinforcing steel in this manner enables it to be held in place with minimal tying. Some ICF manufacturers recommend placement of vertical steel between the alternating horizontal steel, directly beside the form's cross-ties, and concrete placement conducted so the concrete flows toward vertical reinforcing steel, pushing it against the crossties. The reinforcing steel should be placed to avoid congestion, which would impede the flow of concrete as it is placed. Placement and tying of reinforcement should comply with **ACI 117** tolerances.

7.4—Work implementation

7.4.1 Beginning wall construction, first and second courses—Typical block system builders start the first course of insulated concrete forms (ICFs) at the corners and place the blocks, with vertical joints, midway between the corners. The vertical joints are usually located under a window or door opening. A horizontal course of ICFs is usually tied together using wire, wire clips, or plastic zip ties, and then the horizontal reinforcing steel is placed in the first course. Upon placement of the second course, most ICF manufacturers recommend forms be stacked in a running bond pattern with a minimum overlap from block to block. The builder should check the level of the wall after stacking the second course and shim and scribe the bottom course as necessary to level the wall.

7.4.2 Installing subsequent ICF courses—An alternating stacking pattern is used so that the third ICF course is stacked following the pattern of the first course, and the fourth course is stacked following the pattern of the second course. Horizontal reinforcing steel is placed in each course as it is stacked. Typical key recommendations that most ICF manufacturers provide include:

- a) Tie the corner forms back to the next form using wire ties, zip ties, duct tape, filament-reinforced tape, or strapping.
- b) Where vertical joints occur, place strapping across the joints and screw the strapping into a minimum of two cross-ties on either side of the vertical joint.

7.4.3 Openings—Openings are formed using different types of material to frame around the perimeter of the opening, thus capping the cut ICF. The face of the ICF used to cap the open side of the ICF at the opening is often