INSULATING CONCRETE FORMS (ICFS):

A Durable Option for Mid-Rise Construction

By Lionel Lemay, PE, SE, LEED AP

Figure 1 – Apartment building built using ICFs. Image courtesy of Nudura.

ABSTRACT

Combining reinforced concrete with rigid insulation, insulating concrete forms (ICFs) provide a durable option for mid-rise apartments (*Figure 1*), condos, hotels, and dormitories. With increased attention to occupant safety and comfort, design professionals can take advantage of concrete's inherent disaster resilience, fire resistance, and noise reduction qualities. The thermal properties of ICFs offer building owners significant energy savings over the long term. This article provides guidance for architects and engineers on design and construction basics of ICF construction.

ICF WALL SYSTEMS

ICFs combine two well-established building products: reinforced concrete for strength and durability, and expanded polystyrene (EPS) insulation for energy efficiency. Typically, ICF wall units are composed of large molded EPS blocks, similar to Lego® blocks, with a cavity for concrete in the center (*Figures 2* and *3*). The blocks range in size from 48 to 96 in. (1.22 to 2.44 m) long

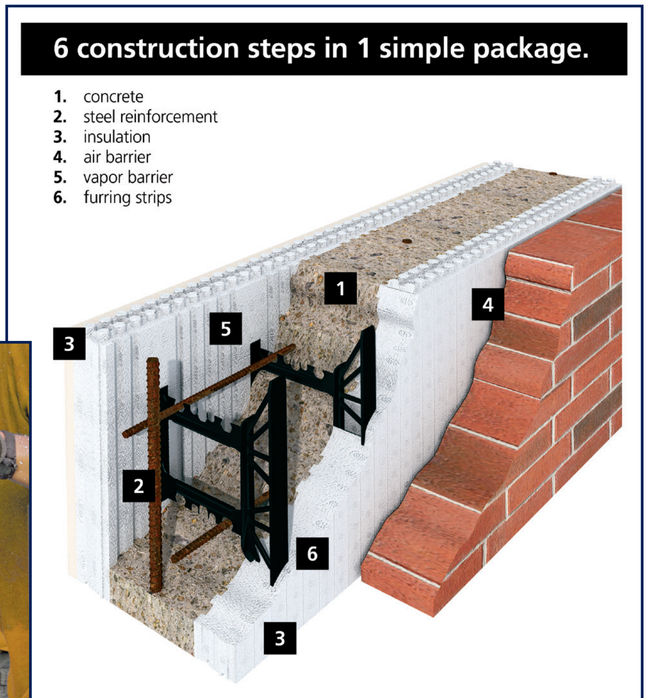

Figure 3 – Typical ICF concrete wall components. Image courtesy of Logix.

Figure 2 – Concrete being placed into ICFs. Image courtesy of Nudura.


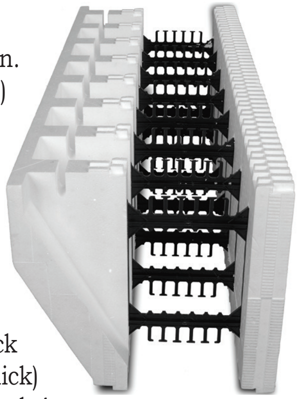
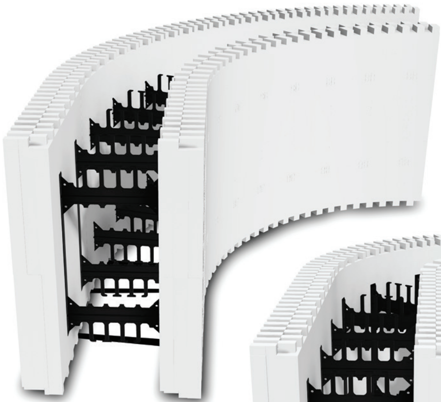
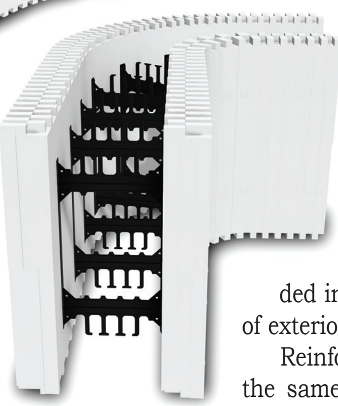
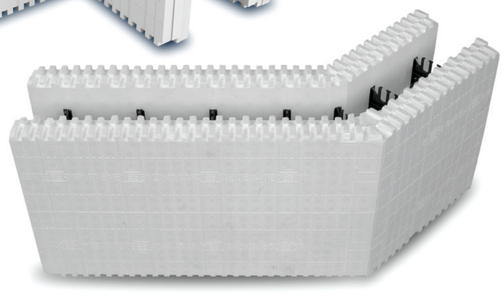

Figure 4 – Examples of ICF wall block configurations. Images courtesy of Buildblock.

and 12 to 24 in. (0.30 to 0.61 m) high, depending on the manufacturer. The most common configuration of an ICF unit is two layers of 2⅜- to 2⅝-in.-thick (60- to 67-mm-thick) EPS panels spaced 4, 6, 8, 10, or 12 in. (102, 152, 203, 254, or 305 mm) apart. The most common cavity is 6 or 8 in. (152 or 203 mm) for most low- to mid-rise buildings; but for taller buildings, taller walls, or exceptionally high loading, thicker walls are necessary. For simplicity, ICFs are generally called out by the width of the cavity; hence, an ICF with a 6-in. (152-mm) cavity is called a 6-in. (152-mm) ICF, and an ICF with an 8-in. (203-mm) cavity is called an 8-in. (203-mm) ICF, and so forth.

ICF blocks are designed to have interlocking teeth that hold the forms together much like LEGOs®. Most manufacturers not only supply straight blocks but have corner blocks, angled blocks, T-blocks, and some even have curved blocks (*Figure 4*). Most manufacturers also provide special blocks with brick ledges. Most companies supply blocks that are fully assembled and ready for installation, but some ship blocks that are folded into a flat configuration and then unfolded for installation. Other manufacturers ship blocks and ties separately that are assembled on site. Many ICF manufacturers have special window and door bucks made of wood, plastic, or steel to provide rough framing around openings to fasten window and door frames. Most manufacturers also provide accessories such as bracing, clamps, and scaffolding to make the construction process more efficient.

There are some ICFs made of other insulating materials, such as extruded polystyrene or polyisocyanurate, and with slightly different cavity configurations and shapes, but ICFs made with EPS and a flat-wall configuration dominate. This can be attributed to the fact that flat-wall ICF units are designed to create standard reinforced concrete structural elements, using the well-documented design criteria for reinforced concrete walls that is found in ACI-318.[1]

EPS insulation used for ICFs is governed by ASTM C578-19,[2] Type II closed-cell foam with an R-value of 4 per inch. Polystyrene pellets are first expanded with steam, forming high-density beads, then are injected into a mold to form the desired shape. Once removed from the molds and cured, EPS is a stable and durable material suitable for construction. No chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), or formaldehyde are used in the manufacturing process, and there is no off-gassing. EPS is moisture-resistant, non-absorbent, and resistant to mold and rot. In addition, EPS contains a flame retardant that is recyclable.

The plastic ties that hold the two sides of the block together are generally made with polypropylene plastic, but it does depend on the manufacturer. They are designed to withstand the liquid concrete pressure during construction. Most manufacturers design their ties to secure horizontal and vertical reinforcing bars into notches in the ties to minimize the need to use tie wire. Although different manufacturers provide a wide range of spacing for ties, the most common spacing is 6 or 8 in. (152 or 203 mm). The ties have no thermal bridging, they do not degrade or rot over time, and all ties have furring strips embedded in the EPS for screw-on attachment of exterior or interior finishes.

Reinforcing steel used in ICF walls is the same used for any other type of concrete structure. Typically, smaller-diameter bars are used, such as #4, #5, or #6, but larger-diameter bars can be used for higher-loading, concentrated loads and pilasters. In most cases, reinforcing steel is placed in one layer in the center of the wall at as wide a spacing as permitted by code, especially for above-grade walls built using 6- or 8-in. (152- or 203-mm) ICFs. For 10-in. (254-mm) and larger ICFs, one can consider using two layers of reinforcing—one on each face. The objective is to minimize congestion and facilitate concrete placement. In some cases, steel fibers have been used in place of reinforcing steel in ICF walls, but most common applications use both horizontal and vertical steel reinforcement.

Concrete is typically placed in ICF walls using a boom-type concrete pump (*Figure 5*), though line pumps or even conveyor belt equipment can be used. Specified compressive strength used in ICF walls is designed to meet or exceed the required structural loading, but most common compressive strength is either 3000 or 4000 psi (20 or 30 MPa). The recommended maximum aggregate size is ½-in. (13-mm) aggregate for 4- and 6-in. (102- and 152-mm) cavity

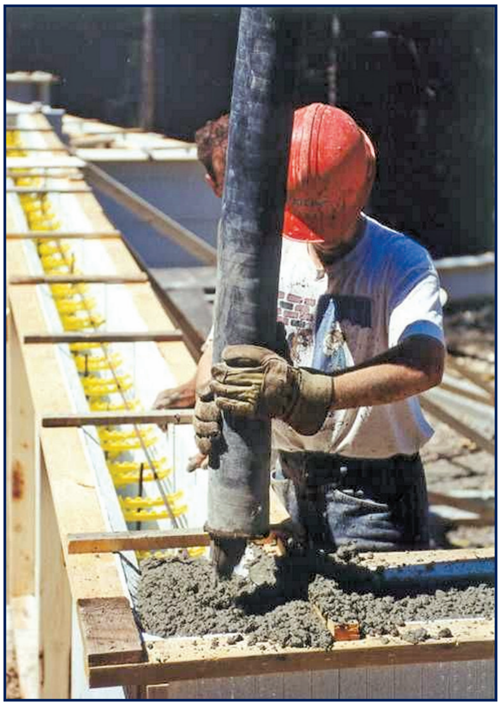

Figure 5 – Concrete is typically placed in ICF walls using a boom pump. Photo courtesy of Quad-Lock.

forms and ¾-in. (19-mm) aggregate for 8-in. (203-mm) and larger cavity forms. The required concrete slump is at least 6 in. (152 mm) but could be up to 8 in. (203 mm) to accommodate pumping using high-range plasticizers and mid-range water-reducing admixtures to achieve necessary flowability.

The concrete is typically placed one level at a time (*Figure 6*). In other words, ICF blocks are stacked in the shape of the wall for a single story. Reinforcing steel is installed as the forms are stacked. Bracing, scaffolding, and window and door bucks are installed. Once the ICF wall is plumbed and straight, concrete can be placed in 4-ft. (1.22-m) lifts. For example, a wall that is 12 ft. (3.66 m) tall would have concrete placed in three different lifts by placing 4 ft. (1.22 m) of concrete at one time for the entire length of wall. By the time the pump hose reaches the starting point, the concrete is usually stiff enough to place the second lift, and so on.

As construction continues, electrical and plumbing lines can be embedded into the interior layer of foam by cutting channels with a hot knife or other tool. Gypsum wall board on the interior, and stucco, brick, stone, or siding on the exterior are common finishes well suited to ICF construction, but nearly any finish can be applied. In most cases, interior or exterior finishes can be applied directly to the surface by screwing into the furring strips. Where finishes are subject to higher loading, ICF manufacturers supply special ties that connect through the foam insulation directly into the concrete.

Figure 6 – Construction process of ICF walls. Images courtesy of Nudura.

Step 1: ICFs are stacked in the shape of the wall, and openings for windows and doors are formed using bucks made of treated wood or plastic.
Step 2: Steel reinforcing is placed into the forms and secured in place.
Step 3: Bracing and scaffolding are installed to keep the wall straight, plumb, and secure and to provide a working platform.
Step 4: Concrete is pumped into the forms.
Step 5: Electrical and plumbing lines are installed into the EPS by cutting channels with a hot knife or other tool.
Step 6: Interior and exterior finish is installed directly to the ICFs by screwing into the embedded furring strips.

ICF FLOOR AND ROOF SYSTEMS

There are many options for floor and roof systems that integrate well with ICF wall systems. ICF walls are simply load-bearing walls made of concrete, so any floor system that is used for other types of bearing wall construction can be used in combination with ICF wall systems. These include traditionally formed reinforced concrete slabs, ICF slabs, precast hollow-core plank, or concrete on metal deck, combined with steel joists or cold-formed joists. Wood framing systems for floor construction can also be adapted for connection to ICF walls using embedded ledger bolts.

However, there are several manufacturers of ICF floor and roof systems. Just like ICF wall systems, ICF decks combine EPS insulation

CASE STUDY:
West Village Student Housing at Texas Tech University, Lubbock, Texas

Figure 7 – West Village Student Housing at Texas Tech University. Image courtesy of Mackey Mitchell Architects.

A design-build project with Whiting-Turner, BGK Architects, and Mackey Mitchell Architects this 230,000-sq.-ft. (21,368-m^2) West Village student housing complex at Texas Tech University (*Figures 7* and *8*) implemented fast-track construction methods to deliver the project within an incredibly compressed schedule—16 months for design and construction.

Opened in 2014, this $54.8-million project contains 455 beds and was designed to meet LEED certification serving as a model for Texas Tech's newly adopted sustainability initiatives. Expected to reduce energy consumption by at least 20% over a typical residence hall, West Village utilized ICF walls and precast hollow-core floors, which delivered a highly energy-efficient, structurally solid, fire-resistant, and acoustically sound dormitory.

Figure 8 – West Village Student Housing under construction. Image courtesy of Fox Blocks.

with reinforced concrete to form a strong and energy-efficient floor or roof system. Ideal for use in both commercial and residential construction, ICF floors combine the strength, security, and reliability of reinforced concrete with energy efficiency, fast construction, and comfort. Many of the ICF wall system manufacturers carry a version of ICF floor and roof systems that interface well with their wall system (*Figure 9*).

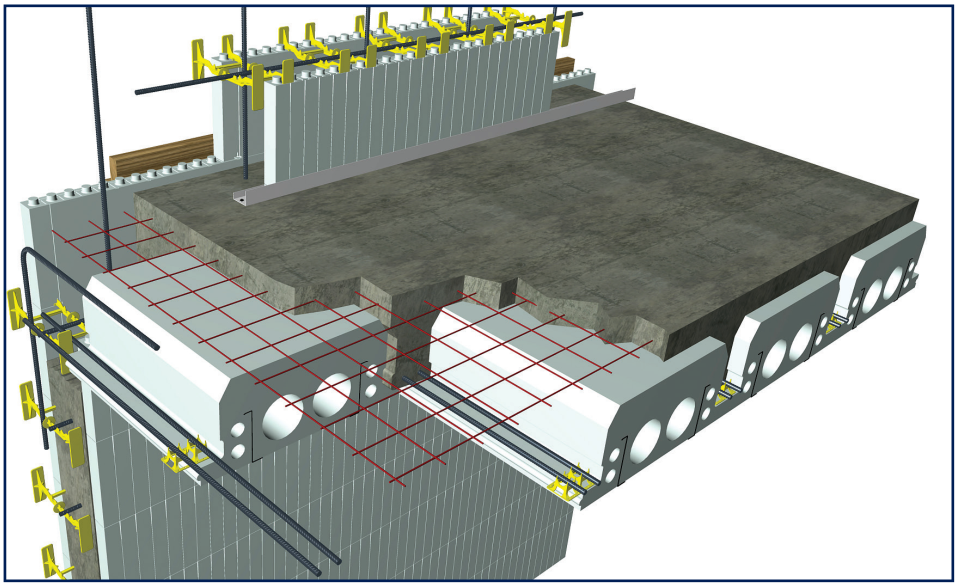

Figure 9 – Typical ICF wall to floor/roof connection detail. Image courtesy of Quad-Lock.

CASE STUDY: 17 South, Charleston, South Carolina

Figure 10 – 17 South Apartments. Image courtesy of EYC Companies.

Figure 11 – 17 South Apartments under construction. Image courtesy of Amvic.

The builders of this 220-unit multifamily apartment complex (*Figures 10* and *11*), EYC Companies, know that strength and durability of the building directly affect the safety of their tenants. And so, they opted for ICFs for the exterior walls for their showcase development. Not only are these buildings safe from high winds and coastal flooding, but they are extremely energy efficient, allowing EYC to master meter the entire complex and pass the energy savings on to the tenants. In addition, EYC opted to install the ICF walls themselves instead of using a subcontractor, which further saved time and money during the construction process, making the project a win-win for both the building owner and his tenants.

PERFORMANCE CHARACTERISTICS OF ICF CONCRETE

Strength and durability

ICF structures are essentially reinforced concrete structures and therefore can be designed to resist high loading. The solid walls act as shear walls to resist wind and earthquake loading following the design criteria for reinforced concrete walls in ACI 318. ICF walls also provide protection from flying debris from hurricanes and tornadoes, according to Federal Emergency Management Agency (FEMA) publication FEMA P-361.[3] Both concrete and EPS are considered flood-damage-resistant building materials (rated as class 5 building materials, the highest classification) according to FEMA, and can be used below base flood elevation (BFE).[4]

Fire resistance

Most ICF manufacturers have tested their products in accordance with standard fire testing protocol, including ANSI/UL 263[5] and ASTM E119-07[6]. In general, 4-in. (102-mm) ICF walls achieve a two-hour fire rating, 6-in. (152-mm) ICF walls achieve a 3- or 4-hour fire rating, and 8-in. (203-mm) and thicker ICF walls exceed a four-hour fire rating. Generally, the assemblies tested include reinforced concrete with a minimum compressive strength of 2,900 psi (20 MPa)

CASE STUDY: Hilton Garden Inn, Lewisville, Texas

With the objective of keeping their guests safe, secure, and comfortable, Hilton Garden Inn in Lewisville, Texas (*Figures 12* and *13*), chose ICF construction for their six-story hotel and convention center. Eight-inch (203-mm) ICF walls were used on the first two levels, and 6-in. (152-mm) ICF walls were used for the top four levels. Hollow-core precast concrete planks were used for the floors. The result is a fire-resistant concrete building with the added benefits of energy efficiency, durability, and peace and quiet.

Figure 13 – Hilton Garden Inn, Lewisville, Texas, under construction. Images courtesy of Nudura.

Figure 12 – Hilton Garden Inn, Lewisville, Texas. Image courtesy of Nudura.

CASE STUDY: Beach Green Dunes, Rockaway, New York

This 101-unit, 94,000-sq.-ft. (8,733-m^2) apartment building (*Figure 14*) was built in an area devastated by Hurricane Sandy in 2012. The Bluestone Organization selected ICFs for exterior, corridor, and demising walls, as well as precast hollow-core floors for disaster resilience and energy efficiency. The building is so energy efficient it is certified by the Passive House Institute. ICFs create a solid concrete wall with continuous insulation, resulting in a comfortable and airtight structure that lowers energy bills. The reinforced concrete system results in a structure that is strong, durable, and can stand up to fire, floods, and wind.

Figure 14 – Beach Green Dunes apartments. Photo © Peter Mauss/Esto.

and ½-in. (13-mm) gypsum wall board on each side.

The EPS used for ICFs is manufactured with flame retardants that render the EPS insulation completely unable to support a flame without an outside flame source. EPS used for ICFs is required to have a flame spread index of less than 25 and smoke-developed rating of less than 450 when tested in accordance with ASTM E84-19[7] and ANSI/UL 723.[8]

Energy efficiency

ICF walls are considered by the IECC[9] and ASHRAE 90.1[10] as mass walls with continuous insulation. Typical whole-wall ICF assemblies have an R-value between R-24 and R-26, depending on the exterior and interior finish materials, compared to similar R-11 and R-19 for 2x4 and 2x6 wood frame assemblies. In addition, because the center of the ICF walls are made with reinforced concrete containing high thermal mass, they typically are more energy efficient than light-frame construction.

Achieving a high-performance building envelope also means minimizing air leakage, and ICF walls typically have lower air-infiltration rates than wood frame or light-gauge steel walls. In tests, they averaged about half as much air infiltration as wood frame. In many cases, the air infiltration rates are as low as 0.5 air changes per hour. Thermal bridging is also eliminated with ICF walls when compared to wood and light-gauge steel.

Noise and vibration

Noise transmission in residential buildings is also important—to reduce noise between units and from the outside. The concrete core of ICF offers excellent noise control in two ways. First, it effectively blocks airborne sound transmission over a wide range of frequencies. Second, concrete effectively absorbs noise, thereby diminishing noise intensity. Because of these attributes, ICF walls and floors have been used successfully in multifamily, hospitality, theater, and school applications.

Six-inch ICF walls typically achieve Sound Transmission Classification (STC) rating of 55. Higher STC ratings up to STC 70 can be achieved with additional gypsum wallboard or special isolation channels. For ICF floors, most meet STC 50 or higher and Impact Insulation Class (IIC) of 50 or higher, depending on the floor and ceiling finish.

Initial Cost and Long-Term Value

ICF construction can help contain construction costs because of the inherent efficiencies of the installed assembly that serves nine functions:

CASE STUDY: The Ricchi, San Antonio, Texas

Figure 15 – The Ricchi condominiums. Image courtesy of Ricchi Group.

The Ricchi in San Antonio, TX, is a contemporary mid-rise building consisting of 87 luxury condominiums (*Figures 15* and *16*). The developers wanted to provide a first-class, secure, and quiet building and chose ICF as part of the plan to achieve their goal. Noise reduction was a major consideration for this project. The Ricchi is located directly below the flight path for airliners approaching San Antonio's international airport and is adjacent to a U.S. Army training camp. The sound attenuation offered by ICFs provided a solution to those concerns while creating significant energy savings. The higher insulation provided by the ICF walls reduced HVAC tonnage by 20 percent.

Figure 16 – The Ricchi condominiums under construction. Image courtesy of Fox Blocks.

1. Concrete form (that stays in place)
2. Thermal barrier
3. Air barrier
4. Moisture barrier
5. Fire barrier
6. Sound barrier
7. Substrate for running utilities
8. Substrate for attaching finish materials
9. Reinforced concrete structure

In conventional construction, many of these features are provided by several different trades, usually at significant added cost. ICF construction embodies all of these characteristics in a simple assembly, usually installed by one crew. This means the general contractors can realize a number of on-site efficiencies, including fewer trades on site, reduced crew size, and an accelerated construction schedule. Because construction schedules are usually much shorter with ICF construction, the general contractor is able to finish on time and within budget. The building owner is able to put the building into service sooner, cutting short his or her financing costs and initiating a quicker revenue flow.

In general, ICF construction costs can equal wood- or steel-frame construction. Building with large ICF units instead of individual, small framing elements such as dimensioned lumber or cold-formed steel can save on initial cost. In addition, the lower floor-to-floor heights of ICF walls and concrete floors (precast plank or ICF) can

CASE STUDY: Martin Hall and New Hall B, Eastern Kentucky University, Richmond, Kentucky

Figure 17 – Martin Hall at Eastern Kentucky University. Image courtesy of Nudura.

Eastern Kentucky University chose ICFs for walls and hollow-core planks for floors for two recent dormitories–the 199,480-sq.-ft. (18,532-m2) Martin Hall and 165,580-sq.-ft. (15,383-m2) New Hall B. Each structure features a recreational room, private and group study areas, a community kitchen, a large multi-purpose room, and two classrooms. The concrete floor design allows for shallow floor-to-floor heights and ease of construction. Additionally, lower floor-to-floor heights save on exterior finish and mechanical runs. The lateral load-resisting system includes concrete shear walls designed to provide stability against wind and seismic forces.

Figure 18 – Martin Hall at Eastern Kentucky University under construction. Image courtesy of Nudura.

help reduce the overall height of a building, which means additional savings from reduced exterior and interior finishes and reduced mechanical, electrical, and plumbing lines, which can be significant.

CONCLUSION

ICFs represent an advancing technology. There are thousands of examples of ICF buildings all over the U.S., Canada, and other parts of the world. ICFs can add value to any type of construction project, but the added fire safety, energy efficiency, and noise reduction qualities make them a good candidate for mid-rise multifamily construction. The most common ICF brands have similar dimensions and, thus, architects can design a building with ICFs without having to design it to a specific manufacturer's specifications. Most of the larger ICF companies have standard specifications, design details, and design manuals to help architects and engineers with the design process.

The largest ICF manufacturers have all the necessary testing required to meet the latest building code requirements, including for fire, energy, sound transmission, and structural design. In addition, because ICFs save so much energy over time, they can help meet LEED and other green building standards. Although ICFs are unique in the sense that the insulation is installed before the structure is installed, in the end the design details are the same as if you installed conventionally formed concrete bearing walls and then attached rigid insulation to the wall.

The best way to find out about ICF construction and concrete construction in general is with Build With Strength, a coalition of the National Ready Mixed Concrete

Association (www.BuildwithStrength.com), and with the Insulating Concrete Forms Manufacturers Association (ICFMA) at www.icf-ma.org.

ENDNOTES

1. ACI 318-19, *Building Code Requirements for Structural Concrete and Commentary*
2. ASTM C578-19, *Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation*
3. FEMA P-361, Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms, Federal Emergency Management Agency
4. Technical Bulletin 2, "Flood Damage-Resistant Materials Requirements for Buildings Located in Special Flood Hazard Areas" in accordance with the National Flood Insurance Program, Federal Emergency Management Agency
5. ANSI/UL 263, *Standard for Fire Tests of Building Construction and Materials*
6. ASTM E119-07, *Standard Test Methods for Fire Tests of Building Construction and Materials*
7. ASTM E84-19, *Standard Test Method for Surface Burning Characteristics of Building Materials*
8. ANSI/UL 723, *Standard for Test for Surface Burning Characteristics of Building Materials*
9. IECC, International Energy Conservation Code
10. ASHRAE 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*

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Lionel Lemay is executive VP of structures and sustainability for the National Ready Mixed Concrete Association (NRMCA). He leads a team of professionals to offer building owners and designers cost-effective, durable, and sustainable concrete building solutions through education, research, and design assistance. He has written many articles and co-authored several books on concrete design and construction. Lemay holds a bachelor's and master's degree in civil engineering from McGill University in Montreal, Canada.

Artist's concept, courtesy of 3XN Architects.

T3 Bayside is currently under construction on the shores of Lake Ontario in Toronto's Bayside community. The 10-story structure will be 42 m (138 ft.) tall upon its completion – the tallest timber office building in North America. A second building of similar size and construction is planned next to it.

Built in cross-laminated timber (CLT), the interior aesthetics will also be reflected in the exterior, with exposed timber and open floor spaces. The structure, designed by Danish architecture firm 3XN, is planned for a LEED® Gold rating.

Plans are for it to be part of a master-planned community which will include two million square feet of luxury condos, shopping and restaurant destinations, cultural venues, and walking promenades along the water's edge.