

# NU Precast Concrete House Provides Spacious and Energy Efficient Solution for Residential Construction



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*In 1990, the University of Nebraska-Lincoln began conducting research to develop a novel precast concrete alternative to traditional wood framing for residential homes in the United States. The main objective of this effort was to produce a new housing system, called the “Nebraska University (NU) Concrete House,” a precast concrete design that would offer superior benefits over conventional construction, including resistance to fire, termites, high winds and storm damage; reduction in home maintenance, dust, and noise; and high energy efficiency for homeowners. Research focused on three new precast concrete systems—a patented fully insulated exterior sandwich wall panel, a floor joist panel, and an under-roof girder framing system designed for fast assembly. The NU Concrete House used only bolted connections, eliminating the need for welding or grouting during erection.*

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Fig. 1. A precast concrete home demonstration project was built for the first time in the United States in 2003.

Research at the University of Nebraska-Lincoln that led to the development of the “Nebraska University (NU) Concrete House” began in 1990 with sponsorship from the U.S. Department of Energy, the Precast/Prestressed Concrete Institute, and other organizations. The impetus for developing a precast concrete design for residential housing was based on the advantages that precast concrete structures offer over traditional wood frame homes. These include material quality control; rapid erection; resistance to fire, high winds, and insect damage; and superior thermal efficiency.

Three new elements were the focus of the research efforts at the university: a fully insulated exterior sandwich wall panel system (patented by the University of Nebraska), a precast concrete floor joist panel system, and an under-roof girder framing system. All precast concrete wall and floor elements for the project were produced by Enterprise Precast Concrete, Inc., of Omaha, Nebraska. The precast hollow-core under-roof girder elements were produced by Concrete Industries, Inc., of Lincoln, Nebraska.

As a culmination of the university’s research efforts, in 2003 a precast concrete home demonstration project of a two-unit (duplex) home was built for the first time in the United States (see Fig. 1). Despite being a novel design to the U.S. housing market, all indications have been that this precast concrete system is cost competitive with

traditional wood framing and, perhaps more importantly, that public perception is changing to a higher degree of acceptance of new concrete designs for home building.

## RATIONALE FOR RESEARCH

The devastating effects of tornados, hurricanes, fires, and termites have increased public awareness of the inherent weaknesses of conventional wood framing for residential construction. But the susceptibility of traditional structures to the unpredictable forces of nature is not the only concern for potential home buyers. With gas, electric, and fuel prices escalating to unprecedented levels through 2004 and into 2005, the increased costs of home heating and air conditioning have generated an economic rationale for seeking alternative, highly energy efficient home framing systems in the United States.

Although the concept of building houses with concrete is still not widely perceived as a realistic alternative to traditional wood framing in the United States, several systems have emerged as both viable and cost effective.<sup>1-3</sup> Types of concrete home building systems have included concrete masonry units (CMU) and insulated concrete forms (ICF) for walls. In both CMU and ICF applications, concrete units are set up on-site, reinforced with steel bars, and grouted with concrete.

Several plant-manufactured precast concrete panel housing systems have been attempted and reported in the lit-

erature. The system described in this paper is unique in that it uses a highly energy efficient 10 in. (250 mm) thick sandwich wall panel patented by the University of Nebraska.<sup>4,5</sup> Special fiberglass bar connectors are installed between the two 2.5 in. (64 mm) wythes, allowing the panel to be fully engaged as a 10 in. (250 mm) thick structural wall. Insulation of 5 in. (127 mm) thick rigid board establishes an excellent wall R-rating of over 25. This superior insulating capacity is achieved because the meticulously designed structural wall connections prevent thermal bridging and loss of thermal efficiency. Previous lab specimens involved a concrete wythe thickness of 2 in. (50 mm) and insulation thickness of 6 in. (150 mm), resulting in an R-value of about 32. However, due to the desire to have 0.5 in. (13 mm) thin clay brick tile facing, the concrete thickness was raised to 2.5 in. (64 mm).

## Changing Public Perception

Presently, a significant obstacle confronts the advancement and acceptance of precast concrete as a viable alternative to wood—that is, the general public’s perception that a concrete design means high cost, lack of design flexibility in initial construction, and restrictions to remodeling. Although the NU Concrete House system does not fully overcome these perceptions, the authors are confident that the new system’s overriding conservation and

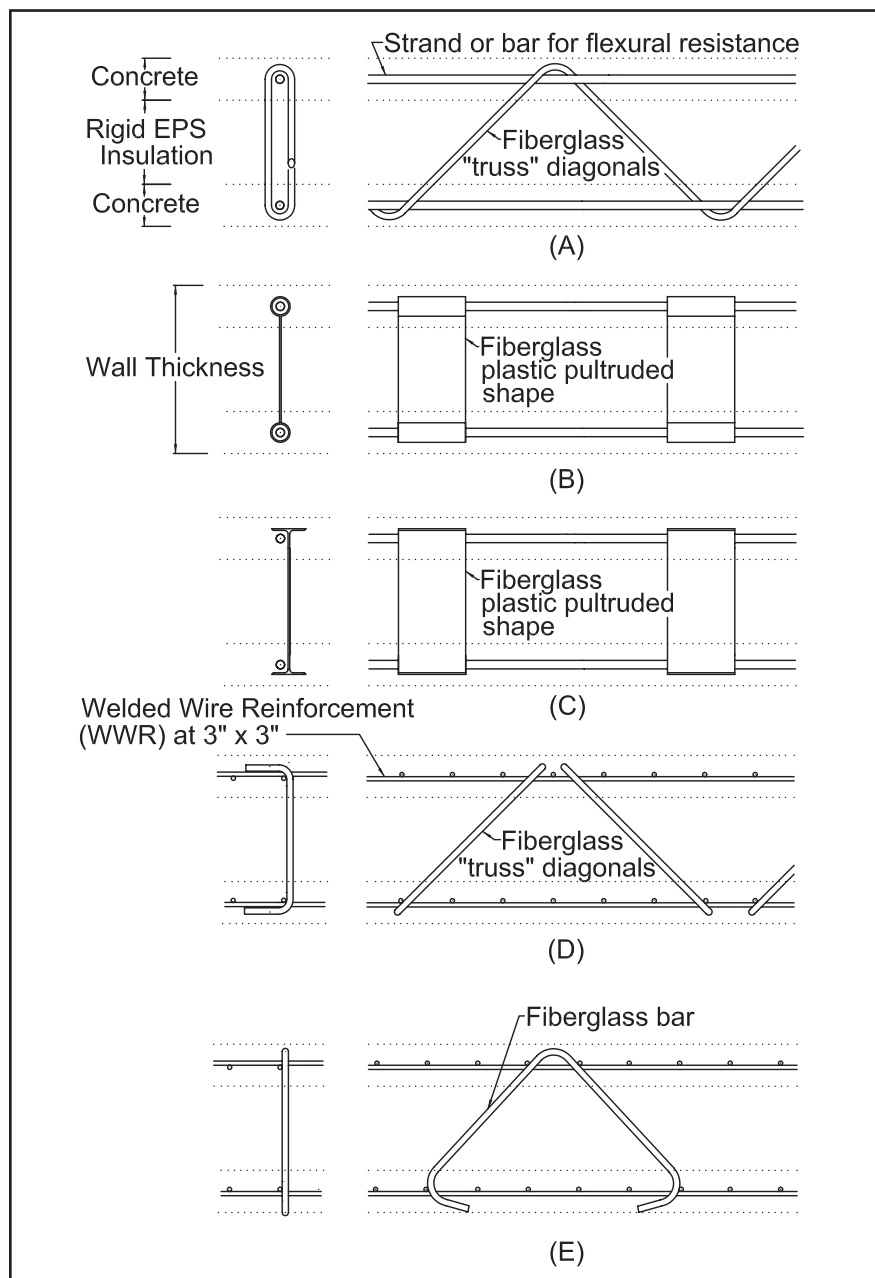


Fig. 2. Precast concrete sandwich panel with various connection details to achieve full composite action without thermal bridging: Details (A), (B), and (C) are examples of details shown in the University of Nebraska Patent 5,440,845; Detail (D) is the one used in the NU House; and Detail (E) is the most recent, used in the Oak Park Condo Project.



Fig. 3. Fiber reinforced shear connector.

safety advantages—superior energy efficiency, strength, and resistance to damaging natural forces—will outweigh any perceived disadvantages.

Because of the confidence of the NU research team in the structural viability and marketability of the proposed system in the U.S. housing market, the authors believe that application outside the United States, where concrete housing is more common, is even more promising. Unlike the U.S. housing market, there is substantially more construction and higher public acceptance of concrete homes in Europe—particularly in Germany and Holland—as well as the Middle East, Mexico, and South America. This greater popularity of concrete homes in other countries is due to differences in culture, history, and the economic availability of various construction materials.

### Competitive Advantages

The NU Concrete House offers significant competitive advantages over traditional wood construction systems for residential homes. These include:

**1. Material durability.** Precast concrete housing provides exceptional long-term durability and requires little or no conventional home maintenance, such as painting, staining, weatherproofing, or aluminum cladding. Resistance to fire and natural disasters such as tornados, earthquakes, and flooding are measurable benefits of a concrete domicile. Insects and dry rot can lead to severe structural damage in any wood-framed home. It is important to note that a new and aggressive invasive species of termite is spreading rapidly through the southern and coastal United States (see sidebar, “Invasive Formosan Termite Ravages the French Quarter”). Obviously, many of the drawbacks of conventional wood-frame homes will not adversely affect a concrete structure.

**2. Variety in architectural finish.** Numerous architectural treatments are possible with precast concrete. Many high-quality surface textures, colors, and finishes are now available with precast plant production methods. Permanent brick and “stucco” exterior finishes offer even more options for architectural designs.

**3. Sustainability and environmental friendliness.** Precast concrete is an environmentally friendly or “green” material for construction. The thermal mass of concrete and the high insulation efficiency of precast concrete systems save non-renewable energy resources through lower fuel and electric costs. Also, a precast concrete envelope maintains steady indoor comfort throughout seasonal and diurnal temperature fluctuations.

**4. Open, flexible design.** Concrete home framing establishes long open spans with loadbearing external wall panels, eliminating the interior support walls and columns of conventional wood construction and creating unobstructed interior spaces. Such structurally open space allows for maximum flexibility in interior design options and offers homeowners creative room layout potential, with minimal structural restrictions on future remodeling. With a standard precast concrete structure, it is possible to achieve ceiling heights of 10 ft (3 m) or more at virtually no additional cost. The height of precast wall panels defines the popular cathedral ceilings, great rooms, and tall window treatments favored by many of today’s upscale housing designs. In regions with high snowfall loading, where roofs with steep slopes are necessary, the use of flat precast concrete roof beams creates usable attic space with adequate headroom for easy conversion into modern lofts or studio apartments. An upper story loft or extra

bedroom is both costly as a construction add-on and difficult to structurally accommodate within the typical design confines of a wood truss roof system.

**5. Lower long-term maintenance costs.** Because precast concrete exteriors maintain their just-built look with little maintenance and their operating costs are much lower than those of a conventional wood house, the concrete building retains high resale value over time. These energy and maintenance savings, and the retention of real estate investment value, are measurable economic benefits for any potential home buyer.

## DETAILS OF NEW PRECAST ELEMENTS

Precast concrete sandwich wall panels are structurally and thermally efficient building elements, and have been used in residential, commercial, and warehouse buildings for a long time. Those used in current practice are designed as either non-composite or composite sections.

Non-composite panels consist of a thick structural wythe and a thin non-structural facing wythe, connected by plastic or steel pins through a layer of insulation. The panel is relatively thick, creating a spatial inefficiency relative to the floor area.

Composite panels consist of two wythes of equal thickness, connected through the insulation with steel trusses and concrete stems. Although the struc-

tural efficiency of a composite panel is quite high, its energy efficiency is low because both steel and concrete are highly thermally conductive materials. Any penetration of the wall’s insulation with a conductive material like steel or concrete, even if the connection area is as small as 2 percent of the surface of the insulation, can result in an overall loss of insulation efficiency of up to 40 percent. In addition, wall areas penetrated with steel or concrete reflect a thermal gradient on the inside wall surface in the form of moisture condensation.

## Sandwich Wall Panel

The NU sandwich wall panel is both a totally composite and a fully insulated system. Based on a patented design, the NU Concrete House incorporates a sandwich wall panel consisting of two relatively thin concrete wythes and an in-between layer of insulation. During its manufacture, the insulation is placed such that it produces full structural composite action and establishes an uninterrupted thermal barrier between the wythes.

Concrete wythes in the NU sandwich panel are connected through the insulation layer with fiber reinforced plastic (FRP) bars that are specially formed. Fig. 2 illustrates the variety of achievable shapes from the “ideal stretched paper-clip” shape given in the patent disclosure to the seemingly less structurally efficient but more cost-effective shapes. Recent testing at the University

## Invasive Formosan Termite Ravages the French Quarter

In 1998, the U.S. Department of Agriculture began a \$5 million termite-control program (Operation Full Stop) to halt the infestation and rapid spread of an invasive, aggressive species, the Formosan termite. New Orleans, Louisiana, has the worst Formosan termite infestation in the United States, with structural damage estimated at \$300 million annually.

In New Orleans’ historic French Quarter, the old wooden Spanish architecture and humid coastal climate present ideal conditions for these formidable wood-eating insects; here, the Formosan termite can cause almost complete destruction of a structure in only two years, with little or no warning to the human residents. Believed to be brought to U.S. shores by naval ships returning from the Pacific Theater after World War II, this alien insect displays a horrific appetite for any material containing wood fibers. Its prolific spread is evident in many other coastal states, including California and Florida. A large 8 x 1 ft (2.4 x 0.3 m) carton nest houses several million industrious individuals, and a typical termite colony will easily produce over 2000 eggs per day. It is common to find termite carton nests in walls and ceilings as well as beneath floors, as this opportunistic subterranean species is able to enter a structure via the ground, or through upper stories in its winged stage. With stealth and organizational skills that would be the envy of any modern army, the Formosan termite has thwarted current conventional insect control technology. The invasive, fecund, and highly successful Formosan termite is now considered to be the most significant structural pest of the new millennium.



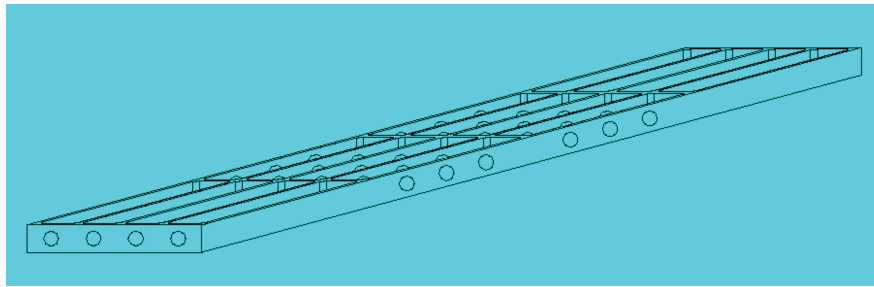


Fig. 4. Isometric view of precast floor panel.

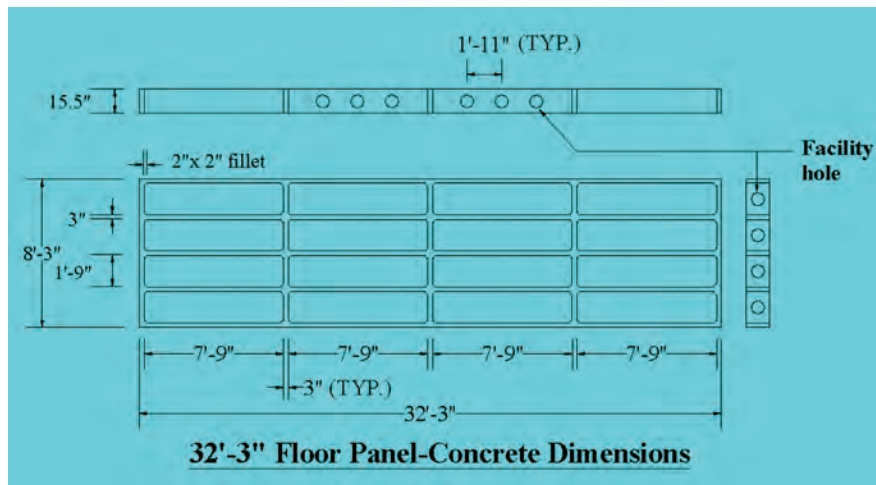


Fig. 5. Plan view of precast floor panel.

of Nebraska, yet to be published, has demonstrated adequacy of the anchorage provided by the latest shape [see Fig. 2 (E)], while avoiding threading the flexural reinforcement through the connector. In this project, the connectors were C-shaped as shown in Fig. 2 (D) and Fig. 3. The connector lines run along the height of the wall panel and are spaced at 2 or 3 ft (0.6 or 0.9 m) on center within the panel. The connectors transfer the shear forces from one wythe to the other, thereby allowing the full panel thickness to effectively resist external forces. Fiberglass was chosen because of its excellent thermal insulation properties, as compared to carbon fibers and steel.

In each concrete wythe, a welded wire reinforcement (WWR) sheet, designated as 3 × 3-D10 × D10 with a steel grade of 550 MPa (80 ksi), is placed at mid-thickness. The relatively narrow spacing between wires in the grid helps distribute forces and control cracking. With WWR, no individual steel reinforcing bars are required, and as a basement foundation wall, the precast concrete panels can resist full soil pressure.

The panel is strong enough to resist hurricane level wind forces—exceeding 160 miles per hour (260 km/hr)—in above-grade applications with no additional reinforcement.

### Floor Joist Panel System

The second element of the NU Concrete House design is its precast floor joist panel system. Designed in accordance with established requirements,<sup>6,7</sup> the main components of this panel system are the thin longitudinal prestressed concrete joists held together with cross-ribs to form an open grid joist panel.

Longitudinal joists are spaced at 2 ft (0.6 m) on center to allow for standard ¾ in. (19 mm) plywood sheeting to be placed as a sub-flooring skin for carpet or tile. Floor joist cross-stems are spaced at 8 ft (2.4 m) or less to brace the longitudinal stems against buckling and to provide floor diaphragm action (see Fig. 4).

Each precast concrete longitudinal stem is 3 in. wide by 15½ in. deep (75 × 394 mm). Two to five longitudinal stems may be connected together with

cross-ribs to form a panel. A panel consisting of two longitudinal stems is 2 ft 3 in. (0.675 m) wide. With prestressing, the panel can span up to 40 ft (12 m) without any intermediate supports below. This advantage provides the homeowner with more layout alternatives in planning basement recreation rooms, lower level bedrooms, or workout areas.

Precast concrete cross-ribs permit panel erection without bracing or bridging. Panels can be made of prestressed, post-tensioned, or conventionally reinforced concrete members. In the middle zone of the panel stems, 8 in. (200 mm) diameter openings provide adequate space for mechanical and electrical hardware within the floor depth (see Fig. 5).

The efficacy of providing relatively large openings in precast concrete flexural members was based on extensive theoretical and experimental research at the University of Nebraska—results that were later adopted in the *PCI Design Handbook*.<sup>7,8</sup> This precast concrete floor may be covered with plywood, oriented strand board (OSB) or any other plate material capable of spanning the 2 ft (0.6 m) gap between ribs. The underside of the floor panel may be finished with gypsum wallboard or other ceiling finishing systems.<sup>9</sup>

The floor panels used in this project can be positioned in contact with one another or spaced apart at intervals as large as 2 ft (0.6 m). Designers can select the optimum length and width of the panels to suit desired overall floor dimensions. The system eliminates vibration and floorboard squeaking, an annoying problem with many wood joist systems. The weight of the floor panels is equivalent to a 2¼ in. (57 mm) thickness of solid concrete, making this product much lighter than any other concrete floor system available in the U.S. market.

The vertical dimension of the longitudinal stem establishes a base for masonry wall coursing if the designer elects to use this floor system with brick or stone. The center-to-center spacing of longitudinal stems integrates well with the use of standard 4 × 8 ft (1.2 × 2.4 m) plywood sheets, with little waste. Other standard cross-rib spacing dimensions of 2, 3, and 4 ft (0.6, 0.9,



Fig. 6. Formwork and reinforcement of a concrete panel.

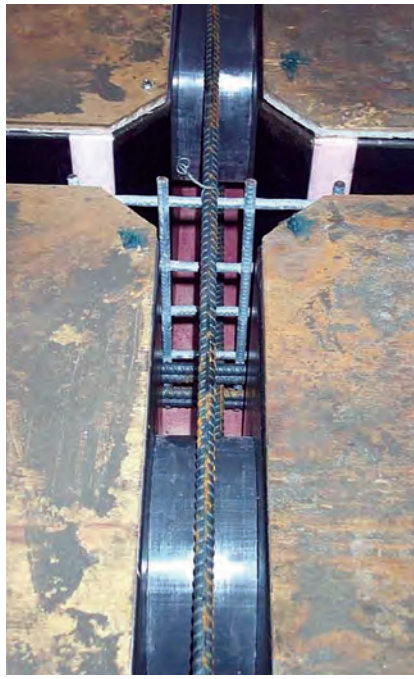


Fig. 7. Detail of area with a tube inserted to create a void in a panel.



Fig. 8. Special design plate installed in floor panel to be used as a connection to the precast sandwich wall panels.

and 1.2 m) help the designer select any panel length between 8 and 40 ft (2.4 and 12 m), in increments of 1 ft (0.3 m). Intermediate stems are 3 in. (75 mm) wide, and end stems vary between 3 and 9 in. (75 and 225 mm) in width to allow for fractional panel lengths.

### Roof Beam Concept

The precast roof beam concept was developed as a consequence of the specific subdivision specifications for the demonstration house site in Omaha, Nebraska. Early in the project planning, it was determined that a total precast concrete roof system would not be economical because the roof appearance needed to match the architectural style of other houses in the development complex.

Subdivision requirements called for a vertical-to-horizontal roof pitch of 3:4 and several dormers, creating a large number of ridges and valleys — a rather complex roof geometry. Thus, wood framing was chosen for the upper roof of the project with the understanding that a total precast concrete design would be attempted in a follow-up project.

Both a challenge and an opportunity were created by the fact that a standard wooden roof truss could not bridge the 55 ft (16.5 m) span between exterior precast walls. The long span of the pre-



Fig. 9. Side view of concrete floor panels at precasting plant.

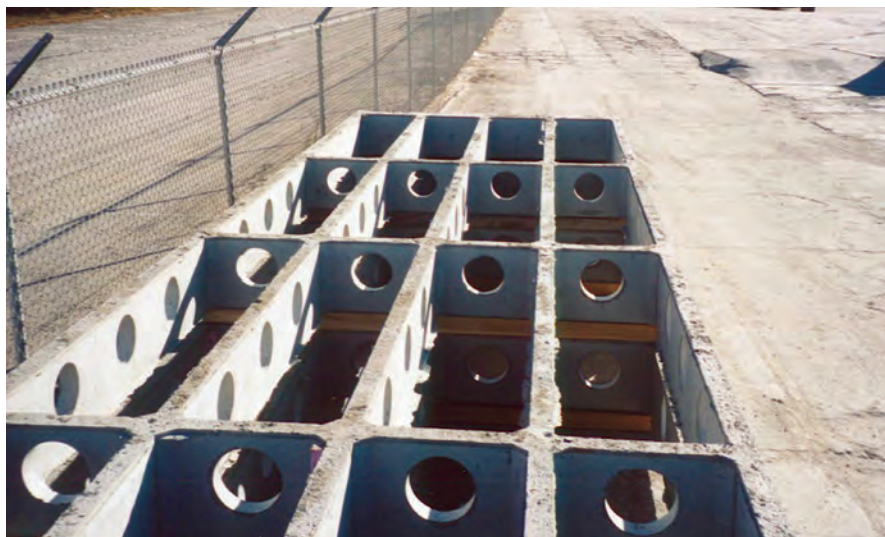


Fig. 10. Top view of a concrete floor panel.



Fig. 11. Workers installing the welded wire reinforcement for the first layer of the triangular sandwich wall panel.



Fig. 12. Workers installing the insulation foam for the middle layer of the rectangular sandwich wall panel.

cast structure would require expensive custom-made wood trusses; however, the long span combined with the steep pitch created a “dead” space in the attic as high as 20 ft (6 m). In addition to these considerations, there was a need to brace the top ends of the precast walls against wind during construction.

These design restrictions led to the idea of using precast concrete roof beams. In addition to bracing the walls during construction, the beams serve as platforms to support the upper trusses at much shorter spans than the distance between the exterior walls. The concrete roof beams are anchored to the exterior walls, and the wood trusses are anchored to these beams, creating a system that can resist the wind uplift of tornados, a common summer weather occurrence in Nebraska and much of the central United States.

Spaced at 15 ft (4.5 m) on center and spanning 35 ft 4 in. (10.8 m), the precast concrete roof beams allow the economical use of small-dimension lumber [2 × 4 and 2 × 6 in. (51 × 102 and 51 × 152 mm)] to create the roof surface and to span between the beams. The roof design provides a flat floor in the attic area for a loft or studio space. The creative use of precast concrete

roof beams with standard wood trusses met the roof-line specifications of the subdivision and converted a sizeable portion of usable attic space into an appealing upper story for a home office or extra bedroom. With the upper story design of the NU Concrete House, about 600 sq ft (50 m<sup>2</sup>) of extra loft living space was made available.

Initially, several steel and concrete products were considered for the roof beams, including an I-shaped conventional steel reinforced concrete beam, an I-shaped steel beam, and a partially prestressed concrete hollow-core slab. Although a steel solution was cost competitive to concrete, the hollow-core slab was selected because it had a cost advantage over other alternatives, and because it maintained the precast concrete design theme of the project. Interestingly, the exposed hollow-core slabs below the cathedral ceiling in the great room turned out to be a highly attractive architectural feature.

The hollow-core slabs were 12 in. thick and 24 in. wide (300 × 600 mm), and reinforced with four ½ in. (12 mm) diameter pretensioning strands and four No. 8 steel reinforcing bars. To avoid interference with the sloping truss upper chords, the slabs were mi-

tered as needed at their ends. To attach the wooden ceiling and roof joists to the hollow-core slabs, a threaded rod was inserted into the fresh concrete of the slabs during precasting. The vertical projecting rods, spaced at 4 ft (1.2 m) on center, provided a convenient means of attaching the wood framing members.

## PRODUCTION AND CONSTRUCTION

Production of the precast panels for the NU Concrete House began in the fall of 2002. Figs. 6 to 10 show selected views of the floor panel production. Typically, one floor panel per day was produced. The panels were made as large as could be handled safely at the plant and on the construction site.

The largest panel was 45 × 11 ft × 10 in. (13.5 × 3.3 m × 250 mm) and weighed about 17.5 tons (16 Mg). The first sandwich wall panel, which was the smallest precast component fabricated for the NU Concrete House, was formed as a triangular shape to serve as the dormer gable end (Figs. 11 to 13).

### Foundation

Construction of the NU Concrete House began in April 2003 by pouring a cast-in-place concrete (CIP) footing. Short CIP round piers were also placed at the garage and walkout areas where local building codes require footing construction to extend below the frost line to avoid frost heave [a depth of 42 in. (1067 mm) in Omaha, Nebraska]. Precast panels were placed either directly on the footings or the pier tops. A 150 ton (136 Mg) mobile crane was used for the erection of the sandwich wall panels (see Figs. 14 and 15).

Fig. 16 shows two of the panels at the southwest corner of the basement immediately after installation. All basement wall and floor panels were completely assembled in three days. Fig. 17 shows the assembled first story.

### Connections

The construction philosophy was to design the precast concrete connections for economy, speed of erection, high tolerance levels at the site, high strength, and durability. Standard

hardware was used for all connections. Installation was designed to eliminate labor-intensive field welding or CIP grouting. The main connection device was a structural steel tube with oversized holes. When two panels were erected next to each other, the tubes from adjacent panels were bolted through the tube holes (see Fig. 18).

Precast walls for the second story and the roof beams were installed in two days in May 2003. Fig. 19 shows the roof beams after their installation was completed, and Fig. 20 illustrates all the precast concrete elements in place on the site. All components were erected in five days. The roof and the interior framing were completed in June 2003, with finish work on the interior of the house beginning that same month.

The total project cost was \$490,000.

## CONCLUDING REMARKS

Innovative precast concrete elements such as the sandwich wall panel, floor panel system, and roof beams of the NU Concrete House demonstration project have proven the potential for precast residential construction, not only for single family homes in the United States, but also for multi-unit dwellings worldwide. The advantages in strength, energy efficiency, and interior design flexibility delivered by precast concrete systems and, in particular, the insulating capacity of the patented sandwich wall panels, have the potential to influence public opinion of concrete home construction.

With today's relatively inexpensive power tools, homeowners can easily perform the familiar surface treatments and interior decorating of typical wood frame construction on concrete surfaces, such as hanging pictures, mounting cabinets, cutting wall openings and other remodeling tasks. The superior durability and safety of precast concrete, and the very high energy efficiency of the system described here, make the NU Concrete House design (see Fig. 21) a more advantageous and attractive option than that of conventional wood frame construction—especially in light of escalating fuel costs.

In purchasing a precast concrete house, homeowners have the assurance



Fig. 13. Erection of the triangular sandwich wall panel. Note the variable opening configurations in rectangular and triangular panels.



Fig. 14. Setting an interior wall panel in place. Note the openings in the floor beams in the foreground.



Fig. 15. Setting an exterior wall panel in place. Note the attractive finish treatment of these panels, emulating brick and masonry construction.



Fig. 16. South end corner walls were the first to be erected.



Fig. 17. Completed basement walls with brick finish details and floor panels.



Fig. 18. Various views of structural connections.

of knowing that their home has the strength to resist the potential damage from tornados, fire, and termites, and will even provide security against projectiles (such as debris from tornados and bullets from firearms). The system minimizes home maintenance. A selected brick, stucco, limestone, sandstone, or other desired precast concrete finish treatment is permanent and essentially maintenance-free. All that is needed is periodic maintenance of sealant joints between the concrete panels.

The precast concrete home's open layout allows interior design flexibility because there are no loadbearing interior walls or columns to interfere with room planning. Stable interior climate control is afforded year-round by the precast concrete sandwich wall system that insulates the occupants from seasonal and diurnal temperature changes. In this day of high fuel prices, an energy efficient precast concrete home is a smart and desirable option for residential construction.

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## CREDITS

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*Precast Concrete Producers:* Enterprise Precast Concrete, Inc., Omaha, Nebraska

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Fig. 19. Roof beams in place between partition wall and exterior wall of home.



Fig. 20. NU Concrete House following installation of all precast concrete panels.



Fig. 21. Completed NU Concrete House.