New Technology Spurs Market for Large Panel Precast Concrete Buildings

Advancing technologies in prefabrication and changing economic conditions have revived the market for large panel precast concrete buildings. The large panel building system is particularly well adapted to high rise housing, such as apartment buildings and hotels. In this article, the author discusses the architectural, structural, and production considerations involved in such building systems. To be successful, industrialized production methods are developed for the efficient manufacture of the concrete elements. Successful use of the large panel system in low rise housing in Switzerland is a significant new development.

The large panel building system currently in use was developed in France by Raymond Camus and Eduard Coignet in the 1950s. From France, the system was exported to other European countries. In the last 30 years, many millions of apartments have been constructed using adaptations of this system, especially in the former Soviet Union and Eastern European countries.

A similar system to the French solution was developed in Denmark by Larsen & Nielsen. Unfortunately, some of the details of this system, for example, insulation, joints, and connections, could not be utilized in other countries. Thus, new systems were developed. These new systems maintained the fundamental principles of the original concept, but used new details and improved production methods.

The Koncz System was developed in 1964 and attempted to eliminate the limitations and mistakes of other systems. Today, many countries are using this system. It was introduced in Korea in 1990 by the Samsung Construction Company and it has met with great success (see Fig. 1). Among the advantages of the Koncz System is the systematic production method, based on a continuous flow of material via a circulating system for both vertical and horizontal production, which produces high productivity rates.

Background information on the various building systems the author has developed over the last 30 years has been reported in Refs. 1 through 5.
Fig. 1. A large apartment house project in Korea uses the Koncz System for high rise large panel buildings.

**STRUCTURAL CONSIDERATIONS**

**Loadbearing Wall Systems**

The structural solutions of large panel buildings are characterized by the orientation of the loadbearing walls and whether the floor slabs are supported as one-way or two-way slabs. According to these characteristics, there are three basic structural solutions for high rise large panel buildings.

**Cross-wall loadbearing system** — This system has one-way slabs (see Fig. 2). Only the external walls in the cross direction are loadbearing. The longitudinal external walls are generally non-loadbearing curtain walls.

The one-way floor slabs have a span of 6.0 to 7.0 m (20 to 23 ft). For these spans, non-prestressed floor slabs can be used with hollow cores. The slabs are 2.4 to 3.6 m (7.9 to 11.8 ft) wide, which leads to a reduction in the number of elements. The floor slabs have to be connected together to form diaphragms that transmit the horizontal forces to the walls.

Stiffness in the longitudinal direction is developed by the longitudinal internal and external walls and by the staircase walls. Because of the non-loadbearing characteristic of the external walls, the architect has freedom in creating attractive design solutions for the external walls.

**Longitudinal wall loadbearing system** — This system has structural characteristics similar to the cross-wall system (see Fig. 3). The external walls support the one-way floor slabs. Because of the architectural layout, these floor slabs have a longer span, between 9.0 and 12.0 m (30 and 39 ft). For these spans, prestressed hollow-core slabs are used. The architectural design of the walls is somewhat more difficult because of the loadbearing function.

The stiffness of the building transversely can be achieved through gable walls (the end facade wall in the transverse direction) and staircase walls. The hollow-core slabs have to be connected together to form a diaphragm.

**All-wall loadbearing system** — This system has two-way floor slabs (see Fig. 4). The floor slabs are generally room size, with a thickness of 150 mm (6 in.). This is sufficient for spans of 4.0 to 4.2 m (13 to 14 ft). The Koncz System uses the all-wall loadbearing system, especially for high rise buildings, because it is easier to achieve stability in both directions.

**Structural Integrity**

Structural integrity for high rise large panel buildings means that the stress normally carried in any one structural component can be safely transferred to adjacent components without overloading them and causing them to fail. If an accident (such as an internal explosion or external impact) occurs that causes failure or removal of a structural component, its stresses are redistributed.
away from the damaged area through alternate paths, thus allowing the structure to remain intact (see Fig. 5).

Structural integrity is more difficult to achieve with the cross-wall and longitudinal wall systems. The one-way slabs will collapse when there is no support unless special connections and precautions are provided. It is possible to have structural integrity with the one-way slab systems, but it is more difficult to achieve.

If structural integrity does not exist, progressive collapse will occur, as happened nearly 20 years ago in London’s Ronan Point apartment building with one-way slabs and exterior loadbearing walls. Since then, however, many advances in building design have been made to prevent such a failure from occurring. For example, a recent explosion in an apartment house in Budapest, Hungary, destroyed only a few elements. The all-wall loadbearing system confined the damage to a small area and allowed the damaged area to be renovated and brought back into use quickly. This example demonstrates structural integrity in the best possible way (see Figs. 6 and 7).

Unfortunately, poor experiences were manifested in the earthquake in Armenia where the cross-wall systems with one-way, hollow-core slabs were heavily damaged. In contrast, the Romanian and Algerian earthquakes had no effect on buildings with all-wall loadbearing systems.

Design Computations

Statistical calculations can be made using standard software for structural analysis. However, sophisticated analyses should be based on a finite element method using a three-dimensional model. Calculations for frames in two directions result in stresses higher than actual values. Wind and earthquake forces can be calculated easily using this model. Our firm is currently using the ANSYS software.

The design of walls has to be done according to the applicable code of the country. For the Korean projects, the ACI Building Code was used. It is important to know that the stresses in the walls and in the connections do not differ appreciably from each other, even though the use of buckling fac-

Fig. 2. Cross-wall loadbearing system — one-way slabs.

Fig. 3. Longitudinal wall loadbearing system — prestressed one-way slabs.
tors results in higher stresses in the wall and reduced stresses in the connections (see Fig. 8). Recent tests on loadbearing walls and connections confirm this behavior.

There are no tension stresses in the walls from wind and earthquake forces if the architectural configuration is properly designed and the building does not have more than about 15 stories.

The All-Wall Loadbearing System

The most important consideration in the all-wall loadbearing system is that all elements of the structure must be connected together in at least two points. The thickness of the loadbearing wall varies according to the number of stories. Up to 15 stories, a wall thickness of 150 mm (6 in.) is generally sufficient; a 30-story building should have 250 mm (10 in.) thick loadbearing walls. Two-way slabs are generally 150 mm (6 in.) thick for spans up to 4.5 m (15 ft). The small slab thickness reduces building costs because walls are thinner or shorter and installation is more efficient.

The external walls are sandwich panels. The loadbearing inner layer is 120 to 150 mm (4 3/4 to 6 in.) thick. The amount of insulation varies according to the requirements of the country; in Europe, it generally consists of 80 mm (3 in.) of polyurethane. The protecting concrete layer is about 70 mm (2 3/4 in.) thick because of the concrete cover requirement which is a minimum of 30 mm (1 1/4 in.) in most European codes. There are no cold transfer bridges between the two concrete layers except for the single connection as close to the center of gravity as possible. This arrangement allows the two layers to move independently without building up stresses due to thermal changes or temperature differentials.

Stairways and other special elements are located in accordance with the architectural design.

CONNECTIONS

The quality of the large panel building system is very much influenced by the design solutions for the connections. Ideally, the connections should be simple and be able to be installed.
quickly and efficiently. In the Koncz System, welding and bolting are eliminated. Only concrete grouting is used.

**Horizontal Connections**

The horizontal connection system between floor units is multifunctional. The suspension hooks for handling and erection of the floor slabs are connected together by spiral reinforcement at two points on the width of the floor slab (see Fig. 9). The 8 to 12 mm (⅜ to ½ in.) diameter spiral will be turned between the two hooks and then the connection will be grouted with concrete. The connection is loadbearing to take in compression, tension, and shear.

The suspension hooks also have another function; they serve as tendons to withstand the tension forces in the diaphragms. The capacity of a spiral connection for tension is about 10 metric tons (22 kips). A variation of the connection is to overlap wire ropes, which are also suspension hooks for handling the floor slabs (see Fig. 10).

**Vertical Connections**

Vertical connections between the walls provide various solutions:

1. Use of lapped reinforcing bars is the cheapest solution (see Fig. 11). Corrugated tubes form holes in the top and bottom of each wall. After the bottom wall is erected, a reinforcing bar is placed in the tube, which is then filled with concrete. After the upper wall is erected over the reinforcing bar, the upper part of the tube is filled with concrete and the connection is complete. The bar is made as long as necessary to develop the reinforcement strength (see Fig. 12).

2. The splice sleeve connection is well known in the United States, and is also used in the Far East, to connect reinforcing bars that extend from precast wall elements (see Fig. 13). This system is also popular in the vertical connection of columns.

3. Prestressing bars are also used to connect walls vertically. The prestressing eliminates tension stresses in high buildings. For this purpose, threaded Dywidag bars should be used, along with special couplers; this produces a very fast and efficient connection (see Fig. 14).
PRODUCTION TECHNOLOGY

The precast concrete elements will be produced in a plant or factory specifically designed for large panels. The capacity of the plant is determined by the anticipated annual production of apartment area. The smallest plant has about 25,000 m² (270,000 sq ft) capacity, which equates to about 250 apartments. The largest plant, which has the same production capabilities, produces about 200,000 m² (2.1 x 10^6 sq ft) of precast elements annually, based on 8-hour working days and 250 working days per year.

Production is designed to maintain a continuous flow of material. It is important that the production areas do not interfere with each other. The technology is based on a circulating system for both vertical and horizontal production.

Circulating System

The circulating system of production has the following advantages:

1. The same work will be done at the same place. The workers do not have to move about because the circulating pallets or trucks come to them.
2. The work stations can be controlled more readily.
3. There is no need for skilled labor; the work can be learned easily.
4. The work is continuous, which means that it is not necessary to wait for the maturation of the concrete, and the production can be doubled or tripled by more shifts.

Production Lines

The factory is divided into production lines that provide the following:

1. Internal walls, partitions, and floor slabs, which consist only of concrete, are produced vertically in the Panelator.
2. External sandwich walls are produced on horizontal circulating pallets.
3. Special elements, such as balcony slabs, staircases, landings, parapets, and other components, are produced in stationary molds.
4. Steel cages are prepared using special machines for cutting and bending of reinforcing bars and wire mesh.
The storage area, which is able to store a maximum of six weeks production, is equipped with racks for vertical storage. A typical production line is shown in Fig. 15. The layout for a complete production facility using the circulating system is shown in Fig. 16.

**Vertical Production**

Concrete internal walls and floor slabs are produced in vertical molds. This provides two flat surfaces that can receive wall paper directly. In addition, production is much faster.

The production machine is the Panelator, which was developed by Prefabtech AG of Zurich, Switzerland (see Fig. 17). The machine consists of fixed and mobile molds, hanging molds, and traveling molds.

The traveling molds are moved from station to station on rails using traction wheels and by transfer bridges. In preparing the molds, they will be equipped with reinforcing bars, wire
mesh, cutouts, and electrical conduits. When all the equipment has been installed, the traveler molds will be brought to the concreting station by means of a transfer bridge.

When the traveling molds arrive at the concreting station, they are lifted up from the rails and locked together with the hanging molds and end molds by hydraulic pressure to form a battery. Concrete will be placed automatically into the molds. The concrete is transported by link belts from the batching plant to the concreting station.

Only one worker is necessary to distribute and vibrate the concrete. Concreting takes about 30 to 50 minutes. Then the elements are heated in the molds for about 1½ hours. After this time, they have enough strength so that the Panelator can be opened and the traveling molds brought to the curing chamber, where they stay about 2 hours. Then the molds, with the elements still in them, go to a station for stripping and repair. Concrete can be placed three to four times in 8 hours at the concreting station, which is very high productivity.

**Horizontal Production**

Horizontal production for the external walls has the same circulating system. The production line is divided into work stations for preparation, vibrating, curing, and stripping. Two vibrating stations are necessary, one for the inner concrete layer and the other for the outer layer. The vibrating stations receive the concrete from a movable concrete distributor, which is fed from the batching plant. The concrete distributor is similar to a half gantry running on rails. The hopper is fixed on a crab.

Concrete placing and vibration are executed by a single operator. After vibration, the pallets are transported by rail and transfer bridge to the curing tunnel. Fig. 18 shows one of the vibrating stations and Fig. 19 shows a pallet and element being moved by the transfer bridge. After leaving the tunnel, the elements are stripped by tilting the pallets (see Fig. 20).

Special elements such as staircases can be produced in horizontal circulating molds or on stationary molds depending on their size and form. The vertical and horizontal circulating production system results in the highest productivity. Production is controlled electronically using special computer software.

**ERECTION AND INSTALLATION**

Erection of high rise buildings is done by tower cranes. The crane erects 30 to 50 elements per day, depending on the layout. The weight of the elements in the all-wall loadbearing system does not exceed 10 metric tons (11 t).

The erection sequence determines the transportation plan and the organization of the storage area. Finally, the production program is defined from the number and type of elements to be produced in the vertical machine and in the horizontal circulating molds. All these steps are fully programmed by software developed for this purpose.

An important advantage of the large panel system is the ability to integrate installations in the elements during production in the factory.
Fig. 16. Factory with circulating molds for the DongAh Company in Korea to produce housing units.
Electrical Accessories

In the all-wall loadbearing system, the electrical installation is embedded in the floor slabs and in the walls. One-way slabs, especially hollow-core slabs, cannot easily integrate electrical conduit.

The conduit for the electrical wiring is fixed in the vertical production on the traveling molds by attaching to the reinforcement and by using special fixing parts. The side molds also have removable inserts where the conduit will be connected at the site after the wiring is placed. The same procedure is also used in the horizontal production. Providing the electrical installation in the factory saves labor on the building site, which is generally more expensive than in the factory.

Plumbing

Plumbing for the kitchen and bath can be done in two ways: the piping can be embedded in the elements; or special room size bath or kitchen modules can be designed. Embedded piping is the easier solution, and sometimes the piping is simply fixed to a precast wall.

The special room size bath and kitchen modules are only suitable when a large number can be used. The reason is that these elements are space cells, made in space molds, where it is difficult to change dimensions. However, when used, these cells can be finished completely in the factory and simply connected together at the building site.

Elevators

The same possibility for modules exists with elevator shafts. This is a more common solution because of the standard dimensions for the equipment coming from the elevator factories. In Switzerland, elevator shafts are often made of precast concrete even if the building is constructed using other materials.

Doors and Windows

Door and window frames are also embedded in the elements during pre-casting. The frames are generally aluminum or galvanized steel, but plastic frames can also be used. For elements
with embedded door frames cast in vertical production, a system was developed to allow setups for subsequent castings without having to remeasure locations on the traveling mold after stripping.

**Finishing**

Finishing work is simplified because the walls and floor slabs have flat, smooth surfaces due to the vertical production. Wall paper can be applied directly to walls without a preliminary plastering operation. Similarly for floor slabs, carpet and padding can be placed directly on the slab when required for sound insulation.

**ARCHITECTURAL TREATMENT**

The architectural design for large panel buildings should reveal that the building is constructed from precast concrete. The system allows a wide range of solutions for the architect to achieve a satisfactory aesthetic appearance. Arrangement of balconies, windows and doors, and use of color and texture on the surface of external elements can give a variety of architectural expressions.

The 22-story apartment and office building in Germany (see Fig. 21), with white colored balconies and exposed aggregate external wall surfaces, along with the irregular floor plan, gives a good impression. The 18-story apartment building in Munich (see Fig. 22) has continuous balconies with highly textured surfaces, using form liners, and gable walls with exposed aggregate. The hotel building in Frankfurt (see Fig. 23) also has an interesting architectural style through the wall and balcony design.

A large real estate development in Korea, built by the Samsung Construction Company, represents the style in which many thousands of apartments are being built in Korea (see Figs. 1 and 24). The apartments have areas of 100 to 150 m$^2$ (1100 to 1600 sq ft), which would be very luxurious in Europe.

In Switzerland, not only high rise large panel structures have been built, but also many low rise housing projects. The price of these houses would...
be higher than wood frame housing in the United States, but in Switzerland they are 10 to 15 percent cheaper than traditional housing. The Swiss firm providing these houses, using the large panel system, has had great success for more than 10 years with imaginative architectural variety.

Fig. 25 is a collage showing several examples of low-rise housing in Switzerland using this large panel system. The examples show that housing need not be dull or repetetive. Aesthetics, function and variety can be built into these structures satisfying both the owner and residents.

It is well known that precast concrete, large panel buildings are very pleasing if designed by a good architect. New large panel buildings in Europe, and indeed throughout the world, have shown a variety of attractive architectural solutions.

CONCLUDING REMARKS

The large panel building system is very suitable for high rise apartment buildings. The reason for this revival is that the loadbearing capacity of the walls can be used effectively and the wall thickness remains relatively small. The most important factor is the structural integrity inherent in the system. The best structural solution to achieve this integrity is the all-wall loadbearing system with two-way slabs. Stability is provided in both directions without special precautions. Embedment of the electrical and other installations in the concrete elements is also possible with this system.

New and improved production technology with circulating molds, both vertical and horizontal, enables automated production directed by special computer software. A large portion of the installation and finishing work can be done in
the factory and site work can be mini-
mized. The architectural solution for
large panel buildings, in the hands of a
good architect, can be attractive and
pleasing, as the examples have shown.

The new precasting technology and
changing economic conditions have
made large panel systems attractive
not only for high rise buildings but
also for low rise housing. Indeed, the
future is very bright for this innovative
application of precast concrete.

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