Apartment Skyscraper Shows Precast's Seismic Capabilities

39-story apartment building in San Francisco takes advantage of the precast concrete seismic designs proven in the PRESSS research program

The capabilities for using precast concrete structural systems on the West Coast are being highlighted this summer by the construction of an $87-million, 39-story apartment building in San Francisco. The project is one of several undertaken recently on both coasts by the general contractor using newly proven techniques for developing precast concrete seismic load-resisting systems.

When finished in October 2001, 680 Mission Apartments on Mission Street will be the tallest concrete structure erected on the West Coast in a high seismic zone. The building, standing 425 feet tall, will contain two floors of retail, one floor of commercial office space and 36 stories of apartments. To achieve this height with the restrictive code requirements for seismic design in San Francisco, the general contractor took advantage of the newly developed precast concrete system that features a hybrid moment-resistant frame. The frame provides seismic resistance in both the longitudinal and transverse directions and brings the structure back into alignment after the deformation energy of an earthquake is dissipated in the beam-to-beam connection region.

"This format definitely offers superior seismic performance, and that's why it was developed and is being used on this project," says Joe Sanders, project manager for Charles Pankow Builders Ltd. of Altadena, Calif. "The hybrid frame's ability to control damage is a major improvement over previous seismic design approaches and will have

The 680 Mission Apartments building, a 39-story skyscraper in San Francisco, currently is under construction using a precast concrete hybrid moment-resistant frame for structural resistance. The structural components also serve as architectural cladding.
Rendering: Elkus/Manfredi

Three full-size mock-up panels were produced for the Mission Apartments project to replicate the different finishes and textures to be incorporated.

a dramatic impact on the construction industry worldwide."

PRESSS Research Was Catalyst

The structural system results from the culmination of research undertaken with Pankow's development work at NIST (the National Institute of Standards & Technology) in conjunction with the PRESSS (Precast Seismic Structural Systems) Research Program. The research began in 1990 at various universities and research institutions around the country. It represents a coordinated effort involving members of the academic, scientific and business communities in the United States and Japan.

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The program is sponsored by the National Science Foundation (NSF), the Precast/Prestressed Concrete Institute (PCI) and the Precast/Prestressed Concrete Manufacturers Association of California (PCMAC). Professor M.J. Nigel Priestley of the University of California at San Diego coordinated the research. Pankow also worked with John Stanton of the University of Washington, who was one of the key researchers in the PRESSS program.

The research and development phases of the PRESSS program culminated in September 1999 with the construction and testing of a five-story building at a 60-percent scale that included five key seismic load-resisting systems (four ductile frames and one jointed shearwall). The key to their success comes from using the joints as a controllable focus for absorbing force and flexing with it, providing an easily inspected and repaired location after a seismic event. In other types of structures, that deformation can occur randomly and at an unknown point, producing time-consuming and expensive inspection and repair processes.

"In recent years, structural solutions that minimize the damage or destruction of the structure itself during a major seismic event have been focused on," explains Sanders. "But these solutions have been expensive and very complex technologically, making them difficult to build in all but the world's most sophisticated construction markets."

The system Pankow adapted for the Mission Apartments consists of a precast concrete moment-resistant frame that absorbs seismic energy in a manner independent of the integrity of the structural members. The post-elastic performance is concentrated in the connection region rather than a structural member. By combining both inelastic and elastic responses, the moment frame shows minimal damage, typically consisting of minor spalling even when tested to a rotation equivalent story drift of 6 percent.

Reusing Existing Technology

"Many structures in the past have used the technology of post-tensioning and prestressing strands; they have a long history," Sanders says. "All we're doing is marrying the two systems together to create something new and more efficient." The Mission Apartments are the company's sixth project using these new design techniques but the first of this substantial size in a high seismic zone. "This project is a quantum leap of the application of the hybrid frame from the structures we've previously built with this system."

Numerous benefits accrue from this hybrid frame. Foremost, in addition to its life safety features, it was more economical. "There are great benefits in general to building a residential building from concrete," Sanders notes. "It allows the building to be built with lower floor-to-floor heights because of the shallower cross-section. So we achieve the same headroom on each floor with a shorter

Beams cast for the project are being stored in the precaster's yard in Corcoran, Calif., until needed to ensure erection moves smoothly and rapidly once the site is ready.

Five Other Projects Use System

Charles Pankow Builders Ltd. has constructed five other projects using the precast concrete hybrid frame being installed in the Mission Apartments building. They comprise:

A three-story New York City parking structure completed in 1995. "That was the first time the components were put together using this principle," explains Joe Sanders, project manager for Pankow. "It gave us the opportunity to review the details and economics of the system in a low-seismic zone."

A four-story, 264-car parking structure in Eugene, Ore., completed in November 1996.

A three-story, 1,504-car parking structure at Stanford University in Palo Alto, Calif. "That was our first use in a high-seismic zone using the hybrid moment-resisting frame."

The West Side Media Center in Los Angeles, a four-story office building under construction. Structural work is finished but architectural interior work is still underway.

An 8-story office building in Daly City, Calif., which currently is under construction with foundation work completed. "The significance of this project is that Daly City sits directly on the San Andreas fault line," Sanders says. "This project is as close to ground zero in an earthquake as one can get. That will be a real test for how well the system performs—and it definitely will have to perform someday."

This moment-frame beam form shows the center PVC duct that holds the prestressing tendons and the six corrugated tubes for the mild steel bars used in the hybrid system.

building, saving material costs." After budgeting the project with a structural steel frame and then with the hybrid frame, Pankow estimated the precast concrete approach saved approximately $4 million.

'Precast concrete is a very city-friendly material and a good approach overall.'

The cost savings becomes greater once the post-earthquake costs are added in, Sanders says. "In steel systems, the deformations can destroy any part of the system, which requires an in-depth inspection following a significant seismic event. This precast concrete system also offers a self-righting force due to the post-tensioning strand. That allows the building to undergo deformation or seismic drift and then restore itself. So the long-term benefits after a seismic event add more savings — and we know there will be a seismic event in this area."

Expanding The Market

Precast also offers a dense material that absorbs vibration between floors, cutting disturbances from neighbors, he notes. Fire-resistance requirements also are achieved without the need for extra fireproofing due to concrete's inherent non-combustible composition. Another more subtle advantage comes about because the system creates a new design approach that allows a wider variety of companies and craftspeople to bid on the structural systems.

"San Francisco has so much construction work that the market is stretched for labor," he says. "This approach not only uses new materials that aren't stretched to capacity but they can be assembled by more efficient crew sizes while achieving a higher level of quality."

It also helps control costs over the design process. "Steel prices are very volatile, which means that a design that begins assuming certain costs is at the mercy of later price rises. So there's a significant risk of moving forward without knowing the pricing that will be in place when you need to buy steel." Pricing on precast concrete, in contrast, remains stable and uses local labor and materials. "Precast concrete is a very city-friendly material and a good approach overall."

Several Connection Systems Used

Because of its unique shape and combined functions, the Mission Apartments project actually uses several connection systems. Its shape features a wide base that rises to the 34th floor before narrowing on each side for five more floors, creating what the architect terms "shoulders" on the lower floors. The façade also includes a curving face that added more architectural interest. The project, which is owned by The Related Companies of California, Irvine, Calif., was designed by Elkus/Manfredi Inc. in Boston with Kwan Henmi Architecture/Planning Inc. in San Francisco serving as executive architect.

To express the unique architectural design on the exterior, the precast concrete structural load-resisting members were designed to serve as the façade cladding as well. This meant that the structural components were cast and finished as architectural precast concrete pieces, killing two birds with

one stone but creating more challenges in the casting process.

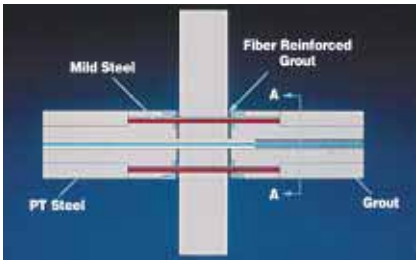
"We have always tried to achieve dual use of concrete structural components for façade design as well," he says. "This project has a significant architectural element to it that adds interest and distinction." Two finish colors were used on the precast components, with the "shoulders" using a darker color than the rest. All of it features a sandblasted finish, with components produced by Pankow's precasting division.

The building was conceived using a tubular post-tensioning frame with a hybrid moment-resistant frame around the perimeter. But because the building is not rectangular, several connection systems were used. The hybrid frame gains efficiency when frames are long and join a number of bays, Sanders explains. In some areas that offered only one bay, the Dywidag brand ductile-connection system was used. In these sections, making up less than one-quarter of the entire frame, the components are bolted together rather than post-tensioned. The first eight floors, including one level of underground parking, were supported with cast-in-place shearwalls and moment frames.

Sleeve System Used

A unique aspect of the post-tensioning system comes in the way Pankow handles corners. Rather than post-tensioning each side separately, creating two sides that must stressed in the same space, the company devised 90-degree angled tubes that let the strands turn the corner and continue along the adjoining side. This allows post-tensioning to occur in only two locations per floor, directly opposite to each other.

This application will be the first time the sleeve system has been used in the field, although Pankow has tested it past design needs at the University of Washington, Sanders says. "Stressing two sides in the same space would have created an engineering complication," he explains. "One of the features that allows the building to attain the height it does is that the tube frame remains uninterrupted around the perimeter of the building. This tube system allows us to deal with the corners."



Pankow Builders has incorporated a precast concrete hybrid moment-resistant frame into the Mission Apartments project, which combines prestressing steel with mild steel reinforcement within fiber-reinforced grouted tubes.

Mission Apartments also will see the first application of the frames using grout-filled columns with splices, he adds. The other projects the company has created could use one-piece precast columns from footing to roof. In a 39-story building, that was impossible. Instead, the columns are being cast in two-story lengths and are locked together with NBM Splice Sleeve brand connections.

"This system requires a more technical approach to concrete construction than a cast-in-place approach would need," Sanders says. "But our efforts were designed to ensure the system was not too technically daunting so ordinary craftsmen could accomplish it. Some technical application is needed in casting and putting together the elements, but it is not a technologically complex design."

That approach, combined with the significant benefits offered by the system, gives Pankow great optimism for the future use of these techniques. "We see this system potentially becoming the dominant approach in many areas," he says. "We see great advantages from it. We've always recognized the benefits that precast concrete provides to the economics of a project. You can control the cost of the components much better than with others that are more volatile; you can achieve higher quality with factory-cast components and you can produce a system that is more economical in first cost and in the long term. When you add in the superior seismic performance, it offers a strong option — especially since it simply uses existing ideas and components and connects them in an innovative way." ■

— Craig A. Shutt

PRESSS Research Proves Systems' Viability

The system detailed in this story is one of five seismic load-resisting systems tested during the PRESSS research for the past decade. The study involved five seismic load-resisting systems (four ductile frames and one shearwall). They included:

A Hybrid Frame Connection with unbonded post-tensioned strands running through a duct in the center of the beam and through the columns. Mild steel reinforcement runs through ducts at the top and bottom of the beam in the connection region and is sleeved through the column and grouted. This system is used in the Mission Apartments.

A Pretensioned Frame with partially debonded strands set on one-story columns. The columns' reinforcing steel extends through the sleeves inside the beams. As the frame displaces laterally, the debonded strand remains elastic, recentering the structure after a seismic event as with the Hybrid Frame.

A Tension-Compression Yielding Gap frame, which leaves a small gap between the end of the beam and the face of the column, with only the bottom portion grouted to provide contact between the beam and column. Post-tensioning bars are centered in the grouted region and clamp the frame together. This keeps the gap open on one side of the column as it closes on the other during a seismic event, eliminating frame elongation.

A Tension-Compression Yielding frame, which models a traditional connection similar to one emulating cast-in-place methods. But the yielding is concentrated at the connection by debonding the beam reinforcement over a short length at the beam-to-column interface.

A Jointed Shearwall System, using connection devices between the vertical joints of the wall panels to provide hysteretic damping. In the initial experiments, researchers used a previously tested U-shaped connection. Now that the system has shown its capabilities, the connection itself will be improved to lower costs and make it less complicated.

For more information on PRESSS research program, see the Winter and Spring 2000 issues of ASCENT.