Precast concrete building system components for the Westin resort hotel, part 2: Design and construction

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The Westin resort hotel in Avon, Colo., (**Fig. 1**) is a nine-story luxury hotel with 500,000 ft^2 (46,000 m^2) of hotel, lobby, parking, and auxiliary space. Avon is located on the western slope of the Rocky Mountains about halfway between Denver, Colo., and Grand Junction, Colo. and the town serves the skiing areas of Beaver Creek, Colo., and Vail, Colo.

The Westin structure was initially designed as flat-slab, two-way, post-tensioned concrete construction with a 30 ft × 30 ft (9.1 m × 9.1 m) column grid. The construction schedule called for the framing work to begin in early November 2006 and to be completed by the end of May 2007.

The construction schedule imposed weather restrictions on the project because all concrete work would have to be completed during the winter months. Winter construction typically requires an enclosed work space and heat to cure the concrete, which adds to the cost and can affect the construction schedule.

The potential lack of reliable all-weather ready-mixed concrete in Avon further complicated construction decisions.

Editor's quick points

- The Westin resort hotel is an all-precast concrete building that emulates flat-slab, post-tensioned construction.
- The project demonstrates that a precast concrete alternative can be constructed in winter conditions on a confined site.
- This paper describes the structural concept, alternative details, fabrication, and construction of the building project.

Figure 1. Nine levels of the Avon, Colo., Westin resort hotel complex main tower are erected.

The closest ready-mixed plants are in Edwards, Colo., about 4 mi. (6.4 km) west of the project site, and Eagle, Colo., about 20 mi. (32 km) west of the jobsite. Competing plants to the east were both farther from the site and over Vail Pass. Winter road conditions raised concerns about maintaining the schedule and delivery of quality concrete to the jobsite.

In addition to concerns about ready-mixed concrete delivery, there was also a shortage of skilled labor. As a resort area, Avon had neither a well-established labor pool nor readily available housing for construction crews. Faced with these conditions, the general contractor approached a precaster to explore a precast concrete alternative for the project. In addition to off-site fabrication, a precast concrete solution would eliminate the shoring and reshoring constraints of cast-in-place concrete construction.

The precaster responded with a precast concrete design that emulated flat-slab construction. The short schedule precluded a redesign program and resulted in a design alternative that not only emulated flat-slab construction but required that the column spacing, structural layout, and building perimeter from the original design be maintained. Consequently, optimization of precast concrete components was not an option for the project. Precast concrete solutions that were based on uniform column placement were not applicable to this site.[1]

Because Rocky Mountain Prestress had been developing a flat-slab-design emulation concept for some time and has filed a patent application on the concept, the Westin project allowed the concepts and research to be refined and put into practice. The main hotel flat-slab emulation could be constructed using four precast concrete components: elevator cores, columns with integrated capitals, beam slabs, and rib slabs with a final cast-in-place topping to level the floor surface and ensure fire protection. Ancillary parking areas would be constructed using traditional double-tee and inverted-tee beams. This paper focuses on the flat-slab-design emulation.

Precast concrete components

The elevator-stairwell core units were precast concrete box units that were field assembled and vertically post-tensioned with strand for strength, continuity, and lateral load resistance (**Fig. 2**). The cores provide the lateral shear resistance for wind loads on the structure and provided temporary lateral support during the precast concrete erection. Ledges on the core edges provide a bearing surface for the floor components.

Precast concrete core pieces were made in three basic sizes in plan: 9 ft 10 in. × 17 ft 3 in. (3 m × 5.3 m), 10 ft 2 in. × 11 ft 6 in. (3.1 m × 3.5 m), and 9 ft 0 in. × 19 ft 4 in. (2.7 m × 4.8 m). Wall thickness was 12 in. (305 mm) for all cores. Blockouts in the core units were provided for door and elevator access. The topmost core components have variable dimensions and a sloped roof. These were made of flat panels and were assembled on-site (**Fig. 3**).

Precast concrete column units consist of the column and the integrated column capital (**Fig. 4**). The column extends through the capital, so the column connection is nearly at the point of inflection in the floor system. In addition to reducing the moment demand, the location allowed the connection to be made away from the slab surface. The 10-in.-thick (250 mm) column capital includes a slight draft to increase the slab thickness at the column face. This ensured that the full shear capacity could be developed.

Proof tests of the column capital validated the strength and serviceability behavior.[2] The integrated column capital is the key element to emulating flat-slab construction. By using eccentric column capitals, the integration of balconies, setbacks, and dropped-slab floors became possible. Penetrations in the column capital were installed in the plant to address the reinforcement congestion and high shear demand.

The columns have match-cast bolted connections above each floor level that provide a partial moment-resisting connection. The structure was analyzed using a partial restraint connection at each column joint. The connection provided sufficient moment capacity for all construction and final loading configurations. Research is in progress to upgrade this connection to a moment-carrying detail to avoid the need for reanalysis.

Beam slabs are nominally 4-ft-wide (1.2 m), 10-in.-deep (250 mm), solid prestressed concrete members that are cast in a long-line operation. They connect the columns and the core units (**Fig. 5**). The beam-slab components can be fabricated with variable width to wrap around columns or fit into unique geometrical locations.

Cazaly hangers placed near the theoretical points of inflection at each end of the beam slab provided the vertical reaction and initial structural stability during erection.[3] The hangers were welded to a connection plate to ensure lateral stability during construction. The vertical capacity of the hanger design was tested to over 100% of the design ultimate capacity during the development program.[2] Reinforcement was detailed to provide a 20-in.-wide (510 mm) zone for field-cut vertical penetrations in both beam and flat-slab units.

The rib slab is a 12-ft-wide (3.7 m), 10-in.-deep (250 mm), modified double-tee with extra-wide webs and a 2-in.-thick (50 mm) slab. Ribs are 6 ft (1.8 m) on center. Hangers in the ribs allowed the slabs to be placed on either the column capital or the beam slabs. Field-cut vertical penetrations may be placed anywhere in the deck outside of the web fillets. This provides considerable flexibility for placement of utilities (**Fig. 6**).

Figure 2. Core components extend above the partially completed Westin resort hotel in Avon, Colo.

Building layout

The Westin tower plan contained two construction difficulties. First, the exterior of the building is irregular so it can accommodate balconies and setbacks. Second, although the column grid pattern is generally regular, the precast concrete components had to accommodate shifts in alignment. Flat-slab-component layout adjustments accommodated balconies and setbacks (**Fig. 7**). By wrapping the flat slab around the column capital, the original architectural design was matched without requiring cast-in-place concrete construction.

Column placement was maintained by using skewed beam-slab and rib-slab components. The northwest wing of the high-rise portion of the building serves as an example of the alignment resolution. In the original post-tensioned design, the floor framed into the building core and the tributary columns. The precast concrete solution placed skewed beam-slab components between the core and the column

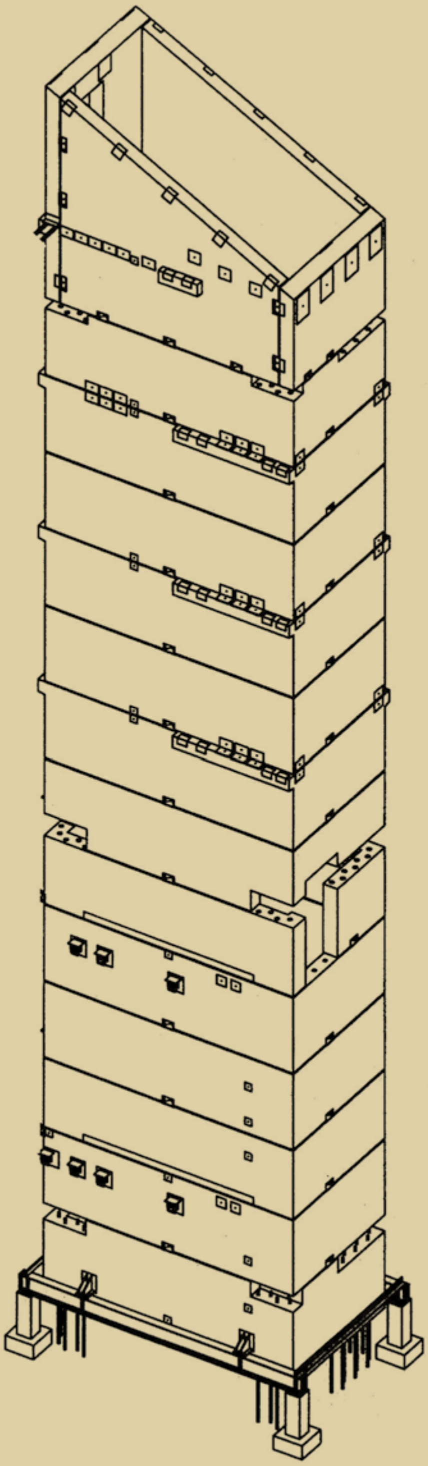

Figure 3. An isometric view portrays the east core tower of the Westin resort hotel in Avon, Colo., sitting on a pony box and a core tower under construction.

and then used skewed rib slabs and wraparound beam slabs to provide the final alignment (**Fig. 8**). Although this made the connection details less uniform, it provided a stable framing system that fit the building layout.

The hangers allowed the bearing support points to be defined, field welding to stabilize the connection, and member eccentricity to be accommodated. Two types of Cazaly hangers were used. A typical hanger carried vertical load and longitudinal forces for temporary structural stability. Slabs with large eccentricities could subject the panel to overturning. For these conditions, two-way hangers that could carry uplift and vertical load were used. These were secured with tie-down bolts through the hanger for the tensile load (**Fig. 9**).

Figure 4. A precast concrete column is being lifted into position for the Westin resort hotel in Avon, Colo.

Figure 5. A beam-slab component is placed in position on the column capital for the Westin resort hotel in Avon.

Figure 6. The spaces between the rib-slab stems of the Westin resort hotel in Avon, Colo., provide flexibility for utility placement.

Figure 7. Variable-width beam slabs allowed duplication of balcony and recess geometry in the Westin resort hotel in Avon.

Fabrication

Formwork for the precast concrete components was designed in anticipation of a large variation in member geometry. Rib-slab forms allowed variable rib-slab width and skewed end geometry. Overwidth forms and magnetic side rails were used for the flat slabs, allowing considerable versatility in geometric layout.

The column and column capital form were built so that variations in capital dimensions could be accommodated. Cast horizontally to facilitate match casting the column joints, the dimensions of the capital were adjusted to the jobsite requirements.

The elevator-stair core components were cast as complete cubes with blockouts for the doors and access ports and ledges for specific beam-slab and flat-slab bearing points. The core components contained the ducts for post-tensioning and post-tensioning anchorage points. Cores were cast in single forms, which precluded match casting.

More than 3700 pieces were fabricated for the project. The replication ratio was about 1.2. Thus, more than 3000 unique pieces were shipped to the jobsite.

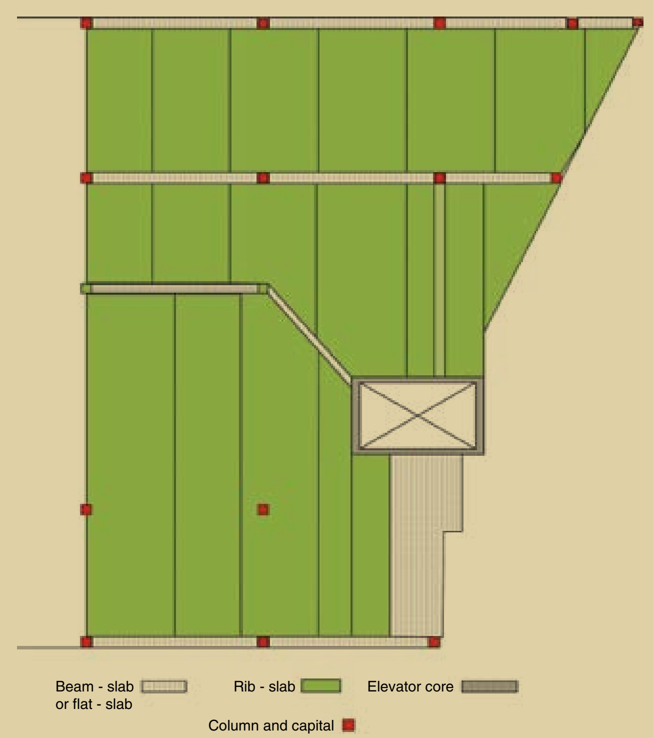

Figure 8. Skewed beam slabs span between irregular support locations in the northwest corner of the Westin resort hotel in Avon, Colo.

Figure 9. Cazaly hangers support beam slabs on a column capital of the Westin resort hotel in Avon.

Figure 10. Field welding the Cazaly hangers secures a beam-slab component for the Westin resort hotel in Avon, Colo.

Shipping, erection, and safety

While the small size of the individual pieces added to the total number of pieces erected, it also allowed multiple pieces to be shipped in the same load. For example, a single trailer could carry a single core unit, three beam slabs, four rib slabs, or five column capital units. Pieces were organized to allow direct placement from the truck. The time from a column capital being lifted from the truck to being placed and secured in the structure was five minutes. Securing the piece depended on its function. Columns were secured using four bolts. An alignment pin ensured that the column was properly oriented to its match-cast location before securing the bolts. The bolts supplied the temporary construction stability for the column and for the beam-slab framing into the column, avoiding the need for temporary bracing on most interior columns.

The Cazaly hangers in the beam slabs and rib slabs were set and welded to anchor plates. There were no elastomeric bearing pads in the new system. The welding was completed prior to the piece's release from the crane hook (**Fig. 10**). Any beam slab or rib slab that had a possibility of overturning during erection included a modified Cazaly hanger that could carry uplift. The bearing plate contained a ferrule insert, and a bolt could be placed through a predrilled hole in the Cazaly hanger (Fig. 9). The bolt provided the uplift reaction to secure the slab component. The combined welding and bolting provided global structural stability prior to placing the cast-in-place concrete floor diaphragm.

The column capital, beam and flat slabs, and rib slab provided a working platform for the erection crew. Free of stirrups common in the top of an inverted-tee and double-tee structural system, the erection crew could easily walk on the wide, completed surface. This allowed the erection to proceed rapidly and safely, even in inclement weather. Once the initial techniques of setting the units were established, a crew could set about 15 pieces per day. The highest production rate was 100 pieces per day using 3 setting cranes. This is the equivalent of placing 7500 ft^2 (700 m^2) of completed structural floor. Because the entire precast concrete system was stable, the contractor was able to schedule the topping placement to optimize the overall construction schedule.

Schedule and problems

The construction schedule called for the first core component to be set in early November 2006, and the final erection was to be completed by the end of May 2007. The contractor erected a pony box for the base component (Fig. 3). The purpose of the pony box was to set the elevation and alignment of the initial core component. One of the seven pony boxes was set slightly rotated out of alignment. The twist was noticed and a decision was made to cast the box into the footing pad and adjust the precast concrete core. The misalignment was minor but required that the next several core units be adjusted slightly to bring the core back into alignment. It also required correction to the beam slabs for proper fit. These corrections affected the construction schedule of one core.

The core erection called for grouted joints and vertical post-tensioning for strength. Core erection was critical to the entire project schedule because the lateral stability of the other components could not be ensured until the cores were post-tensioned. Under normal conditions, a two-day cycle was required to place a core component and let the grout cure prior to placing the next core unit. December and January were extremely cold (between 2 °F and 26 °F [17 °C and -3 °C]), which increased the time needed for the grout to cure. Post-tensioning prior to proper curing of the grout could cause localized cracking in the walls. Thus, the construction of the cores was initially perceived as delaying the entire project. An additional month was needed to accommodate the cold weather and the correction of the core alignment.

Post-tensioning the cores also affected completion. The large blockouts in the tower core required the post-tensioning jacking force to be adjusted for the openings. The intermittent nature of the openings required some field adjustment of the post-tensioning to maintain the vertical core alignment.

Once the cores were grouted and post-tensioned, the column and floor-component erection began. It required about two weeks for the erection crew to familiarize themselves with the new system and to achieve the placement levels described earlier. The last pieces were erected the second week of May 2007, two weeks ahead of schedule.

Lessons learned

The project illustrated several design and construction lessons:

- The erection and layout efficiency of a large number of unique smaller pieces was thought to be the antithesis of precasting logic. However, the ability to use adjustable forms to make a large number of pieces and to coordinate the delivery of those pieces to the jobsite proved highly effective on this project.

- The core component completion design needs improvement to eliminate field grouting and post-tensioning that can be affected by winter construction. A field-installed moment-resisting connection that does not rely on a grouted connection would allow the placement of the column and slab components earlier, improve the construction schedule, and reduce the impact of cold-weather construction.

- The column connection needs a full moment-resisting detail. This would provide greater stability during erection and would eliminate any temporary structural bracing.

- The overall fabrication and construction concept needs to be assessed for other locations. The remote site and winter construction facilitated meeting the cost and schedule targets of flat-slab, post-tensioned construction. Some aspects of the all–precast concrete solution suggest that it could have significant advantages in confined urban construction sites. For instance, the contractor had flexibility to place openings in the rib slabs and beam slabs in combination with smaller, lighter pieces; erection was rapid and safe; working platforms were stable immediately after securing the slab units; and shoring and reshoring were eliminated.

Acknowledgments

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Synopsis

The Westin Resort Hotel is an all–precast concrete building that emulates flat-slab, post-tensioned construction. Constructed in Avon, Colo., about 100 mi (160 km) west of Denver, Colo., the project demonstrates that a precast concrete alternative can be constructed in winter conditions on a confined site. The building was completed two weeks ahead of schedule using four basic precast concrete components: elevator and stair cores, columns with integral capitals, beam slabs, and rib slabs. About 3700 precast concrete pieces were required to complete the project. This paper describes the structural concept, alternative details, fabrication, and construction of the building project.

Keywords

Building, Cazaly, construction, emulative design, flat slab, hotel, post-tension.

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