Chad Van Kampen and Alex Mihaylov

Panelization and connections for rapid erection of high-rise elevator and stair cores

- Stair and elevator cores are often designed for significant loads due to life-safety requirements, and design teams are using them as part of the lateral load resisting system as well.
- Precast concrete components were used for an elevator core, two stair cores, and a freestanding shear wall in a 12-story dormitory.
- This article discusses the unique design and construction challenges related to the precast concrete components of the project.

Stairs and elevator shafts are the means of vertical transportation in multistory buildings. These structures not only allow vertical movement of occupants from floor to floor but their cores often serve as the main lateral stability system for these structures. Typically centrally located in buildings, they have become an integral part of building design and architecture. The code requires that occupants be able to exit during catastrophic events and be protected from fire.[1] Due to the magnitude of loads often applied to these cores, they are stout and consume valuable space, which has prompted construction teams to make them more than just an anchor for the tower.

All of these challenges and more were present in the project in this case study. The building is a 12-story-plus-basement dormitory in Ann Arbor, Mich. The precast concrete components include an elevator core, two stair cores, and a freestanding shear wall. The core height exceeds 160 ft (48.7 m). One of the stair cores has a reduced footprint above the fourth floor, which creates an irregularity requiring transfer of significant forces at the wall discontinuity. This paper presents the process of development and implementation of the cores from a design concept to completed construction. It focuses primarily on the cores because of the unique logistic challenges that are presented in the following sections. Another paper presents the hierarchy of the decision-making process for wall panelization and discusses in depth the weighing of various considerations.[2]

Precast concrete cores are shown during the construction of a 12-story-plus-basement dormitory in Ann Arbor, Mich. Courtesy of Kerkstra Precast.

Materials selection

For the general contractor on the Collegian North project, speed was of the essence. Construction on a main thoroughfare of a major university came with a restriction that prohibited a long schedule. To complicate this, the construction of the main shear wall elements had to be done in winter to allow the cold-formed metal structure to be built during warmer months. The university was adamant that the main road could not be blocked, and access to all businesses had to remain open and unobstructed by construction activities.

When weighing the use of conventional cast-in-place construction versus precast concrete components, the contractor took into consideration the timing of the project, associated costs, and overall schedule. Multiple budget-reduction efforts were made during this vetting process and different erection configurations were reviewed. This included locating the crane in the foundation excavation and installing each core to its full height separately instead of all at the same time. The geometry of the structure and the aspect ratio of wall width to height created engineering challenges that influenced the construction methods.

The construction of the shaft towers was going to be a challenge for either building material strictly due to weather conditions. The winter weather restricted or even eliminated the use of any casting of concrete, grouting, or welding. The use of a prefabricated system would allow the pieces to be cast in a controlled environment, minimizing weather impacts to the critical path and overall project schedule. Bolted connections or connections not requiring grout were available in precast concrete construction, and once vetted by the precast concrete design engineer, it was determined that construction could be accomplished without grouting and with limited welding. With the casting and connections selected and its ability to be used in the winter months, precast concrete was selected as the material of choice.

Panelization criteria for stair cores

Shipping and crane limitations usually dictate precast concrete panel size and orientation. For this project, locating precast concrete panel joints involved a number of additional considerations, such as the locations of embed plates for connections to structural steel and the locations of pockets for stair-panel connections. Pockets for the mechanical reinforcing bar splices had to remain accessible after stair-panel installation for deferred grouting. Providing precast concrete panels with identical dimensions was also desirable to keep forming costs down, despite the variations in story heights within the building. However, to enhance stability during erection, it was decided not to set all horizontal panel joints within a core at the same elevation, as in floor-by-floor erection. Instead, the goal was to erect each precast concrete core in a sequence, similar to a helical pattern. In many cases, these requirements were mutually exclusive. It took a number of iterations to optimize the panel dimensions until the requirements were met or reasonable compromises were found.

Panelization criteria for elevator core

Except for the requirements uniquely related to stair panels, the panelization of the elevator core had to meet the same requirements as the stair cores. In addition to embed plates for connections to structural steel floor members outside the core, precast concrete panel joint locations had to accommodate large embed plates for connections to elevator guideway components inside the core. Most of these embeds are located at elevations that are random relative to the floor elevations.

Design approach

Considering the building height and loads, the specified precast concrete panel thickness of 10 in. (254 mm) pushed the limits for congestion in panel boundary zones. Once wall forces were calculated, it was quickly realized that the approach of each wall being an individual shear wall, referred to as a two-dimensional (2-D) approach, was inefficient due to the large number of longitudinal bars in wall boundary zones. At lower levels of minor core walls with door openings, it was geometrically impossible to accommodate all of the boundary zone bars that were needed. A different approach was adopted where each precast concrete core acts as a three-dimensional (3-D) tube. For each tube, flexural behavior was assumed where precast concrete walls parallel to the lateral force (webs) resist shear, and precast concrete walls perpendicular to the lateral force (flanges) resist flexure by acting as tension/compression chords. To achieve this behavior, connections at tube corners with adequate strength and stiffness had to be provided. A full monolithic emulation with corner closure placement would have been too expensive, and in this case it was not needed.[3] An approach similar to partial composite action where connections are designed for a strength corresponding to the shear flow demands at tube corners was adopted. As a result, the overall core stiffness increased while the number of boundary zone longitudinal bars decreased so that boundary zone reinforcement ratios were within 0.01 and 0.04 and there was enough room for mechanical splice sleeves.[4]

To enhance stability during erection, the precast concrete core was erected in a helical installation sequence pattern. Courtesy of Kerkstra Precast.

Design loads and structural behavior during construction

Although it is rarely the case, it was calculated that the wind loads on some cores were greater during construction than in service.[5,6] It should be noted that the in-service core loads were provided by the structural engineer of record in the form of a computer output from a finite element analysis of the structure for gravity and lateral loads. The greater demands during construction required another round of component design, which resulted in additional connections and reinforcement.

Because grouting of horizontal joints was deferred until a time without freezing temperatures, serious attention was paid to the placement of shims in the horizontal panel joints. Concrete bearing strength was checked under maximum compression resulting from both wind and gravity loads at shim locations. A shim schedule that specified a minimum number of shim stacks at each building level was developed.

Connection types

It was important to minimize the number of connection types to increase the speed of construction while accounting for access limitations and erection sequence. Corner connections across vertical panel joints were welded, while connections across horizontal joints were mechanical splices in the form of sleeves, thus ensuring monolithic emulation along the height of each wall. Two types of mechanical splice sleeves were used: grouted and bolted. Bolted splices required pockets in the precast concrete panels that had to be filled with concrete later. The pockets in turn required roughened surfaces to improve the bond between precast concrete and cast-in-place fill. Connections with bolted splices were more expensive than grouted sleeves. This is why the number of bolted splice connections was limited to what was required for strength during construction. Bolted splice sleeves allowed for instant panel connections independent of weather conditions. Grouting of the splice sleeves was also deferred until ambient temperatures allowed grouting operations according to the manufacturer's requirements and the floor plates were completed, providing access without heavy equipment. To simplify production, only one size was used for both the bolted and grouted sleeve connection type. The welded connections were also designed and detailed to contain only one type. The previously described approach to the selection of precast concrete panel connections allowed a streamlined erection process independent of cold temperatures while keeping costs down by providing repetition at a large scale.

Constraints

The main obstacle of this project was access and the university and city's request to keep the road open to both pedestrian and vehicular traffic. The use of a ground control crane was mandated by the size of the precast concrete units. The crane was located in the parking lane just outside the footprint of the structure. Additional shoring to foundation walls along an interior wall allowed the crane to sit at street level and avoid moving while setting all three towers from a single location.

Shipping in the region during the project installation phase was often affected by weather conditions that caused the roads to thaw, requiring a 25% reduction of all truck traffic wheel loads. Because the trailer and equipment weight does not change, all loads required a 33% cut in payload capacity. Panels were reviewed with the precast concrete producer's logistics department to make sure that all loads could be shipped should the frost laws be invoked by the local department of transportation. This affected the panelization, increasing the panel count, connections, and duration of installation. All precast concrete panels were shipped flat and rolled to their vertical position on-site. Overwidth loads had to be coordinated with site crews to ensure that vehicle traffic was directed by signal people because the panels overhung the trailer into the traffic lane.

In all, the project had 122 precast concrete wall core pieces spread over two stair towers and one double elevator shaft. The two stair cores each had 24 precast concrete stair units with integral landings and cast-in nosings. All of these components were designed to be handled, shipped, and installed within the limits of the site and transportation to the site. Each precast concrete component and the logistics for shipping it had to be preapproved by the contractor and coordinated with the university's class schedule to ensure student movements around campus were not affected.

Connection selection

From the onset of the project, the contractor insisted that any connection used be capable of full installation without being affected by weather. This complicated the installation planning because the use of grouted and welded connections are the two most common methods for connecting precast concrete elements. In addition to the final connections, the structures had to be designed to be constructed and stand free without any braces to allow the construction of the surrounding structure.

To resolve these connection issues, multiple connection types that satisfied the project schedule requirements and the erection stability requirements were selected. Mechanical bolted reinforcing bar sleeve connections were used to support the structure during installation. The use of a pocket in the lower panel allowed the mechanical connection sleeve to slide over the protruding reinforcing bar from the upper panel. Once the bolts were engaged, the capacity of the reinforcement was used to support the panels in a similar manner to a grouted mechanical connector or a more common welded connection.

Minimal welded connections were used during the installation as part of the bracing system. By having few

This panel is ready to ship from the precast concrete manufacturer's plant. Shipping during the project installation phase was often affected by weather conditions that required a 25% reduction of all truck traffic wheel loads. The producer's logistics department made sure that all loads could be shipped with the weather constraints. This had the effect of increasing the panel count, connections, and duration of installation. Courtesy of Kerkstra Precast.

Bolted mechanical splice pockets in the precast concrete panels had to be filled with concrete later. Therefore, the pockets required roughened surfaces to improve the bond between precast concrete and cast-in-place fill. Courtesy of Kerkstra Precast.

required welded connections, the erector was able to minimize the risk of the weather affecting the construction schedule of the towers. When the weather was good, the welding team continued to make progress on the welds as required by the project design for the final conditions.

For full in-service loading, the typical grouted mechanical connector was used. These connections were only required when the floor diaphragm was in place and the space enclosed. With the space enclosed and temperature controlled, these could be grouted for full capacity. These connections were located such that the ports for the grout were accessible from the lower floor plate and inside the heated floor.

Installation considerations

The installation of the two box stair towers was not as much of a concern to the installer as the three-sided double elevator shaft was. This shaft had to be left open to accommodate the future installation of a luffing jib-style tower crane. The analysis of the structure as freestanding vertical shaft wall 162 ft (49.4 m) tall was daunting. After multiple iterations of sequencing and review of the calculations, the plan was accepted. Similar to the procedure for the pipe bracing, a review of each connection that was ungrouted was completed every morning. Grouted areas were checked to ensure that the grout was performing as required and not cracking, as well as to check for any missing grout.

The result was the installation of 146 pieces in 18 working days. The contractor was extremely pleased with the success of the precast concrete cores and the rapid installation process that made up a significant amount of time for the project. The use of a precast concrete specialty engineer in the design of the cores was viewed as a necessity for future projects, particularly with respect to the amount of coordination and precast concrete–specific issues that needed to be addressed.

Conclusion

This project was defined from the beginning with a project schedule and requirements to minimize or eliminate weather impacts. The success of the project was due to the early engagement of the structural engineer of record, contractor, erector, and specialty precast concrete engineer. Specific focus on the connection design and the incorporation into the project erection sequence allowed the team to openly discuss connection options. By having these discussions with a team that was completely invested in achieving the same goal, there were no surprises during the submittal review.

The engagement of the installer early in the project schedule allowed them to review and respond to the connection details and layout. Access to and finishing of connections were discussed with both the precast concrete specialty engineer and the contractor. This ensured that safety measures on-site were observed and maintained, and that all the requirements for a free-standing structure were met during the installation of the precast concrete panels.

This project demonstrates that precast concrete stair and elevator cores are viable alternatives to cast-in-place concrete stair and elevator cores in areas of low and moderate seismicity for buildings of various heights. In addition to the advantages of speed of construction and low weather sensitivity, precast concrete offers the ability to deliver custom-tailored design solutions that address any atypical challenges a project may face. When precast concrete producers are offered an opportunity early in the design or design-build process to contribute ideas based on their expertise and experience, the results are telling. A precast concrete specialty engineer can offer new perspectives to the architecture/engineering team and propose solutions that the design team may not be aware of. Offering case studies like this one to the architectural/engineering community helps make the case for integrating precast concrete partners into a design-build team easier by demonstrating that the process delivers the desired results.

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In 18 working days, 146 pieces were installed to construct the cores. Courtesy of Kerkstra Precast.

About the authors

Chad Van Kampen, PE, is a licensed engineer in multiple states and a project manager with Kerkstra Precast in Grandville, Mich. He has a degree in civil engineering from Calvin College in Grand Rapids, Mich., and extensive senior-level management experience with large complex projects centered on the precast concrete construction industry. He has worked on precast and prestressed concrete structural and architectural projects with a focus on conversion from other materials and is a leader in promoting alternate reinforcement. An active member with PCI and AltusGroup, he currently serves as chair of the PCI FRP Composites Committee.

Alex Mihaylov, PE, SE, is a principal with Vector Structures in Auburn, Wash. He has a degree in structural engineering from the University of Architecture, Civil Engineering, and Geodesy in Sofia, Bulgaria. He is a registered professional civil and structural engineer in multiple states. His practice is focused primarily on precast, prestressed concrete design, specializing in high-seismic and special criteria design and projects involving conversion to precast concrete. He is a member and past chair of several PCI technical committees.

Abstract

Stairs and elevator shafts not only allow vertical movement of occupants from floor to floor, their cores often serve as the main lateral stability system for these multistory structures. Due to the magnitude of loads often applied to these cores, they are stout and consume valuable space. This case study is of a 12-story-plus-basement dormitory that has a precast concrete elevator core, two precast concrete stair cores, and a free-standing precast concrete shear wall. This paper presents the process of development and implementation of the cores from a design concept to completed construction.

Keywords

Core, elevator, site restraint, stair, weather.

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