Rising High

The engineers for two steel-framed Chicago towers provide insight into the current trends in high-rise office building design.

One South Dearborn

Hyatt Center

Courtesy Halverson and Partners

On November 8, 2005 engineers from the Chicago structural engineering firm Halvorson and Partners spoke with the staff of *Modern Steel Construction* and an AISC Regional Engineer about the structural design of two of the firm's recent high-rise office building projects—Chicago's Hyatt Center and One South Dearborn. The highlights of their discussion touch on current design issues and trends for composite high-rise office structures.

Framing System

Stine: What kind of study did you do to determine exactly what type of framing system you would use—whether you would use concrete shear walls or a braced frame [system]? Was it based on past experience or what you thought was economical?

Swanson: We did look at a lot of different concepts. Past experience certainly helps to zero in on the right solution. I think that it gives you a feel for limitations of various systems. We also worked with the project's general contractor, Bovis Lend Lease, who was involved with the project from the early design stages. We were able to discuss cost and constructability issues with them. To some extent, the geometry of the building and architectural intent points you in certain directions.

Melnick: Can you elaborate on that in relation to the buildings?

Swanson: For the Hyatt Center, perimeter views were a significant design feature. There was a strong desire to minimize the structure along the skin of the building, which dictated placing the lateral load resisting systems in the core. Once this was established, we looked at steel bracing schemes, concrete shear wall schemes, and outrigger systems as well. The outriggers created zones within the building that would be difficult to lease, and were eventually discarded. An internally braced steel frame scheme was not stiff enough and would have required outriggers extending out beyond the core. We decided on the concrete core, which was capable of withstanding all of the building's lateral loads alone.

Warner: Is Hyatt Center one of the taller composite structures where only the core takes the lateral loads?

Swanson: That's somewhat dependent on the size of the core. For these particular dimensions, we probably wouldn't have been able to utilize the concrete core alone if the building grew significantly. The walls at the base are already fairly thick and consist of very high-strength concrete. To go any taller would have steered us back to some type of supplemental outrigger system or structural components on the face of the building.

Warner: On One South Dearborn, time was the issue, and we were working with a very sophisticated developer. They pretty much knew what they wanted coming in—an efficient office tower that could be designed and built on an incredibly tight schedule. One South Dearborn is about 100' shorter than Hyatt Center, which puts in right in the middle of the height range where composite concrete core systems are optimal.

We presented schemes for both a steel braced core and a concrete core for comparison. Right away, the developer priced both systems and confirmed that the concrete core was going to be more efficient.

Special Load Conditions

Melnick: Did you have any load requirements for paper and that sort of thing?

Swanson: They were consolidated into localized areas to minimize cost. Several of the building's major tenants were on board very early on, so we were able to work with their architects to locate all high-load areas and reinforce the structure accordingly. We created designated high-load areas which the tenants, for the most part, were able to stay within. Later on, only a few areas required reinforcing.

Warner: One South Dearborn's situation was two-part. We had something similar to Hyatt Center, where the major tenant was on board early and consolidated the high-density files. We designed for those high-load areas for all of the floors in the building.

In addition, we were able to provide slightly higher than typical live load capacity for all of the floors. In Chicago, a one-hour fire rating is required for a high-rise with sprinklers. This can be achieved with a 3"-thick deck plus 2½" lightweight concrete—it's the bare minimum, but it meets the code. Considering the possible vibration problems at long spans with light floors, we talked with the owner and decided on 3" deck and 3¼" concrete, which is a more conventional two-hour slab. This required slightly heavier beams to support the slab during the pour, but we then were able to add a few more studs to achieve a live load capacity of 100 psf for a whole floor—as opposed to the typical 50 psf plus 20 psf—and the developer actually marketed that.

Melnick: And for the Hyatt Center?

Swanson: It's the standard Chicago office live load, 50 psf plus 20 psf for partitions. We allowed 175 psf for the specified high loads areas, which is high enough to accommodate the standard rail-type file systems and easily accommodates file cabinets or similar loads. We tried to keep these areas in the core for the most part where the beam spans were shorter. It was much more cost-effective to upsize the framing in those bays than out in the longer lease areas, where you had the 40' or 45' spans.

Stine: How much did you have to go back and reinforce? Five percent of them, or just a few random ones?

Swanson: For the major tenants that had input on the design, very little had to be reinforced later. Maybe just a handful of areas. With the newer tenants that were coming in later, we're finding that

Discussion Participants

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Scott Melnick, Editor In Chief
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several of the designs required floor reinforcement of some sort. If they're not taking a full floor, they may have parcels away from the core areas, which is where most of the high-load conditions occurred.

Melnick: What type of cost difference did you experience going from standard floor load up to the reinforced floor?

Warner: For the 100 psf capacity, they bought it at basically nothing. Because we were tying to alleviate this vibration concern with extra concrete and because we were pushing the edge of the envelope for the beam depths at the 45½' span, we already had to have a certain beam to hold that concrete in the first place. With a few extra studs, they basically got it at no cost premium.

Swanson: On any office building, you're going to review a significant number of tenant requests for high loads, stair openings, and penetrations through beams. We haven't had any problem accommodating them with the original steel floor framing and have had limited reinforcement, if any. Reinforcing or upgrading the structure before it is built is certainly much less expensive than doing it afterwards.

Security

Melnick: Let's talk about the owner's program in brief. I've heard that security was a concern for Hyatt Center's owner.

Swanson: The Hyatt Center certainly emphasized security as a primary design component, and the owner used that feature to market the building. The final version of the design began shortly after 9/11. We were working on an earlier concept for the Hyatt Center a year or so prior to 9/11, with a dramatically different building. That changed with the renewed emphasis on security, and with changes in the economic climate as well.

Melnick: What kind of economic changes?

Swanson: With the dip in the stock market and overall United States economy immediately after 9/11, the real estate market suffered as well. The building was somewhat downsized and reduced in cost, as well as having a greater emphasis on security placed on it than was in the original design.

Melnick: Four years later, are these trends continuing?

Swanson: I don't think so, particularly in the private sector. In general, structural designs are almost back to where we were before 9/11. There are some exceptions, primarily government buildings that are instituting mandatory requirements for structural reinforcement. Some code revisions are being proposed, but it could be a while until they are actually enforced.

To ensure structural security, rigorous vulnerability analyses were performed on the Hyatt Center's proposed design. These studies revealed areas where blasts from both inside and outside the structure could have posed credible structural threats to its tenants.

Along with the project's blast consultant, Halvorson and Partners developed solutions in which blasts would be isolated from the building's occupied spaces while mitigating the potential for progressive collapse of the structure. Hardened structural components included an enhanced steel frame and multiple concrete blast-resistant walls and slabs. At some locations, factored steel beam connection design forces exceeded 1,000 kips for a single level of framing.

Despite these significant upgrades, the modified structural frame fit within the original profiles of the gravity support members. The modifications were therefore transparent to the building's tenants and did not affect aesthetics.

Melnick: What's the difference in cost between the more standard building and one upgraded for security?

Swanson: It's difficult to put an exact dollar figure on it. We never had an exact structural cost breakdown of a standard building versus the upgraded building for the Hyatt Center. The security design concept was incorporated from day one so we never had a complete design estimate to compare to the final building. It was a significant investment.

The structural upgrades, Swanson estimated, accounted for a small percentage of the overall $200 million project cost. This, however, does not include other security measures taken within the finished building, such as metal detectors, surveillance, and other security systems—not to mention the ongoing cost of providing staff to operate and maintain these systems.

Schedule

While the design of Hyatt Center was driven largely by security concerns, One South Dearborn's design was driven by the project's fast-track schedule.

Warner: The story for One South Dearborn was time. The developer had an anchor tenant, a large law firm, whose lease was about to expire, and so time became critical. They pulled together a team who they knew could do an office building efficiently. The project manager for the architect often referred to the project as a 'textbook' high-rise office building.

Halvorson and Partners were given a 46-week delivery period for the project—less than half that of other recently constructed high rises in Chicago, according to Warner. A series of floor framing studies for the 45′-6″ clear span (core to glass) assessed beam depth and weight options. Considering this structural efficiency and its impact on floor-to-floor heights, W18 floor beams were deemed optimal. The beams used for the spans were designed to carry 100 psf live loads—while offering outstanding flatness and vibration performance—at a total steel floor framing weight of less than 7 psf. The entire steel structure (gravity columns, floors, and connections) totaled less than 11 psf.

Raised Floors

The Hyatt Center's design includes a raised floor system, which Swanson said is not uncommon but does affect the load design because of weight shifted in pounds per square foot.

Stine: What's the benefit of choosing a raised floor?

Swanson: It allows for much greater flexibility in laying out the building cabling. Some buildings have actually run air into their raised floors as well, but not that often in Chicago. If you ever need to access cabling in the raised floor, there's no need to pull out portions of the ceiling. You simply open up the raised floor panels. The use of raised floors also allows curtain wall anchors to bear directly on the slabs, rather than being pocketed into them. But there is the extra cost associated with the raised floor that owners have to weigh into their decision.

Hyatt Center

The Hyatt Center was the first high-rise office building designed and constructed in Chicago after September 11. The 700'-tall, 1.75 million sq. ft structure provides Class A office space for some of the city's most prominent tenants, while addressing newly heightened security concerns.

The curved exterior of the building follows the curve of the central concrete core. This allows equal length steel beams to span from the core to the exterior columns and spandrel beams. To accommodate differential shortening, certain steel columns were lengthened and adjustable field splices were designed into the perimeter columns to allow for adjustments during construction.

Structural Elements

Structural steel and reinforced concrete components were used for the 49-story building's composite structural system. All primary structural elements to resist lateral loads are located in a narrow concrete core. Reinforced concrete walls within the core resist all of the tower's wind loads, as well as portions of the building's gravity loads, while long-span structural steel beams support lightweight concrete slabs outside the core.

The concrete walls vary in thickness up to 32"-thick, with strengths up to 10,000 psi. The walls are arranged in a curved profile parallel to the exterior wall configuration, which permitted repetition in the steel floor framing. Radial beams of the same length span from the interior walls to perimeter steel columns. Such efficiencies are not typically achieved in curved buildings, but were made possible in the Hyatt Center. Formwork systems allowed the curved concrete walls to be constructed with minimal cost premiums over standard rectangular wall systems.

Despite a narrow profile, with a height-to-width aspect ratio of more than 12:1, the concrete core walls alone met target lateral wind load accelerations at the top floors. Supplemental bracing or outrigger schemes, which would have disrupted perimeter tenant spaces, were unnecessary. The core wall configuration is also torsionally efficient, resisting the eccentric wind forces that act on the 300' exposed face.

All major mechanical systems were to be placed within the building core at each level. The concrete walls became potential barriers to the many pieces of ductwork and piping accessing the floor spaces. Carefully coordinated bands of wall openings—3,500 in total—accommodated these systems without compromising the walls' integrity.

The concrete core walls exhibit a different axial shortening behavior than the perimeter steel columns due to differences in stress levels and materials. A time-history study, which closely examined material properties and construction scheduling, concluded that the differential vertical shortening between the two could be significant and potentially detrimental to the structure. Steel columns were lengthened appropriately and adjustable field splices were designed into the perimeter columns to allow additional corrections to perimeter steel elevations, if necessary, as construction progressed.

Secure by Design

A rigorous vulnerability study identified several credible threats to occupants from both internal and external explosive charges. With the project's blast consultant, Halvorson and Partners developed solutions that isolated explosive threats from the building's occupied spaces while mitigating the potential for progressive collapse of the structure.

Significant blast mitigation provisions were incorporated into the structural design without imposing significant restrictions on the building's function or aesthetics. Hardened structural components were developed by enhancing the steel frame and incorporating multiple blast-resistant walls and slabs. Factored beam connection design forces exceeded 1,000 kips for single levels of framing at some locations. The modified structural frame fit within the original profiles of the gravity support members, despite the significant upgrades, and is transparent to tenants.

Accommodating Tenants

Structural steel floor framing permitted 42' clear spans in the lease spaces, with 38' column spacings along the perimeter. The structural steel design also accommodated an array of tenant requirements, including inter-story stairs, dense filing systems, and multi-story atriums. Additional amenities became part of the building's base design as tenants further customized their spaces.

Developer
Higgins Development Partners, Chicago

Architects
Design Architect: Pei Cobb Freed and Partners Architects LLP, New York
Architect of Record: A. Epstein and Sons International, Inc., Chicago

Structural Engineer
Halvorson and Partners, Chicago

Fabricator and Detailer
Cives Steel Co. Mid-West Division, Wolcott, Ind., AISC member, NISD member

Steel Erector
Midwest Steel, Inc., Detroit, AISC member

General Contractor
Bovis Lend Lease, Chicago

One South Dearborn

The structural drawings for One South Dearborn, a 40-story, 820,000 sq. ft composite steel and concrete office tower in Chicago, were completed in just four months. This fast-track design by Halvorson and Partners responded to both the developer's schedule and a challenge for design efficiency.

Structure

A concrete core provides the primary lateral system for the building, while steel columns carry most of the gravity loads. Floor framing studies resulted in minimum-depth W18 floor beams at 10' on center, spanning 45'-7" from the interior core to the perimeter girders.

Vibration was a primary concern for the floor design, given the long spans and minimized beam depths. A 3" deck with 2¾" lightweight concrete would have met the Chicago building code's requirement for a one-hour fire rating with sprinklers. However, Halvorson and Partners demonstrated that 3¼" topping would help alleviate vibration. And by adding a few additional studs, it would allow a floor live load capacity of 100 psf at a total steel weight under 11 psf for the entire structure (and under 7 psf for the floor framing). The developer was eventually able to market this capacity to potential tenants.

Wind tunnel studies allowed the central shear wall, only 50' by 60' in plan at the lower levels, to be 12" to 18" thick at the office floors. Only a portion of the walls extend to the top of the tower.

Floor-to-ceiling curtain wall glass was achieved by pocketing the curtain wall seat 3" into the slab. This required the base structure support to fit with the remaining 3¼" slab depth. The detail selected used a 3"-deep HSS that was embedded in the slab and that cantilevered from the top flange of the spandrel beam. This provided adequate support for the curtain wall.

Thirty-foot-high screen walls are topped by catwalks and extend above the roof. A system of diagonal braces, horizontal struts, and cantilevered steel was created to support these walls. Halvorson and Partners worked with corrosion experts and paint manufacturers to specify a state-of-the-art, four-layer coating system for exposed steel supporting the architectural panels at the roof, which is subjected to corrosive chemicals from cooling towers below.

At its 40-story height, differential shortening between the highly stressed steel gravity columns and the more lightly stressed concrete core (which was primarily sized for lateral stiffness) was an issue. Halvorson and Partners devised a simple scheme to accommodate this after in-depth analysis. Steel columns and perimeter spandrels were built slightly higher than the concrete core at each floor to match the erection diagram. At "leveling floors," located every six stories, column length compensations were prescribed and shims were used at column splices. This allowed the erector to adjust to achieve the prescribed elevation differences and keep the framing within erection tolerances. By the time tenants moved in, the steel columns had shortened to provide nearly level floors. Future core shortening, due to continued creep and shrinkage, would be minor and would still allow floors to remain within the allowable tolerance.

Parking

The first five floors above grade are parking levels framed with W18 steel beams composite with 3" deck and 4½" normal weight concrete. These beams are similarly configured to the typical floors, but framing was sloped to accommodate the ramped floors.

The parking floors were originally designed as a formed concrete slab, but the contractor offered substantial savings to use composite metal deck with topping. Corrosion and durability concerns were addressed by Halvorson and Partners after consulting AISC's recommendations for steel parking garages. Perforated metal deck and appropriate deck sealant and membranes were specified. Slabs were designed assuming the deck only serves as a form.

One typical exterior column needed to shift 10'-0" at the ground level to accommodate the parking garage entry. Costly transfer girders were avoided by sloping the gravity column over multiple floors. Between floors nine and three, where the column slope started and stopped respectively, steel beams were introduced in the floor framing to create a horizontal diaphragm/truss to stabilize the transfer. Had these horizontal forces been taken in the slab diaphragm only, unwanted cracking would have occurred in the parking floors.

Developer
Hines, Chicago

Architect
DeStefano Keating and Partners, Chicago

Structural Engineer
Halvorson and Partners, Chicago

Fabricator and Detailer
Cives Steel Co. Mid-West Division, Wolcott, Ind., AISC member, NISD member

General Contractor
Turner Construction, Chicago

To accommodate the parking level entrance, one column had to be shifted 10'. Costly transfer girders were avoided by sloping the gravity column over multiple floors.

Warner: Does it help with floor leveling or flatness?

Swanson: It certainly does. The raised floors installed are leveled with lasers after the floors are poured. The slab finish doesn't need to be as flat as it would with an exposed floor because you are going to be covering it up eventually. If you have a little bumpiness in your slabs, it's easily accommodated with the raised floor's adjustable pedestals.

Grubb: What kind of adjustability do they have?

Swanson: It depends on the pedestals because you can purchase different heights. Generally, there's adjustability of a couple inches within standard pedestals.

For One South Dearborn, the decision to forgo a raised floor system yet maintain a horizontal mullion at each floor led to challenges in attaching the floor-to-ceiling curtain wall glass. The connection was hidden in a pocket in the typical 6¼" slab. It was a "trickier condition," according to Warner.

Warner: A horizontal mullion was right at the floor line. The design intent was to pocket into the 6¼" slab edge to create a recessed seat for the curtain wall connection. It was a tough detail; with a 3" recess, only 3¼" of concrete remains. Also, this concrete slab would be cantilevering from the spandrel, with 1'-2" from the edge to beam center line.

Melnick: What did you end up doing?

Warner: The original detail was recommended by a curtain wall consultant advising the owner during design development, but we were not convinced that 3¼" of concrete could be counted on, considering consolidation and aggregate size. Having discussed this concern with the team, we ended up showing the detail on our drawings, noting that the curtain wall contractor was responsible for ensuring the reduced slab section was designed for their curtain wall loads.

In the end, the curtain wall contractor selected for the project did not rely just on the 3¼" of concrete for this detail. Instead, a 3"-deep steel tube was embedded in the slab, cantilevering from the top flange of the spandrel beam. This provided a clear, reliable load path through the steel. MSC