Beating the Odds

BY WILLIAM B. KUSSRO, P.E., S.E.

Staggered steel truss framing makes this Detroit casino/hotel a winner, while maintaining both the floor-to-floor and overall structure heights of the original concrete frame design.

WHEN A PROJECT CHANGES HANDS EARLY IN THE DEVELOPMENT CYCLE, IT'S COMMON FOR THE NEW OWNER TO REEVALUATE PRELIMINARY DESIGN WORK. It's not as common, however, for that evaluation to result in fundamental changes to the structural system. Such was the case with Detroit's MotorCity Casino. Its 17-story hotel tower was originally conceived as a post-tensioned, cast-in-place concrete structure, but was redesigned as a steel-framed staggered truss system to alleviate concerns about cold-weather construction and concrete labor.

Giffels, a full-service architecture and engineering firm in Southfield, Mich., was contracted to perform the design services for the tower. The design team faced a significant challenge: Design a steel tower while maintaining the floor-to-floor and overall heights already established by the preceding structural concrete design. Maintaining the heights was important in order to avoid cost overruns caused by additional cladding and increased frontal wind area in the form of increased frame and foundation costs. In addition, the owner also desired a flexible interior space that allowed for interior design changes to be made while the structural design progressed.

Innovative Structural Framing Concepts

The initial design concept for the hotel tower was a cast-in-place concrete frame consisting of 10-in.-thick post-tensioned flat plate slabs and cast-in-place concrete columns. Cast-in-place concrete core walls located at the ends of the building were proposed to provide the lateral load resistance for the structure. The typical residential floors had a floor-to-floor height of 10 ft with this initial concrete design.

The steel alternative chosen consisted of staggered steel trusses supporting 10-in.-thick precast, prestressed hollow-core slabs for the residential floors, and traditional composite steel beams and girders supporting cast-in-place concrete slabs on metal deck for the other floors. The staggered truss system is a framing configuration with specific application to long, rectangular plan buildings such as hotels, dormitories, and other similar residential structures. Story-high trusses span between exterior column lines, and adjacent trusses are vertically staggered such that the floor slabs span from the top chord of one truss to the bottom chord of the adjacent truss. The system is repeated throughout the entire length and height of the building to provide a column-free interior space. On this project, the staggered steel trusses were spaced at 30 ft on center on alternate floors. The design resulted in column-free space of approximately 75 ft by 60 ft on any one given floor. The floor-to-floor height on the fourth through 14th residential floors was maintained at 10 ft, which resulted in a finished ceiling height

View of the 16th floor. The staggered trusses at this level are fairly light, because there are few supported levels above. Composite beam and girder framing was used for the 17th floor slab and upper mechanical penthouse levels.

of 8 ft, 10 in. in the living areas of the guest rooms. Slightly higher floor-to-floor and ceiling heights were used on the 15th and 16th suite level floors.

A total of 46, story-high, 7-panel, Pratt-style staggered steel trusses were used in the tower to frame the fourth through the 16th floors. The center panel of the trusses was a Vierendeel configuration, which allowed uninhibited passage through the center corridor. While the length of the trusses varied slightly based on the geometry of the building, their depth in the standard guest room floors was 10 ft from the top of the uppermost chord to top of the bottom chord and approximately 10 ft, 10 in. out-to-out of the truss. All trusses on the standard residential floors were completely shop-welded. Higher floor-to-floor heights were required for the upper suite floors and field-assembled trusses were required for these levels. W10 wide-flange beams were used for the truss top, and bottom chords and square and rectangular HSS members were used for the web members. Due to the unsymmetrical nature of the offset curved long faces of the tower, each staggered truss had a slightly different length and geometry. The trusses ranged in length from 65 ft to almost 70 ft, depending on the column line and location within the building.

Forty-six story-high, 7-panel, Pratt-style staggered steel trusses were used in the tower to frame the fourth through the 16th floors. Due to the unsymmetrical nature of the offset curved long faces of the tower, each staggered truss had a slightly different length and geometry.

Composite beam and girder framing was used for the second (spa) and third (lobby) floors, as well as the 17th (restaurant) floor and upper mechanical penthouse levels. In general the slabs consisted of 6½-in. lightweight concrete on 3-in. composite metal floor deck. However, for the cantilevered ends of the building, 5-in. lightweight concrete on 1½-in. composite metal deck was used to lighten the dead load on the cantilevered framing. The elevator lobbies and other miscellaneous floors were framed with non-composite beam and girders supporting a lightweight concrete slab on metal deck. All slab thicknesses were selected to provide the required 2-hr fire rating without having to spray the underside of the metal deck.

The structure had an average width of 75 ft and an overall length of 300 ft, excluding the cantilevered structures on the ends of the building. The staggered trusses were designed to transfer all vertical loads to the perimeter columns on the long faces on the building. Vertical bracing was considered for the design, but the 18-in.-thick cast-in-place concrete end core walls from the initial design were chosen in an effort to provide lateral stability and resist all imposed lateral wind and seismic loads. This decision resulted in significantly less shear demand on the precast plank floor diaphragm and allowed the staggered steel trusses and columns to be designed for gravity loads only.

An integrated three-dimensional structural model was built in ETABS to study the stiffening effect of the trusses, even though they were not designed to carry any lateral load. Due to the rectangular geometry of the tower, wind load controlled the lateral design in the building's short direction and seismic load controlled the design in the long direction.

It is important to note that in using the staggered steel truss system as opposed to a traditional steel beam and girder system, the overall structure height was reduced by approximately 15 ft. By using the staggered steel truss concept, the steel structure could essentially match the cast-in-place concrete flat plate design.

Precast Concrete Floor System

The floor system is composed of 4-ft-wide sections of 10-in.-thick extruded precast, prestressed hollow-core plank. The planks span the 30 ft between the staggered truss top and bottom chords. No structural topping was required on the planks. However, a nominal 1-in.-thick cementitious underlayment was used to essentially level the floors and provide a uniform surface for the installation of the latter trades' work. The precast floor slabs form the horizontal elements of the lateral load resisting system, transferring the lateral wind and seismic diaphragm shear to the concrete core walls. The floor plates were modeled and found to act rigidly, so accidental and actual eccentricity due to applied wind and seismic loads were calculated and resolved into the core wall elements.

Nominally 10-in.-thick wet-cast solid precast slabs were used on the long faces. Custom formwork for the slabs was fabricated in order to match the curving edge of the floor plate. The solid precast slabs serve as the chords of the rigid diaphragms and also resist column stability forces, resolving those forces into the vertical elements of the lateral load resisting system and eliminating the need for traditional steel spandrel beams under the slabs. This also was in accordance with the architectural design requirements. In addition, the aluminum and glass curtain wall system is supported at every third floor through the use of inserts cast into the edges of the solid slabs, which allowed attachment of the façade panels. In order to transfer the diaphragm and stability loads, mild reinforcing, in addition to the prestressing strand, was added in the solid slabs. Giffels worked closely with the precaster to design and detail connections to transfer the design forces between the planks and also through the columns and into the concrete core walls. A total of 154 10-in.-thick, 4-ft-wide precast, prestressed hollow-core planks and solid slabs were used on each floor, resulting in a total of about 2,000 pieces for the entire tower.

Carrying the Load

One signature feature of a staggered steel truss building is that the interior columns are removed, and all of the gravity loads are transferred to the perimeter columns. The perimeter column loads approached 3,200 kips, and as a result the lower column sections became very large. Thus it was determined that the use of ASTM A913 Grade 65 material would be beneficial for the lower columns tiers where the axial loads were the highest and the floor-to-floor heights the largest. The floor-to-floor heights of the lower levels housing the building services, spa, and main lobby were slightly larger, at 11 ft, 6 in.; 12 ft, 9 in.; and 26 ft, respectively, compared to the typical residential levels. With the introduction of the high-strength steel, the lower tier column sections—which ranged from W14×426 to as high as W14×605—were reduced, saving approximately 40 tons of steel. The remaining column tier sections used the more-standard ASTM A992 Grade 50 material.

About 615 tons of the ASTM A913-Grade 65 jumbo steel material was used on the project. The decision was made early enough in the project so that ordering the Grade 65 steel through Arcelor Steel in Luxembourg caused no schedule delays or cost impacts. As the design progressed, several of the columns were subjected to additional loads due to design changes in regards to the pedestrian bridges intersecting the tower. However, the higher strength and residual capacity in the Grade 65 columns afforded the flexibility to modify the pedestrian bridge tie-in locations without having to reinforce the columns.

While ASTM A913 Grade 65 material was used for the lower tier columns, ASTM A992 Grade 50 material was used for the balance of the columns, trusses, floor, and roof framing members. In all, approximately 2,800 tons of structural steel were used in the tower.

Taking Advantage of the System

The staggered steel truss system for the tower had several major advantages over the previous concrete options. For starters, it resulted in large column-free spaces for the owner to alter interior design as desired. In addition, the design significantly reduced structural dead weight resulting in foundations savings. The primary columns along the perimeter of the building reduced the number of deep drilled pier foundations, and the size of the foundations that remained was also reduced due to the decreased gravity dead loads. Furthermore, foundations supporting the more lightly loaded interior columns supporting the lower two floors were shallow spread footings proportioned for equal settlements when compared to the heavily loaded drill pier supported columns.

The steel system also decreased the construction duration and allowed construction in almost any weather condition—a big plus for building in Detroit—unlike the previous concrete schemes. Finally, the steel framing avoided the use of costly transfer levels in the lower portion of the tower, as the interior columns in the upper portion of the tower did not align with the preferred location of the interior columns in the lower three floors. The selected system allowed for longer spans with no interior columns, which provided more usable column-free space and afforded the owner flexibility in planning the interior spaces.

A Winning Design

The 17-story hotel tower has a total square footage of 395,200 and 400 guest rooms. There are 13 residential floors, which include 11 standard guest room floors and two floors dedicated to suites and super suites. Other significant portions of the project are a 45,000-sq.-ft addition to the existing casino building, a 204,200-sq.-ft convention center—which includes 67,000-sq.-ft of exhibit space and a 1,200-seat theater—a 933-space, four-level parking structure, two pedestrian bridges connecting the hotel to the rest of the complex, and extensive interior renovations to the existing casino and related buildings. An additional 700 tons of structural steel was used on the casino building expansion and another 1,100 tons on the convention center.

Staggered trusses were framed into the walls between hotel rooms. Floors are framed with 4-ft-wide, 10-in.-thick precast prestressed concrete planks. The planks span 30 ft between the bottom chord of one staggered truss and the top chord of the next.

With an overall structure height in excess of 250 ft, the MotorCity Casino Hotel Tower is an eye-catching new addition to the downtown Detroit skyline and is the first use of staggered steel trusses on a major project in Southeast Lower Michigan. The staggered steel truss framing system was readily implemented and met all of the owner's requirements, matching the physical attributes of the cast-in-place concrete tower as outlined in the preliminary design phase. The $275 million project is scheduled to be completed by August 2008. MSC

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