Hat Truss-Supported Office Tower in Salt Lake City

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111 Main's innovative "balanced" structural system supports the 25-story high-rise above an adjacent performing arts center.

In Salt Lake City, Utah, at 387 feet above grade, 111 Main has become the newest and one of the tallest additions to the skyline. Currently under construction in the heart of the downtown City Center neighborhood, the roof hat-truss structure of the 25-story, 501,455 square foot Class A office tower was topped off this past January, with its loads successfully transferred from a temporary shoring support system to the permanent structural system during a one-day 12-hour period. Designed by architect and structural engineer of record Skidmore, Owings & Merrill LLP with VCBO Architecture and Dunn Associates Inc., the building's structural engineering features an innovative and integrated solution to a complex site challenge – how to suspend a portion of the tower over an adjacent building. *Figures 1* and *2* show the building under construction and the final rendering, respectively.

Figure 1. 111 Main under construction. Courtesy of City Creek Reserve, Inc.

Air Rights Collaboration

An air rights agreement with the neighboring property owner defines the project site's south property line. 111 Main is on a contiguous parcel with the new Salt Lake County Center for the Arts' George S. and Dolores Doré Eccles Theater, which overlaps on the lower four stories and basement level of the tower footprint. The required structural system could not extend columns below the fifth level of the tower on the south side to accommodate the Eccles Theater under the southern portion of 111 Main's tower. While the design development and construction of the two projects were undertaken simultaneously, in parallel but separate timeframes over three-plus years, the air rights collaboration allowed for adaptation of the final property line configuration, on the south side, to meet both project design objectives. *Figure 3* shows an early concept design sketch of the building section and interface with the new performing arts center to the south.

"Balanced" Hat Truss Concept

The design of the penthouse roof level comprises a "balanced" two-way steel hat truss system that supports all of the office tower's 18 perimeter columns in an integrated load-balanced structure. The system supports 20 suspended levels in the south side terminating at Level 5, and 23 suspended levels in the east, west and north sides terminating at Levels 2 and 3, such that no perimeter columns meet the ground level. The unequal bay sizes in the north (40 feet 3 inches) to south (45 feet) direction help to balance the

Figure 2. 111 Main rendering of design. Courtesy of Skidmore, Owings & Merrill LLP, 2016.

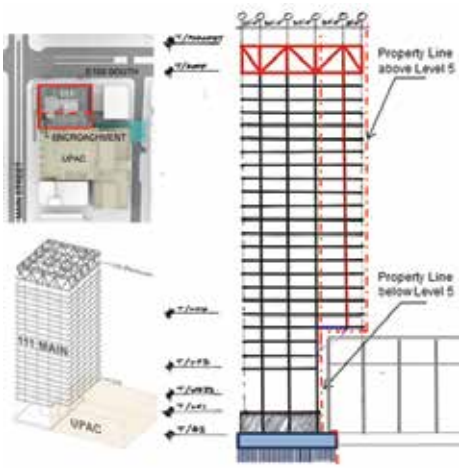

Figure 3. 111 Main site plan and section concept.

Figure 4. 3D structural (REVIT) model.

eccentric loading caused by the unequal termination of floors in the north and south directions. The central reinforced concrete core walls provide the only connection of the tower to its foundation and transfer all gravity loads, as well as wind and seismic vertical and lateral loads. Conventional long-span, lightweight composite deck slab and steel floor framing construction connects the central core walls to the steel perimeter frame and suspended columns, providing clear span open office bays and a completely column-free lobby at the tower's base. *Figure 4* shows the 3D structural REVIT (Autodesk) model with views looking from the northwest and southeast.

With 18 perimeter tower columns, only 7 of the 18 impacted the new performing arts center footprint at grade to the south. The design team considered several alternate schemes including one-sided "eccentric" trusses, which created an undesirable 4¾-inch gravity "lean" to the south, while further considering vertical core wall post-tensioning to compensate for the eccentricities. The two-way hat truss system was selected, providing balance under gravity loads while NOT creating a penthouse roof outrigger truss system in resisting tower overturning seismic loads. *Figure 5* shows the constructed penthouse roof hat truss system in shored condition just before load transfer in early January 2016.

Superstructure Description

Steel Hat Truss System

The steel two-way hat truss system encompasses approximately 1870 tons of structural steel in support of the 18 suspended perimeter columns. Approximately 40% of building gravity dead and live loads are transferred at the roof penthouse hat trusses to the top of the reinforced concrete core wall superstructure via six steel spherical structural bearings. The bottom chords of the truss system, along with in-plane diaphragm bracing and the concrete deck slab, act as the framed mechanical penthouse floor framing at Level 25 just above the last occupied tenant space at Level 24. The reinforced concrete core walls terminate just below the Level 25 bottom truss chords, as shown in the section in *Figure 6*. The top chords of the truss system, which include in-plane diagonal bracing, form the top of the roof penthouse. Throughout, the top to bottom chord centerline distance of the hat truss system is maintained at 28 feet 1½ inches deep. In plan, the trusses span over the core walls on three primary grid lines 30 feet apart in the north-south direction. In the east-west direction, two additional primary trusses span over the core walls separated by 42 feet 3 inches, with skewed truss cantilevers extending out from the concrete core to connect with perimeter 30-foot bay spacing. Typical truss chord and diagonal members range from W14x398 to W14x730 Gr 50 ASTM A992 steel.

At the perimeter, in-plane "V" configured belt trusses act to pick-up each hanging column node connection below, at the V intersection, while also connecting to primary bottom and top truss chords. These perimeter trusses act to cantilever out 30 feet horizontally off the ends of the primary trusses to pick-up an additional "outlier" hanging column. There is a total of eight outliers with two at each corner picked up by the double cantilevered truss system. Perimeter WF column members, designed for both temporary shored compression loads and final hanging tension loads, range from W14x132 to W14x550 Gr 50 ASTM A992 steel. Perimeter truss cambers were set up +1½ inches at primary column "nodes" and +2 inches at outlier columns. The

Figure 5. Penthouse roof hat trusses just prior to load transfer. Courtesy of City Creek Reserve, Inc.

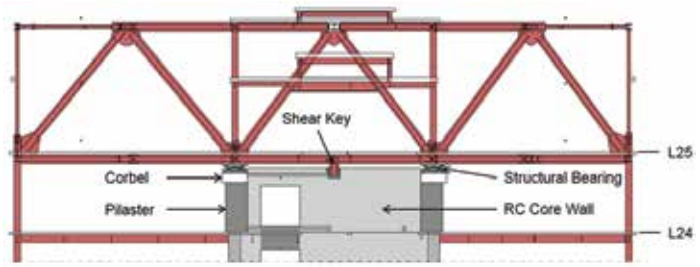

Figure 6. Section through hat truss at top of core wall in transverse north-south direction.

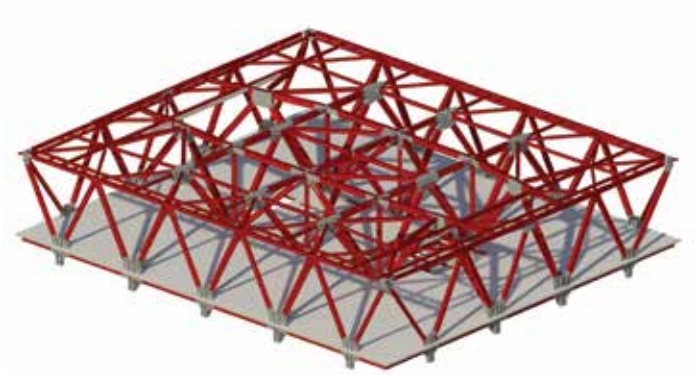

Figure 7. Balanced two-way roof hat truss system.

3D layout configuration of the hat truss system above Level 25 is shown in *Figure 7* along with typical shop fabricated built-up plate truss connection nodes as indicated in *Figure 8* (*page 34*). At the four core wall corner structural bearing supports, the maximum connection node weighed 22 tons. The overall centerline footprint of the hat truss system is 130 feet by 150 feet.

Articulated Spherical Structural Bearings

Six articulating spherical structural steel bearings are provided at the top of the reinforced concrete core wall superstructure to transfer compressive gravity and lateral loads from the penthouse roof hat trusses to the core walls extending to the deep piling foundation system. The bearings act as "pinned" connections, allowing for truss chord rotations in all directions as well as temperature movements under exposed environmental conditions. Seven W14x730 shear keys, with pockets at the top of the core walls, extend down from bottom truss chords providing horizontal shear bearing support.

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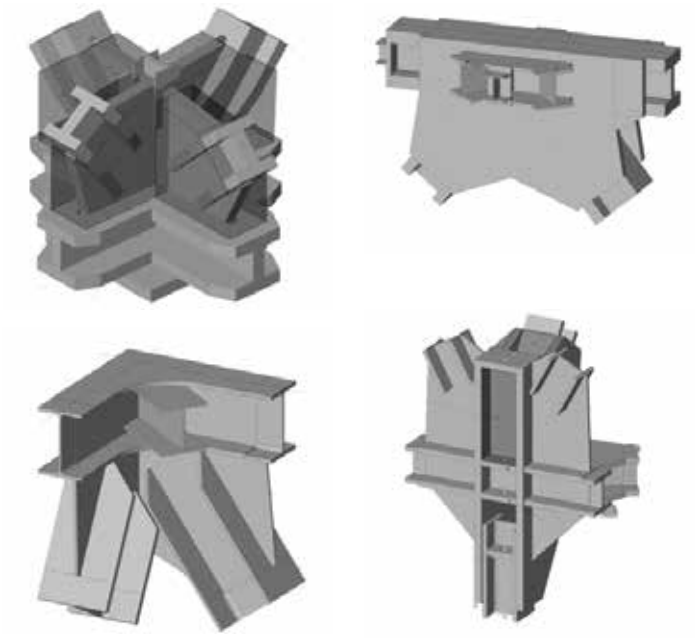

Figure 8. Typical detailed shop fabricated built-up plate truss connection nodes.

The bearings, which measure 60 x 60 inches in plan, 16½ inches in height and are rated with a vertical capacity of 19,000 kips under combined vertical gravity and earthquake loads, include a 40-inch diameter articulated slider. Earthquake Protection Systems, Vallejo, CA, manufactured the bearings.

Ductile Reinforced Concrete Core Wall Superstructure

Located in a region of high seismicity near the active Salt Lake Segment of the Wasatch Fault Zone, 111 Main was designed to meet the requirements of the 2012 *International Building Code* (IBC) and ASCE 7-10 provisions. The superstructure construction incorporates a ductile reinforced concrete core wall system that exceeds the height limit of 160 feet per ASCE 7-10 Table 12.2.1. Thus, as an alternate design method permitted by IBC Section 104.11, performance-based seismic design procedures were adopted following the guidelines of the Pacific Earthquake Engineering Research Center (PEER) *Tall Building Initiative Guidelines* (TBI, 2010). This methodology and permit approval included a peer review process. The core walls are 30 inches thick, extending from the pile cap foundations to the top below the penthouse level.

Steel H-pile Deep Foundations

A deep foundation system consisting of driven steel HP-piles, extending to depths of 100 feet and greater below grade, transfers the core wall loads. A total of 373 HP14x89 and HP14x117 piles, located primarily beneath the supporting core wall reinforced concrete pile caps, provide a balanced fixity of the core walls, with the center of gravity of the piling system in close alignment with the center of gravity of the core walls to minimize eccentric loading.

Temporary Shoring and Construction Sequencing

The SOM design team proposed a "saddle cable" system concept to provide temporary shoring support for the seven interrupted columns to the south side above Level 5 over the performing arts center under construction below, as shown in *Figure 13*. In meeting a demanding construction schedule, over a 2-year period,

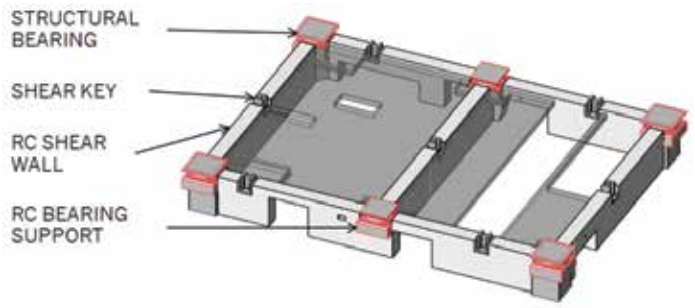

Figure 9. Balanced two-way roof hat truss system.

Figure 10. Construction placement of nodes at top of core walls. Courtesy of Sean Tuite, City Creek Reserve, Inc.

Figure 11. Placement of truss node connection at a top of articulated structural bearing. Courtesy of Sean Tuite, City Creek Reserve, Inc.

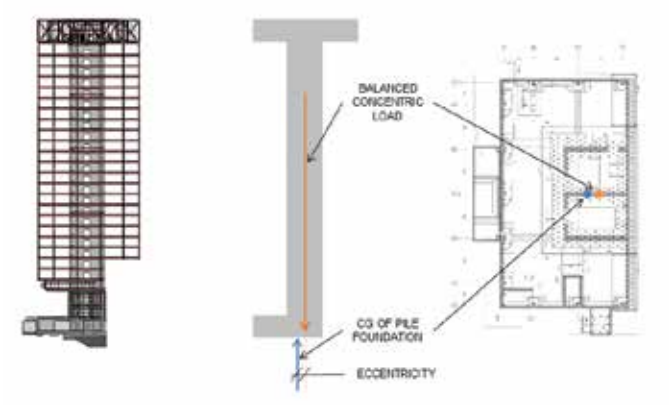

Figure 12. Eccentricity of balanced concentric core loads with deep pile foundation.

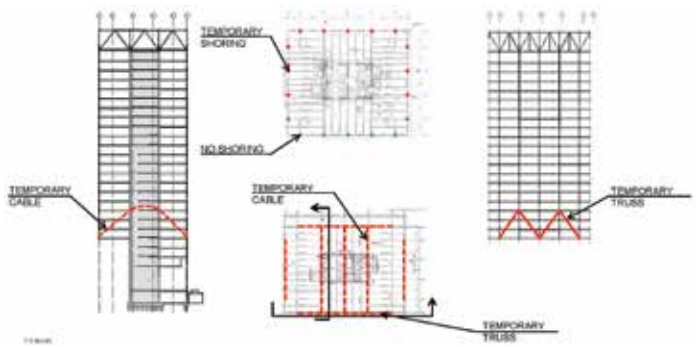

Figure 13. Saddle cable system through core wall concept providing temporary shoring at Level 5.

the construction and engineering design-assist team developed a sequential, bottom-up staged construction sequence that allowed a conventional approach to the construction of the reinforced concrete core and steel composite floor framing system, level by level. The collaborative team effort developed the saddle cable system anchored through the core walls north to south at Level 5 with temporary hydraulic jacks and additional steel temporary bracing as shown in *Figures 14* and *15*. Temporary hydraulic jacks were provided at the remaining shored eleven columns at Level 1. This system permitted the load transfer to occur after final construction of the roof hat truss system, in a single day with a synchronized construction sequence. With the unwavering support of the owner developer, City Creek Reserve, Inc., Salt Lake City, the design assist effort was led by general contractor Okland Construction Company, Inc. with SME Steel Contractors, Inc. and Hassett Engineering, Inc., exterior wall subcontractor Steel Encounters, Inc., and the SOM structure and architecture design team.

Conclusion

With the hat truss construction completed, inspected and exterior wall glazing components installed through Level 18, on Saturday, January 9, 2016, at nine a.m., approximately 45 workers entered the shored building. The workers began a stepped construction sequence over the next 12-hours, using jacks at Levels 1 and Level 5 to lower the building at its perimeter columns approximately 3½ inches, transferring the compressive loads from the temporary shored columns to the roof hat truss system, reversing the stress in the perimeter columns from compression to tension. The 111 Main's anticipated completion date is August 2016.▪

Acknowledgments

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Figure 14. Temporary saddle cable system at Level 5 South. Courtesy of City Creek Reserve, Inc.

Figure 15. Erection of temporary shoring and saddle cable system at Level 5 North. Courtesy of City Creek Reserve, Inc.