Modern Steel Construction

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Inside Job

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SEATTLE'S KEYARENA began life as a World's Fair Pavilion and is now nearing completion of its transformation into a world-class sporting and entertainment venue.

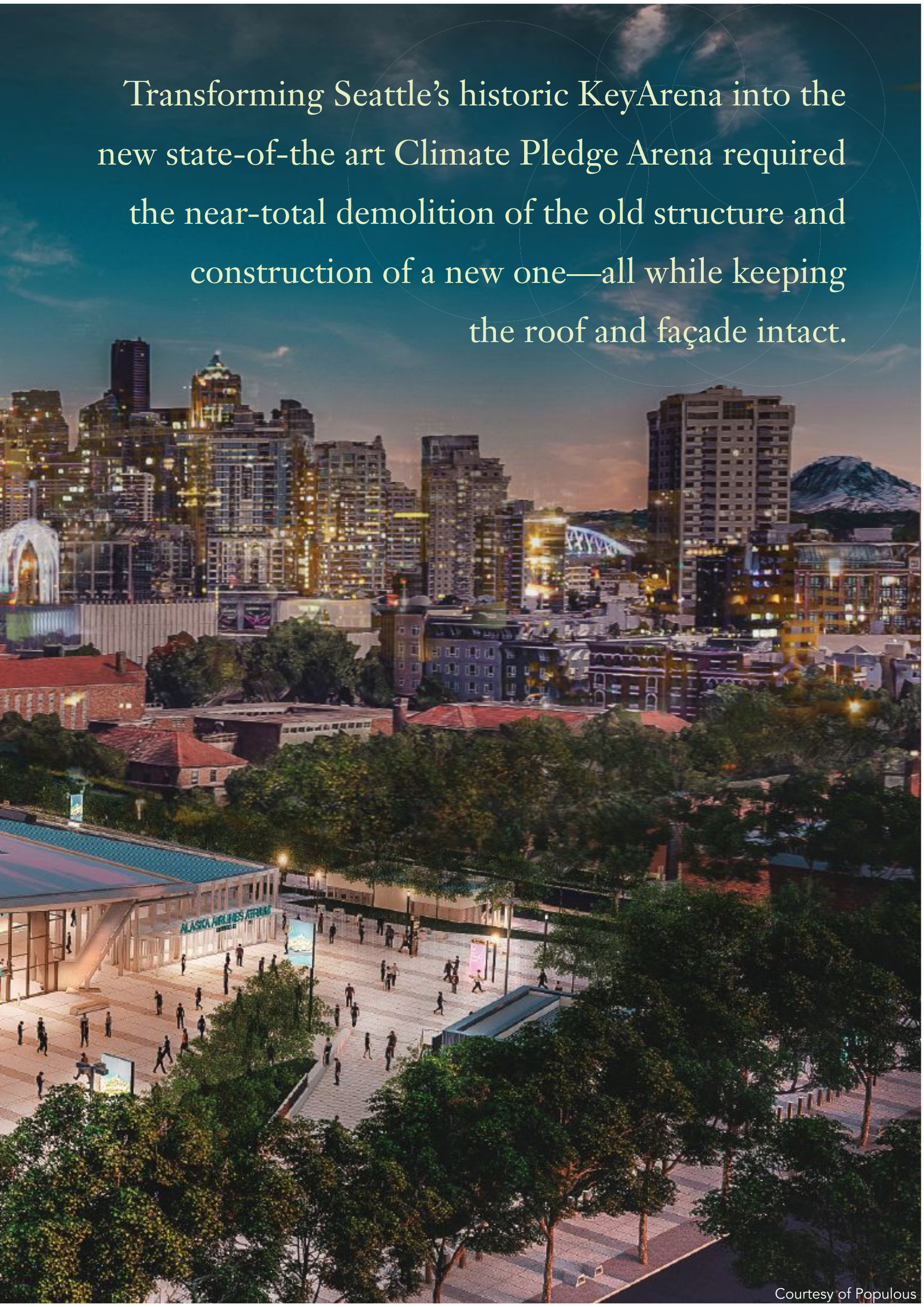
The historic venue, which started out as the Washington State Coliseum for the 1962 Seattle World's Fair and was the longtime home of the Seattle SuperSonics, will soon be home to the NHL's newest franchise, the Seattle Kraken. Slated for completion in late 2021, the $930-million renovation and expansion will result in Climate Pledge Arena, a new 800,000-sq.-ft below-grade venue that will hold more than 17,000 fans for hockey, basketball, concerts, and other events, along with a new parking garage. What makes this project unique, however, was that it preserves the 1960s-era building's iconic 22,000-ton steel-framed roof structure and the exterior curtain wall.

The project presented several complex challenges for architect Populous and structural and construction engineer Thornton Tomasetti. Most notable among these was determining how to demolish the existing structure and excavate 680,000 cubic yards of soil to make space for a new below-grade arena, all while temporarily supporting the 400-ft by 400-ft roof structure above it. Further complicating matters, the arena is located in a high-seismic zone, just two miles from a fault line—and on top of that, opening the facility in time for the 2021–2022 NHL season necessitated a very aggressive schedule.

Preserving an Icon

In fall 2017, KeyArena was classified by the Seattle Landmarks Preservation Board as a local landmark. This distinction required the Paul Thiry-designed roof, curtain wall, and exterior concrete

Transforming Seattle's historic KeyArena into the new state-of-the art Climate Pledge Arena required the near-total demolition of the old structure and construction of a new one—all while keeping the roof and façade intact.



Courtesy of Populous

At 800,000 sq. ft, the new Climate Pledge Arena is twice the size of the former KeyArena.

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elements to be preserved as part of the Oak View Group's renovation of the arena. Consequently, supporting the existing roof while work occurred below drove nearly all facets of the project's design and construction.

The original roof was supported vertically by 20 concrete Y-columns on shallow foundations spaced approximately 60 ft around its perimeter. The lateral loads were resisted by a tripod of sloping concrete legs at the center of each side. The tripods, working as pylons, consisted of two chevron legs parallel with the perimeter concrete ring beam and one buttress leg in line with the roof's steel arch truss.

Temporary Roof Support

Since the foundations below the Y- and chevron columns would be undermined by the excavation for the new event level, a temporary roof support (TRS) system would need to support the vast majority of the roof's gravity load as well as resist wind and seismic lateral forces during construction. The 3,700-ton temporary steel framing for the

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left: A view of the project from the south end of the site, showing the existing roof fully supported by temporary shoring structure. A steel "kickstand" was used to transfer thrust from the existing south pylon to a new perimeter foundation wall.

below: The new below-grade venue will hold more than 17,000 fans for hockey, basketball, concerts, and other events.

Elliott Veazey of CAA ICON

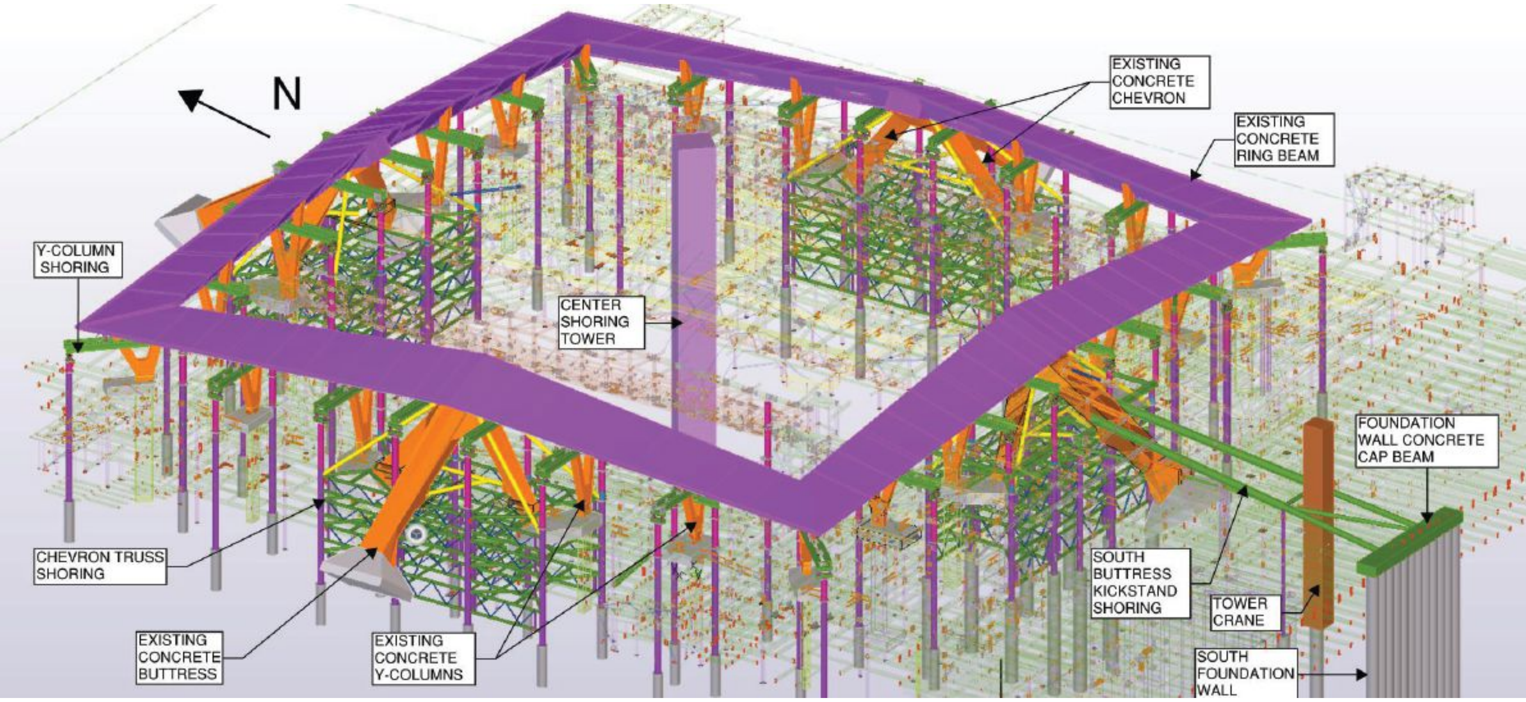
Courtesy of Populous

TRS was fabricated and installed by LeJeune Steel and Danny's Construction, the same team that would construct the new arena.

Supporting the gravity loads was accomplished by installing a shoring frame at each Y-column. A pair of W36 beams sandwiched the Y columns with a bearing pad placed under the concrete roof structure. At each end of the beams, a 36-in.-diameter shoring pipe was socketed into the earth from the existing ground level to the new arena floor level, some 85 ft below. The weight of the existing roof was transferred to the pipe shores via jacks and shims at the ends of the W36 sandwich beams prior to undermining the existing footings. This pre-loading resulted in nearly zero movement of the rigid roof upon load transfer.

On the north, east, and west sides of the building, the buttress footing was untouched by the excavation, except for the removal of the support below the chevron footings. The new parking garage at the south side, however, required the removal and temporary support of the buttress footing. Since the buttresses resist both thrust from the steel roof arch truss and wind and seismic forces, the approximately 3,300-kip force was resisted by a "kickstand" using a cone-shaped steel plate sleeve around the concrete buttress leg and large-diameter pipe struts flying above the garage construction. This assembly transferred the load to the new foundation wall at the south property line 160 ft away, and trussed moment frames temporarily replaced the chevrons at all four sides to resist vertical and lateral forces.

Evaluation, design, and construction planning for the temporary lateral force-resisting system required extensive collaboration from the entire project team. The system configuration and its capacity/stiffness continually changed as excavation progressed, and as areas of excavation proceeded in alternate quadrants, the bracing trusses were installed as soon as soil removal allowed. Work



above and left: Temporary roof shoring and excavation.

below: W36 beams supporting existing Y-columns.

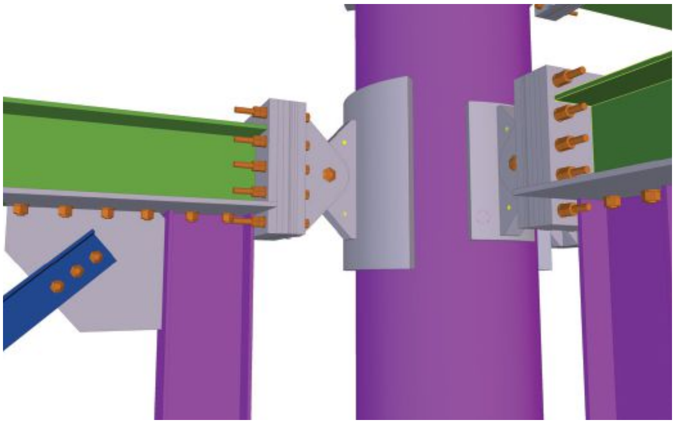
sessions with construction manager Mortenson and the steel, excavation, and foundation teams resulted in a series of colored maps defining the critical stages of analysis and design coordinated with construction activities. The steel team developed prefabricated drop-in steel truss panels with pinned connections designed with up to 8 in. of tolerance to accommodate the inherent tolerances of the 36-in.-diameter pipe shores.

The lateral force from the roof was delivered into the trussed frame system by massive 16-ton, 20-ft-long steel wedges installed at the triangular intersection of the roof and chevron leg. These wedges transferred the force in compression only, as the transfer in tension would have required an impractical number of post-installed anchors that would damage the surface of the structure. The decision to use steel pins and wedges to connect the trussed frames was the result of several hours of brainstorming between Thornton Tomasetti, Mortenson, Danny's Construction, and LeJeune.

"When all the parties get into a room and start melding the conceptual design with the work in the field, it can steer the final design toward the best solution possible," said Eric Fielder, a senior structural engineer with Danny's Construction. "Specifically, with the brace frame system, there was an emphasis on speed of installation and adjustability to accommodate the large caisson tolerances. This solution saved considerable time in that it didn't hold up excavation."

Ship in a Bottle

Designing and constructing a new steel-framed arena below the temporarily supported roof and around the temporary shoring was much like building a ship in a bottle. The arena, which will be the world's first net-zero-carbon-certified venue, consists of a new event



Thornton Tomasetti

A Tekla model (left) and as-built (right) connection of the drop-in steel truss panels to the pipe shores. This connection accommodated the tolerance of the pipe shore locations and plumbness that resulted from installing the pipe shores from the existing ground level.

level 15 ft below the existing undersized event floor elevation, four complete arena levels at and below the surrounding grade, and two levels above the surrounding grade. All levels extend to or beyond the perimeter of the existing roof. The typical floor construction consists of steel beams with concrete slab on metal deck. Seating for the new bowl was framed with precast concrete stadia units supported by steel rakers.

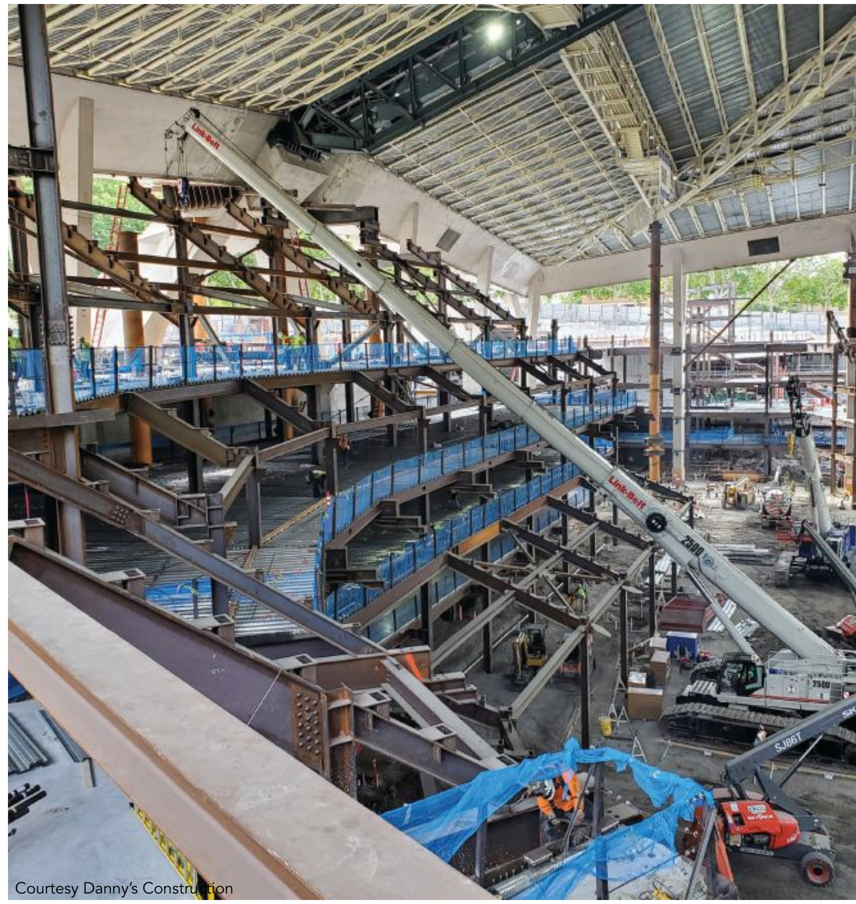
On the west side of the arena, a new press-level bridge floating above the seating bowl is supported by two trusses, a front Vierendeel truss and a back warren truss, spanning 275 ft between the new steel-framed elevator cores. The elevator core towers also support the existing corner roof trusses to facilitate the removal of existing corner columns. Slide bearings were provided between the new elevator core steel and the existing roof structure to seismically isolate the roof from the new bowl structure below. To minimize weight on these long-span floor trusses, a sandwich panel system (SPS) was used on the floor.

In addition to seismic retrofits to the roof, other measures included strengthening the steel roof trusses and their connections to bring them up to current code requirements, and supporting the additional loading of the new structure. The roof will now be able to support two 30-ton video boards along with hoisting equipment, a new catwalk, and a rigging grid with 100 tons of rigging capacity to accommodate modern touring and award shows.

Earthquake-Resistant Design

The 20 Y- and eight chevron columns that support the existing roof were extended

Steel framing for the seating bowl.


Courtesy Danny's Construction

down to the event level and once again support the gravity load of the nearly 60-year-old roof. These extended columns support local gravity loads from the new arena floor while being isolated from seismic forces. The chevron legs plus three original and one modified buttress deliver the roof's lateral load to the new upper concourse level framing.

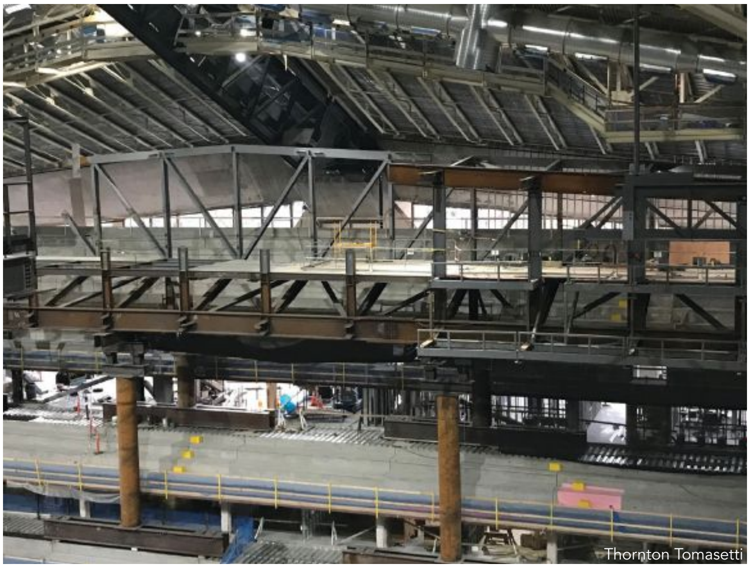
Buckling-restrained braces (BRBs) were used in the elevator cores to resist lateral loads from the press-level bridge and transferred down to the main concourse diaphragms. And for occupant comfort, two tuned mass dampers, located near the center of the long-span trusses, are used to control vibrations of the long-span floor system. Thornton Tomasetti also employed a demanding computational nonlinear response history analysis on the existing structure, including the incorporation of soil-structure interaction effects into the ground motions and the use of BRBs to control the demands at the new rigging grid. As a result, it was able to eliminate the need to retrofit the existing concrete roof elements and was also able to significantly reduce the number of steel roof members that would require retrofitting due to seismic loading.

above: Existing Y-columns are extended down to the bottom of excavation to support the existing roof and new arena structure.

left: The 8-ft-thick shear wall tying into the existing south pylon.

Saving Time and Cost

Complex projects like Climate Pledge Arena necessitate an integrated approach to solving challenges. All stakeholders, including owner, architect, engineer, construction manager, and steel contractor, provided timely input and feedback to produce innovative, practical, and constructable solutions. Thornton Tomasetti also implemented its Advanced Project Delivery (APD) services, which helped achieve considerable schedule and cost efficiencies. Using APD, Thornton Tomasetti engineers and the steel detailers are integrated into the design process to provide early fabrication, erection, and detailing input while developing a coordinated structural steel model. This early model provides the construction team with more complete and detailed information that can be relied on much earlier than traditional delivery methods. The model is then shared with the steel fabricator, and it becomes the base from which they can execute their final shop drawings as well as drives their CNC equipment during fabrication. The firm's construction engineering and structural design teams worked in parallel with LeJeune to provide a fully coordinated and connected Tekla model for the 8,700 tons of permanent steel for the arena and parking garage while producing full shop drawings for the 3,700 tons of TRS structural steel. This helped reduce the cost, schedule, and execution risk related to the complicated steel framing, connections, and tight confines of building under the roof around the TRS. With APD, the team was able to accelerate the steel procurement and detailing processes, enabling fabrication to begin much earlier and shaving approximately four months



The press level bridge truss supported on temporary columns during erection.

off the schedule while virtually eliminating RFIs, late coordination, and typical field issues.

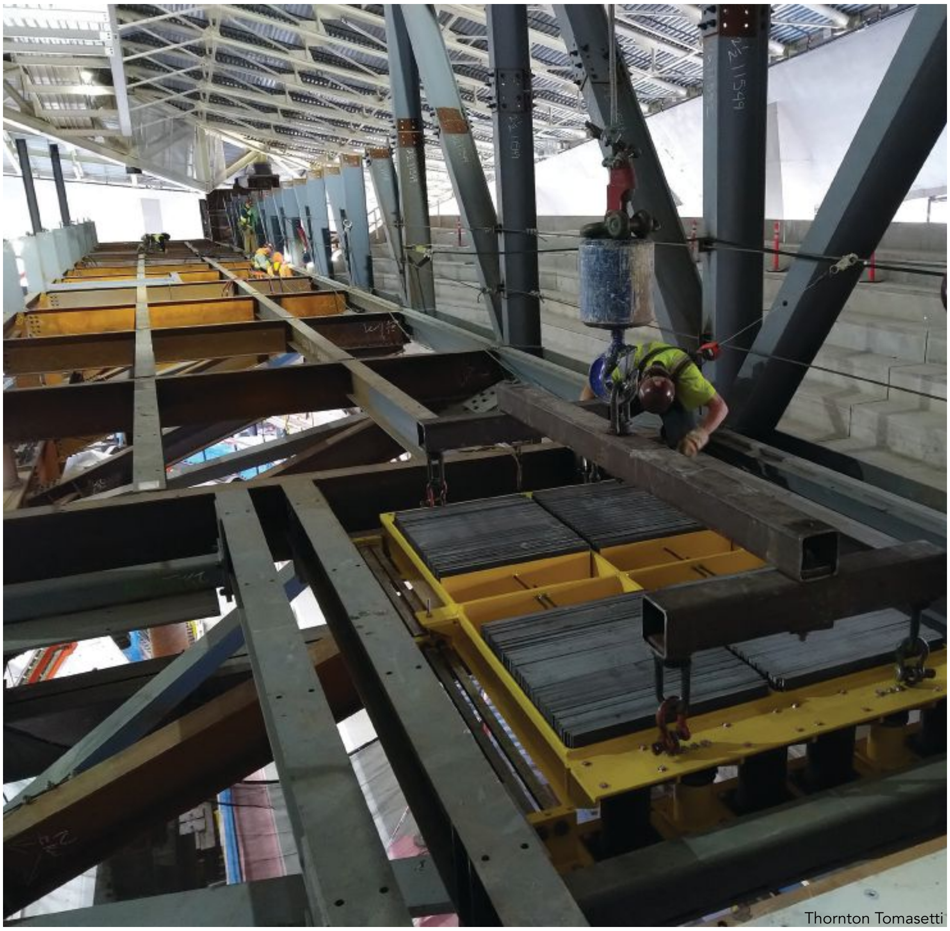
A Strong Team

In sports, you need a strong team and an effective strategy to be the best. The same can be said for sports venue design. The efficiency of a single-source structural engineering firm collaborating with experienced and familiar fabricators and construction management was instrumental to the overall success of the Climate Pledge Arena project.

At the outset, Greg Knutson, field operations manager with Mortenson, laid out the "rules of the road" for addressing the project's many complexities. "When we come upon a challenge, it doesn't matter whose challenge it is; we will solve it together," he said. When the Seattle Kraken take to their new home ice later this year, the entire project team can take satisfaction in a job well done while cheering them on. ■

right: Installing the tuned mass dampers.

below: A new catwalk and rigging grid supported from the existing roof.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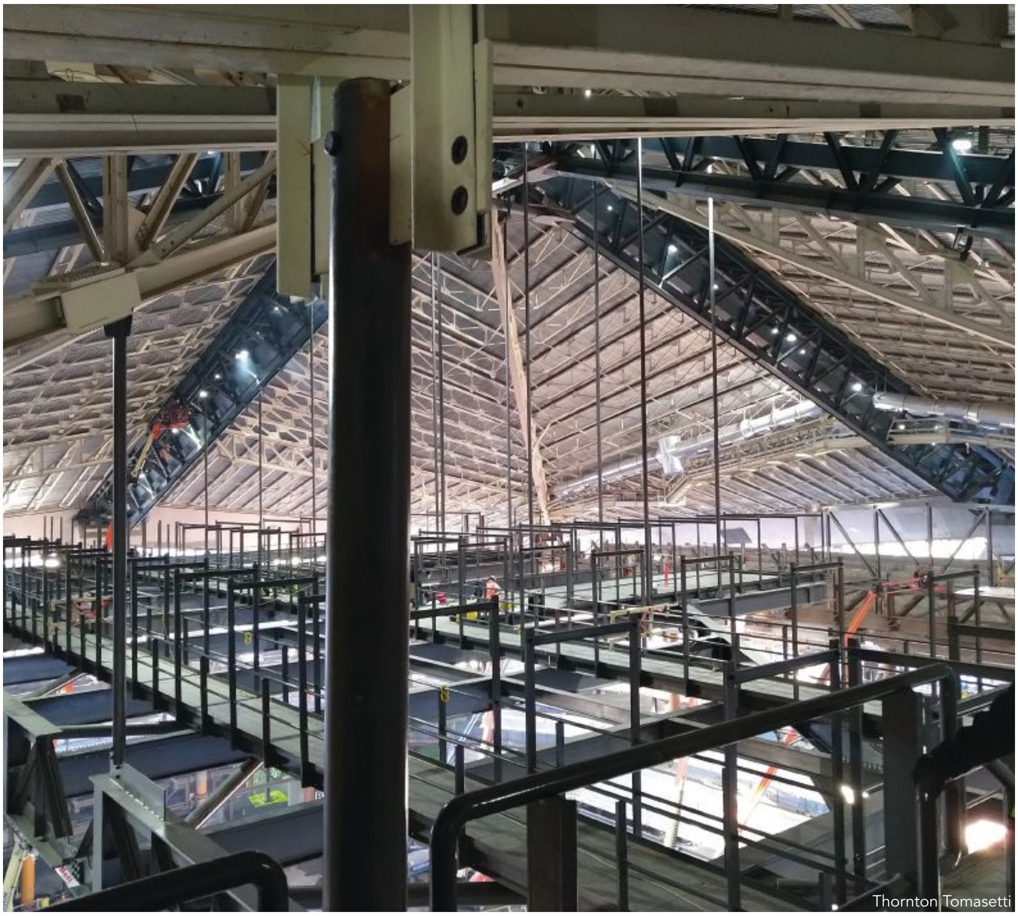
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Corebrace, LLC/SME Steel Contractors, Inc. (AISC Certified Fabricator), West Jordan, Utah (BRBs)

Erector
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Detailer
LTC, Inc. (AISC Detailer), Onalaska, Wis.