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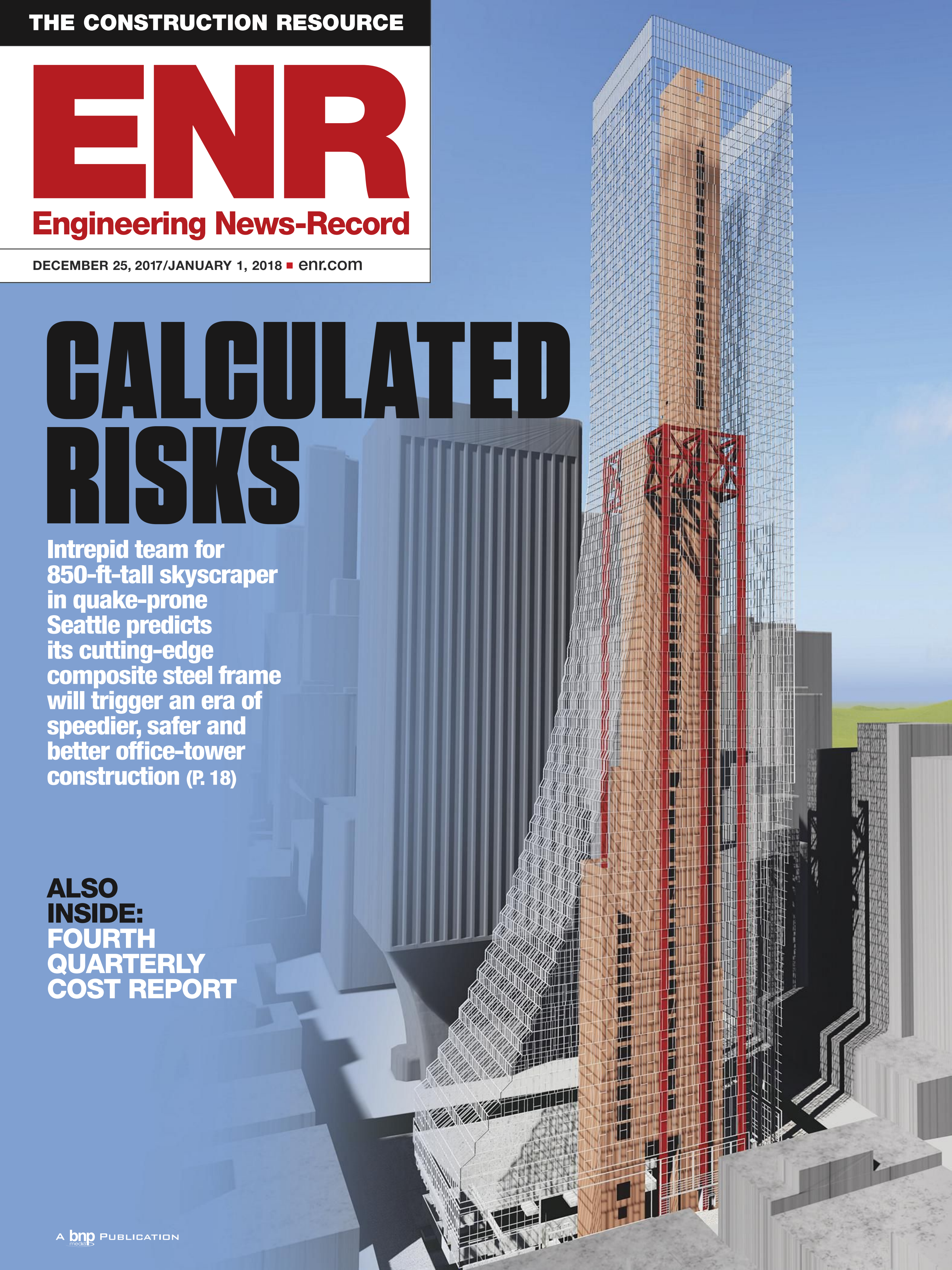

CALCULATED RISKS

Intrepid team for 850-ft-tall skyscraper in quake-prone Seattle predicts its cutting-edge composite steel frame will trigger an era of speedier, safer and better office-tower construction (P. 18)

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'STEELING' THE SHOW

The team setting the stage in seismic Seattle for a 58-story composite steel frame calls the project "a game-changer" By Nadine M. Post

A team in earthquake-prone Seattle is daring to deliver an 850-ft-tall "proof of concept" for a composite structural-steel frame, instead of a steel frame around a reinforced concrete core. For the players, it's not just about eliminating concrete's bedeviling rebar congestion and potentially dangerous jump forms. And it's not just about keeping ironworkers and concrete casters out of each other's hair.

The team gearing up for the $570-million Rainier Square Tower is immediately motivated by the prospect of slashing 40% off the time required to build a standard steel frame with a concrete core. The overarching aim, however, is to usher in an era of speedier, safer and better office-tower construction—everywhere.

"This is going to be a watershed in terms of high-rise construction," predicts Shannon Testa, senior project manager for Lease Crutcher Lewis (LCL), general contractor for the 58-story tower. Rainier Square is on deck to be the city's second tallest, after the 931.8-ft Columbia Center.

Key to the predicted speed is a composite steel frame with a shear-wall core, consisting of a modular "sandwich" system of cross-tied steel-plate walls, field-filled with concrete. There is no rebar congestion because there is no rebar, and there are no forms of any kind.

Further, there are no steel embeds in the core walls. Most significantly, there is no "leading" concrete core and trailing perimeter frame, which means there is no time wasted watching the concrete cure.

Rainier Square's steel erector predicts superstructure work, set to start in August, will take about one year—some nine months less than it would the old way. "We will erect this building, totally, in less time than it would have taken to [cast] a concrete core by itself," says Adam

MOCK-UP The first of two full-scale mock-ups, conventionally plywood-formed and stripped, helped the contractor to work out details for casting the steel sandwich modules' self-consolidating concrete infill.

PHOTO LEFT COURTESY MKA; RIGHT COURTESY LCL.

CONCEPTUAL GRAPHICS COURTESY MKA

SPEED COMPARISON The steel erector predicts the new system (top) will take 40% less time to erect than it would to build a superstructure with a leading concrete core surrounded by a steel frame.

Jones, president of The Erection Co. Inc. (TEC).

If all goes as planned, demolition to certificate of occupancy should take 31 months, compared to 40 months for a concrete-core building, says Testa.

For the developer, the reduced schedule means fewer carrying costs and an earlier revenue stream, says Cindy Edens, director of development for Wright Runstad & Co. (WR), which is leading the Rainier Square project.

The $370-million construction cost represents a 2% savings over the job's original concrete-core scheme. There are lower costs for general conditions, support staff, cranes and hoists, and more. "Even if the cost was the same, we would go with steel," says Testa.

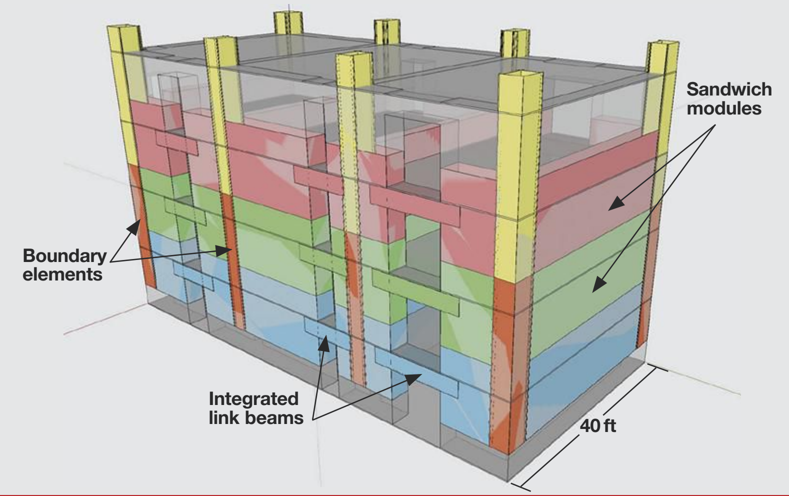
Structural engineer Ron Klemencic, the system's mastermind, is all but staking his reputation on its success. "I have always challenged the norm and sought a better way to design and build," says Klemencic, chairman and CEO of Magnusson Klemencic Associates (MKA). "Rainier Square brings together my insatiable search for 'better,' passion for research and development, and intense collaboration with the entire design and construction team to create a breakthrough in how tall buildings are constructed."

Klemencic's application is a first for such a tall building and for a quake-resistant core. The system is appropriate to resist lateral loads—both wind and seismic—on office towers taller than 30 or 40 stories, says Klemencic. MKA already is in discussions for its use in Boston and San Francisco.

The predictions for Rainier Square may be brash, but they are not rash. "It's fully within our wheelhouse," says Testa. "We all believe in it."

For MKA, the project is the culmination of three decades of exploration into composite steel structures. The tall steel core's earliest ancestors had large-diameter steel pipe columns filled with concrete. For Seattle's

COMPOSITE STEEL CORE



STACKING UP The plan is to stack and field-weld the steel modules. When the erector finishes four levels, crews will add concrete.

federal courthouse, the structural engineer joined the pipes with steel-plate shear walls and braced frames (ENR 2/24/02 p. 30). Klemencic himself has been exploring the steel core for nearly 20 years, including organizing the first load tests at Purdue University in 2006.

Rainier Square's players have been collaborating for decades, often on other novel MKA projects. "We can finish each other's sentences," WR's Edens says.

"A project like Rainier Square will come to fruition only when you have people who are willing to engage and take risks," adds LCL's Testa.

"We've done a lot of work with MKA and find them to be very innovative," says Mike Eckstein, business and project development manager for the steel contractor, Supreme Steel Portland (known as Canron Western Constructors until last January). Eckstein's only reproach is that MKA's scheme "took so long to get to the table."

"People very much trust Ron," adds Testa. "He takes risks, but they are very calculated."

Even the structure's peer reviewers are impressed. "On the basis of what we've seen, this is an excellent application [of the module], and it will be pioneering in its use in further high-rise construction," says Michel Bruneau, a professor of engineering at the State University of New York at Buffalo (UB).

Bruneau is a co-investigator for ongoing physical load tests at Purdue and UB to improve the efficiency of the modules—$600,000 worth of research championed by Klemencic and funded by the American Institute of Steel Construction (AISC) and the Charles Pankow Foundation (ENR 10/9 p. 9). The system is "so clever, I don't understand why it hasn't been done before," says Bruneau.

Peer reviewer Jim Malley, a senior principal of Degenkolb Engineers, adds, "Potentially, this system could be a game-changer and create unique opportunities beneficial to the marketplace."

The Rainier Square team, aware of the possible pitfalls, has been hammering out the kinks in the system for three years. "We stepped into the unknown and figured it out," says Edens.

The prefabricated modules present challenges. The biggest is that penetrations through the composite steel-plate sandwich, as thick as 45 in., need to be designed into the steel-mill order. There is no field flexibility.

Rainier Square architect NBBJ has been working "diligently" with mechanical, electrical, fire service and plumbing subcontractors "to recognize this fact and accelerate their design efforts," says Mindy Levine-Archer, an NBBJ principal. Despite the limitations, she says she is "very excited" to be part of rethinking how high-rise shell-and-core buildings are designed.

Commitment

In May 2014, the landowner, the University of Washington, chose WR to redevelop the city block, called Rainier Square. On Oct. 3, WR and an institutional investor, advised by J.P. Morgan Asset Management, announced their joint-venture partnership for the mixed-use development, the start of the project's 80-year ground lease with UW and a commitment from Amazon to lease the tower's 722,000 sq ft of office space.

The steel core system has been "well vetted," says John Palewicz, just-retired major projects director for UW, still overseeing the job. "We feel comfortable."

The design of the carved-back building, nicknamed "the kinky boot," was inspired by the adjacent, 40-story Rainier Tower. The 1977 tower, considered an icon, was designed by the original New York City World Trade Center team of architect Minoru Yamasaki and an MKA predecessor, Skilling Helle Christiansen Robertson.

Rainier Square will have retail at its base and offices until level 37, followed by three mechanical, elevator transfer and amenity levels. The upper 18 floors will contain 200 residential units. There are seven levels of underground parking.

Starting at the fourth level, both the east and south faces slope inward. The more dramatic east slope is a parabolic sweep. The tower's footprint gradually shrinks to a 120-ft square in plan from 140 ft x 245 ft. There is no typical floor until level 40.

The original concrete-core concept had mid-height steel outrigger trusses to stabilize the tall and slender building. The scheme put schedule and cost pressure on the project, especially because of the need to embed the outrigger ends in the concrete core.

"I challenged the team to come up with a lower cost and a faster time line," says Eden. That's when Klemencic saw the opportunity to introduce the steel core. The switch was made early in design development, in 2015.

As engineered, the frame consists of the "sandwich"

CONCEPTUAL GRAPHIC COURTESY LCL

wall core connected to steel perimeter columns by a conventional floor system. Columns on the east face slope over as few as two floors and as many as 16.

The need for stiffening elements remains in the new scheme. In the north-south direction, from floor 38 to floor 40 on each side of the core, three lines of 40-ft-deep outrigger trusses, with buckling-restrained braces (BRBs), will span from the core to steel perimeter box columns with cross ties. Similar to the core modules, the ties provide confinement for the box columns' cast concrete infill. They also provide stability during construction and restraint for the concrete filling operation.

The BRBs absorb quake energy like fuses by going through their yield cycle and "living to tell the tale," says Klemencic. BRBs allow MKA to cap the load to the outrigger columns, he says.

Outrigger braces engage into the core's boundary elements with a direct steel-to-steel connection of the BRBs aligned with module face plates, says Brian Morgen, MKA's project manager. A similar connection ties outriggers to perimeter outrigger columns.

Outrigger columns are interconnected by east-to-west perimeter trusses, which provide a redundant load path between the core and the outriggers, adds Morgen.

A 12-ft-thick mat is 180 ft x 128 ft in plan. It supports outrigger columns, most of the wide-flange perimeter columns and the 870-ft-tall core, with a maximum footprint, at the base, of 93 ft x 40 ft. Gravity-only columns at the base, outside the mat, bear on spread footings.

Before 2000, MKA predecessor firm Skilling Ward Magnusson Barkshire had an idea for a tall composite steel-plate sandwich shear-wall core. During an investigation, the team discovered a patented British Steel product, called Bi-Steel. The tied-plate module, filled with concrete, was developed in the mid-1990s to contain concrete in case of an explosion on an offshore platform.

Inspiration

Bi-Steel, with friction welds for the ties on the inside of the plates, was the initial inspiration for the first series of load tests at Purdue, sponsored by Pankow. Pankow's research rules exclude testing proprietary systems, so the engineers developed a generic module with fillet welds.

Rainier Square's core will have a stacked system of modules, with cross ties, between steel-box boundary elements. Both the modules and the boundary elements will be field-welded together and field-filled with 10,000-psi self-consolidating concrete.

Modules are robust enough to carry erection loads. They also do double duty as formwork and containment for the concrete infill.

Performance-Based Seismic Design

The system is not yet in the building code. MKA had to seek approval under the alternate means and methods section. To meet the intent of the code, MKA used performance-based seismic design. PBSD was pioneered in the U.S. by Klemencic, coincidentally in parallel with the modular wall development. "We were able to proceed confidently with the R&D for the sandwich walls, knowing there was a path allowing for approval outside of direct codification," says Klemencic.

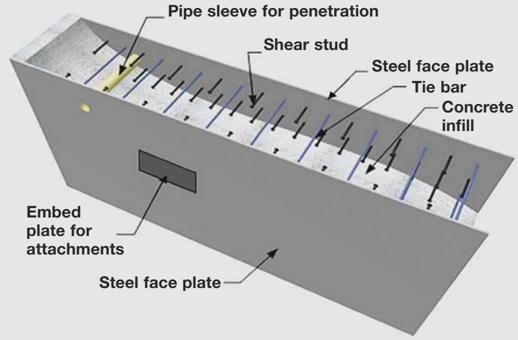
MKA first approached the Seattle buildings department about the possibility of the new core system in 2015. "We felt comfortable with MKA moving forward with this in our peer-review process," says Cheryl Burwell, engineering and technical codes manager for the Dept. of Construction and Inspections.

But the city required three structural peer reviewers—two practitioners and an academic—instead of one practitioner. Simpson Gumpertz & Heger's Ronald Hamburger completes the Rainier Square review team.

The peer review is far enough along that no one expects any "showstoppers," says Burwell.

MKA designed the system using provisions for the modules added to AISC's Seismic Provisions for Structural Steel Buildings: AISC 341-16, which was in approved draft form at the time. The provisions are based on the initial Purdue tests.

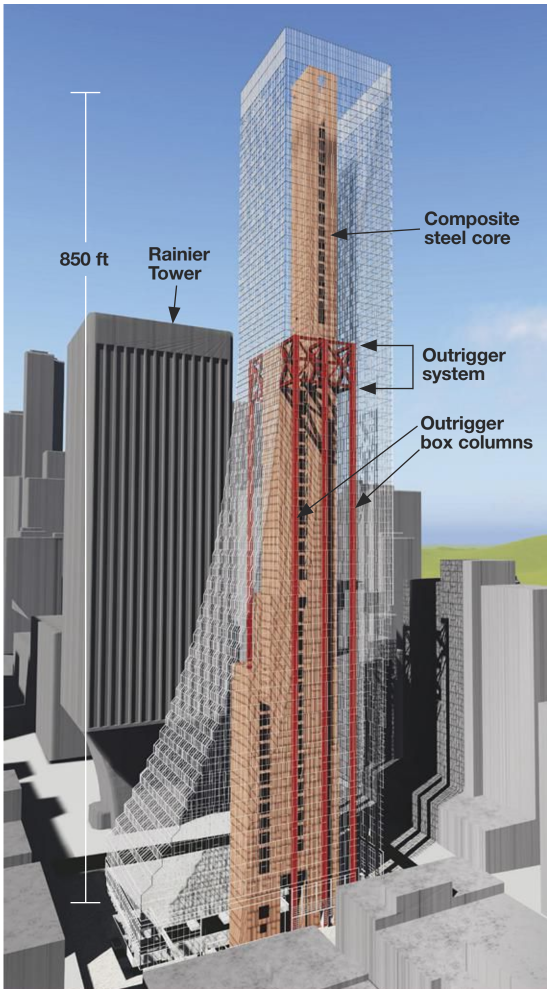
Demolition of the block's low-rise structures is done. Shoring work starts by January. The excavation should be complete by July. Foundations are scheduled to start in June and be done by the end of August. LCL expects the superstructure to be finished by August 2019. The



TEST MODULES

GOOD GRADES In an ongoing load-test program, the performance of the sandwich modules, with dfferent tie-bar spacings, has exceeded initial expectations so far.

PHOTO AND CONCEPTUAL GRAPHICS COURTESY AISC



TALL AND SLENDER Rainier Square Tower needs a system of outrigger trusses to reduce its sway.

certificate of occupancy is expected in April 2020.

In the concrete core scheme, LCL, which is performing concrete work, expected to complete one core level every three days. TEC had to hold off starting steel framing until the core had reached level 12.

"Adam says he will complete two floors of framing every one to two and a half days," says LCL's Testa, who anticipates slowing down, even with the steel core, at the "complicated" outrigger floors.

The concrete infill, which follows four floors of core steel, is still on the critical path. "Until the core is filled, we can't jump the tower crane," says Testa. For each of the 12 jumps, the core has to be filled to the jump level, where the crane ties into the building.

The team is doing full-scale mock-ups, even before module fabrication begins. "We didn't want to get to our first lift of the core and not have this dialed in," says Testa. "When we are placing concrete, we will not have good visibility inside the plate-wall cells because the core will be erected a couple of tiers above us."

The original plan to build one steel-plate concrete-filled mock-up evolved into a plan for two mock-ups. First, crews built a strippable plywood-formed, one-cell mock-up. In a month or so, Supreme and TEC will build a steel-plate mock-up.

The first mock-up helped to determine the number and location of access ports for the hoses. LCL also tested several baffle-hole layouts in the boundary elements and measured and monitored concrete temperature.

Ron McDonell, LCL's project superintendent, not only suggested two mock-ups but also advised simplifying concrete casting, which is typically done from the bottom up, by placing the mix from the top down through a side hole near the module's top. After the casting, crews will weld a plate to close the hole. The next casting fills the void left near the top of the module.

Supreme, located in Portland, Ore., still is figuring out its systems for the production of the more than 500 modules. There are several challenges, says Eckstein. Topping the list is having enough shop space to lay out the modules, which will be 14 ft wide by 30 ft to 40 ft long. Balancing different cutting, fitting and welding activities, to prevent bottlenecks, is another challenge.

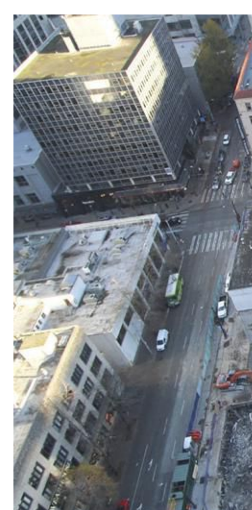
Supreme still is seeking out the most automated cutting and welding equipment. The modules have a great deal of overall dimensional repetition, but virtually each panel has different penetrations, connections or depths, says Eckstein.

The numerous penetrations make the modules look a bit like Swiss cheese, says MKA's Morgen. There are 250,000 cross ties, which translates to 500,000 fillet welds.

Supreme currently is detailing the two-story steel mock-up, which should solve some of the challenges related to shipping, hoisting and welding. The mock-up, 40 ft x 14 ft in plan, will include boundary elements.

Eckstein is tight-lipped about some of Supreme's plans, including for the modules' permanent internal

CONCEPTUAL GRAPHIC COURTESY MKA; PHOTO BY SCOTT BLAIR/ENR



ON A PEDESTAL Special shoring is going in beside Rainier Tower—monitored for settlement.

BOOT-LIKE East-face setbacks of Rainier Square Tower lessen visual impact on adjacent Rainier Tower.

stiffening system to prevent deflection in the shop, in the yard, on the road and during erection. The challenge is to keep the stiffeners out of the way of the mix.

Supreme expects to start module production early next year and finish more than 60% before erection begins. There will be 125 built-up columns and 500,000 sq ft of panels flowing through a 10-acre yard. The plan is to stack two or three modules.

In Seattle, the site is hemmed in. There is little laydown space. "We will ship right to the hook," says Eckstein, adding that each module weighs as much as 20 tons.

Soil Surprises

The job has other site complications. In early 2014, core drillings turned up weak soils, called slickenside clay, caused by Ice Age glaciers. Slickenside clay has roughly one-third the strength of normal soils in the area, says Brice Exley, project manager for the geotechnical engineer, Hart Crowser.

The weak clay would not be an issue were it not for Rainier Tower, standing over an excavation that will be as deep as 85 ft, which is 60 ft below Rainier Tower's mat foundation. (Klemencic's 32nd-floor office in Rainier Tower overlooks the site.)

To keep Rainier Tower still, Hart Crowser designed a secant pile wall along the Rainier Tower side of the site. The secant piles, which will extend into dense glacial till about 20 ft below the base of the future excavation, will be encased in lean-mix concrete, from the ground down to the bottom of the excavation, and structural concrete, down to the toe of each reinforced pile. Soil conditions necessitated using a composite beam beneath the base of the excavation.

As designed, the secant pile wall is supported laterally under Rainier Tower by drilled tieback anchors inclined at 17.5° and on a 4.5-ft by 5.5-ft grid along the wall. The tiebacks are as long as 135 ft and are prestressed to loads as high as 150 kips to resist Rainier Tower's surcharge loads.

Hart Crowser is installing a monitoring system with 380 targets on Rainier Tower, the secant wall and the soldier piles along the rest of the future excavation's perimeter. Tiltmeters are monitoring deformation of Rainier Tower's mat. All data is recorded automatically and uploaded to a website. A baseline of the movement of Rainier Tower already has been established.

John F. Kvinsland, a vice president of the project's shoring contractor, Malcolm Drilling Co. Inc., views the job as his "most risky" of his 24 years in the business.

Challenges aside, all team members for Rainier Square are excited about the project. WR's Edens and Supreme's Eckstein even have delayed retirement to see the tower to completion. "We feel confident [the approach] is going to work," says Eckstein.

Though also excited about the scheme, UB's Bruneau adds, "The proof will be in the pudding." ■

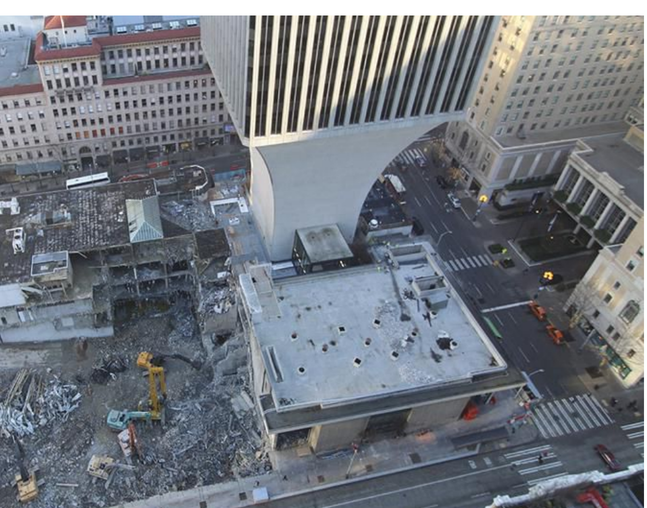


PHOTO COURTESY LCL; RENDERING COURTESY NBBJ