ROOF SHORING JUST HAD TO BE RIGHT

KICKSTAND
Temporary pipe assembly shores south buttress after 68-ft-deep excavation, mostly for subgrade parking.

PHOTO BY CHRIS MAST OF BLUE PIXEL

ARENA'S BUILDING TEAM IN QUAKE-PRONE SEATTLE USES 4D BIM TO MANAGE THE CONSTRUCTIBILITY NIGHTMARE ASSOCIATED WITH SUPPORTING AN ICONIC COVER DURING CONSTRUCTION

BY NADINE M. POST

Most contractors would jump at the chance to have a roof overhead during a major rebuild. But for the team turning earthquake-prone Seattle's 411,000-sq-ft KeyArena into the 932,000-sq-ft Climate Pledge Arena, the city-owned facility's historic helmet has been a 44-million-lb design and construction headache.

Keeping the roof in place "ended up being more complicated than anticipated," says Ken Johnsen, construction executive for Oak View Group (OVG), the developer of the privately financed sports and entertainment venue.

COVER STORY
SPORTS CONSTRUCTION

"More complicated" is an understatement. The excavation for the mostly subgrade redevelopment, which has a larger footprint than KeyArena, required undermining the foundations of the 400-ft-square roof. The lid had be kept safely in place due to a city-imposed imperative to preserve the old arena's landmarked looks.

Extensive shoring was needed to keep the roof intact. The temporary support system, which also had to resist seismic loads and limit movement to ¼ in., ended up costing $35 million and weighing 4,400 tons.

To top that, the shoring was extremely challenging. "It's one of those projects that screamed 'Run away,'" says David Mortenson, chairman of the arena's general contractor, Mortenson, which is operating under a CM-at-risk contract with a guaranteed maximum price of about $850 million. But "it's going exceptionally well, given all we have to deal with," he adds.

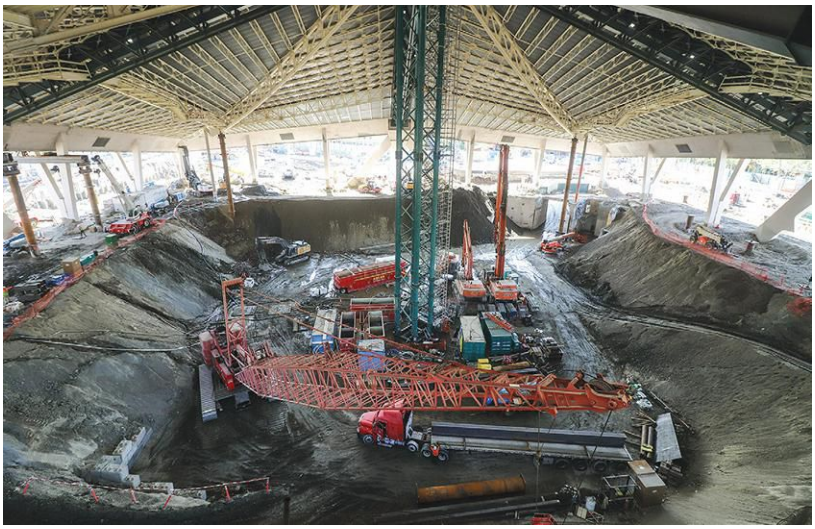
Costs for the mind-boggling redevelopment—now at $1 billion—have increased by $250 million from OVG's early budget. And the developer extended the planned opening by a year, to next fall.

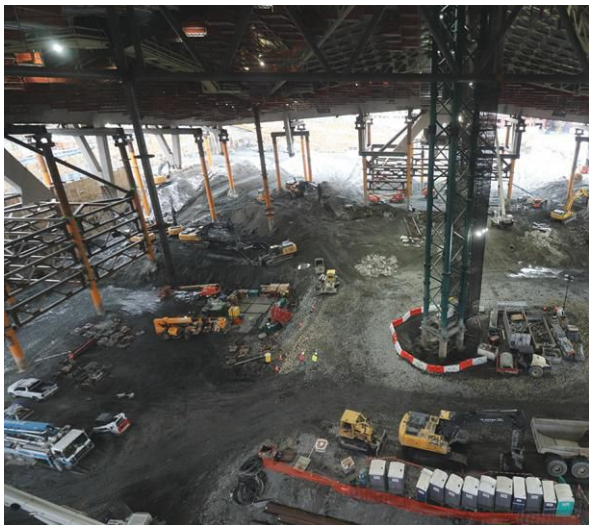
The toughest part is done. There were no collisions or mishaps. The roof is bearing on its permanent supports and the shoring is all but removed. The job, 55% complete, is on schedule.

Mortenson says the job would have been nearly impossible, taken longer and cost even more without "extreme" planning, intense team collaboration, top-down construction and, especially, digital tools. "We're using 4D modeling to figure this out," says Derek Cunz, a Mortenson senior vice president.

The contractor has been using 4D—which combines a 3D model with a project schedule to simulate construction—for more than 15 years. It began by experimenting with it on parts of the inscrutable Walt Disney Concert Hall, built in the early 2000s.

It's no coincidence that Mortenson assembled its Dis-





ney leadership team to figure out the equally mystifying, though drastically different, arena project.

One major constructibility puzzle was how to design the shoring so it would not interfere with the new seating bowl structure and so that it could be cut out after construction of the new structure.

"The sequences of this job are so complex," says Chris Rust, executive vice president of steel erector Danny's Construction Co. LLC. Danny's is responsible for shoring and jacking the roof, the installation of permanent steel and the shoring removal.

This project is "pretty insane," adds Adam Running, project executive for Malcolm/DBM JV, a joint venture of Malcolm Drilling Co. Inc. and Donald B. Murphy Inc. The JV is responsible for the 3-ft-dia drilled shafts, perimeter foundation wall's permanent shoring, temporary and permanent foundations and dewatering.

The arena saga started in 2017, when the city selected OVG to redevelop the site. OVG, which is financing the development, and the city signed a lease agreement for 39 years, with two, eight-year renewable options. Under the terms, the city will receive annual rent of $2.8 million, with a baseline tax guaranty of $2.2 million, adjusted annually. OVG will receive a rent abatement of $350,000 during the initial 10 years.

The first hiccup happened before a shovel hit the ground, soon after a July 2018 construction contract award to a joint venture of Skanska USA and AECOM Hunt. OVG and the joint venture soon parted company, amicably, because the project needed a dedicated single-source team, according to OVG.

UNDER THE BIG TOP
After the steel erector engaged the central shoring tower, crews could begin transferring loads from Y-columns to their shoring frames (left). Top-down construction of drilled shafts in limited headroom around the perimeter supports included erection of trussed chevron shoring frames at all the buttresses (right).

Mortenson was engaged in December 2018, just before the official start of construction. It didn't take long to gear up. The contractor had spent six months working for OVG, "trying to figure out the right cost and schedule," says Mortenson. Then, it lost its bid for the job due to its higher price and longer schedule.

Fossil-Fuel Free

In the spring, there was another hurdle for the building team, traceable to the sale of the naming rights, for an undisclosed sum, to Amazon, which selected the new name. At the same time, OVG, Amazon and the National Hockey League (NHL) Seattle decided to create a fossil-fuel-free facility, powered only by electricity. They are also adding a "rain-to-rink" system for ice production and solar arrays, on and off site.

"The idea of creating a healthy arena for the planet is in alignment with the ethos" of the developer, the NHL, the team and with Amazon, says Rob Johnson, vice president of sustainability for the Climate Pledge Arena and the Seattle Kraken hockey team.

The arena is aiming to be the first International Living Future Institute Zero-Carbon-certified pro-

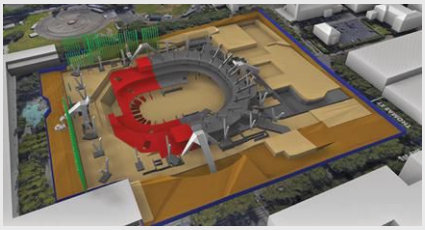
PHOTOS COURTESY OF MORTENSON

VIRTUAL BUILDING IN THE 4D MODEL

The arena redevelopment would have been nearly impossible without the help of 4D modeling, which combines a 3D model with the schedule. The team prebuilt the arena virtually in the model to work out in advance as many conflicts and clashes as possible. 4D is also helping to resolve problems encountered in the field.

COLOR KEY

- Demolition
- Activity Start
- Activity Complete
- Excavation
- Shoring Complete
- Permanent Steel Complete



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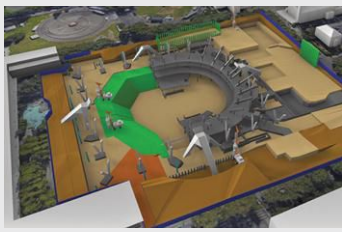

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fessional sports venue, and a model for other arenas. "We ripped out all the [designed] natural gas infrastructure," says Jason F. McLennan, CEO of McLennan Design, the arena's sustainability advisor, ILFI's founder and the 2016 ENR Award of Excellence winner.

One hitch: The infrastructure, which had already been permitted, had to be redesigned and repermitted. "We were building the plane while we were flying it," says Johnson.

The project is the second reincarnation of the Seattle Center building, first built at grade with a clear-span pitched roof as the exhibit hall for the 1962 Seattle World's Fair. The building has been known as KeyArena since a 1995 expansion to create a mostly sunken seating bowl.

Both the roof and the glass curtain wall became landmarks in 2017. Before the gut demolition of the 1995 interior, crews removed and stored the curtain wall. They are currently putting it back.

The landmark lid bears on perimeter reinforced-concrete supports, Y-columns and buttresses expressed architecturally. The cap covered KeyArena's sloping sunken bowl with an event floor taken to 38 ft below grade in the 1995 expansion.

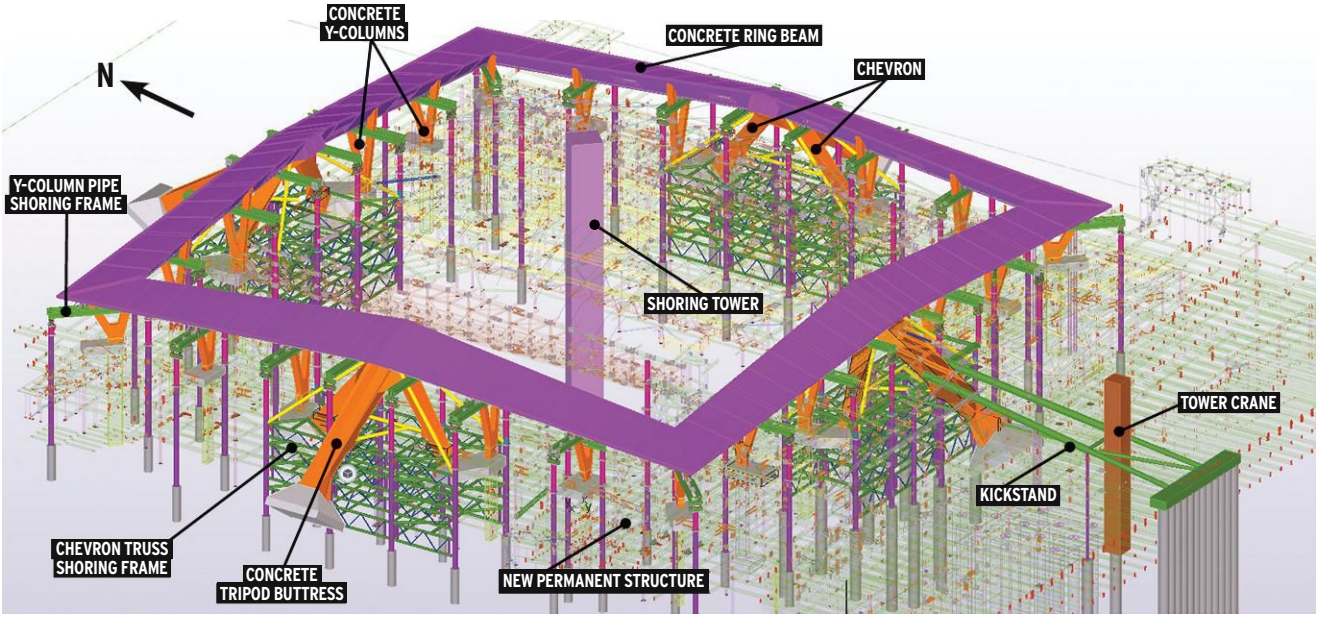
The new sports and entertainment venue, with four levels below grade and two above, will contain 17,400 seats for hockey and host the Seattle Kraken. It will offer 18,600 seats for basketball and will host the Women's National Basketball Association team Seattle Storm.

Climate Pledge Arena's footprint is 720 ft x 580 ft and the event floor will now be 60 ft below grade. The redevelopment includes the 740,000-sq-ft venue and a 192,000-sq-ft parking garage under the south entry plaza.

When finished, the arena will look virtually the same as the original, except for a new entrance pavilion attached to its hip on the south side.

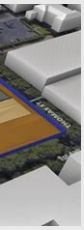
"This is essentially a brand-new modern venue that lives within this historic structure," says Geoff Cheong, lead designer for the job's architect, Populous.

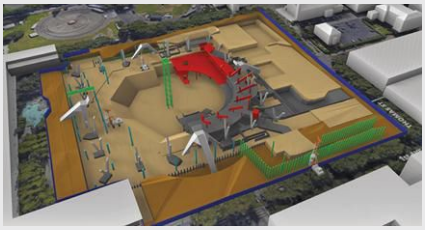
The combination of a mostly subgrade building and



INTERLACED Shoring frames were located to both allow the insertion of permanent structure and the removal of the frames.

SOURCE: THORNTON TOMASETTI





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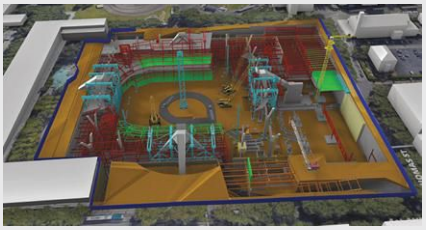

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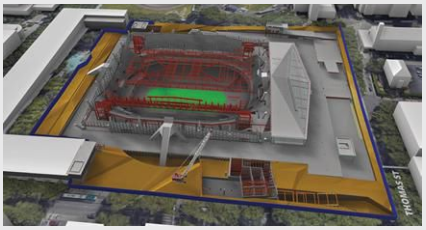

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SOURCE: MORTENSON

a roof that was off limits for equipment and louvers complicated the mechanical system. "We couldn't penetrate the roof or put anything on it," says Jeff Sawarynski, a principal with the project's consulting engineer, ME Engineers.

After much head-scratching, ME devised four air intake and exhaust "snorkels," one at each corner of the site. The buried shafts, 20 ft to 40 ft wide and 20 ft in height, are 50 ft to 60 ft long horizontally. They pop out of the ground 25 ft above the outdoor plaza level. Each snorkel also will contain exit stairs.

Site Orchestration

There were other limitations. The roof overhead meant no headroom for a tower crane in the bowl. All deliveries have to arrive by truck.

At one point, 75 trucks were making four trips each night into the bowl. "It was a major orchestration," says Greg Huber, Mortenson's project executive.

Mortenson initially used KeyArena's truck access ramp, which went about 38 ft below grade, while it built a 400-ft-long two-way temporary ramp that would allow trucks to circle around and exit. The ramp, which occupies the southwest snorkel alongside the original building, progressed with the mass excavation. Starting in January, all deliveries will come into the new event-level loading dock area, which is 60 ft below grade, via a ramped 185-ft-long truck access tunnel, which is permanent. To complicate matters, the tunnel passes 120 ft under the one-story landmark Bressi Garage, which is protected and sensored.

The roof slopes down on four sides to about 30 ft above grade. That meant little headroom at first, especially for drilling equipment.

All the job's minor issues pale compared to the challenges associated with keeping the roof from collapsing. "We had to be right," to protect the hundreds of workers there every day, not just the roof, says Greg Knutson, Mortenson's field operations manager.

To choreograph the entire job and minimize field clashes between the temporary steel and the permanent structure during construction, "we 'big roomed' the temporary roof system and the structure, with all the stakeholders present," says Mortenson's Cunz. The meetings started in advance of construction.

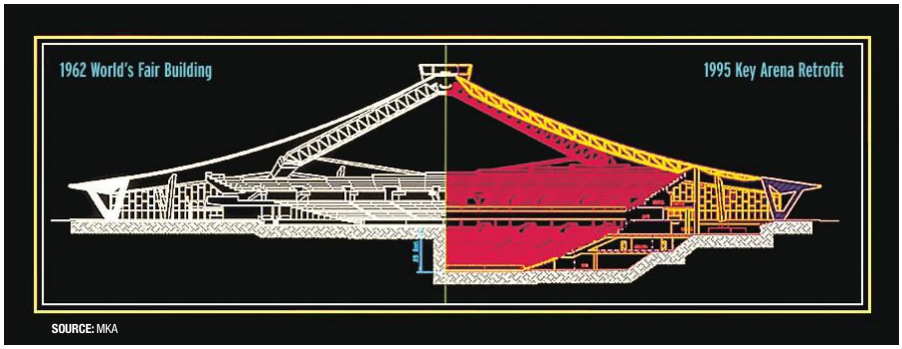
For the shoring locations, the new permanent structure served as the baseline and the temporary supports changed. However, at times, the permanent structure was revised to accommodate the temporary structure, "when there was no other choice or it made economic sense," says Huber.

It helped that the same structural consultant—Thornton Tomasetti—provided construction engineering and structural engineering services. And it helped that TT had plans from the 1962 cable-suspended roof, designed by structural engineer Peter Hostmark & Associates (ENR 3/29/1962 p. 36).

TT also had the drawings for a 1995 roof retrofit, engineered by Skilling Ward Magnusson Barkshire (now Magnusson Klemencic Associates). The 1995

CUT OFF Perimeter Y-columns with loads transferred out to shoring frames and stems cut off, await stem extensions down to new foundations.

PHOTO BY ANNA HALSTEAD OF MORTENSON, MAP COURTESY MORTENSON



DEEPER AND DEEPER The redevelopment is creating a mostly subterranean arena with an event floor that is 60 ft below grade (cutaway, top). The 1962 building had no basement (cutaway, right). A 1995 retrofit created a sunken seating bowl, with an event level 38 ft below grade (cutaway, far right).

work replaced the flexible cable net—which caused roof leaks—with rigid intermediate trusses (ENR 6/14/1993 p. 17). But it kept the four original main trusses, which spring from four tripod perimeter buttresses, creating four hyperbolic paraboloid quadrants.

Also in 1995, Skilling kept the concrete ring beam and perimeter Y-columns, which take gravity loads only. And it added four 8-ft-deep clear-span trusses that span from the roof peak to reinforced-concrete corner columns.

The tripod buttresses resist all the wind and seismic forces of the roof. The thrust generated in the primary trusses by dead and live loads on the roof is resisted by the large leg of each buttress. Lateral loads are taken by the two short buttress legs, called a chevron.

Seismic Upgrade

TT's charge included a seismic upgrade. Better understanding of local seismicity since the 1990s, stricter seismic codes and the significant modifications to roof supports "prompted analytical evaluations beyond the norm," says Steve Hofmeister, TT's principal-in-charge. The strategy, intended to result in minimal damage during the "design" earthquake, avoided significant seismic retrofits to the lightly reinforced Y-columns and chevrons, he adds.

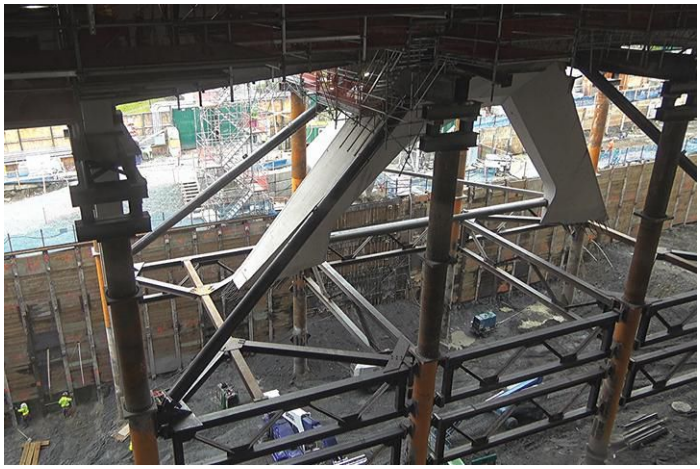
The new bowl structure consists of steel framing with composite metal decking and precast concrete seating risers. TT's nonlinear response history analysis, also known as performance-based seismic design, subjected the entire structure's analytical model to site-specific ground motions provided by the project geotechnical engineer. The approach led to the addition of strategically placed "seismic fuses" between the new and old structure.

The shoring had to resist the roof's weight, construction loads, wind and seismic loads. "The seismic analysis during the construction stages took as much effort as for most new buildings," says Hofmeister.

Each Y-column shoring frame consisted of an inbound and outbound pipe column and two cross beams that sandwiched and engaged the top of the Y. There was space for a removable jack at the top of each pipe.

The four chevron shoring frames, to resist lateral loads, were more intrusive because they had to steer clear of the future permanent structure. Each frame had eight pipe columns. The pipes were connected with four trussed moment frames, with some diagonal bracing. The trusses were shallow and not continuous so there would be space between each tier to build the future floor plates.

Also, the assemblies could not be cut out before the floor plates, which provide lateral resistance for



CHEVRON FRAMES
Steel erector installed temporary trusses for chevron shoring frames from the top down, starting with the top tier (left). On all but the south side, after excavation and the installation of perimeter wall tie-backs, the erector installed the second tier below the first. The sequence was repeated two more times.

PHOTOS COURTESY OF MORTENSON

the permanent structure, were finished.

The chevron frames had four flexible pinned connections to the pipe columns—which started out as drilled shafts—because Malcolm could not drill the shafts perfectly plumb "in the blind."

At the interface of the top of the chevron frame and the existing ring beam, girders with a jacking assembly at each end spanned perpendicular to the ring beam. Four skewed pipe braces were wedged between the top of the chevron and the underside of the ring beam to transfer lateral load from the roof to the chevron frame.

The arena's excavation to the south undermined the foundation of the long leg of the south buttress. For temporary support, Danny's installed a bicycle-like kickstand until after the excavation was complete, so that crews could remove the old foundation and build a new one to support a new shear wall for the buttress.

The kickstand consisted of pipe columns that spanned from a collar around one end of the buttress across nearly 200 ft to bear on a section of the south wall.

Work during the shoring operation was performed around the clock, six days a week, with some work on Sundays.

"During the shoring period, we ran a very heavy night shift for excavation and hauling, as well as critical path concrete work, such as the forming and reinforcing of the permanent Y-columns and chevrons," says Mortenson's Huber.

Divided Into Quadrants

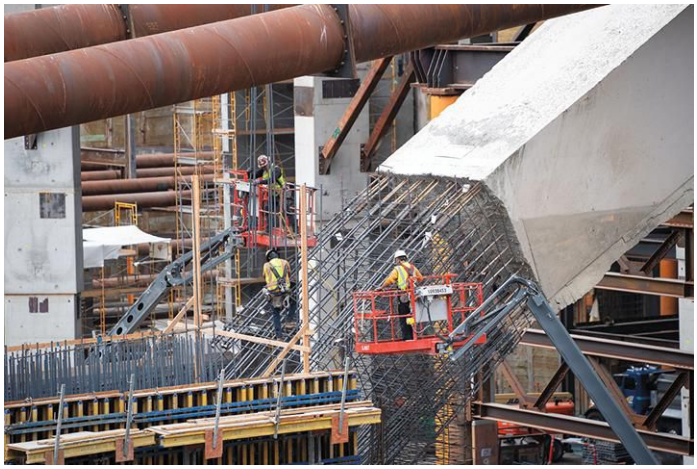
The job, which was sequenced, was divided into the four roof quadrants. The top-down installation of the roof shoring started under the northeast quadrant. Malcolm/DBM JV installed the 76 temporary pipe shafts to support the roof, starting in May 2019, and completed them five months later.

The work was all done in and around the building's existing footings and walls, and mostly underneath the existing roof line, where there was limited headroom.

In December 2019, following the completion of one quadrant of the shoring system, Malcolm/DBM JV started installing permanent shaft foundations for the undermined Y-columns and chevrons, near the installed temporary ones. The permanent shafts, done by last May, were the first step in completing the second phase—transferring loads from the shores to permanent supports, after they were extended 60 ft to their new foundations.

For the inbound shafts drilled in low-overhead conditions, Malcolm/DBM JV installed the pipes in sections, using custom equipment. "We would drill as deep as we could go, pull a pipe out, bolt on an extension and drill it back in," says Malcolm/DBM JV's Running.

After a central shoring tower under the roof peak had been erected and engaged, work could begin in earnest on the perimeter shoring and sequential jacking operation.



PHOTOS BY CHRIS MAST OF BLUEPIXEL; RENDERING BY POPULOUS

For Y-columns, Danny's extended Malcolm/DBM JV's 3-ft-dia shaft and erected the 20 Y-column jacking frames.

Danny's jacked the roof sequentially, moving the 24 jacks as needed. Each Y-column was loaded with 1 million lb to 1.5 million lb of force, enough to transfer the load from the existing foundation to the shoring frame.

Once each Y-column was jacked, crews could cut it from its foundation and hydrojet the concrete off the end, to expose the reinforcing steel for eventual reattachment to rebar for a lengthened column.

Column tops were left hanging while crews cast the extended column stem. Meanwhile, Danny's erected the chevron shoring frames, which resisted both lateral and gravity loads.

The top-down construction sequence meant that the trusses were erected from the upper tier down.

SPECIAL SOUTH BUTTRESS
The excavation undermined only the long leg of the south buttress (left). Workers prepared the leg for an extension (left) to connect it to a new foundation and shear wall, under the south plaza, in the parking garage.

The shafts allowed crews to cut the chevron from its foundations and prepare it for its extension.

For the chevron frames, the general sequence was to excavate, install tiebacks in the perimeter wall nearby, excavate, install a truss tier and repeat three times.

The entire roof was sitting on temporary supports by mid-November last year. Standing under the shored roof, "you had to trust the work," says Mortenson's Cunz.

Danny's job was not done. As the new and extended structure was finished in an area, Danny's would reinstall the jacks and transfer roof loads back to the permanent structure.

The steel erector then had to cut out the chevron frame assemblies from the maze of permanent structural steel. The operation presented logistical and hoisting challenges to avoid damaging the new framing, says Mortenson's Huber.

ORIGINAL LOOKS
When Climate Pledge Arena is finished next fall, it will look very much like the 1995 KeyArena.

All Permanent Support in Service

By Aug. 17, all permanent supports were in service. The last of the shoring will be out by early December.

Mortenson only lost four work days to the pandemic—at the end of March. During the stoppage, it created its COVID-19 procedures to achieve social distancing, as a response to mandates from the state.

In the event work procedures cannot be amended for social distancing, Mortenson created "crew families" to minimize workers' exposure to each other.

Facewear has been a bit of a problem. Mortenson continues to explore face coverings to minimize fogging, including mesh eye protection.

To date, with hundreds of workers on site, Mortenson says there have only been 10 people who tested positive for COVID-19.

Work continues on the simpler parts of the arena. Looking back, Danny's Rust sums up the shoring job, which he calls unique, by saying that, "at the end of the day, people will look at the [building] and not understand all that went into saving that roof." ■