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SEISMIC SURVIVAL

Switch from steel frame to novel post-tensioned concrete structure rescues San Francisco building

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TENSIONING EASES STRESS

Resilient concrete structure, with post-tensioned core walls, helped save a budget-challenged building project in seismic San Francisco By Nadine M. Post

COMPLEX SKIN Curtain-wall supplier put its "A-team" on the job, which has 12 types of cladding units.

Structural engineer Steven Tipping doesn't often attend industry events, let alone introduce himself to keynote speakers. But he is glad he did just that on Dec. 5, 2007. So is the team for the $145.5-million San Francisco Public Utilities Commission Headquarters, a nearly finished job with a difficult past.

Tipping's actions at the Dec. 5 breakfast—at which a project of his was recognized and he heard Webcor Builders' Phillip Williams speak—inadvertently helped recenter the ailing job. The 13-story showcase for sustainable design and construction owes its existence, in part, to serendipity.

At the breakfast, hosted by McGraw-Hill Construction (ENR's parent) to honor California's "Best of 2007" projects, Tipping was so impressed with Williams' ideas and philosophy that he invited him to come to Tipping Mar's office in Berkeley, Calif.

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"I think we are kindred spirits. I'd be tickled to death if we could get together and show you our stuff," the Tipping Mar president recalls saying to Williams, also a structural engineer.

A month later, Tipping and his partner, David Mar, briefed Williams on Tipping Mar's performance-based seismic design scheme, adapted from bridge engineering (see sidebar, p. 22). The concrete shear-wall core system relies on unbonded vertical post-tensioning (PT) in core walls to resist lateral loads and recenter, or re-plumb, the structure after a major earthquake.

Tipping Mar's scheme is expected to preserve a building, allowing for its immediate reoccupancy. Williams was impressed. "I catalogued it in my brain," he says.

Currently, after weathering three hiatuses, changes in the project team and a cost-cutting design switch from a resilient steel to a resilient PT concrete structure designed by Tipping Mar, the 277,500-sq-ft building is on course to open at least two months before its late August substantial-completion date.

The decision of the San Francisco Public Utilities Commission to go back to the drawing board midway during construction documents saved $5 million on structural costs alone. And the switch to concrete improved the building, agrees the SFPUC, the architect and Webcor, the job's construction manager-general contractor. "This was that elegant solution," says Williams, vice president of technical systems for the San Francisco-based builder. "One good solution kept on bringing other positive results."

Shaky Start

In 1989, the Loma Prieta quake damaged beyond repair a state building in San Francisco's civic center. In 2000, the city acquired the site for a new administrative building and assembled a design team, led by local

PHOTO COURTESY OF BENSON GLOBAL

architect KMD/Stevens, a joint venture that includes Kaplan McLaughlin Diaz and Stevens and Associates.

The SFPUC put the new building on hold in 2002, following design development, in part because of 2001's dot-com bust, which hit the city's tax revenues particularly hard. Plans had called for a base-isolated building to allow for immediate reoccupancy. The concept engineer was Arup. SOHA Engineers, San Francisco, remains structural engineer of record (EOR).

In June 2006, SFPUC, a city and San Francisco County agency that provides water, wastewater treatment and power, acquired the project. SFPUC's goal was to consolidate 1,000 employees from leased space into a "global model for optimizing energy performance, water conservation and indoor air quality." That meant achieving the top level of the U.S. Green Building Council's Leadership in Energy and Environmental Design rating system: LEED-Platinum.

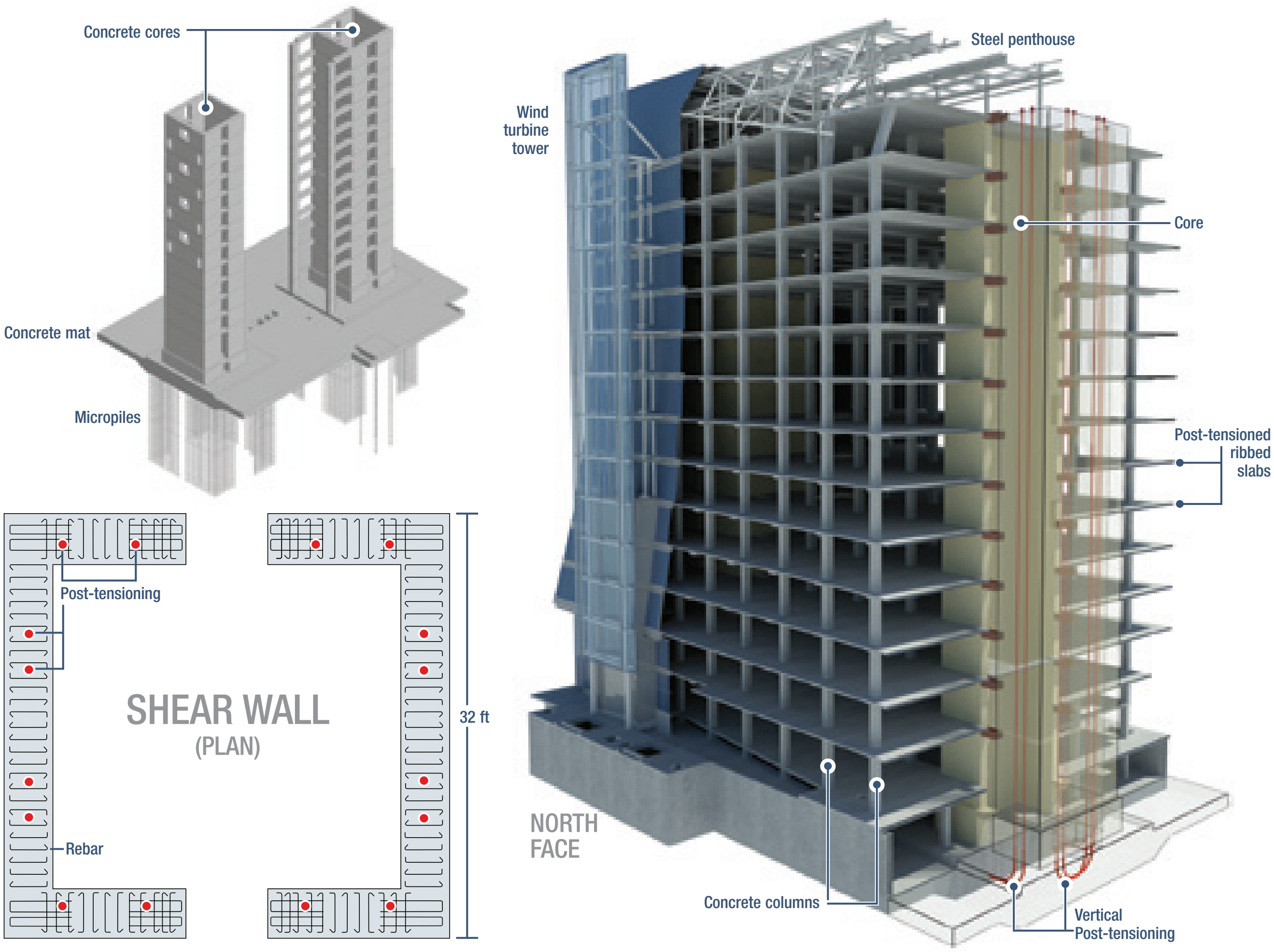
The SFPUC expects the building, financed by bonds backed by commission assets, to save $3.7 billion in rent over its 100-year life. Besides wastewater treatment and re-use, its green features include power generation via rooftop solar panels and north-facade wind turbines. The facade has daylighting controls, such as fixed sunshades and exterior blinds that move.

PLUMB CORE Crews install conduits for vertical post-tensioning in cores, which recenter after a quake.

CHANGED Switch from steel to concrete structure allowed for an extra floor.

TOP PHOTO COURTESY OF TIPPING MAR; BOTTOM OF SAN FRANCISCO DEPT. OF PUBLIC WORKS

INSPIRED BY BRIDGE DESIGN *The performance-based design for the building limits seismic drift, which is expected to minimize building damage in a major earthquake and allow immediate reoccupancy following the event. The system, adapted from bridge construction, relies on vertically post-tensioned concrete shear walls in the cores.*



IMAGES ON LEFT COURTESY OF WEBCOR BUILDERS; RIGHT COURTESY OF TIPPING MAR

In 2006, KMD/Stevens restarted design, with Forell/Elsesser as structural designer for the lateral-load-resisting system. Webcor signed its contract in January 2008, nearly halfway through construction documents. Plans had called for a 12-story building with a steel moment frame with viscous dampers.

Soon, a budget crisis triggered a major value engineering (VE) exercise: Webcor's cost estimate was $62 million over the $133-million "target" budget.

When Williams heard, he thought of Tipping Mar's vertical-PT wall and wondered if it might cut costs. Soon, he introduced Tipping Mar to Webcor, which was initially skeptical. Even Tipping wasn't sure Tipping Mar could both meet the strict seismic performance objective and keep the steel column grid and two-core layout.

'Aha' Moment

Webcor gave Tipping Mar a $10,000 stipend to study the scheme. Tipping Mar's "aha" moment came with the idea of a two-way PT floor slab with shallow PT beams that would maintain the existing grid with 40-ft spans, says Leo Panian, Tipping Mar's project manager.

The architect liked the PT scheme. Eliminating deep spandrel beams meant better daylighting. No ceiling plenum meant no dropped ceiling. And much of the structure could be exposed, saving on finishes.

KMD also liked the drift limits and "self-healing" feature of the system, which closes cracks that occur during flexure at the base's hinge point. Also, spalling at the edges of the wall, at the base, could be fixed.

"There would be incredible seismic performance, tracked to all building systems, including the facade," says Michael Rossetto, KMD's project architect.

The SFPUC wasn't as excited at first. "It was outside their comfort zone to put a project on hold while it is redesigned," says Williams. There were also questions about whether the novel system, never used on such a scale and untested in a quake, would provide performance equivalent to a damped steel frame.

An independent review allayed any doubts. "I concluded that the wall system would perform as well,"

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says Ronald O. Hamburger, senior principal of local engineer Simpson Gumpertz & Heger.

The SFPUC OK'd the switch, which saved $4 million in direct structural costs, says Brook Mebrahtu, the commission's project manager in the city's Dept. of Public Works (DPW). Indirect structural costs, including changes to the basement that reduced shoring, excavation and waterproofing, cut costs by another $1 million, says Matt Rossie, Webcor's project director.

Downstream changes, including to finishes, meant another $3 million in savings. Other big VE changes saved $11 million on skin, $10 million on the mechanical system and $3.7 million on the electrical system.

Third Time-Out

Still, the project was not out of the woods. In June 2008, it went on hold for six months, while the SFPUC considered, then rejected, buying and upgrading a building. Webcor got a notice to proceed with demolition in January 2009. But the new design team, with Tipping Mar as structural designer, did not begin the redesign until that June. At that point, the recession had cooled prices, and "we were able to add a 13th floor," thanks to concrete's reduced floor-to-floor height, says David Hobstetter, KMD's principal in charge.

During the redesign, Tipping Mar's Mar, seeking a greener concrete-mix performance specification, convened a four-hour design charrette with KMD, SOHA and Central Concrete Supply Co. Inc. It was the first pre-bid charrette for Tipping Mar. The challenge was to find the greenest mix possible with no compromises on cost, finish or cure time for the mat foundation, the slabs, and the columns and core, says Mar. To ensure multiple bidders, mixes could contain no exotic material.

NOVEL LINK Steel-and-concrete link beam needs no diagonal rebar.

MORE CONSTRUCTIBLE *Combination of vertical post-tensioning and composite link beams reduces rebar congestion in the core walls, easing construction of cores and wall openings in high seismic zones.*

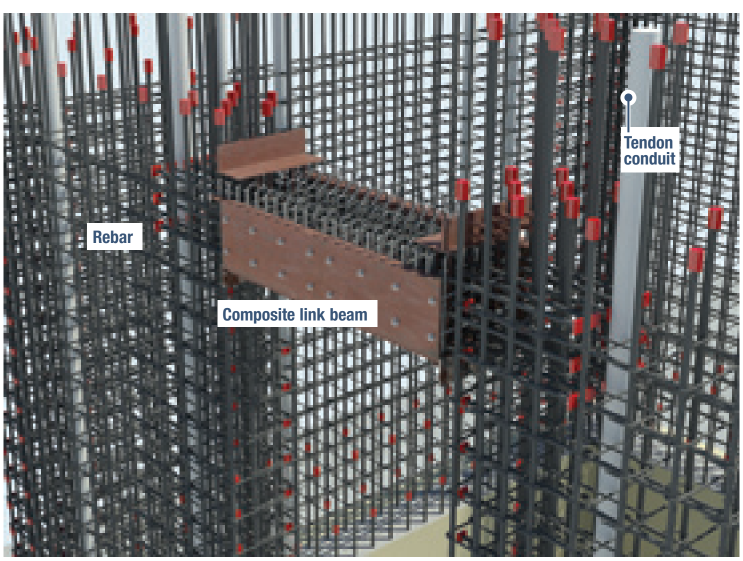

IMAGE AND PHOTO COURTESY OF TIPPING MAR

Central, which won the job, was not paid for the charrette but "knew they had a decent chance of winning because of their investment," Mar says. Central declined to comment on any aspect of the project.

Greener concrete usually means replacing 15% to 20% of the high-carbon cement with recycled materials, such as fly ash and slag. Traditional mixes reach specified strength at 28 days. Low-cement mixes can delay a job because they gain strength more slowly.

"We knew we could take advantage of how long the foundation had to cure and specified design strength be measured after 90 days, not 28," says Mar. That beat Tipping Mar's own record of specifying 56 days of cure time.

Tipping Mar also specified the mat mix contain no more than 200 lb—instead of 800 lb—of cement per cu yd.

Overall, the resulting spec called for six different mixes, which cut about half the cement, or the carbon footprint, over a traditional design. That was a net savings of 7.4 million lb of carbon, says Mar. Tipping Mar has applied for LEED "innovation" credits for both the low-carbon concrete and the resilient structure.

During construction, the team monitored the con-

BUNDLES
Post-tensioning subcontractor adapted a method used by electricians to pull tendon bundles through 375 ft of vertical conduit. The rooftop operation relied on a winch-and-beam apparatus.

LEFT PHOTO COURTESY OF WEBCOR BUILDERS; RIGHT COURTESY OF AVAR CONSTRUCTION

crete cylinder breaks for strength. "There is a risk associated with this," says Mar. Only one two-story sloped lobby column needed remediation, adds Rossie.

Tipping Mar designed the PT system to limit interstory drift to 1%, compared to the 2% allowed by building code. Mechanical systems, stairwells and cladding are designed to remain damage-free and without permanent deformation with up to 1% drift.

The resilient PT wall scheme can cost about 0.5% more than a conventional seismic shear wall, says Tipping Mar's Panian. The premium is for thicker core walls and added materials and labor in the mat, which is thicker under the cores, says Webcor's Rossie. There is also an added slip and expansion joint at the first floor.

The impact from the perspective of concrete forming, placing and finish work is primarily in thicker core walls, which translates into a higher volume of ready-mix, adds Rossie. Some 20% of the wall cost is ready-mix, and the vertical PT walls are about 30% thicker. Vertical PT increased the $30- to $35-per-sq-ft cost of a seismic shear wall by $2 per sq ft, or 6%.

The 32 x 33-ft cores of the 164-ft-tall building sit on mats secured by micropiles. Core walls have novel composite link beams over wall openings, made of a steel-plate jacket containing reinforced concrete. The jacket acts as formwork (see drawing, p. 5). It also creates a shallower, more flexible beam, says Tipping Mar. Link beams span between boundary elements within the core wall. The beams are simpler to construct because of fewer and smaller steel-reinforcing bars compared with conventional concrete link beams, says Rossie.

Each PT core contains eight continuous tendon bundles in a 375-ft-long, U-shaped hollow conduit, 184 ft tall. Crews installed conduit with the rebar, starting with the curved section in the mat foundation.

Each bundle has 28 strands, each 0.6 in. in diameter,

U.S. RESILIENT SYSTEMS NOT YET TESTED BY A QUAKE

Tipping Mar's vertically post-tensioned concrete shear walls in the 164-ft-tall San Francisco Public Utilities Commission Headquarters is the most ambitious—and tallest—example to date of a family of lateral-load-resisting structures designed to minimize damage in a major earthquake and allow immediate reoccupancy. U.S. structural practitioners and researchers have been developing the self-centering systems, modeled after PT bridge construction, for about a decade.

Self-centering structures, when designed in structural steel, have become known as "rocking frames." In addition to concrete systems, there are examples of self-centering PT structures in precast concrete and in composite steel-and-precast structures.

There has been research, including physical testing, on the systems, which are not yet included in U.S. building codes. In 2009, a steel rocking frame was tested at Stanford University (ENR 9/14/09 p. 90). Tests at Lehigh University on a PT reinforced-concrete shear wall, planned for last year, have been delayed (ENR 3/28/11 p. 20).

PT systems are not only designed to return a building to its plumb prequake position, they also are expected to limit seismic drift to about 1%, which is more than building codes mandate for life safety. The idea is to minimize quake damage to all building systems in an effort to protect the investment in the building and limit repair work.

Tipping Mar (TM) has used the system in five buildings to date. Three of them are still under construction. None of the PT systems in the U.S. has yet been tested by a major quake.

For PT concrete, "it's a little bit of a balancing act" between the right amount of prestressing so the concrete is not overstressed and the need to get enough recentering capacity, says Stephen Mahin, director of the Pacific Earthquake Engineering Center at the University of California, Berkeley, and one of two peer reviewers on TM's performance-based seismic design for the public utilities commission. "I think it's a good system. The next earthquake will show us," says Mahin.

CIVIC EXAMPLE
Glass-clad 13-story SFPUC building (center) is more costly than a conventional building but is packed with features intended as a model for sustainable design.

PHOTO BY MICHAEL O'CALLAHAN

anchored at the roof by over one million pounds of permanent force. PT allowed almost a 50% reduction in mild-steel vertical rebar in the walls between link beams, reducing congestion and labor, says Tipping Mar.

Tendon installation began from the roof after completion of the concrete structure. The final step—the sequenced post-tensioning of the bundles—was conventional. The big challenge was the bundle installation because of the verticality and the curve, says Carrick Pierce, division manager for Avar Construction Systems Inc. The Freemont, Calif.-based PT contractor had never done vertical PT on a such a tall building and grand scale or with a curve.

Against Gravity

After learning that conventional pushing of the bundles would not work because of the curve and the need to go against gravity, Avar adapted a method used by electricians when they pull wire. For each U-shape bundle, crews on the roof first dropped a special balloon, with a rope attached, into the conduit. They then blew air into the hole, inflating the balloon and pushing it down, around the curve and up, until it came out the other end—20 ft away from where it went in.

Workers then untied the balloon and attached a strong steel cable to one end of the 400-ft rope. Using a winch, they pulled the other rope end, which pulled the cable into the conduit. Finally, workers attached a tendon bundle to the cable. Using a winch, they pulled the cable out of the conduit, replacing it with the tendon bundle. "Once we worked out the bugs, it was a lot easier than we thought," says Pierce.

Post-tensioning, using hydraulic rams, followed after crews had installed all eight bundles. Avar finished the PT work in two days.

The PT system was not the only one that called for intense engineering. The unitized curtain wall has 12 systems instead of two or three. These include kinetic blinds, cold-warped glass, operable windows, sloped glass, interior metal light shelves, interior shades with valance boxes and more. The job ranks as the third most complicated building skin "we've ever done," says Jeremy Mucha, vice president of engineering for Benson Industries LLC, Portland, Ore. "That's why we put our A-team on this job."

Of 2,295 curtain-wall units, 880 are unique. For every drawing package, "you can fabricate about three units, which means there is no economy of scale," Mucha adds. The 145,000-sq-ft curtain wall costs $151 per sq ft. Most jobs in San Francisco with two or three wall types cost about $90 per sq ft, says Mucha.

Rossie says the challenge of the SFPUC job isn't in any one individual system; rather, "it is how many new or unique techniques have been combined. The project has touched the boundaries of the amount of sustainability you can apply to a project and still remain commercially viable," Rossie says. "The cost per square foot is significantly higher than any other commercial office building" in the area, he adds.

However, the SFPUC didn't want an ordinary building; it wanted to set an example for sustainable commercial development. "From an asset-preservation standpoint, we get a 100-year building," says DPW's Mebrahtu. "We are very happy with it." ■