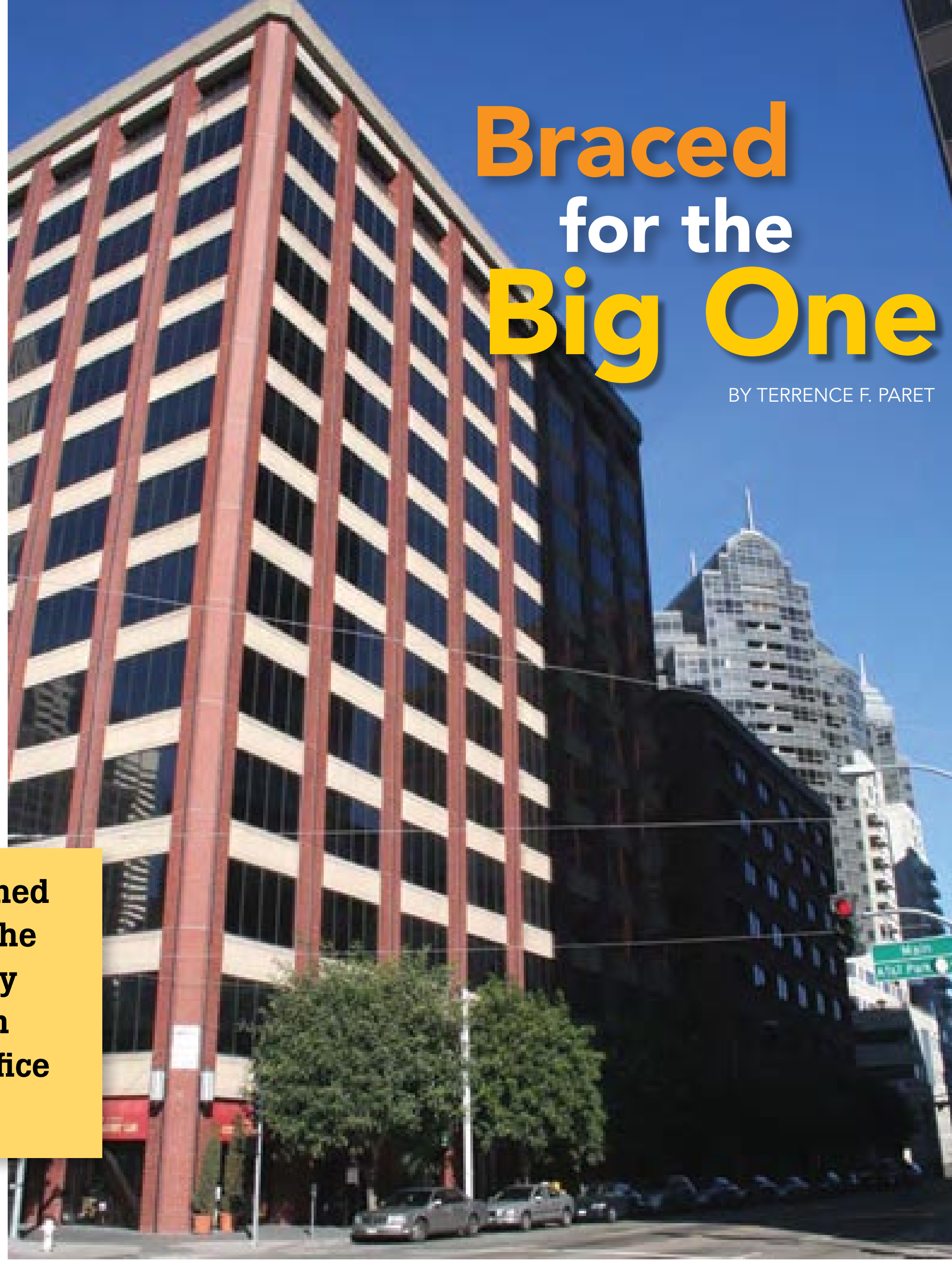
Braced for the Big One

BY TERRENCE F. PARET



Photos: Courtesy Wiss, Janney, Elstner Associates

Buckling-restrained braces improve the seismic reliability of this downtown San Francisco office building.

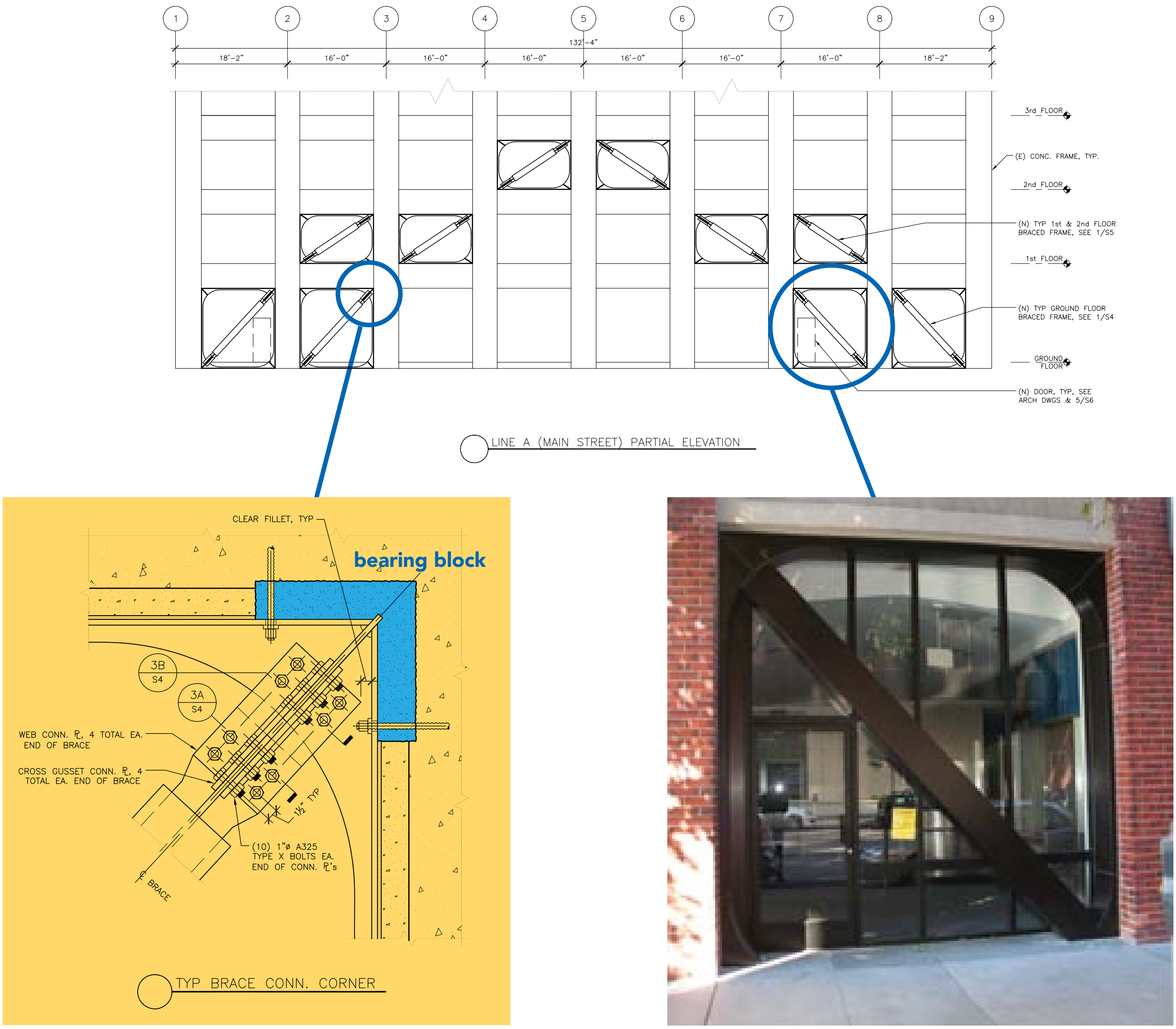
IT'S SAFE TO SAY THAT THE U.S. CITY MOST ASSOCIATED WITH THE WORD "EARTHQUAKE" IS SAN FRANCISCO. So it's a given that seismic considerations are near the top of the priority list when it comes to new high-rise construction in the city.

But when it comes to older high-rises, there's often room for improvement. Such was the case with The State Bar of California Building, a thirteen-story 1970s-era reinforced concrete structure in downtown San Francisco. The building recently underwent a seismic improvement project that employed a state-of-the-practice seismic mitigation technology and a number of other innovations.

The goal was to cost-effectively mitigate a very undesirable primary characteristic in the response of the existing structure to strong earthquake shaking. The deficiency involved the expected performance of the tall ground story, which was predicted by nonlinear response history analyses to experience large inter-story drifts and significant inelastic behavior verging on collapse in the event of a large earthquake. The building owner and occupant, The State Bar of California, desired improved seismic reliability—if it could be achieved without severely disrupting operations—and embarked on a voluntary effort to mitigate the seismic hazard.

A First for San Francisco

The most cost-effective and least disruptive solution that targeted the deficiency and avoided wholesale upgrading consisted of the addition of buckling-restrained bracing—infilled within new structural steel



The lower three floors of the 1970s concrete frame were retrofitted with a series of steel buckling-restrained braces. When the perimeter concrete frame displaces laterally in-plane during an earthquake, the new infilled steel framework is loaded by bearing blocks at the corners of the braced bays.

WT framing—to the lowest three stories of the existing perimeter reinforced concrete moment frame. This was the first application of this technology for seismic retrofit of a concrete building within the jurisdiction of the City of San Francisco.

Buckling-restrained braces consist of a ductile structural steel core located within a grout-filled HSS. The core is isolated from the grout by a bond-breaker, which enables the steel core to deform and yield without engaging the surrounding HSS. As the name implies, buckling-restrained braces exhibit very stable hysteresis relative to other steel bracing systems because they can yield in a ductile manner in both tension and compression. Furthermore, because the material properties of the core steel are tightly controlled, the strength of the braces is very predictable.

The complexity of anchoring an infilled structural steel bracing system to an existing reinforced concrete frame provided the opportunity for significant innovation, particularly with respect to the philosophy employed in designing the load path for the braces and the use of unconventional structural shapes that minimized welding, provided an improved gusset plate design, minimized obstruction of the windows, and promoted an overall sleek appearance.

The design of the infilled diagonal bracing system, including the new steel framework and its attachment to the existing concrete frame, was predicated on a capacity analysis of the braces and iterative performance analyses of the building. Essentially, the maximum force that can be developed by each brace (i.e., the strength of each brace) was identified, and the whole of the supplemental system—including all welds, bolts, plates, and the WTs that created the infilled frames—was designed for those computed forces using LRFD with lower bound yield strengths and associated phi factors. As a result, other than the desired yielding expected to occur in the new buckling-restrained braces, the supplemental system of steel framework is not expected to experience yielding even in the maximum considered earthquake event.

The seismic load path into and out of the new buckling-restrained braces and surrounding steel framework was designed in recognition of the likely behavior of infilled bracing at ultimate. Instead of transferring forces into the braced frames via shear dowels embedded into the concrete frame as might typically be done, loading of the bracing is forced to occur through reinforced epoxy-grout bearing blocks installed at the four corners of each braced-frame assembly. When the perimeter concrete frame displaces laterally in-plane during an earthquake, the new infilled steel framework is loaded by bearing blocks at the corners of the braced bays.

For braces in compression, the bearing blocks at the two corners of the framework—through which the line-of-action of the diagonal braces passes—transfer forces directly from the perimeter concrete frame to the infilled braced frame. For braces in tension, the bearing blocks in the corners—opposite those along the line-of-action of the braces—transfer forces from the perimeter concrete frames to the supplemental steel framework. The steel framework then transmits these forces toward the brace ends via compression of the WTs. Therefore, the WTs are designed as compression members with unbraced lengths equal to the maximum spacing of the epoxy dowels connected to the perimeter concrete frame members through oversized holes. The design spacing of the epoxy dowels enabled the WT webs to be trimmed down to 3 in. in the regions away from the bearing blocks, thus minimizing the visual impairment normally associated with retrofit bracing and allowing for ADA-compliant doors to fit beneath the braces where required.

Using the Web

Another innovation on this project was developed specifically to avoid a failure mode that had been identified during laboratory testing of other buckling-restrained braced frames for other projects. During some of these tests, the braced assembly failed by brittle fracture of welds between the gusset and the steel framing to which it was connected, as the gussets deformed out-of-plane under severe loading. Instead of using traditional gusset plates for the project, the WT webs were employed as the primary gussets; they were spliced together with only longitudinally loaded fillet welds at a cross-gusset used to create the cruciform shape needed to mate with the ends of the braces. The WT webs, which were profiled to minimize obstruction over the majority of the bay openings, were radiused at the frame corners. This radius is reflected in the sheet metal weather-tight covering for the infilled frames and adds to the visual appeal of the frames. Use of the WT webs as gussets minimized total project welding and required only a few fillet welds per bay to be installed outside of shop.

Late Nights

The State Bar of California Building is now better prepared for the next Big One, whenever it may come. And the construction team was able to meet another owner goal as well: Construction was performed in the evening, eliminating loss of occupancy. MSC

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