An Enduring Solution

WaMu Center/Seattle Art Museum Expansion

By E. Douglas Loesch, P.E., S.E.

In an unlikely—but wildly successful—pairing, a creative business deal made roommates out of the nation's fifth largest bank and Seattle's preeminent art museum. The deal resulted in the creation of a first-of-its-kind high-rise structure that recently received a Grand Award from the American Council of Engineering Companies at their 2007 Engineering Excellence Awards competition in Washington, D.C.

For detailed information on the unique collaboration between Washington Mutual Bank (WAMU) and the Seattle Art Museum (SAM) in the development of this site, see the article on page 40 of this issue.

Figure 1: A "win-win" business deal provided WaMu with land to develop a new headquarters tower and SAM with expansion space located adjacent to its existing museum. The long, narrow site, however, brought its own set of challenges.

The project site brought its own set of challenges (*Figure 1*). The development is set in the midst of a busy downtown, facing Elliott Bay at the foot of the renowned historical Pike Place Market. A 100-year old train tunnel, adjacent to the block at the northeast corner, and abandoned street tunnels and areaways posed challenges to the shoring and foundation systems. The site is also long and narrow, constraining building geometries, and a zoning restriction on building height bisects the site north-to-south, resulting in the bay side of the building being limited to 240 feet in height.

These complex constraints paled in comparison to the program integrating the bank's and museum's often-conflicting space planning, budgeting, and schedule goals. Even the very nature of the businesses involved increased the project's complexity: decision-making in the financial world takes place at lightning speed, whereas museum consensus takes a longer view toward the future. According to David Yuan, Principal for NBBJ (Design Architect for WaMu Center and Executive Architect for the shell and core), "This is one of the most complicated mixed-use buildings I've ever done. It was almost as if we were building two buildings at the same time."

The project took the form of a 42-story, 540-foot-tall office tower with a 16-story 240-foot-tall museum component housing 4,000 WaMu employees and SAM's prestigious art collection (*Figure 2*). The city's sixth tallest skyscraper, it has a luxurious roof garden on the 17th floor. Under the deal negotiated, SAM will initially occupy four floors in the lower tower and ultimately take possession of 12 floors (two floors at a time), with the bank occupying the floors in the interim (*Figure 3*).

Figure 2: The new development features a 42-story, 540-foot-tall office tower and a 16-story, 240-foot-tall museum/office component. The two towers function as one structure but were designed to visually reflect the separate identities of the tenants, WaMu and SAM. Courtesy of Michael Dickter/MKA.

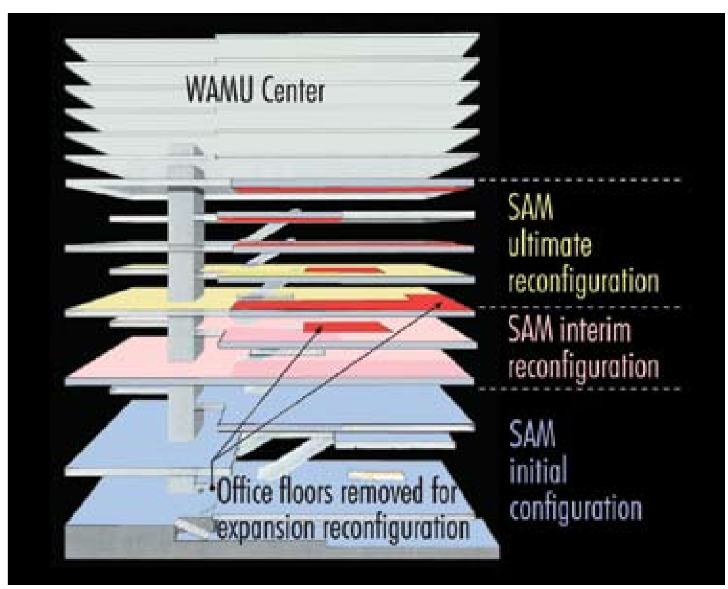

Figure 3: Conversion of state-of-the-art office space into two-level, world-class gallery space will occur two floors at a time over a number of years. MKA provided for hundreds of beam penetrations in the original design that are actually for future systems and designed floors with "cut-along-the-dotted-lines" for future removal.

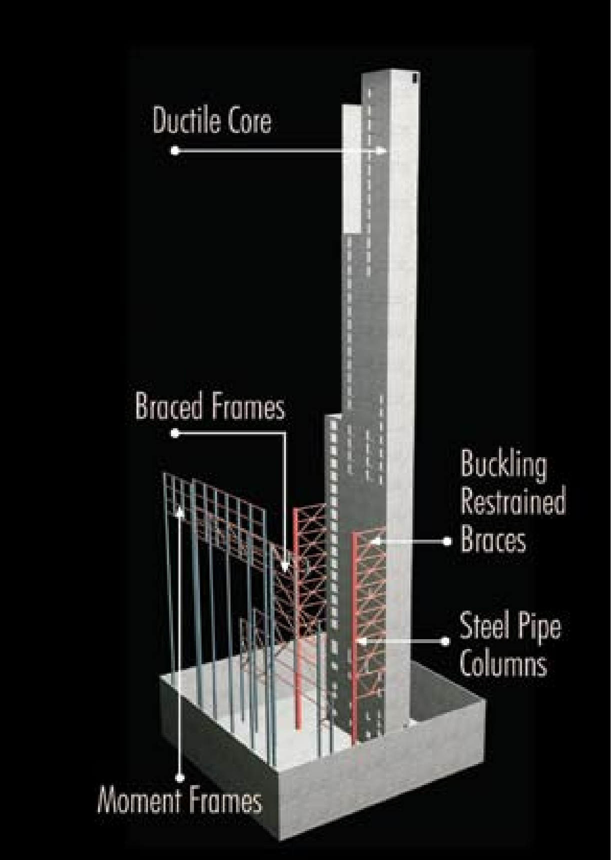

Figure 4: The structural system developed for WaMu Center, created using a performance-based seismic design approach, employs a 31' wide by 610' tall ductile concrete core stiffened by a BRB/concrete-filled pipe column outrigger system. The system doubled the core's effective width to an achievable slenderness ratio of 13:1 and eliminated the need for a backup steel moment frame.

Advanced Seismic Design

The building, located in a region of relatively high seismicity, was designed by structural engineers Magnusson Klemencic Associates (MKA) under the provisions of the Seattle Building Code (which at the time was based on the 1997 Uniform Building Code). An elastic lateral analysis was performed for a site-specific seismic response spectrum for a design-basis earthquake, with a probability of exceedance of 10 percent in 50 years. The maximum considered earthquake was based on a probability of exceedance of 2 percent in 50 years, used for the development of time-history pairs for a site-response analysis. The building was analyzed using a three-dimensional nonlinear time-history model. In fact, MKA's nonlinear analyses simulated building response to 14 quakes of different magnitudes, compared to a typical code analysis of just a single earthquake.

By employing a cutting-edge "performance-based seismic design" (PBSD) approach, MKA eliminated the need for a backup perimeter moment frame and produced a building that is safer, more predictable, quicker to construct, very flexible for space layout, and less expensive. The structural system incorporates a ductile concrete shear wall core with concrete-filled steel pipe columns connected by buckling-restrained braces (BRBs) in a light, compact outrigger frame (*Figure 4*). Extensive sequential analyses—and two sets of design documents—were completed for the conversion from office to museum, with portions of existing floors literally cut away and structural loads rerouted as the conversion takes place.

PBSD Benefits Project

Performance-based seismic design is gaining momentum in the structural engineering profession. The benefits to this project and others are significant: a savings of \$3 to \$5 per square foot compared to traditional systems; 50-percent reduction in the structural floor cycle construction schedule; elimination of a costly, view-blocking perimeter moment frame; and last, but certainly not least, a safer structure with more predictable response and performance.

PBSD is also key to urban densification. The structural systems currently allowed by the Building Code are not applicable for super-tall buildings of 1,000 feet or more. The new engineering approach offered by PBSD can and will produce safe buildings of extraordinary height, important as the urban densification movement gains momentum.

Additional PBSD benefits include more leasable structures, since the need for a bulky, view-blocking backup perimeter moment frame is eliminated, and increased sustainability, since eliminating unnecessary structural elements and refining those that are selected reduces the amount of materials used. MKA-sponsored PBSD research currently underway at UCLA and UC-Berkeley has resulted in improved connection and construction details and enhanced the engineering community's understanding of the response of critical building elements when subjected to varying levels of earthquake demands.

Since PBSD qualifies as an "Alternate System" in terms of the building code, building departments currently require that the designs be peer reviewed by a second engineering team to verify that the intent of the code is met. Validity of the approach is evidenced by the fact that building departments in five U.S. cities—those charged specifically with protecting the public's interests—have given their acceptance, acknowledging the safety, merit, and sound engineering principles of MKA's PBSD approach. The cities of Seattle, Bellevue, San Francisco, Sacramento, and Los Angeles have all adopted or are working to develop PBSD standards.

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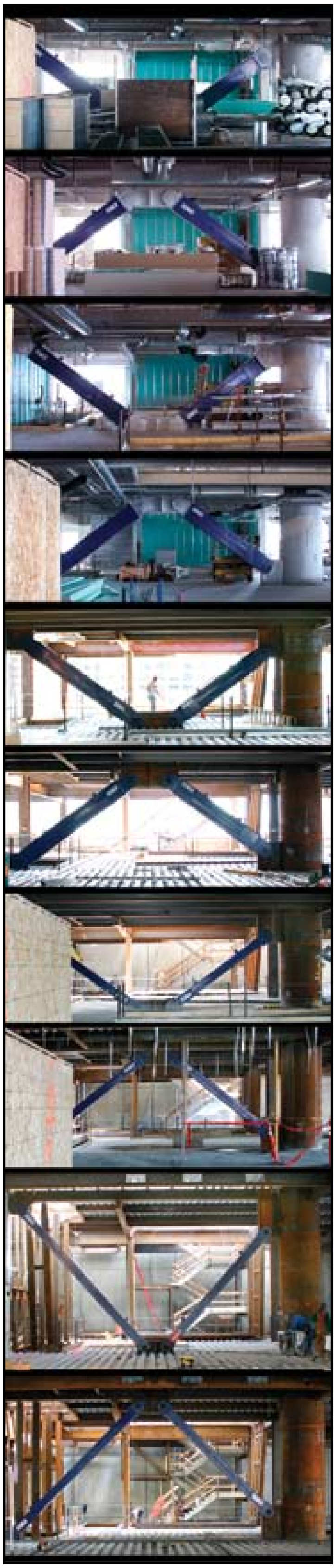

Figure 6: Forty-four buckling-restrained braces were strategically positioned on Levels 1 through13 and sized (or "tuned") to the building's response.

An Enduring Decision, Easily Modified

The site's unique below-grade conditions, with tunnels and areaways, complicated foundation design. MKA custom-shaped the building's mat to most economically match the loading conditions, specifying thicknesses ranging from 6 to 14 feet, depending on demand. Special underpinning was designed to interface with the immediately adjacent existing SAM museum building, which remained operational. MKA also developed a unique slip joint detail between the existing SAM building and the new structure that locked the buildings together in the north/south direction, while allowing them to move relative to each other in the east/west direction in the event of an earthquake. This reduced the required joint from a large gap to a narrow sliver of space that could be covered entirely by floor boards, an aesthetic appreciated by SAM.

The restrictions of the long, narrow site combined with the world-class museum gallery space planning requirements left just 31 feet for the 610-foot-tall core, resulting in a structural slenderness ratio of 21 to 1. MKA's structural design augmented the ductile concrete core with an outrigger system of concrete-filled pipe columns and BRBs, the first time ever used in a U.S. high rise (*Figure 5*). Through the action of steel yielding within concrete confinement, the BRBs act as a "seismic fuse" during an earthquake, absorbing energy and preventing damage to the rest of the structure. Forty-four BRBs were strategically positioned on Levels 1 through 13 and sized to the building's response (*Figure 6*). The BRB/outrigger system stiffened the building's core and nearly doubled its effective width to a more realistic structural slenderness ratio of 13 to 1. Strategically located special purpose frames address building eccentricity caused by the core's non-central location (*Figure 4, see page 47*).

Figure 5: Buckling-restrained braces connect the core to concrete-filled pipe columns and, through the action of steel yielding within concrete confinement, act as a "seismic fuse" during an earthquake, absorbing energy and preventing damaging to the rest of the structure.

As SAM assumes possession of more space over time, entire sections of floors are removed to convert office areas into two-story soaring galleries (*Figure 3, see page 46*). Since the transformation needs to take place incrementally two floors at a time, the logistics were daunting. The structural system had to support the building in its original condition as well as several incremental states as floors are removed, new loads added, etc. The structural system also had to address the removal and addition of entire elevator banks, multiple escalators, and a complete HVAC system (with corresponding penetration and routing implications), along with issues of changing security separations between tenants, sprinkler system conversion, routes of travel for bringing new systems into the building, etc. MKA performed sophisticated sequential analyses to examine the building at Day 1, final configuration, and multiple stages in between to address all conditions.

The project was delivered to WaMu two months early and on budget. To facilitate early move-in, the design team addressed tenant improvements for WaMu "on the fly" so the steel for the tenant improvement work could be included in the original steel mill order, saving time and money.

The soaring dramatic shape of WaMu's flagship tower and the striking, restrained architecture of SAM's expansion are formed by 11,000 tons of structural steel surrounding one of the most advanced lateral force-resisting systems ever developed for an office building. The high degree of seismic performance from the use of buckling-restrained braces, verified by the rigorous criteria for the performance-based seismic lateral analysis, results in a building of unparalleled performance (*Figure 7*).▪

Figure 7: The award-winning tower perfectly embodies the needs and desires of WaMu and SAM and makes a dramatic statement on Seattle's skyline. Courtesy of Michael Dickter/MKA.

Doug Loesch, P.E., S.E., is a Principal at MKA and a senior member of the firm's Office Specialist Group, with a focus on high-rise structures. MKA, with offices in Seattle and Chicago, has designed projects in 46 states and 44 countries.