PERFORMANCE-BASED EARTHQUAKE ENGINEERING: The First in St. Louis

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Unity Health, one of the largest health care providers in St. Louis, operates about 30 hospitals in the Midwest. When Unity Health decided to consolidate its corporate and administrative operations from five locations into one, protecting their employees and business operations from earthquakes was a major consideration in the design of their new facility. "We need our corporate headquarters to be operational in the event of an earthquake," said Unity Health's director of design and construction, Terry Bader.

Unity Health selected their design/build team with this in mind. ACI Boland provided architectural services and EQE International furnished structural and seismic engineering. McCarthy served as general contractor and Hammerts Iron Works was the steel fabricator. All key team members had worked together before and understood the client's needs from the project inception.

The new Unity Health office complex is located in Town & Country, MO, a St. Louis suburb. It consists of three interconnected office buildings prominently overlooking Interstate 270. The first and second buildings were completed in the spring of 1998, and the third building is planned to accommodate future growth.

The center building contains 120,000 sq. ft. on five floors, and the south building contains 88,000 sq. ft. on four floors. The future north building will mirror the south building and also will connect to the center building. Each building has a full subterranean parking level. A separate, 850-car parking structure complements the office buildings and can be expanded in the future when the north building is built.

The exterior of the buildings consists of blue-green reflective glass, brick and rock-faced brick accents. Column bay sizes typically are from 30 x 30′ to 30 x 45′, creating column-free space on all sides of the building core. Pairs of columns at each end of the five-story building were eliminated, creating 45 x 45 bays to accommodate a column-free auditorium and cafeteria on the first floor.

"It was very important for Unity Health to have complete flexibility to make changes to the office complex in the future," noted ACI Boland's principal in charge, Paul Sabal. He added, "The interior design evolved during the design and construction of the shell, so it was important that we weren't limited by the building's columns."

The two office buildings will house about 750 employees in indispensable system-wide departments such as finance, the medical group, information systems, legal, managed-care contractors, support services and human resources. Unity Health's data center, where all of the hospital system's electronic data and files are stored and handled, also is located in one of the new buildings.

Brick spandrel frames.

Earthquake Risk in the Central US

The central United States is the most active seismic area east of the Rockies. Large earthquakes have occurred here regularly throughout the recent geologic past, and earthquake activity continues today. The New Madrid seismic zone has dominated the earthquake history of the central U.S. and generates about 350 measurable earthquakes a year. The epicenters of the great earthquakes of 1811-1812 were located about 150 to 200 miles south-southeast of St. Louis in the Missouri "Bootheel" and in the northeast corner of Arkansas. Those earthquakes were felt as far away as Boston and Washington, D.C., and did damage in southern Canada and in Georgia. The aftershock sequence of this series included literally thousands of earthquakes that were felt in Louisville, KY, almost 300 miles northeast of the epicentral area.

Performance-Based Structural Design Criteria

When this project began, the building code used in the City of Town & Country was the 1996 BOCA National Building Code, which is a "life safety"-based design code. Those code-prescribed earthquake design procedures result in a high degree of occupant safety during a major earthquake: the design of the structure allows occupants to exit after a large earthquake without additional injury. However, the code is not intended to limit damage to the structure itself or to prevent interruption to business operations housed inside. Thus, a structure designed to merely meet life-safety code requirements may not be usable after a large earthquake. But Unity Health needed their new office facility to be safely habitable immediately following a major earthquake, a criterion that the basic "life safety" code does not guarantee.

To help solve this common dilemma, a new engineering philosophy has recently emerged: performance-based design. Performance-based seismic design can be defined as the selection of a desired level of performance for a selected level of earthquake ground motion. Those at the forefront of the engineering community now offer choices of performance level to their clients. Owners can consciously decide how they want their new structure to perform during an earthquake. This step also gives owners an opportunity to recognize and accommodate their risk tolerance for business-interruption potential for that structure.

Structural steel erection in progress.

When EQE presented the concept of performance-based seismic design to Unity Health for the design of their new headquarters, they embraced the idea.

Recognizing the essential nature of the operations within their new complex, Unity Health made the forward-thinking decision to design their new headquarters for an enhanced level of earthquake performance. This required a more rigorous design than that of the basic "life safety" code requirements. After considering the options, Unity Health chose Immediate Occupancy as the enhanced earthquake performance objective that would best meet their needs (Table 1).

For this design, EQE used the most recent seismic design code, the National Earthquake Hazards Reduction Program (NEHRP) Recommended Provisions for Seismic Regulations for New Buildings and Other Structures and its Commentary (FEMA 302 and FEMA 303, February 1998). Since the building joint created two "regular" building structures, EQE was able to perform a linear static seismic analysis instead of a more complicated dynamic or non-linear analysis.

EQE first designed the office building's lateral force-resisting structural system to accommodate two-thirds of the Maximum Considered Event (MCE), a very rare, large earthquake corresponding to a 2% chance of exceedance in 50 years or a 2500-year return period. The design also complied with the strength requirements of the 1996 BOCA Code that is based on ground motions generated by a 500-year event, corresponding to a 10% chance of exceedance in 50 years.

Once the structural members met the FEMA 302 and 1996 BOCA Code requirements, they were checked against the requirements of the NEHRP Guidelines for the Seismic Rehabilitation of Buildings (FEMA 273, October 1997) using a performance level of Immediate Occupancy. FEMA 302 distinguishes between deformation-controlled and force-controlled members and components. The procedure also employs an element demand modifier (m) that accounts for the expected ductility of the element at a selected performance level.

Office Building Structural Systems

EQE was challenged with delivering the structural design documents for an Immediate Occupancy performance level on an ultra-fast-track schedule within a structural construction budget only about 5% higher than a code-level design (Table 2). After a preliminary comparison of various structural systems using both reinforced concrete and structural steel schemes, a composite structural steel frame best met the project's objectives (Figure 2).

EQE selected eccentrically braced frames (EBFs) in two orthogonal directions to resist the earthquake and wind lateral forces (Figure 3). These EBFs act in conjunction with reinforced concrete floor diaphragms and collector beams. They were chosen to take advantage of their increased ductility and the associated reduction in seismic base shear. A seismic joint was painstakingly detailed through the building link to accommodate building movements and separate the buildings into two regular structures.

The gravity system for the buildings is a 3-1/4" lightweight concrete slab on a two-inch composite metal deck over composite steel beams. The steel beams were sprayed with fireproofing such that the floor system meets the two-hour assembly rating of UL D916. Steel columns transmit loads to spread footings or drilled piers bearing on rock.

The buildings were modeled separately on RamFrame, using appropriate factors to account for the FEMA 273 member design requirements and some 64 different load combinations. AISC Load & Resistance Factor Design (LRFD) was used throughout the project. EQE completed the structural steel mill order documents containing some 1400 tons of structural steel in only six weeks. Unity Health began occupying the buildings only 16 months after ground was broken.

Early Fabricator Involvement

The buildings' exterior cladding consists of brick masonry veneer backed up by metal studs and continuous "strip" windows. The spandrel beams carry the gravity weight of the window system and the masonry at each floor level with a maximum live load deflection criterion of 0.25". Due to erection speed, sequencing considerations and local construction practice, the design team decided against using the metal stud back-up to carry the masonry gravity dead load. EQE worked closely with the architect, contractor and fabricator very early in the design phase. Their goal was to devise an economical structural steel back-up system that could be repetitively

Beam web opening for duct.

There are several overlapping earthquake source zones that affect the St. Louis area (Figure 1). The Wabash Valley seismic zone has generated earthquakes having intensity values of 6 or greater and is thought by geoscientists to be capable of generating a magnitude 7.5 earthquake. The Southern Illinois seismic zone generated an earthquake of magnitude 5.5 in 1968. Although the geophysical mechanism causing earthquakes here is not well understood, seismicity is common and believed to be capable of generating a magnitude 6.5 event. The Ozark Mountain source zone consists of the St. Francois Mountains and the surrounding area. The exposed rock in this area, among the oldest in North America, has undergone extensive faulting and folding. Earthquakes still occur here, and most geoscientists believe this area is capable of generating a magnitude 6.5 earthquake.

The Commerce fault zone is located northwest of the New Madrid seismic zone. It trends southwest-northeast and extends from northeast Arkansas, through Missouri, across southern Illinois and into the Wabash Valley of southwest Indiana. Evidence of major faulting in this zone recently was found in the English Hills and Holly Ridge areas in southeast Missouri. The Commerce fault zone is believed capable of generating magnitude 7.5 earthquakes. The Eastern Tennessee seismic zone is the site of consistent low to moderate earthquake activity. This zone is related to the evolution of the ancient Appalachian Mountains and could be capable of generating a magnitude 7.5 earthquake. The Appalachian Foreland seismic zone is a transition area on the western flank of the Appalachian mountains. This zone could be capable of generating a magnitude 6.5 earthquake.

aWhile many earthquakes can be associated with the New Madrid and other seismic zones, many more also occur outside these zones. The locations of these events are random. A seismic mapping study, funded by the Federal Emergency Management Agency (FEMA), has concluded that a magnitude 5.5 earthquake can occur anywhere in the Central United States. This is background seismicity. At a recent meeting of geoscientists planning the 2001 edition of these seismic maps, most researchers agreed to increase the background seismicity of the central US, and some felt it could be as high as magnitude 7 or 7-1/2. That jury is still out.

fabricated in large sections, shipped to the site and quickly and accurately erected.

The system chosen was a channel ladder system (Figure 4). Vertical C6 channels, spaced 48″ o.c., were shop-welded to horizontal top and bottom C6s. The brick shelf angle was shop-attached to the bottom C6 by bolts in vertical slots.

"Once we got set up in the shop, the frames went very fast because of the repetition," said Roy Kinsey of Hammerts Iron Works, the AISC member fabricator for the project. The frames stacked easily for shipping. In the field, each ladder frame was hoisted and tacked to the floor edge plate in two places before the crane lines were detached. Then, without any crane time, each frame was aligned and plumbed and all vertical C6s welded off to the floor edge plate.

The top and bottom horizontal C6s were clipped to the columns for added stiffness, and light-gage metal studs were infilled between the vertical channels to handle out-of-plane wind loads. The brick shelf angle was aligned and field-welded to the ladder frame. All welding could be performed from the floor slab inside the building. For torsional stability where the purlins were parallel to the spandrel beams, angle-kickers were field-welded from the bottom of the spandrel beam to the top of the adjacent floor beam at approximately eight feet on center. When floor purlins framed into the spandrel beams, angles were field-welded to the bottom flange of the spandrel beam at each C6.

The erector reported no problems during construction. "We were able to keep well in front of the mason because the brick frames went up so fast," says McCarthy's project manager, John Heidbreder.

The large, column-free floor plates complicated the design. Since the floor-to-floor heights were fixed at the beginning of the project by local ordinance, web openings in some of the deeper girders had to accommodate mechanical duct trunk lines. Close coordination between EQE, the design/build mechanical contractor and the fabricator was required to properly size and locate the required openings (Figure 5). Using AISC's WebOpen computer software allowed many of the openings to be unreinforced while others were economically reinforced with only horizontal stiffener plates above and below the opening.

Eccentric braced frames.

Earthquake risk is inherent in all structures built in the central US. Unity Health had the foresight to recognize that risk to their new corporate headquarters and was receptive to engineering options available. By making a conscious decision to manage that risk through an enhanced level of performance-based seismic design, Unity Health's corporate operations will be only minimally affected by large, future earthquakes.

"I've heard it said that 'Earthquakes aren't a problem until you have one,'" said Unity Health's Terry Bader. "And with this enhanced design, we feel that we've taken a major step toward being ready."

John P. Miller is a Vice President at EQE International, St. Louis, MO. He served as Project Manager for the Unity Health project.

PROJECT TEAM

OWNER:
Unity Health

ARCHITECT:
ACI Boland, St. Louis

STRUCTURAL ENGINEER:
EQE International, St. Louis

GENERAL CONTRACTOR:
McCarthy, St. Louis

FABRICATOR:
Hammerts Iron Works, St. Louis

ERECTOR:
McCarthy, St. Louis

DETAILER:
Hammerts Iron Works, St. Louis

SOFTWARE:
RamFrame and WebOpen