Civil Engineering News

Seismic Engineering

Retrofit of Stadium Straddling Active Fault Moves Forward

The University of California at Berkeley has an unusual problem: its football stadium—California Memorial Stadium—straddles the active northern segment of the Hayward Fault, which could see an earthquake of magnitude 7.5. For this reason a seismic retrofit of the stadium, which was built in 1923, is currently in the final stages of design development. In addition to the shaking possible from a strong earthquake, the retrofit design addresses seismic creep (the incremental movement of the plates on either side of the fault that occurs continuously), as well as the possibility of a surface rupture along the fault during a seismic event.

According to David Friedman, S.E., a senior principal and chairman of the board of directors of San Francisco–based Forell/Elsesser Engineers, Inc., the fault is a strike slip "right lateral" fault, meaning that a viewer standing on one side of the fault would perceive the other side shifting to the right. The fault experiences up to 5 mm of total horizontal "creep" annually, the west side moving northward and the east side southward. Friedman says that a report produced by AMEC Geomatrix—which is based in Oakland, California, and served as the geologic and geotechnical consultant—revealed that during a large seismic event the ground along the fault could displace up to 6 ft horizontally and 1 to 2 ft vertically in a matter of seconds. "For those portions of the stadium that sit over the fault, the issue isn’t just intense ground shaking; it’s the fact that the fault can rupture and displace a significant amount," says Friedman, who directed a team of engineers that included principals Mason Walters, P.E., S.E., M.ASCE, and Rene Vignos, P.E., S.E., M.ASCE.
The University of California at Berkeley’s California Memorial Stadium, opposite, straddles the northern segment of the Hayward Fault, which could produce an earthquake of magnitude 7.5. For this reason, the entire interior of the stadium will be gutted and reconstructed, with emphasis given to new foundations and highly ductile shear walls.

The largest movements would be associated with a temblor of magnitude 7.5 with its epicenter along the northern segment of the fault. Such an event would match the largest ever recorded along the fault. Earthquakes of this magnitude have a mean return period of 1-40 years, and given that the most recent large earthquake along the Hayward Fault occurred in 1868, the likelihood of a large seismic event occurring along the fault is increasing, Friedman says.

The stadium is sited in a location known as Strawberry Canyon, which contains a steep slope created, in part, by the fault's movement. According to Friedman, the canyon was selected as the location for the stadium in the early 1920s by the architect, John Galen Howard, in part because the topography limited the amount of excavation and earthen fill that would be required. While the engineers at the time knew that there was a fault at the location, “they didn’t know what we know today about earthquakes—about earthquake forces and fault rupture mechanics,” Friedman says.

Because of the original topography, the oval stadium contains two types of structural systems, which are enclosed by a full-height perimeter wall along the stadium’s northern, western, and southern sides. The eastern half of the stadium is built into an area carved from the hillside, the seating built atop a concrete slab on grade. The western half of the bowl is a hybrid of a nonductile concrete frame and a sloping concrete slab. The slab is on a small man-made soil berm. The playing field is located on graded soil and is surrounded by the seating bowl.

Friedman notes that the precise line of the fault cannot be determined, although a fairly accurate determination of its location was recently made using trenching, borings, and geologic analysis methods. “A fault rupture won’t necessarily occur along a straight line and may not actually fracture exactly where we think it will,” he says. “There can be some meandering, especially where the fault is overlain by soil fill.”

Because of the creep that has been experienced since the stadium was constructed—approximately 4 in. in the horizontal plane—columns in the stadium have tilted, slabs have cracked and distorted, and walls have separated. “What was very interesting to us as we studied the building very closely was that creep and the [resulting] cracking and displacement of the columns were telling us pretty much exactly where the fault really wants to rupture,” Friedman says.

For the seismic retrofit, the perimeter wall of the stadium will be saved, but the entire interior of the stadium stands will be entirely removed to create a new space. A new grid foundation system containing intersecting grade beams connected to footings will be constructed, including a new foundation under the perimeter wall. Moreover, new concrete columns, floor beams, and raker beams will be used to re-create the seating bowl in this portion of the stadium. The lateral-force-resisting system for the building will be provided by radial and circumferential shear walls of concrete that has been reinforced in such a way as to improve its ductility.

The fault roughly bisects the stadium, extending north to south through both end zones and thereby splitting the playing field. “It goes through sections of elevated structure at each end, and we call those the surface rupture zones,” Friedman says. The solution creates two sections within the seating bowl, one at either end of the stadium atop the fault line. Each section will act as an independent building and will be framed by stiffening shear walls. “We are going to take these surface rupture zones and turn them into independently sliding blocks,” says Friedman, who adds that “we’re not using elaborate engineering materials or technologies; we’re using very basic, fundamental engineering principles here.”

The two surface rupture block areas

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The image contains a diagram labeled "Fault Rupture Model" with the following elements:

- California Memorial Stadium
- Hayward Fault Zone
- Scenario Fault Traces
- Student Athlete High Performance Center

The diagram illustrates the location of the stadium and the fault zone, showing the relationship between the two.
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will be separated from the rest of the stadium by 12 in. wide seismic joints extending upward through the entire superstructure as well as down through the foundation. The seismic joints are unusually large and will take the form of gaps topped with cover plates at the surface to protect the stadium's occupants. Friedman notes that the perimeter wall will be “sawcut” to purposely weaken it at the rupture blocks' seismic joints so that the perimeter wall will readily move in response to seismic creep. This will allow a controlled amount of damage to the wall within the zone of the seismic joint.

The fault rupture blocks will be situated on rigid mat foundations that may be as much as 48 in. thick. Beneath the mat foundations, each fault rupture block will be placed atop several sheets of polyethylene plastic to “separate it from the ground below to give it almost a sliding plane,” Friedman explains. “It's not trying to isolate it, as with base isolation. We're just trying to give it a definitive sliding plane.”

The sliding plane will enable the blocks to move with the seismic creep experienced along the fault line while forcing the stadium to behave in a prescribed manner during a seismic event. As the blocks twist during a surface rupture, “those twelve inch joints will probably open up, as opposed to close down,” Friedman notes. However, if such an impact occurs, it would be “a glancing blow,” he notes, and should not create any safety issues for the occupants. Depending on the vertical displacement experienced in the seismic event, the blocks might also tilt slightly.

The western and eastern portions of the stadium will experience only the strong shaking associated with being located near a fault, not the surface rupture that will occur along the fault line. “What we've learned from earthquakes in the last ten or fifteen years is that when you're perpendicular to the fault and close to the fault, there can be a significant amplification or even a pulse effect,” Friedman says. “And we do design buildings that are within a kilometer or two of the fault for these higher seismic forces,” he notes. However, he adds, “if you're a foot away or a kilometer away, it's essentially the same heightened design force.”

The guiding principle of the design has been to ensure the safety of the stadium's occupants, Friedman says. The design is “more than life safe.” As he puts it, “The engineering team at Forell/Elsesser is more than willing to buy season tickets in the fault rupture zones.”

Work on the stadium site has also included the development of a new athletic center that will be open to all students. Currently under construction adjacent to the stadium, the center is designed with ductile shear walls of reinforced concrete and will have two seismic joints along its nearly 900 ft length.

Although the new building is adjacent to the stadium, it has been designed to be structurally independent and is sited away from the fault line, a fact confirmed by numerous exploratory trenches dug in the area surrounding the stadium.

The building's roof will be planted with 15 trees and will serve as a plaza for the stadium. The planters for the trees are embedded within the building; a soil-filled gap for the tree roots will be located between the exterior topping slab and a waterproof surface that tops the structural system of the building. Geometrically, the athletic center was a complicated building to design because its crescent shape and warped plaza surfaces required that a radial grid be used for the columns, Friedman says. For this reason, the engineering firm used the project as a challenging test for its first building information modeling (BIM) design.

The new athletic facility is expected to be complete by September 2011 and will provide more than 500,000 sq ft of space for use as a sports, health, and fitness center for the university.

The design development phase of the stadium's seismic retrofit project has just concluded. Forell/Elsesser anticipates that the contract documents phase will be completed this summer and that demolition within the stadium will begin in the early fall. Full demolition and construction will commence in January 2011.

—CATHERINE A. CARDNO, PH.D.