# FUTURE HOSPITAL DESIGN:

# FOCUSING ON PERFORMANCE

## Hospitals in seismic areas are now being designed not just to survive an earthquake, but also to remain fully operational during and after a seismic event

Steel frames and column bays of the VA Palo Alto Replacement Hospital

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A COMMON MISCONCEPTION OF THE GENERAL PUBLIC is that a structure built to the current building code is "earthquake-proof." In reality, the seismic provisions in today's building codes strive mainly to protect occupants from severe injury or death during a strong earthquake, not to prevent building damage. One area, however, in which steps have been taken to reduce building damage and improve functionality is in the design of hospitals. Ever since the 1971 San Fernando earthquake in California, when some hospitals were heavily damaged and required immediate evacuation, the public has insisted that steps be taken to keep hospitals and other essential facilities operational after an earthquake. To limit damage to these types of structures, engineers and public policy makers have enacted increasingly tougher criteria for emergency facilities over the past 25 years.

Instead of relying only on increased design lateral forces, some engineers are turning to the concept of performance-based design to increase the certainty that hospitals will be operational after a major earthquake. This idea, recently discussed in Vision 2000, an outline for future codes written by the Structural Engineers Association of California, would allow any structure to be predictably designed for any performance objective. Although future building codes are starting to implement these performance-based concepts today, engineering judgement and expertise must always be exercised to optimize the design.

Degenkolb Engineers, a consulting structural engineering firm with offices in San Francisco, Los Angeles and Portland, has recently designed several hospital projects that exemplify this focus on total building performance. Although constructed for different clients and utilizing different structural solutions, the following two examples illustrate how stringent code provisions coupled with expertise in structural engineering can be used to design buildings for improved earthquake performance.

*Top: The perimeter cladding system of the VA Palo Alto Replacement Hospital.*
*Above: Artist's drawing of the final VA Palo Alto Replacement Hospital.*

## VA PALO ALTO REPLACEMENT HOSPITAL

After its main hospital was heavily damaged in the 1989 Loma Prieta earthquake, the VA Medical Center in Palo Alto, California, decided to replace the existing structure with a new facility that would not only withstand the next big earthquake but would remain operational afterward. The result was a new state-of-the-art, 500,000-sq.-ft. hospital completed last year. This steel-framed building is four stories above grade with a partial basement and contains more than 5,000 tons of structural steel. It was designed by the Ratcliff Architects of Emeryville, California and Stone Marraccini Patterson of San Francisco. The general contractor was Turner Construction of San Francisco and the steel contractor was Gayle Manufacturing of Woodland, California.

The new building was designed using one of the world's strictest seismic criteria, H-08-8: Earthquake Resistant Requirements for VA Facilities. This document was developed shortly after the collapse of a VA hospital during the 1971 San Fernando earthquake and was last updated in 1986. The performance objective for the replacement hospital was to remain operational after a major earthquake. Because the Palo Alto site is within 10 miles of the San Andreas Fault, the expected level of shaking during a future earthquake is very large. This combination of an operational performance objective and large design groundmotions required that critical decisions about the building's intended performance be made at every step of the design process.

One of the most important early performance decisions made by Degenkolb and the design team was the choice of lateral force resisting systems. Although the VA favored moment-resisting frames for ultimate future planning flexibility, the system was quickly ruled out not only by the requirements of H-08-8 but also by the team's desire to limit the amount of drift-induced nonstructural damage. Concrete shear walls were eliminated because of restrictive functional concerns and for their increased construction costs relative to steel frames.

"We wanted a lateral system that would provide sufficient ductility, toughness and redundancy to resist the large expected groundmotions expected at the site," said Jim Malley, Senior Principal and project manager for the VA Palo Alto project. "The answer we finally came up with was to use a dual system of steel eccentrically-braced frames (EBF) with a full back-up steel moment frame." Eccentrically braced frames utilize a discrete zone called a "link" to concentrate structural damage in a controlled area and to dissipate energy. The addition of moment-resisting frames in both directions creates lines of resistance at every column line, which back up the braced frames during a very large seismic event.

Decisions regarding the building configuration were also made with the ultimate seismic performance of the building in mind. As these critical decisions occurred early in the design process, they required close cooperation and coordination with the architect and planning teams on the project. In this case, all column bays were made the same dimension in both directions and were laid out to optimize both the EBF and moment frames as well as the hospital programming requirements. Braced frames were located throughout the perimeter and core of the structure in a regular, symmetric arrangement that minimized their impact on hospital functions. All the braced frames, 28 total in each direction, were continuous from roof to foundation with no offsets or setbacks in any of the frames.

Hundreds of smaller decisions were also critical to ensuring the building's overall seismic performance. Two such important details included the elevator guide rail support tubes and the perimeter cladding connections. In an effort to keep the plan as open as possible, EBF frames were located at the perimeter of the building and at the building core. These locations happened to coincide with the elevator tube supports and the precast panel connections. The calculated movement of each EBF link during the design earthquake was about four vertical inches over a four-foot length. The elevator

*Top: Elevation of the Davis Wing—the distributed moment frame with W36 columns and W30 girders*
*Above: The façade of the Davis Wing, front elevation, nears completion.*

supports and precast panels could not be attached directly to the link because they could not accommodate this much movement. If connections in this area were not designed properly, the elevators might possibly be rendered inoperable or a precast panel might detach from the building. Consequently, the team developed special details that allowed the link to move during an earthquake without adversely affecting the elevators or cladding connections.

The team also devoted time to ensuring that the nonstructural systems would remain in operation after a major earthquake. It is important to illustrate the proper design, anchorage and bracing of cladding, equipment, piping, ductwork, ceilings and elevators in the contract documents since this work is often left to the contractor to design and install. For the VA project, the team developed additional specifications that addressed the bracing of many of the nonstructural components. Because of the potential for large groundmotions due to near-field effects, the importance factor used for nonstructural equipment was 2.0 instead of 1.5, the typical factor for hospitals in California. The team relied on the details contained in the National Uniform Seismic Installation Guidelines (NUSIG) handbook for pipe and duct bracing and required shop drawings, submittals and calculations for all other types of proprietary bracing systems.

The use of a dual structural system is obviously not appropriate for non-critical building types. But in this case, where it was essential that the building remain fully operational during and after an earthquake, it made sense to spend the extra money.

### U.C. DAVIS MEDICAL CENTER, DAVIS WING

The U.C. Davis Medical Center Davis Wing project is a 13-story (plus basement), 400,000-sq.-ft. building which, when complete in July of 1998, will house one of the Sacramento area's finest hospital facilities. The architect for the project is Hammel Green and Abrahamson of Minneapolis. The general contractor is Centex Rodgers of San Diego. Gayle Manufacturing of Woodland, California fabricated and erected the more than 6,000 tons of structural steel on the job.

This hospital falls under the jurisdiction of Title 24 of the California Building Code, which requires the new wing to be designed for 1.5 times the seismic force level for typical buildings in the Uniform Building Code. Degenkolb implemented numerous other provisions in the design, and worked beyond the basic code, to help increase the assurance of hospital functionality after a major earthquake. For example, after the owner, architect and engineer agreed on a steel moment-resisting frame to allow maximum planning flexibility, a strict drift limit of 50 percent of the code allowable drift was utilized to limit damage to nonstructural components.

As with VA Palo Alto, the structural system for the Davis Wing was laid out with performance in mind from the earliest stages of design. As a result, the team chose to reject irregular plan shapes — such as those with large projecting wings or with weak stories at the ground floor — because they often concentrate damage at critical locations.

"We wanted to stay away from irregularities which have been known to cause problems in structures during earthquake events," said Maryann Phipps, Principal at Degenkolb Engineers and structural engineer of record for the project. "At the same time, we wanted to develop a regular and redundant structural core that did not limit architectural design opportunities. The team was free to create architectural forms outside the structural grid providing a highly distinctive look for the center."

The final moment frame layout used for the Davis Wing consisted of W36 columns at 16'-6" on center at the perimeter of the structure with W30 girders between columns. This allowed the interior of the structure to have columns at 33' on center, providing large open spaces for hospital use. The moment-frames run uninterrupted from the roof to the foundation. A 4'-thick concrete mat foundation was designed to support the large column loads from the tower and to minimize settlement of the supporting soil.

The 1994 Northridge earthquake occurred after the design for the Davis Wing was complete and under review by the Office of Statewide Health Planning and Development (OSHPD). Because of the earthquake damage to steel moment-frame connections observed in some buildings, the viability of the steel moment-frame system came under close scrutiny by the engineering community. Knowing that such a discovery could jeopardize the schedule and budget for the Davis Wing project, Degenkolb undertook a sophisticated non-linear analysis of the building to examine the expected demands on the frame members and connections. The results of the non-linear analysis showed that because the building had been designed for increased seismic forces, stricter drift criteria, and with a regular structural system, there should be no connection fractures and only minimal yielding in the panel zone of some beam-column joints during the design level earthquake.

Degenkolb also incorporated many other precautions to improve building performance. Every welder who would be making a beam-column connection was required to pass a qualification test that went far beyond what is typically mandated by the industry. The test simulated field conditions and required welders to weld in the awkward positions that they often face on the job. After each test was com-

*Top: Front elevation of the Davis Wing showing the more than 6,000 tons of structural steel near completion of erection*

*Above: Rear elevation of the Davis Wing façade nears completion*

pleted, the weld samples were bend-tested and also v-notch tested for weld toughness. Welders who did not pass these rigorous checks were not allowed to weld critical joints. Additionally, the structural specifications were modified to require that weld materials and processes be designed to meet strict toughness criteria: 20 foot-pounds at minus 20 degrees-Fahrenheit. Steel backing bars were also removed from bottom-flange, complete-penetration welds, the root pass was back-gouged, and the area reinforced with an additional fillet weld. The top flange connection was also modified by the addition of reinforcing fillet welds at the backing bar and run off tabs for all welds were removed and ground smooth. These steps, although increasing the cost of welding, allowed the structural system, steel tonnage and schedule to remain virtually unchanged.

One of the important concepts in performance-based design is that the best designs are worth little if not properly executed during construction. For this reason, Degenkolb worked closely with the owner to select a testing and inspection firm that could optimize the integrity of the design. (This type of prequalification of contractors also can be obtained by including a requirement for AISC Quality Certification and Erector Certification in bid documents.)

"We spent considerable time working with the testing lab and contractor to be sure that the drawings and specifications were fully understood and executed as specified," said Jorn Halle, Associate and assistant project manager for the Davis Wing. "Active cooperation between the engineer, owner, contractor and testing lab allowed for construction to proceed on schedule and with less than 0.5 percent in structural change orders relative to the total construction cost."

## CONCLUSIONS

These projects illustrate how improved code provisions and expert structural engineering can be combined to create designs that perform well beyond the minimum criteria of the basic code. By focusing on total performance, building designers can more reliably construct hospitals that the public can count on to be functional immediately after a major earthquake.

But the benefits of performance-based design go beyond just building better hospitals. Performance-based design also allows engineers to develop reliable standards above the minimum level established by current building codes for all types of structures and occupancies. In the future, an owner will have a broader range of performance design levels from which to choose: to protect a building and its occupants, or to prevent loss due to business interruption. Projects such as the VA Palo Alto Replacement Hospital and the Davis Wing of the U.C. Davis Medical Center are helping to define that future.

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