Strong Medicine

By Douglas R. Wilson, P.E., Russell D. Kent, P.E., Stephen Stanek, P.E., and David B. Swanson, P.E., S.E.

A much-needed seismic retrofit is just what the doctor ordered for this aging naval hospital serving thousands on Washington's Puget Sound.

Naval Hospital Bremerton, in Bremerton, WA, serves 60,000 military families in the Puget Sound area. Located near Seattle, it is only one of two major hospitals on Washington's Kitsap Peninsula. In the aftermath of a serious natural disaster, like a large-scale earthquake, the hospital could be called on to immediately serve more than 250,000 people.

First Step

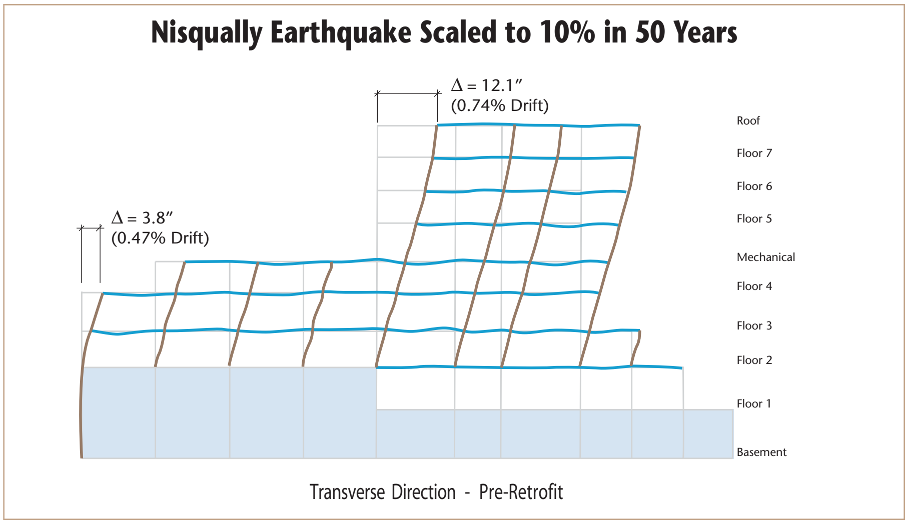
The hospital complex includes more than 20 buildings, some of which were constructed as early as the 1930s. The US Navy wanted to know the seismic risk of the Bremerton medical facility, and how best to go about mitigating that risk. Starting in 1999, structural engineers from Reid Middleton embarked on a series of seismic screenings and evaluations of the various naval hospital facilities to systematically determine seismic deficiencies.

The first step was to understand the extent and type of seismic structural hazards and evaluate the risk based on building type, use, and occupancy. FEMA 154 – *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook* techniques were employed to screen and document initial findings. This effort provided the US Navy and the design team with a "big picture" overview of the building stock and seismic hazards, as well as an initial relative ranking of seismic risk among the facilities. It was an exceptional tool to prioritize further work for investigating in more detail those facilities with the highest risk.

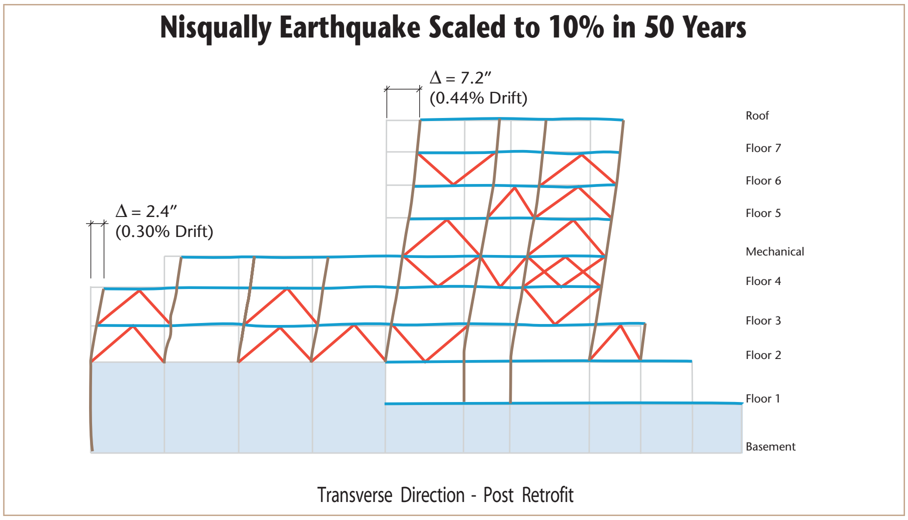
One of the high-risk buildings was the late 1960s-era main hospital building—a nine story, 250,000 sq ft. structure with a structural steel moment frame, composite concrete on metal deck floors, precast concrete cladding, and concrete stair towers. The main hospital building did not have the worst hazard score. However, the structure is significantly larger than any of the other medical buildings in the complex and is home to the most essential medical functions.

Recommendation

A detailed seismic evaluation of the hospital using performance-based engineering standards (FEMA 310 – *Handbook for the Seismic Evaluation of Buildings–A Prestandard* and FEMA 356 – *Prestandard and Commentary for the Seismic Rehabilitation of Buildings*) was performed to gain a better understanding of the potential seismic deficiencies.



In its pre-retrofit state, the hospital's story drifts could be significant.



The seismic retrofit significantly reduces story drifts. It will also reduce floor accelerations by about ⅓ for all floors.

The building's lateral force resisting system (LFRS) is comprised of a highly redundant steel moment frames system at all beam-to-column connections. With more than 1,200 moment connections, the LFRS has a large amount of redundancy. However, it is too flexible, resulting in excessive drift, large torsional response of the narrow tower, high expected rotational demands, and forces on the "pre-Northridge" 1960s-era moment frame connections.

Additionally, there was incompatibility between the flexible LFRS and the rigid concrete stair. The cladding panel connections were not designed to accommodate the expected drifts from a design-level earthquake and presented a potential falling hazard for the building exit paths. Excessive drifts also caused some of the building columns to be overstressed in axial load, combined with biaxial bending.

This detailed seismic evaluation was completed in late 2000 and recommended a comprehensive seismic retrofit of the hospital.

Mother Nature Steps In

In February 2001, the magnitude 6.8 Nisqually Earthquake shook the Puget Sound area. Shaking at the hospital was modest because of the earthquake's depth, and because its epicenter was located approximately 30 miles away. A seismograph in the hospital recorded a horizontal peak ground acceleration of 0.11g at the basement level and a peak roof acceleration of 0.47g. The hospital structure experienced significant lateral drifts during the small, "less than design-level" earthquake, particularly on the upper floors of the tower. Calculated peak roof displacements from this modest earthquake shaking were over 6″ (a drift ratio of 0.5%). The movement caused a significant amount of damage to non-structural features and finishes in the hospital—especially at upper floors.

It could have been much worse. If a design level earthquake had struck Puget Sound, roof displacements of the nine-story hospital could have been several feet, resulting in much more significant damage and loss of hospital function.

Approximately six hours after the earthquake, the facilities staff had performed rapid inspections of the hospital, and enough information had been collected and analyzed to allow the hospital be reopened for further operations. It took several days for Reid Middleton to complete detailed inspections. It took several months for all of the earthquake repairs to be made and for the building to be restored to full use.

Because the main hospital was constructed in the late 1960s with pre-Northridge steel moment frame connections, a detailed inspection and testing program in accordance with the FEMA 350 series standards was undertaken to investigate whether the earthquake had damaged the moment frame connections. Thirty of the approximately 1,550 moment connections were exposed and visually inspected for damage. Several of these connections were also inspected using non-destructive ultrasonic and magnetic particle test procedures to increase the likelihood of finding damage not identified by visual inspection. Of the 30 connections inspected, no damage (significant cracks or fractures) related to the modest earthquake shaking was observed.

Performance-Based Design

Because a traditional seismic retrofit by strengthening and stiffening the moment frame LFRS would have been costly and disruptive, alternative retrofit design schemes were evaluated. The use of supplemental seismic damping proved to be the best design scheme to improve the seismic performance of the 30-plus-year-old building while minimizing disruption during construction.

The purpose of supplemental passive damping is to reduce lateral displacement of the building through benign dissipation of the earthquake's energy through heat created in the damper system. One of the challenges of seismic

Mock-ups of the dampers were used at various locations in the hospital to gauge the aesthetic and operational impact of damper locations.

retrofit projects is “not making things worse.” Retrofits can potentially alter the original load paths, causing members to carry loads they were not originally designed for.

The passive damping mechanism supplements the existing LFRS. It is a permanent installation that remains in place and is functional for the life of the structure, even following a seismic event. Through energy dissipation, dampers significantly reduce the seismic forces, displacements, and floor accelerations in the structure, thus reducing or eliminating earthquake damage to the building’s primary structural system and many of the non-structural systems.

Supplemental seismic damping was designed to be installed at discreet locations throughout the main hospital building. Because the seismic damping system is passive and supplemental, it does not appreciably change the fundamental LFRS response for wind loading in the building.

One benefit of this damping system is the ability to shift damper locations from floor to floor to avoid extremely sensitive areas of the hospital. Also, shifting damper locations reduces the demands placed on the existing building columns, compared to a traditional retrofit where the lateral elements are stacked from floor to floor.

Analysis

State-of-the-art 3D nonlinear finite element analyses were used in the design of the hospital seismic retrofit. Target performance levels are “Immediate Occupancy” for the 10%/50 year Design Basis Earthquake (DBE) and “Collapse Prevention” for the 2%/50 year Maximum Considered Earthquake (MCE).

Because the design team had an actual record of the building’s roof, fifth floor, and basement responses to the Nisqually Earthquake, the geotechnical engineer was able to “tune” his site-specific ground response study to the characteristics of the site and building. This response record provided the design team with a benchmark response, and the owner with a clear understanding of future building performance.

Slated for construction in 2005, a total of 88 seismic dampers will be installed at 44 select locations in the building. Each damper has a 200 to 300 kip capacity with a ±3” stroke. Some of the dampers will be left exposed to the view of patients and staff, while others will be concealed in existing wall cavities and by new finishes. The installation of seismic dampers is an effective means to seismically retrofit essential facilities like Naval Hospital Bremerton to improve their earthquake performance and post-earthquake functionality.

Cost

The estimated replacement cost of the main hospital is $60 million, while the estimated cost of a seismic retrofit is $4 million. Because the existing building is expected to support the hospital’s mission for at least 30 years, investment in earthquake performance improvements just made sense.

Results

The retrofit will have significant impact on the building’s behavior:

- Story drifts and floor accelerations reduced by approximately 30% at all floors
- Damped response for a 2,500-year event reduced to the same magnitude as the response of the un-retrofitted building to a 500-year event
- Diaphragm rotations reduced by 30% to 70% at all levels

The use of fluid viscous dampers, along with performance-based design, provides a solution that is cost effective and, just as importantly, has the flexibility to minimize the impact of construction on essential hospital operations. The project will breathe life back into the building for a cost in line with other upgrades to the facility. ★

Douglas Wilson is a project engineer for Reid Middleton, Inc.’s Structural Engineering Group. Russell Kent is facility manager for Naval Hospital Bremerton. Stephen Stanek is a project lead with Engineering Field Activity Northwest. David Swanson is director of Reid Middleton, Inc.’s Structural Engineering Group.

Owner
US Navy

Architect
CollinsWoerman, Bellevue, WA

Structural Engineer/Prime Consultant
Reid Middleton, Inc., Everett, WA

Engineering Software
ETABS