Seismic Upgrade of a One-Story Pre-Northridge Moment Frame Hospital Building by Attaching Its Roof Diaphragm to a Newly Constructed Concrete Shear Wall Building with Friction Dampers

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Abstract

The addition of new catheterization and interventional radiology (CATH/IR) labs to the existing 1991 emergency department (ED) building at St. Francis Hospital, located in the greater Seattle area, triggered a mandatory seismic retrofit of the 1991 ED building. The existing 1991 ED building is a one-story steel-framed structure with a pre-Northridge moment frame lateral force resisting system.

The seismic retrofit of the 1991 ED building utilized a unique approach by attaching the 1991 ED building to the adjacent 2007 intensive care unit (ICU) building with friction dampers. The 2007 ICU building has a concrete shear wall lateral force resisting system and was built over the top of and encompasses the entire 1991 ED building. The space between the original roof of the 1991 ED building and the first elevated floor of the 2007 ICU addition currently serves as a mechanical, electrical, and plumbing (MEP) interstitial/mezzanine floor which provided the construction access to install the friction dampers. This retrofit approach allowed the upgraded 1991 ED building to achieve an immediate occupancy (IO) structural performance level, was extremely cost efficient when compared to conventional seismic upgrade approaches, and allowed the 1991 ED building to remain fully operational during construction.

This paper presents the design approach used for the seismic retrofit as well as construction photos of the completed seismic retrofit.

Background

St. Francis Hospital is located at 34515 9th Avenue South in Federal Way, WA, which is about 30 minutes south of Seattle. The hospital campus consists of the original steel framed hospital building constructed in 1985, a steel framed ED expansion in 1991, the steel framed ambulatory services building constructed in 2001, a steel framed central plant expansion built in 2006, and a steel framed ICU addition and constructed in 2007, see Figure 1.
As can be seen in Figures 1 and 2, the 2007 ICU addition is built on top of and completely encompasses the entire 1991 ED building as well as a portion of the original hospital building. The gravity framing for the 2007 ICU addition consists of long-span steel trusses which span between the exterior concrete walls and selectively located interior column locations. The exterior concrete walls provide the lateral force resisting system for the building. The space between the original roofs of the 1991 ED and the 1985 original hospital buildings and the first elevated floor of the 2007 ICU addition currently serves as a mechanical, electrical, and plumbing (MEP) interstitial space and mezzanine floor. The 2007 ICU building was seismically isolated from the 1991 ED building through the use of horizontal seismic joints in the exterior walls at the interstitial floor level and almost all of the exterior walls were hung from the 2007 ICU building above. It is likely that when the 2007 ICU building was constructed it was known that there were some potential seismic deficiencies in the 1991 ED building, however, no efforts were made to evaluate and retrofit the 1991 ED building at that time.

As part of the hospital campus master planning effort, the lead author of this paper performed a seismic evaluation of the entire inventory of buildings in 2013. During this evaluation several seismic deficiencies were noted with the 1991 ED building due to its lateral force resisting system which consisted of pre-Northridge steel moment frame connections. The deficiencies were as follows:

- The strength of the columns relative to the beams (strong column/weak beam condition) was inadequate.
- The moment frame members did not meet the minimum compactness requirements.
- The bottom flanges of the moment frame beams were not braced out-of-plane.
- The strength of the moment-resisting connections was inadequate to develop the strength of the adjoining members.
- The anchorage of the steel moment frame columns to the foundation was inadequate.
- The width of seismic joints between the 1991 ED building and the shear walls of the 2007 ICU building as well as the 1985 original hospital buildings were insufficient, which would result in building pounding during a seismic event. The pounding to the side of the three story tall shear walls of the 2007 ICU building could result in building collapse.

In 2016, the lead author of this paper was selected to be the structural consultant for a proposed tenant improvement and expansion of the CATH/IR lab located within the 1991 ED building. While the footprint of this CATH/IR expansion was relatively small it triggered a required seismic upgrade of the 1991 ED building due to the following reasons:

1. Previous expansions to the 1991 ED building which occurred in 2007 as well as the proposed CATH/IR expansion had increased the seismic demand forces on the main lateral-force resisting system by more than the code allowance of 10%.
2. Excessive building seismic drift would have resulted in pounding against the adjacent buildings. The pounding against the shear walls of the 2007 ICU building could result in its total collapse.
3. New medical equipment which was very expensive would be housed in the new CATH/IR expansion which substantially extended the useful physical and economic life of the building.

Retrofit Approaches

Several different approaches were considered for the seismic retrofit of the 1991 ED building which are summarized as follows:

Option 1 - Retrofit Moment Frame Connections
The option of retrofitting the existing moment frame connections to provide additional strength and ductility proved to be unfeasible because the existing steel moment frame members were not proportioned to comply with the strong column/weak beam provisions. In addition, the construction access required to strengthen the existing moment resisting connections would have had substantial impacts on the emergency department operations during construction.

Option 2 - Provide Rigid Connection to the 2007 ICU Building
The option of rigidly connecting the 1991 ED building to the 2007 ICU building's concrete shear walls was explored, however, the connection forces that were required were very large and would have been difficult to implement, so additional options were explored.

Option 3 - Provide Friction Dampers at Connection to 2007 ICU Building
The seismic retrofit option that was chosen for this project utilized a unique approach by attaching the 1991 ED building to the adjacent 2007 ICU building's concrete shear walls with friction dampers. The interstitial space between the original roof of the 1991 ED building and the first elevated floor of the 2007 ICU addition provided the construction access to allow new horizontal trusses to be constructed just above the roof of the 1991 ED building. These horizontal trusses were then connected to the 1991 ED building moment frame columns which had been extended above the original 1991 ED building roof level with new HSS columns. The horizontal trusses were then connected to the 2007 ICU building's concrete shear walls with new friction dampers. This retrofit approach allowed the upgraded 1991 ED building to achieve an immediate occupancy structural performance level, was extremely cost efficient when compared to conventional seismic upgrade approaches, and allowed the 1991 ED building to remain fully operational during construction.
Retrofit Design Approach

The seismic demand was based on the unreduced maximum considered event (MCE) for the project area with a 10% probability of being exceedance in 50 years. The purpose of the friction dampers was to keep the moment frame members in the 1991 ED building within the elastic range. The moment frame column sections in the 1991 ED building are W14x84's and the moment frame beam sections are heavy W24s. Due to the pre-Northridge style connections the columns will yield at the joint prior to any other elements in the system, especially considering the frame sizes, see Figure 5. Thus, for the structure to remain in the elastic range with MCE forces, the columns had to remain in the elastic moment range. To maintain elastic level forces within the columns the drift had to be limited to a maximum of 2.4 in., or 1.5% drift.

For calculating friction damping properties, a simplified Capacity Spectrum Method approach was taken, following ATC-40 Section 8.2 recommendations. Using the linear ETABS model, the 1st mode period in each fundamental direction was calculated. Knowing the mass of the roof structure, a fixed stiffness was calculated in each fundamental direction. The MCE Response Spectrum was then converted to a Base Shear vs Displacement Response Spectra format which allowed both the demand curve and capacity curve to be plotted on the same graph, see Figure 6. Using a visual trial-and-error approach, the damper slip force was modified until the performance point intersected with both demand and capacity curves, see Figure 7.

In order to calculate $\beta_{\text{eff}}$, the effective viscous damping, a $\kappa$ factor is multiplied by $\beta_0$, the hysteretic damping previously found, and that product is added to 5, as shown in Figure 8. $\kappa$ is a measure of the extent to which the building hysteresis is represented by the parallelogram shown in the calculation for $E_D$. 

![Figure 6 - Demand Curve and Capacity Curve](image)

![Figure 7 - Trial & Error Design Approach Summary](image)
After the damper slip force was determined the horizontal truss frames, the moment frame column extensions and the damper connections to the concrete shear walls were designed for this slip force. For simplicity of the design and construction all dampers were designed and fabricated for the same slip force. The concrete shear walls and foundations were then checked for the additional seismic forces that were being applied to them and were found to have adequate capacity for the relatively small amount of additional load. Finally, the existing moment frame beams were checked as drag struts for the loads from the horizontal truss frames and were found to be adequate as well.

**Time History Analysis Validation**

A time history analysis was used to validate the design using the simplified method. A pair of ground motion time histories in the greater Seattle area with similar geotechnical conditions were utilized for the validation. The results are shown in Figures 9 and 10. As one can see, although the building was treated as a single degree of freedom structure without consideration of diaphragm torsional rotations and only one size of friction damper was used to simplify the damper design and fabrication, the simplified method is not only reasonable but also practical. More pairs of ground motion time histories would likely provide the same result.
Design Details

The following figures, Figures 11 and 12, are examples of the damper connection and horizontal truss frame connection details.

**Figure 11 - Column Extension Details**

**Figure 12 - Damper Connection Details**

Construction

The contractor for this project, Sellen Construction, was able to keep the 1991 ED building fully operational during construction by phasing the construction activities appropriately. The steel framing and wall enclosures for the new CATH/IR lab addition were fully completed before the existing exterior wall of the 1991 building was removed. This meant that the horizontal trusses and damper connections in that area could not be completed until the first phase of work was completed. It also required some creative diaphragm shear connections to tie the roof of the new CATH/IR addition to the roof of the existing 1991 ED building. Horizontal steel plates were used to attach the new steel beams in the CATH/IR lab to the existing steel beams from the 1991 ED building, however, the plates had to be sized and spaced to fit between the existing cold-formed steel wall framing, in order to maintain the existing enclosure integrity during the first phase of construction.

The first phase of construction as well as the erection of the new steel framing for the seismic retrofit is now complete. The following are photos of the final damper connections and horizontal truss frames.
Conclusions

This paper presented a unique design solution for the seismic retrofit of a hospital emergency department building with pre-Northridge steel moment frame connections by attaching its roof diaphragm to an adjacent concrete shear wall structure with friction dampers. The retrofitted building achieves a structural immediate occupancy performance level under MCE level forces for a 10% in 50 year seismic event. The main advantages of this retrofit approach are that it was extremely cost efficient when compared to conventional seismic retrofit approaches and that it allowed the 1991 ED building to remain fully operational during construction.

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References
