Seismic Retrofit of A Reinforced Concrete Hospital Building in the Eastern US

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ABSTRACT

This poster presents the results of a retrofit analysis of a non-ductile reinforced concrete hospital building in the eastern US. The seismic evaluation is carried out using a SAP2000 model by following FEMA 356 and NEHRP 2000 specifications. Four retrofit schemes: reinforced concrete jackets, reinforced concrete shear walls (RCSW), steel braces, and steel plate shear walls (SPSW) are separately applied on the original structure and seismic performance of each retrofitted structure is compared with that of the original structure.

BACKGROUND

Acute care facilities such as hospitals are expected to continue operational and functional or to meet performance objectives of “immediate occupancy” after a major natural hazard event such as earthquake or strong storm. In most of the eastern US area such as New York State, earthquake design was not considered until 1990, which left many hospital buildings vulnerable to seismic hazard, even though they are located at a low to moderate seismic hazard zone.

OBJECTIVES

- Evaluate seismic performance of existing hospital building in New York State
- Analyze the structure under what-if (retrofitted) condition, test efficiency of various retrofit techniques
- Connect engineering demands with damage state of non-structural system and effect of hospital operation. Therefore, give better presentation of seismic performance under different scenarios (original, retrofitted with different measures) to policy maker, hospital owner etc.

METHODS & RESULTS

- **Building Description & Structural Modeling:**

The hospital building was constructed in 1967. It is composed of a 4 story reinforced concrete frame main building occupied about 254.3ft in north-south direction and 87ft in east-west direction and a 1 story reinforced concrete frame plaza occupied 100ft in both directions. The height of main building is 78ft from ground level to roof including penthouse.

The lateral force resisting frame is comprised of beam-column moment resisting frames in N-S direction, slab-column frames in E-W direction. Additional gravity load of each floor was calculated by a review of architecture and structural drawing. A 3D beam element finite element model of the hospital structure is developed in SAP 2000 environment. Behavior of the original and retrofitted buildings was evaluated by 3D elastic dynamic and inelastic static pushover analysis.

- **Analysis of Original Building:**

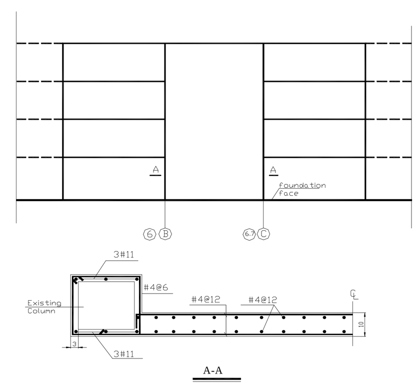
The design ground motions developed by MCEER researchers are used for linear time history analysis. The maximum inter-story drift ratio, i.e. inter-story drift normalized by story height, under each ground motion are 0.33%, 0.43% and 0.78% respectively. All are less than the drift limit per NEHRP2000 which is 1.0%.

Components were checked under load combinations per ACI318. For columns, there are 13 columns in which design shear force developed by the combination of earthquake load and gravity load is larger than the shear strength. The average value of demand/capacity ratio (DCR) is 1.56 for the overstressed column under shear. There are 19 columns in which longitudinal reinforcements are not enough to resist the interaction under the axial and bidirectional moment load (P-MM interaction). The average value of DCR is 1.30 for the overstressed column under P-MM load.

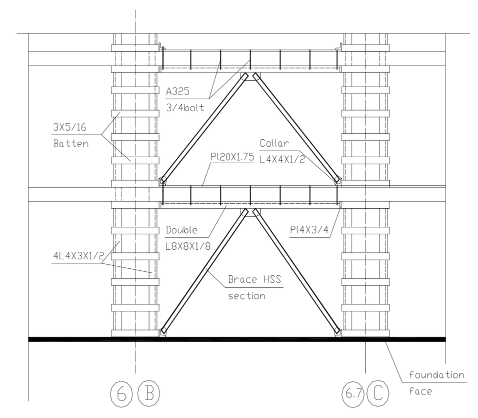
Plastic hinge rotations in components under target displacement were checked by push-over analysis. For some columns in Y(E-W) direction, maximum rotation of plastic hinge is larger than the rotation capacity. The maximum one is even almost two times of its rotation capacity.

- **Analysis of Retrofitted Structure:**
  - **Retrofit schemes:**

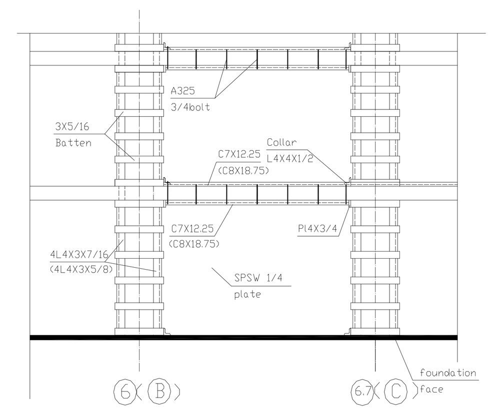
  Four retrofit schemes are evaluated, which include one local modification (adding 3” thick with #4@9in hooks as transverse confinement reinforced concrete jackets) and three global retrofits (i.e. adding 10 inch thick with #4@12X12 double sides double directions reinforced concrete shear walls (RCSW), adding invert “V” pattern HSS section steel braces, and adding 1/4in thick A36 steel plate shear walls (SPSW)). The vertical view of the retrofitted frames are illustrated in following figure.



RC Shear wall



Steel Braces



Steel Plate Shear Wall

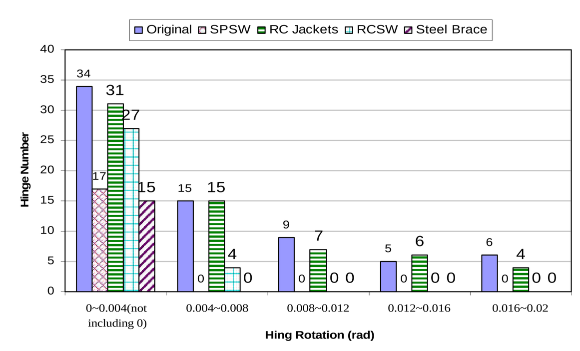
- **Performance of retrofitted structures:**

The maximum inter-story drift are reduced by 78% in the structure retrofitted by RC shear walls, by 9% in the structure retrofitted by steel plate shear walls, and is almost same as that in original structure by steel braces and RC jackets. RCSWs reduced the peak inter-story drift of all stories under all ground motions in both directions.

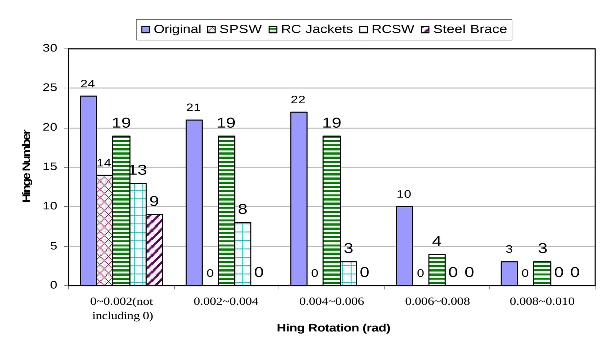
There is no shear overstressed columns in all retrofitted structures since adding transverse reinforcement in local scheme provide enough shear capacity or new added later-force resisting system in global schemes resist most of lateral load, and so design shear forces in moment resisting frames are significantly reduced. The DCR of overstressed columns under axial load and moment interaction (P-MM) are all decreased to lesser than 1. The average P-MM DCR in retrofitted structures of those P-MM overstressed columns in original structures are changed into 0.85, 0.37, 0.77 and 0.60 respectively for RC Jackets, RCSW, steel braces and SPSW schemes.

The number and maximum rotation of plastic hinge are all reduced in Y (E-W) direction. While in X (N-S) direction, the number and maximum rotation of plastic hinge under target displacement in X (N-S) direction are all increased due to the in-elastic behavior introduced by new retrofit schemes. In terms of building performance level based on plastic hinge: RC shear walls improve all performance levels into S2 (DC). Steel braces and SPSW improve the performance levels into S1 (IO) in both directions. Retrofitting by RC jackets does not change the building performance levels.

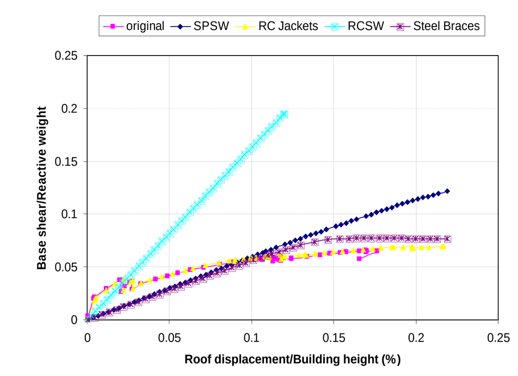
The comparison of push-over curves of the four retrofit schemes with that of the original structure is shown in following figure. The stiffness of structure is increased most significantly in RC shear wall retrofit scheme, followed by SPSW and steel brace retrofit schemes. Actually the stiffness of retrofitted structure by these two schemes is almost same. And they both display ductile behavior. It can be observed from the curves the reduction of lateral force capacity after yielding of the added steel braces. Retrofitting by RC jackets does not increase the stiffness much.



Plastic hinge histogram of beams in Y direction of 4 retrofit schemes



Plastic hinge histogram of columns in Y direction of 4 retrofit schemes



Push-over curves in Y direction of 4 retrofit schemes

Summary

This poster provides a set of seismic evaluation results of retrofitting a non-ductile reinforced concrete hospital building in the eastern US. For the building and selected ground motions, the results of this study show that: All selected schemes could improve seismic performance of the original frame evaluated by stress analysis; Adding RC jackets is suitable for improving local stress level. The maximum inter-story drift, the building performance level based on maximum plastic rotation are not seen to be improved by this scheme; Adding RCSW significantly increase the lateral stiffness. The retrofitted structure still performed within elastic range under target displacement. Maximum inter-story drift is reduced dramatically. This retrofit scheme will be effective on the structure when displacement control is a main retrofit concern; The steel braces and SPSW retrofit schemes performed similarly in some degree. The maximum inter-story drift in both retrofitted structures are almost the same as that in original structure, while the number and maximum rotation of plastic hinges in columns and beams were significantly reduced. The building performance level based on maximum plastic rotation could be improved to S1 (Immediate Occupancy) level in both directions.

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