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Nonlinear Static Pushover Analysis of Existing and CFRP Retrofitted RC Shear Wall Frame

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ABSTRACT: The seismic events in Saudi Arabia in 2009, in the Western Region, have led to concerns about safety and vulnerability of reinforced concrete buildings, which were designed only for gravity loads in the past, devoid of any ductile detailing of joints. In this study, a nonlinear static pushover analysis of eight-story reinforced concrete shear wall frame of a building in Madinah was carried out before and after retrofitting of the building. The static pushover analysis was carried out using SAP2000 incorporating inelastic material behavior of concrete and steel. Moment curvature and P-M interactions of frame members were obtained by cross sectional fiber analysis using the software XTRACT. The shear walls were modeled using shell element and mid-pier approach. The damage modes include a sequence of yielding leading to failure of the members, and structural levels were obtained for the target displacement under the expected design earthquake. Retrofitting of the existing frame is done based on the demand displacement of the existing frame obtained using the FEMA356 capacity spectrum method (CSM). The deficient columns were retrofitted with CFRP jacketing and the length of existing shear walls was increased to enhance the seismic response capacity of the building. The seismic displacement response of the retrofitted frame obtained using pushover analysis shows a significant increase in the lateral load capacity of the building.

1 INTRODUCTION

In the 80’s and 90‘s most of the RC frames in seismically active areas of Saudi Arabia were designed only for gravity load and therefore, they have limited lateral load resistance and are susceptible to column-side sway or soft-story mechanisms under earthquake effects. For high-rise buildings, lateral forces due to wind loads were considered, however. Also non ductile detailing practice employed in these structures makes them prone to potential damage and failure during earthquake. The nonlinear static pushover analysis for seismic design and evaluation is being implemented in many codes and is being used to evaluate the seismic response of the existing and retrofitted frame.

In this paper, a case study involving seismic evaluation and retrofitting of a typical eight storey reinforced concrete building in the city of Madinah in Saudi Arabia is presented. The building is 3-D reinforced concrete frame-shear wall structure A typical frame of the building with shear wall is considered for investigations. The seismic displacement response of the existing and the retrofitted frame are obtained using the method of pushover analysis. The static pushover analysis was carried out using SAP2000 incorporating inelastic material behavior for concrete and steel, and moment curvature and P-M interactions of frame members obtained by cross sectional fiber analysis using the software XTRACT.

2 OUTLINE OF BUILDING

The structure is an existing building located in Madinah, Saudi Arabia, constructed in 1996. The building has eight stories with a typical storey height 3.2 m for five storeys and remaining three storey heights are 4.2 m, 2.4 m and 5 m, respectively. Plan area of the building is 40 m x 40 m. The building has a dome at the roof level with reinforced concrete frames, elevator shafts and ribbed and flat slab systems at different floor levels. From the available design data, the strength of concrete and steel reinforcement are 30 MPa and 420 MPa, respectively. The loading for the building includes; self weight of members, superimposed load of 1.44 KN/m^2 for floors and 1.93 KN/m^2 for roof. Ad live load of 4.8 KN/m^2 for floors and 2.4 KN/m^2 for roof. The building is located in the Seismic Zone 3 as per SBC-301 and Zone 2B as per UBC-1997, with site class D (stiff soil) and Building Importance Coefficient (I) equal to 1.25.A plan for building and shear wall frame used in this investigation is shown in Figures 1 and 2. The accidental eccentricity is ignored in the seismic loading in order to directly observe the lateral load effect on the walls.

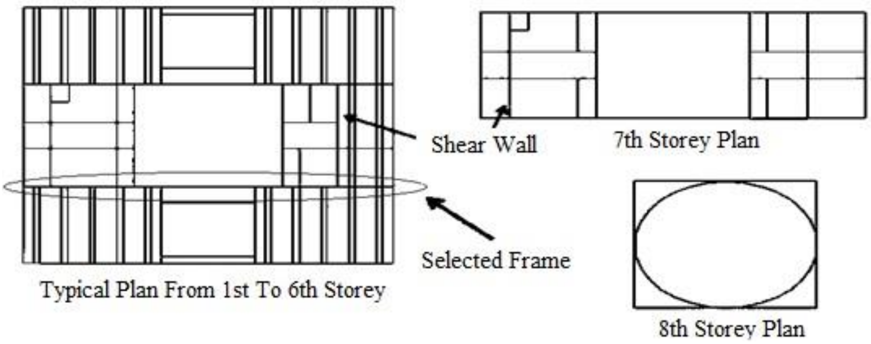


Figure 1: Plan of Building

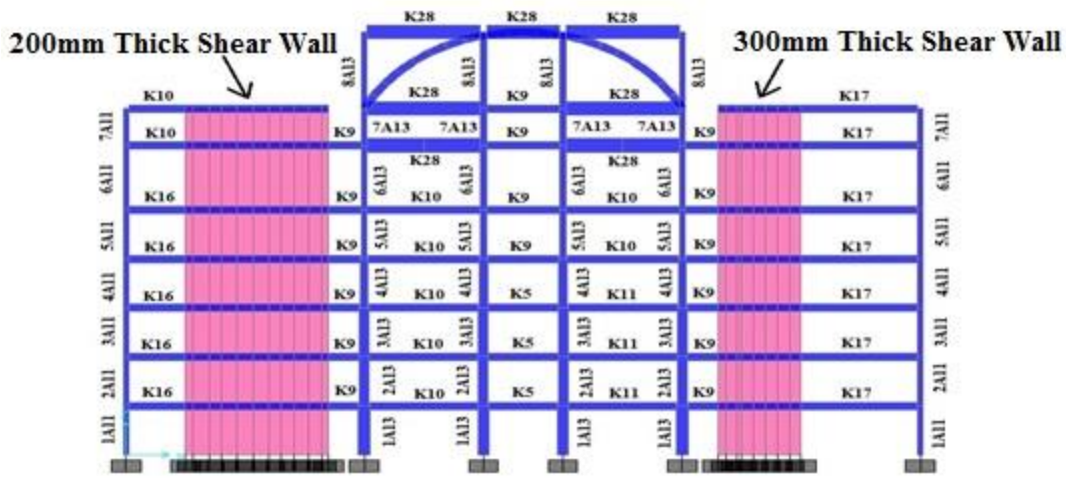


Figure 2: Model of Frame Selected for Investigation

3 MODELING OF THE RC FRAME

Column and beams are modeled using line elements. The shear walls are modeled using smeared multi-layer shell elements and mid-pier approach. The multi-layer shell element is based on the principles of composite material mechanics. Mid pier approach is based on line elements where shear wall is taken as equivalent mid-pier and rigid beams.

To analyze the cross-sections, Mander confined and unconfined concrete model (1988) and elasto-plastic steel model with strain hardening were used for existing members and Lam & Teng CFRP confined concrete model were utilized to model retrofitted members. XTRACT (2007) software is utilized to determine the moment-rotation curves for beams and PMM interaction curves for columns.

4 PUSHOVER ANALYSIS OF EXISTING RC FRAME

The nonlinear analysis of the building is performed using SAP2000 (CSI, 2009). The nonlinear properties for columns and beams are assumed to be a plastic P-M-M hinge and one component plastic moment hinge, respectively. The user defined plastic hinges are utilized. The axial force for columns, and shear force for beams is considered from a combination of dead and live loads (D+0.25L).The pushover analysis is carried in both positive and negative x-directions. The pushover curves for the existing frame with x-directions are shown in Figure 3.

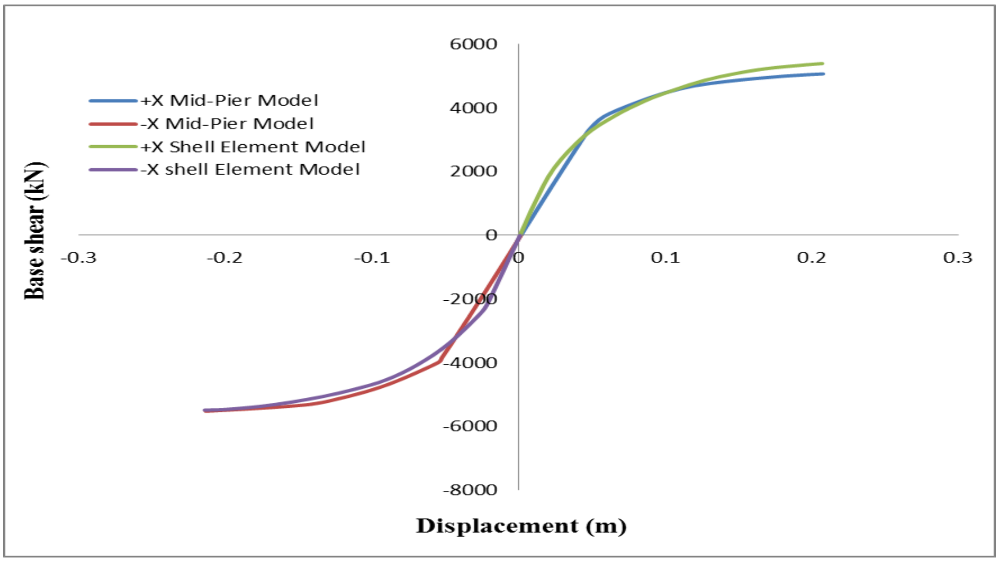


Figure 3: Pushover Curves for Existing Frame in Positive and Negative X-Directions

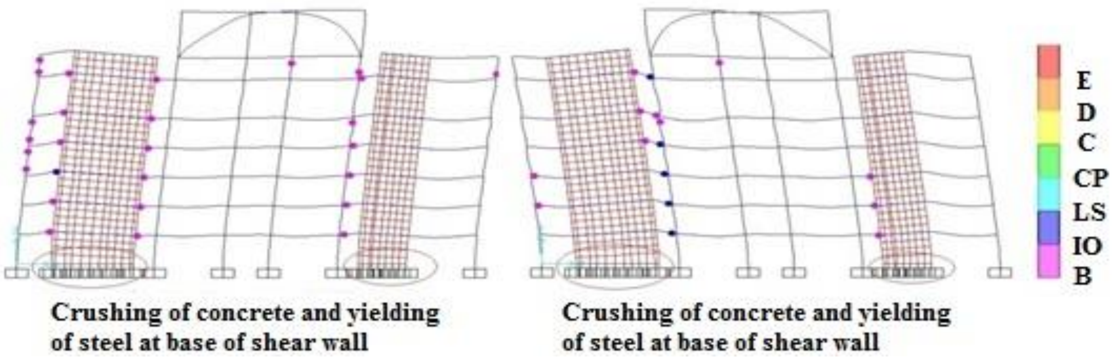
5 PEROFMANCE EVALUATION OF EXISTING FRAME

Performance point of existing typical frame is obtained using FEMA-356 Capacity Spectrum Method (CSM). The base shear and displacement performance point of existing frame in positive and negative x-directions is given in Table 1.

Table 1: Base Shear and Displacement at Performance Point

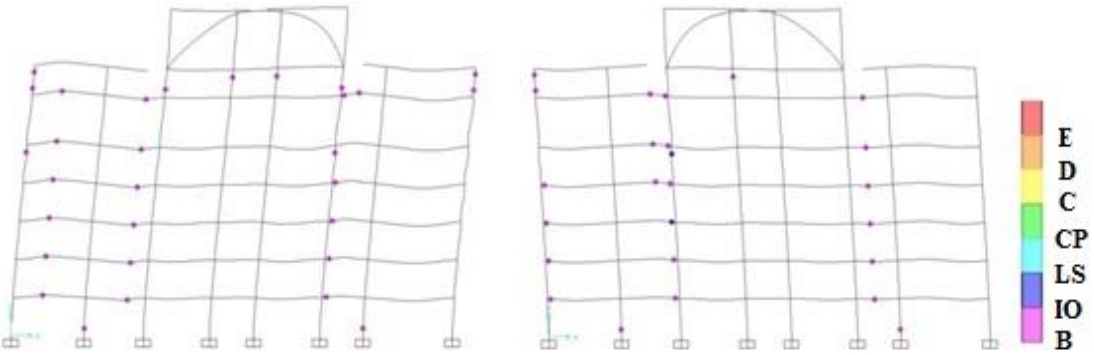
Directions	Base shear (kN)	Displacement (m)
Positive x	4076	0.08
Negative x	4228	0.077

From the pushover analysis of the existing frame it was observed that top columns are failing in tension because of low axial load and high moments acting on columns due to lateral loads Also, it was observed that at low level of displacement most of the beams yield which is a clear indication that beams are designed purely for gravity loads. It can also be seen that at demand displacement shear walls are also failing due to crushing of concrete and yielding of steel. Figures 4 and 5 show the formation of hinges in the frame from the movement in the positive and negative x-directions. Figures 6 and 7 shows that the crushing of concrete occurs on the compression side and yielding of steel occurs on the tension side of shear wall at the demand displacement.



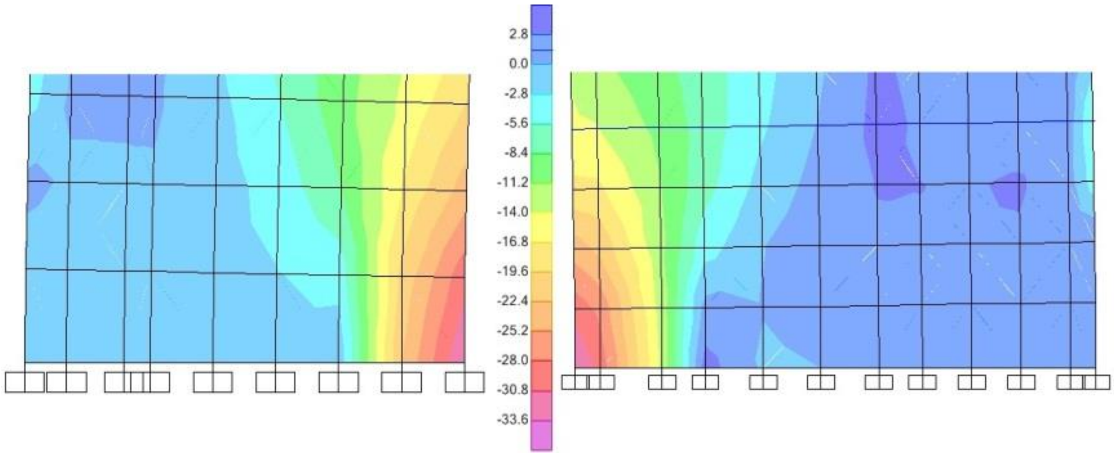
a) Positive x-direction b) Negative x-direction

Figure 4: Hinges Formation at Demand Displacement for shell element model



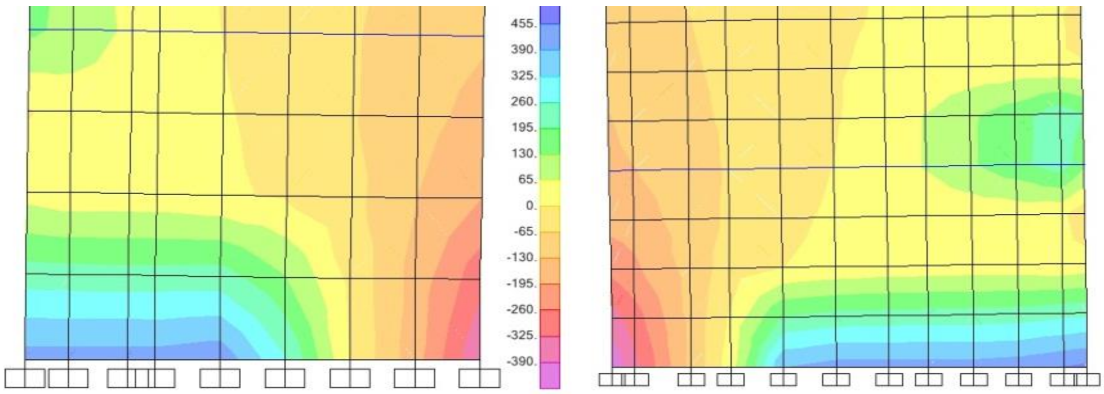
a) Positive x-direction b) Negative x-direction

Figure 5: Hinges Formation at Demand Displacement for mid pier approach



a) Positive x-direction   b) Negative x-direction

Figure 6: Crushing of Concrete at the Base of Shear Wall at Demand Displacement



a) Positive x-direction   b) Negative x-direction

Figure 7: Yielding of Steel at the Base of Shear Wall at Demand Displacement

*Note: Stresses are in MPa

6 RETROFITTING SCHEME

From the pushover analysis of existing frame, it is clear that at performance point the shear walls are failing due to crushing of concrete and hinges are formed in top storey columns. After reviewing various options, it was found that retrofitting of shear walls should be done by increasing the length of shear walls using high strength concrete (HSC) (availability of space is not a problem) and jacketing top columns with CFRP. Shear walls are extended 1.2 m using HSC of 45 MPa. Figure 8 shows the retrofitting schemes for shear wall and columns.

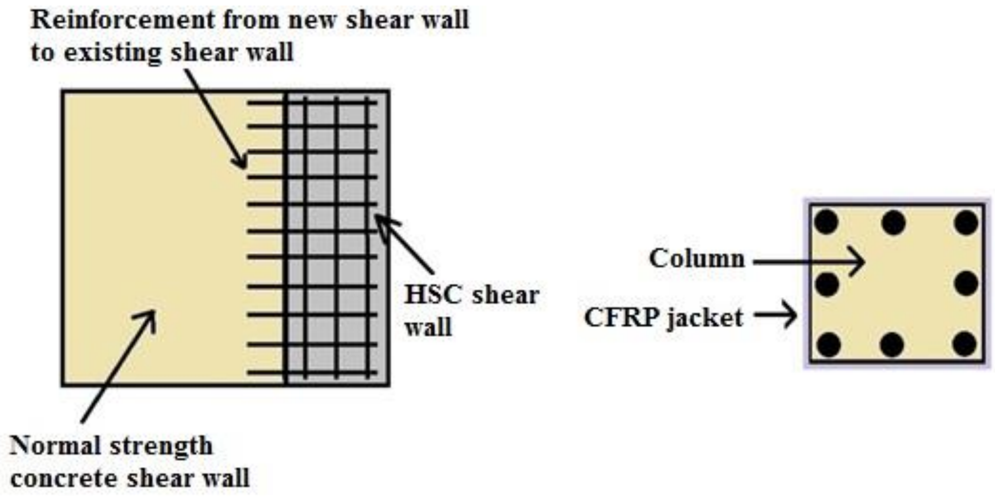


Figure 8: Retrofitting Strategy for Existing Frame

7 PUSHOVER ANALYSIS OF RETROFITTED FRAME

Pushover analysis has been carried out following the retrofitting of the frame. Figure 9 shows the pushover analysis curves for the existing and retrofitted frame. Figure 9 shows the significant increase in lateral load capacity of the existing frame after retrofitting. The proposed scheme reduces significantly the lateral displacement. Figures 10 and 11 show the inter-storey drift ratio (IDR) and total drift of the existing and retrofitted frame.

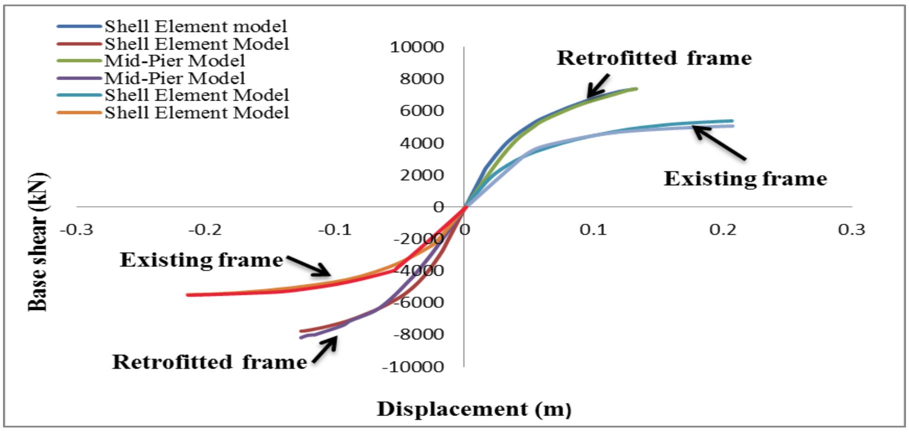


Figure 9: Pushover Analysis of Existing and Retrofitted Frame

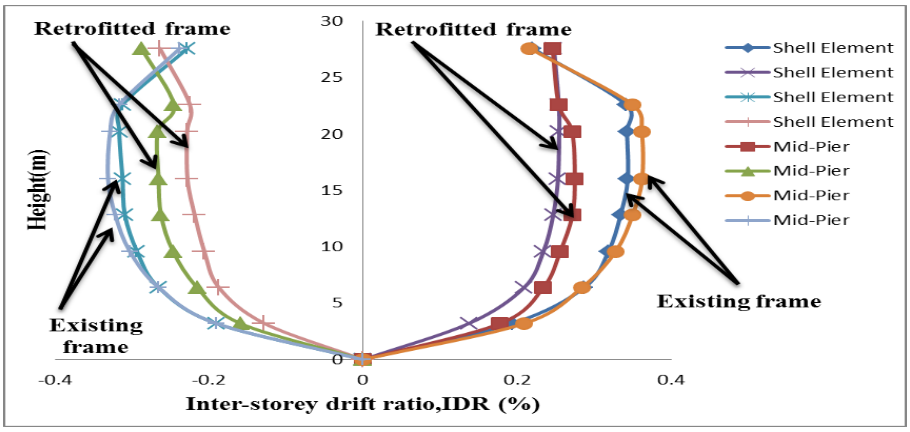


Figure 10: Inter Storey Drift Ratio for Existing and Retrofitted Frame model

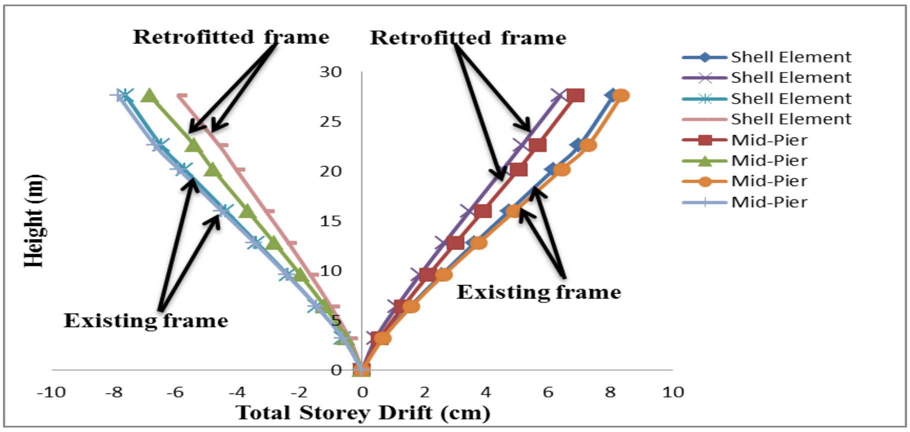
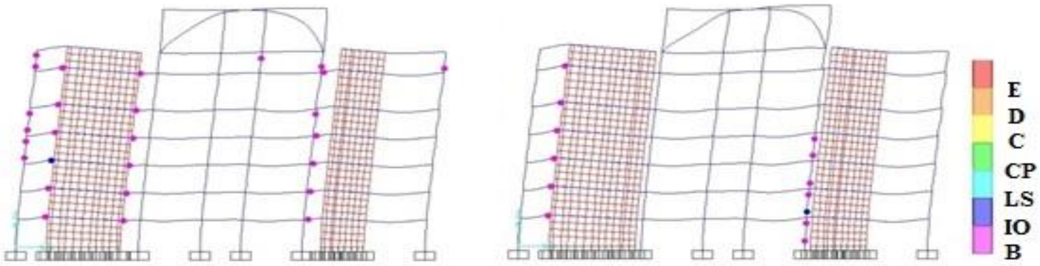


Figure 11: Total Storey drift of existing and retrofitted frame at demand displacement

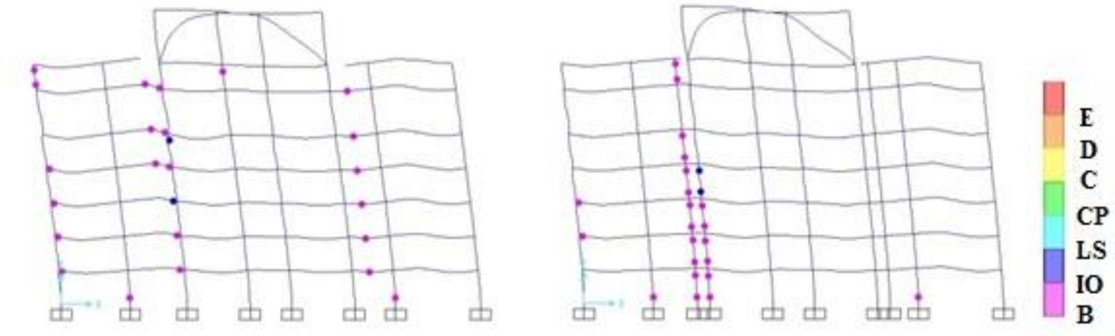
From Figures10 and 11, it can be seen that inter-storey drift ratio and total storey drift of the existing shear wall frame is high which may cause damage to the structural and nonstructural components of the frame. Collapse of frame may occur due to excessive inter-storey drift because excessive inter-storey drift often results from the local concentration of deformation at a particular "weak storey". After retrofitting, inter-storey drift and total storey drift reduces which lowers the seismic vulnerability of the frame under design earthquake.

8 COMPARISON OF HINGE FORMATION IN EXISTING AND RETROFITTED FRAME AT DEMAND DISPLACEMENT



a) Existing Frame b) Retrofitted Frame

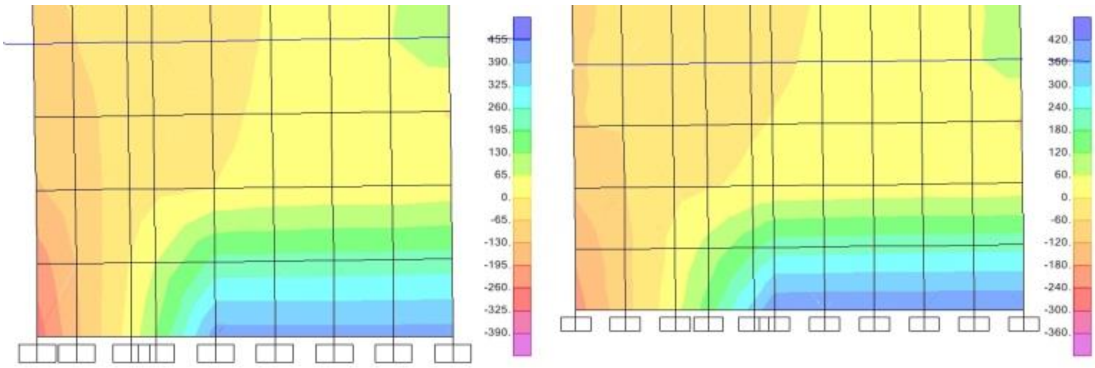
Figure 12: Hinge Formation in the Positive x - direction at Demand Displacement for shell element model



a) Existing Frame　　　　　　　　　　b) Retrofitted Frame

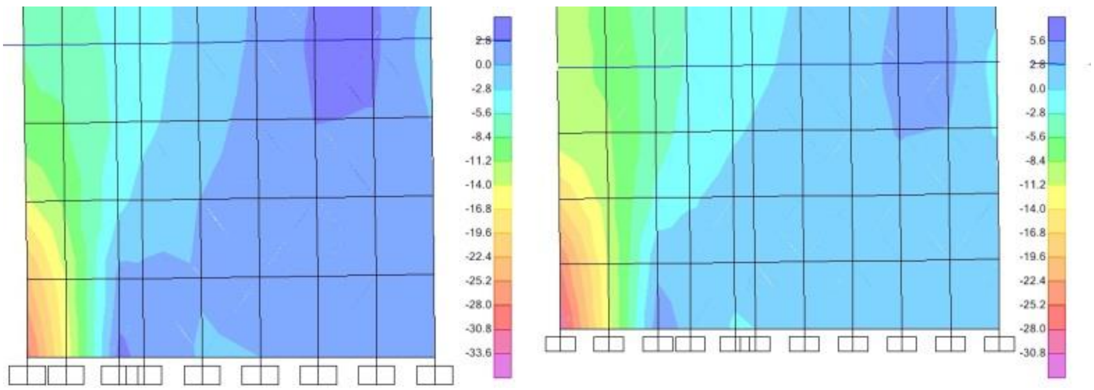
Figure 13: Hinge Formation in the Negative x - direction at Demand Displacement for mid-pier model

Figures 12 and 13 clearly show that after strengthening of existing frame there is no flexural hinge in top storey columns which were failing earlier. Also most of the beams which were yielded previously are not yielding after retrofitting. It is also observed that after retrofitting, bottom storey columns start yielding. Figures 14 and 15 clearly show the effect of retrofitting of existing frame as there is no yielding of steel and crushing of concrete at the base of the shear wall in contrast to the conditions in the non-retrofitted frame.



a) Existing Frame　　　　　　　　　　b) Retrofitted Frame

Figure 14: Stresses in Steel at Base of Shear Wall



a) Existing Frame　　　　　　　　　　b) Retrofitted Frame

Figure 15: Stresses in Concrete at Base of Shear Wall

*Note: Stresses are in MPa

9 CONCLUSIONS

Pushover analysis of a typical shear wall frame of building in the city of Madinah shows that the frame is deficient to resist seismic loading at the expected design earthquake. Formation of hinges clearly shows that the members of the building are designed purely for gravity loads, and the building behaves in a non-ductile manner because almost all the seismic load is carried by the shear walls at very small displacement and hinges start forming in shear walls. Retrofitting of existing shear wall frame by the extension of shear walls using high strength concrete and CFRP jacketing of the columns results in significant increase in lateral load capacity of the frame. No flexural hinges are found in top storey columns which were originally failing at demand displacement. Inter-storey drift ratio of the retrofitted shear wall frame is significantly, reduced decreasing the seismic vulnerability.

10 ACKNOWLEDGEMENT

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