Nonlinear Static Pushover Analysis of an Eight Story RC Frame-Shear Wall Building in Saudi Arabia

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SUMMARY:
The Western region of Saudi Arabia lies in a moderate seismic zone and seismic events of magnitude 5.7 were recorded in 2009 in areas near the holy city of Madinah. A historical event involving ground cracking and fissuring with volcanic activity took place in the year 1256. The recent seismic events have led to concerns on safety and vulnerability of RC buildings, which were designed only for gravity loads in the past devoid of any ductile detailing of joints. This paper presents a 3D nonlinear static analysis for seismic performance evaluation of an existing eight-story reinforced concrete frame-shear wall building in Madinah. The building has a dome, reinforced concrete frame, elevator shafts and ribbed and flat slab systems at different floor levels. The seismic displacement response of the RC frame-shear wall building is obtained using the 3D pushover analysis. The 3D static pushover analysis was carried out using SAP2000 incorporating inelastic material behavior for concrete and steel. Moment curvature and P-M interactions of frame members were obtained by cross sectional fiber analysis using XTRACT. The shear wall was modeled using mid-pier approach. The damage modes includes a sequence of yielding and failure of members and structural levels were obtained for the target displacement expected under design earthquake and retrofitting strategies to strengthen the building were evaluated.

Keywords: Reinforced concrete shear wall, pushover analysis, plastic hinges, response spectra

1. INTRODUCTION

Recent awareness of a potential seismic events in low to moderate seismicity regions of Saudi Arabia such as Otaibah, Makkah (2005), Haradh, Eastern Province (2006) , Al-Hadama, Al-Amid, Al-Qarasa and Yanbu (2009), Eastern Province (August,2010) have led to concerns of safety and vulnerability of reinforced concrete buildings, in which ductile detailing has not been provided explicitly in the design process. Majority of the structures built in Saudi Arabia in the seismically active Western region are designed primarily for combination of gravity and wind loads and are not able to resist seismic loading.

Gravity load designed RC frames in Saudi Arabia have limited lateral load resistance and are susceptible to column-side sway or soft-story mechanisms under earthquake effects. In some cases, for relatively taller buildings in Saudi Arabia, the design may have considered lateral forces due to wind loads, it is still important to carry out a complete seismic evaluation, since higher mode effects sometimes lead to soft-story mechanisms in the mid to upper levels of the building. Also non ductile detailing practice employed in these structures makes them prone to potential damage and failure during earthquake. Therefore analysis of such buildings are required which have not been designed to take care of seismic forces. The nonlinear static approach is used to evaluate the seismic response of the building.Modeling of shear wall is done by mid-pier approach. The nonlinear model of the mid - pier frame is generally based on plastic hinge concept and a bilinear moment-rotation relationship. Taking into account the analysis purpose, the plastic hinges (P-M-M Interaction) can be assumed either on the plastic zones at the end of the structural elements or distributed along the member span length (Otani, 1980).

This paper presents a 3D nonlinear static analysis for seismic performance evaluation of an existing eight-story reinforced concrete frame-shear wall building in Madinah. The building has a dome, reinforced concrete frame, elevator shafts and ribbed and flat slab systems at different floor levels. The seismic displacement response of the RC frame-shear wall building obtained using the 3D pushover analysis. The 3D static pushover analysis was carried out using SAP2000 incorporating inelastic material behavior for concrete and steel. Moment curvature and P-M interactions of frame members were obtained by cross sectional fiber analysis using XTRACT. The shear wall was modeled using mid pier approach.

2. BUILDING DESCRIPTION

The structure is an existing municipality building located in Madinah, Saudi Arabia constructed in 1996.The building has eight stories with typical story height 3.2m for five stories and the rest of three story height are 4.2m,2.4m and 5m.Plan area of the building is 40 x 40 m. The building has a dome, reinforced concrete frame, elevator shafts and ribbed and flat slab systems at different floor levels. From the available design data, the strength of concrete is 30 MPa and reinforcement is 420 MPa. The slab load composed of self-weight and superimposed load (D) and 25 % of the live load (L),where D= self-weight + 1.435 kN/m^2 ,L= 4.8 kN/m^2 for all story and for roof D= self-weight + 1.925kN/m^2 , L= 2.4kN/m^2 ,respectively. The center of the mass of the building is calculated based on mass distribution at each node. The design seismic load is calculated based on the Saudi building code. The building is located in the third seismic zone, with site class D and building importance coefficient (I) equal to 1.25. Typical plan and designed response spectra of the building are shown in Fig.1 and Fig.2. The accidental eccentricity is ignored in the seismic loading to directly observe the lateral load effect on the walls. SAP2000 finite element software is utilized for three dimensional modeling and analyses of the example building. Three dimensional physical and analytical model is shown in Fig.3.

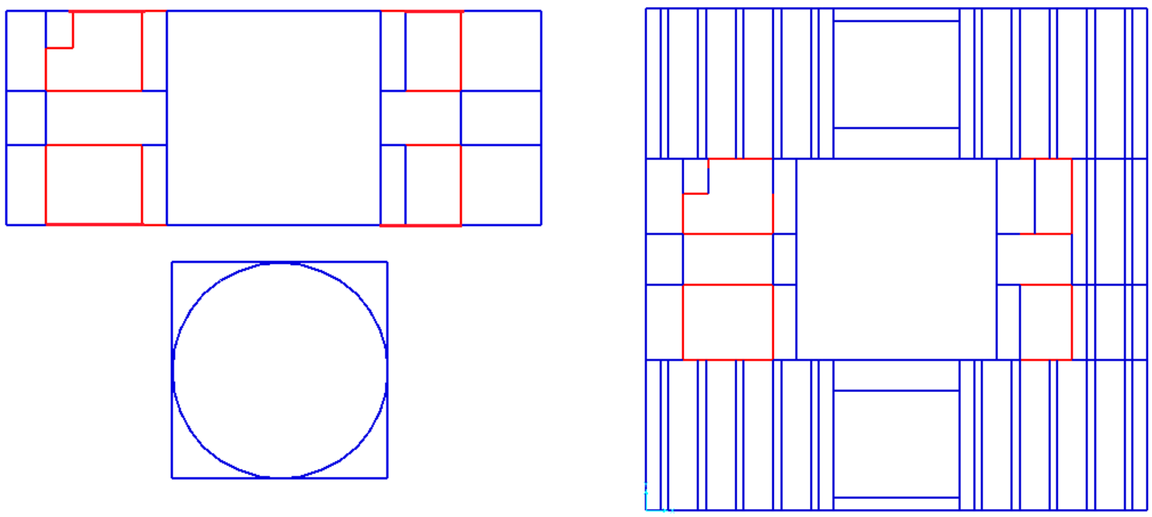

Figure 1. Structural plan of the building for various storeys

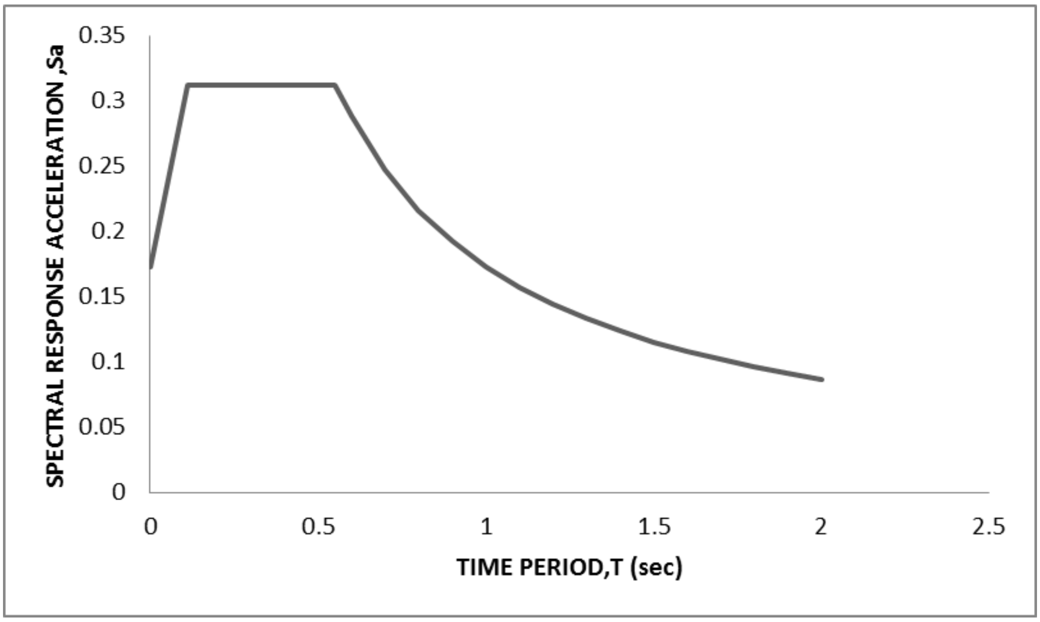

Figure 2. Design response spectrum used in the analysis (SBC 301,2007)

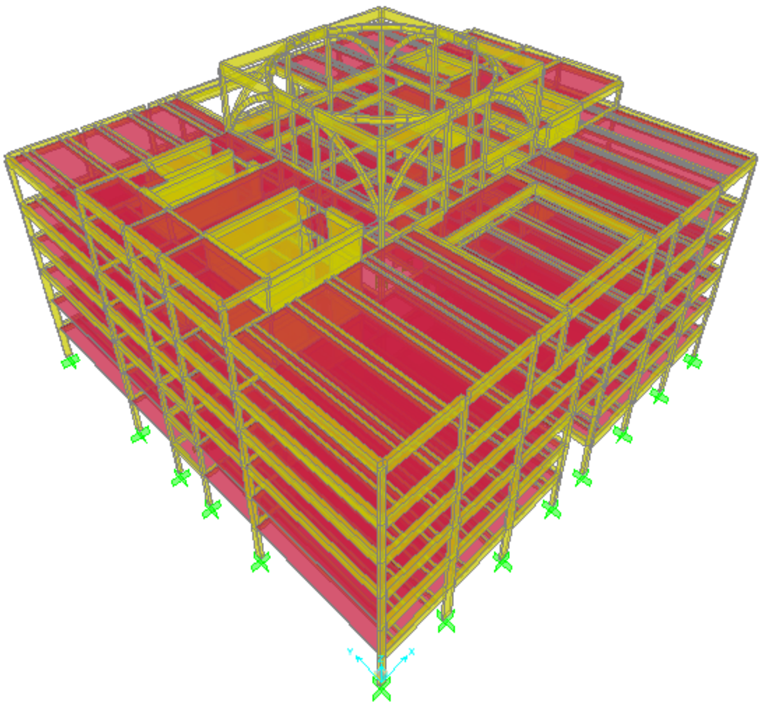

Figure 3. Three dimensional physical and analytical model of the example building

3. CROSS SECTIONAL ANALYSIS AND SHEAR WALL MODELING

3.1 Sectional analysis

To analyze the cross-sections, Mander confined and unconfined concrete model (1988) and elasto-plastic steel model without hardening were used. Summary of the Mander model with graphical representation is given in Fig. 4. XTRACT (2007) software is utilized to determine the moment-rotation curves for beam and PMM interaction curves for columns and shear wall.

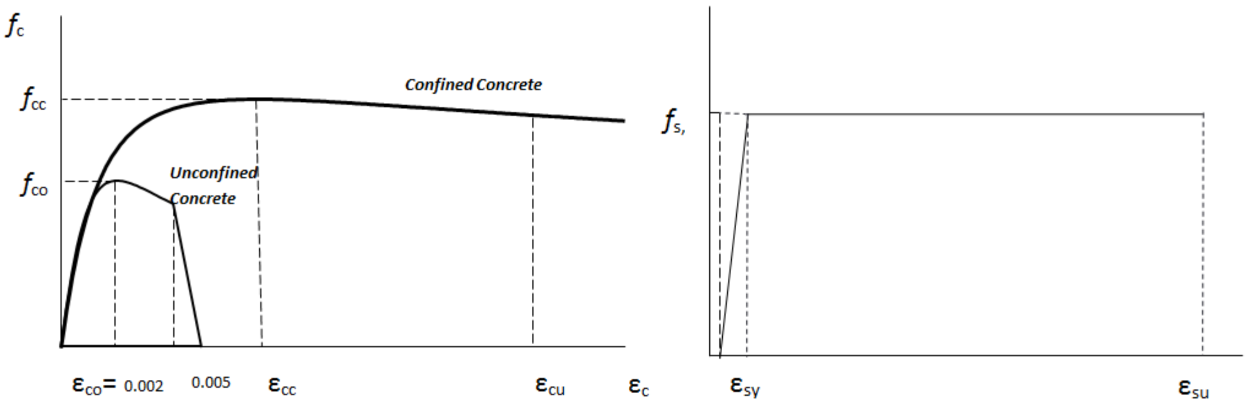

Figure 4. Mander Unconfined, Confined Model and Elastoplastic Steel Model

3.2 Shear wall Modeling

Shear walls are modeled by Mid-Pier Frame with plastic hinges defined according to FEMA 356.Mid-Pier is modeled as a frame element with the shear wall cross sectional parameters. Thickness of the rectangular rigid beam section can be considered the same as the wall itself. Fig. 5 represents the Mid-Pier frame model. The plastic P-M-M hinge is defined according FEMA 356 with the given rebar distribution. The axial force level is considered from a combination of dead and live loads (D+0.25L) and the transverse reinforcing is assumed not to provide the confinement.

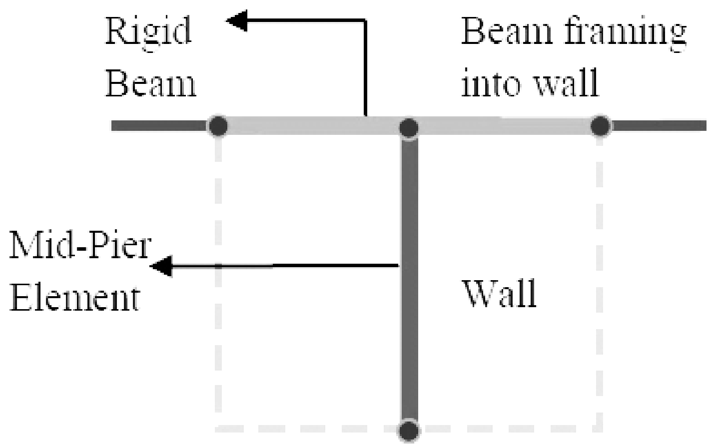

Figure 5. Mid-Pier model for shear wall

4. STRUCTURAL ANALYSIS

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 building in x-directions, story drift ratio and plastic hinge formations are shown in Fig.6, Fig.7, Fig. 8 and Fig. 9 , respectively.

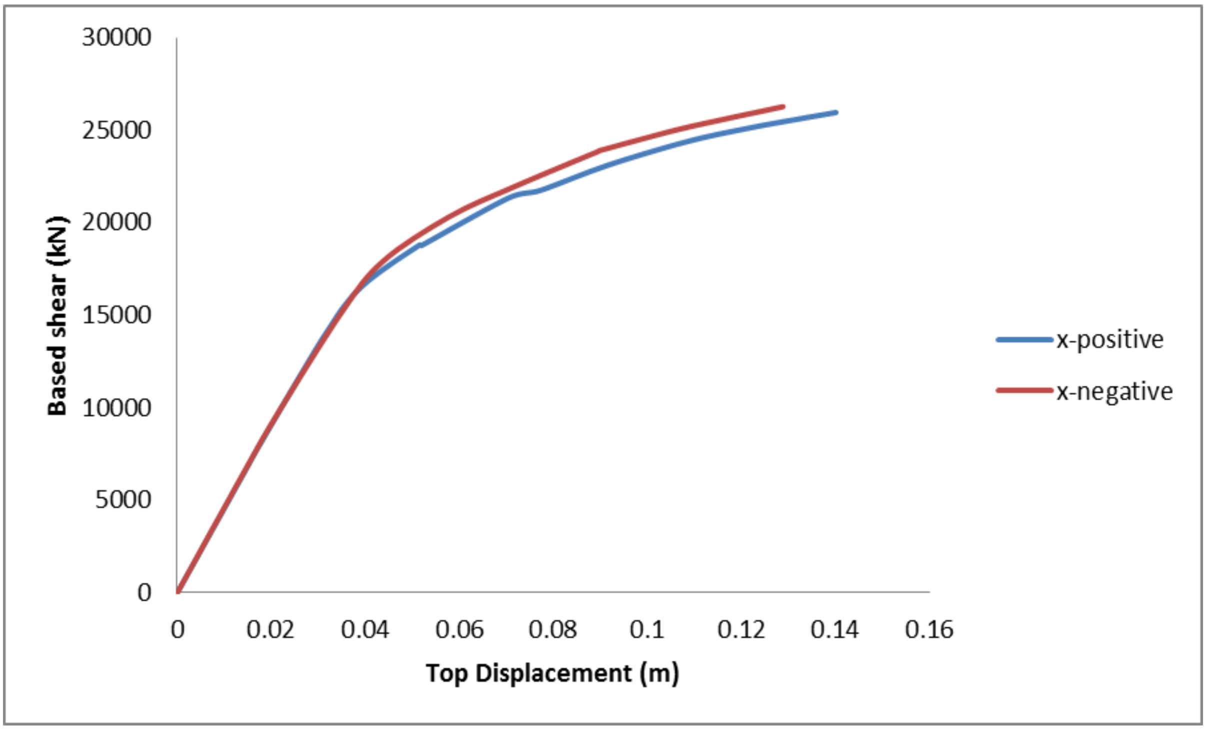

Figure 6. Pushover curves in x-directions

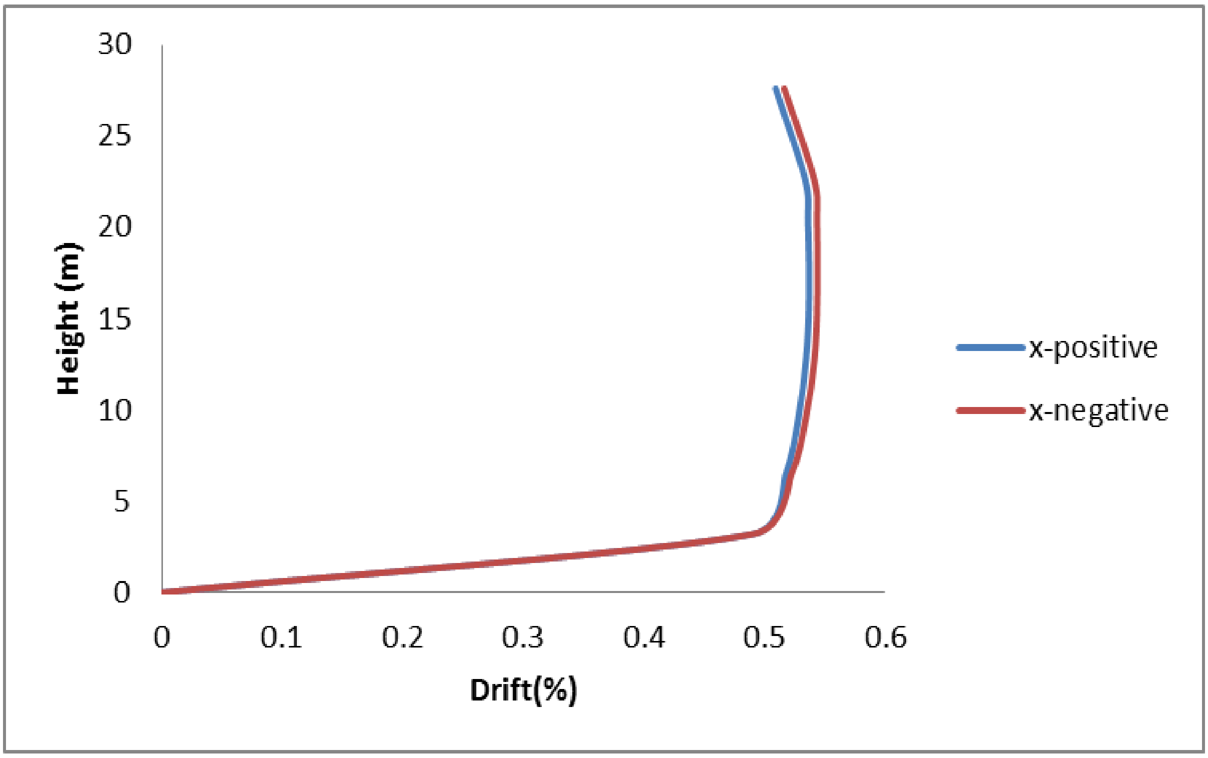

Figure 7. Storey drift ratio of the building

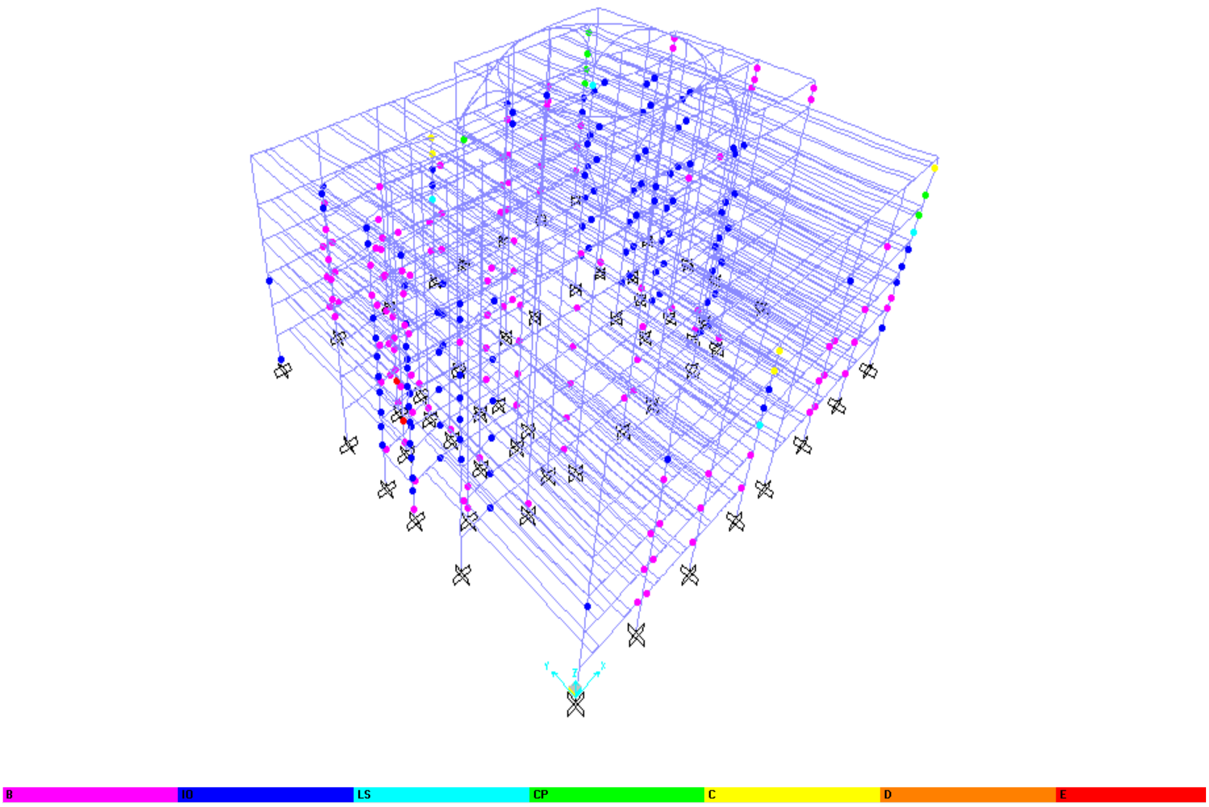

Figure 8. Plastic hinges status when pushed in positive x – direction

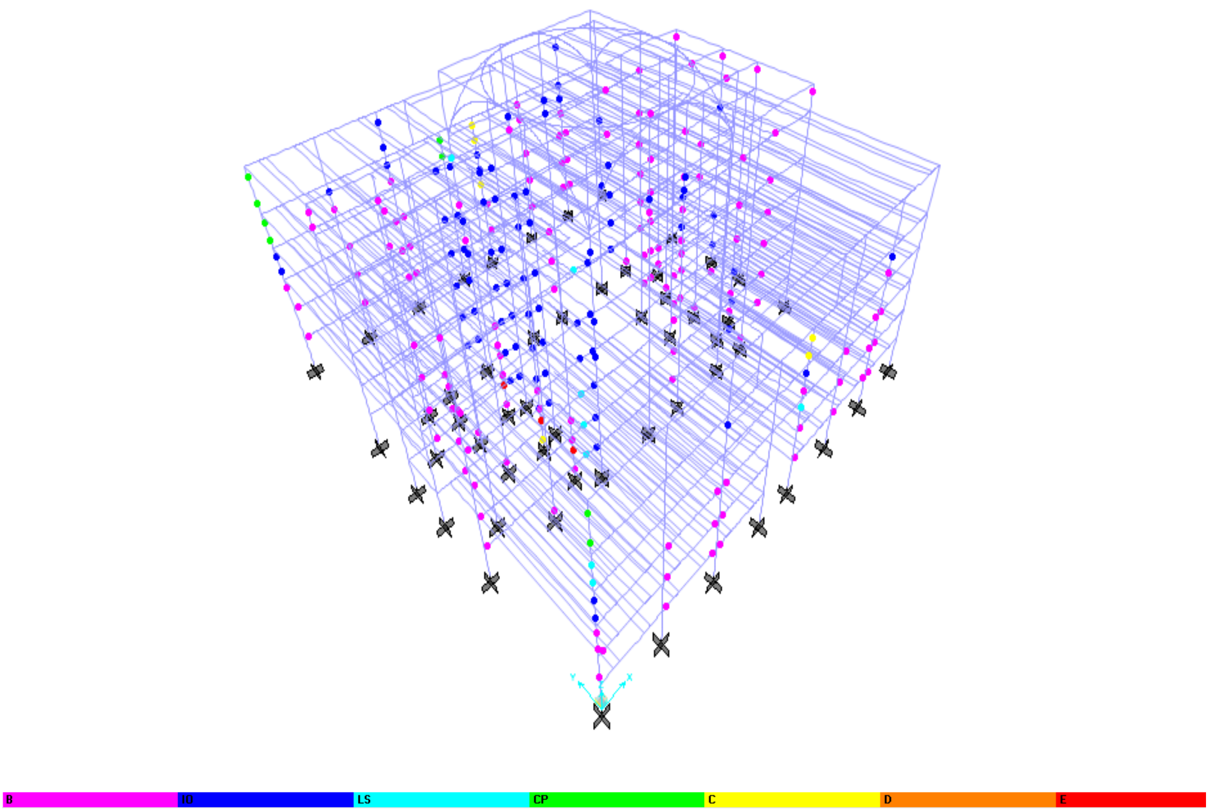

Figure 9. Plastic hinges status when pushed in negative x – direction

5. CONCLUSIONS

Pushover analysis of the Madinah Municipality building showed the building is deficient to resist seismic loading. Formation of hinges clearly shows that the members of the building are designed purely for gravity loads as with a small increment of displacement, most of the members start yielding. Pushover curves show non-ductile behavior of the building, because almost all the seismic load is carried by the shear walls and at very small displacement, hinges start forming in shear walls. This indicates that strengthening of the shear walls in the building is required. The performance points of the building in positive and negative x-directions are 0.094m and 0.097m based on actual response spectra available for the Madinah area. The ductility ratio in the positive x-direction is 14% higher than the negative x-direction due to the different arrangement of shear walls.

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