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SEISMIC PERFORMANCE EVALUATION OF A POST-TENSIONED FRAME BUILDING

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Abstract. *The precast construction technology is used not only for industrial buildings today, but also used for other building types such as residences, schools etc. On the other hand, the requirement of the seismic safety must be satisfied for such buildings constructed in earthquake regions. Thus, seismic safety evaluation of this type of buildings to estimate the potential damage is a critical issue and must be made as realistic as possible. Realistic damage estimation requires considering the nonlinear behavior of structure. In this study, performance evaluation of a seven story post-tensioned frame building which was in the state of immediate occupancy after the Van Earthquakes (October 23rd and November 9th, 2011), is carried out on the basis of Turkish Seismic Design Codes provisions.*

The maximum displacement demand of the design earthquake is estimated by using the pushover curves of the structure. The construction stages of the structure have been taken into account as the initial condition of pushover analysis. Finally, damage of all the structural elements has been determined, based on their plastic deformation demands, under the effect of the design earthquake by using the section damage classification of Turkish Seismic Design Code.

1 INTRODUCTION

The precast construction technology is used not only for industrial buildings today, but also used for other building types such as residences, schools etc. On the other hand, the requirement of the seismic safety must be satisfied for such buildings constructed in earthquake regions. Thus, seismic safety evaluation of this type of buildings to estimate the potential damage is a critical issue and must be made as realistic as possible. In this study, performance evaluation of a seven story post-tensioned frame building which was in the state of immediate occupancy after the Van Earthquake (October 23rd, 2011), is carried out on the basis of Turkish Seismic Design Code provisions [1].

The maximum displacement demand of the design earthquake is estimated by using the push-over curves of the structure. The construction stages of the structure have been taken into account as the initial condition of pushover analysis. Finally, damage of all the structural elements has been determined, based on their plastic deformation demands, under the effect of the design earthquake by using the section damage classification of Turkish Seismic Design Code [1].

2 DESCRIPTION OF THE BUILDING

The investigated structural system is formed of 7 story frames in both two directions. Columns are precast and continuous along the building height. The story height is 3.13m. Post-tensioned tendons are used at column-beam joints so that structural integration can be provided. Prefabricated slabs and topping (7 cm) are used at all story levels to construct the slab system of the building. Topping also helps to provide diaphragm behavior. The typical floor plan is shown in Figure 1.

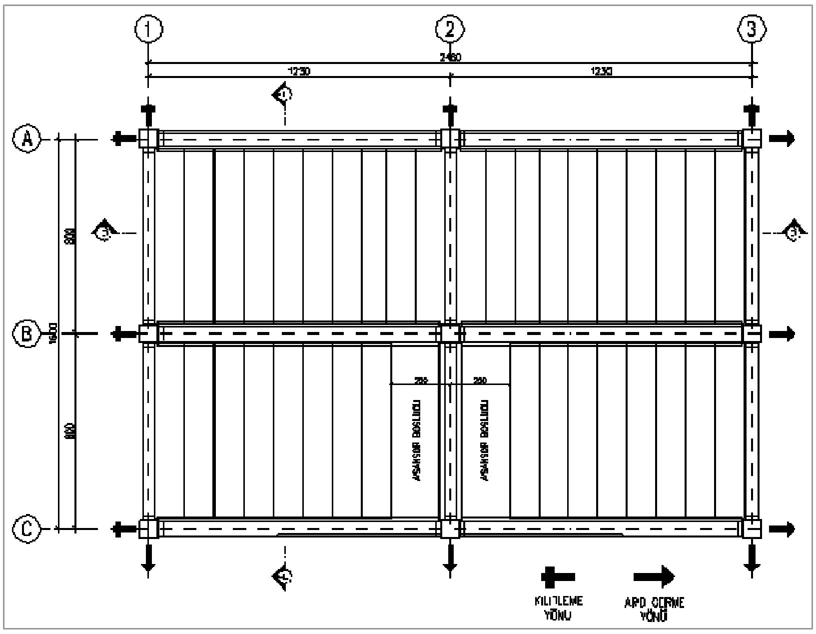

Figure 1: Typical floor plan of the building.

The characteristic concrete strength is 50 MPa and 40 MPa for frames and sabs, respectively. The reinforcement steel's characteristic yield strength is 420 MPa. Low-relaxation prestressing strand with the yield strength of 1700 MPa is used for post-tension tendons. Figure 2 shows a typical column-beam connection.

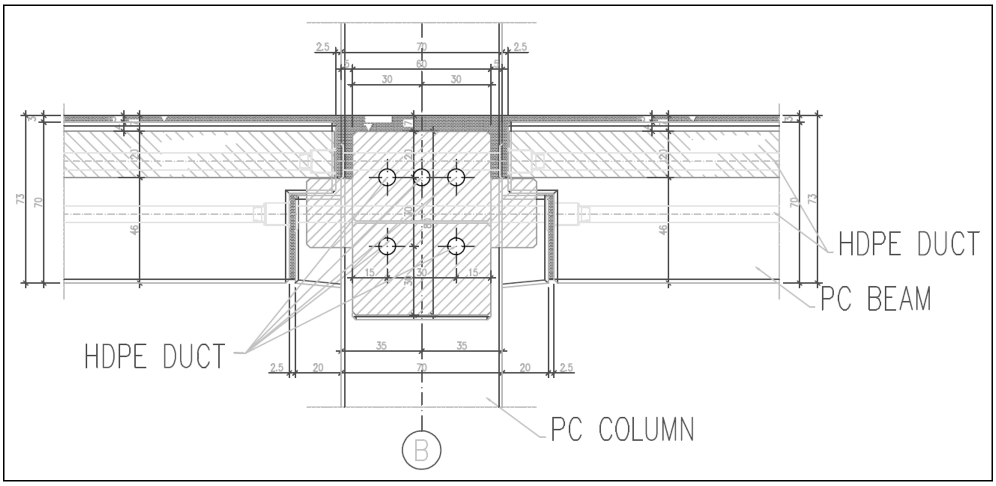

Figure 2: Typical column-beam connection.

3 PUSHOVER ANALYSES OF THE BUILDING

3.1 Material properties

Pushover analyses are carried out -in both two directions- to determine the performance of structural elements under the effect of the design earthquake. Kent&Park model [2] is used for both unconfined and confined concrete. The Figure 3 shows the stress-strain relation of considered model.

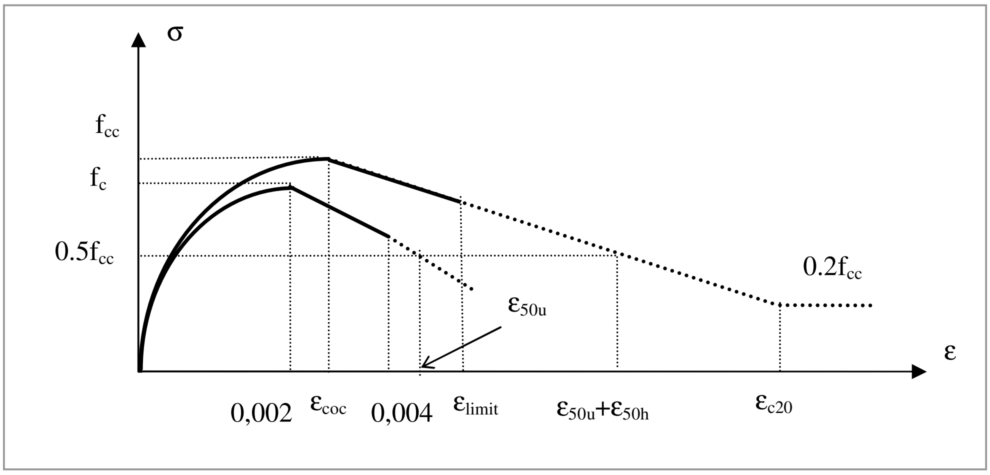

Figure 3: Kent&Park model.

The stress-strain curves of reinforcement steel and post-tension steel are given in Figure 4 and 5, respectively.

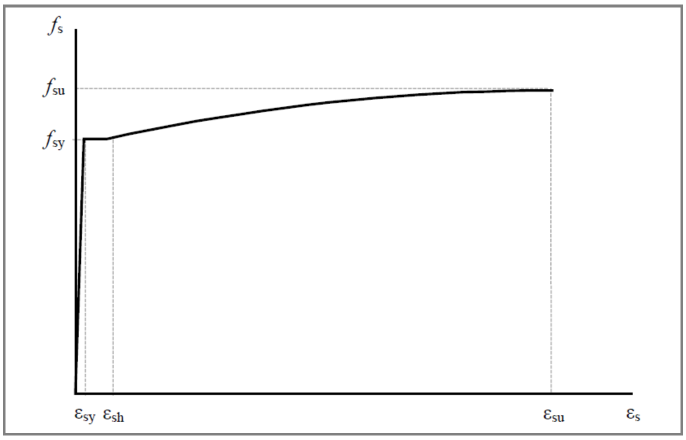

Figure 4: Stress-strain curve of reinforcement steel model.

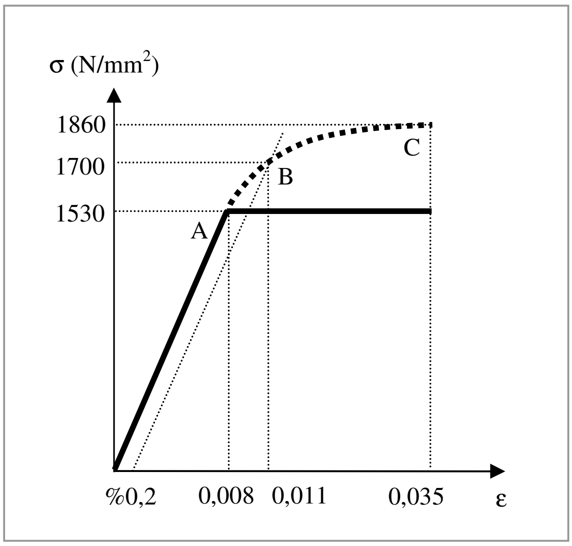

Figure 5: Stress-strain curve of post-tension cable.

3.2 Load-deformation relation for structural system elements

Moment-rotation diagrams and yield surfaces are determined for beam and column end sections where the possible plastic hinges can be occurred. For the beam end sections tri-linear moment-rotation diagram is assigned as shown in Figure 6.

The first reduction in stiffness of the section is observed with cracking (Point I). The second one is observed at Point II with bond slip. Beyond the yield point (Point II) there is no strain-hardening and stiffness is zero. Bond slip is assumed to be occurred when the strain of post-tension cable reaches 0.008. The mean bond stress is assumed to be 1.42MPa for the computation of section rotation [3, 4, 5]. The moment-rotation is assumed to be elastoplastic for columns. A typical yield-surface is given in Figure 7.

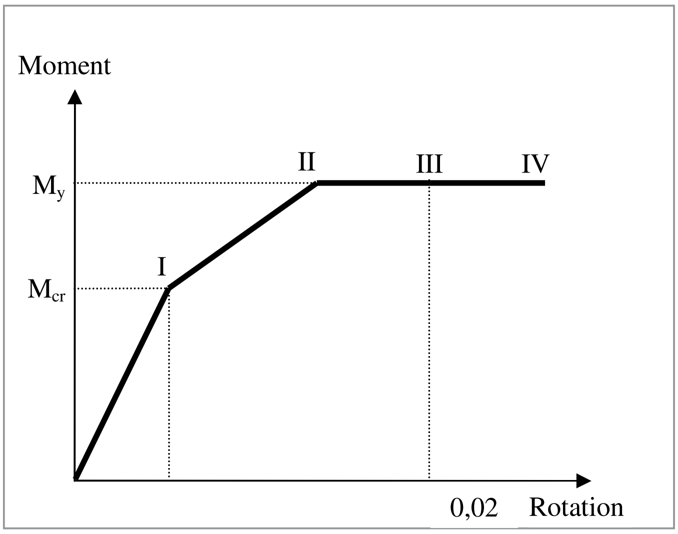

Figure 6: Typical moment-rotation diagram.

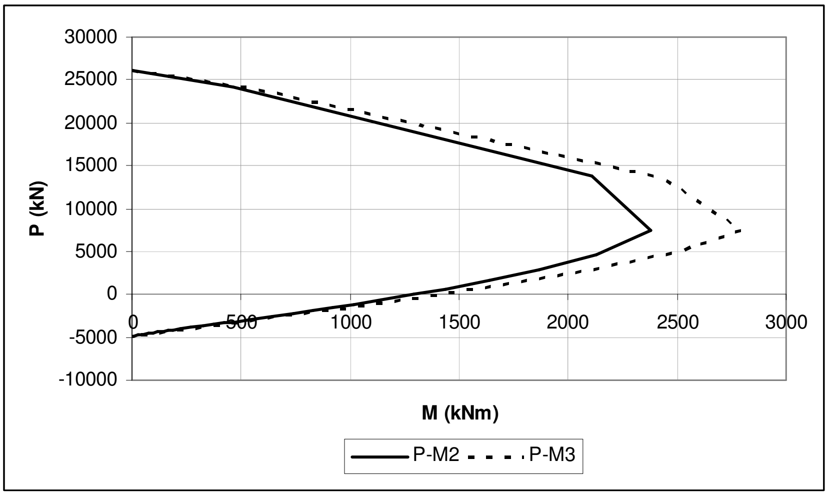

Figure 7: Typical yield-surface for column sections.

3.3 Construction Stages

Construction stages are considered as the initial conditions of pushover analysis. The followings are the sequence of loadings;

a. Installation of columns,
b. Installation of first story beams,
c. Installation of first story slabs,
d. Installation of beams and slabs for other story levels,
e. Post-tensioning of each story level,
f. Topping concrete for each story level,
g. Live and other dead loads.

Figure 8 shows the considered construction stages.

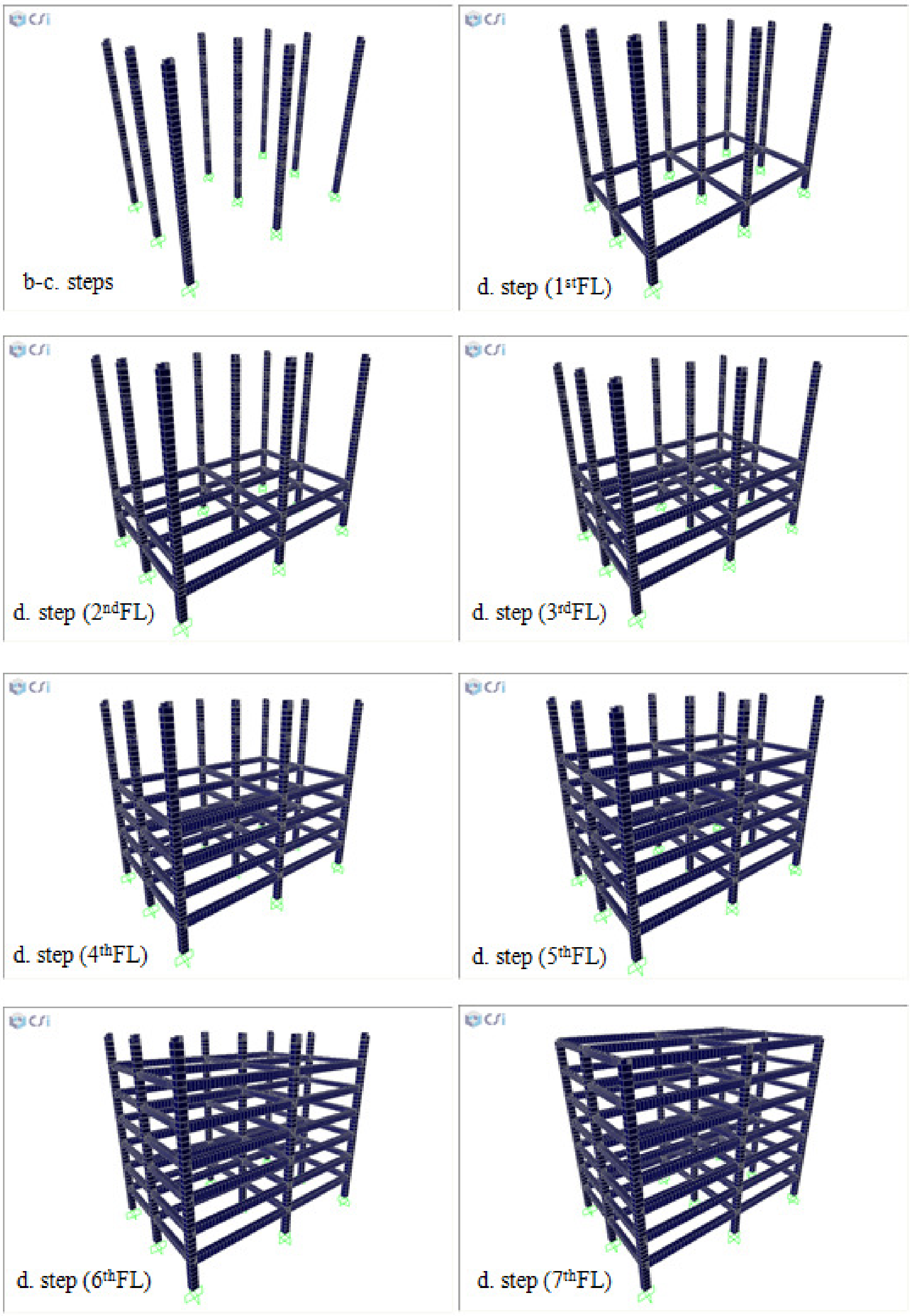

Figure 8: Construction stages

3.4 Pushover Curves

The pushover curves of both two direction are given Figure 9.

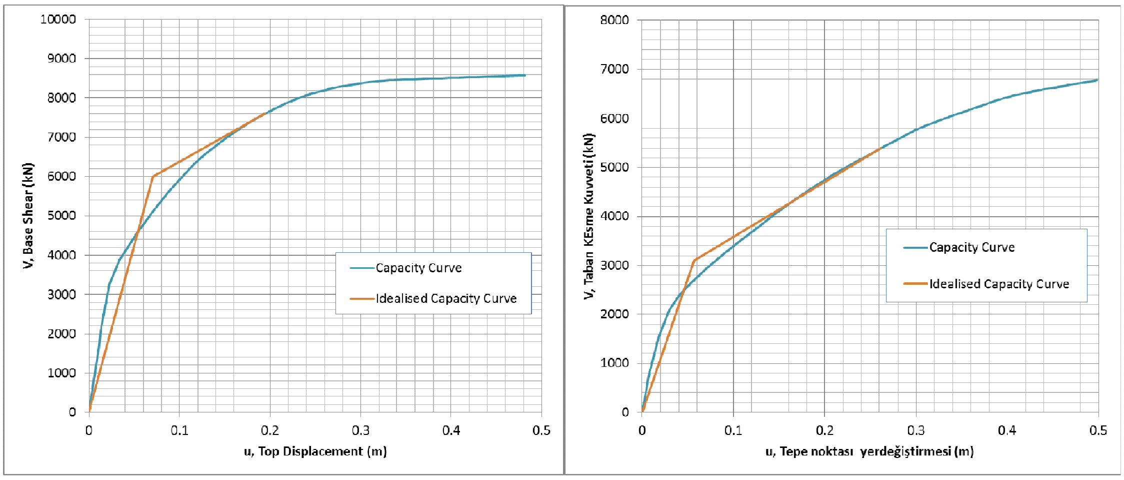

Figure 9: Pushover curves in X and Y direction.

The inelastic displacement demands are determined by using the method given by Turkish Seismic Design Code [1]. Figure 10 shows the design spectrum of Earthquake Zone 2 given by Turkish Seismic Design Code [1].

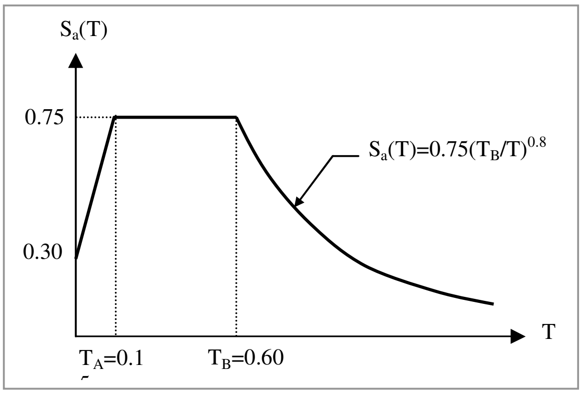

Figure 10: Design spectrum.

Figure 11 shows capacity spectra and inelastic displacement demands of each direction determined by using the method given by Turkish Seismic Design Code [1]. Sakata et. al. [3, 4] showed that origin-oriented hysteresis model can represent the sectional behavior of partially post-tensioned frames. Furthermore, considering the results of the study Ruiz-Garcia and Miranda [6] the inelastic displacement demand of elastoplastic model given by Turkish Seismic Design Code [1] has been increased %20.

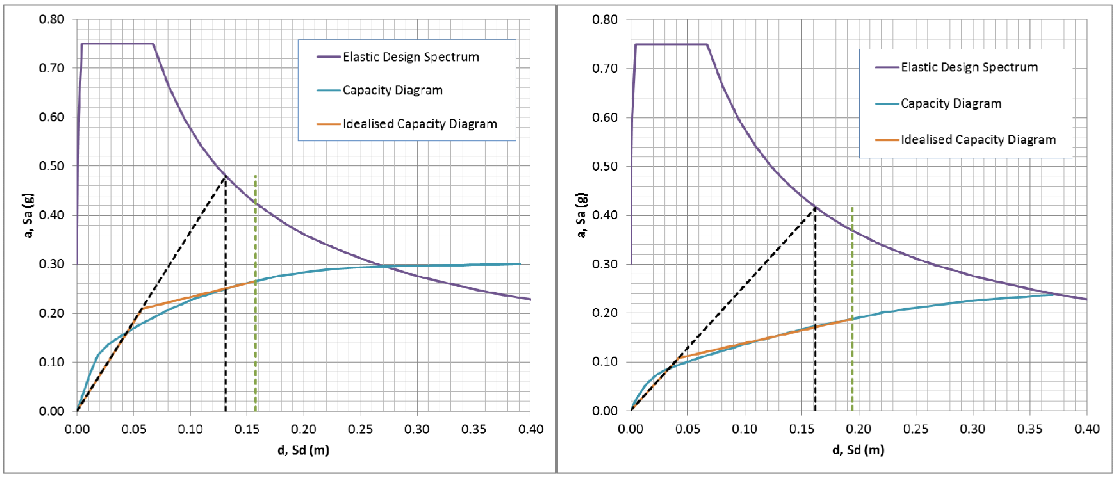

Figure 11: Inelastic displacement demand.

4 PERFORMANCE EVALUATION

The nonlinear deformations of the structural system elements were assessed considering the deformations limits given by Turkish Seismic Design Code [1]. Figure 12 shows the section damage limits.

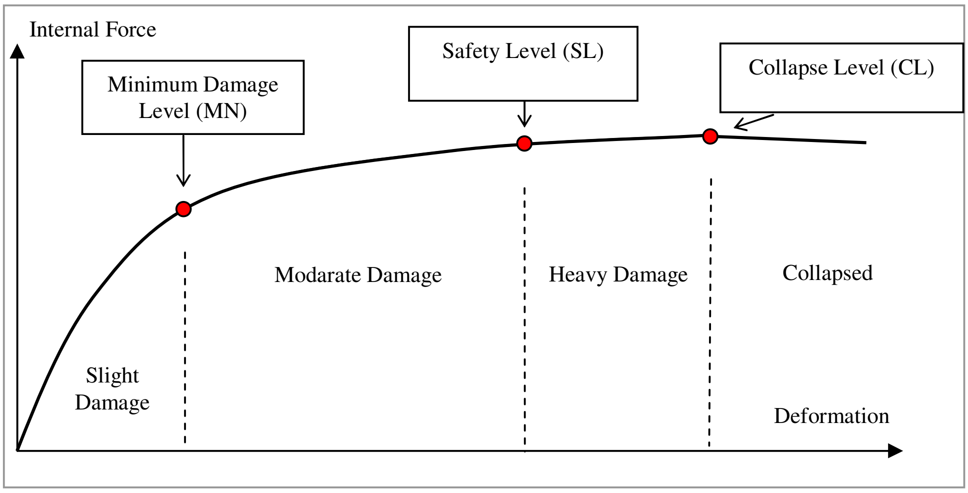

Figure 12: Section damage limits.

The plastic rotation demands of the beam sections are given in Figure 13 and 14 for both directions.

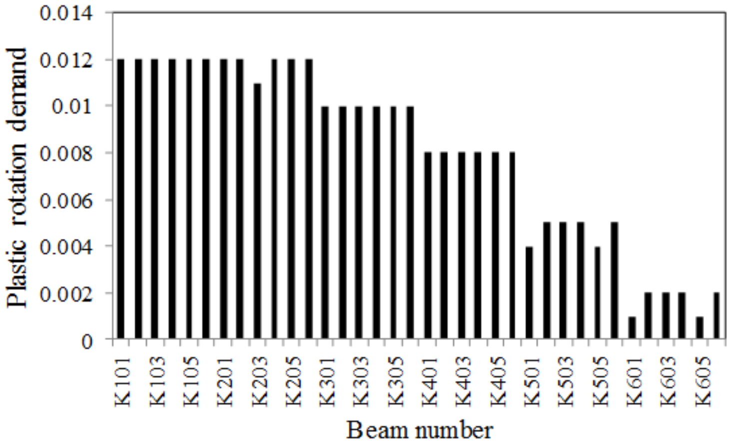

Figure 13: Plastic rotation demands of beams in X direction.

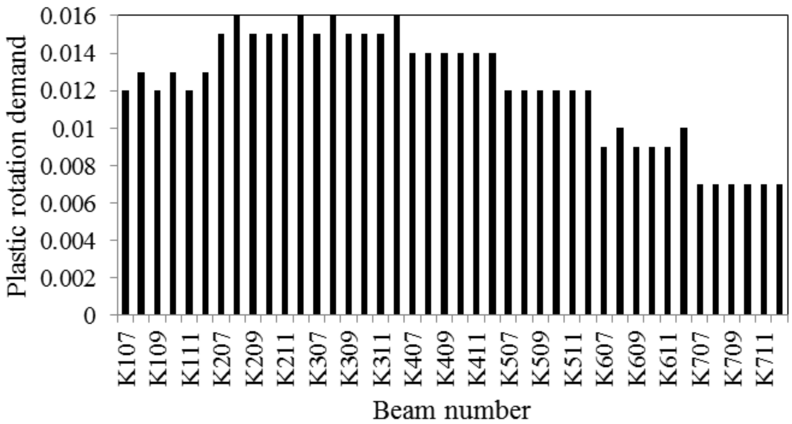

Figure 14: Plastic rotation demands of beams in Y direction.

All the plastic rotation demands of columns can not be given here because of space limitations. However plastic rotation demands and section damage limits for each direction of the mid-column are given in Fig. 15 and 16.

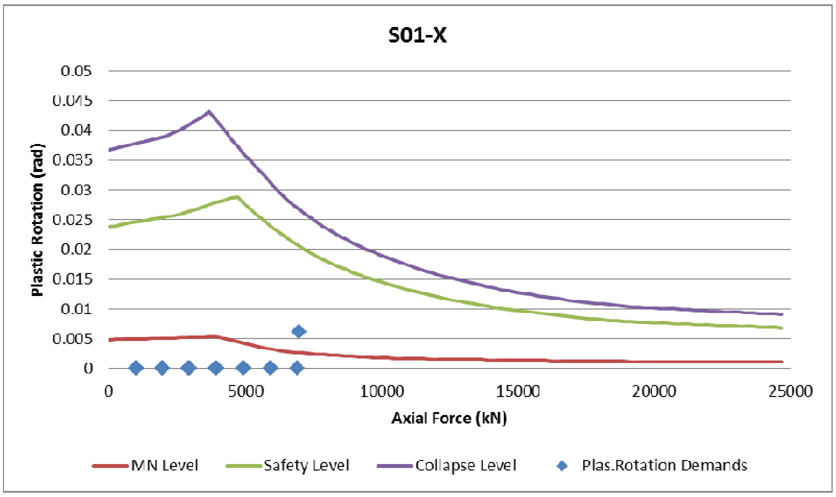

Figure 15: Plastic rotation demands of S101 in X direction.

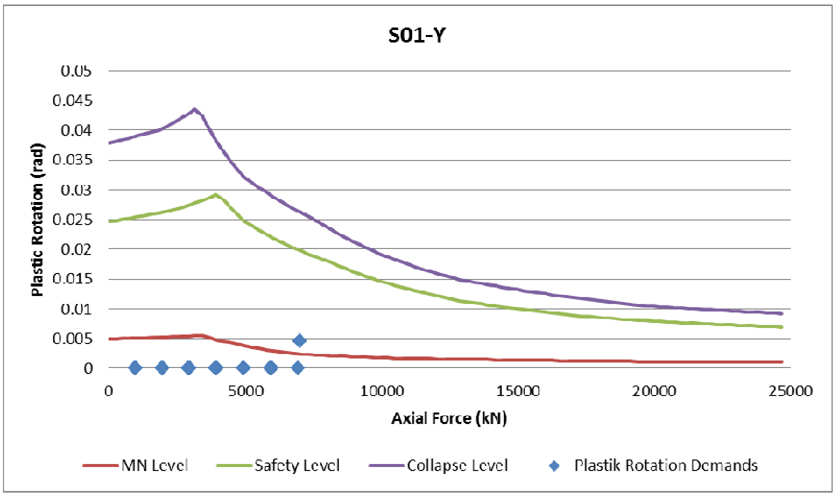

Figure 16: Plastic rotation demands of S101 in Y direction.

Plastic hinge distribution of 2-2 and B-B axis are given in Figure 17 and 18.

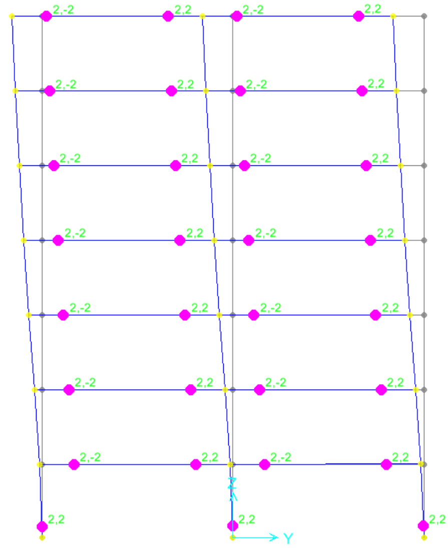

Figure 17: Plastic hinge distribution demands of 2-2 axis.

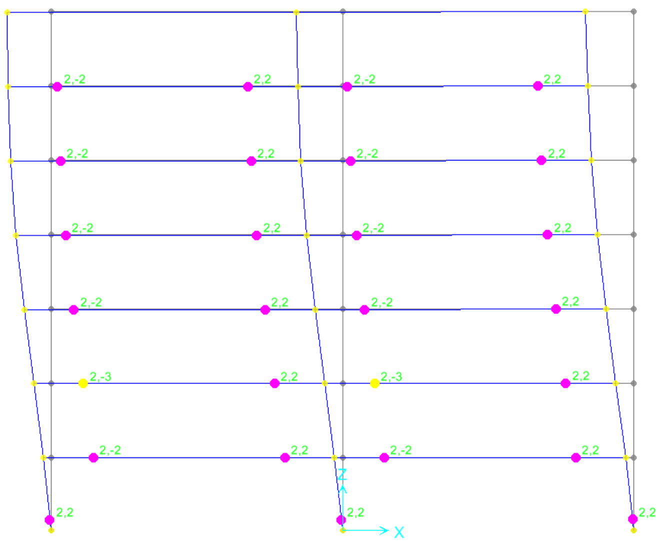

Figure 18: Plastic hinge distribution demands of B-B axis.

5 CONCLUSIONS

- All the plastic hinge rotations of beams are less than 0.02 for the design earthquake (%10 probability of being exceeded in 50 years). The only plastic hinge formation in columns is observed at ground level sections of columns. The plastic hinge mechanism is beam mechanism and damage is under the level of minimum damage for almost all section.

- The maximum interstory drift is %1.28 and %1.43 in X and Y directions, respectively.

- The building performance is Life Safety in both two directions for the design earthquake according to the regulations of Turkish Seismic Design Code.

- The building experienced two major earthquakes in 2011 with the moment magnitudes of 7.2 and 5.6 (October 23rd and November 9th, Van). The distance between the location of the building and the epicenter of the Earthquakes is about 30 km and 16 km, respectively. It should be noted that any structural damage was observed and the building was in the state of immediate occupancy after those Earthquakes.

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