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Effect of Effective Bending Rigidity in Pushover Analysis Considering Different Code Approaches

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Abstract:

The nonlinear behavior of reinforced concrete (RC) members under seismic loads can be different from predicted design behavior. The cross sectional effective bending rigidity (EI) of these members don't have same values with design process. This situation is one of the most crucial parameters effected nonlinear performance of RC structures. To define the behavior of cracked section of RC members, there are different approaches in earthquake design codes. These approaches are used to analyze and asses the performance of RC structures. In the study, values of effective bending rigidity (EI) of cracked section given in Eurocode-8, Turkish Seismic code 2007 and new draft Turkish seismic code 2016, are used in a case study of RC structures. The cracked section EI of structural elements on these structures are calculated according to the different design code approaches. They are also evaluated using moment-curvature relationship in Xtract programme. The pushover analysis are applied using all these different values on the different structural types. The base reaction force-top displacement demand, story displacement and drifts, plastic hinge mechanisms obtained from the analysis are compared.

Key words: Effective bending rigidity, earthquake codes, reinforced concrete elements, pushover analysis

1. Introduction

To determine the behavior of RC structures is very crucial when the nonlinear analysis methods are applied to assess the performance level of RC structures. Pushover analysis is the generally used method to evaluate performance of reinforced concrete structures under earthquake loads. In this method, displacement demand of a structure is calculated by increasing monotonically when force distribution due to lateral earthquake load is taken into account in a compatible form of fundamental first mode to the structure at story levels [1]. This increase of seismic displacement demand should been proceed until a reliable target displacement. Each structural element of RC structures is important in nonlinear analysis. In nonlinear analysis every single part of structural element affects the nonlinear behavior and performance level of RC structures directly. To define the behavior of RC structural elements, it should be known cross-sectional properties and behavior of these elements. Moment-curvature relationship is the best theoretical approach to represent the behavior of RC elements [2]. The effective bending rigidity of cracked section and ductility of cross section can be determined using this approach [3]. To define nonlinearity of the cross-sections, Mander confined and unconfined concrete model are used in pushover analysis [4]. In the study, twelve incremental single mode pushover analyses are achieved using the effective bending rigidity of cracked section for different design codes. These rigidities are

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defined in Turkish earthquake code (TEC 2007), Eurocode-8, Turkish draft earthquake design code for buildings (TECB 2016-Draft) respectively [5, 6, 7]. Besides the effective bending rigidity of cracked section are calculated using Xtract section analyze programme to define in pushover analysis for all same cross-sections [8]. All pushover analyses are completed using Sap2000 finite element software package [9].

2. Numerical Modelling and Parametric Study

In the study, an incremental single mode pushover analysis is achieved to evaluate real nonlinear displacement demand of structures under seismic loads. The displacement demand affects nonlinear deformations of structural elements directly. These deformations are evaluated using plastic hinge properties of each cross-section. Therefore defining plastic hinge properties of cross sections is very important to determine nonlinearity of structures in pushover analysis. In this part of the study, methodology of modelling are explained to archive numerical model in nonlinear analysis. In this research, to determine effect of EI twelve pushover analyses are applied for an eight stories RC frame structural model. In the analyses different cracked section EI are used considering different code approaches to compare values obtained from Xtract. The analysis results are compared in terms of nonlinear force-displacement relationship, story drifts, plastic hinge rotation and variation of first fundamental vibration mode of structure.

2.1. Modelling Superstructure

Three dimensional numerical models are designed as an eight-story RC structure according to the minimum design conditions defined in TEC 2007. It is accepted that all structural systems are constructed in first degree seismicity risk zone. Therefore they should have high ductility. Moreover soil conditions are assumed Z4 soil class defined in TEC 2007 for all structural models. In TEC 2007 it is proposed that the peak ground acceleration (A0) should have taken as 0.4g for first degree seismicity risk zone. Elastic-perfectly plastic behavior is defined for the stress-strain relationship of steel reinforcement. Mander confined and unconfined approaches are used for the nonlinearity of concrete material. Plastic hinge properties of each cross section are calculated by considering reinforcing details. These plastic hinges are determined according to the moment-curvature relationship of each different cross-section assigned end points of structural elements. The frame in red box is selected as a reference axis to be able to compare analysis results. Cross sectional and reinforcement details of the structural elements are tabulated in Table 1. Besides general layouts and plan views of three dimensional numerical models are given in Figures 1 and 2.

Table 1. Material and section properties of superstructure

Name	Element	Concrete - Reinforc.	Mod. of Concrete (Mpa)	Mod. of Reinfor. (Mpa)	Yield Strength of Reinforc. (Mpa)	Dimensions (mm)	Long. – Trans. Reinforc.
C1	Column	C25 – S420	30000	210000	420	600x250	10Φ16–Φ10/10
C2	Column	C25 – S420	30000	210000	420	250x600	10Φ20–Φ10/10
C3	Column	C25 – S420	30000	210000	420	600x250	10Φ20–Φ10/10
B1	Beam	C25 – S420	30000	210000	420	250x500	6Φ16–Φ10/10
B2	Beam	C25 – S420	30000	210000	420	250x500	6Φ20–Φ10/10

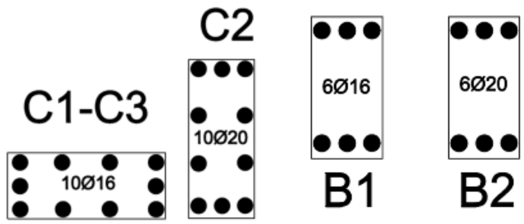

Figure 1. Reinforcement details of structural elements

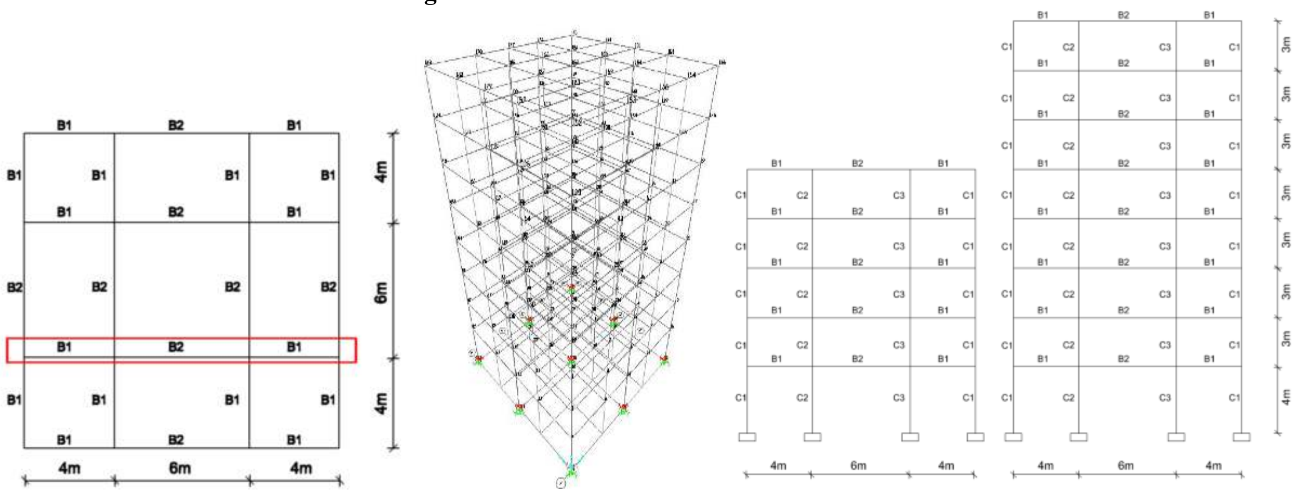

Figure 2. Plan view, 3D model and General layout of structural model

2.2. Parametric study

The EI of cracked section can be a very crucial parameter in nonlinear analyses. The parameter of cracked section EI is defined as different values in different earthquake design codes. The aim of this study is determining different EI of cracked section considering approaches of earthquake codes. Moreover these values of EI will be compared with the values obtained from Xtract section analysis programme. In the study, the EI of cracked section are used considering values defined in TEC 2007, Eurocade-8, and TECB 2016 draft earthquake codes respectively. The cracked sections EI are defined as a constant value for frame beam and column elements in Eurocode-8 and TECB 2016 draft version. In TEC 2007 the EI of for frame beam element are constant like others. For column elements this value should be calculated between 0.4-0.8 of initial rigidity according to the axial load level of columns. In Xtract programme the value of cracked section EI can be calculated with step by step solution for all beam and column elements. In the section analyses any axial load level can be taken into account for all column section. Moment-curvature relationships are used when these values are calculated. In every step of section analysis the deformation of reinforcement, confined and unconfined concrete are controlled according to the limit deformation which are defined for failure mode of material. Each EI value is given as a ratio of initial rigidity for Xtract and other earthquakes codes in Table 2. These values are defined in structural models using Sap2000 when pushover analyses are applied. The nonlinear force-displacement relationship obtained from pushover curves, story displacements and drifts, plastic hinge rotation and variation of first fundamental vibration mode of structure are selected to be able to make a comparison between analysis results.

Table 2. Material and section properties of superstructure

Name	Element	Dimensions (mm)	Initial EI (kNm^2)	EI of Eurocade-8	EI of TEC 2007	EI of TECB 2016 draft	EI of Xtract
C1	Column	600x250	135000	0.5	0.48-0.62	0.7	0.33-0.35
C2	Column	250x600	23438	0.5	0.78	0.7	0.34
C3	Column	600x250	135000	0.5	0.74	0.7	0.355
B1	Beam	250x500	78125	0.5	0.4	0.35	0.22
B2	Beam	250x500	78125	0.5	0.4	0.35	0.32

3. Results

In the study, pushover curve is used to explain the relationship between base shear force and roof displacement in nonlinear analysis. In numerical analysis displacement and force demand of structures which are obtained from pushover curves are compared in Figure 6. Moreover pushover curves are also used to determine for performance level of each numerical model. In the analysis four different EI ratio of initial EI obtained from different design codes, are used and compared using pushover analysis. Firstly, only the EI of beams are changed when the columns are as constant and initial value for EI. Secondly only the EI of columns are changed when the EI of beams are accepted as constant and initial value. In last part of the study, calculated EI obtained from design code and calculated with Xtract are used for beams and columns. The results obtained from analysis are compared in Figure 6 and Figure 7. When the analysis result are compared that the nonlinear force and displacement demand increases when calculated EI obtained from Xtract is taken into account in nonlinear analysis. Additionally, yield force and displacement are changing with the different approaches of design codes.

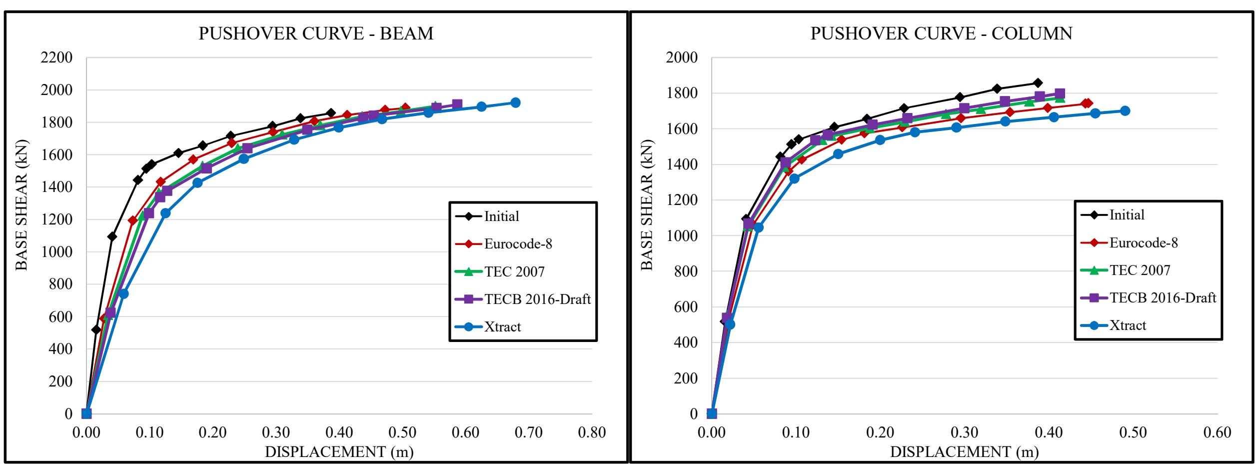

Figure 6. Pushover curves

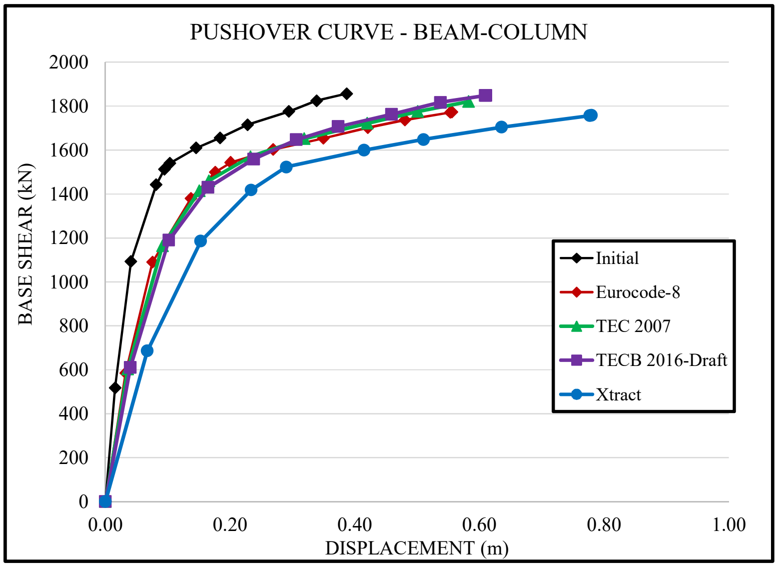

Figure 7. Pushover curves

3.2. Structural demands

Determining target displacement values is the most crucial part of nonlinear analysis. The plastic deformations of RC elements obtained from nonlinear analysis are calculated according to these target displacement values. These plastic deformations determine the real nonlinear performance level of a structure. Target displacements are calculated by means of measuring horizontal deflection value at the top of structures. The difference of base shear, roof displacement, displacement ductility and period of fundamental mode for different structural models are tabulated Table 3 considering different code approaches. The variation between structural models are shown for models whose EI is changed for beams, columns, both beam and columns separately.

Table 3. Variation of structural demands

Element		Initial	Eurocode-8	TEC2007	TECB2016-Draft	Xtract
Beam	Base Shear (kN)	1856.86	1889.15	1899.45	1909.78	1921.45
	Roof Disp. (m)	0.39	0.50	0.55	0.59	0.68
	Periyod T (s)	1.25	1.55	1.67	1.75	1.97
	Ductility	3.75	4.21	4.8	5.02	5.43
Column	Base Shear (kN)	1856.86	1742.91	1773.36	1798.15	1700.77
	Roof Disp. (m)	0.39	0.45	0.41	0.41	0.49
	Periyod T (s)	1.25	1.41	1.33	1.32	1.54
	Ductility	3.75	4.18	4.8	4.72	5.02
Beam-Column	Base Shear (kN)	1856.86	1772.52	1820.52	1848.40	1758.45
	Roof Disp. (m)	0.39	0.56	0.58	0.61	0.78
	Periyod T (s)	1.25	1.71	1.75	1.82	2.26
	Ductility	3.75	3.16	3.85	3.7	4.04

3.3. Story drifts

Story drift is calculated by dividing the difference in horizontal deflection of top and bottom of a story to the height of this story. This drift is one of the most direct values to make an assessment about the nonlinear performance level of a structure. In different earthquake design codes of different countries some limitations are defined for story drifts when determining performance level of structures. The limitations of TEC2007 are used in this study and defined for immediate occupancy, life safety and collapse prevention performance levels as 2%, 3% and 5% respectively. The difference of story drifts obtained from different structural models calculated according to the story displacement. The variations of story drifts and displacements are shown in Figure 7, 8 and 9.

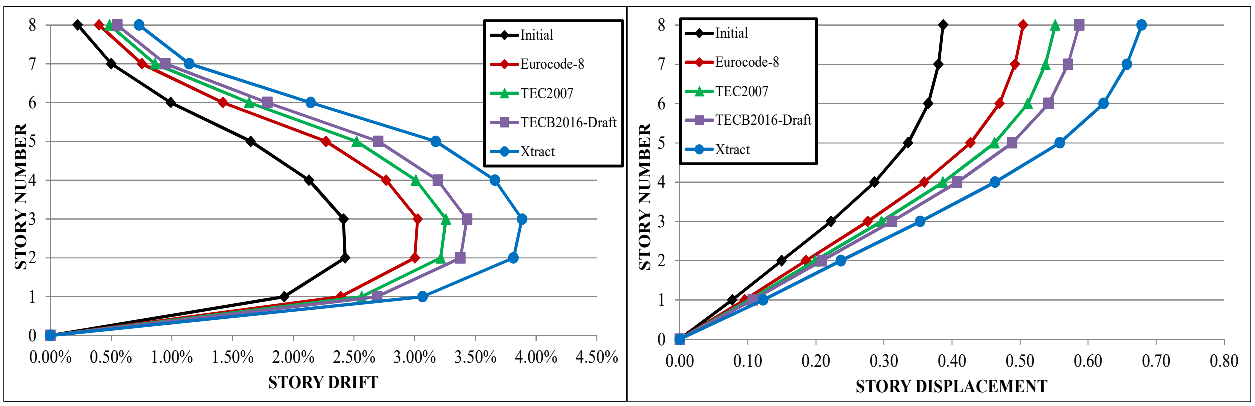

Figure 7. Story displacements for model changed EI of only beams

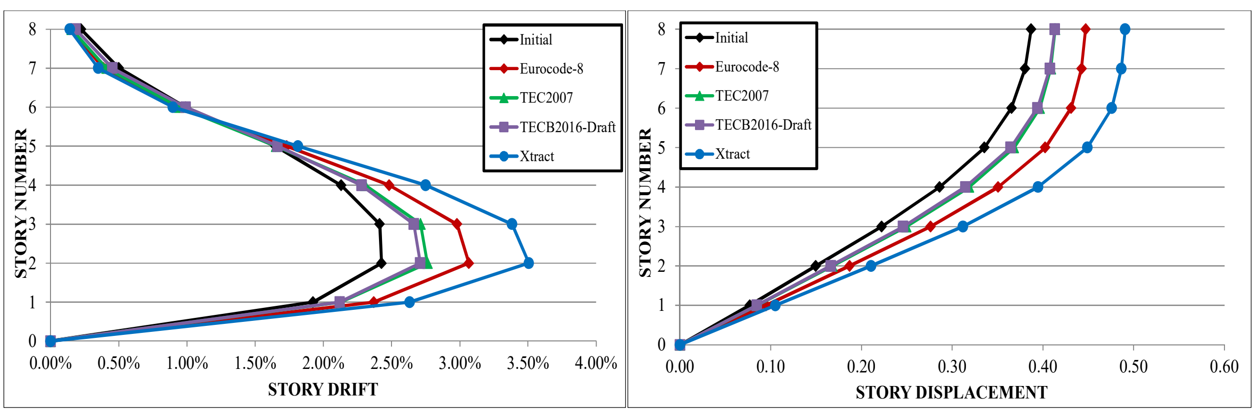

Figure 8. Story displacements for model changed EI of only columns

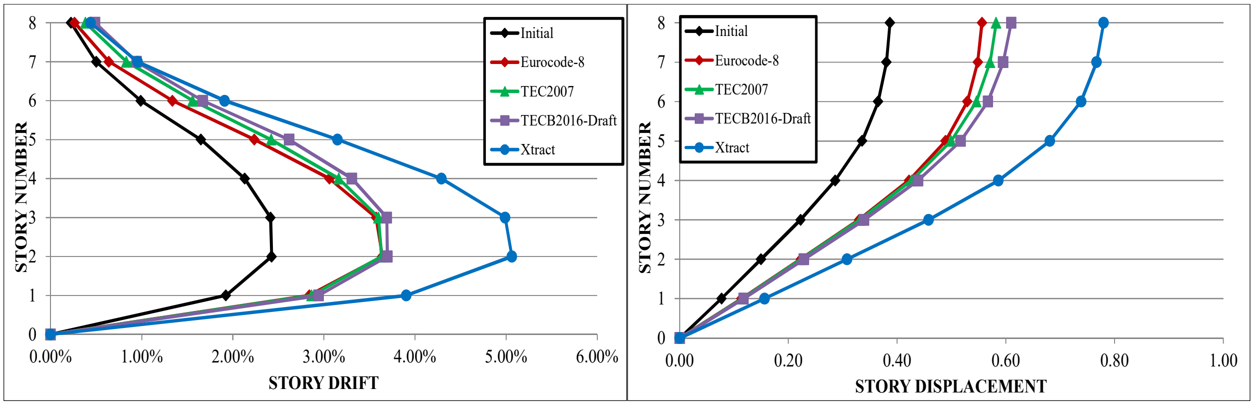

Figure 9. Story displacements for model changed EI of both beam and columns

3.4. Plastic Hinge Mechanisims

In earthquake design codes column-beam connections are defined one of the most crucial part of a structure under seismic loads. To prevent brittle collapse, there are defined some special design rules for these connections. Strong column - weak beam assumption is generally proposed to be able to make more ductile design for RC structures. In the study, analysis results showed that this analogy couldn't be provided due to different approaches of design codes. Moreover, some new plastic hinge mechanism can be observed in a structural system according to the value of EI. By means of using different EI approaches, these plastic hinge rotations can increase when results are compared. For instance, the differences of plastic hinge mechanisms are shown in Figure 9.

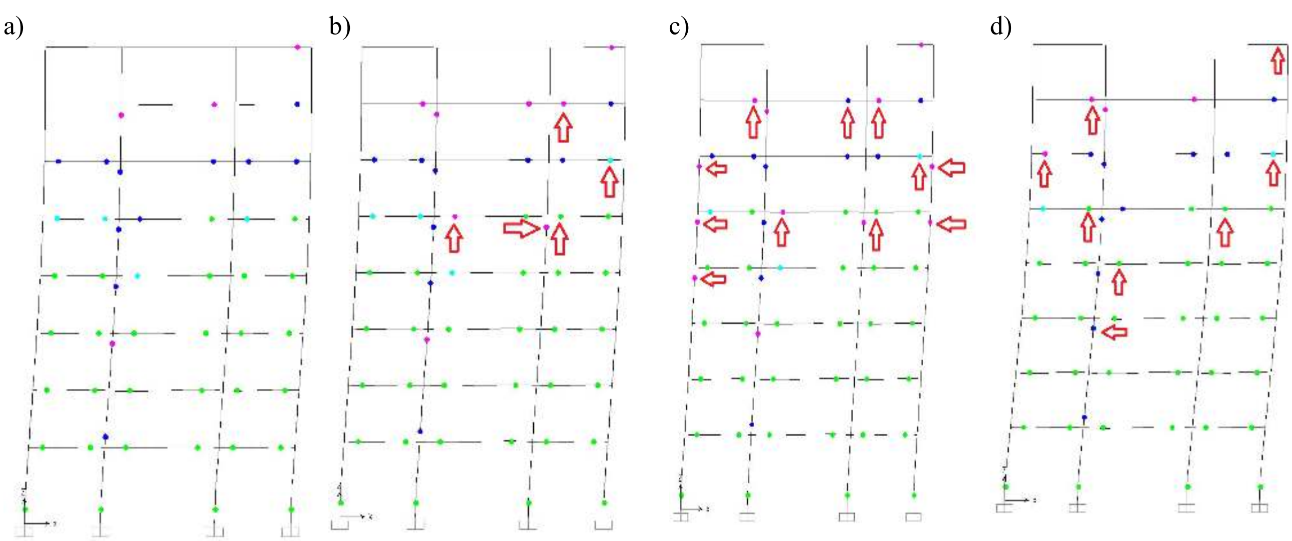

Figure 9. Plastic hinge formation a) Eurocode-8 b) TEC2007 c) TECB2016-Draft d) Xtract

4. Conclusions

The effect of EI is seemed that different approaches of codes can cause making different assessment for same structures in nonlinear analysis. As the EI decreases due to the code assumptions, performance levels of structures can change in numerical models negatively. Moreover, the numerical model whose EI value calculated with Xtract programme has more displacement demand than other numerical models whose EI defined according to the design codes. From analysis results, the following conclusions can be concluded:
1-) When pushover curves are compared, structural system has different displacement and force demand. The numerical model whose EI calculated with Xtract is less rigid than the other models.
2-) It is seemed that the roof displacement and the displacement demand can become bigger values as the rigidity of structure decreases. Besides the greatest displacement demand occurs in numerical model whose EI calculated with Xtract. This numerical model has more ductile behaviour than the others.
3-) The story drifts can reach critical limit values with different assumptions of EI. The difference of story drifts between numerical models decreases at the top of structures. The critical difference occurs at the first three stories of structures generally. The results of story drifts can be observed apparently when the EI of only beams are changed.
4-) When the effect of EI is taken account into in nonlinear analysis, it is observed that some beam mechanism can change to column hinge mechanism for numerical models. Plastic hinge rotations can reach high values with the increasing of displacement demand. The differences between models are more apparent when the EI of column and beam are changed together.

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