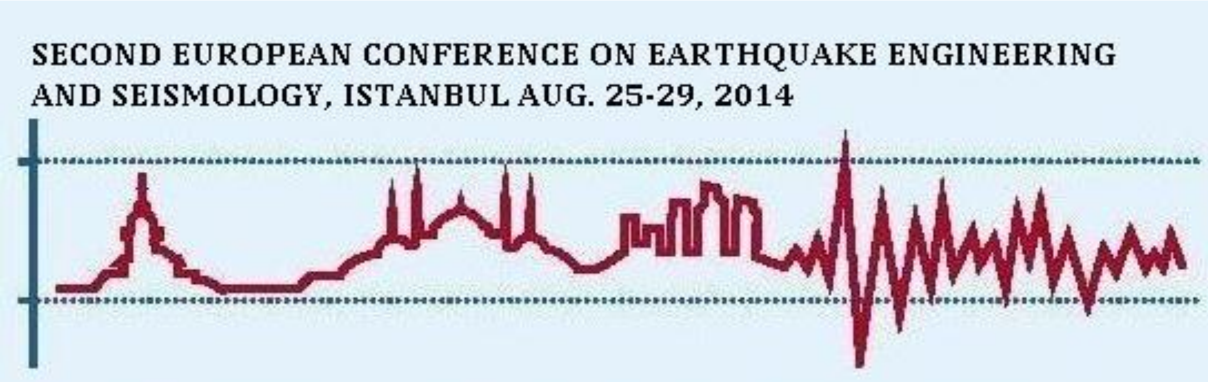

EFFECT of NUMBER of STORY and SOIL CLASS in NONLINEAR PUSHOVER ANALYSIS of TWO DIMENSIONAL RC FRAMES CONSIDERING SOIL STRUCTURE INTERACTION

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ABSTRACT

Two-dimensional soil structure interaction analysis is carried out with nonlinear pushover analysis to discuss the effect of story number and soil class on the performance level of RC structures. Nonlinear incremental single mode pushover analysis method is used in finite element software package, SAP2000 for a three bay frame structure with three, five and eight stories. Soil-structure interaction is modeled by means of foundation impedance functions, which represent static stiffness of surface foundations for elastic soil behavior. These functions are defined by taking shear wave velocity for each soil types given in American Society of Civil Engineering (ASCE) 41-06 for spread foundation with 2.0 m x 2.0 m in dimension. Comparison criteria are selected as target displacements, story drifts, plastic hinge mechanisms and rotations obtained from pushover analysis of superstructure. All these results from rigid soil behavior are compared with those obtained from three, five and eight story and C, D, E soil classes. The effect of story number is more apparent if soil interaction is ignored. As the soil rigidity softens the displacement demand and the plastic hinge rotations increase. In other words, an elastic deformation in the structure can change into a plastic deformation when impedance functions are employed in the analysis.

INTRODUCTION

Evaluation of seismic force resisting capacity of structures is extensively made by pushover analysis. In pushover analysis seismic demands are computed by increasing lateral forces monotonically until a target displacement is reached. Force distribution is applied in a form like fundamental mode. (Chopra A.K. et al., 2001). Nonlinear seismic analysis of soil-structure interaction (SSI) system can also be done by pushover method if it is modified and adopted for the nonlinear seismic analysis (Liping L. et al., 2012). However, using SSI in pushover analysis is generally ignored due to the modeling difficulties of defining the effect of soil condition to the superstructure, Defining SSI by employing foundation impedance functions given in ASCE 41-06 can be a solution to define the soil-structure interaction behavior in pushover analysis. In recent years, there are also some limited pushover analysis related researches in which impedance functions are employed. Some researchers used nonlinear impedance functions defined by Gazetas (1990) to model the seismic behavior of framed structures. In a research influence of inelastic dynamic soil–structure interaction on the seismic vulnerability assessment of buildings is also investigated and it has been found that a there is a reduction in seismic demand when SSI is considered (Saez E. et al., 2011).

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In this study, effect of foundation geometry and soil class in nonlinear pushover analysis is investigated by considering two-dimensional soil structure interaction. Nonlinear incremental single mode pushover analysis is used for the purpose of modeling three stories and three bay Reinforced Concrete RC frames with commercial finite element software package, SAP2000.

NUMERICAL MODELLING

Numerical modelling of structure is constructed by employing commercial software package, SAP2000, which can handle pushover analysis. Nonlinear incremental single mode pushover analysis is essential in this study because nonlinear displacement demand is required to represent the real behavior of structure excited with earthquake loads. Performance level of structures are addressed with this displacement demands. Defining plastic hinge properties of cross sections, which are needed in pushover analysis, is very important. Modelling strategies of superstructure and substructure is given in detail in this section.

Modelling of Superstructure

Three bay-three, five and eight story, RC frames are designed with the minimum cross-section design conditions required by Turkish Earthquake Code 2007 (TEC2007). Steel reinforcements are modeled as elastic perfectly plastic. Concrete material behavior is modeled by employing Mander approach. Plastic hinge property of each confined cross section is determined by considering longitudinal and transverse reinforcement given in Table 1 by calculating moment-rotation capacity. Once these plastic hinges are determined then they are assigned at the end points of columns and beams.

General layouts of the frames are presented in Figure 1. Cross section details of the structural elements are given in Table 1.

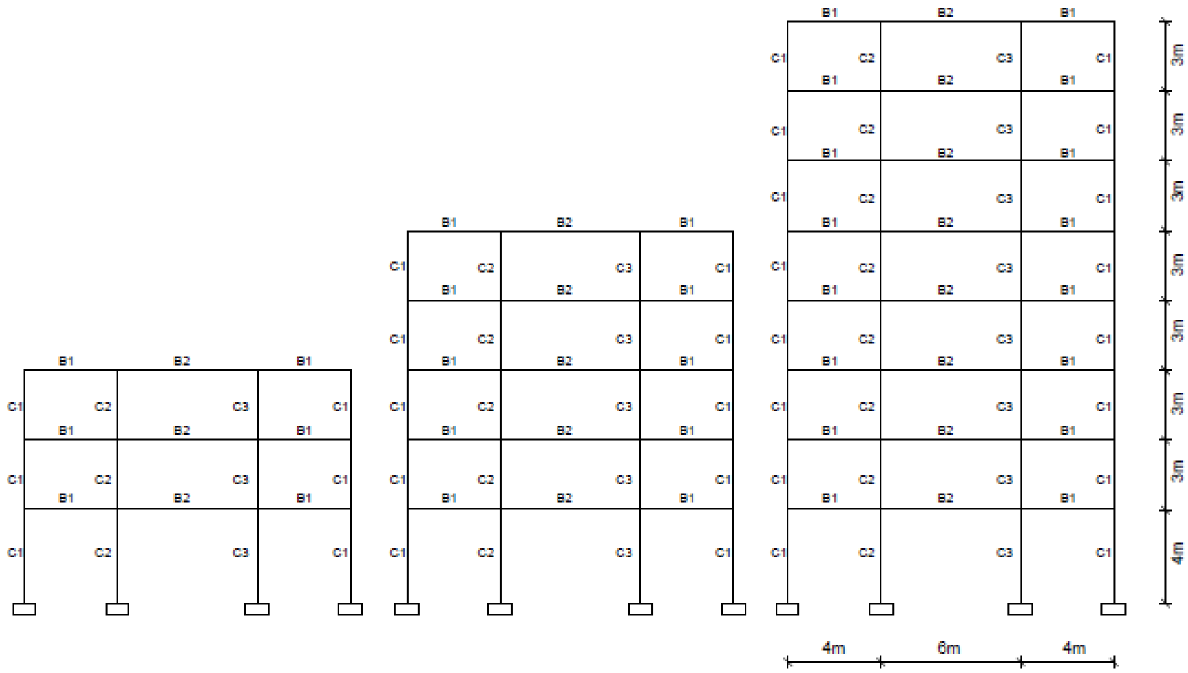

Figure 1. General layout of the frames

Table 1. Material and section properties of superstructure

Section Name	Element	Material Concrete – Reinforcement	Modulus of Concrete (Mpa)	Modulus of Reinforcement (Mpa)	Yield Strength of Reinforcement (Mpa)	Dimensions (mm)	Longitudinal – Transverse Reinforcement
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

Modelling of Substructure

Soil structure interaction is modelled by using spring stiffness solutions that are applicable to any solid basement shape on the surface of a homogeneous half space studied by Gazetas (1990). Thus, soil-structure interaction is modelled by means of foundation impedance functions, which represent static stiffness of surface foundation for elastic soil behavior. In this study translational and rocking stiffness for spread footing given in American Society of Civil Engineering (ASCE) 41-06 is considered. Gazetas (1990) defined these impedance functions by using both dimensions of the footing and shear modulus calculated by using shear wave velocity of soil along with its Poisson’s ratio. Spring stiffness representing soil classes are calculated for four different soil classes by using equation 1&2 and they are tabulated in Table 2.

$$K_{x,translition} = \frac{GB}{2-\nu}\left[3.4\left(\frac{L}{B}\right)^{0.65} + 1.2\right] \quad (1)$$

$$K_{xx,rocking} = \frac{GB}{2-\nu}\left[0.4\left(\frac{L}{B}\right) + 0.1\right] \quad (2)$$

PARAMETRIC STUDY AND RESULTS

Four different soil classes and three different structural heights are used to find out the effect of number of story and soil class on the pushover analysis of structure. C, D and E soil classes are selected from ASCE 41-06 for having lower shear velocities. However, a sub soil class of E with 70 m/s shear velocity is also selected to show the importance of SSI in soft soils. Foundation geometry is selected 2 m by 2 m square. For each soil classes and shear modulus, translational and rocking stiffness are calculated and tabulated in Table 2. These stiffness values are used to define the spring properties used in finite element modeling.

Table 2. Translation and rocking stiffness of springs represent different soil classes

Soil Class	Shear Wave Velocity (m/s)	Shear Modulus (kN/m^2)	Stiffness (kN/m^2)					
			Translation Along			Rocking About		
			x	y	z	x	y	z
C	564	572573	3154294	3154294	4016557	3418346	3418346	4763807
D	275	136125	749910	749910	954907	812687	819188	1132560
E	120	25920	142793	142793	181827	154746	155984	215654
E (2)	70	8820	48589	48589	61872	52657	53078	73382

Once the pushover analysis are completed by employing finite element software package, the effects of soil classes and number of story are evaluated by comparing values of target displacements, story drifts and plastic hinge mechanisms formation obtained from both considering rigid soil medium behavior and impedance function.

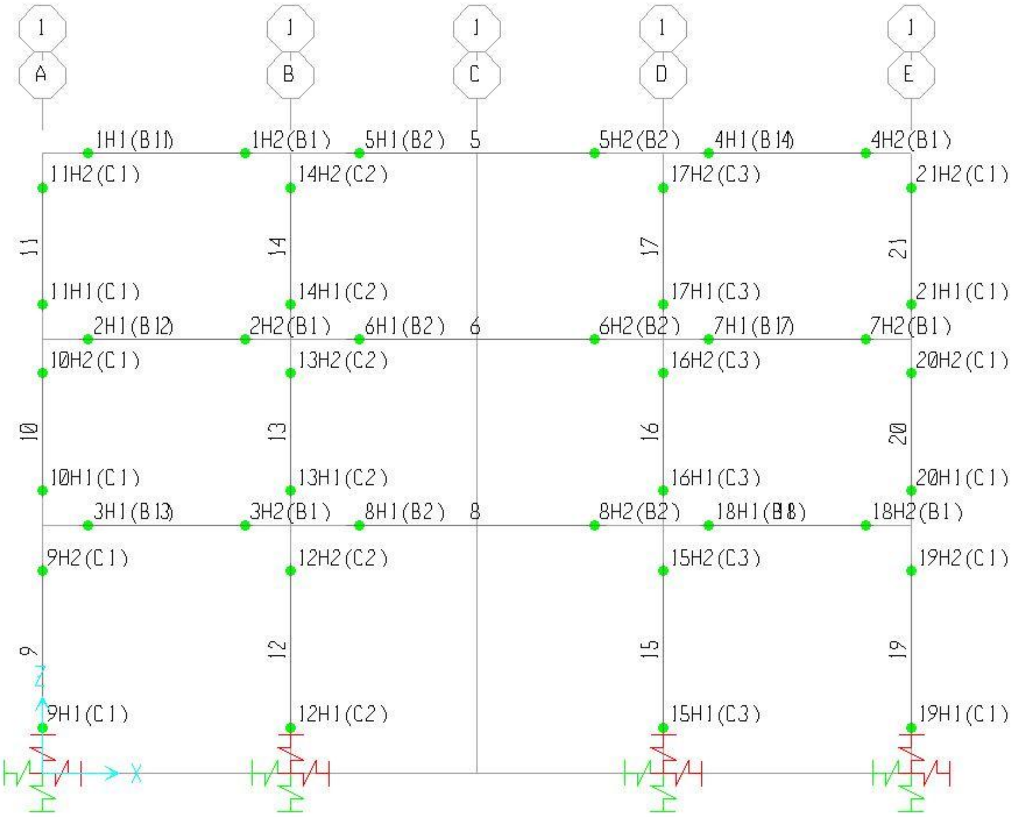

Figure 2. Finite element model of superstructure considering SSI with plastic hinge assignments at member ends

Target Displacements

Target displacement values are used to calculate the plastic hinge rotations that are needed to determine the performance level of a structure. Target displacement is the horizontal deflection value at the top of the given structure. Variation of target displacement demand of different structural heights for each soil classes are given in Table 3. As the soil rigidity softens and the number of story increases the displacement demand gets higher. In other words elastic deformation in the structure can change into a plastic deformation when impedance functions are employed in the analysis. Ignoring soil-structure interaction behavior for soil class C and D is not very sound. Maximum difference between rigid case and soil-structure interaction case is calculated 51.2%.

Table 3. Variation of displacement demand for soil classes

Number of Story	Displacement Demand for Soil Classes (m)											
	Class C			Class D			Class E			Class E (2)		
	Rigid	Imp. Func.	Variation (%)	Rigid	Imp. Func.	Variation (%)	Rigid	Imp. Func.	Variation (%)	Rigid	Imp. Func.	Variation (%)
3	0.079	0.079	0	0.139	0.141	1.4	0.189	0.206	9.0	0.189	0.236	24.9
5	0.144	0.144	0	0.250	0.253	1.2	0.346	0.376	8.7	0.346	0.428	24.0
8	0.250	0.251	0	0.435	0.445	2.3	0.603	0.663	10.0	0.603	0.912	51.2

Story Drifts

Story drift value, the difference in horizontal deflection at the top and bottom of a story, can be used to determine the performance level of a structure. In ASCE41-06 there are story drift limits for each performance level of the structures. For Immediate Occupancy performance level 2%, for the Life Safety performance level 3%, for the Collapse Prevention performance level 5% story drift value are determined. Story drift value for each story level is plotted in Figure 3 for each structural height. In each plot effect of SSI is also considered. For soil class E(2) performance level changes into an unconservative way for the same structure if impedance functions are not included in the analysis. When SSI considered the performance level changed into Collapse from Collapse Prevention performance level. Story drift value for each story level is plotted in Figure 3 and Figure 4 for each RC frame.

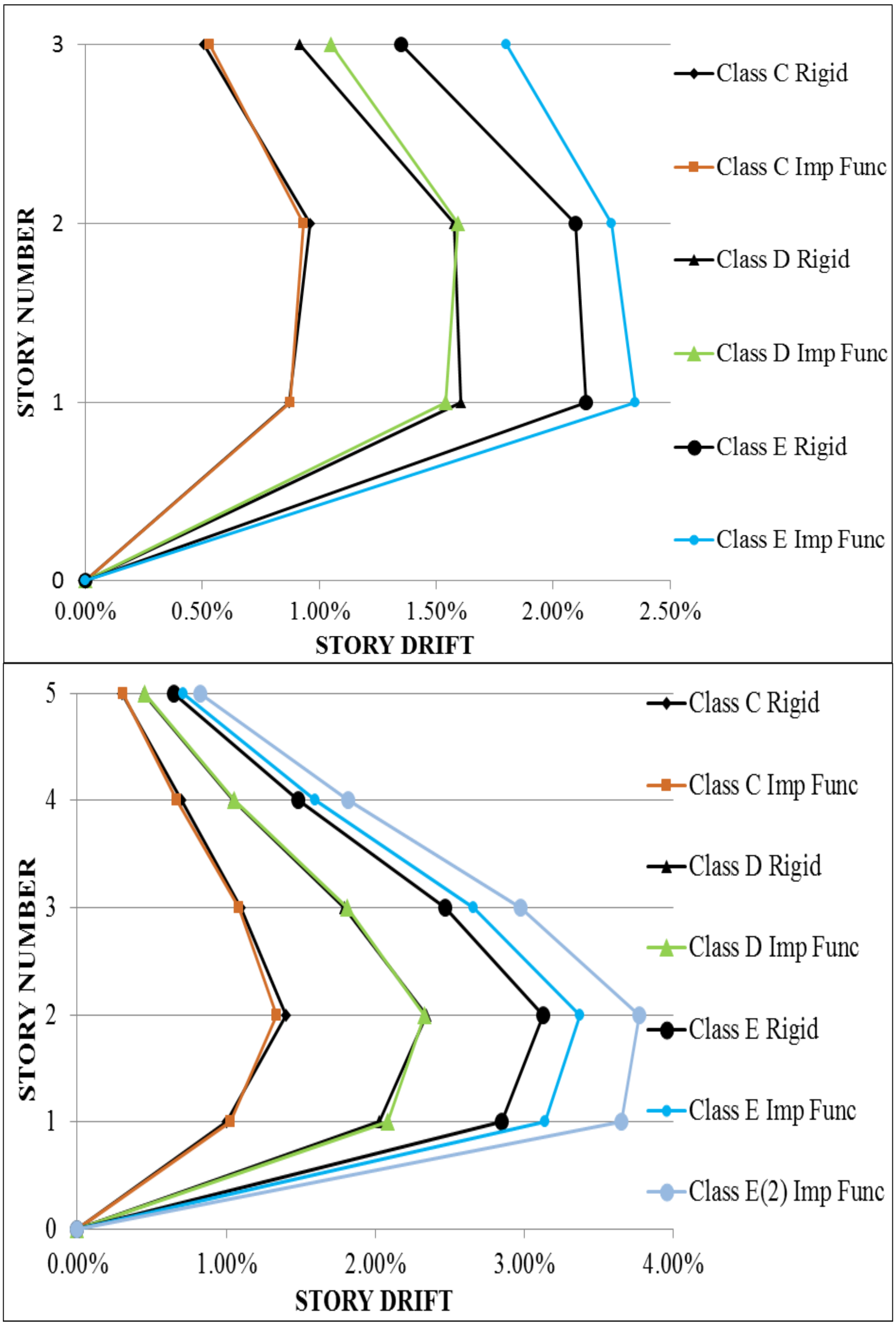

Figure 3. Comparisons of story drift variation for different soil conditions with rigid soil behavior a) three story frame b) Five story frame

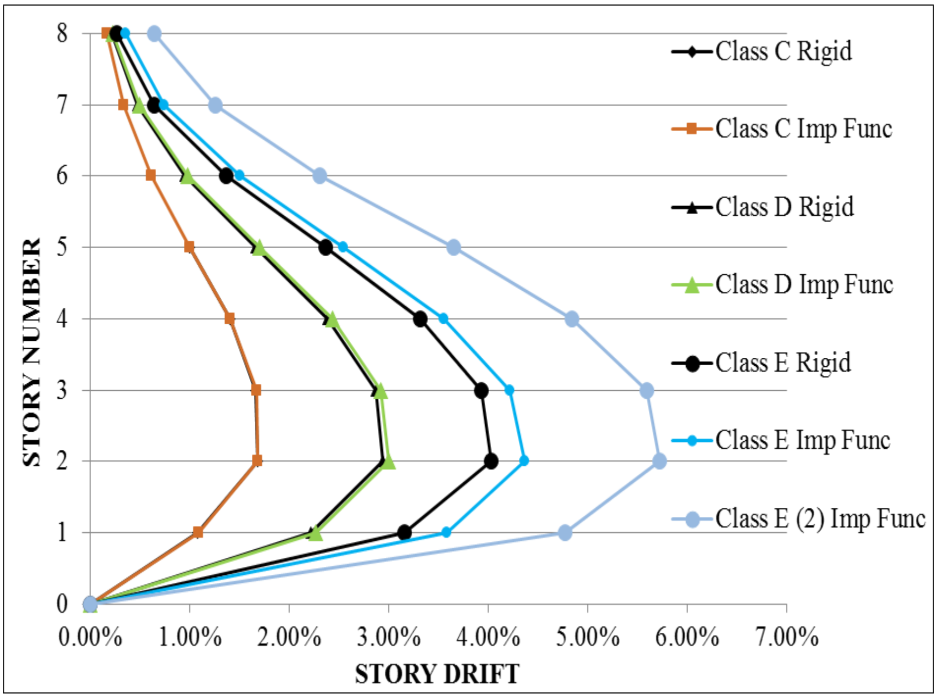

Figure 4. Story drift variation for different soil conditions with rigid soil behavior eight story frame

Plastic Hinge Mechanisms

It is desired to have plastic mechanism at beam edges for achieving beam mechanism rather than frame mechanism. Results showed that mechanism formation sequence could be changed when soil-structure interaction is considered. Moreover, a plastic hinge formed in a model with soft soil condition can disappear in a model with rigid soil condition. For instance, the change in the Plastic hinge formation sequence can be seen in Figure 5 and in Figure 6 for five and eight story RC frame.

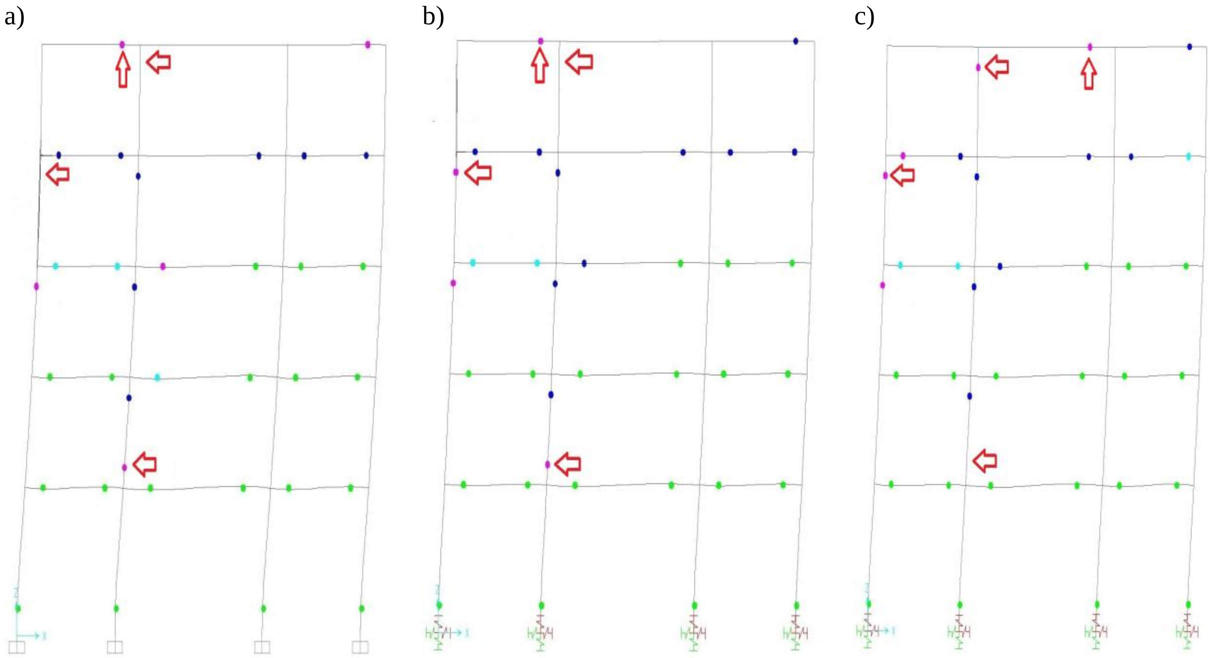

Figure 5. Variation of plastic hinge formation mechanism on five story RC frame for a) Rigid soil condition b) Soil Class E – V_{shear} = 120 m/s c) Soil Class E – V_{shear} = 70 m/s

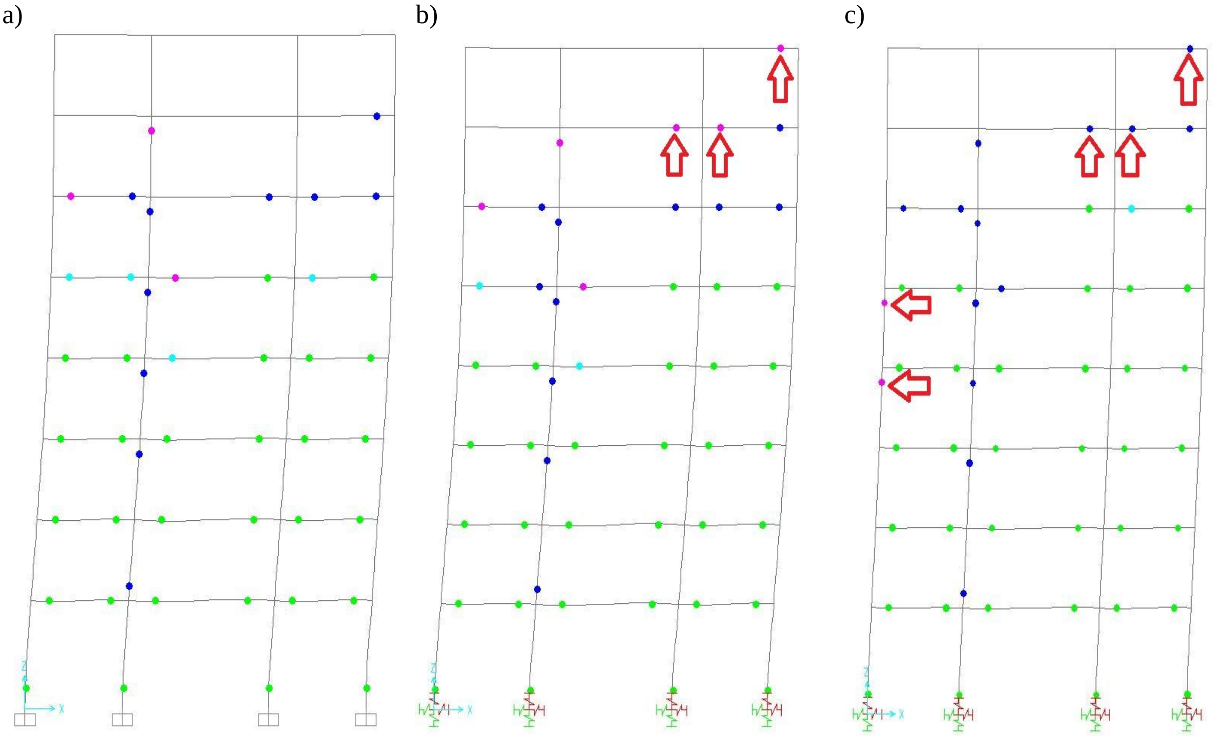

Figure 6. Variation of plastic hinge formation mechanism on eight story RC frame for a) Rigid soil condition b) Soil Class E – V_{shear} = 120 m/s c) Soil Class E – V_{shear} = 70 m/s

CONCLUSIONS

Including soil-structure interaction behavior in pushover analysis must be considered especially when soil class E are used. Neglecting such behavior can change performance level in unconservative way. Furthermore, as the shear wave velocity in soil class E decreases, the SSI effect gets sounder than other situations. According to the analysis results, the following conclusions can be summarized:

1-) The roof displacement and the displacement demand increase as the soil rigidity decreases when pushover analysis is used considering soil-structure interaction. The biggest difference between results when impedance functions are not ignored is obtained for in soil class E. Moreover, the difference also gets higher with the increased structural height.

2-) The story drift, which also defines performance level in ASCE 41-06, reaches critical limit when the structural height increases whereas the soil rigidity decreases. Especially these results are more significant on eight story RC frame.

3-) Plastic hinge rotation value gets higher as the roof displacement increases. Plastic hinge formation mechanism also changes especially in columns of five and eight story RC frame when soil structure interaction is considered.

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