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SEISMIC PERFORMANCE OF A RC SCHOOL BUILDING CONSIDERING DIFFERENT SOIL CLASSES

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Abstract: Occurrence of major material damage and loss of lives due to earthquakes in our country show that the earthquake safety of existing building stock is not enough. It is important of great importance to determine seismic performance of existing buildings. However, some building types have great importance such as school buildings, hospitals etc. A reliable performance estimation is very important to achieve seismic safety of this type of buildings. Seismic performance of a building depends on not only its behavior but also the soil class on which it is constructed.

In this study, performance estimation of an existing RC school buildings has been conducted considering different soil types. The aim of this study is to determine the seismic behavior of school type RC buildings considering different soil classes. For this purpose, a five-story reinforced concrete (RC) school building was selected to evaluate the seismic performance and this building designed according to Turkish Seismic Code (TSC) 1975. The seismic performance of the existing building is estimated according to TSC 2007 using Nonlinear Static Procedure (NSP) considering different soil classes as A, B, C and D. NSP is also referred to as Pushover Analysis Method. Pushover curve is transformed to modal capacity diagram and the inelastic displacement demand of the building is estimated by intersecting the modal capacity diagram and the behavior spectrum, which is estimated by transforming the design spectrum given in TSC 2007. Soil class is considered by changing the corner periods of design spectrum. Thus, performance level is estimated for the design earthquake by using the design spectrum.

Keywords: Seismic performance, reinforced concrete, pushover analysis, soil class.

Introduction

Most of existing buildings do not meet the current design standards due to design shortage or construction shortcomings. There are various reasons such as the lack of a national code, the noncompliance with applicable code requirements, the updating of codes, the design practices and changes in the use of buildings. Therefore, existing buildings should be evaluated regarding their capacity for resisting expected seismic effects before rehabilitation works [1].

It is believed that the conventional elastic design analysis method cannot capture many important aspects that affect the seismic performance of the building. The ability of a building to undergo inelastic deformations determines the structural behavior of building during seismic ground motions. For that reason, the evaluation of a building should be based on the inelastic deformation applied demanded by an earthquake, besides the stresses induced by the equivalent static forces as specified in seismic regulations and codes [2, 3].

Nonlinear dynamic analysis is a principally convenient approach. However, it is very complex and not practical for every design. Such analysis faces certain difficulties, such as the complexity of the three dimensional modeling structure, uncertainty of the structural properties, and the randomness of the ground motion data

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required for analysis. From the practical point of view, this method is not suitable for every design use, and for the time being it is mostly appropriate for research and design of important structure [4, 5].

Turkish Earthquake Code (TSC) 2007 presents various methods to be used in the evaluation of seismic performance of buildings. Some of these methods are linear method a force based method, inelastic methods a deformation based method.

To estimate seismic demands of a building, the structural engineering profession is now using the non-linear static procedure, known as pushover analysis. The term static implies that static analysis is applied to represent a dynamic phenomenon [6, 7].

Static pushover analysis is a nonlinear calculation method which is done by constant increment of horizontal loads under constant vertical loads. In the static pushover analysis method, the deformation behaviors of all elements of a building are defined. In this calculation method, the material also utilizes the plasticity capacity outside the elasticity limits. [1].

Estimation of seismic performance of an existing building is important but it is more important to estimate the seismic performance of a public building such as schools, hospitals. It is important because these type of buildings should be used after an earthquake and has no damage or insignificant damages. Thus, the reliability of seismic performance estimation of this type of buildings is very important.

Analytical models of the buildings are prepared very carefully for seismic performance estimation however, soil – structure interaction has a considerable effect on performance of the buildings. Soil classes on which buildings were constructed should be known clearly.

In this study, seismic performance of a five-storey reinforced concrete school building, which was designed according to the Earthquake Regulations of 1975, was conducted considering different soil classes. Performance evaluation was estimated according to TSC 2007. The selected performance estimation method is nonlinear static procedure (NSP).The building was modeled in SAP2000 software.

The Concept of Pushover Analysis and Performance Analysis

Nonlinear analysis methods give quite approximate results on seismic behavior of structures. It also allows realistic solutions to be produced because it can provide results that will show the state of the mechanism related to the behavior of the building under the effect of an earthquake. There are three types of nonlinear analysis methods within the scope of TSC2007 [9]. These; Incremental Equivalent Earthquake Load Method, Incremental Mode Combination Method and Time History Analysis Method. In this study, Incremental Equivalent Earthquake Load Method was used as a performance estimation method.

Analysis Method

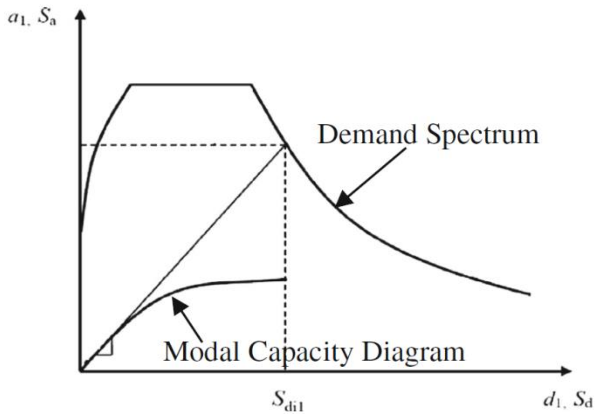
NSP can be applied to buildings not exceeding eight storeys and have $\eta bi<1.4$. In addition, the first mode mass participation factor should not be less than 0.70. Cracked section stiffness (effective stiffness) is used and lumped plasticity assumption for plastic hinge is used for nonlinear behavior. Effective bending rigidities (EI)e of cracked sections were used for the RC components under bending. The determination of effective bending rigidity of beam and column sections is given in the following equations, respectively:

$$\text{For beams: } (\mathrm{EI})_e = 0.40(\mathrm{EI})_o, \quad (1)$$

$$\text{For columns: } (\mathrm{EI})_e = 0.40\ (\mathrm{EI})_o \text{ if } N_D/(A_c \cdot f_{cm}) \leq 0.1;\ (\mathrm{EI})_e = 0.80\ (\mathrm{EI})_o\ N_D/(A_c \cdot f_{cm}) \geq 0.4. \quad (2)$$

Linear interpolation can be applied for the intermediate values of axial pressure force levels. ND will be determined via a pre-gravity load calculation in which bending rigidities of the non-cracked sections (EI)o are used and the loads consistent with the total masses used in the seismic calculations are considered. Ac is the column area and fcm is the compressive strength of concrete of existing building.

Yield surfaces and moment–rotation relations of structural components were determined according to TSC 2007 [9]. A pushover curve is obtained in NSP, where the horizontal axis is roof displacement and the vertical axis is base shear. The pushover curve is then converted to the modal capacity diagram to calculate the inelastic displacement demands of the considered building. The determination of inelastic displacement demand is given in Figure 1, in which Sdi is the inelastic spectral displacement demand.



Inelastic Displacement Demand		
Soil Class	For Design Earthquake (mm)	For Maximum Earthquake (mm)
A	103	152
B	130	191
C	179	264
D	219	319

Figure 1. Estimation of inelastic displacement demand

Nonlinearity was considered by defining plastic hinges at the end of the column and beam elements. The lumped plasticity hypothesis is assumed for the definition of plastic hinges, and yield surfaces and moment–rotation relations of structural components were determined according to TSC 2007 [9]. Height, number of storeys and torsional irregularity factor of the considered building are in compliance with the limitations of TSC 2007 to apply a performance evaluation method.

The total curvatures are calculated that occur in the sections in the structure pushed to the demand point. From these curvatures, the unit strain values for concrete and steel are calculated for each section. The strain values are compared with the section damage limits. Thus, the damage level is found for the section. Damages in all sections are evaluate according to the TSC 2007. As a result of this evaluation, the building performance level is decided according to Figure 2.

TSC 2007 [9] offers using damage states of structural members for performance evaluation of a structure. Strains in the structural members were used as damage measure for nonlinear methods. TSC 2007 [9] defines three damage limits to describe possible damages at the critical sections of structural members: minimum damage limit (MN), safety limit (SL) and collapse limit (CL). The strain limits of concrete and reinforcement for each damage limit are given in the following equations:

$$\varepsilon_{cc,MN} = 0.0035; \quad \varepsilon_{s,MN} = 0.01, \tag{3}$$

$$\varepsilon_{cc,SL} = 0.0035 + 0.01\left(\frac{\rho_s}{\rho_{sm}}\right) \leq 0.0135; \quad \varepsilon_{s,MN} = 0.04, \tag{4}$$

$$\varepsilon_{cc,CL} = 0.004 + 0.014\left(\frac{\rho_s}{\rho_{sm}}\right) \leq 0.018; \quad \varepsilon_{s,MN} = 0.06. \tag{5}$$

The usage purpose and the Type of the Building	***Probability for the Earthquake to be exceeded***		
	50 % in 50 years	*10 % in 50 years*	*2 % in 50 years*
The buildings that should be used after earthquakes: Hospitals, heath facilities, fire stations, communications and energy facilities, transportation stations, provincial or district administrative bodies, disaster management centers etc.	–	**RU**	**LS**
The buildings that people stay in for a long time period: Schools, accommodations, dormitories, pensions, military posts, prisons, museums, etc.	–	**RU**	**LS**
The buildings that people visit densely and stay in for a short time period: cinema, theatre and concert halls, culture centers, sports facilities	**RU**	**LS**	–
Buildings containing hazardous materials: The buildings containing toxic, flammable and explosive materials and the buildings in which the mentioned materials are stored.	–	**RU**	**PC**
Other buildings: The buildings that does not fit the definitions given above (houses, offices, hotel, tourist facilities, industrial buildings, etc.)	–	**LS**	–

RU: Ready for Usage; **LS**: Life Safety; **PC**: Pre-Collapse (See **7.7**)

Figure 2. Estimation of building earthquake performance

Accordingly, four damage states are defined as minimum damage state where sectional damage is below MN, significant damage state where sectional damage is between MN and SL, heavy damage state where sectional damage is between SL and CL, and collapse damage state where sectional damage is above CL. These limits can be seen in Figure 3.

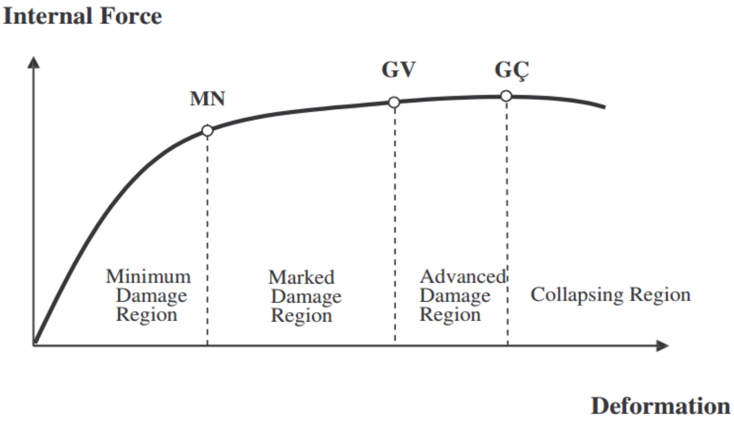


Figure 3. Section damage limits

Numerical Application

In this section, the NSP is used to determine the performance level of a five-storey building, which is a school for use, according to TSC 2007. The loads (seismic loads, moving loads, fixed loads) are constant in the system. Soil classes were changed and the effects of these parameters on building performance level were investigated. The plan of structure is given below. The floor height of the building is 3.40 meters on each floor and the building is constructed as a frame system in Figure 4.

Building and Material Information

- Story number: 5
- Building floor height: 3.40 m
- Total building height: 17.00 m
- Use purpose: School

- Concrete C16 (fck = 16 MPa)
- Accessory steel S220 (fyk = 220 MPa)
- Reinforced concrete elasticity module: 28 GPa
- Accessory stainless steel elasticity Module: 200 GPa
- Concrete material safety factor: 1.00
- Accessory steel material safety coefficient: 1.00

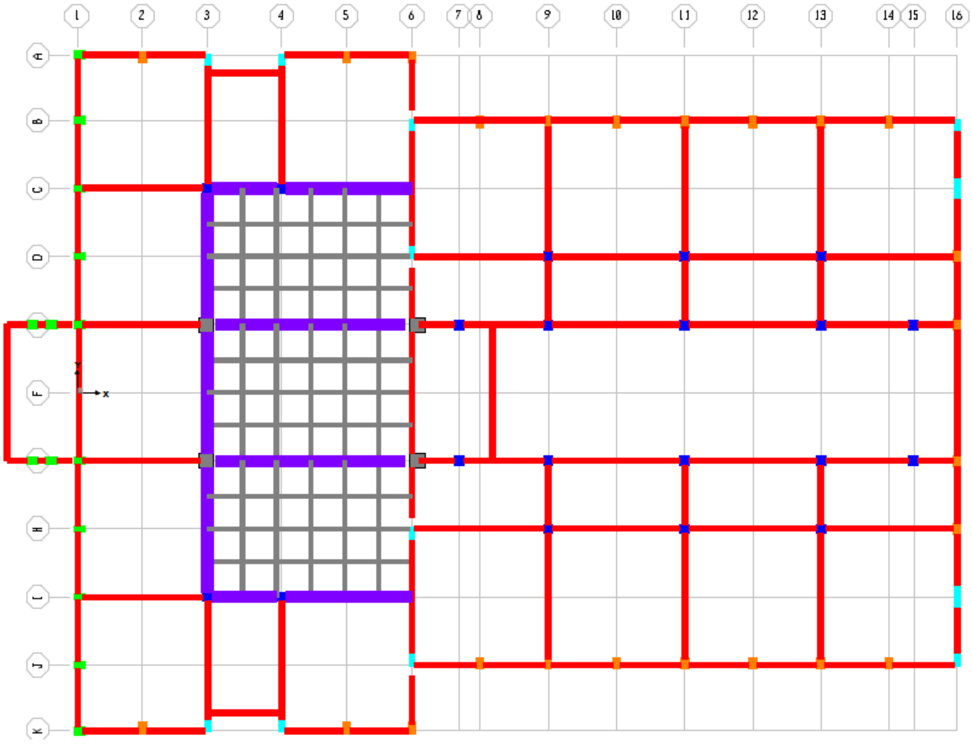


Figure 4. Structural System Plan View

Analysis Result

Pushover analysis was conducted and the pushover curve was obtained which is given in Figure 5. It is seen that the building base shear force is maximum 12000 kN and the maximum displacement limit is 200 mm.

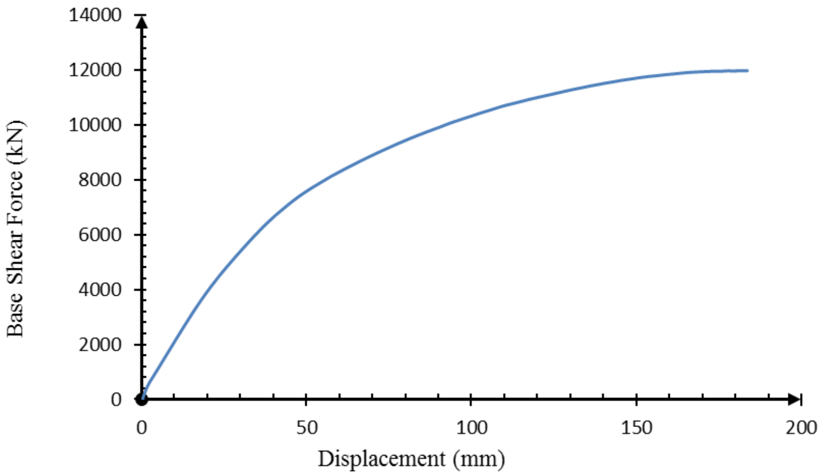


Figure 5. Pushover curve of building in X-direction

Following the initial solutions, the demand points described in Figure 1 were found for different soil classes. The building was pushed to these demand points and the results were taken. The story drifts shown in Figures 6 and 7 were found by these analyzes. The building cannot be pushed until the displacement demand for soil classes C and D since the building reaches to mechanism situation for these demand values. Therefore, these results have not been achieved.

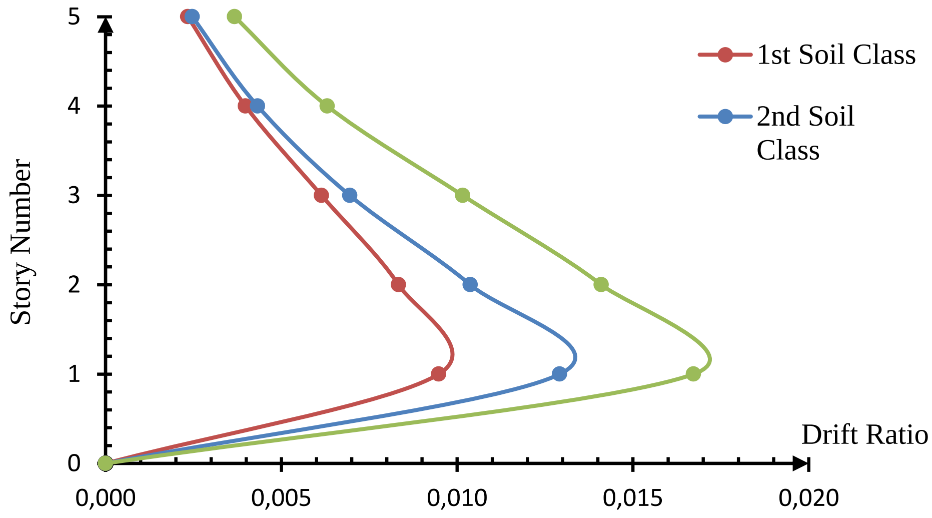


Figure 6. Drift ratios under demand of design earthquake spectrum (%10 in 50 years) for different soil class

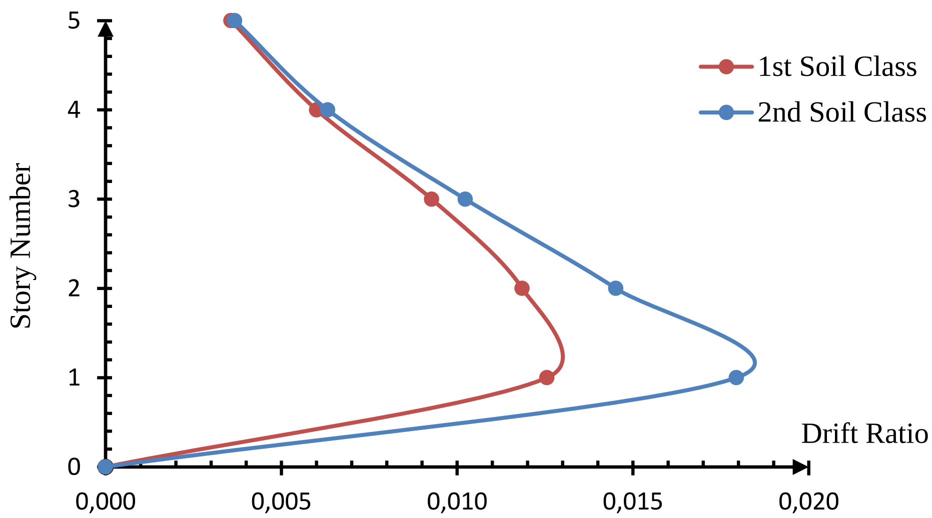


Figure7. Drift ratios under demand of maximum earthquake spectrum (%2 in 50 years) for different soil class

Total curvature and corresponding unit shape changes are calculated. The calculated values are compared with the limit values obtained by equations 3, 4, 5. In accordance with the methodology given in Section 2.1, plasticized sections for each level of damage are given in Tables 1, 2, 3 for design earthquake (%10 in 50 years) performance level. The performance level of ready for usage is not provided according to the regulation because of 10% of the beams have passed into the marked damage zone.

Table 1. Section damage results under demand of design earthquake spectrum for soil class A

			Column Damage Results (%)				**Beam Damage Result (%)**			
Story	**Column Number**	**Beam Number**	**Minumum Damage**	**Marked Damage**	**Advanced Damage**	**Collapse Region**	**Minumum Damage**	**Marked Damage**	**Advanced Damage**	**Collapse Region**
1	74	106	3	78	19	0	50	50	0	0
2	74	106	49	50	1	0	53	47	0	0

3	74	106	80	20	0	0	82	18	0	0
4	74	106	95	5	0	0	96	4	0	0
5	74	106	100	0	0	0	96	4	0	0
Total	370	530	65	31	4	0	75	25	0	0

Table 2. Section damage results under demand of design earthquake spectrum for soil class B

			Column Damage Results (%)				**Beam Damage Result (%)**			
Story	**Column Number**	**Beam Number**	**Minumum Damage**	**Marked Damage**	**Advanced Damage**	**Collapse Region**	**Minumum Damage**	**Marked Damage**	**Advanced Damage**	**Collapse Region**
1	74	106	3	74	5	18	50	50	0	0
2	74	106	26	69	5	0	53	47	0	0
3	74	106	73	27	0	0	81	19	0	0
4	74	106	92	8	0	0	94	6	0	0
5	74	106	100	0	0	0	96	4	0	0
Total	370	530	59	36	2	4	75	25	0	0

Table 3. Section damage results under demand of design earthquake spectrum for soil class C

			Column Damage Results (%)				**Beam Damage Result (%)**			
Story	**Column Number**	**Beam Number**	**Minumum Damage**	**Marked Damage**	**Advanced Damage**	**Collapse Region**	**Minumum Damage**	**Marked Damage**	**Advanced Damage**	**Collapse Region**
1	74	106	1	47	30	22	48	52	0	0
2	74	106	20	72	8	0	49	51	0	0
3	74	106	32	68	0	0	58	42	0	0
4	74	106	89	11	0	0	89	11	0	0
5	74	106	99	1	0	0	93	7	0	0
Total	370	530	48	40	8	4	68	32	0	0

Along with the sliding of the soil class to the soft grounds (soil class D), the damage to the sections reached to advanced levels. Tables 4 and 5 are given the level of section damage for maximum seismic (%2 in 50 years) demands. The life safety performance level is provided for beams. Column elements are provided for the soil class A, but conditions for soil class B ground are not provided.

Table 4. Section damage results under demand of maximum earthquake spectrum for soil class A

			Column Damage Results (%)				**Beam Damage Result (%)**			
Story	**Column Number**	**Beam Number**	**Minumum Damage**	**Marked Damage**	**Advanced Damage**	**Collapse Region**	**Minumum Damage**	**Marked Damage**	**Advanced Damage**	**Collapse Region**
1	74	106	1	73	14	12	49	51	0	0
2	74	106	30	65	5	0	49	51	0	0
3	74	106	57	43	0	0	61	39	0	0
4	74	106	92	8	0	0	91	9	0	0
5	74	106	99	1	0	0	94	6	0	0
Total	370	530	56	38	4	2	69	31	0	0

Table 5. Section damage results under demand of maximum earthquake spectrum for soil class B

Section Damage Results			**Column Damage Results (%)**				**Beam Damage Result (%)**			
Story	**Column Number**	**Beam Number**	**Minumum Damage**	**Marked Damage**	**Advanced Damage**	**Collapse Region**	**Minumum Damage**	**Marked Damage**	**Advanced Damage**	**Collapse Region**
1	74	106	1	39	35	24	47	53	0	0
2	74	106	16	74	9	0	49	51	0	0
3	74	106	31	69	0	0	58	42	0	0
4	74	106	89	11	0	0	89	11	0	0
5	74	106	99	1	0	0	93	7	0	0
Total	370	530	47	39	9	5	67	33	0	0

Conclusion

In this study, the aim is to evaluate the performance level of a school building considering different soil conditions. 3D finite element model of building is modelled via SAP2000 software. For school building, base shear force is maximum 12000 kN and the maximum displacement limit is 200 mm. It can also be seen from the figures given for the drift values that limit values are not provided on the B and C soil classes for performance level of ready for usage.

The building was pushed to the demand points determined according to the building regulations and the level of section damage was found. Demand displacement values are increasing along with the movement of the soil class towards soft grounds (D). As a result, the damage levels in the sections are getting higher values. The performance level of ready for usage is not provided in any soil classes. The performance level of life safety is only provided for a soil class A. These results show the necessity of performance evaluation for important structures built on weak grounds.

References

ATC, (1996). Seismic Evaluation and Retrofit of Concrete Buildings, Applied Technology Council, Redwood City, California.

Gülkan, P., Sözen, M. (1974). Inelastic Response of Reinforced Concrete Structures to Earthquake Motions. ACI Journal, pp. 604-610.

Freeman, S. A. (1998). Development and Use of Capacity Spektrum Method, 6th US National Conference on Earthquake Engineering.

SEAOC, (1999). Recommended Lateral Force Requirements and Commentary, 7th Ed.

Fajfar, P. (2000). A Non-Linear Analysis Method for Performance-Based Seismic Design, Earthquake Spectra, pp. 573-592.

Aschheim, M. A., Black, E. F. (2000). Yield Point Spectra for Seismic Design and Rehabilitation, Earthquake Spectra, pp. 317-336.

UBC, (1997). Uniform Building Code, International Conference of Building Officials.

SAP2000, (2017). Structural Analysis Program, Computers and Structures Inc. Berkeley, California.

TSC, (2007). Turkish Seismic Code, Chamber Of Civil Engineering, Ankara.