RESEARCH GROUP

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Research Article

The effect of material strength and discontinuity in RC structures according to different site-specific design spectra

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Article Info	Abstract
	Seismic-induced damages in reinforced-concrete (RC) buildings were primarily associated with materials' low strength and poor properties. This study aims to investigate the seismic response of RC structures according to the different material's strength and design spectra. Adaptive static pushover and eigenvalue analysis were performed for four different design spectra, five types of concrete, and two reinforcement grades. Four different design spectra were obtained by considering discrete geographical locations with different earthquake risks via the updated Turkish Earthquake Hazard Map 2018. Structural analysis was carried out for a sample RC building using these spectrum curves and material strengths. It has been observed that the structure becomes more rigid as the strength of concrete increases. This situation manifested itself with an increase in period values and a decrease in the stiffness values. Stiffness values of the building are independent of reinforcement. As the concrete strength decreases, the structure's seismic capacity decreases while the displacement's demand for predicted performance levels increases. Moreover, an increase in the tensile strength of reinforcements substantially increases the seismic capacity of the building. The study also determines that the site-specific design spectra obtained for different provinces are used in the analysis affects the demand displacements values considerably. The material differentiation between the stories in the building was also examined in this study. It can be a source in terms of how material discontinuity affects building performance.

1. Introduction

In recent years, destructive earthquakes have caused large-scale losses for lives and properties, bringing forward the importance of seismic studies, research, and scientific developments. Several parameters such as number of stories, soft/weak story, short column, irregularity in plan, local soil conditions and hill-slope effect will adversely affect the behaviour of structures following earthquake loads. These parameters were also investigated and considered for rapid evaluation of structures. Parameters that will decrease the structural resistance mechanism will increase the amount of damage that might occur [1,2]. Numerous methods are developed to evaluate the building's seismic safety and performance, such as rapid visual screening [3–8] and application of modern computational techniques including machine learning [9–11], but design spectra are one of the most essential parameters to be used in determining the seismic safety factor of buildings. Design spectra can be obtained by combining the local soil conditions and seismicity elements of that particular region. Local ground conditions significantly affect

the design spectra. Moreover, changes in spectra also affect the target displacements of structures [12–16]. Building design and evaluation become more meaningful by using site-specific earthquake spectra.

Reinforced-concrete (RC) structures are widely used in developed countries and have an important role in terms of seismic-induced damage [17-19]. In such structures, the structural elements are made by joining reinforcement and concrete. Earthquake resistance of such structures decreases due to weaknesses in resistance mechanisms. Their vulnerability increases even in low-intensity earthquakes, depending on the amount of these weaknesses. In RC structures, it is associated with low strength and weak properties of concrete as the first cause of damage. Also, it should not be overlooked that the reinforcement used is straight or ribbed.

Seismic zones were expressed in four different ways, according to the Turkish Seismic Design Code-2007 (TSDC-2007) [20]. These seismic zones were removed with the updated seismic design code in 2018 (TBEC-2018) [21]. Site-specific design spectra should be used for any geographic location. One of the aims of the study is to examine the effect of different design spectra. In terms of seismicity level, Bingöl is located on level 1, Ağrı on level 2, Artvin on level 3, and Konya level 4, respectively, which were selected as case studies. Site-specific design spectra were obtained for these settlements according to the updated Turkish Earthquake Hazard Map-2018. Eigenvalue and static adaptive pushover analyses were carried out separately for the five-story RC building using these design spectra. In addition, C8, C12, C16, C20 and C25 selections as a concrete class, S220, and S420 selections were made as to the reinforcement class. Concrete and reinforcement classes are taken into consideration as variables, and all other structural characteristics are kept constant. Interpretations were made by comparing all the obtained results.

This study aims to reveal how the material strengths predicted primarily affect building performance as a cause of damage, especially in RC structures after the earthquake. While acknowledging these differences, settlements with different seismicity risk were taken into consideration. The relationship between site-specific design spectra and material strengths has been tried to be revealed. Earthquake parameters were obtained for selected provinces by using updates earthquake hazard maps for Turkey. Short period mapping coefficient, spectral acceleration coefficient, maximum ground acceleration (PGA), maximum ground velocity (PGV), local ground effect coefficients, design spectral acceleration coefficients, and horizontal elastic spectrum curve were calculated individually here for selected provinces. The related information about earthquake damages due to concrete strength is also provided. Detailed information about obtaining design spectra for selected settlements is given. The RC building model used as an example is detailed. Information about the analysis used is presented.

Additionally, uncertainties in material strength are one of the essential factors to be taken into account. Concrete and reinforcement grades were selected when projecting RC buildings. In this case, it is impossible to attach the material grades selected at the project design stage on the building for various reasons. This means that the material strengths stipulated in the project cannot be achieved. Therefore, the calculations made during the projecting phase do not make any sense for the envisaged structure. This study also explains the failure of the stipulated material strengths at the project design stage. At the same time, the differentiation of material strength was also examined with the study. The discontinuities occur in material strength in RC structures due to different reasons for using different strength materials between stories.

2. Selection of Site-specific Earthquake Spectra

There are many useful structural analysis parameters under earthquake risk [22-27]. Seismicity elements are one of these parameters. These elements are briefly defined as local soil conditions, fault groups, and their characteristics, historical earthquakes, and necessary periods. These parameters vary based on different geographic locations. Within the study's scope, four various settlements with different seismic risks were selected as Bingöl, Ağrı, Artvin, and Konya. Changes in analysis with varying risks of earthquakes were tried to be revealed within the scope of the study. The seismic zone expressions are no longer used in the updated Turkish Earthquake Hazard Map [28]. The usage of site-specific design spectra has emerged as the most significant change in updated Turkish Building Earthquake Code -2018. The site-specific seismic hazard evaluation is the main advantage of the new seismic code. It is necessary to mention that the latest update yields more reasonable assessments in structural performance. The representation of the selected provinces on this map was shown in Figure 1.
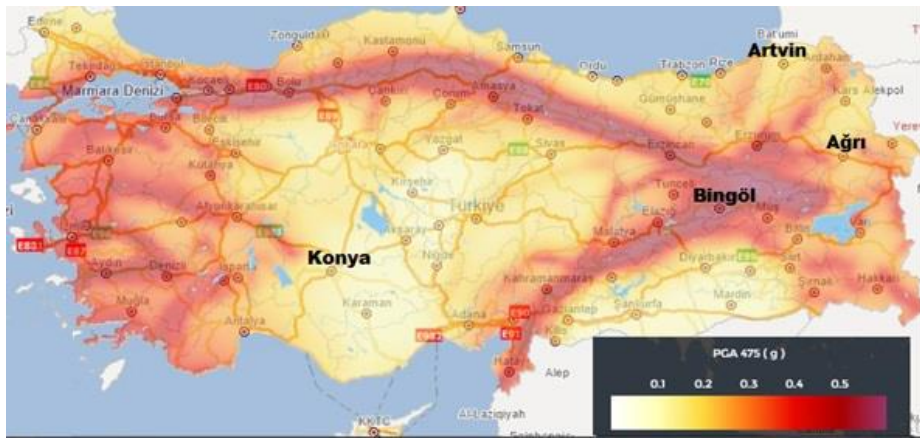
Fig. 1 Four different settlements that selected for this study

For all geographic locations, the standard design earthquake ground motion (DD-2) for an earthquake with a 10% annual probability of excess (recurrence period 475 years) and local soil conditions ZA class were selected for spectra curves and earthquake parameters. The properties of the ZA class were given in Table 1.

Table 1. Properties of ZA type according to TSDC-2018 [18]

Local Ground Type	Type of Ground	Average at the top 30 meters $(V_S)_{30}$ [m/s]
ZA	Strong, hard rocks	> 1500

In this study, the map spectral acceleration coefficient (SS), map spectral acceleration coefficient for the period of 1.0 second (S1), the most significant peak ground acceleration (PGA), the peak ground velocity (PGV), local ground impact coefficients (FS and F1), design spectral acceleration coefficients (short-period design spectral acceleration coefficient (SDS), and design spectral acceleration coefficient (SD1) for 1.0 second period) and horizontal elastic spectrum values were calculated separately via the Turkey Earthquake Hazard Maps Interactive Web Application [28]. SS for 0.2s and S1 spectral acceleration values in 1.0s are calculated directly from the application for a 5% damping ratio. Local

ground effect coefficient FS is derived from Table 2 in the short period zone and F1 was calculated according to Table 3 in the 1.0s period for local ground type ZA.

Table 2. Local soil effect coefficients (F_S) for ZA soil type according to TBEC-2018 [21]

Local Soil Type	Local ground effect coefficient F_S for the short period zone					
	$S_S \leq 0.25$	$S_S = 0.50$	$S_S = 0.75$	$S_S = 1.00$	$S_S = 1.25$	$S_S \geq 1.50$
ZA	0.8	0.8	0.8	0.8	0.8	0.8

Table 3. Local soil effect coefficients (F_1) for ZA soil type according to TBEC-2018 [21]

Local Soil Type	Local ground effect coefficient F_1 for 1.0 second period					
	$S_1 \leq 0.10$	$S_1 = 0.20$	$S_1 = 0.30$	$S_1 = 0.40$	$S_1 = 0.50$	$S_S \geq 0.60$
ZA	0.8	0.8	0.8	0.8	0.8	0.8

Referring to the Table 2 and Table 3, FS and F1 coefficients for ZA take a constant value of 0.8. This situation is also valid for ZB soil type and it differs for other soil types that given in TBEC-2018 (ZC, ZD; ZE). This is due to the fact that ZA and ZB soil types are solid ground. Short period design spectral acceleration coefficient (SDS) and design spectral acceleration coefficient (SD1) values for 1.0 seconds are calculated as follows;

$$S_{DS} = S_S . F_S \tag{1}$$

$$S_{D1} = S_1 . F_1 \tag{2}$$

The comparison of the earthquake parameters obtained for selected provinces in this study are presented in Table 4.

Table 4. Comparison of earthquake parameters for selected provinces

Parameter	Province			
	Bingöl	Ağrı	Artvin	Konya
S_S	1.596	0.547	0.425	0.307
S_1	0.419	0.152	0.116	0.073
PGA (g)	0.648	0.234	0.185	0.133
PGV(cm/s)	41.836	13.588	10.467	6.688
F_S	0.800	0.800	0.800	0.800
F_1	0.800	0.800	0.800	0.800
S_{DS}	1.277	0.438	0.341	0.246
S_{D1}	0.335	0.122	0.093	0.058

A comparison of horizontal elastic design spectra obtained for selected cities was shown in Figure 2. Here, the horizontal axis represents the period value (T), and the vertical axis represents the horizontal elastic design spectral acceleration (Sae).
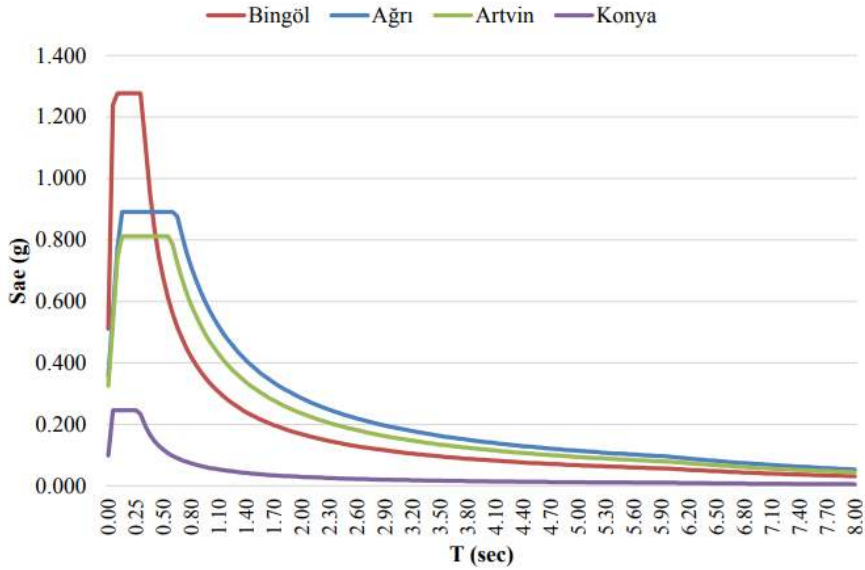
Fig. 2 Comparison of horizontal elastic design spectra

3. Failures According to Low Strength of RC

The strength of materials directly affects structures under various loads. Materials that are insufficient alone can become sufficient in terms of strength by combining additional materials. RC is a widely used composite building material that obtained by combining two different materials such as concrete and steel. The most important property expected from concrete is compressive strength and the tensile strength expected from steel. The classification of these two materials is made by considering these properties. Earthquake damages are primarily associated with concrete with poorer properties than these two materials in any RC structure. Therefore, the quality of these two materials largely determines the quality of any RC structural system. Concrete is a composite material, including various materials such as cement, aggregate, water and other additional materials. Furthermore, concrete production steps are very much, such as calculation of composition, transportation, concreting, compaction, and curing of concrete. The fact that it is obtained by combining many materials and the production stages are very different affects the concrete strength negatively. A concrete with low strength that seems sufficient under vertical loads cannot withstand horizontal loads during an earthquake. The concrete shows a more ductile behaviour as a result of the different reinforcements placed in the concrete in the RC structural system. However, if the compressive strength of concrete is low, it causes adherence between concrete and reinforcement to be sufficient even at low stresses. In this case, longitudinal reinforcements are easily stripped from the concrete, longitudinal reinforcements bonded with tight stirrups sprains. The materials contained in concrete, environmental conditions, application errors, bad workmanship, degree of compression, insufficient protection/maintenance and cement type generally cause low strength of concrete. However, inappropriate grain distribution and size in aggregate, direct use of aggregate obtained from rivers found in the region, and inadequate concrete compression processes led to concrete with a little resistance to segregation. The usage of smooth reinforcement in RC reduces the capacity in terms of both strength and adherence. This situation has been revealed again in the 2020 Sivrice (Elazığ) earthquake lastly in Turkey as presented in the Figure 3.

Fig. 3 Damages in RC according to poor/low strength after 2020 Sivrice earthquake

Due to the low concrete strength and the smooth reinforcement used, damage was observed in different earthquakes. Some of these damages were shown in Figure 4.

Fig. 4 Poor quality/ low strength material damages after different earthquakes [29–37]

4. Structural Analyses

Structural analysis for the provinces was performed using the Seismostruct software (Seismosoft, 2018). The static adaptive pushover analysis, which is applied in predicting the horizontal capacity of a structure, taking full account of the effect that the deformation of the latter and the frequency content of input motion have on its dynamic response characteristics, was used. Here, analyses were performed by considering the mode shapes and participation factors obtained from the eigenvalue analyses in each step during the adaptive pushover analysis. This method allows the use of site-specific spectra. Load control types used in this study are similar to conventional pushover analysis [38-46]. Material models have an essential place in structural analysis [47]. The nonlinear concrete model [48] and steel model [49] were used for concrete and steel material, respectively. The stress-strain relationship of the material models considered for these models is demonstrated in Figure 5. Here, the vertical axis represents stress and horizontal axis represents the strain under the stress.
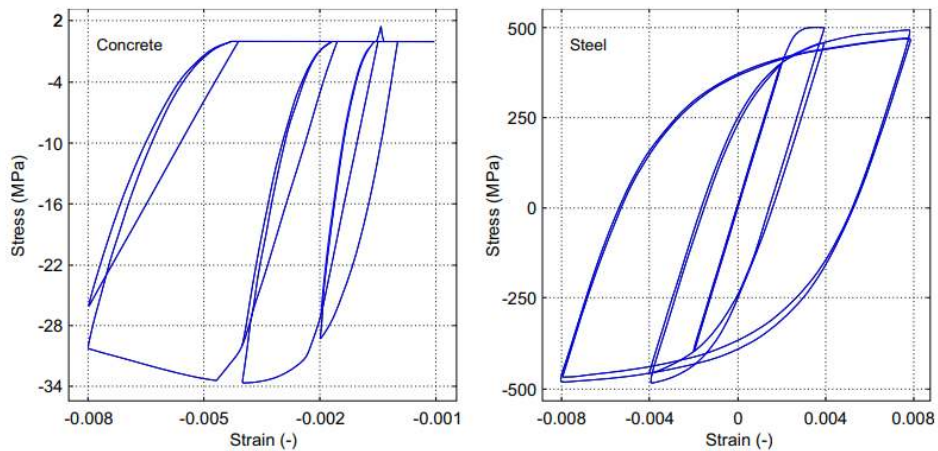
Fig. 5 Material models for concrete and steel considered in the study [50]

The characteristics of the five different concrete grades considered in this study are given in Table 5. The properties of the two different reinforcement grades considered in this study are given in Table 6.

Table 5. Properties of different concrete grades [51]

Parameter	C8	C12	C16	C20	C25
Mean compressive strength (kPa)	16000	20000	24000	28000	33000
Nominal value (kPa)	8000	12000	16000	20000	25000
Mean tensile strength (kPa)	1600	2000	2400	2800	3300
Modulus of elasticity (kPa)	1.88E+007	2.10E+007	2.30E+007	2.48E+007	2,69E+07
Strain at peak stress (m/m)	0.002	0.002	0.002	0.002	0.002
Specific weight (kN/m³)	24.00	24.00	24.00	24.00	24.00

Table 6. Properties of different reinforcement grades [51]

Parameter	S220	S420
Mean compressive strength (kPa)	253000	483000
Modulus of elasticity (kPa)	2.00E+08	2.00E+08
Nominal value (kPa)	220000	420000
Yield strength (kPa)	253000	483000
Specific weight (kN/m3)	78	78
Strain hardening parameter (-)	0.005	0.005
Transition curve initial shape parameter	20	20
Transition curve shape calibrating coeff. A1 (-)	18.50	18.50
Transition curve shape calibrating coeff. A2 (-)	0.15	0.15
Isotropic hardening calibrating coeff. A3 (-)	0	0
Isotropic hardening calibrating coeff. A4 (-)	1.00	1.00
Fracture/buckling strain (-)	0.10	0.10

The blueprint of the selected RC structure is presented in Figure 6, and the 2D and 3D structural models and the applied loads are shown in Figure 7.
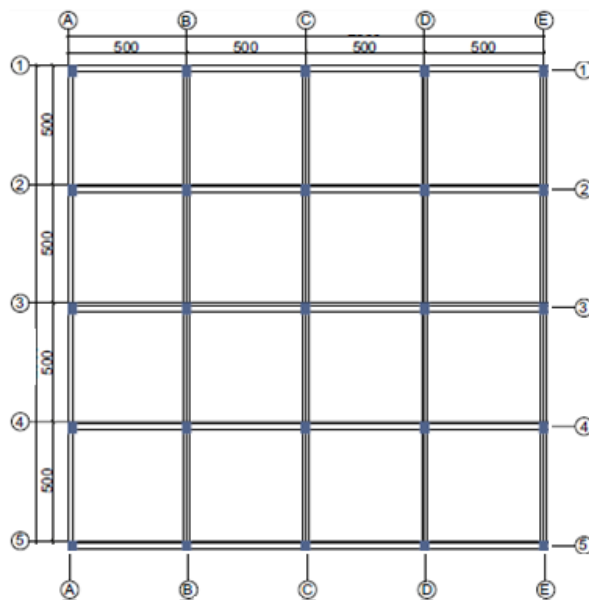

Fig. 6 The blueprint of sample model RC building
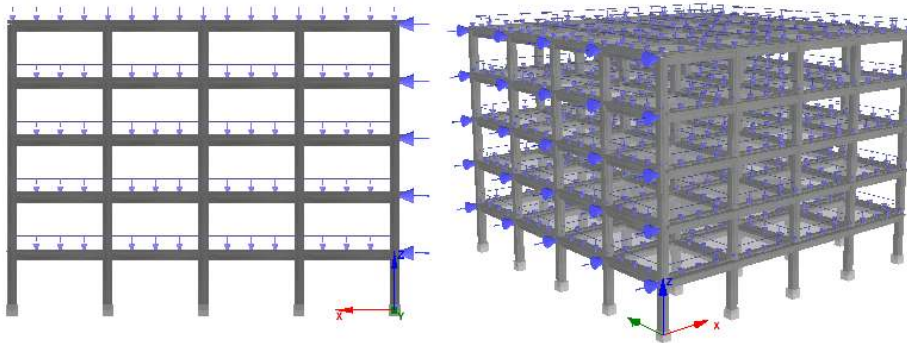
Fig. 7 2D and 3D models of the sample model RC building

Each story had an equal height and taken as 3 m. All columns were selected as 0.40 × 0.50m and beams were selected as 0.25×0.60m. The transverse reinforcements used in both elements were selected as ϕ10/10. The reinforcements used in the columns were selected as 4ϕ20 at corners and 4ϕ16 top bottom and left-right sides. The reinforcements used in the beams were selected as 4ϕ16 at lower side, 5ϕ14 upper side and 2ϕ12 at side. The columns and beams used in the structure are shown in Figure 8. The damping ratio was taken as % 5 in all structural models. The ZA soil type was chosen as the local soil condition. The importance of structure was taken into consideration as Class II. The slabs were selected as rigid diaphragms.
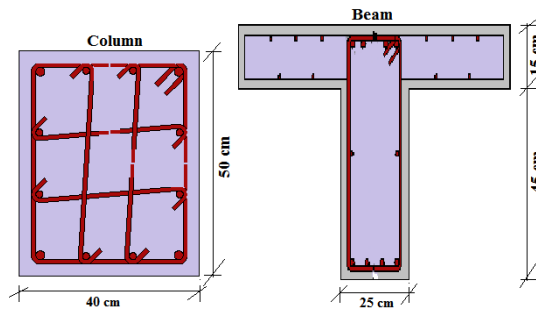
Fig. 8 Column and beam cross-sections

The dy value refers to displacement at the moment of yield and dint value refers to the intermediate displacement. Elastic stiffness (K_elas) and effective stiffness (K_eff) values were also calculated separately for selected provinces for different material strengths. Three different performance criteria were obtained for damage estimation. These are considered as near collapse (NC), significant damage (SD) and damage limitation (DL) according to Eurocode-8, (Part-3) [52].

5. The Interaction Between Material Strength and Site-Specific Spectra

The comparison of all values obtained in X direction for S220 and S420 has been presented in Tables 7 and 8, respectively. The comparison of the static pushover curves for S220 and S420 grades are presented in Figures 9.

Fig. 9 Comparison of pushover curves for S220 and S420 for different concrete grades

Table 7. Comparison of values obtained in X direction for S220

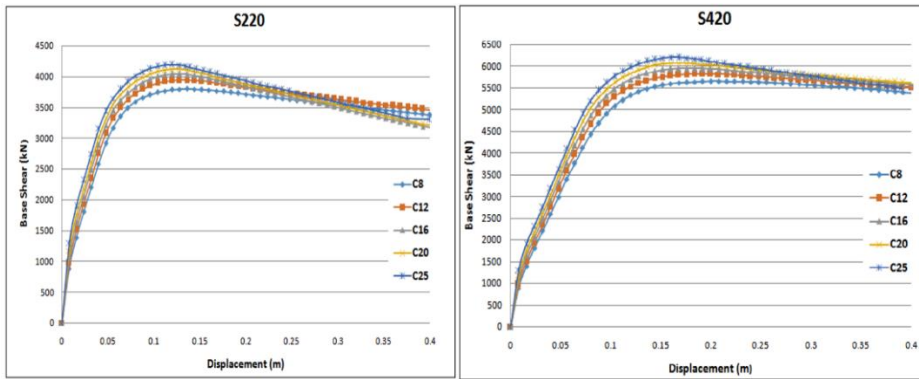| Province	Concrete	Period	d_{int}	d_y	$K_{\_elas}$	$K_{\_eff}$	Base Shear	DL	SD	NC
Bingöl	C8	0.4429	0.061	0.136	109949.2	61788.6	3796.05	0.0948	0.1217	0.2109
	C12	0.4227	0.060	0.128	121202.8	65952.4	3943.33	0.0918	0.1178	0.2042
	C16	0.4066	0.058	0.128	132308.9	70333.2	4044.74	0.0889	0.1140	0.1977
	C20	0.3933	0.055	0.120	146060.4	74676.7	4118.61	0.0863	0.1107	0.1919
	C25	0.3795	0.052	0.120	160602.3	80067.8	4189.83	0.0833	0.1069	0.1853
Ağrı	C8	0.4429	0.061	0.136	109947.7	61783	3796.18	0.0342	0.0439	0.0762
	C12	0.4227	0.060	0.128	121201.6	65950.5	3943.51	0.0331	0.0425	0.0737
	C16	0.4066	0.058	0.128	132307.9	70332.8	4044.75	0.0321	0.0412	0.0714
	C20	0.3933	0.055	0.12	146059.6	74677.2	4118.51	0.0312	0.0400	0.0693
	C25	0.3795	0.052	0.12	160601.4	80069.6	4189.79	0.0301	0.0386	0.0669
Artvin	C8	0.4429	0.061	0.136	109948.2	61787.5	3796.04	0.0272	0.0349	0.0605
	C12	0.4227	0.060	0.128	121202	65954.2	3943.42	0.0263	0.0338	0.0586
	C16	0.4066	0.058	0.128	132308.1	70328.6	4044.85	0.0255	0.0327	0.0567
	C20	0.3933	0.055	0.12	146059.8	74677.5	4118.55	0.0248	0.0318	0.0551
	C25	0.3795	0.052	0.12	160601.6	80085.5	4190.07	0.0239	0.0307	0.0532
Konya	C8	0.4429	0.061	0.136	109951.8	61791.1	3796.04	0.0195	0.0250	0.0433
	C12	0.4227	0.060	0.128	121205.6	65959.6	3943.48	0.0188	0.0242	0.0419
	C16	0.4066	0.058	0.128	132312.0	70320.8	4045.17	0.0182	0.0234	0.0406
	C20	0.3933	0.055	0.12	146065.4	74677.3	4118.56	0.0177	0.0227	0.0394
	C25	0.3795	0.052	0.12	160608.4	80080.7	4189.87	0.0171	0.0219	0.0380

Table 8. Comparison of values obtained in X direction for S420

Province	Concrete	Period	d_{int}	d_y	K_{elas}	K_{eff}	Base Shear	DL	SD	NC
Bingöl	C8	0.4429	0.100	0.208	110005.30	56604.8	5651.61	0.099	0.127	0.220
	C12	0.4227	0.096	0.1917	121199.82	60691.12	5817.87	0.096	0.123	0.213
	C16	0.4066	0.092	0.1758	132293.06	64565.63	5950.22	0.093	0.119	0.206
	C20	0.3933	0.089	0.1681	146011.31	67995.43	6068.52	0.090	0.116	0.201
	C25	0.3795	0.087	0.1601	160527.06	71447.68	6201.31	0.088	0.113	0.196
Ağrı	C8	0.4429	0.100	0.2162	110003.83	56504.29	5656.65	0.036	0.046	0.080
	C12	0.4227	0.096	0.1917	121198.56	60685.68	5817.96	0.035	0.044	0.077
	C16	0.4066	0.092	0.1757	132292.02	64562.52	5950.07	0.034	0.043	0.043
	C20	0.3933	0.089	0.1681	146010.48	67994.95	6068.47	0.033	0.042	0.073
	C25	0.3795	0.087	0.1601	160526.14	71457.95	6201.32	0.032	0.041	0.071
Artvin	C8	0.4429	0.100	0.2157	110004.32	56587.24	5652.91	0.028	0.036	0.063
	C12	0.4227	0.096	0.1914	121198.95	60715.11	5817.7	0.027	0.035	0.061
	C16	0.4066	0.092	0.1758	132292.31	64563.81	5950.21	0.027	0.034	0.059
	C20	0.3933	0.089	0.1681	146010.69	67996.45	6068.59	0.026	0.033	0.058
	C25	0.3795	0.087	0.16	160526.38	71459.39	6201.24	0.025	0.032	0.056
Konya	C8	0.4429	0.100	0.2076	110007.89	56548.47	5653.91	0.020	0.026	0.045
	C12	0.4227	0.096	0.1916	121202.59	60688.62	5818.07	0.020	0.025	0.044
	C16	0.4066	0.092	0.1758	132296.18	64566.97	5950.38	0.019	0.024	0.042
	C20	0.3933	0.089	0.1681	146014.4	67997.1	6068.63	0.019	0.024	0.041
	C25	0.3795	0.087	0.1601	160530.61	71449.63	6201.2	0.018	0.023	0.040

The comparison of PGA and target displacements for damage estimation was given in Table 9.

Table 9. Comparisons of earthquake – structural parameters

Province	PGA	C25-S220			C25-S420		
Bingöl	0.648	0.0833	0.1069	0.1853	0.088	0.113	0.196
Ağrı	0.234	0.0301	0.0386	0.0669	0.032	0.041	0.071
Artvin	0.185	0.0239	0.0307	0.0532	0.025	0.032	0.056
Konya	0.133	0.0171	0.0219	0.038	0.018	0.023	0.040

6. The Effect of Material Discontinuity on Building Performance

The differentiation of material strengths in the building has also been taken into account within this study's scope. The construction of the stories can be built at different times due to various RC structures that have no engineering services. Since concrete casting is carried out at different times, discontinuities occur in material strength within the building. As a result, concrete and reinforcement are used in different qualities in the first built parts and later built parts. This situation increases the difference of material strength between stories, especially with the widespread of ready mixed concrete. The difference in material strengths within the building increases as the construction date of the first parts of the buildings gets older. These differences to reveal the name of the specified minimum concrete and reinforcement grade in Turkey in the last three regulations were taken into account. Analyses were carried out using the RC building example in the previous section and the design spectrum obtained for Bingöl province. The lowest concrete and reinforcement grades were considered, which were specified in the last three seismic design codes in Turkey. The building models selected in this context are given in Table 10.

Table 10. Models selected for material discontinuity

Model	Description
Model 1	C14 - S220 (In whole structure)
Model 2	C14 - S220 (only in 1st story)/ C20-S220 (All other stories)
Model 3	C14 - S220 (only in 1st story)/ C20-S420 (All other stories)
Model 4	C14 - S220 (only in 1st story)/ C25-S220 (All other stories)
Model 5	C14 - S220 (only in 1st story)/ C25-S420 (All other stories)
Model 6	C14-S220 (only in 1st and 2nd stories) C20-S220 (All other stories)
Model 7	C14-S220 (only in 1st and 2nd stories) C20-S420 (All other stories)
Model 8	C14-S220 (only in 1st and 2nd stories) C25-S220 (All other stories)
Model 9	C14-S220 (only in 1st and 2nd stories) C25-S420 (All other stories)
Model 10	C20-S220 (In whole structure)
Model 11	C25-S220 (In whole structure)

The analysis results obtained for the eleven different building models are shown in Table 11.

Table 11. Results obtained from the change of the material grade within the building

Model	Period	d_{int}	d_y	$K_{\_elas}$	$K_{\_eff}$	Base Shear	DL	SD	NC
Model 1	0.4142	0.0587	0.1280	126800.97	68139.18	4000.29	0.090	0.116	0.201
Model 2	0.4011	0.0531	0.1120	143574.93	75468.82	4011.05	0.086	0.111	0.192
Model 3	0.4011	0.5070	0.0880	143540.79	79580.68	4034.21	0.084	0.108	0.186
Model 4	0.3927	0.0496	0.1042	154168.61	80902.27	4015.26	0.083	0.107	0.186
Model 5	0.3927	0.0480	0.0880	154122.84	84990.65	4036.07	0.081	0.104	0.181
Model 6	0.4076	0.0551	0.1202	138776.00	72623.01	4003.96	0.088	0.112	0.195
Model 7	0.4076	0.0544	0.1200	138746.22	73661.28	4005.81	0.087	0.112	0.193
Model 8	0.4034	0.0529	0.1199	143621.45	75860.41	4005.73	0.086	0.110	0.191
Model 9	0.4034	0.0523	0.1120	143587.62	76593.32	4008.77	0.085	0.109	0.189
Model 10	0.3933	0.0890	0.1681	146011.31	67995.43	6068.52	0.090	0.116	0.201
Model 11	0.3795	0.087	0.1601	160527.06	71447.68	6201.31	0.088	0.113	0.196

Table 12 gives examples of the load factors obtained for equal displacements when structural building systems contain different material strengths. The concrete grade was selected as a variable by keeping the reinforcement grade constant while making these comparisons.

Table 12. Comparison of load factors for equal relative displacement

Model	Relative Displacement (m)					Load Factor
	N511	N411	N311	N211	N211	
Model 1						15.82
Model 10						17.71
Model 11						19.16
Model 2	0.016	0.015	0.012	0.008	0.0033	17.28
Model 4						18.31
Model 6						16.66
Model 8						17.16

The comparison of relative displacement values in building models under equal load factors were shown in Table 13. Two different load factor values have been taken into account as an example.

Table 13. Comparison of relative displacement under equal load factors

Model	Relative Displacement (m)									
	Load Factor = 25					Load Factor = 40				
	N511	N411	N311	N211	N111	N511	N411	N311	N211	N111
Model 1	0.034	0.031	0.0025	0.0167	0.071	0.127	0.121	0.109	0.088	0.046
Model 10	0.030	0.028	0.023	0.0153	0.064	0.089	0.084	0.074	0.055	0.026
Model 11	0.027	0.026	0.021	0.0141	0.059	0.079	0.075	0.065	0.048	0.023
Model 2	0.031	0.029	0.024	0.0163	0.069	0.104	0.098	0.089	0.070	0.039
Model 4	0.028	0.027	0.022	0.0154	0.068	0.096	0.091	0.082	0.065	0.037
Model 6	0.032	0.030	0.024	0.0166	0.070	0.120	0.115	0.101	0.081	0.043
Model 8	0.030	0.028	0.024	0.0166	0.070	0.111	0.106	0.097	0.079	0.041

7. Conclusions

Eigenvalue and static adaptive pushover analysis for sample RC buildings were made for three different variables. All three selected parameters directly affect the earthquake behaviour of the structures. The first variable is the site-specific design spectrum according to the updated Turkish Earthquake Building Code-2018, which is one of the most important changes in this code. An analysis was carried out for four different cities which each located on different seismicity levels. Five different concrete classes have been selected as another variable. Meanwhile, two different reinforcement grades were considered as the last variable. As concrete strength increases, the deformability of it decreases.

As the strength of the concrete increases, the building's period value decreases, and the elastic and effective stiffness values increase. These show that the structure will be more rigid with the rise of the strength of the concrete. The decrease in concrete strength reduces the seismic capacity of the building. With the reduction of concrete strength, the target displacement values foreseen for the performance criteria expected from the building have increased. These results on concrete strength have remained valid for both reinforcement classes. The period value of the buildings did not change according to the reinforcement class. Elastic and effective stiffness values, which are calculated over crack and cracked sections, also remained constant. The seismic capacity of the buildings was significantly increased due to increasing the reinforcement strength. With the increase of reinforcement strength, the target displacement values have increased. The highest risk values among the provinces considered were calculated for the Bingöl province. The site-specific design spectra did not change the period, elastic and effective stiffness, and seismic capacity values. However, the design spectra significantly altered the target displacement values for the performance criteria for damage estimation. The increase in PGA value also caused the target displacement to increase. The use of site-specific design spectra in the analysis and evaluation of structures allows a more realistic calculation of performance levels expected from the structure. It is clearly seen that a complete agreement was observed between the earthquake-structural analysis results by using the site-specific design spectra. The importance of material strength in RC structures with site-specific design spectra has been revealed once again in the light of the 2020 Sivrice earthquake. Since the seismicity elements of each geographic location are different, the results are expected to be varied. The construction of material strengths as projected in the project by obtaining engineering services will decrease the damage levels that may occur in the buildings to a lower level.

In columns and beams, both the normal and shear force capacities have increased with the increase in concrete strength. An effect of steel grade is not considered in seismic design code for limit values in normal force and shear force in columns and beams. The reinforcement ratios in the columns take constant values independently in the concrete and steel grade. However, this ratio of both concrete and reinforcement grade directly affects in the beams. As the concrete strength increased, the reinforcement ratios foreseen for the beams increased. As the reinforcement strength increased, the rate of reinforcement decreased. One of the most important causes of earthquake damages has revealed the effect of material strength on the building performance and limit conditions foreseen for forces with this study. In addition, analysis was carried out using the site-specific design spectra foreseen in the updated Turkish seismic design code. The final results obtained once again demonstrated the importance of obtaining site-specific design spectra.

The material strengths can vary between stories in RC structures that do not receive engineering services and whose stories are built at different times. This causes

discontinuity of the material in the building. In this context, analyses were performed by considering the minimum concrete grade, which was states in Turkey's last three seismic design codes. Low strength concrete is the leading cause of earthquake damage in RC structures in Turkey. In this respect, while the minimum concrete grade to be used in the 1975 code was C14, it was raised to C20 in 2007 and to C25 in the current 2018 regulation. The differentiation of the reinforcement grade within the structure affected the analysis results at minimal levels. With the increase in the number of low-strength concrete stories, the periods increased, and the structure's total rigidity decreased. The base shear forces obtained for building models with different strengths are very close to the whole structure's value for the lowest strength concrete in the structure. This situation has preserved its validity for the relative displacements. Equal displacements occurred at higher load factors with the increase in concrete strength in different building models. As the concrete strength increases, the structure behaves more rigid and makes fewer displacements. The change in concrete strength within the structure also negatively affected the relative displacement values. All the results obtained once again revealed that concrete strength directly affects the earthquake behaviour of structures.

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