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Original Paper

The effects of different storey heights on structural behavior of RC buildings according to 1998 and 2018 Turkish earthquake codes: comparative study

Batuhan Aykanat[a]

[a]Düzce Üniversitesi, Mühendislik Fakültesi, İnşaat Mühendisliği Bölümü,Düzce, 81100 Türkiye.

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ABSTRACT

Turkey is located on active fault zone. For this reason, earthquakes are an inevitable reality for Turkey. In our country, where major earthquakes occur frequently, there is a great loss of life and property. In order to prevent these losses, earthquake regulations are continuously updated. In this study, with the aim of comparing two different earthquake codes, numerical models of reinforced concrete structures with different storey heights were created and structural analysis were carried out according to the 1998 and 2018 earthquake codes. As a result of the analysis, the period, maximum displacements, relative interstory drifts, base shear forces and torsional irregularity coefficients were compared. As a result of the study, it was determined that the selection of a simple and symmetrical structural system could prevent irregularities, but the structural system was negatively affected when the storey height increased.

I. INTRODUCTION

There have been devastating earthquakes at regular intervals in our country, and these earthquakes have caused great loss of life and property. Due to the location of our country, earthquakes will always be an inevitable reality. Therefore, when disasters are mentioned in Turkey, the first thing that comes to mind is earthquakes. Studies to reduce the damage of earthquakes were first started after the Erzincan earthquake of 26.12.1939, which was one of the largest and most destructive earthquakes in our history and in which 32.962 people lost their lives according to official records [1]. After the Erzincan earthquake, similar earthquakes also occurred on the North Anatolian Fault Zone. As a result of this seismic activity, it became necessary to take precautions against earthquakes and in 1940 the first earthquake regulation was published under the name of "Building Instructions for Construction to be Constructed in Earthquake Zones". As a result of subsequent updating studies, earthquake regulations with different names were published in 1944, 1949, 1953, 1962, 1968, 1975, 1998, 2007 and 2018. With the development of technology and the contemporary changes made in 2018, our country has the most comprehensive earthquake regulation [2]. As earthquake regulations were renewed, studies comparing regulations increased rapidly and regulations were examined and compared from different perspectives [3–10] . The effects of developing computer technologies and construction technologies first began to be seen in the 1998 Earthquake Code [11]. Regulation about the buildings constructed in the disaster regions-1998, first addressed some issues called irregularity for earthquake-resistant building design. It defined the horizontal and vertical irregularities of the building and requested that these rules be followed during the design. In addition, the regulation provides rules for all reinforced concrete elements under the title of earthquake-resistant structural design. The sections of

*Corresponding author. Tel.: +90-541-644-4917; e-mail: batuhanaykanat@duzce.edu.tr

columns, their positions, their reinforcement, the dimensions of beams, beam reinforcement, and the rules regarding shear walls are explained with figures and stated in the form of tables, formulas or equations. All reinforced concrete structural elements have been examined in detail. In addition, earthquake resistant design rules for steel, wood, masonry and retaining structures have been determined [2]. Turkish Building Earthquake Code – 2018 (TBEC-18) [12], includes more realistic seismic parameters and a more reliable calculation method compared to previous earthquake codes [13, 14]. For this reason, it can be described as the most contemporary earthquake regulation used in our country today. Before the 1998 earthquake code, simpler approaches were used in seismic calculations. However, since the Regulation about the buildings constructed in the disaster regions-1998, first addressed some issues called irregularity for earthquake-resistant building design, the calculation method has begun to be prepared in more detail based on scientific data. Regulation about the buildings constructed in the disaster regions-1998, first addressed some issues called irregularity for earthquake-resistant building design form the basis of the 2007 and 2018 earthquake codes. Therefore, the 2018 earthquake code was compared with the regulation about buildings constructed in the disaster regions-1998. Calculation and analysis methods have been improved with the current 2018 earthquake code. In TBEC-2018, the concept of an earthquake zone has been eliminated, earthquake hazard maps (Figure 1) have been developed, and site-specific design spectrums have begun to be used.

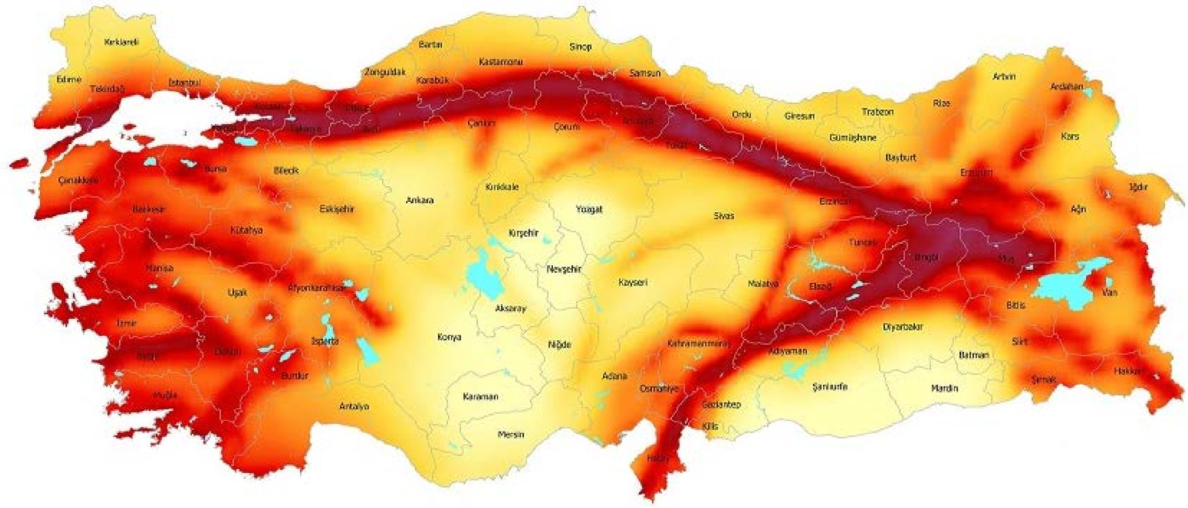

Figure 1. 2018 Earthquake hazard map

In this study, 6-storey reinforced concrete structures with different storey heights (2.80m, 3.00m and 3.20m) were modeled using SAP2000 [15]. Structural analysis was carried out when earthquake loads were applied to these structures according to the 1998 and 2018 earthquake regulations. The period, maximum displacement values, relative storey drifts, base shear forces and torsional irregularity coefficients obtained because of the analyses were compared.

II. EXAMINATION of 1998 and 2018 SEISMIC DESIGN CODES in TURKEY

The calculation details of the 1998 and 2018 Earthquake regulations used in the study are given in detail in this section.

2.1 Regulation about the buildings constructed in the disaster regions-1998

According to the 1998 Earthquake Code, the total equivalent earthquake load acting on the structure was calculated using Eq. (1).

$$V_t = \frac{WA(T_1)}{R_a(T_1)} \geq 0.10 A_0 IW \tag{1}$$

In this equation, V_t is the equivalent seismic load (base shear), W is the weight of the structure, $A(T_1)$ is the spectral acceleration coefficient, A_0 is the local seismic acceleration, $R_a(T_1)$ is the seismic load reduction coefficient, T_1 is the first natural period of the structure, and I is the structure importance factor, respectively. For the relevant regulation, the first natural period of the structure is calculated according to Eq. (2), the spectral acceleration coefficient is determined according to Eq. (3), and the seismic load reduction coefficient is determined according to Eq. (4) and Eq. (5).

$$T_1 = 2\pi \left[\sum_{i=1}^{N} \left(m_i {d_{fi}}^2 \right) \Big/ \sum_{i=1}^{N} \left(F_{fi} d_{fi} \right) \right]^{1/2} \tag{2}$$

$$A(T) = A_0 IS(T) \tag{3}$$

$$R_a(T) = 1.5 + (R - 1.5)\, T/T_A \rightarrow (0 \leq T \leq T_A) \tag{4}$$

$$R_a(T) = R \rightarrow (T > T_A) \tag{5}$$

2.2 Turkish Building Earthquake Code-2018

According to TBEC-2018, the total equivalent earthquake load acting on the structure was calculated using Eq. (6).

$${V_{tE}}^{(X)} = m_t S_{aR}\left({T_p}^{(X)}\right) \geq 0.04 m_t I S_{DS} g \tag{6}$$

Where, m_t is the mass of the structure, and $S_{aR}\left({T_p}^{(X)}\right)$ is the reduced design spectral acceleration calculated by taking into account the predominant period of the structure (${T_p}^{(X)}$) in the earthquake direction under consideration. In addition, I is the structure important factor, S_{DS} is the design spectral acceleration coefficient defined for the short period, and g is the gravitational acceleration. The reduced design spectral acceleration of the structure is calculated according to Eq. (7) and the predominant period of the structure is determined according to Eq. (2) by considering the direction of the earthquake (X, Y).

$$S_{aR}(T) = S_{ae}(T)/R_a(T) \tag{7}$$

In this equation, $S_{ae}(T)$ is the corner period of the horizontal elastic design acceleration spectrum. $R_a(T)$ is the seismic load reduction coefficient. The calculation of the horizontal elastic design acceleration spectrum and the seismic load reduction coefficient is summarized by Eq. (8–13).

$$S_{ae}(T) = \left(0.4 + 0.6\frac{T}{T_A}\right)S_{DS} \rightarrow (0 \leq T \leq T_A) \tag{8}$$

$$S_{ae}(T) = S_{DS} \rightarrow (T_A \leq T \leq T_B) \tag{9}$$

$$S_{ae}(T) = \frac{S_{D1}}{T} \rightarrow (T_B \leq T \leq T_L) \tag{10}$$

$$S_{ae}(T) = \frac{S_{D1}T_L}{T^2} \rightarrow (T_L \leq T) \tag{11}$$

$$R_a(T) = \frac{R}{I} \rightarrow (T > T_B) \tag{12}$$

$$R_a(T) = D + \left(\frac{R}{I} - D\right)\frac{T}{T_B} \rightarrow (T \leq T_B) \tag{13}$$

According to these equations, T_A and T_B are the horizontal elastic design acceleration spectrum corner periods, T_L is the transition period to the constant displacement region, R is the structural system behavior coefficient, and D is the overstrength factor, respectively. According to TBEC-2018, S_{DS} and S_{D1} are calculated according to Eq. (14) and Eq. (15). Where S_S is the map spectral acceleration coefficient for the period of 0.2 s, S_1 is the map spectral acceleration coefficient for the period of 1.0 s, F_S is the local soil effect coefficient for the period of 0.2 s, and F_1 is the local soil effect coefficient for the period of 1.0 s.

$$S_{DS} = S_S F_S \tag{14}$$

$$S_{D1} = S_1 F_1 \tag{15}$$

The total equivalent seismic load is expressed as the sum of the equivalent seismic loads acting on the floors of the structure in Eq. (16).

$$V_{tE}^{(X)} = \Delta F_{NE}^{(X)} + \sum_{i=1}^{N} F_{iE}^{(X)} \tag{16}$$

2.3 Building Detail and Analysis Details

The equivalent lateral force method was used in this study. In addition, calculation of seismic parameters of the structure was carried out separately according to the principles of each earthquake code considered. The seismic load calculated according to each earthquake code was defined separately in the SAP2000 structural analysis program, and analysis of the structure was carried out. While performing the analyses according to the TBEC-2018, it was assumed that the structure had a ZD Soil class (T_A=0.105s, T_B=0.525s) in the Düzce Central District. According to the 1998 Earthquake Regulation, the soil class is evaluated as Z3 (T_A=0.15s, T_B=0.60s). The design spectra based on the 1998 and 2018 earthquake codes are shown together in a Figure 2. To determine the effects of changes in storey height on the seismic behavior of the building, the building was modeled as a 6-storey building with 3 different storey heights (2.80m, 3.00m and 3.20m). The plan of the structural system reinforced concrete building selected to be modeled within the aim of this study is given in the Figure 3. Column and shear walls details of structural systems are given in Table 1. In addition, images of the created model are given in the Figure 4. In the analysis, the concrete class was selected as C30/37 and the steel class as B420C. For TBEC-2018, DD-2 was selected as the Design Earthquake Ground Motion Level. Since the building type is residential, the importance factor (I) is taken as 1. Building Height Class (BYS) was taken from the relevant table in TBEC-2018 depending on the building height and Earthquake Design Class (EDC). The Overstrenght Factor (D) is 2.5 in both directions (Plan I (REF) D=3), and the Earthquake Design Class (DTS) is taken from the relevant tables in TBEC-2018 depending on the Building Usage Class (BKS) and the Short Period Design Spectral Acceleration coefficient (SDS=1.351). Design and analysis of the structure were performed using the SAP2000 structural analysis program. The seismic loads calculated according to TBEC-2018, and 1998 Earthquake Regulation was defined, and the dynamic analysis of the structure was carried out separately. In addition, torsional moments of at least ±5% eccentricity at the geometric center of the structure, depending on the seismic forces acting on the floors, were included in the calculations.

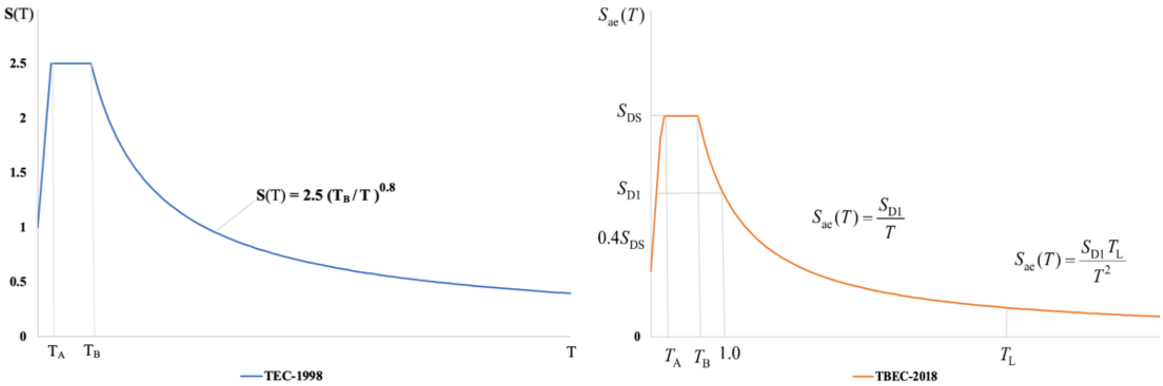

Figure 2. The design spectra based on the 1998 and 2018 earthquake codes

Table 1. Structural details

Column, Shear Walls and Beam Detail	
Column dimensions and number of columns	40 *pcs* 70x40 *cm* 4 *pcs* 95x40 *cm* 2 *pcs* 130x30 *cm*
Shear wall dimensions and number of shear wall	12 *pcs* 180x30 *cm* 1 *pcs* 320x30 *cm*
Beam dimensions	30x50 *cm*

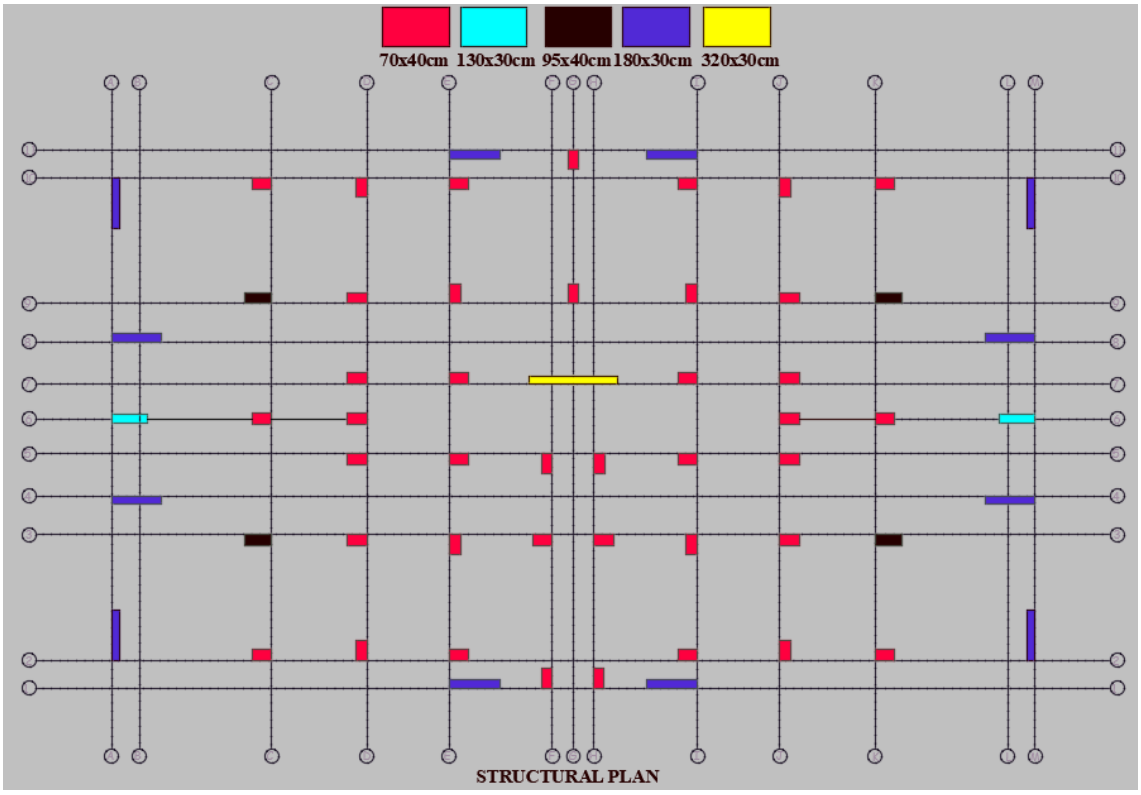

Figure 3. Structural Plan

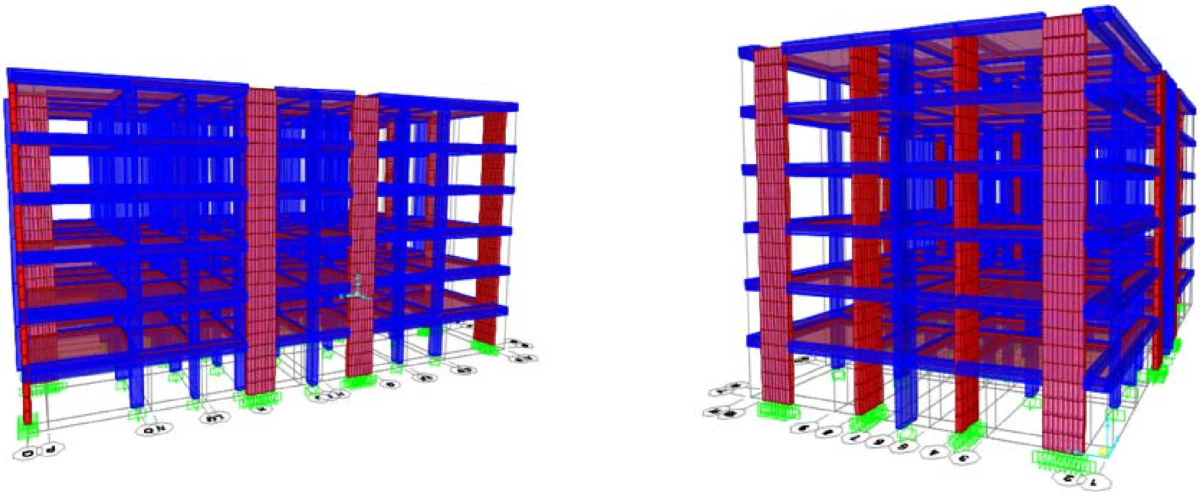

Figure 4. SAP2000 Model

III. NUMERICAL ANALYSIS RESULTS

The structural analysis results of the buildings, which was analyzed in the SAP2000 program according to the 2018 and 1998 Earthquake Regulation, are given in Table 2.

When Table 2 is examined, it is seen that the building periods are close to each other. It is seen that the highest period value is 3.20 storey height in both regulations. As is known, the period of the structure depends especially on the rigidity and mass of the structure. For this reason, the fact that the highest period is obtained in the model with the highest storey height confirms this information. The maximum displacement in the structure occurred at the top point of the building (Storey 6). The graphical representation of Maximum Displacements is given in the Figure 5.

Table 2. Structural analysis results

	Relevant Earthquake Code					
	2018			**1998**		
	Storey Height (*m*)					
	2.80	**3.00**	**3.20**	**2.80**	**3.00**	**3.20**
Period (**T**) (*s*)	0.7318	0.7947	0.8698	0.5510	0.5996	0.6560
Base shear force (*kN*)	7633.50	7067.67	6592.30	5397.50	5376.21	5354.69
Max. Displacement (**X Direction**) (*m*)	0.0284	0.0306	0.0337	0.0111	0.0129	0.0153
Max. Displacement (**Y Direction**) (*m*)	0.0321	0.0348	0.0382	0.0151	0.0177	0.0211
Torsional Irregularity (η_{bi}) **(X Direction)**	1.14	1.14	1.14	1.15	1.13	1.17
Torsional Irregularity (η_{bi}) **(Y Direction)**	1.21	1.17	1.22	1.20	1.21	1.20

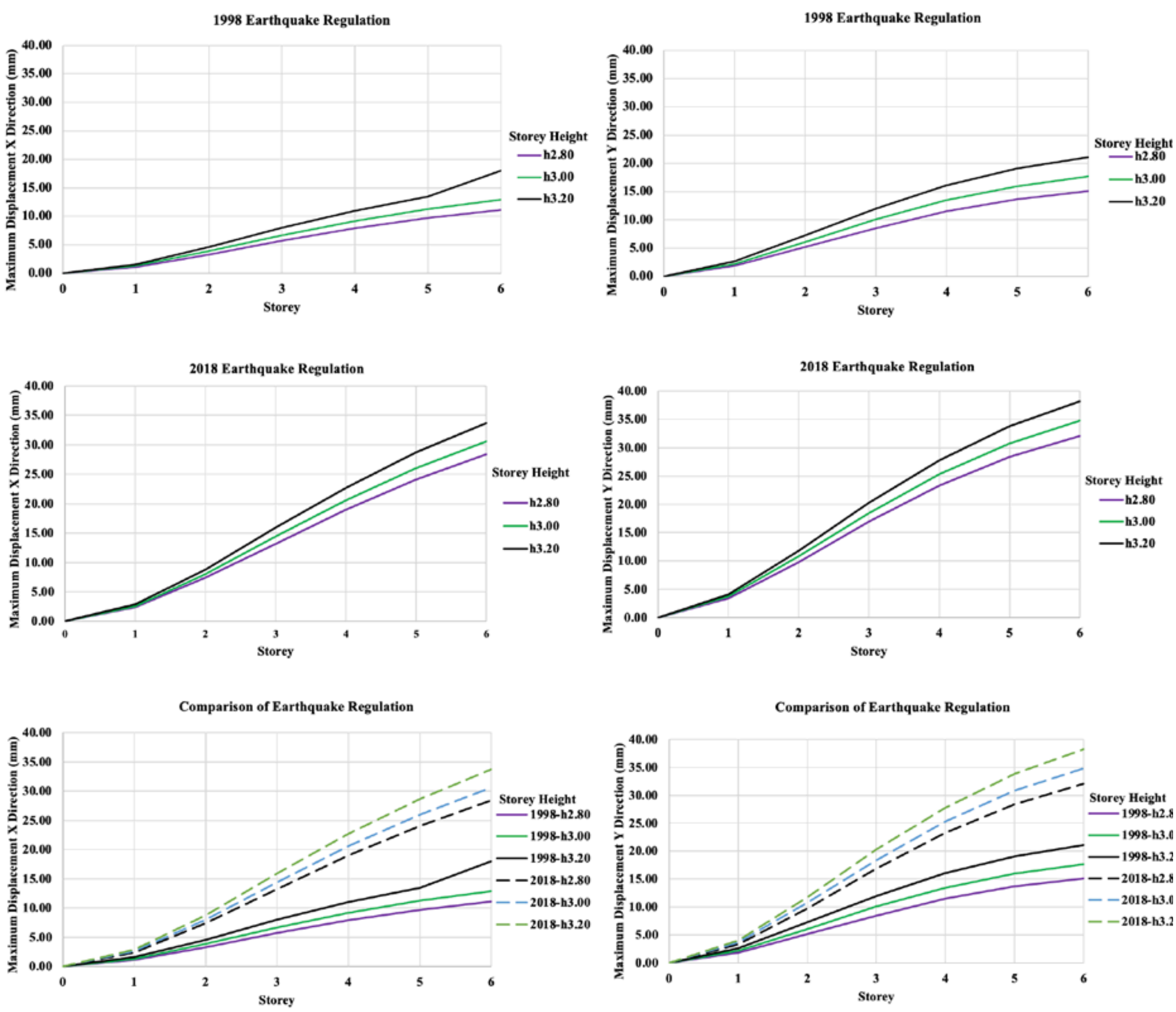

Figure 5. Maximum displacement values

When the Figure 4 is examined, it is seen that the displacement values in both directions are close to each other since a simple and symmetrical structural system was chosen. When the analysis results made according to the

1998 Earthquake Code were examined, it was determined that the maximum displacements increased in both directions as the storey height increased, as expected. In addition, when the analysis results made according to the 2018 Earthquake Code were examined, it was seen that the maximum displacements increased in both directions as the storey height increased, like other results. When all displacement results were examined comparatively, the highest displacement result was obtained in the model with a storey height of 3.20m, because of the analysis made according to the 2018 Earthquake Code. This situation can be explained by the fact that the earthquake load is higher than the 2018 regulation, as seen in Table 2.

Torsional irregularity is a kind of plan irregularity. Torsional irregularity occurs due to the eccentricity between the centre of mass (CM) and the centre of resistance (CR). The η_{bi} values obtained in the calculations made according to the regulation are given in the Table 2.

When the η_{bi} values calculated were examined, it was determined that there was no torsional irregularity in the selected structural systems X direction. In the Y direction, it is understood that the distance between the center of mass and the center of rigidity is large depending on the placement of the structural system. Therefore, the irregularity coefficients are higher than in the X direction. If the torsional irregularity coefficients exceed the limits permitted by the regulation, the torsional irregularity can be prevented by changing the placement of the load-carrying elements or changing their dimensions. Since this study was a relative comparison on the same floor plan, no changes were made to the load-carrying system.

Choosing a simple and symmetrical structural system is of great importance in preventing torsional irregularities. In addition, the use of shear walls in different directions to absorb earthquake loads makes the carrier system safer against torsion effects.

Interstory drift is an important indicator of structural system behaviour in structural analysis. In this study, interstorey drifts were calculated as the difference in displacement between two consecutive storeys for any storey. The graphical representation of the interstorey drifts calculated separately in both directions is given in the Figure 6.

When the results obtained according to both regulations are examined, as expected (Figure 6), the largest relative interstorey drifts (X and Y Direction) were obtained in models with a storey height of 3.20 m. In addition, when the 2018 and 1998 regulations were examined comparatively, the largest relative interstorey drift values were obtained in the analysis made according to the 2018 regulation with a Y direction and a storey height of 3.20 m. The changes in the storey heights caused increases in the relative interstorey drift values as expected. This is thought to be due to the changes in the rigidity and slenderness of the structural elements. According to TBEC-2018, the stiffness of the cracked section must be considered in the design and performance determination of reinforced concrete structural system. Therefore, effective section stiffness coefficients are calculated and used. However, for TEC-1998, uncracked section stiffness is used. According to TBEC-2018, different effective section stiffness coefficients are defined for each structural element. This stiffness change affects load distribution of the structure. In this case, the cross-sectional effects on the structural elements change. It causes different displacements to occur at each joint. These changes made in the rigidity of the structural elements according to the TBEC-2018 directly affected the analysis results such as period, displacement base shear force and interstorey drift values.

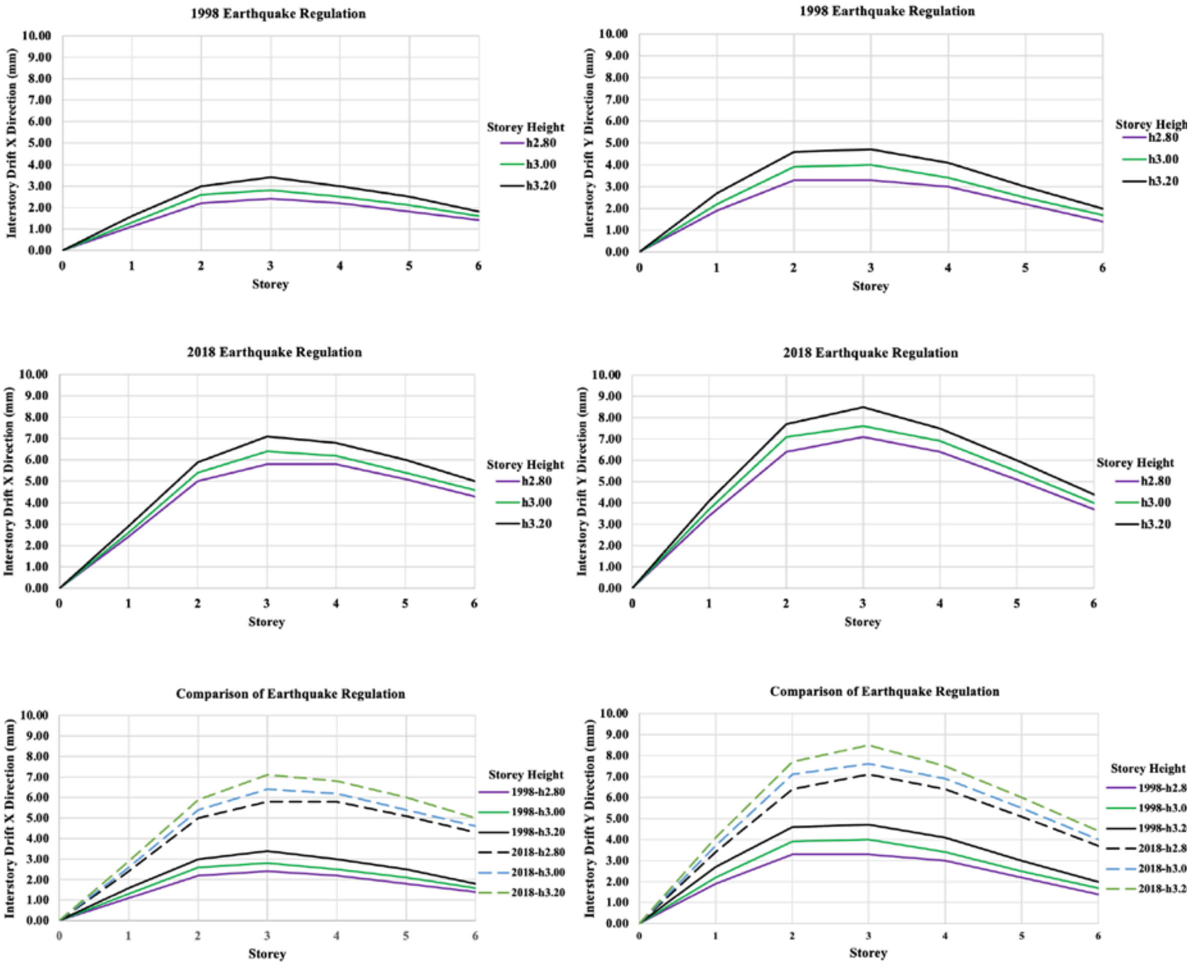

Figure 6. Interstory drift values

IV. RESULTS AND DISCUSSION

In this study, different structural systems with changed storey heights were modeled according to the 2018 and 1998 earthquake codes. Structural analyses of these models were performed using SAP2000 structural analysis program to the relevant regulations. As a result of the analysis, it was determined that the period, base shear force, torsional irregularity, displacement and interstory drifts changed depending on the change in the structural system storey height. It is thought that these changes are caused by changes in rigidity as a result of the increase in the storey height. As a result of the analysis, it is thought that choosing a simple and symmetrical structural system is important and that irregularities in the plan can be prevented accordingly. In cases where the storey heights need to be increased, it is thought that making changes in the sections of the structural elements and making them suitable can prevent irregularities. Finally, the behaviors of reinforced concrete buildings with different storey heights and the same structural system layout can be very different from each other. For this reason, it is thought that it would be correct to optimize behavior by making changes to the structural system and element dimensions.

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