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Determination of Earthquake Performance of Existing RC Buildings According to FEMA-356 and TBEC-2018

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Abstract: Türkiye, located in a seismically active region with a high concentration of active fault lines, has experienced numerous devastating earthquakes, underscoring the critical need for seismic safety. Over the past 30 years, the country has been struck by several major earthquakes, resulting in significant loss of life and extensive property damage. The 06.02.2023 Kahramanmaraş earthquakes highlighted the severity of seismic activity, emphasizing the need for earthquake-resistant building design and retrofitting of buildings that do not meet modern standards. This ensures resilience and reduces economic losses in the face of earthquakes. This paper assesses the seismic performance of an existing G+2 reinforced concrete (RC) building. A static pushover analysis was performed in accordance with FEMA-356 and TBEC-2018 guidelines. The building was modeled in SAP2000 using the original cross-section and reinforcement details. Target displacements and damage distributions were compared to evaluate structural performance under both codes.

Mevcut Betonarme Binanın Deprem Performansının FEMA-356 ve TBDY-2018'e Göre Belirlenmesi

Öz: Türkiye, aktif fay hatlarının yoğun olduğu sismik açıdan aktif bir bölgede yer almakta olup, birçok yıkıcı depreme maruz kalmıştır. Bu durum, deprem güvenliğinin önemini açıkça ortaya koymaktadır. Son 30 yıl içinde ülke, ciddi can ve mal kaybına neden olan birçok büyük depremle sarsılmıştır. 06.02.2023 Kahramanmaraş depremleri, sismik aktivitelerin ciddiyetini gözler önüne sermiş ve depreme dayanıklı bina tasarımı ile modern standartlara uymayan binaların güçlendirilmesi gerekliliğini vurgulamıştır. Bu, depremlere karşı dayanıklılığı sağlar ve ekonomik kayıpları azaltır. Bu çalışmada; mevcut bir Z+2 betonarme binanın sismik performansı değerlendirilmiştir. Statik itme analizi, FEMA-356 ve TBEC-2018 yönetmeliklerine göre gerçekleştirilmiştir. Bina, orijinal kesit ve donatı detaylarına göre SAP2000 programında modellenmiştir. Hedef yer değiştirmeler ve hasar dağılımları karşılaştırılarak, her iki yönetmeliğe göre yapısal performans değerlendirilmiştir.

1. INTRODUCTION

Türkiye is one of the most seismically active countries in the world. It is intersected by two major active fault lines: the North Anatolian Fault (NAF) and the East Anatolian Fault (AEF) [1]. The Anatolian Plate is located between the Arabian Plate and the Eurasian Plate, and is among the fastest-moving tectonic plates globally, exhibiting high seismic activity due to its rapid compressive movement

[2]. According to the Disaster and Emergency Management Presidency (DEMP) map, the Seismic hazard map, these fault systems pass through 24 cities in Türkiye. The EAF is a left-lateral strike-slip fault located in the southern part of the country, serving as a tectonic boundary between the Eurasian and Arabian Plates [3]. Extending from the Arabian Plate in the east to the Aegean Sea in the west, these fault lines have caused numerous destructive earthquakes throughout history, as

shown on the DEMP map [2], [3], [4]. The locations of these Earthquake faults are shown in Figure 1.

Figure 1. The Earthquake Map faults of Türkiye [5].

Performance-based design is based on designing a structure by choosing a performance target under design criteria to increase the structure's resistance against earthquakes [6]. This concept is crucial for designing important buildings like hospitals, schools, fire stations, and residential buildings, ensuring performance-designed qualities [7]. In recent years, the concept of structural evaluation and design based on displacement and deformation performance criteria has been introduced and developed, particularly in efforts to more accurately assess the seismic safety of existing structures in earthquake-prone areas [8]. The aim of performance-based design for existing buildings under earthquake conditions is to ensure the structure performs well during seismic events, minimizing damage and ensuring occupant safety. Performance is determined by the extent of damage a building sustains during an earthquake, and it is essential to fulfill and manage these requirements effectively [9]. The United States has been developing performance-based seismic design since the 1970s, starting with the 1976 Uniform Building Code (UBC) [10]. The ICBO introduced Occupancy Importance factors to calculate seismic forces, aiming to enhance robustness and performance. However, Civil engineers realized that strength alone wasn't enough. Over time, additional features were developed. In Türkiye it was added the performance-based design was added to the code of TBEC-2007 and TBEC-2018. While the United States of America developed different codes in different years, the Performance-based design, which includes: 1997 FEMA-273, 2000 FEMA-356, and 2007 ASCI/41-13-17.

Different researchers investigated different buildings based on FEMA-356 and TBEC-2018, Such as Tolunay and Hakkan (2021). The performance level of a reinforced concrete building designed by the Turkish building earthquake code, Seismic Code (TBEC-2018), was assessed through static single-mode pushover analysis. The analysis was compared to the target performance level set in the Turkish Seismic [11]. Metin and Besian (2019) investigated the performance evaluation of existing reinforced structures, using the static pushover

analysis method, and evaluated their performance and damage levels, comparing them to the Turkish Building Earthquake Code (TBEC-2007) and Eurocode standards [12]. Rey and Geffren (2024), A Four-Story Professional School Building in the University of Mindanao, was assessed using ASCE/SEI 41. They were evaluated using various seismic design principles, including ATC 40, FEMA 356, and FEMA 440. Linear and nonlinear analyses were used, with a pushover curve drawn for plastic hinge behavior, deformation-controlled, and force-controlled actions [13]. Ashwini and his friends (2024) investigated an eight-story structure to evaluate its structural performance using pushover analysis. The assessment was based on parameters such as moment-curvature, ductility, overstrength, inter-story drift, and a detailed computation of base shear [14]. Rohullah (2024) investigated the scope of reinforced concrete buildings, using TBECC-2018 and ASCI-41-17 methods. It discussed the incremental equivalent earthquake load calculation and simplified nonlinear static analysis methods, and performed performance analysis comparing results [15]. Recent earthquakes, particularly the 2023 Kahramanmaraş earthquakes, have demonstrated the vulnerability of reinforced concrete buildings in Türkiye, with widespread collapses attributed to soft-story mechanisms, poor detailing, and inadequate seismic design [16], [17], [18], [19].

Previous studies have focused primarily on evaluating seismic performance using either international guidelines like FEMA-356 or earlier versions of the Turkish seismic code. However, few comparative studies have examined the differences between TBEC-2018 and FEMA-356 in evaluating the same structure. This study fills that gap by applying both regulations to a real, existing building and comparing the outcomes. The findings highlight how the evolution in Turkish seismic code provisions influences performance expectations and design decisions. Thus, the study provides a unique comparative analysis that can inform both national and international retrofitting strategies.

Previous studies have primarily focused on assessing the seismic performance of structures using either previous revisions of the Turkish seismic code or international guidelines like FEMA-356. Comparing FEMA-356 to TBEC-2018, the current national code in Türkiye, when applied to the same structure, hasn't been done much, though. In order to close that gap, this study compares the performance of a real, existing building using both standards. The results show how recent changes to the Turkish seismic code affect design choices and performance expectations, providing insightful information that can guide national and international retrofit and assessment plans.

In this study, the seismic behavior of a three-story (G+2) reinforced concrete residential building in Sakarya Province, Türkiye, was examined through nonlinear static pushover analysis. The structure that was designed as per TBEC-2018 was analyzed and modeled by using SAP2000. Target displacements were determined as per TBEC-2018 and FEMA-356 provisions, and the damage

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distributions of the structural elements obtained were compared. The results are compared in this dual-code approach to understand the performance differences between the two regulations.

2. METHOD AND ANALYSIS PROCEDURE

The structure examined in this study is a mid-rise reinforced concrete building designed in accordance with TBEC-2018 guidelines. it was selected because it reflects the latest seismic provisions currently used in Türkiye, allowing for direct comparison of how modern code-compliant structures perform under different assessment standards.

To determine how international standards and national regulations compare when assessing the seismic performance of newly designed structures, the study will evaluate a building that was designed using both TBEC-2018 and FEMA-356.

This influences code development as well as engineering practice by pointing out possible inconsistencies or conservatism in performance evaluation techniques

2.1. Turkish Building Earthquake Code(TBEC-2018)

The Turkish Building Earthquake Code (TBDY-2018) is a set of guidelines and regulations developed by Türkiye's Ministry of Environment and Urbanization to ensure the safety and structural integrity of buildings during earthquakes. Updated in 2018, it aligns with modern seismic research and engineering practices. The code provides detailed standards for the design, construction, and retrofitting of buildings to withstand earthquake forces. It defines seismic hazard zones across Türkiye, considers regional earthquake risks, specifies guidelines for structural systems and materials such as reinforced concrete and steel, and establishes requirements for earthquake-resistant design to absorb seismic forces. It also includes performance criteria to ensure life safety and minimize damage during an earthquake, along with retrofitting guidelines to strengthen existing buildings for better earthquake resistance.

2.1.1. Determination of performance analysis method according to tbec-2018

In order to assess the seismic performance of existing concrete structures following TBEC-2018, the target displacements should be calculated, plastic hinge properties should be defined, and plastic limits should be determined. Chapter 15 of TBEC-2018 outlines the principles for determining the performance levels of existing buildings. To calculate the maximum displacement of the modal single-degree-of-freedom system in the earthquake direction under analysis, the nonlinear spectral displacement (in meters) corresponding to the first natural vibration period (T_1) must be determined. This value can then be used in Equation 1 to find the maximum displacement of the system.

$$d_{x,max}^{X} = S_{di}(T_1) \tag{1}$$

Where S_{di} is the nonlinear spectral displacement, the corresponding S_{di} can be found by using Equation 2.

$$S_{di}(T_1) = C_r S_{de}(T_1) \tag{2}$$

Where C_r= the spectral displacement ratio and T_1 first natural vibration period. To calculate the spectral displacement ratio (CR), the ductility demand $\mu(RyT_1)$, calculated based on the yield strength reduction coefficient and the first natural vibration period, is divided by the yield strength (R_y).

$$C_r = 1 \quad when \quad T_1 > T_B \tag{3}$$

$$C_r = \frac{1 + (R_y - 1)\frac{T_B}{T_1}}{R_y}, when \, T_1 < T_B \tag{4}$$

In Figure 2, corresponding to the case where Equation 3 is used together, it is necessary to demonstrate that the natural vibration time occurs at the initial thrust phase. period at the first thrust step ($T_1 > T_B$) or the first (dominant) mode natural angular frequency values ($\omega_1 \leq \omega_B$) found in the free vibration calculation, renewed at each thrust step.
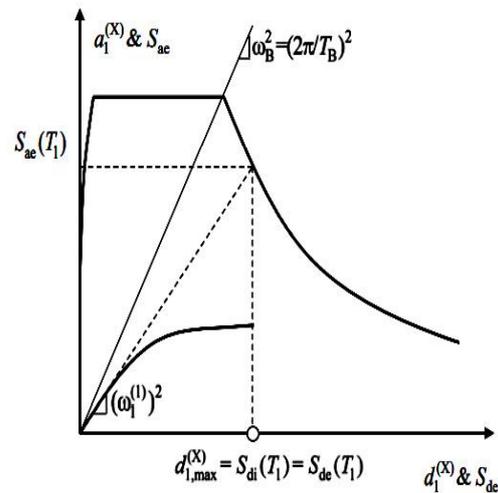
Figure 2. Modal Displacement Demand [20].

In another case given in Figure 3a, the spectral displacement ratio (C_R) is obtained by the successive approximation method. First, the spectral displacement ratio (C_R=1) is assumed. Thus, initially, the modal capacity diagram is transformed into a two-line elasto-plastic diagram. In this process, the areas under the diagrams must be equal. Based on these values, the elasto-plastic diagram is reconstructed as shown in Figure 3a. These graphs were fully explained in TBEC-2018 in section 5B.3.

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a)

b)
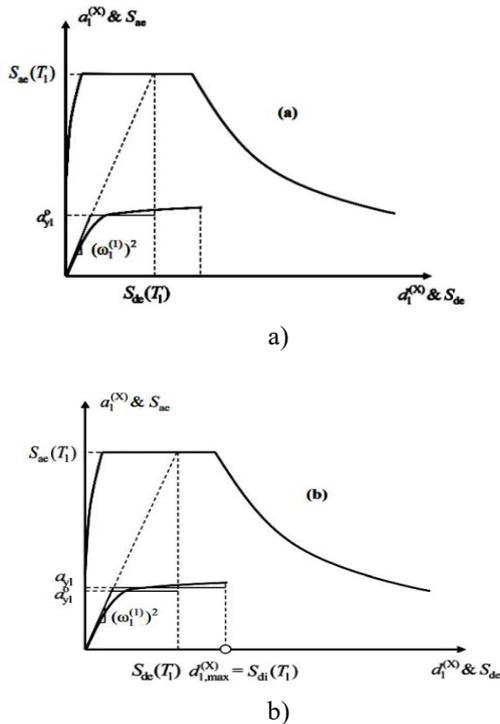
Figure 3. Modal displacement Demand graph according to TBEC-2018

2.1.2. Determination of performance damage levels by TBEC-2018

The moment rotations in Beams, columns, and Shear walls for definitions in SAP2000 can be calculated according to TBEC-2018 in Equation 5.

$$\theta^p = (\phi_u - \phi_y)L_p \qquad (5)$$

The Axial forces of Column sections in the definition of Plastic hinges can be calculated in Equation 6.

$$N_d = 0, \quad N_d = 0.2A_cF_{ck} \quad , \quad N_d = 0.4A_cF_{ck} \qquad (6)$$

The Collapse Prevention Performance Level for inelastic behavior, Plastic Behavior, according to TBEC-2018, can be found in Equations 7-9.

$$\theta_p^{(CP)} = \frac{2}{3}\left[\left(\phi_u - \phi_y\right)L_p\left(1 - 0.5\frac{L_p}{L_s}\right) + 4.5\phi_u d_p\right] \qquad (7)$$

$$\theta^{(CD)} = 0.75 \times \theta^{(G\ddot{o})} \qquad (8)$$

$$\theta^{(LD)} = 0 \qquad (9)$$

$\theta^{(CP)}$= Allowable roatation for Collapse Prevention, $\theta^{(CD)}$= Allowable roatation for Controlled Damage, $\theta^{(LD)}$= Allowable roatation for Limited Damage and N_d= is the axial force of the section. The definition of plastic rotation limits and unit deformations for TBEC-2018 is provided in Chapter 5.8 of the code. TBEC-2018 defines seismic performance levels for structures, which are categorized as Limited Damage (LD), Controlled Damage (CD), and Collapse Prevention (CP). The Limited Damage level corresponds to minimal structural damage, where the building remains fully functional. The Controlled Damage level allows for minor structural damage that is repairable. The Collapse Damage level indicates extensive structural damage that may compromise the building's safety during an earthquake. The performance damage levels according to TBEC-2018 are illustrated in Figure 4.
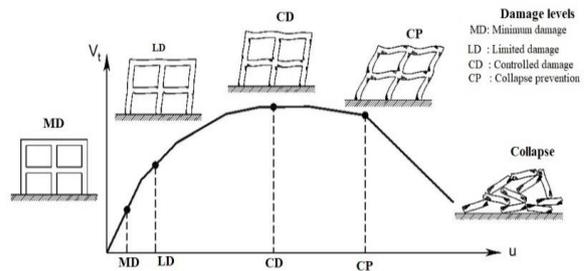
Figure 4. The Performance damage levels of TBEC-2018 [20]

2.2. Determination of Performance Analysis Method According to FEMA-356

FEMA-356 outlines performance-based evaluation procedures, providing detailed guidelines on modeling parameters, acceptance criteria, and methods for performing pushover analysis [21]. FEMA-356 classified two main criteria for determining the yielding behavior of frame members during pushover analysis, as shown in Figure 5. These criteria are categorized as either deformation-controlled (ductile behavior) or force-controlled (brittle behavior) plastic hinges [22]. The displacement-controlled action under flexure is idealized using performance levels A, B, C, D, and E, which represent strain, curvature, rotation, or elongation, allowing engineers to evaluate structural response and predict seismic behavior. Figure 5b illustrates the inelastic force-deformation relationship for displacement-controlled actions under flexural loading [23].
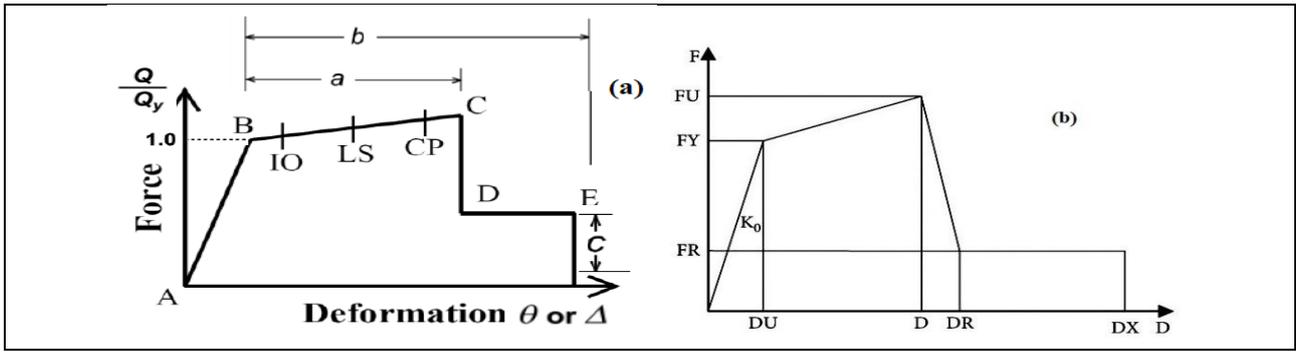
Figure 5. A) Deformation control and B) Force-deformation [24], [25].

According to FEMA-356, the designations IO (Immediate Occupancy), LS (Life Safety), and CP (Collapse Prevention) represent acceptance requirements or performance levels for the plastic hinge that develops near the ends of columns and beams. The P-M interaction curve (ACI code 2000), the stress-strain curve for concrete (Kent Park) [26], and the M-θ relationship, which indicates acceptance criteria corresponding to performance levels, are all represented by default values provided in the software SAP 2000 v24 [27]. The performance damage levels of FEMA-356 can be determined as shown in Figure 6.
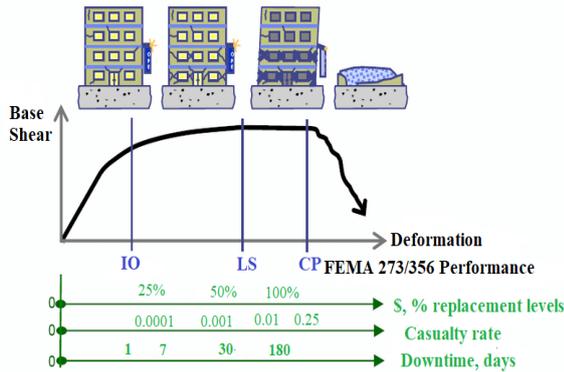
Figure 6. The Performance damage levels of FEMA 273/356 [25], [28].

In the analysis phase, FEMA-356 offers four methods: Linear Static, Linear Dynamic, Nonlinear Static (Pushover), and Nonlinear Dynamic (Time-History). The choice of method depends on the complexity of the structure and the desired accuracy. After analysis, engineers compare results to acceptance criteria for deformation- and force-controlled actions. If elements exceed thresholds, retrofitting strategies like adding shear walls, column jacketing, or base isolators are implemented. Visual outputs such as 3D models, deformed shapes, and pushover curves support decision-making throughout the process.

2.2.1 Target displacement by FEMA-356

According to FEMA 356, the target displacement, δt, at each floor level shall be computed according to Equation (10) and as specified in Section 3.3.3.3.1;

$$\delta_t = C_0 C_1 C_2 C_{C3} S_a \frac{T_e^2}{4\pi^2} g \tag{10}$$

C_o, C_1, C_2, and C_3 are modification factors used to adjust the displacement response of a building under seismic loading. Co relates the spectral displacement of an equivalent SDOF system to the building's roof displacement. C_1 accounts for expected maximum inelastic displacements, C_2 adjusts for the effects of pinched hysteretic behavior, stiffness degradation, and strength deterioration, and C_3 represents increased displacements due to dynamic P-Δ-effects. Sa refers to the response spectrum acceleration.

Figure 7-8 demonstrates the displacement coefficient method used to determine the target displacement (δ_T). This process begins by establishing the effective fundamental period, which takes into account the inelastic behavior of the structure. The effective fundamental period represents the linear stiffness of an equivalent Single Degree of Freedom (SDOF) system and is associated with the maximum spectral acceleration (S_d) of the system. Once the effective fundamental period is determined, the target displacement can be calculated.
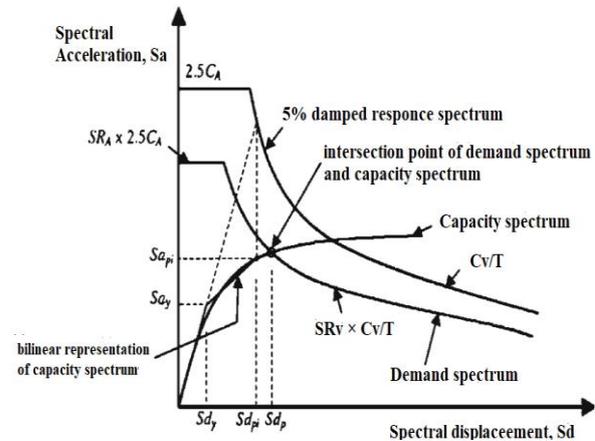
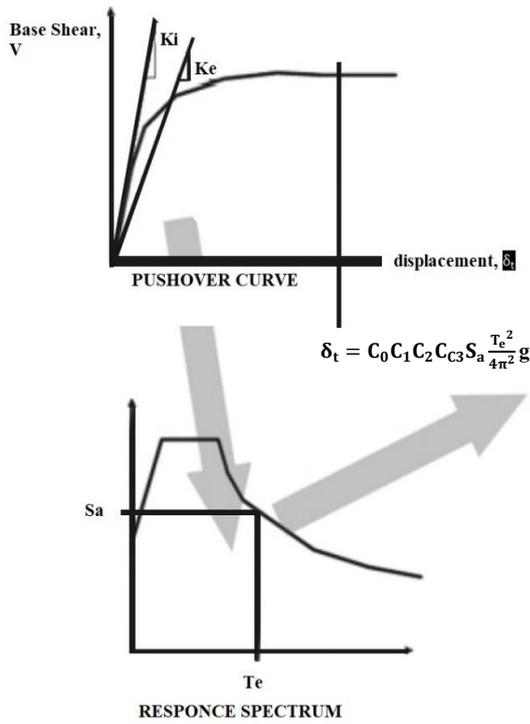**Figure 7.** Target displacement method according to FEMA-356 [25].

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Figure 8. Target displacement method according to FEMA-356 [25]

$$\delta_t = C_0 C_1 C_2 C_{C3} S_a \frac{T_e^2}{4\pi^2} g$$

2.2.2 Determination of performance damage levels by FEMA-356

To determine the performance levels of concrete structures according to FEMA-356, the section rotations of structural elements can be assessed. Section rotations are expressed in radians, and factors such as axial load, section area and properties, concrete weight, and transverse reinforcement distribution are considered. The performance criteria, as outlined in FEMA-356, can be determined for both beams and columns, as shown in Tables 1 and 2.

Table 1. Section rotation limits for reinforced concrete columns

Cross-Section Properties				Damage Limits (plastic rotation angle, radians)				
				Type of building element				
				Primary			Secondary	
$P / (A_g \times f_c)$	Winding feature	$V / (b_w \times d \times f_c)$	IO	LS	CP		LS	CP
≤0.1	C	≤ 3	0.005	0.015	0.020		0.020	0.030
≤0.1	C	≥ 6	0.005	0.012	0.016		0.016	0.024
≤0.4	NC	≤ 3	0.003	0.012	0.015		0.018	0.025
≤0.4	NC	≥ 6	0.003	0.010	0.012		0.013	0.020
≤0.1	NC	≤ 3	0.005	0.005	0.010		0.010	0.015
≤0.1	NC	≥ 6	0.005	0.004	0.005		0.008	0.012
≤0.4	NC	≤ 3	0.002	0.002	0.003		0.006	0.010
≤0.4	NC	≥ 6	0.002	0.002	0.003		0.005	0.008

Table 2. Section rotation limits for reinforced concrete beams

Cross-Section Properties				Damage Limits (plastic rotation angle, radians)				
				Type of building element				
				Primary			Secondary	
$P / (A_g \times f_c)$	Winding feature	$V / (b_w \times d \times f_c)$	IO	LS	CP		LS	CP
≤0	C	≤ 3	0.010	0.02	0.02		0.02	0.05
≤0	C	≥ 6	0.005	0.01	0.025		0.02	0.04
≥0.5	NC	≤ 3	0.005	0.01	0.02		0.02	0.03
≥0.5	NC	≥ 6	0.005	0.005	0.015		0.015	0.02
≤0	NC	≤ 3	0.005	0.01	0.02		0.02	0.03
≤0	NC	≥ 6	0.0015	0.005	0.01		0.01	0.015
≥0.5	NC	≤ 3	0.005	0.01	0.01		0.01	0.015
≥0.5	NC	≥ 6	0.0015	0.005	0.001		0.005	0.01

2.3. Building Details

The seismic performance of a G+2 reinforced concrete building located in the Sakarya province of Türkiye was evaluated in this study. The building consists of a 3.4-meter-high ground floor and two upper stories, each with a uniform height of 2.4 meters. It is designed for residential use (Figure 9). The structural system includes C30-grade concrete and B420C-grade reinforcing steel. The slab thickness is 12 cm. Detailed reinforcement information for columns and beams is provided in Figures 10–11 and Table 3. The site soil classification for the building location is type ZE, according to TBEC-2018. SAP2000 v24 was chosen to simulate the seismic performance of the building because it has strong capabilities in structural modeling and nonlinear analysis [27]. The software provided a precise representation of the building's geometry, material properties, and loading conditions. This made it possible to conduct a detailed pushover analysis following FEMA-356 and TBEC-2018 guidelines.
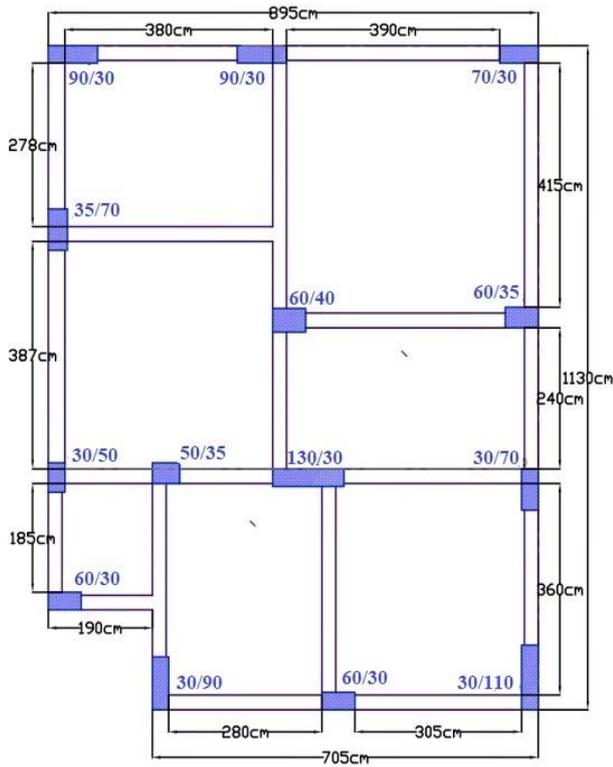
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Figure 9. The building Plan layout

Table 3. The reinforcement details of columns

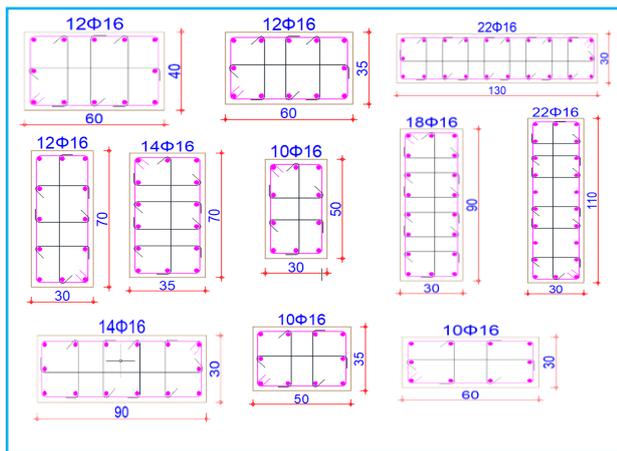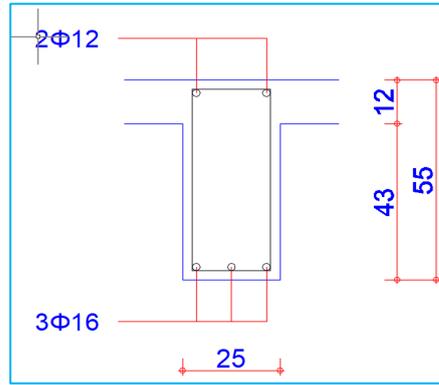| Column dimensions (cm)	Reinforcement details
90×30, 70×35	14Φ16
70×30, 60×40, 60×35	12Φ16
50×35, 50×30, 60×30	10Φ16
110×30	18Φ16
130×30	22Φ16

Figure 10. Column reinforcement details

Figure 11. Beam reinforcement detail

3. RESULTS AND DISCUSSIONS

In SAP2000, the target displacement of the model is calculated by default according to FEMA-356 guidelines. For this analysis, the target displacement was found to be 0.08 meters. The relationship between displacement and base shear is shown in Figure 12, which illustrates how the structure's displacement increases with the applied lateral forces. It is important to note that the structural target displacement of the building did not reach the maximum value, indicating that the building's seismic capacity was not fully used during the analysis.
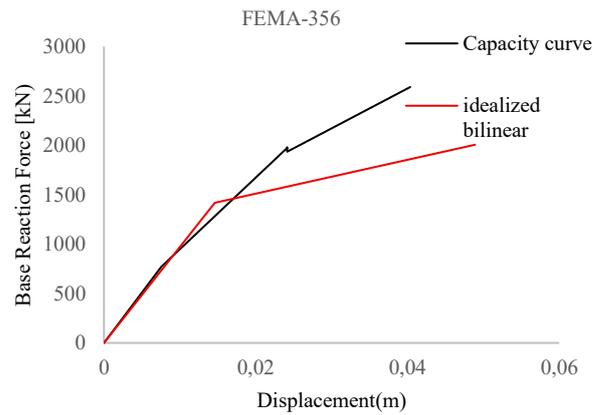
Figure 12. Base shear force-displacement by pushover curve

FEMA 356 3.3.3.3.2, The target displacement, δ_t, for each floor level must be calculated by Equation (3-15) and as outlined in Section 3.3.3.3.1. The program established defaults and provided the coefficients listed in Table 4, which were determined by SAP2000, while the target displacements were calculated manually.

Table 4. Target displacement coefficient according to FEMA 356

C0	1.3505	Te	0.461
C1	1.1253	Ti	0.4537
C2	1	Ki	101682.7
C3	1	Ke	98481.49
Sa	1.1	Alpha	0.1616

$$\delta_t = C_0 C_1 C_2 C_{C3} S_a \frac{T_e^2}{4\pi^2}g$$

$$\delta_t = 1.3505 \times 1.1253 \times 1 \times 1 \times 1.1 \times \frac{(0.461)^2}{4 \times \pi^2}9.81 = 0.08m$$

3.2 According to FEMA-356 Performance Evaluation Results

According to the analysis results, the building was investigated, and its status is controlled according to FEMA-356. The damage distribution of structural elements is presented in Figures 12-13, and the status of the building is summarized in Table 5, where the column damage levels in the X and Y directions are 31% and 18%, respectively, for the significant damage zones. The column conditions in both the X and Y dimensions were determined under the limited damage (LD) conditions, as per the results and regulations of FEMA-356. Additionally, the beams' relative damage levels are 60% and 78% in the X and Y dimensions, respectively. Based on the FEMA-356 guidelines, the performance status of the beams is also under Controlled Damage. Additionally, the shear damage levels are within the limited Damage according to FEMA-356, as indicated by the results obtained. According to Figure 13-14, the LD is the Limited damage, SD is the significant Damage, and AD is the advanced damage.

Table 5. Building performance evaluation

Earthquake level	Performance target	Directions	Most critical floor	Status of building
DD-2	Controlled damage	X and Y	1	Controlled

FEMA-356 Damage disttibutions X direction

	LD	SD	AD	CP
Columns	69	31	0	0
Beams	40	60	0	0
Shear walls	100	0	0	0
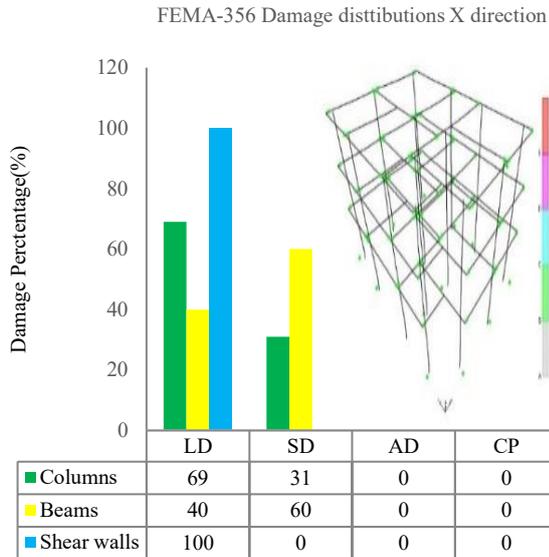
Figure 13. Damage distributions of structural elements in the X direction

FEMA-356 Damage disttibutions Y direction

|	LD	SD	AD	CP
Columns	82	18	0	0
Beams	22	78	0	0
Shear walls	100	0	0	0
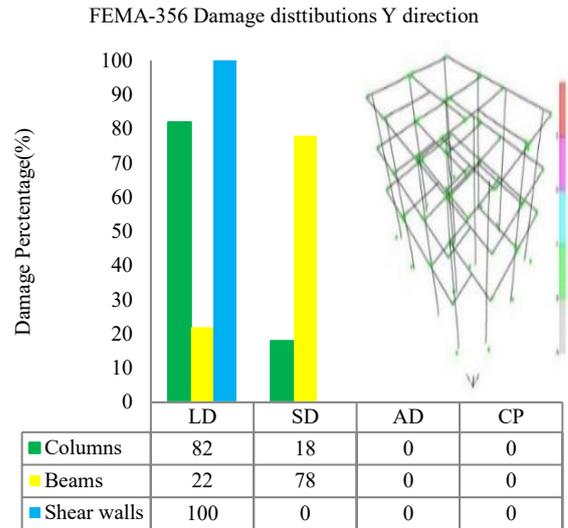
Figure 14. Damage distributions of structural elements in the Y direction

3.3 Target Displacement Results According to TBEC-2018

In order to calculate and find the target displacement of the building, the TBEC-2018 building's spectral demand is determined from the pushover curve and is presented in Figure 15.
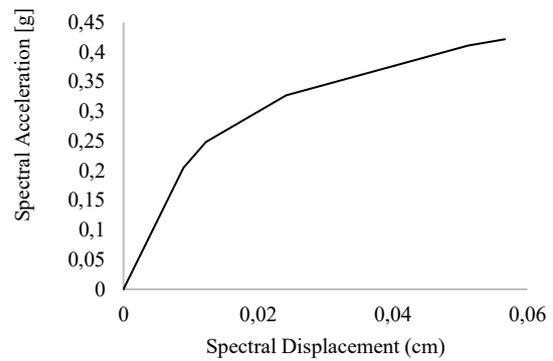
a)
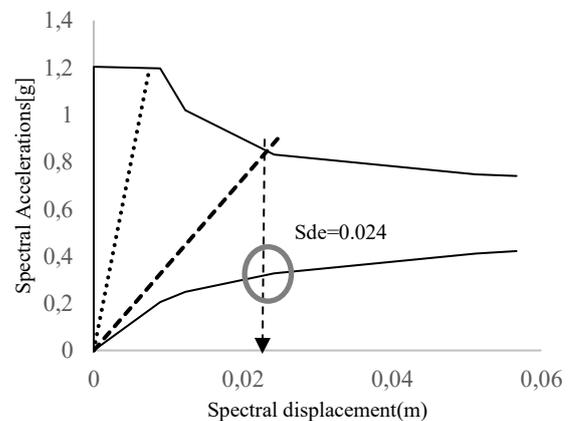
b)

Figure 14. a) Capacity and b) Demand spectrum of the building according to TBEC- 2018

After obtaining the capacity spectrum, the demand spectrum and demand spectrum, converted to spectral acceleration-spectral displacement format, is plotted on the same graph, and an estimated point is selected as the performance point using the equal displacement approach. Displaying the capacity spectrum and demand spectrum together and determining the estimated performance point are given in Figure 14.

As per TBEC-2018 Section 5B.3, the Modal maximum displacement in a single degree of freedom system is defined as nonlinear spectral displacement in Equation 10.

$$d_{1\,max}^{(1)} = S_{di}(T_1) \tag{11}$$

$$d_{1\,max}^{(1)} = 0.024m$$

$d_{1\,max}^{(1)} = Cr S_{di}(T_1)$ where Cr depends on the First natural period of building.

$$d_{1\,max}^{(1)} = Cr S_{di}(T_1), \quad 2.548 \times 0.024 = 0.061m$$

Therefore, the target displacement of the building according to TBEC-2018 was determined based on Equation 12.

$$u_{xN1}^{(p)} = \emptyset_{di} \times \Gamma \times d_1 \tag{12}$$

Where $\emptyset_{di}$ is the Structure peak mode shape amplitude? Γ =Modal participation factor, d_1 = Peak displacement in a single-degree-of-freedom system.

$u_{xN1}^{(p)} = 0.09m$ The Target displacement of the building according to TBEC-2018 was determined

3.4. Performance Evaluation Results According to TBEC-2018

According to TBEC-2018, the results of the pushover analysis with the incremental equivalent earthquake load method, which is one of the non-linear inelastic methods, the element damage levels of the columns and beams at the critical floor in both directions are determined. As shown in Figures 16-17, the column damage levels in the X and Y directions are 48% and 41%, respectively, for the control damage zones. According to TBEC-2018, the column conditions in both the X and Y directions are classified under the Controlled Damage Zone. The damage levels of the beams in the X and Y directions are 38% and 48%, respectively. Based on the results and TSC-2018 guidelines, the performance status of the beams is also under the Controlled Damage Zone. Additionally, the shear damage levels are within the limited Damage Zone according to TBEC-2018, as indicated by the results obtained.
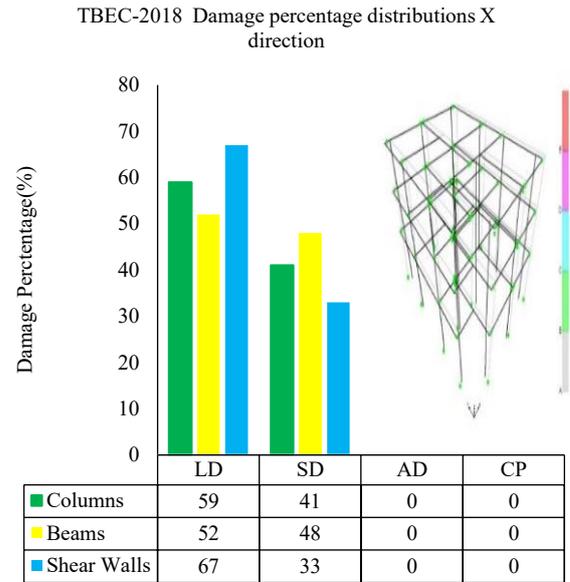

TBEC-2018 Damage percentage distributions X direction

	LD	SD	AD	CP
Columns	59	41	0	0
Beams	52	48	0	0
Shear Walls	67	33	0	0

Figure 16. The Damage distributions of structural elements in the X direction according to TBEC-2018

TBEC-2018 Damage percentage distributions Y direction

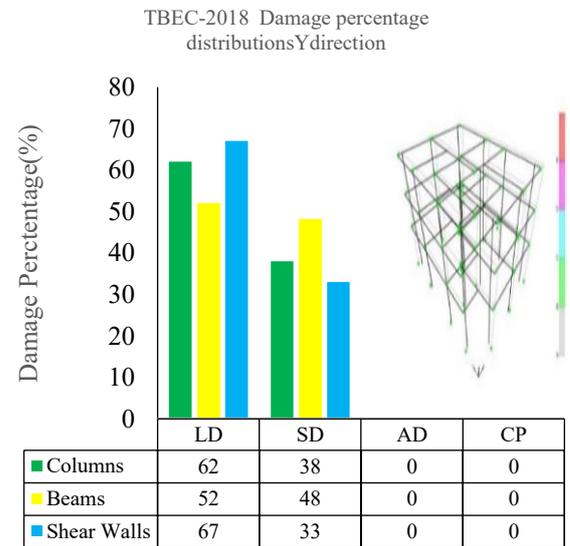|	LD	SD	AD	CP
Columns	62	38	0	0
Beams	52	48	0	0
Shear Walls	67	33	0	0

Figure 17. The Damage distributions of structural elements in the Y direction according to TBEC-2018

3.5. Comparison Of Results From TBEC-2018 And FEMA-356

Based on the results from both the TBEC-2018 and FEMA-356 regulations, it is observed that the structural damage levels for the building elements are similar, with only minor differences in the classification of damage. Both codes use distinct methodologies for evaluating and classifying structural damage, but the overall performance of the building appears to align closely.

Column Damage Analysis:

- FEMA-356: According to the FEMA-356 guidelines, the column damage levels in the X and Y directions are reported as 31% and 18%, respectively, within the Significant damage zones. This indicates that the columns are performing relatively well and are not subjected to a Limited damage level.
- TBEC-2018: reports the column damage levels at 48% and 41% for the X and Y directions, categorizing

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them under the Significant Damage zones. While the TBEC-2018 damage levels are higher than those found by FEMA-356, they still fall under the Controlled Damage classification, which implies that the columns are experiencing moderate damage but still within acceptable performance limits.

Beam Damage Analysis:

- FEMA-356: The damage levels for the beams in the X and Y directions are 60% and 78%, respectively. According to the FEMA-356 guidelines, these levels indicate significant damage, but the performance status remains under the Controlled Damage zone.
- TBEC-2018: The beam damage levels in the X and Y directions, as per TBEC-2018, are 38% and 48%, respectively, which are slightly lower compared to the FEMA-356 results. These values fall under the Controlled Damage zone, similar to the FEMA-356 classification, although the damage levels in the Y direction are slightly higher.

Shear Damage Analysis:

- FEMA-356: The shear damage levels in both directions are within the Limited Damage zone, suggesting that the shear capacity of the building elements remains within a safe range.
- TBEC-2018: Similarly, the shear damage levels according to TBEC-2018 also fall within the Limited Damage zone, suggesting consistent performance between the two codes in terms of shear damage classification.

Target Displacement:

- FEMA-356: The target displacement for the building, as determined by FEMA-356, is 0.08 m. This value reflects the expected deformation of the building under seismic loading and aligns with the controlled damage classification for the beams and columns.
- TBEC-2018: While the target displacement for TBEC-2018 were determined 0.09m.

4. CONCLUSIONS

This study thoroughly assessed the seismic performance of a G+2 reinforced concrete building using static pushover analyses, following TBEC-2018 and FEMA-356 guidelines. The results show that the building stays in a Controlled Damage state under design-level seismic loads. There is moderate but acceptable damage to columns, beams, and shear components in both main directions. Although there are slight differences in the predicted damage levels, the overall structural behavior and performance classification closely match, strengthening the trustworthiness of these assessment methods.

Notably, TBEC-2018 consistently predicts more conservative damage levels compared to FEMA-356. This difference arises from TBEC-2018's more detailed damage index calculations, which incorporate cumulative inelastic deformations and stiffness degradation, as well as higher target displacement values reflecting greater ductility demands. Additionally, TBEC-2018 applies stricter force-reduction factors and narrower damage classification thresholds, leading to earlier and higher

damage categorization. Understanding these methodological distinctions is essential for accurately interpreting seismic assessment results and making informed retrofit decisions.

The study shows that columns and beams keep their structural integrity within set safety limits. Shear components show little damage, which demonstrates the building's ability to withstand major seismic events. However, some damage, especially in beams, points out the need for ongoing structural health monitoring. Targeted retrofitting can help address potential weaknesses and ensure long-term safety.

Overall, this work shows that code-based pushover analyses are effective for assessing existing RC buildings. It highlights the importance of comparing multiple codes to better understand seismic performance. The insights gained form a strong base for guiding strategies to reduce seismic risk and plan retrofits. This work ultimately improves safety and sustainability in areas prone to earthquakes.

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