Investigation of Deformation-Based Damage Limits for RC Columns in Different Seismic Codes

Saeid Foroughi * and Suleyman Bahadir Yuksel **

**Department of Civil Engineering, Konya Technical University, Konya, Turkey

*Corresponding author: saeid.foroughi@yahoo.com

Submitted : 06-04-2021

Revised : 28-11-2021

Accepted : 12-12-2021

ABSTRACT

The seismic performance of reinforced concrete (RC) columns is related to the expected damage limits under seismic loads and how this damage relates to the safety of the structure. To assess the performance of RC columns under seismic loads, performance-based deformation and damage limits have been proposed by seismic codes. Adequacy of the deformation and damage limits provided in the American Society of Civil Engineers, Seismic Evaluation and Retrofit of Existing Buildings Standard (ASCE/SEI-41, 2017) and the Turkish Building Earthquake Code (TBEC, 2018) were evaluated by performing parametric studies for RC columns. RC circular columns are designed in parametric studies to elucidate the effects of the compressive strength of concrete, axial load levels, and spiral reinforcement ratio on performance-based damage limits. The performance limits corresponding to each performance level obtained using different seismic guidelines were compared. The cross-section damage limits of ASCE/SEI-41 (2017) and TBEC (2018) were significantly different, which could change the performance level of the building. TBEC (2018) yielded approximately 50% conservative limits compared to the ASCE/SEI-41 (2017) limits. As a result, TBDY (2018) seems to offer safer and more ductile solutions than ASCE/SEI-41 (2017).

Keywords: Columns; Seismic codes; Performance level; Damage limits; Deformation.

INTRODUCTION

The philosophy behind the design of reinforced concrete (RC) frames is to provide them with sufficient ductility (Abdelwahed, 2020). Lateral force- and moment-resisting structural systems should be designed with adequate strength and ductility. The behavior of RC frames subjected to seismic loads is mainly based on the ultimate strength of concrete and its ductility (Foroughi & Yuksel, 2020; Yuksel & Foroughi, 2019; Subramanian & Velayutham, 2014). The ductile deformation capacity of RC columns (the main lateral force- and moment-resisting elements) is a key factor in achieving high seismic performance (Cheng et al., 2017). One of the most important steps for the performance-based assessment of RC buildings relies on the comparison of deformations obtained by nonlinear structural analyses of deformation limits or acceptance criteria (Xinxian et al., 2016; Yakut & Solmaz, 2012).

The preliminary design of civil-engineering structures is typically based on traditional force-based design procedures, which are used to judge their performance (Abd-Elhamed & Mahmoud, 2016). The structural collapse of RC structures during an earthquake has been attributed to the loss of the lateral-loading capacity of their vertical load-carrying members (Al-Ogaidi et al., 2021).

The seismic performance of a structure is related to the level of damage that occurs under the influence of a particular earthquake and how this damage affects the safety and use of the structure. Therefore, in determining the seismic performance, it is crucial to calculate the deformations rather than the internal forces that occur under the influence of earthquakes. The purpose of nonlinear calculation methods used to determine structural performance is to calculate the plastic deformation and plastic rotation demands that are related to the ductile behavior of the structure for a given earthquake (Foroughi et al., 2020a; Foroughi & Yuksel, 2019). Understanding the nonlinear response and damage characteristics of RC buildings subjected to earthquakes is essential for assessing the seismic performance of existing buildings, as well as the safety and cost of new buildings (Foroughi et al., 2020b; Uçar et al., 2015). Knowing the behavior of load-bearing elements and the parameters affecting this behavior in the RC structure is crucial in terms of seismic performance, as it will primarily affect the elements of a building and then the entire structure (Meral, 2018). Limits, which are an important part of the methods used in many earthquake codes to determine the seismic safety of buildings, are set according to many design parameters. To determine earthquake safety, it is necessary to first identify the damage level of each carrier element (Ulutaş, 2019; Ulutaş et al., 2015). In the evaluation methods of existing buildings, regulations generally determine the performance of the building elements based on their plastic rotational capacities (Elci & Göker, 2018). The structural elements are therefore modeled by means of plastic hinges, which are determined according to the non-linear behavior of the structure and the element's properties (Özmen et al., 2007). Seismic-induced damages in RC buildings have been primarily associated with the low strength and poor mechanical properties of the materials (Işık, 2021; Işık et al., 2021).

Recently proposed changes to modeling and acceptance criteria in seismic regulations for RC columns suggest that a comprehensive examination is required for improved limit definitions and their corresponding values. Columns that can be classified as primary members of these structures dominate the seismic performance of RC frame buildings. In this study, deformation-based damage limits for RC members, which are mentioned in the American Society of Civil Engineers, Seismic Evaluation and Retrofit of Existing Buildings Standard ASCE/SEI-41 (2017) and the Turkish Building Earthquake Code (TBEC) (2018), have been analytically studied to determine the earthquake performance of the structural members. In addition, the ASCE/SEI-41 (2017) procedures to determine the idealized shear force-chord rotation curves of RC circular columns were reviewed. Circular columns are generated in parametric studies to present the effects of various parameters such as the concrete grade, axial load levels, and spiral reinforcement ratios on performance-based displacement limits. Here, deformation values for RC columns were calculated at the performance levels defined in ASCE/SEI-41 (2017) and TBEC (2018). Column damages corresponding to the displacement demands were estimated and the damage limits were evaluated. By determining the unit deformation demands, the allowable concrete and reinforcing steel deformation limits were calculated. For this purpose, we considered different section damage limits in RC ductile structural elements where plastic deformations occur. According to the critical values obtained from the moment-curvature relationships of the RC columns modeled according to the lumped plastic behavior, yield rotation values and plastic rotation values for the plastic hinge regions of the columns were calculated for different performance levels.

PERFORMANCE LEVELS FOR REINFORCED CONCRETE MEMBERS

To assess the performance of RC columns under a given earthquake effect, deformation-based damage limits are proposed by seismic codes. The ASCE/SEI-41 (2017) and TBEC (2018) seismic codes have defined three discrete damage limits and two performance ranges for flexure-dominant ductile members (Figure 1). In ASCE/SEI-41 (2017), the performance levels are immediate occupancy (IO), life safety (LS), and collapse prevention (CP). The damage limits defined in TBEC (2018) are limited damage (LD), controlled damage (CD), and collapse prevention (CP).

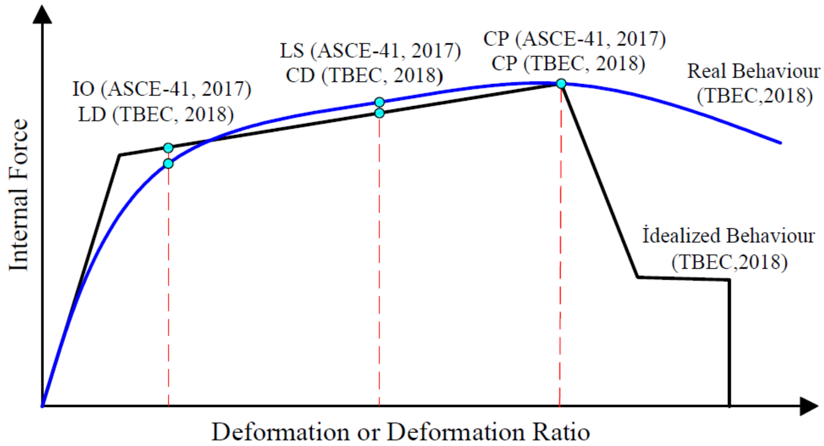


Figure 1. Performance limits for RC members

Structural Performance Levels and Ranges According to ASCE/SEI-41 (2017)

The main objective of this section is to assess the appropriateness of the ASCE/SEI-41 (2017) modeling parameters for the load-deformation relationships of RC columns with various designs. After the chord yield rotation is determined, the deformation and strength parameters listed in Table 1 are used to establish the notable points (B, C, D, and E) in the idealized load-deformation curve shown in Figure 2. The axial load levels, transverse reinforcement ratio, and the ratio of shear demand at flexural yielding to shear capacity (V_{yE}/V_{Col0E}) are used to calculate the modeling parameters and acceptance criteria of the RC circular columns. The shear strength of the RC column is defined in ASCE/SEI-41 (2017) by Equation (1), in which V_{Col} is the shear strength of concrete ($k_{nl} = 1$) in regions where displacement ductility demand is less than or equal to 2, and $k_{nl} = 0.7$ in regions where displacement ductility is greater than or equal to 6. $\alpha_{Col} = 1$ for $s/d \leq 0.75$, $\alpha_{Col} = 0$ for $s/d \geq 1$. A_v is the area of shear reinforcement, $f_{ytL/E}$ is the expected yield strength of the transverse reinforcement (f_{ytE}=1.25f_{yt}), $f'_{cL/E}$ is the expected concrete strength (f'_{CE} =1.5f'_C), d is the effective depth of the cross-section, s is the spacing of the transverse reinforcement, and A_g is the cross-section area of the column. $\Lambda = 1$ for normal-weight aggregate concrete. N_{UG} is the axial force and $M_{UD}/(V_{UD}\ d)$ is the moment-to-shear ratio for the effective depth of the column.

$$V_{Col} = k_{nl} V_{Col0} = k_{nl} \left[\alpha_{Col} \left(\frac{A_v f_{ytL/E} d}{s} \right) + \lambda \left(\frac{0.5\sqrt{f'_{cL/E}}}{M_{UD}/(V_{UD} d)} \sqrt{1 + \frac{N_{UG}}{0.5 A_g \sqrt{f'_{cL/E}}}} \right) 0.8 A_g \right] \quad (1)$$

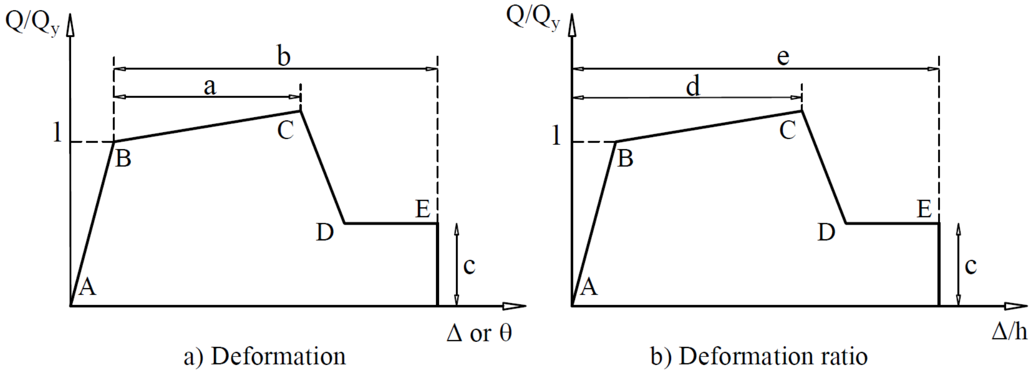


Figure 2. Generalized force-deformation relationships for concrete elements or components

Table 1. Modeling parameters and numerical acceptance criteria for nonlinear procedures

Modeling Parameters	Acceptance Criteria		
Plastic Rotation Angle (Radians)			
a and b (radians) residual strength ratio, c	Performance Level		
	IO	LS	CP
Columns not controlled by inadequate development or splicing along the clear height			
$a = \left(0.06 - 0.06\frac{N_{UD}}{A_g f'_{CE}} + 1.3\rho_t - 0.037\frac{V_{yE}}{V_{ColOE}}\right) \geq 0$	$0.15a \leq 0.005$	$0.5b$	$0.7b$
$for\ \frac{N_{UD}}{A_g f'_{CE}} \leq 0.5 \left\{ b = \frac{0.65}{5 + \frac{N_{UD}}{0.8 A_g f'_{CE}} \frac{1}{\rho_t} \frac{f'_{CE}}{f_{ytE}}} - 0.01 \geq a \right.$			
$c = 0.24 - 0.4\frac{N_{UD}}{A_g f'_{CE}} \geq 0$			

Limits for Structural Damage Proposed by TBEC (2018)

The Turkish building code was updated as a result of developments in earthquake engineering and TBEC (2018) entered into force on January 1, 2019. TBEC (2018) introduced many new criteria, including deformation-based damage limits used in the description of element damage and performance targets to be considered during performance evaluation. TBEC (2018) also focuses on nonlinear analysis methods. Thus, with the renewed earthquake regulation, more realistic earthquake modeling and analyses are possible. To predict the performance level, the strain limits of concrete and steel are used as the main parameters in the nonlinear static procedure of TBEC (2018). Three limit conditions have been defined for ductile elements on the cross-section: LD, CD, and CP. To evaluate the LD, CD, and CP performance levels, the behaviors of the concrete and reinforcement steel are modeled in accordance with the spreading plastic behavior model. The total deformations allowed by the limits are listed in Table 2.

Table 2. Unit deformations according to different performance levels

Deformation Limits	Damage Limit	
	Concrete	Reinforcement
Limited Damage (LD)	$\varepsilon_c^{(LD)}$=0.0025	$\varepsilon_s^{(LD)}$=0.0075
Controlled Damage (CD)	$\varepsilon_c^{(CD)} = 0.75\varepsilon_c^{(CP)}$	$\varepsilon_s^{(CD)} = 0.75\varepsilon_s^{(CP)}$
Collapse Prevention (CP)	$\varepsilon_c^{(CP)} = 0.0035 + 0.07\sqrt{\omega_{we}} \leq 0.018$	$\varepsilon_s^{(CP)} = 0.40\varepsilon_{su}$

The mechanical reinforcement ratio of the effective confining reinforcement (ω_{we}) is calculated using Equation (2). The confinement effectiveness coefficient (α_{se}) of the circular cross-section elements and volumetric spiral reinforcement ratio (ρ_{sh}) are given in Equation (3).

$$\omega_{we} = \alpha_{se}\, \rho_{sh,min} \frac{f_{ywe}}{f_{ce}} \text{ , } f_{ce} = 1.3 f_{ck} \text{ , } f_{ye} = 1.2 f_{yk} \tag{2}$$

$$\alpha_{se} = \left(1 - \frac{s}{2D}\right)^n \quad , \quad \rho_{sh} = \frac{2A_{os}}{Ds} \tag{3}$$

In Equations (2) and (3), A_{os} and s is the area and spacing of the spiral reinforcement, respectively, D is the distance between the spiral reinforcement axes, f_{ywe} is the expected yield strength of the spiral reinforcement, and f_{ce} is the expected compressive strength of concrete. n = 2 for the circular stirrup and n = 1 for spiral reinforcement are considered. For new RC buildings including tall structures, the limits for plastic rotations are calculated according to the lumped plastic behavior model, using the equations given in Table 3. The length of the plastic zone is taken as half of the depth of the member as suggested by the code ($L_p = 0.5h$). If the shear force ratio of the RC section is calculated as $V_e/b_w d f_{ctm} < 0.65$, the upper limits of the deformation that are calculated according to different performance levels are valid. If the shear force ratio is greater than 1.30, the upper deformation limits that are calculated for different performance levels will be reduced by multiplying by 0.50.

Table 3. Plastic rotations according to different performance levels

Deformation Limits	Plastic Rotations
Limited damage (LD)	$\theta_p^{(LD)} = 0$
Controlled damage (CD)	$\theta_p^{(CD)} = 0.75\theta_p^{(CP)}$
Collapse prevention (CP)	$\theta_p^{(CP)} = \frac{2}{3}\left[(\emptyset_u - \emptyset_y)L_p\left(1 - 0.5\frac{L_p}{L_s}\right) + 4.5\emptyset_u d_b\right]$
$\emptyset_u, \emptyset_y$: maximum and yield curvature, L_s: shear span, d_b: longitudinal reinforcement diameters	

MATERIALS and METHODS

RC columns with circular cross-sections were designed according to the ACI318 (2014) and TBEC (2018) regulations. Column models with 565-mm-diameter circular cross-sections were designed (Table 4). Different spiral reinforcement diameters (Φ8, 10, and 12 mm) and spiral reinforcement spacing (50, 60, 70, and 80 mm) were used to investigate the effect of the spiral reinforcement on the cross-section behavior. The longitudinal reinforcement in all models was 8Φ20 mm. For the modeling of all circular RC columns, C30, C40, and C50 concrete types were used and B420C was selected as a reinforcement (Table 5). The combined effect of vertical and seismic loads (N_{dm}) and the cross-section of the RC column shall satisfy the condition $A_c \geq N_{dmax}/0.40 f_{ck}$ (TBEC, 2018). To investigate the effect of the axial force on the cross-section behavior, the models were evaluated under four axial load levels.

Table 4. Designed column section details

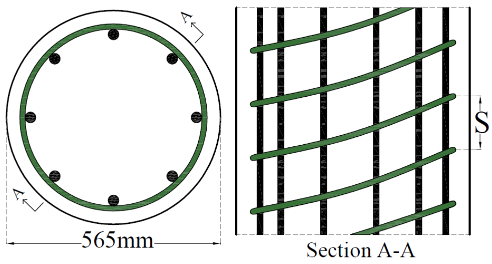
Cross-section of RC Circular Column Models	Longitudinal Reinforcement	Material (MPa)	Transverse Reinforcement	N/N_{max}
	8Φ20 mm	C30 C40 C50	Φ8/50 mm	0.10 0.20 0.30 0.40
			Φ8/60 mm	
			Φ8/70 mm	
			Φ8/80 mm	
			Φ10/50 mm	
			Φ10/60 mm	
			Φ10/70 mm	
			Φ10/80 mm	
			Φ12/50 mm	
			Φ12/60 mm	
			Φ12/70 mm	
			Φ12/80 mm	

Table 5. Material parameters for concrete and reinforcement (TBEC, 2018)

Standard Strength	Parameters	Values
Concrete: C30–C50	Strain at maximum stress of unconfined concrete (ε_{co})	0.002
	Ultimate compression strain of concrete (ε_{cu})	0.0035
	Characteristic value of concrete compressive strength (f_{ck})	30–50 MPa
Reinforcement: B420C	Yield strain of reinforcement (ε_{sy})	0.0021
	Strain-hardening value of reinforcing steel (ε_{sp})	0.008
	Strain in reinforcing steel at ultimate strength (ε_{su})	0.08
	Characteristic yield strength of reinforcement (f_{yk})	420 MPa
	Ultimate strength of reinforcement (f_{su})	550 MPa

Circular columns are popular for structural design because their strengths under seismic loads are similar in any direction. Spiral reinforcement plays an important role in improving the strength and ductility of columns, especially when subjected to severe ground motion. Hence, circular cross-section column models were considered in this study. The aim was to examine the necessary conditions for using the nonlinear calculation method and to examine the seismic performance of the circular cross-section RC columns in detail, using the nonlinear calculation method and applying different design parameters. The deformation limits and plastic hinge properties were calculated and compared for the different performance levels given in the ASCE/SEI-41 (2017) and TBEC (2018) codes. For this purpose, 144 RC circular column models were designed for different compressive strengths of concrete, spiral reinforcement ratios, and axial load levels. The element damage limits in ASCE/SEI-41 (2017) and TBEC (2018) were examined by considering these factors. ASCE/SEI-41 (2017) and TBEC (2018) define the performance levels of RC components, using different performance limits. In addition, the ASCE/SEI-41 (2017) procedures to determine the idealized shear force-chord rotation curves of the RC circular columns were reviewed. The nonlinear behaviors of the RC circular columns were theoretically calculated by applying the cantilever column model. Cantilever columns exposed to different axial load levels were considered in the moment-curvature and stress-strain analyses of the columns. Thus, the damage limits calculated according to TBEC (2018) and ASCE/SEI-41 (2017) are valid for circular cantilever columns.

RESEARCH FINDINGS and DISCUSSION

The limits for element damage set in ASCE/SEI-41 (2017) and TBEC (2018) were examined by considering different axial load levels, spiral reinforcement ratios, and compressive strengths of concrete for the cross-sections of the RC circular columns. The deformation limits were calculated for the LD, CD, and CP structural performance levels defined in TBEC (2018). The deformation limits were calculated for the IO, LS, and CP structural performance levels defined in ASCE/SEI-41 (2017). Column damage corresponding to displacement demands was obtained and the damage limits were evaluated. For different performance levels, plastic rotation values were calculated for the plastic hinge regions of the columns.

Deformation Limits for Different Performance Levels According to TBEC (2018)

One of the most important steps for evaluating performance in the nonlinear method is determining the LD, CD, and CP damage levels in structural elements. The damage limits provided for reinforcement steel were obtained by multiplying the unit deformation value corresponding to the ultimate strain of reinforcement steel by constant coefficients (Table 6).

Table 6. Calculated deformation limits for reinforcing steel

Material	Deformation Limit	Performance Level		
		$\varepsilon_s^{(CP)}$	$\varepsilon_s^{(CD)}$	$\varepsilon_s^{(LD)}$
B420C	ε_s	0.0320	0.0240	0.0075

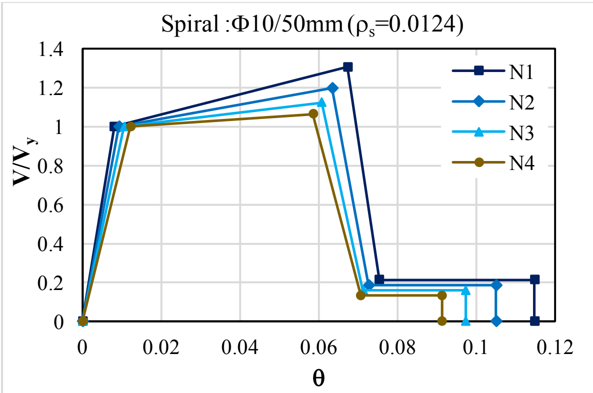
The damage limits for the confined concrete ($\varepsilon_c^{(CP)}$, $\varepsilon_c^{(CD)}$) are calculated based on the f_{ye}, f_{ce}, ρ_{sh}, and the configuration of the spiral reinforcement. Plastic rotational damage limits (θ_p) for different performance levels are determined by the functions $\emptyset_y$, $\emptyset_u$, L_P, L_S and d_b. Therefore, parameters affecting $\emptyset_y$ and $\emptyset_u$, such as f_{ck}, N/N_{max}, and ρ_{sh} also affect the θ_p values. The upper deformation limits corresponding to the cross-section damage levels are presented in Table 7. The plastic rotation values of the RC circular columns for different parameters are listed in Table 8.

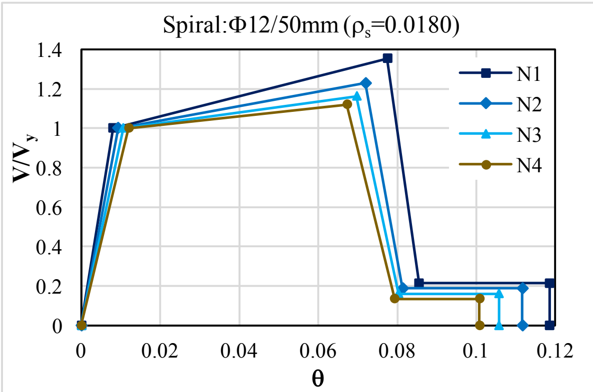
Table 7. Calculated ε_c values for different design parameters

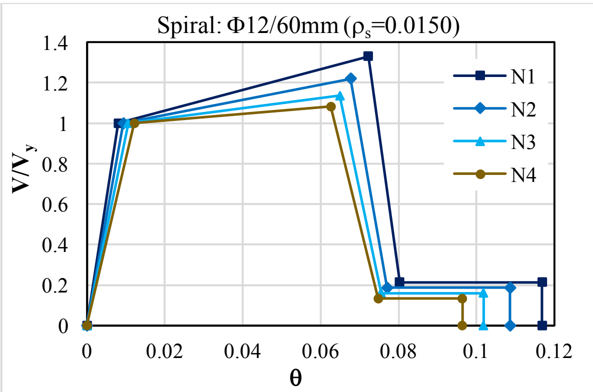
Material	ρ_s	Deformation Limit	Performance Level		
					$\varepsilon_c^{(LD)}$
C30	0.0112	ε_c	0.0216	0.0162	0.0025
	0.0124		0.0229	0.0171	
	0.0128		0.0230	0.0172	
	0.0150		0.0246	0.0183	
	0.0180		0.0268	0.0201	
C40	0.0180		0.0236	0.0177	
C50			0.0215	0.0161	

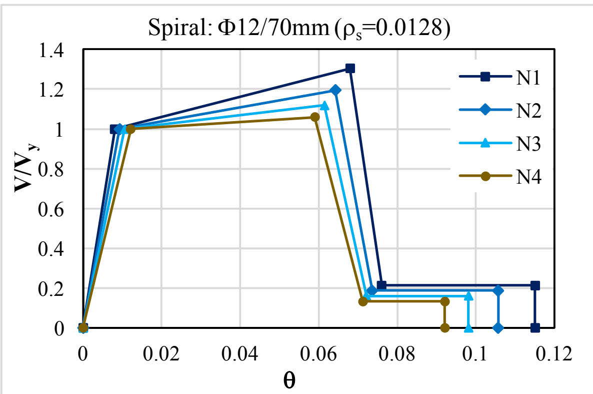
Deformation Limits for Different Performance Levels According to ASCE/SEI 41 (2017)

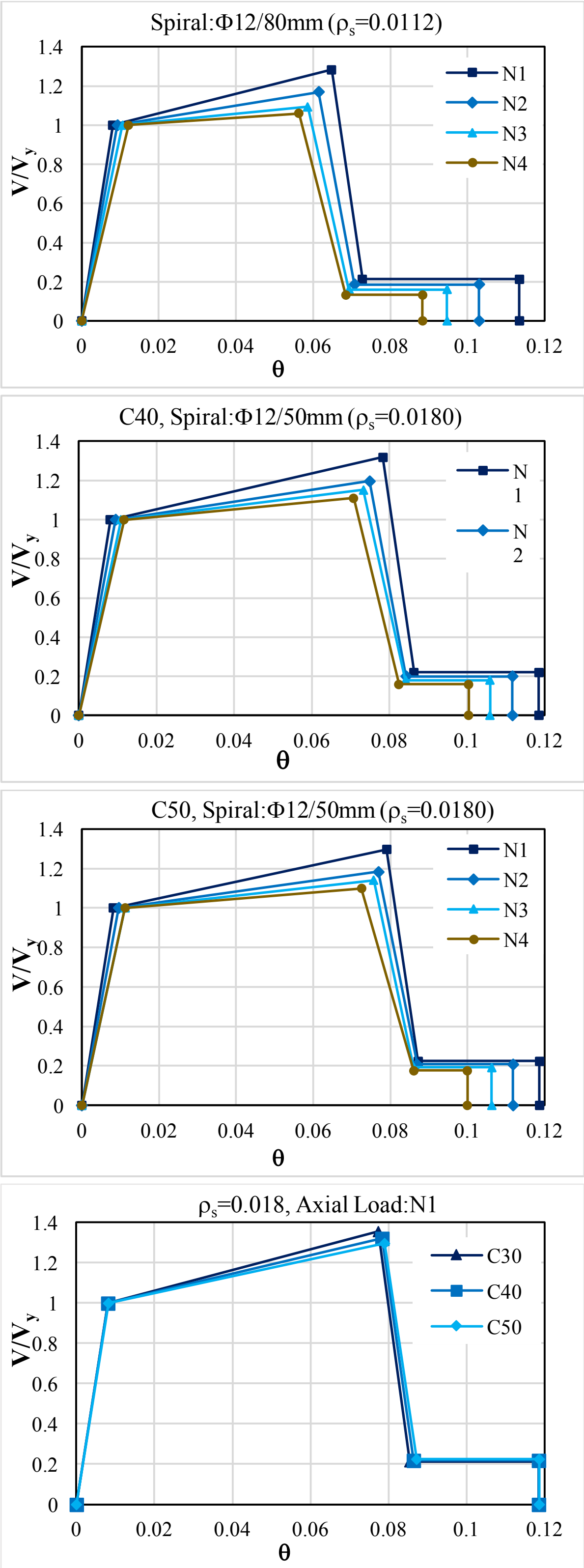
Load-deformation relationships were obtained for the RC column models, using the guidelines provided in ASCE/SEI-41 (2017). For the nonlinear static procedure, the graphs describing the generalized force-deformation relationship for the RC circular columns are displayed in Figure 3. The axial load ratio, spiral reinforcement ratio, and the ratio of shear demand at flexural yielding to shear capacity (V_{yE}/V_{Col0E}) were used to calculate the modeling parameters and acceptance criteria for the columns.










Spiral:Φ12/80mm (ρs=0.0112)
V/Vy
θ
N1
N2
N3
N4
C40, Spiral:Φ12/50mm (ρs=0.0180)
V/Vy
θ
N1
N2
C50, Spiral:Φ12/50mm (ρs=0.0180)
V/Vy
θ
N1
N2
N3
N4
ρs=0.018, Axial Load:N1
V/Vy
θ
C30
C40
C50

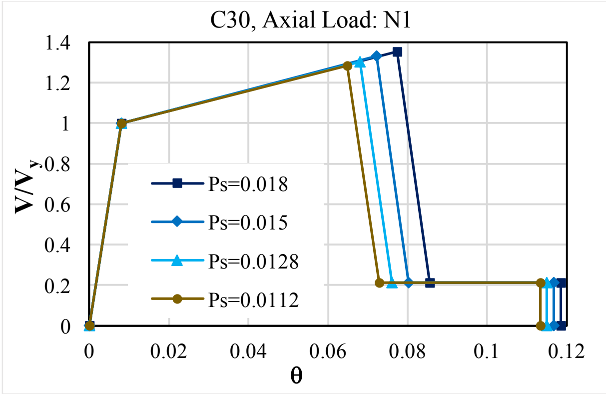
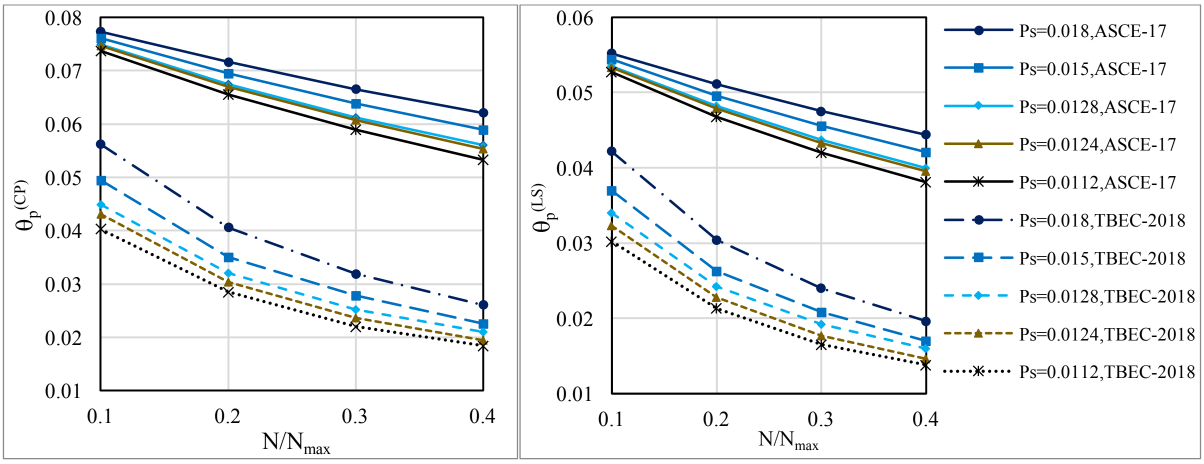


Figure 3. Generalized force-deformation relationship according to ASCE/SEI-41 (2017)

According to ASCE/SEI-41 (2017), the V/V_y value of the column increases with the increase of ρ_s. The V/V_y value decreases with increasing N/N_{max} and f_{ck}. The deformation ratio (θ) of the column increases with the increase of ρ_s and f_{ck}. The deformation ratio decreases with an increasing N/N_{max}. The LS and CP values increase with an increasing ρ_s and decrease with an increasing N/N_{max}. By contrast, the LS and CP values in the circular column remain constant with an increasing f_{ck}.

Comparison of The Performance Levels Obtained

The deformation limits for the different performance levels set in ASCE/SEI-41 (2017) and TBEC (2018) are shown in Figure 4. The results of the analyses for ASCE/SEI-41 (2017) are compared with the results of TBEC (2018) in Table 8. The differences between the performance level values calculated according to ASCE/SEI-41 (2017) and those obtained according to TBEC (2018) are presented in Table 8 [$D\% = (ASCE, 2017 - TBEC, 2018)/ASCE, 2017)$].



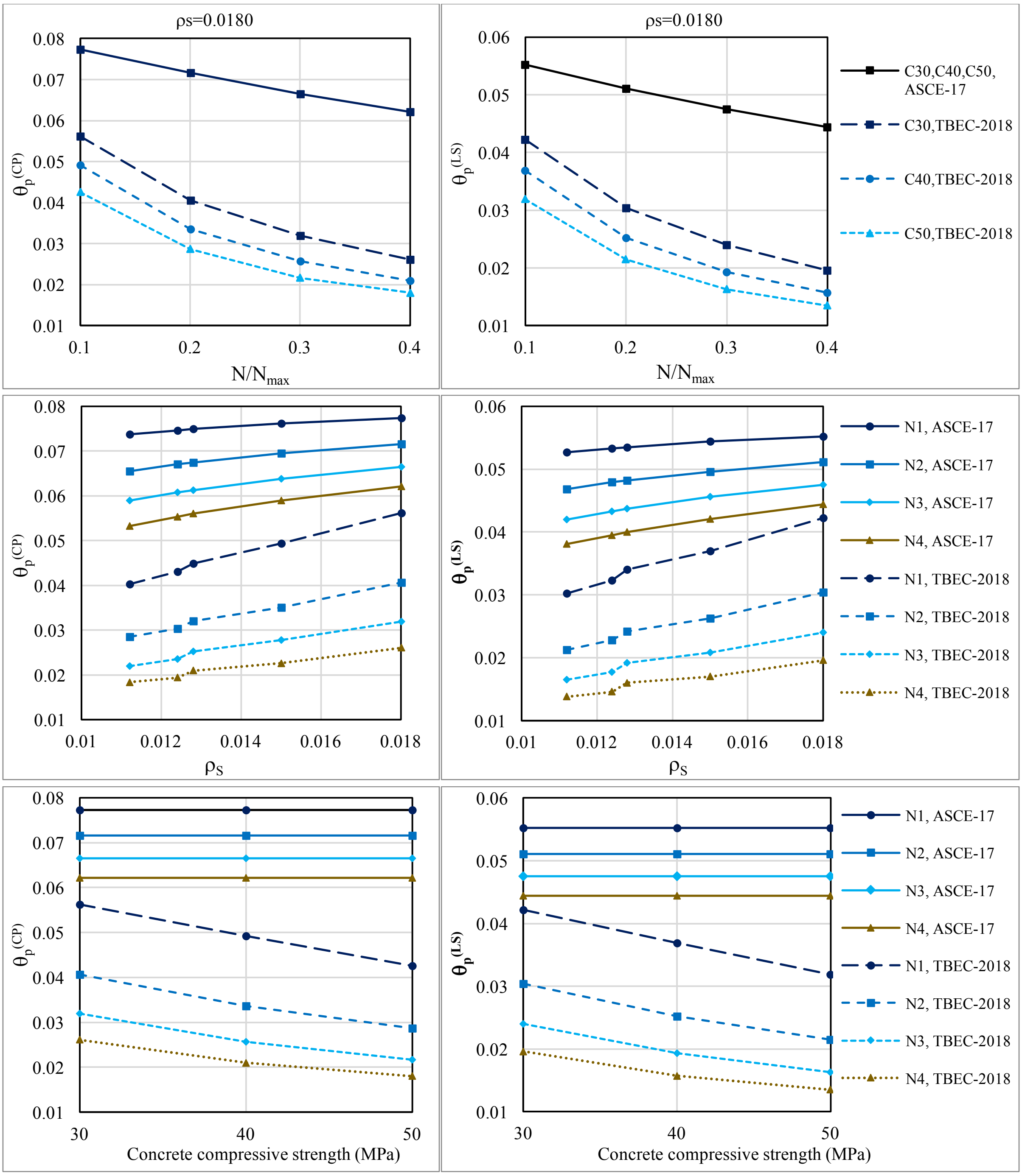


Figure 4. Comparison of deformation limits for different performance levels

Table 8. Comparison of the performance levels calculated for the different design parameters

Material	ρ_s	N/N_{max}	Performance Level					
			ASCE/SEI-41 (2017)		TBEC (2018)		D (%)	
			θ_p(LS)	θ_p(CP)	$\theta_p^{(CD)}$	$\theta_p^{(CP)}$	LS (CD)	CP
C30	0,0112	0.1	0.053	0.074	0.030	0.040	43	45
		0.2	0.047	0.066	0.021	0.029	54	56
		0.3	0.042	0.059	0.017	0.022	61	63
		0.4	0.038	0.053	0.014	0.018	64	65
	0,0124	0.1	0.053	0.075	0.032	0.043	39	42
		0.2	0.048	0.067	0.023	0.030	52	55
		0.3	0.043	0.061	0.018	0.024	59	61
		0.4	0.040	0.055	0.015	0.019	63	65
	0,0128	0.1	0.054	0.075	0.034	0.045	36	40
		0.2	0.048	0.067	0.024	0.032	50	53
		0.3	0.044	0.061	0.019	0.025	56	59
		0.4	0.040	0.056	0.016	0.021	60	63
	0,015	0.1	0.054	0.076	0.037	0.049	32	35
		0.2	0.050	0.070	0.026	0.035	47	49
		0.3	0.046	0.064	0.021	0.028	54	56
		0.4	0.042	0.059	0.017	0.023	60	62
	0,018	0.1	0.055	0.077	0.042	0.056	24	27
		0.2	0.051	0.072	0.030	0.041	41	43
		0.3	0.048	0.067	0.024	0.032	49	52
		0.4	0.044	0.062	0.020	0.026	56	58
C40	0.018	0.1	0.055	0.077	0.037	0.049	33	36
		0.2	0.051	0.072	0.025	0.034	51	53
		0.3	0.048	0.067	0.019	0.026	59	61
		0.4	0.044	0.062	0.016	0.021	65	66
C50		0.1	0.055	0.077	0.032	0.043	42	45
		0.2	0.051	0.072	0.022	0.029	58	60
		0.3	0.048	0.067	0.016	0.022	66	67
		0.4	0.044	0.062	0.014	0.018	70	71

CONCLUSIONS

The deformation-based damage limits calculated according to the TBEC (2018) and ASCE/SEI-41 (2017) regulations are valid for circular cantilever columns. Significant differences were observed in the cross-section damage limits of ASCE/SEI-41 (2017) and TBEC (2018), which could change the performance level of the building. The estimated damage limit for each performance level had an average value of 0.09%. TBEC (2018) yielded lower values for all performance levels compared to ASCE/SEI-41 (2017). Furthermore, the ASCE regulation resulted in a 51% higher LS and 54% higher CP performance level compared to TBEC (2018). With the increase in the spiral reinforcement ratio, plastic rotation values increased for both LS (CD) and CP performance levels in both codes. Moreover, the increase in the spiral reinforcement ratio resulted in an increase in plastic rotation values for both LS (CD) and CP performance levels. By applying the TBEC (2018) regulation, increased compressive strength of concrete resulted in decreased plastic rotation values for both CD and CP performance levels. On the other hand, the LS and CP performance levels calculated according to ASCE/SEI-41 (2017) remained constant. For both regulations, when the axial load levels increased, the plastic rotation values decreased for both LS (CD) and CP performance levels. Therefore, as the axial load levels increased, the damage limits decreased and the amount of spiral reinforcement became more crucial. The limitation stipulated by the regulation is thus highly effective. The difference between ASCE/SEI 41 (2017) and TBEC (2018) decreased with an increasing spiral reinforcement ratio for both LS (CD) and CP performance levels. The difference in the IO performance level remained fixed. The differences between ASCE/SEI-41 (2017) and TBEC (2018) increased with increasing axial load levels and compressive strengths of concrete for different performance levels. TBEC (2018) yielded approximately 50% conservative limits compared to the ASCE/SEI-41 (2017) limits. As a result, TBEC (2018) seems to offer safer and more ductile solutions than ASCE ASCE/SEI-41 (2017).

REFERENCES

Abdelwahed, B.S. 2020. A Review on RC Beam Column Joint: Role, Modeling and Recent Details. Journal of Engineering Research. 8(4): 63-79.

ACI 318. 2019. Building Code Requirements for Structural Concrete (ACI Standard), American Concrete Institute Committee, ISBN: 978-1-64195-056-5.

ASCE Standard, 41. 2017. Seismic Evaluation and Retrofit of Existing Buildings, (ASCE/SEI 41-17), Published by the American Society of Civil Engineers, Reston, Virginia, 20191-4382.

Abd-Elhamed, A. & Mahmoud, S. 2016. Nonlinear static analysis of RC framed buildings-A case study on Cairo earthquake. Journal of Engineering Research. 4(4):1-23

Cheng, X.C., Bai, Z.Z. & Au, F.T.K. 2017. Effect of Confinement on Flexural Ductility Design of Concrete Beams, Computers and Concrete, 20(2): 129-143.

Elci, H. & Goker, K.A. 2018. Comparison of Earthquake Codes (TEC 2007 and TBEC 2018) In Terms of Seismic Performance of RC Columns, International Journal of Scientific and Technological Research. 4(6): 9-21.

Faiud Al-Ogaidi, Y.K., Wilson, J., Al-Mahaidi, R., Hashemi, J. & Abdouka, K. 2021. Collapse Simulation of CFRP Retrofitted Column using Hybrid Testing Technique. Journal of Engineering Research. Vol 9 No ICRIE (2021): 1-15.

Foroughi, S., Jamal, R., & Yüksel, B. 2020a. Effect of Confining Reinforcement and Axial Load In Determining Deformation Based Damage Limits. Journal of Engineering Sciences and Design. 8(4): 1042-1052.

Foroughi, S., Jamal, R. & Yüksel, S.B. 2020b. Effect of Confining Reinforcement and Axial Load Level on Curvature Ductility and Effective Stiffness of RC Columns. El-Cezeri Journal of Science and Engineering. 7(3): 1309-1319.

Foroughi, S. & Yuksel, S.B. 2020. Investigation of the Moment-Curvature Relationship for RC Square Columns, Turkish Journal of Engineering (TUJE), 4(1): 36-46.

Foroughi, S. & Yuksel, S.B. 2019. Investigation of Deformation Based Damage Limits of RC Column. International Journal of Engineering Research and Development. 11(2): 584-601.

Işık, E., Harirchian, E., Bilgin, H., & Jadhav, K. 2021. The effect of material strength and discontinuity in RC structures according to different site-specific design spectra. Research on Engineering Structures & Materials. 7(3): 413-430.

Işık, E. 2021. A comparative study on the structural performance of an RC building based on updated seismic design codes: case of Turkey. Challenge Journal of Structural Mechanics, 7(3): 123-134.

Meral, E. 2018. Effects of Structural Parameters on Curvature Ductility of RC Columns. Osmaniye Korkut Ata University Journal of Natural and Applied Sciences. 1(1): 28-43.

Özmen, H., İnel, M. & Bilgin, H. 2007. Effect of Confined Concrete Behavior on RC Sections and Systems. Journal of the Faculty of Engineering and Architecture of Gazi University. 22(2): 375-383.

Subramanian, K. & Velayutham, M. 2014. Seismic performance of lateral load resisting systems, Structural Engineering and Mechanics. 51(3): 487-502.

TBEC. 2018. Specifications for Building Design Under Earthquake Effects", Turkish Building Earthquake Code, Ministry of Public Works and Housing, Turkey.

Ulutas, H. 2019. Comparison of TEC (2007) and TBEC (2018) Earthquake Codes in terms of Section Damage Limits. European Journal of Science and Technology. 17: 351-359.

Ulutaş, H., Tekeli, H. & Demir, D. 2015. Confinement Effect on The Determining Seismic Damage Level. International Burdur Earthquake & Environment Symposium (IBEES2015), 7-9 May 2015, Mehmet Akif Ersoy University, Burdur-Türkiye.

Ucar, T., Merter, O. & Duzgun, M. 2015. Determination of lateral strength and ductility characteristics of existing mid-rise RC buildings in Turkey, Computers and Concrete, 16 (3): 467-485.

Xinxian, Z., Xiaolei, H., Jing, Ji., Yongle, Qi. & Chao, H. 2016. Component-level Performance-based Seismic Assessment and Design Approach for Concrete Moment Frames, The Open Civil Engineering Journal (TOCIEJ), 10: 25-39.

Yüksel, S.B. & Foroughi, S. 2019. Analytical Investigation of Confined and Unconfined Concrete Strength of RC Columns. Konya Journal of Engineering Sciences, 7(3): 611-629.

Yakut, A. & Solmaz, T. 2012. Performance based Displacement Limits for RC Columns under Flexure, 15 Wcee, Lisboa.