Research Article

Investigation of moment-curvature and effective section stiffness of reinforced concrete columns

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ABSTRACT

In determining the seismic performance of reinforced concrete (RC) structures in national and international seismic code, it is desired to use effective section stiffness of the cracked section in RC structural elements during the design phase. Although the effective stiffness of the cracked section is not constant, it depends on parameters such as the dimension of the cross-section, concrete strength and axial force acting on the section. In this study, RC column models with different axial load levels, concrete strength, longitudinal and transverse reinforcement ratios were designed to investigate effective stiffness. Analytically investigated parameters were calculated from TBEC (2018), ACI318 (2014), ASCE/SEI41 (2017), Eurocode 2 (2004) and Eurocode8 (2004, 2005) regulations and moment-curvature relationships. From the numerical analysis results, it is obtained that the axial load level, concrete strength, longitudinal and transverse reinforcement ratios have an influence on the effective stiffness factor of RC column sections. The calculated effective stiffness for RC columns increases with increasing transverse reinforcement ratio, longitudinal reinforcement ratio and concrete strength. Due to the increase of axial force, effective stiffness values of concrete have increased.

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1. Introduction

Reinforced concrete (RC) columns are the critical members of moment-resisting structural systems and have to be designed adequately in strength and ductility (Yüksel and Foroughi, 2019). Usually, it is desirable to design a (RC) member with sufficient curvature ductility capacity to avoid brittle failure in flexure and to insure ductile behavior, especially under seismic conditions (Foroughi and Yüksel, 2020). The correct estimate of curvature ductility and effective stiffness of (RC) members has always been an attractive subject of study as it engenders a reliable estimate of the capacity of buildings under seismic loads (Foroughi et al., 2020). It is generally accepted that, in the interest of safety, it is essential to provide a minimum level of flexural ductility, which will allow energy dissipation and moment redistribution as required (Baji and Ronagh, 2015). The moment-curvature relation for simple bending is a well-studied subject and the classical moment-curvature diagram is commonly found in the literature (Petschke et al., 2013). The flexural response is usually calculated with a numerically-based moment-curvature diagram of the base section and equivalent plastic hinge length (Gentile and Raffaele, 2018).

Seismic analysis and design of RC structures are performed based on linear behavior. However, taking into account the effect of cracking under severe earthquakes, nonlinear analysis is performed (Pique and Burgos 2008). Cracked section properties must be used for the analysis of existing structures. Cracked section properties may also be used when performing advanced analyses (Wong et al. 2017). Cracks in concrete, which reduce the stiffness of (RC) members, occur at loads much smaller than those corresponding to the yielding of the reinforcement and bearing capacity of the members (Vidović et al., 2012). Concrete cracking reduces the bending and shear stiffness of (RC) members. Therefore,

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analyzing (RC) structures without considering the cracking effect may not represent the actual behavior (Çağlar et al., 2015). The effective flexural stiffness EI of the column represents the equivalent stiffness of a fictitious column with constant stiffness, whose effective buckling length and critical axial load agree with those of the real column (Bonet et al., 2011).

Various research studies have been conducted on the effective stiffness of RC structural members. In the studies on the effective section stiffnesses, the equations proposed for the design were investigated by considering the parameters affecting the bending stiffness of the columns. The researchers proposed equations for the examination of the effective section stiffnesses of (RC) columns, taking into account different parameters and section properties. Various parameters such as the axial load level, the eccentricity of the axial load and the effect of the longitudinal reinforcement, the normal and high strength concrete, the concrete compressive strength and the reinforcement ratio were taken into account (Avşar et al., 2014; Kumar and Singh, 2010; Elwood and Eberhard, 2009; Khuntia and Ghosh, 2004; Mehanny et al., 2001; Panagiotakos and Fardis, 2001; Paulay and Priestley, 1992; Mirza, 1990).

Current design codes and technical recommendations often provide rough indications on how to assess effective stiffness of RC frames subjected to seismic loads, which is a key factor when a linear analysis is performed (Micelli et al., 2015). In widely used codes and guidelines, the effective stiffness of (RC) members is expressed as a proportion of their stiffness, calculated on the basis of the cross-section properties. Several procedures are suggested to consider effective stiffness: Turkish Building Earthquake Code (TBEC, 2018), American Concrete Institute (ACI318, 2014), Seismic Evaluation and Retrofit of Existing Buildings (ASCE/SEI41, 2017), Design of Concrete Structures (Eurocode 2, 2004), Design of Structures for Earthquake Resistance (Eurocode 8, 2004) and Eurocode 8-Part 3: Assessment and Retrofitting of Buildings (Eurocode 8, 2005). The effective section stiffnesses of (RC) columns according to different parameters were calculated and compared according to the mentioned methods and codes. Analytically investigated parameters were calculated from different earthquake regulations, various procedures recommended by researchers and moment-curvature relationships. In this study, a simple formula as a securer, quicker and more robust is proposed to determine the effective flexural stiffness of cracked sections of RC columns. The effective stiffness of RC columns is obtained by based moment-curvature analyses depending on member properties such as axial load levels ($N/N_{max} = N/A_c f_{ck}$), concrete compressive strength (f_{ck}), longitudinal reinforcement ratio (ρ_s) and transverse reinforcement ratios (ρ_{st}). The analysis results obtained for different RC column models are examined by summarizing in graphs. The results obtained at the end were examined by comparing them according to different parameters and models.

2. Effective Section Stiffness of RC Column Elements

2.1. Effective section stiffness coefficient according to moment-curvature relations

The flexural stiffness affects the load-bearing capacity of the structural element. One of the realistic ways to calculate the effective section stiffnesses of reinforced concrete sections is to use moment-curvature relations. The effective stiffness does not reflect only the effect of cracking but also the state of the RC members determined from moment-curvature relationships. Effective stiffness (EI_e) of the cracked section in RC sections is determined by the ratio corresponding to the yield moment (M_y) and the yield curve ($\emptyset_y$), taking into account the moment-curvature relationship ($EI_e = M_y/\emptyset_y$). The stiffness of the uncracked section (EI) is calculated according to the gross moments of inertia (I) of the RC elements and the modulus of elasticity of the concrete (E_c). For concrete classes, concrete elasticity modulus ($E_c = 3250\sqrt{f_{ck}} + 14000\ MPa$) are calculated according to the concrete compressive strengths (f_{ck}) given in Requirements for Design and Construction of RC Structures (Turkish Standard-TS500, 2000). Effective stiffness coefficient of (RC) elements; it is calculated as $k_e = EI_e/EI$.

2.2. Effective section stiffness coefficient proposed in TBEC (2018)

Effective cross-sectional stiffness multipliers will only be applied to calculations that are included in earthquake-effect load combinations and under loads entered into these combinations. TBEC (2018) specifies the effective stiffness coefficient for the RC columns is specified as 0.7. Effective cross-sectional stiffnesses (EI) of the RC members designed according to the lumped plastic behavior will be determined according to Eq. (1), where M_y is the yield moment, θ_y is the chord rotation at the yielding end and L_s is the shear span. Shear span can be taken as approximately half of the span length of the columns. For the nonlinear calculation, chord rotation at the yielding (θ_y) of the RC members is calculated by Eq. (2). In the equation; f_{ye} is the expected yield strength of transverse reinforcement (f_{ye}=1.2f_{yk}) and f_{ce} expected compressive strength of concrete (f_{ce}=1.3f_{ck}), h is the section height, d_b is the longitudinal reinforcement diameter and $\emptyset_y$ is the yield curvature. $\eta = 1$ in columns.

$$(EI)_e = \frac{M_y}{\theta_y}\frac{L_s}{3} \tag{1}$$

$$\theta_y = \frac{\emptyset_y L_s}{3} + 0.0015\eta\left(1 + 1.5\frac{h}{L_S}\right) + \frac{\emptyset_y d_b f_{ye}}{8\sqrt{f_{ce}}} \tag{1}$$

2.3. Effective section stiffness coefficient proposed in ASCE standard (2017)

In ASCE/SEI-41 (2017), EI_{eff} for columns with a design gravity load less than $0.1A_g f_c$, EI_{eff} is specified as $0.3E_c I_g$. For columns with a compressive force greater than $0.5A_g f_c$, this coefficient is given as 0.7.

2.4. Effective section stiffness coefficient proposed in ACI standard (ACI 318, 2014)

In ACI318 (2014) specifies the effective stiffness for the RC columns is specified as $0.70E_cI_c$. Alternatively, the moments of inertia of compression members, I, shall be permitted to be computed as follow Eq. (3). I need not be taken less than $0.35I_g$ for the compression members. In the equation, A_{st} is the total area of longitudinal reinforcement, A_g is the gross area of concrete section, M_u is the factored moment at section, P_u is the factored axial force, P_o is the nominal axial strength and h is the height of members.

$$I = \left(0.80 + 25\frac{A_{st}}{A_g}\right)\left(1 - \frac{M_u}{P_u h} - 0.5\frac{P_u}{P_0}\right)I_g \leq 0.875 I_g \quad (3)$$

2.5. Effective section stiffness coefficient proposed in Eurocode 8 (2005)

Part 3 of Eurocode 8 (2005) provides an equation based on moment-to-shear ratio and yield rotation, which can be used for the determination of a more accurate effective stiffness ($M_y L_v/3\theta_y$). The chord rotation at yielding θ_y, calculated at Eq. (4).

$$\theta_y = \Phi_y \frac{L_V + a_V z}{3} + 0.0014\left(1 + 1.5\frac{h}{L_V}\right) + \Phi_y \frac{d_{bL} f_y}{8\sqrt{f_c}} \quad (4)$$

$a_V z$ is the tension shift of the bending moment diagram; $z = d - d'$ in beam section; $\varepsilon_y = f_y/E_s$, d and d' are the depths to the tension and compression reinforcement, respectively; and d_{bL} is the diameter of the reinforcement. $a_V = 0$, if $V_{Rc} > M_y/L_s$ and $a_V = 1$, if $V_{Rc} \leq M_y/L_s$. $V_{R,c}$ is taken in accordance with 1992-1-1 (2004).

2.6. Effective section stiffness coefficient proposed in Eurocode 8 (2004)

In Eurocode 8 (2004), recommends that the elastic flexural and shear stiffness properties of concrete elements are taken as 50% of the corresponding stiffness of the uncracked element.

2.7. Effective section stiffness coefficient proposed in Eurocode2 (2004)

The following model may be used to estimate the nominal stiffness of slender compression members with arbitrary cross section:

$$EI = K_c E_{cd} I_c + K_s E_s I_s \quad (5)$$

where E_{cd} is the design value of the modulus of elasticity of concrete ($E_{cd} = E_{cm}/\gamma_{CE}$, the recommended γ_{CE} value is 1.2); I_c is the moment of inertia of concrete cross section; E_s is the design value of the modulus of elasticity of reinforcement; I_s is the second moment of area of reinforcement, about the centre of area of the concrete; K_c is a factor for effects of cracking, creep etc.; and K_s is a factor for contribution of reinforcement. As a simplified alternative, provided $\rho = A_s/A_c \geq 0.01$, the following factors may be used in Eq. (6). φ_{ef} is the effective creep ratio.

$$K_s = 0 \quad , \quad K_c = \frac{0.3}{(1 + 0.5\varphi_{ef})} \quad (6)$$

The stiffness should be based on an effective concrete modulus:

$$E_{cd,eff} = E_{cd}/\left(1 + \varphi_{ef}\right) \quad (7)$$

3. Material and Method

In determining the seismic performance of RC structures in national and international earthquake regulations, it is desired to use effective stiffness of the cracked cross-section in RC structural elements during the design phase. One of the realistic analyses of calculating the effective stiffness of RC structural members is the use of moment-curvature relations. Effective stiffness of the cracked cross-section in RC structural members are determined by the ratio of yield moment to yield curvature considering the moment-curvature relationship. The effective stiffness of the cracked cross-section depends on parameters such as structural member size, concrete strength and axial load levels. RC square and circular column models with different axial load levels, concrete strength, longitudinal and transverse reinforcement ratios were designed to investigate effective stiffness. The effective stiffness coefficient of the cracked cross-section of the RC structural members designed in different parameters were obtained analytically. Analytically investigated parameters were calculated from TBEC (2018), ACI318 (2014), ASCE/SEI41 (2017), Eurocode 2 (2004), Eurocode 8 (2004, 2005) regulations and moment-curvature relationships of cross-sections.

Reinforced concrete column models having different cross-sections were created in order to examine the effects of effective cross-sectional stiffness of design parameters of RC column cross-sections. In order to investigate the effect of axial load levels, longitudinal and transverse reinforcement ratio on the effective stiffness coefficient, the column models having dimensions of 500mm×500mm square cross-section and 600mm diameter circular cross-sections were designed. Six different longitudinal reinforcement (LR) diameters, two different transverse reinforcement (TR) diameters and three different transverse reinforcement spacing are used for each RC column model. In (RC) column models, longitudinal reinforcement diameters were selected as 20mm, 22mm, 24mm, 26mm, 28mm and 30mm. In (RC) column models, transverse reinforcement diameters; 10mm and 12mm and transverse reinforcement spacings; it was chosen as 50mm, 75mm and 100mm. The reinforcement ratios used in the RC columns cross-sections have been determined by considering the limitations given in TS500 (2000) and TBEC (2018). Details for the designed RC column cross-sections with different parameters are given in Table 1 and Fig. 1. Accurate calculation of moment-curvature relations of (RC) elements is a reliable indicator of the load capacity of structures subjected to seismic loads. It is essential for the calculation of cross-section strength, flexural stiffness and ductility, and for the nonlinear analysis of (RC) structures. Theoretical moment-curvature analysis for RC members indicating the available bending moment and curvature can be constructed providing that the stress-strain relations for both concrete and steel are known. Moment-curvature relationships were obtained by SAP2000 Software which takes the nonlinear behavior of materials into consideration. The combined effect of vertical and seismic loads (N_{dmax}), cross-section area of RC column shall satisfy the condition $A_c \geq N_{dmax}/0.4f_{ck}$. In this study, the moment-curvature relationships of the RC column cross-sections were investigated for the values of N/N_{max} ratios of 0.10, 0.20, 0.30 and 0.40. To investigate the effect of axial force on the cross-section behavior; the RC rectangular, square and circular columns were investigated under four different axial load levels. The designed RC columns are considered to be composed of three components; cover concrete, confined concrete and reinforcement steel. A confined and unconfined concrete model proposed by Mander et al. (1988) used to determine the moment-curvature relationships of RC members. In moment-curvature analyses, material models given in Fig. 2 are used for concrete and reinforcement steel. RC members having different geometries were designed considering the regulations of ACI318 (2014) and TBEC (2018). For all RC members, C30, C35, C40, C45 and C50 were chosen as concrete grade and B420C was selected as reinforcement for the reinforcement behavior model. In the moment-curvature analysis, the effect of concrete tensile strength is neglected because it is insignificant.

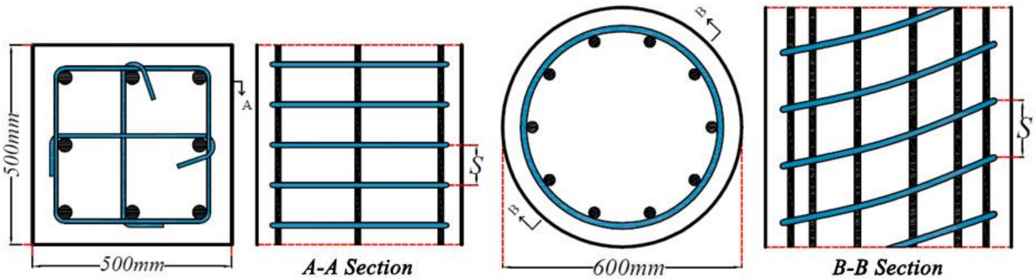

Fig. 1. Cross-sectional dimensions.

Table 1. Details for the designed RC column cross-sections.

Material	Longitudinal reinforcement	Transverse reinforcement		N/N_{max}
		Diameter	Spacing	
C30 C35 C40 C45 C50	Φ20mm Φ22mm Φ24mm Φ26mm Φ28mm Φ30mm	Φ10mm Φ12mm	50mm 75mm 100mm	0.10 0.20 0.30 0.40

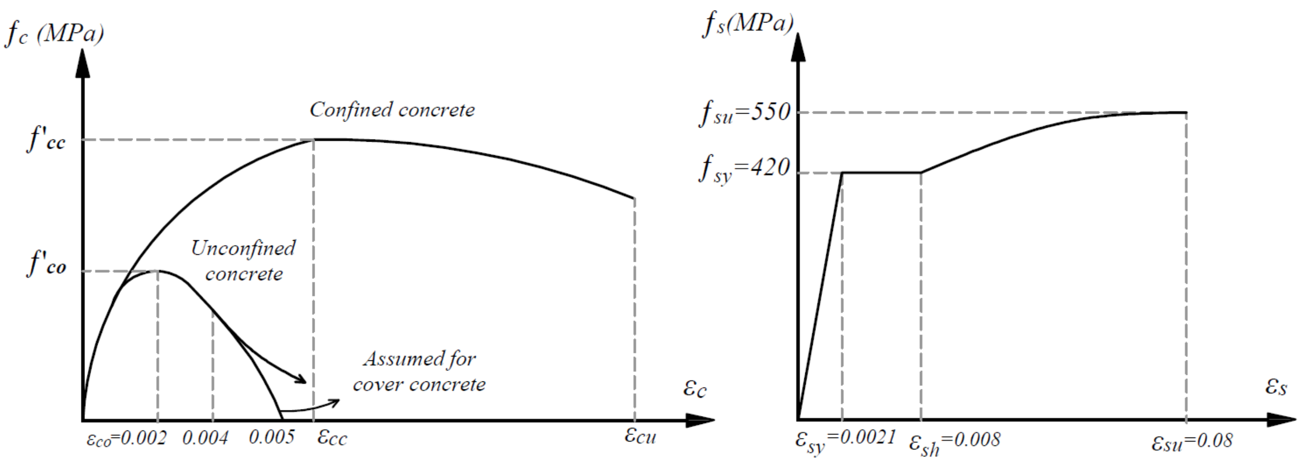

Fig. 2. Stress-strain relationships for concrete and reinforcement.

Analytically investigated parameters were calculated from different standards and codes and moment-curvature relationships of cross-sections. In this study, the effect of the axial load levels, concrete strength, longitudinal reinforcement and transverse reinforcement ratios were considered for square and circular RC column cross-sections. This study is based on parametric analysis of the cross-sectional response of a wide range of RC column cross-sections. The major factors affecting the effective stiffness of the RC column cross-sections are investigated. The effective section stiffness coefficient obtained from the analyses were compared with the effective cross-section stiffness coefficient given for RC columns in different regulations. The results of the comparison are examined in detail. The effective stiffness values obtained from the analysis results are presented in detail in the Research Findings and Discussion section.

4. Research Findings and Discussion

The effective flexural stiffness resulting from concrete cracking depends on some important parameters such as confinement, level of axial load, cross-section dimensions and material properties of concrete and reinforcement. The results of the parameters investigated for (RC) column models are summarized in the following sections according to cross-section geometries. The effective stiffness and effective stiffness coefficient of the cracked cross-section of the RC structural members designed in different parameters were obtained analytically. Analytically investigated parameters were calculated from TBEC (2018), ACI318 (2014), ASCE/SEI41 (2017), Eurocode2 (2004) and Eurocode8 (2004, 2005) regulations and moment-curvature relationships. The effective section stiffness coefficient obtained from the analyses were compared with the effective section stiffness coefficient given for RC square and circular columns in different regulations. The results obtained at the end were examined by comparing them according to different parameters and models.

4.1. Nonlinear moment-curvature analysis of reinforced concrete columns

In this part of the study, the moment-curvature relations are obtained by changing the axial load levels, concrete strength, longitudinal and transverse reinforcement ratio. A total of 1440 different analyzes were performed to determine the moment-curvature relationships and effective stiffness coefficients of square and circular (in two geometries) cross-section columns with different parameters. Each cross-sectional analysis is compared according to criteria which can change the effective stiffness of RC column cross-sections. The moment-curvature curves were drawn for different RC column models and were interpreted by comparing the curves. Moment (M_y, M_u) and curvature ($\emptyset_y$, $\emptyset_u$) values were calculated for yield and ultimate conditions from moment-curvature relationships according to different parameters in the designed (RC) square and circular column models (Figs. 3 and 4).

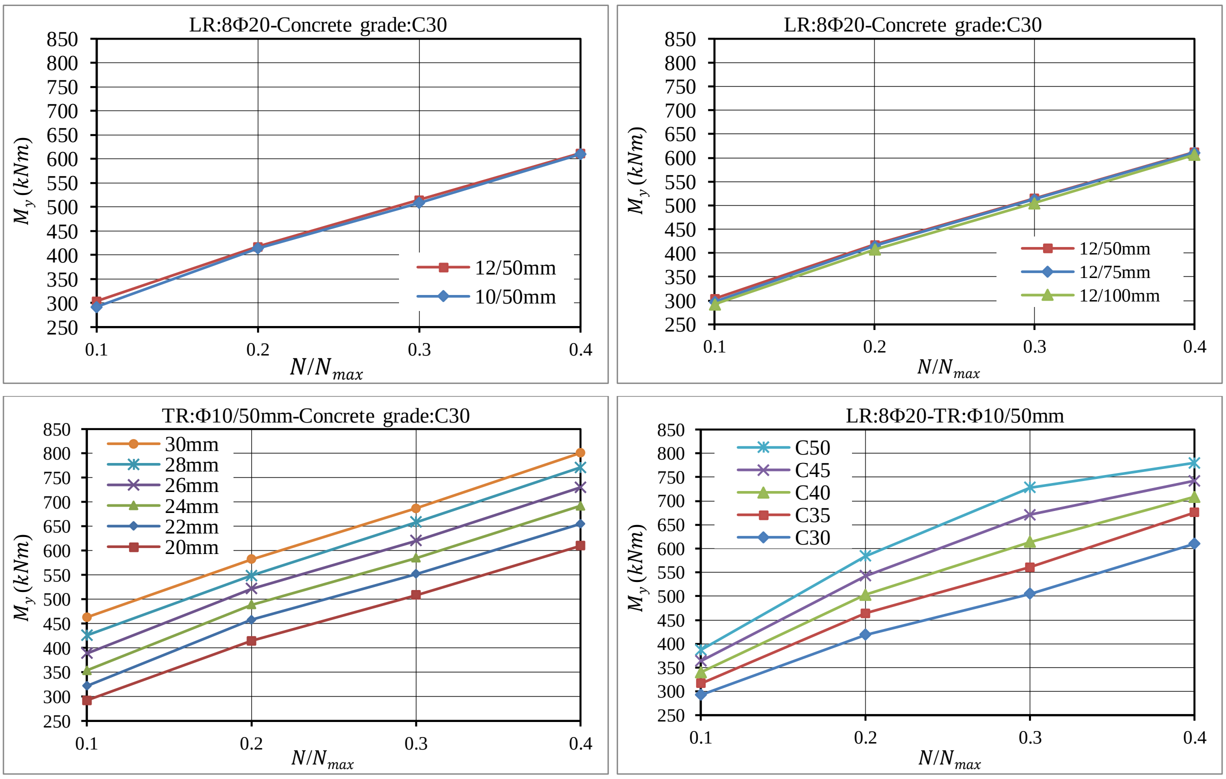

Fig. 3. (continued)

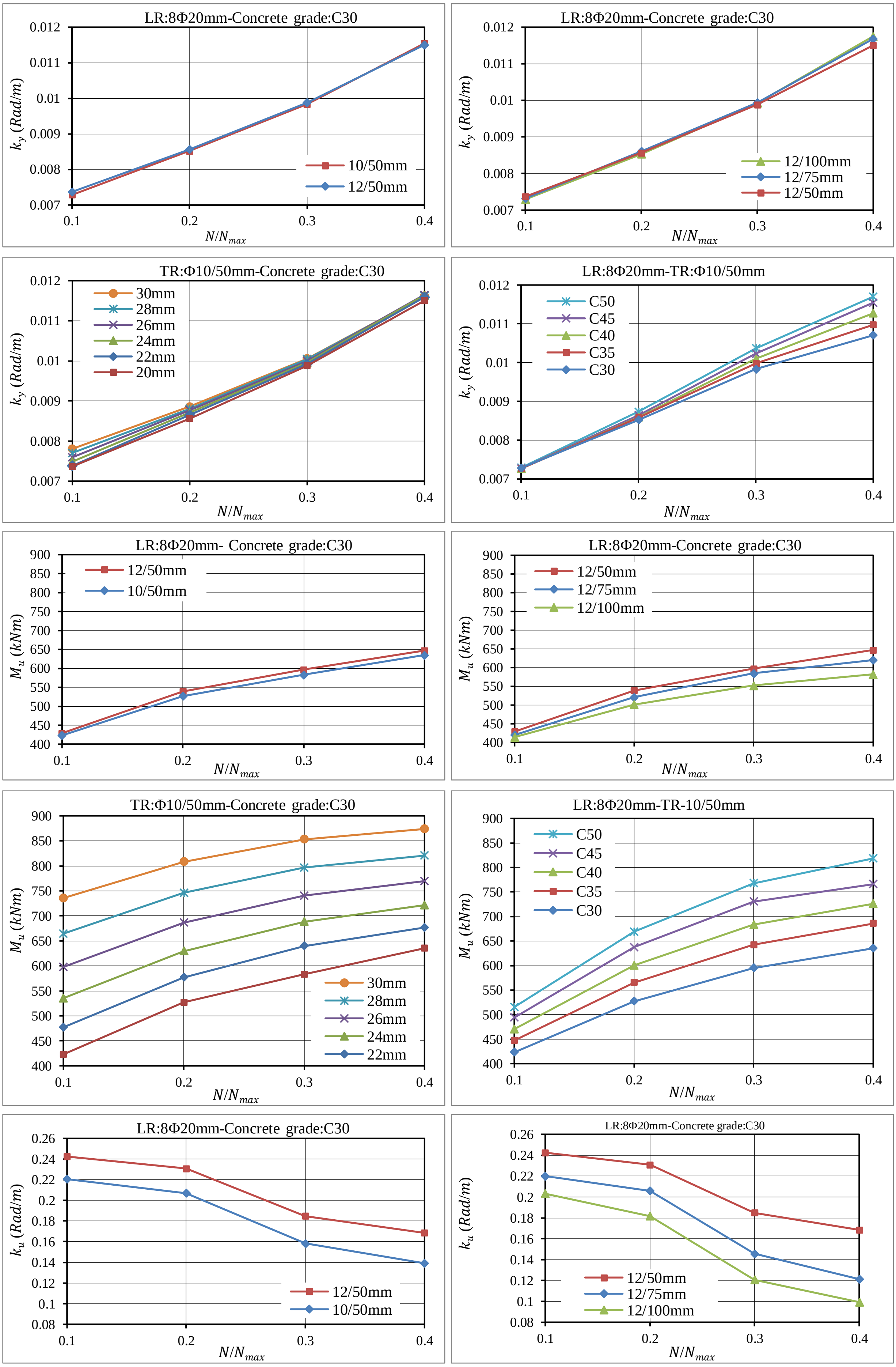

Fig. 3. (continued)

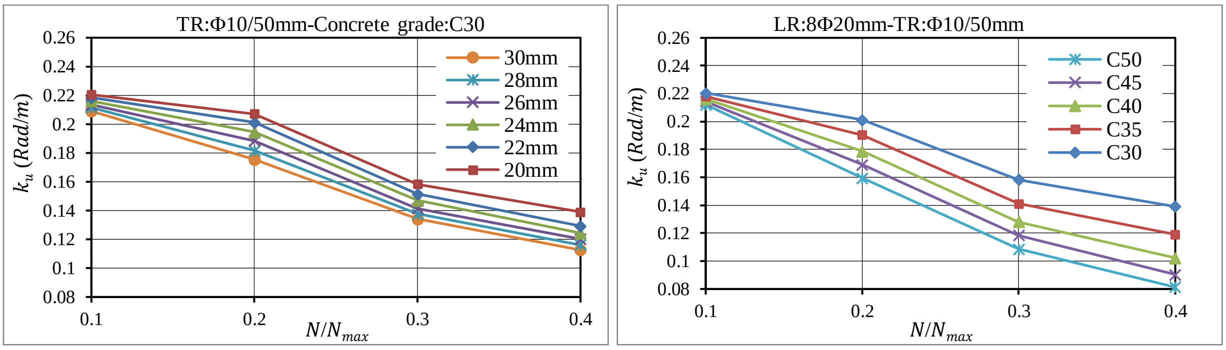

Fig. 3. Influence of $\boldsymbol{N/N_{max}}$, concrete strength, longitudinal and transverse reinforcement on the moment-curvatures (square columns).

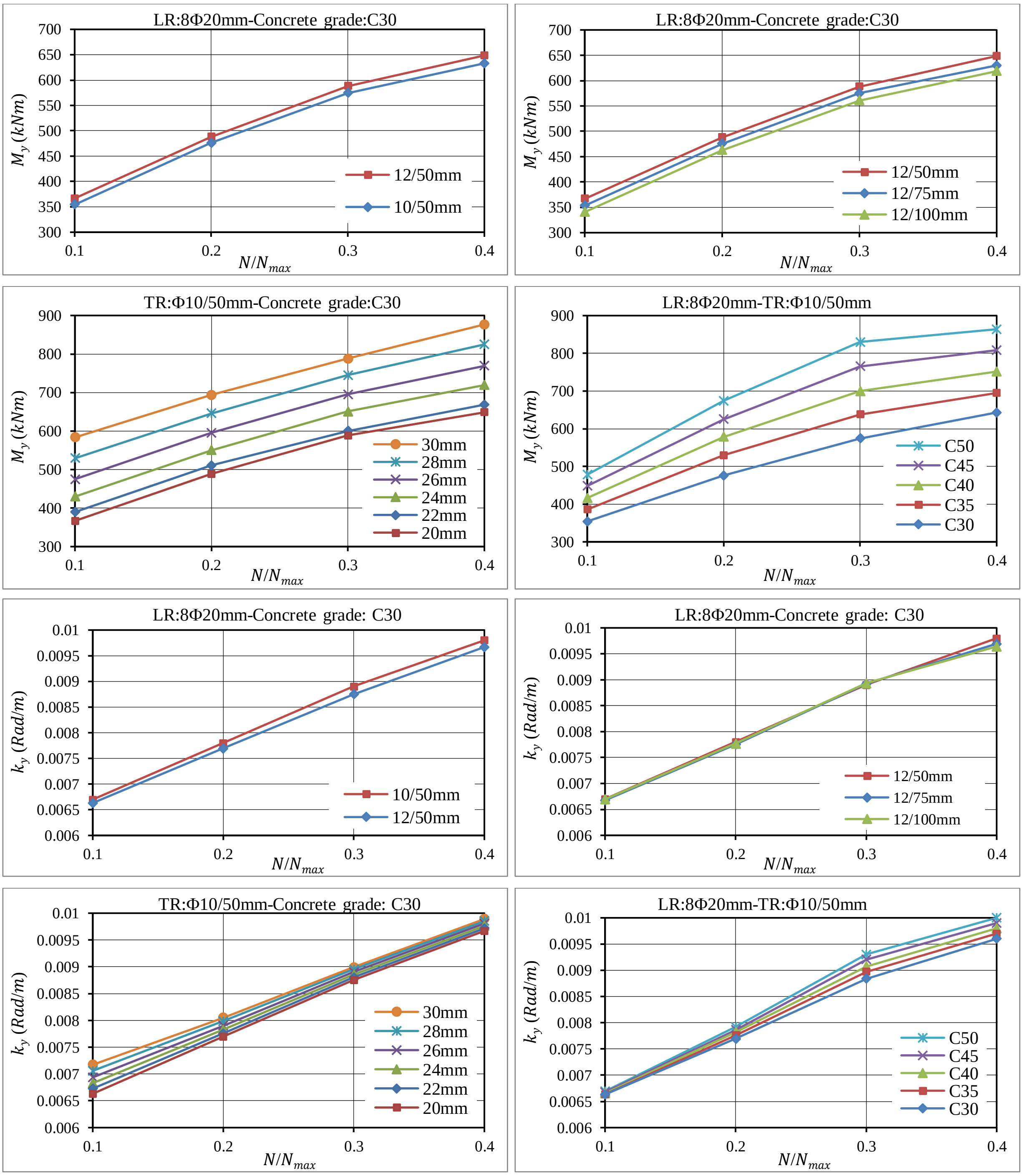

Fig. 4. (continued)

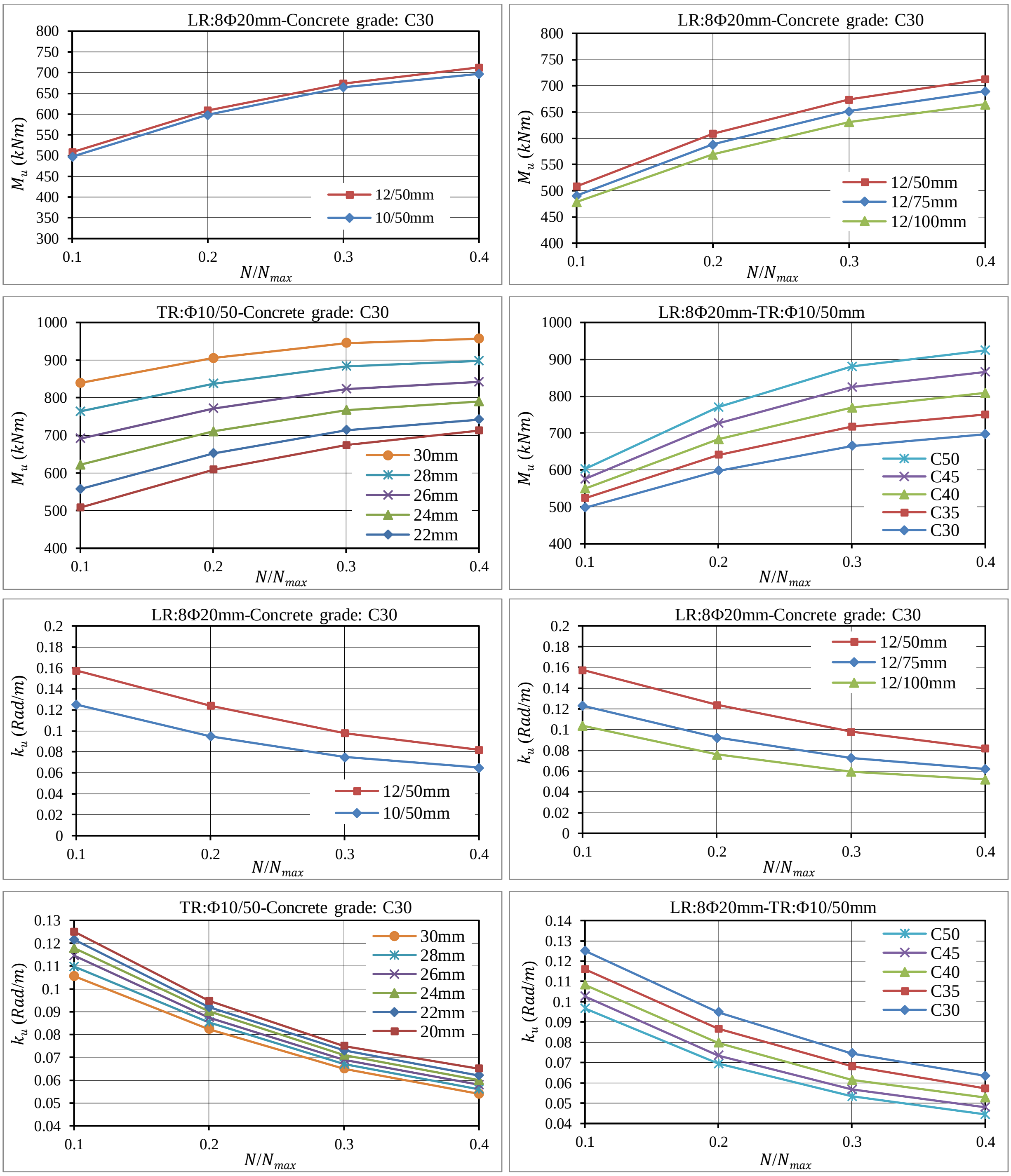

Fig. 4. Influence of N/N_{max}, concrete strength, longitudinal and transverse reinforcement on the moment-curvatures (circular columns).

4.2. Effective stiffness analysis of reinforced concrete columns

The effective stiffness coefficient of the (RC) square and circular column cross-sections designed according to different design parameters was investigated using the relationships proposed in different regulations and non-linear moment-curvature analysis. The effective stiffness of the RC columns is obtained by nonlinear moment-curvature analyzes depending on different design parameters. The effective stiffness coefficient obtained from analysis for different RC column models are examined by summarizing in graphs. The results obtained at the end were examined by comparing them according to different parameters (axial load, concrete compressive strength, longitudinal and transverse reinforcement ratio) and models (Square and circular cross-section). The effective stiffness coefficient obtained from the analyzes were compared from moment-curvature relations and different seismic codes (TBEC, 2018; ACI318, 2014; ASCE/SEI41, 2017; Eurocode 2, 2004; Eurocode 8, 2004; Eurocode 8-Part 3, 2005). The calculated effective stiffness coefficient are comparatively given in Figs. 5-17.

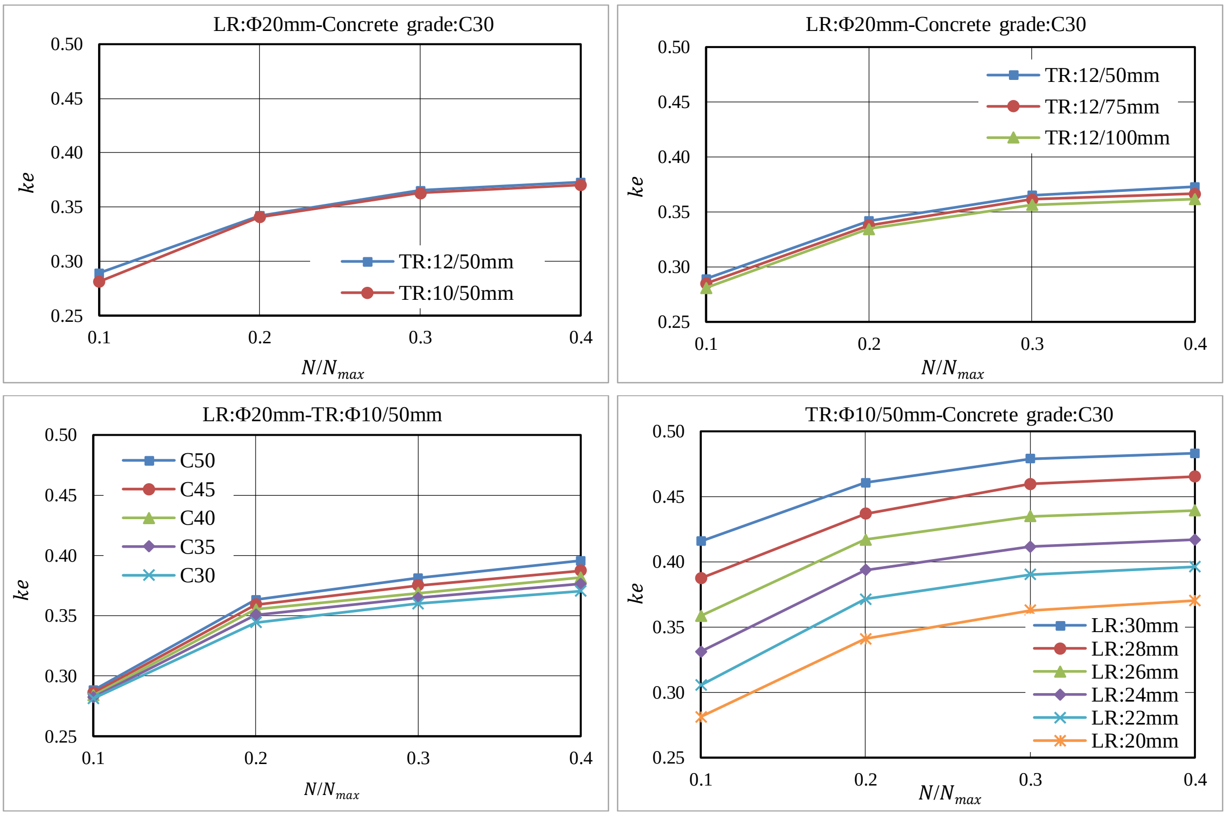

Fig. 5. k_e values obtained from moment-curvature relationships according to different parameters of the square column.

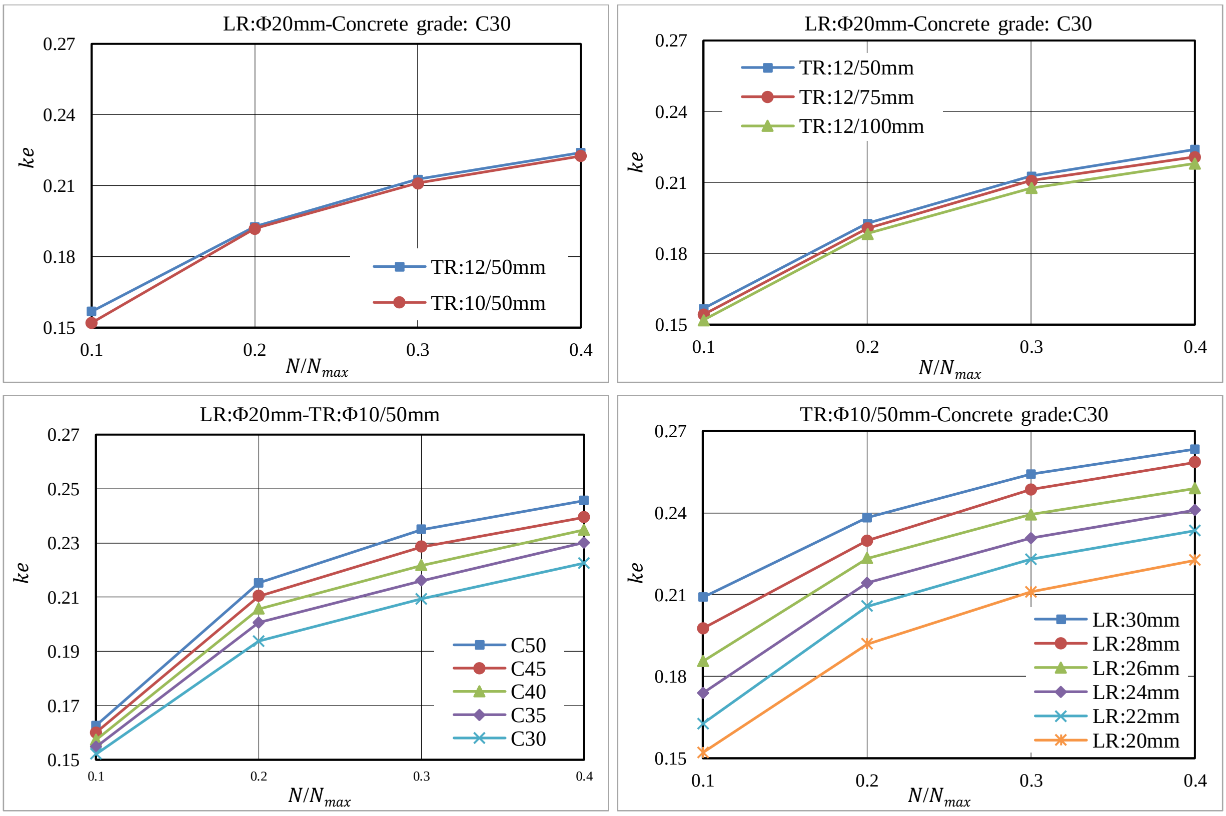

Fig. 6. k_e values obtained according to the non-linear behavior defined in TBEC (2018) of the square column.

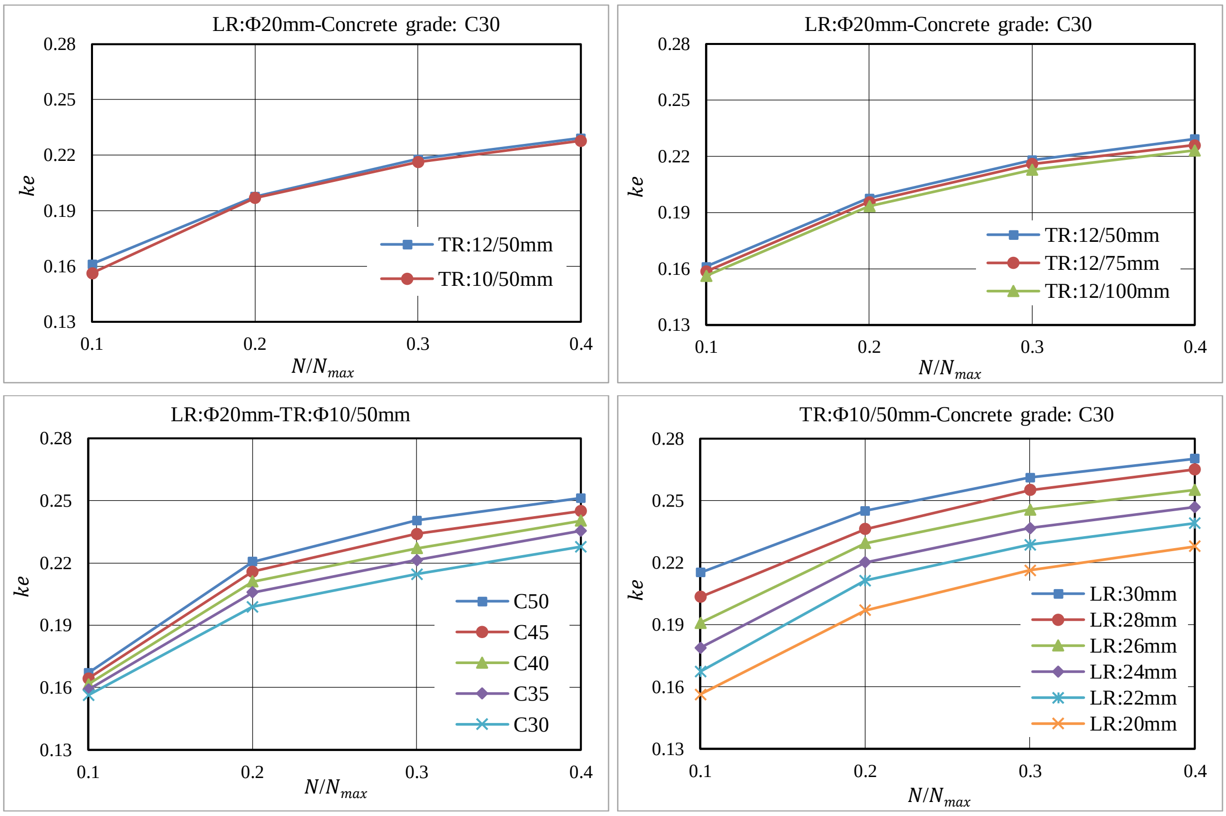

Fig. 7. k_e values obtained according to part 3 of Eurocode 8 (2005) of the square column.

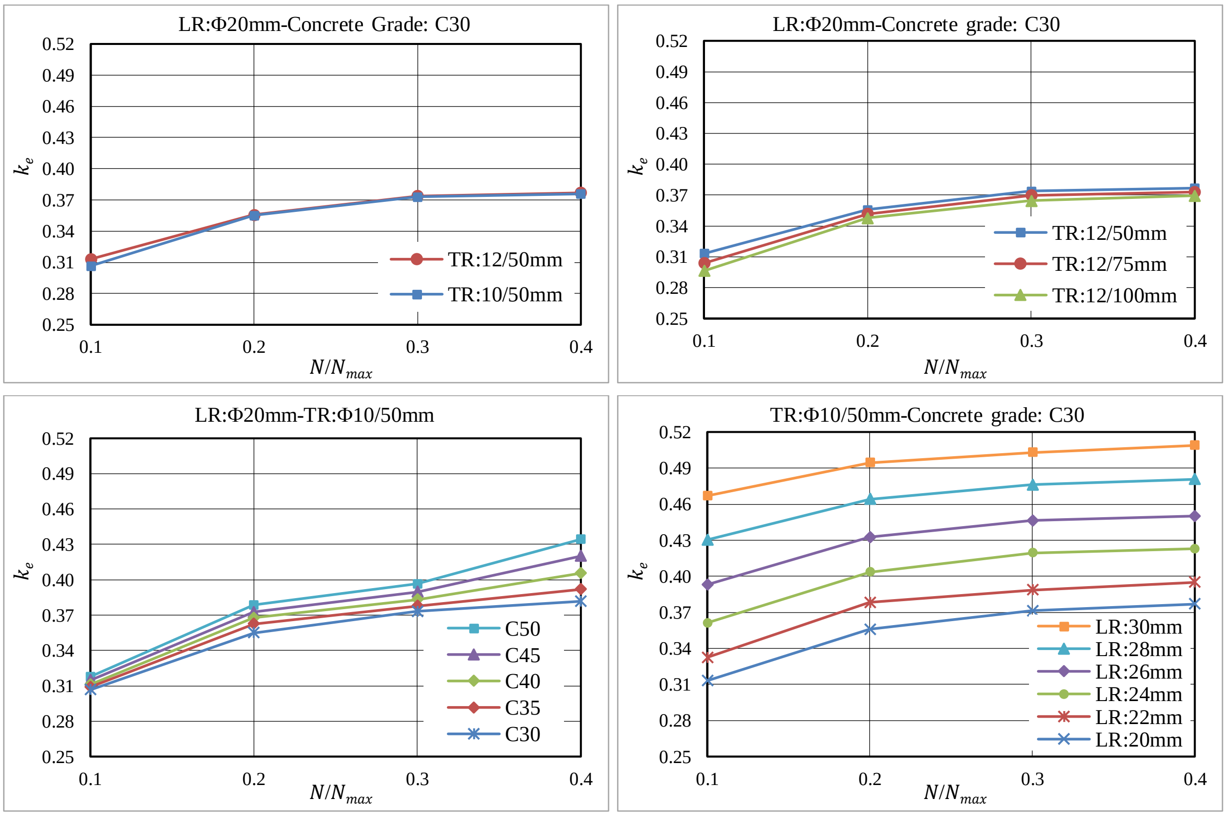

Fig. 8. k_e values obtained from moment-curvature relations according to different parameters of circular column.

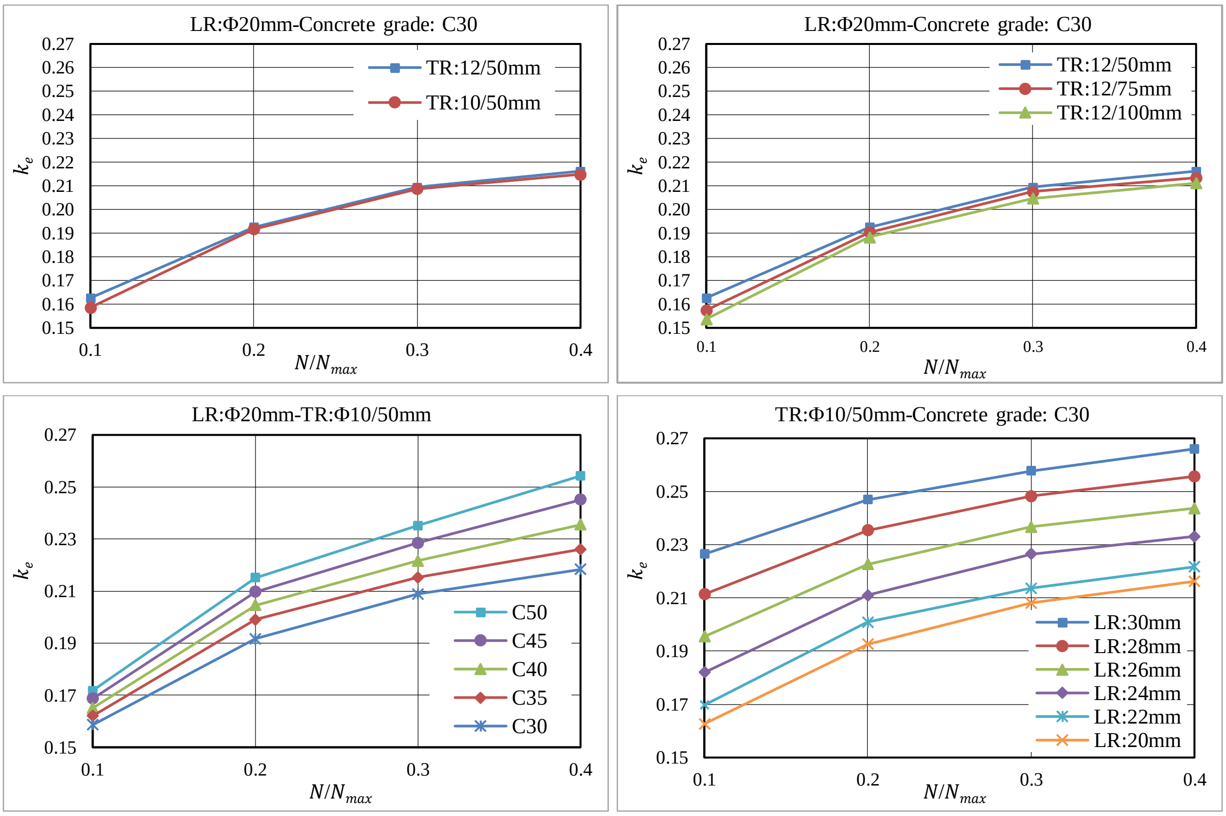

Fig. 9. k_e values obtained according to the non-linear behavior defined in TBEC (2018) of circular column.

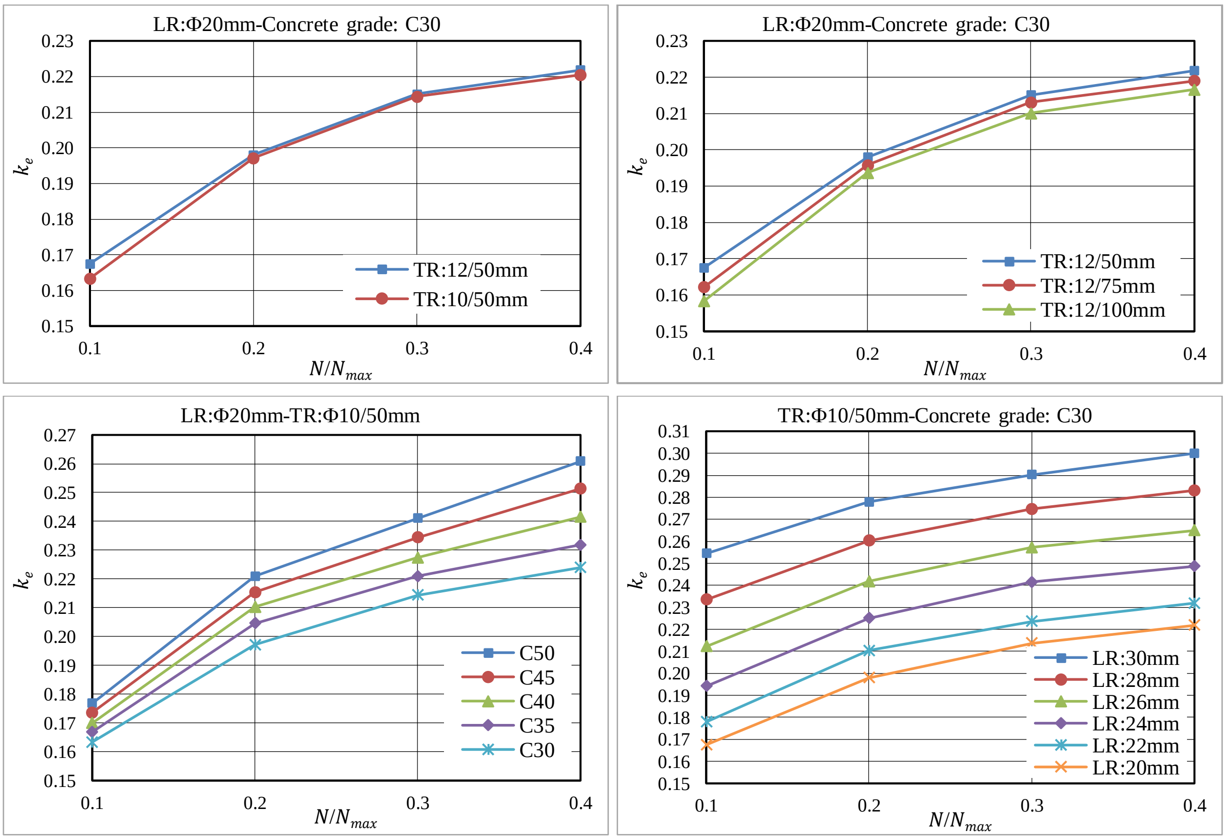

Fig. 10. k_e values obtained according to part 3 of Eurocode8 (2005) of circular column.

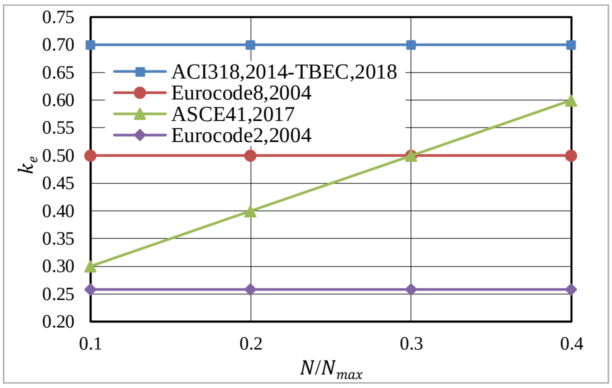

Fig. 11. k_e values obtained according to different seismic codes and standard of the columns.

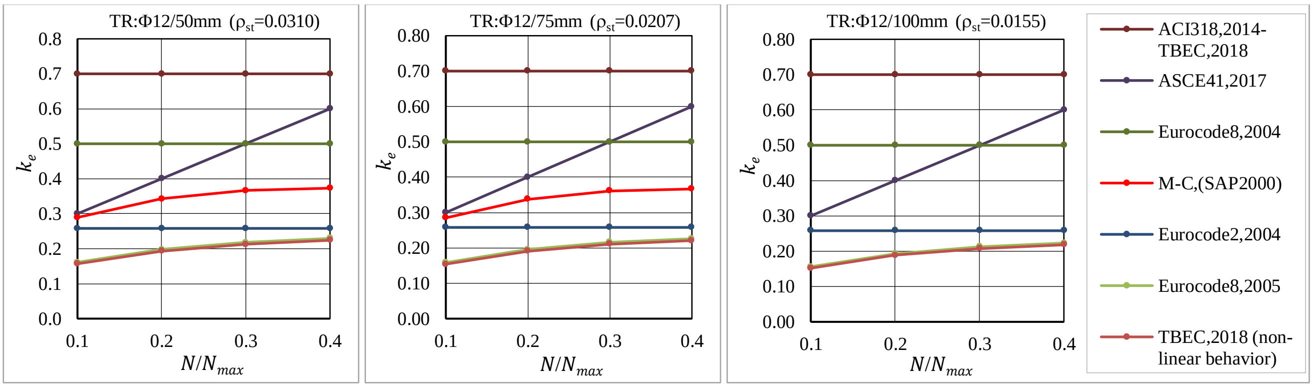

Fig. 12. Effect of transverse reinforcement on k_e of square column cross-sections (LR: Φ20mm-C30).

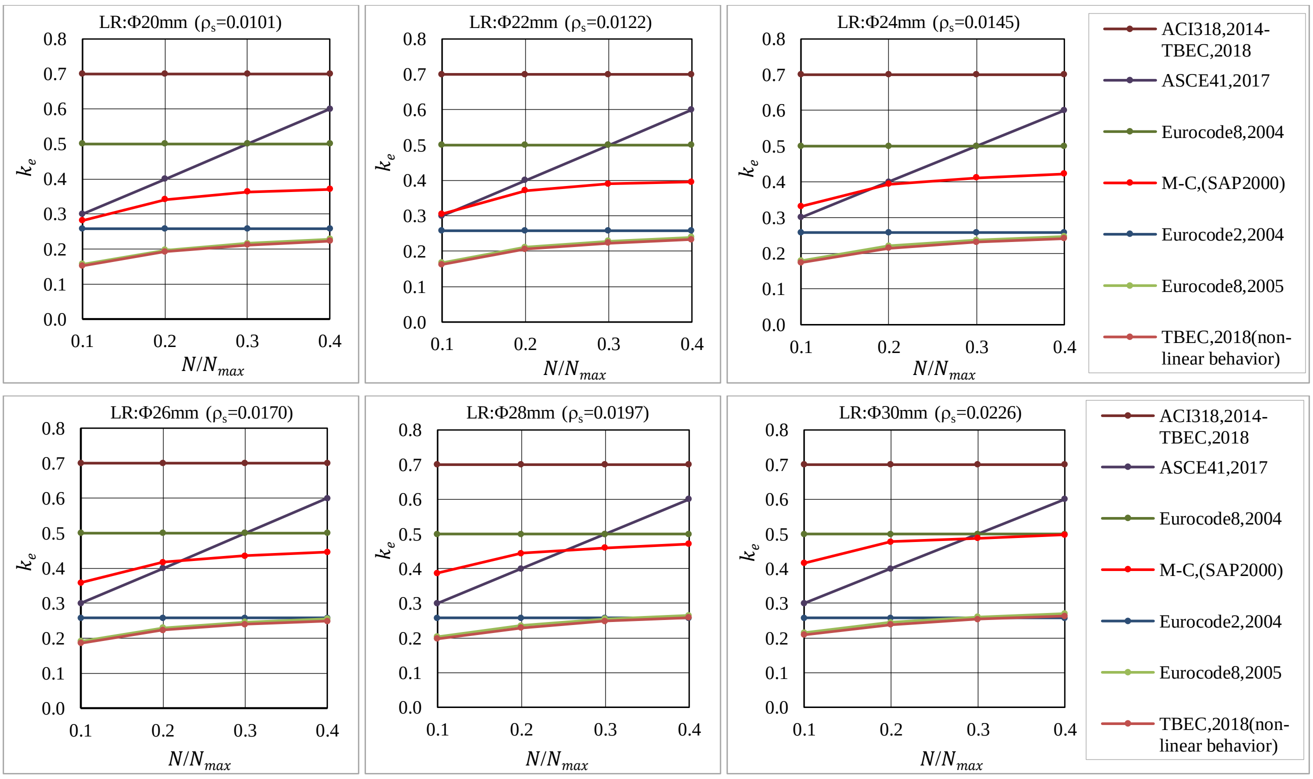

Fig. 13. Effect of longitudinal reinforcement on k_e of square column cross-sections (TR: Φ10/50mm-C30).

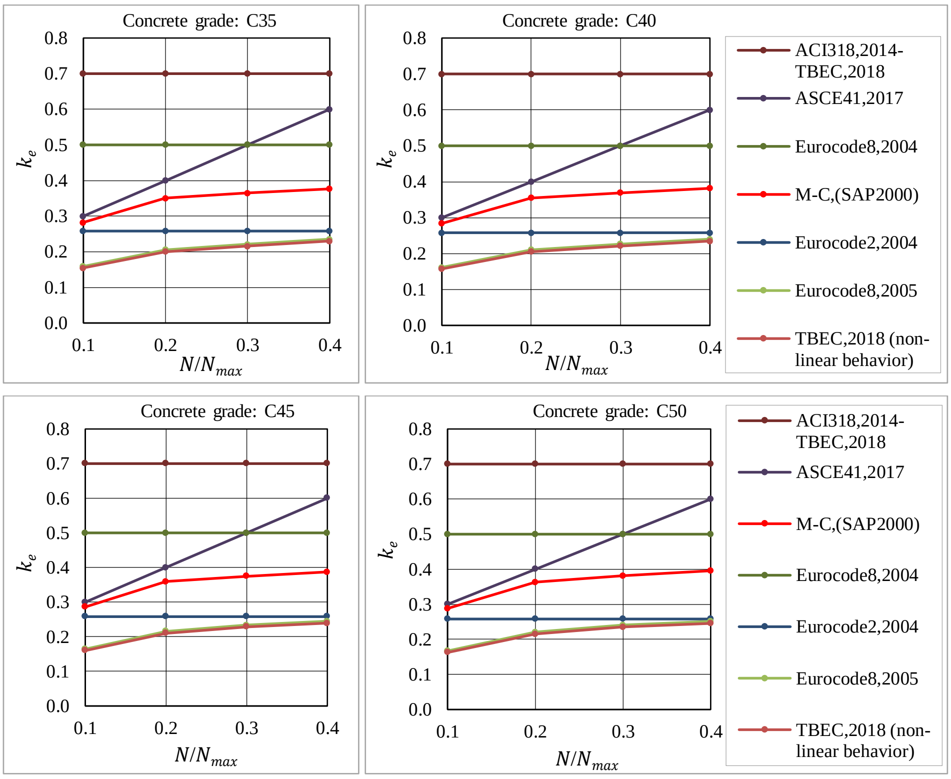

Fig. 14. Effect of concrete compressive strength on k_e of square column cross-sections (LR: Φ20mm, TR: Φ10/50mm).

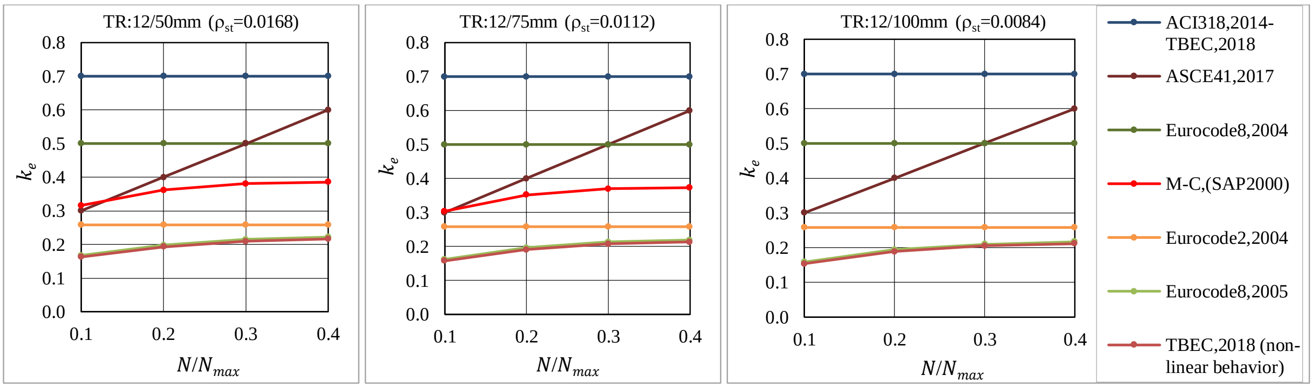

Fig. 15. Effect of transverse reinforcement on k_e of circular column cross-sections (LR: Φ20mm-C30).

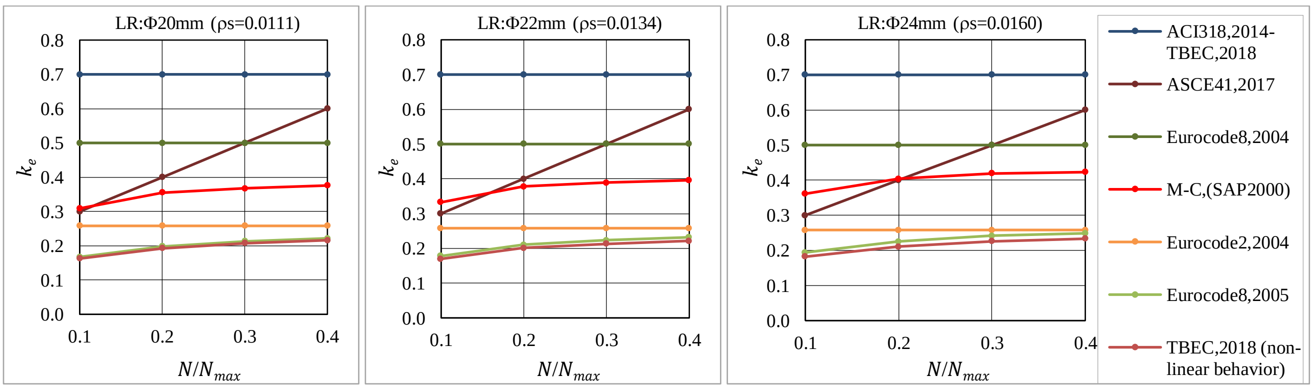

Fig. 16. (continued)

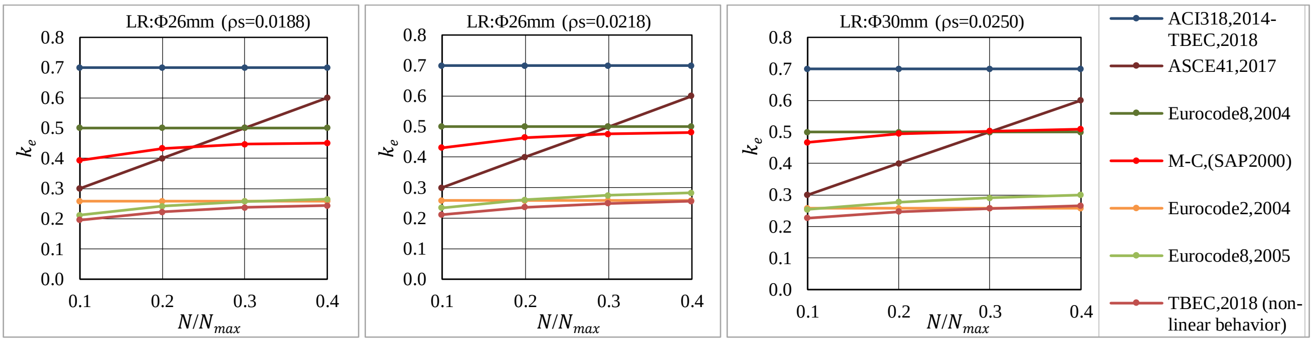

Fig. 16. Effect of longitudinal reinforcement on k_e of circular column cross-sections (TR: Φ10/50mm-C30).

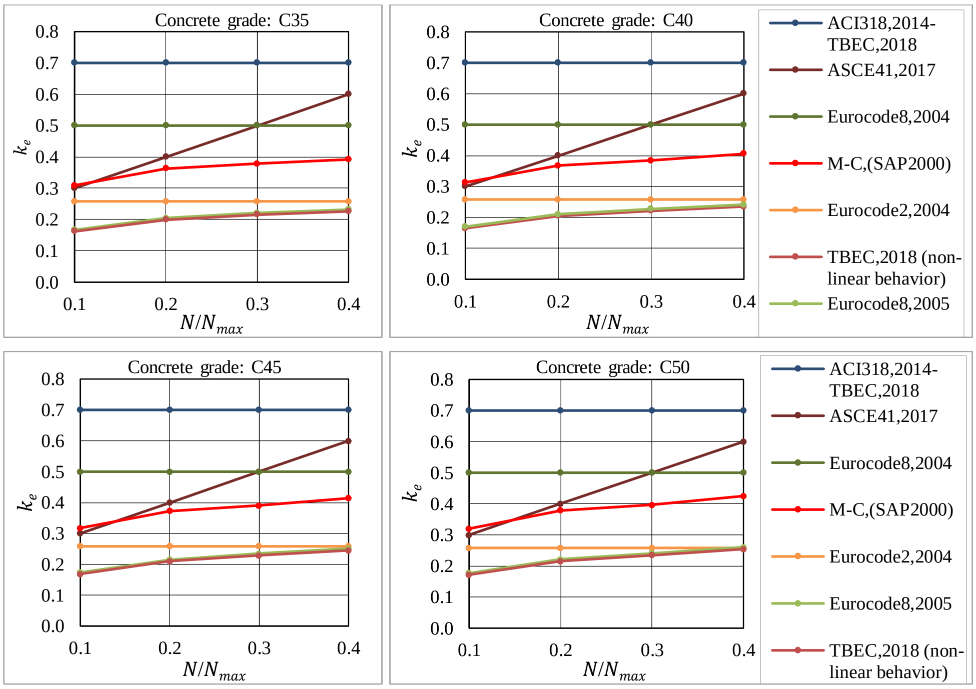

Fig. 17. Effect of concrete compressive strength on k_e of circular column cross-sections (LR: Φ20mm, TR: Φ10/50mm).

When the moment-curvature analysis results are examined, it is observed that the variation of the axial load, longitudinal reinforcement diameter, transverse reinforcement ratio have an important effect on the moment-curvature behavior of the (RC) columns. Yielding and ultimate moment capacities of the sections increase when the transverse reinforcement spacing decreases. The increase in the transverse reinforcement diameter increases the ultimate moment, ultimate curvature and curvature ductility values, but yield moment and yield curvature values remain almost constant. The increase in the axial load level causes curvature values to decrease. Yield and ultimate moment capacities of the members increase with the increment of longitudinal reinforcing ratio for the columns.

ACI318 (2014) gives a constant ratio of $0.70E_cI_c$ for columns. In ASCE/SEI-41 (2017), f or columns with a design gravity load less than $0.1A_gf_c$, EI_{eff} is specified as $0.3E_cI_g$. For columns with a compressive force greater than $0.5A_gf_c$, this coefficient is given as 0.7. The effective stiffness value of the cracked section given in Eurocode 8 (2004) is fixed. The effective stiffness of the cracked section is considered to be half of the initial stiffness. In Eurocode 8 (2004), features such as concrete strength, cross-section geometry, longitudinal and transverse reinforcement ratio and axial force acting on the cross-section are not taken into consideration. Part 3 of Eurocode 8 (2005) provides an equation based on moment-to-shear ratio and yield rotation, which can be used for the determination of a more accurate effective stiffness. Both the ultimate level and serviceability level loads are addressed in Eurocode 8 for linear and nonlinear analysis. According to Eurocode 2 (2004) in a second-order analysis based on stiffness, nominal values of the flexural stiffness should be used, taking into account the effects of cracking, material non-linearity and creep on the overall behavior. Similarly, in TBEC (2018), effective stiffness is assumed to be constant and effective stiffness coefficient values of the cracked section are 0.70 for the column. The effective stiffness of reinforced columns modelled according to the lumped plastic behavior in TBEC (2018) can be calculated depending on the effective yield moments, yield rotation and the shear span.

5. Conclusions

When the moment-curvature analysis results are examined, it is observed that the variation of the axial load, longitudinal reinforcement diameter, transverse reinforcement ratio have an important effect on the moment-curvature behavior of the (RC) columns. Yielding and ultimate moment capacities of the cross-sections increase when the transverse reinforcement spacing decreases. The ductile behavior for (RC) column cross-sections is observed due to the increment of curvature ductility with the increase of the transverse reinforcement ratio. The increase in the transverse reinforcement diameter increases the ultimate moment, ultimate curvature and curvature ductility values, but yield moment and yield curvature values remain almost constant (transverse reinforcement spacing and axial load levels are the constant). Yield moment, yield curvature, ultimate moment and ultimate curvature values increase however, curvature ductility values decrease as the longitudinal reinforcement diameter increases while other parameters kept constant. The increase in the axial load level causes curvature values to decrease. In cases where the axial load is low, (RC) cross-sections have a ductile behavior. Yield and ultimate moment capacities of the members increase with the increment of longitudinal reinforcing ratio for the columns cross-section.

In the relations suggested for the effective stiffness coefficient, the confining effect is not taken into account as in the regulations. Therefore, it means neglecting the effects of parameters such as cross-section dimension, concrete strength, confining effect and axial force acting on the cross-section. Determining the moment-curvature relationship in the design and evaluation of (RC) elements and obtaining effective stiffness values are of great importance in order to obtain more realistic results. Existing codes and previous studies revealed that the effective stiffness is often expressed in terms of the axial load level in the columns. The axial loads, concrete strength and the amount of longitudinal and transverse reinforcements have been identified as the most important factors affecting the cross-section yield point as well as the effective stiffness of the RC column cross-section. As can be seen from the comparison results, the effective stiffness values calculated from the SAP2000 program, from different regulations are different from each other. Taking the effective stiffness higher than the required value will cause the structural stiffness to be overestimated. As a result, problems will arise in the calculation and evaluation of structures. As can be seen from the comparison of effective stiffness coefficient values obtained with different regulations and relations for RC columns designed in different parameters; the calculated effective stiffness for RC columns increases with increasing transverse reinforcement ratio, longitudinal reinforcement ratio and concrete strength. Due to the increase of axial force, effective stiffness values of concrete have increased.

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