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DETERMINING MOMENT-CURVATURE RELATIONSHIP OF REINFORCED CONCRETE COLUMNS

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Abstract: Determining the behavior of reinforced concrete (RC) members is crucial in RC structures. The nonlinear attributes of RC members are defined according to the cross sectional behavior of RC members to evaluate the performance of structures. To be able to determine cross sectional behavior of RC members, moment-curvature relationship should be known well. In the RC structures, using moment-curvature (MC) relationship is the best way to represent cross sectional behavior and nonlinear properties of RC members. The MC relationship of RC cross sections can be evaluated by both experimentally or numerically. Some experimental studies on RC members which are applied with 1:1 scale can be difficult to define moment-curvature relationship. The purpose of the study is to obtain the MC relationship of RC rectangular and circular and circular columns numerically. By the way this study is tried to achieve determining the parameters which affect MC relationship of RC members. In the study, to evaluate MC relationship of RC members XTRACT programme which represents influentially MC relationship is used. Compressive strength of concrete, axial load on the RC sections, longitudinal and transverse reinforcing ratio, are selected as comparison parameters which affect MC relationship. As a consequence of this study curvature ductility and effective flexural stiffness of RC rectangular and circular sections are determined using these parameters. Effective flexural stiffness is compared with the values defined in design codes. As a result of comparison, it is observed that the moment curvature relationship can be defined as a formulation according to the parameters which affect directly.

Keywords: Moment-curvature relationship, Reinforced concrete columns

Introduction

In the Reinforced Concrete (RC) structures, that is known RC columns are one of the most crucial elements under earthquake loads. Column mechanisms are very critical to prevent total collapse in earthquakes. The objective performance levels of RC structures could not be ensured due to the failure of some critical RC columns. Because of this determining the behavior of the structures should be known well to design earthquake resisting structures. In the RC structures, the structural behavior can change according to the behavior of the RC members. To determine the behavior of RC members, it has to be known the behavior and properties of the RC Thus the cross sectional capacities and attributes are used to define behavior of structural members. Moment curvature (MC) is one of the best solution to evaluate and represent the behavior of RC cross sections. It should be known that the experimental research is the best way to determine cross sectional behavior. Experimental studies are not practical due to the difficulties of composing 1:1 scale models for RC members. Therefore some complicated numerical iteration methods and some finite element softwares are developed to define MC relationship. In this study, XTRACT program is one of the these softwares is used to define MC relationship. using It also uses one of these iteration methods to determine MC relationships.

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In recent years, to define MC relationship of RC members and affecting parameters of MC relationships for R many engineering applications are developed. (Caglar and Garip 2013, Caglar 2009, Gunaratnam and Gero 2008, Pala 2006, Adeli and Samant 2000, Bishop 1995, Kulkarni 1994) Some formulations to numerically define MC relationship are investigated. RC columns behave under combined affect of bending moment and axial load in structural systems. To be able to determine MC relationship of RC circle columns and formulate their effective bending rigidity Caglar et al. 2015 researched about a new approach. They also investigated affecting parameters of this formula. It has be known from recent studies that confinement, axial load level, section dimension and vertical and horizontal reinforcement are determined as the most critical parameters affecting moment-curvature relationship. To find parameters affecting moment-curvature directly some experimental studies are completed (Jadid and Fairbairn 1996). Arslan (2012) studied to define the parameters affecting curvature ductility of RC columns. The curvature ductility has to be known to determine global ductility of RC structure and to evaluate performance level by appliying pushover analysis. Petschke et al. (2013) tried to define MC curves considering asymmetrically reinforced cross-sections for RC beams in their studies.

Moment and Curvature

The structural behavior has to be determined according to the behavior of RC structural members which can be understood by their MC relationships. These structural members behave under effect of bending or combined with bending and axial load. Strength, stiffness and ductility properties of the cross sections should be defined by the MC relationship. Curvature (C) is a geometrical parameter representing cross sectional deformation is defined as unit rotation angle of a cross section under bending effect. It is obtainable the derivative of the inclination of the tangent with respect to arc length (Figure 1).

$$Curvature: \phi = \frac{d\theta}{dy} = \frac{d^2 y}{dx^2} = \frac{1}{\rho} \qquad (1)$$

$$\phi = \frac{M}{EI} \qquad (2)$$

EI: Flexural stiffness

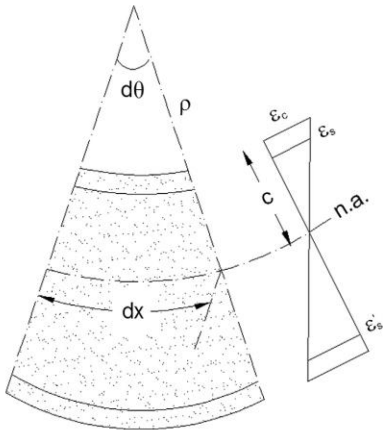

Figure 1. Moment curvature relationship (Caglar et al. 2015)

MC relationship can be evaluated experimentally and analytically. Analytical methods are commonly used due to the difficulties of experimental studies for RC members when the MC is needed. In the study, XTRACT program is used instead of experimental study to be able to obtain MC relationship for RC columns. MC relationships of RC columns are obtained by using a cross sectional analysis program (XTRACT). It is an interactive and adaptive program for analysis of cross sections step by step to find MC relationships. The program can constitute MC relationship for concrete, steel, prestressed and composite structural cross sections. Cross section and any material input from the nonlinear material models can be analyzed input of any permissive. MC relationship of RC column is derived from XTRACT and its bilinearized curve are shown in Figure 2.

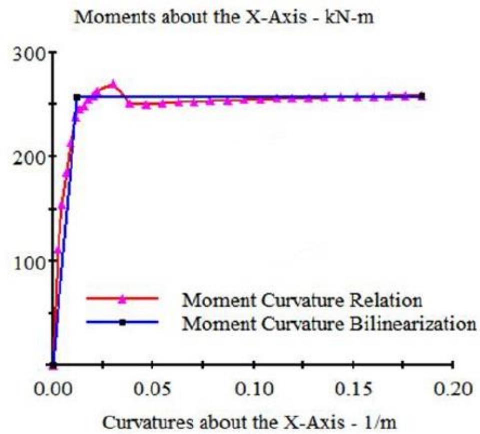

Figure 2. Moment curvature bilinearization (Caglar et al. 2015)

Numerical Study

In the study, Xtract section analysis programme was applied to evaluate the moment-curvature relationship of reinforced concrete rectangular and circular columns which have constant dimensions and different longitudinal and transverse reinforcing configurations. For this purpose; 54 rectangular and circular and circular reinforced concrete columns sections which have different longitudinal and transverse reinforcing configurations considering under three different axial load level. The cross-sections of rectangular and circular columns were composed and designed according to both Turkish Earthquake Code (TEC 2007) and Turkish design and construction code for reinforced concrete structures (TS 500). The dimensions of columns are chosen as 250 mm width and 600 mm length and also diameter of circular column is D=450 mm. These values are constant in all cross-sectional analysis. The dimensions are composed considering nearly equal cross sectional area of both sections. There different longitudinal reinforcement and transverse configurations configurations are used both cross sections of RC columns. The cross-sectional details are given in Figure 3. Concrete material behavior is modelled by employing Mander approach. Linear elastic-ideal elastoplastic (bilinear) stress-strain relationship is assumed for behavior of longitudinal and transverse reinforcements. Strain-hardening behavior is neglected for reinforcements. Three different compressive strength (C20, C30, C40) for concrete and constant tensile strength for reinforcements (S420) are employed in the cross-sectional analysis. The material models and the strength of materials are shown in Figure 4 and Table 1 respectively. The reinforcement configuration are given in Table 2.

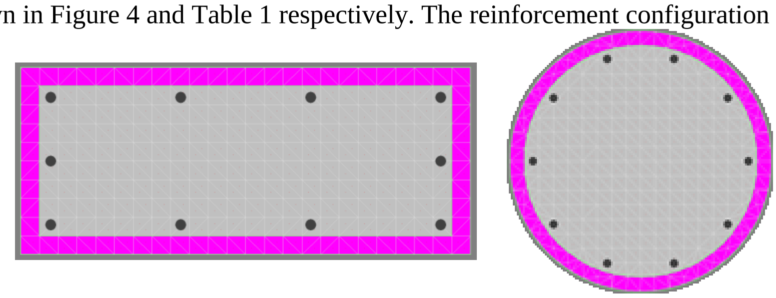

Figure 3. Cross section of rectangular and circular columns

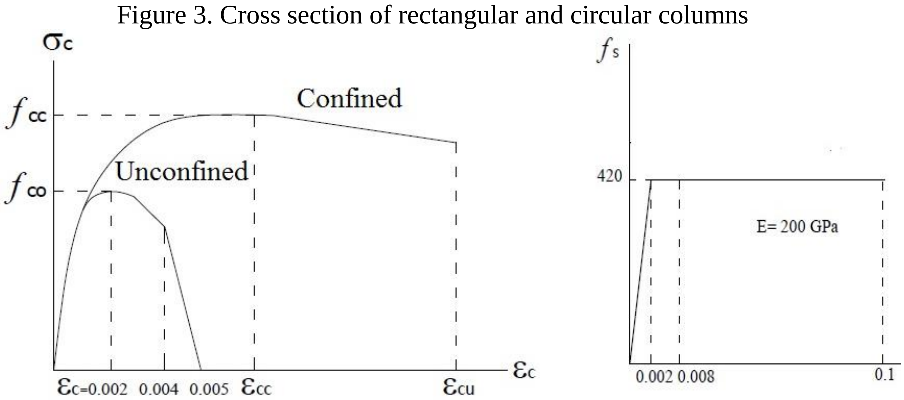

Figure 4. Stress-strain relationship for concrete and reinforcement

Table 1. Strength of materials

Concrete	Concrete Strength (Mpa)	Longt.&Tran. Rein.	Longt. Rein. Strength (Mpa	Trans.Rein. Strength (Mpa)

C20	20			
C30	30	420	420	420
C40	40			

In the study, according to the Xtract section analysis moment-curvature relationship changed with compressive concrete strength, longitudinal and transverse reinforcing ratio. These analysis are numbered between 1-27 for each material class and given Table 2 in details. Rectangular and circular reinforced concrete columns sections are designed and analyzed totally 54 different cross sectional configurations whose compressive strength of concrete longitudinal and transverse reinforcements are different from each other. Curvature ductility of each rectangular and circular cross section column get different values when reinforcing ratios and material type change. Each cross sectional analysis is compared according to criteria which can change curvature ductility of rectangular and circular column cross sections.

Table 2. Strength of materials

Analiz#	Concrete	Section (Analysis Name)	Axial Load	Long. Rein.	Long. Rein. Ratio	Trans. Rein.	Trans. Rein. Ratio
1						Ø8/50	0.0073 / 0.005
2				10Ø14	0.01	Ø8/100	0.0037 / 0.025
3						Ø8/150	0.0024 / 0.017
4						Ø8/50	0.0073 / 0.005
5			$0.1f_{cm}A_c$	10Ø20	0.02	Ø8/100	0.0037 / 0.025
6						Ø8/150	0.0024 / 0.017
7						Ø8/50	0.0073 / 0.005
8				10Ø24	0.03	Ø8/100	0.0037 / 0.025
9						Ø8/150	0.0024 / 0.017
10	C20	Rectangular				Ø8/50	0.0073 / 0.005
11		(RS)		10Ø14	0.01	Ø8/100	0.0037 / 0.025
12		/				Ø8/150	0.0024 / 0.017
13	C30					Ø8/50	0.0073 / 0.005
14		Circular	$0.3f_{cm}A_c$	10Ø20	0.02	Ø8/100	0.0037 / 0.025
15		(CS)				Ø8/150	0.0024 / 0.017
16	C40					Ø8/50	0.0073 / 0.005
17				10Ø24	0.03	Ø8/100	0.0037 / 0.025
18						Ø8/150	0.0024 / 0.017
19						Ø8/50	0.0073 / 0.005
20				10Ø14	0.01	Ø8/100	0.0037 / 0.025
21						Ø8/150	0.0024 / 0.017
22						Ø8/50	0.0073 / 0.005
23			$0.5f_{cm}A_c$	10Ø20	0.02	Ø8/100	0.0037 / 0.025
24						Ø8/150	0.0024 / 0.017
25						Ø8/50	0.0073 / 0.005
26				10Ø24	0.03	Ø8/100	0.0037 / 0.025
27						Ø8/150	0.0024 / 0.017

For axial force value of columns is evaluated acting on the section was selected by following requirements of above codes:
$Nd_m \leq 0.5$ fck Ac (TEC 2007)
$Nd_m \leq 0.6$ fck Ac (TS 500)

In all analysis three different axial load level are used. They are given as $0.1f_{cm}A_c$, $0.3f_{cm}A_c$, $0.5f_{cm}A_c$ respectively in Table 2. In the study, $0.1f_{cm}A_c$ axial load level is used for the analysis between 1-9, $0.3f_{cm}A_c$ axial load level is used for the analysis between 10-18, $0.5f_{cm}A_c$ axial load level is used for the analysis between 19-27respectively.

Results and Discussion

Moment-curvature relationship of RC rectangular and circular columns was determined by using XTRACT and it is defined as a bilinear curve with 3 parameters showed in Table 1 and Table 2. By using curvature parameters; yield curvature (ϕ_y) and ultimate curvature (ϕ_u) and moment parameters; yield moment (My) and ultimate moment (Mu), flexural stiffness (Effective EI) and curvature ductility were created respectively. Having performed the numerical analyses these values of each cross sections were compared according to the analysis results for each material class. Analyses results are given in Figure 5, for C20, C30, C40.

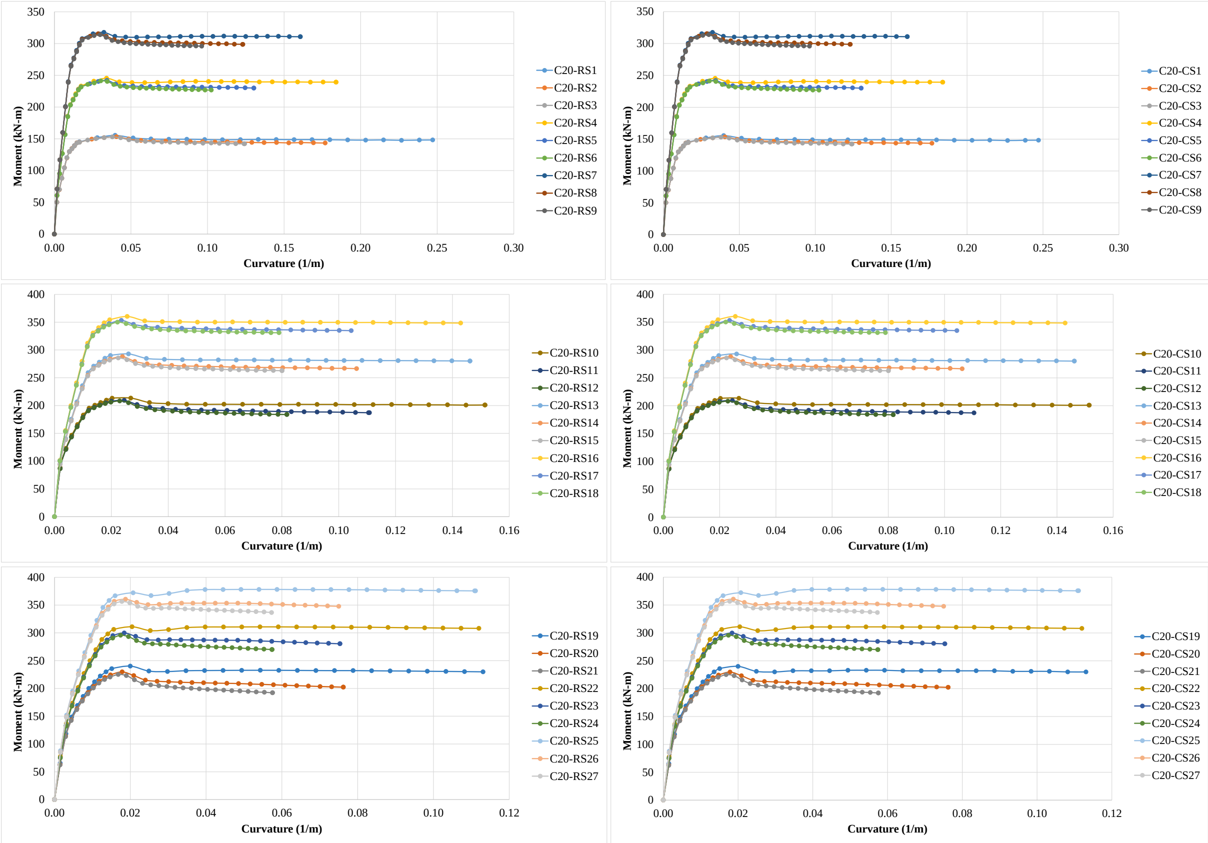

Figure 5. Moment-curvature relationships rectangular (left) and circular (right) sections for C20

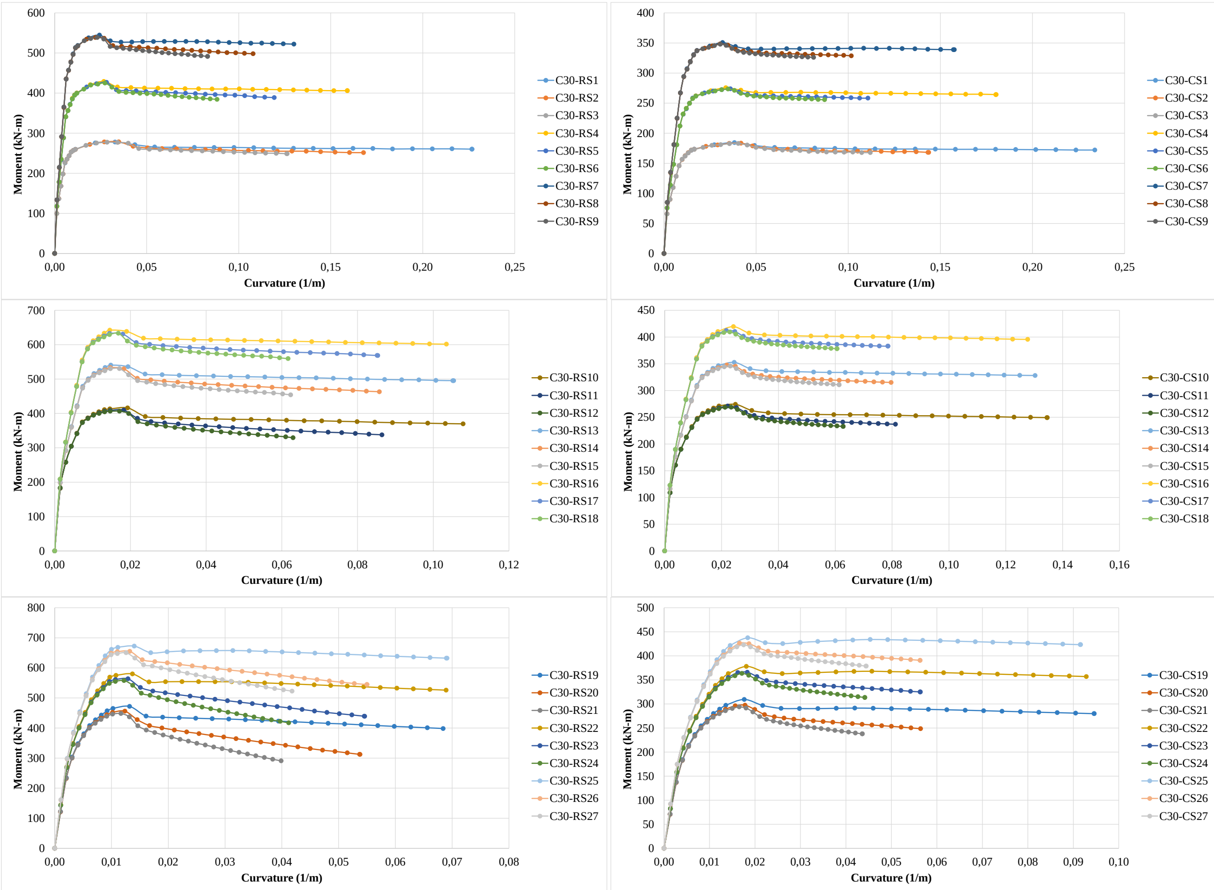

Figure 6. Moment-curvature relationships rectangular (left) and circular (right) sections for C30

In the study three different longitudinal and five different transverse reinforcing ratios are used for each concrete material class. It can be understood from the Fig. 6 that ductility of the members improves as transverse reinforcing ratio increases. Moreover a grouping is experienced in moment curvature relationship according to longitudinal reinforcing ratios. For this reasons, it seems that the moment-curvature of all rectangular cross sections show nearly same behavior. It is seemed from Fig. 7 that curvature ductility of the cross sections decreases as the longitudinal reinforcing ratios increases.

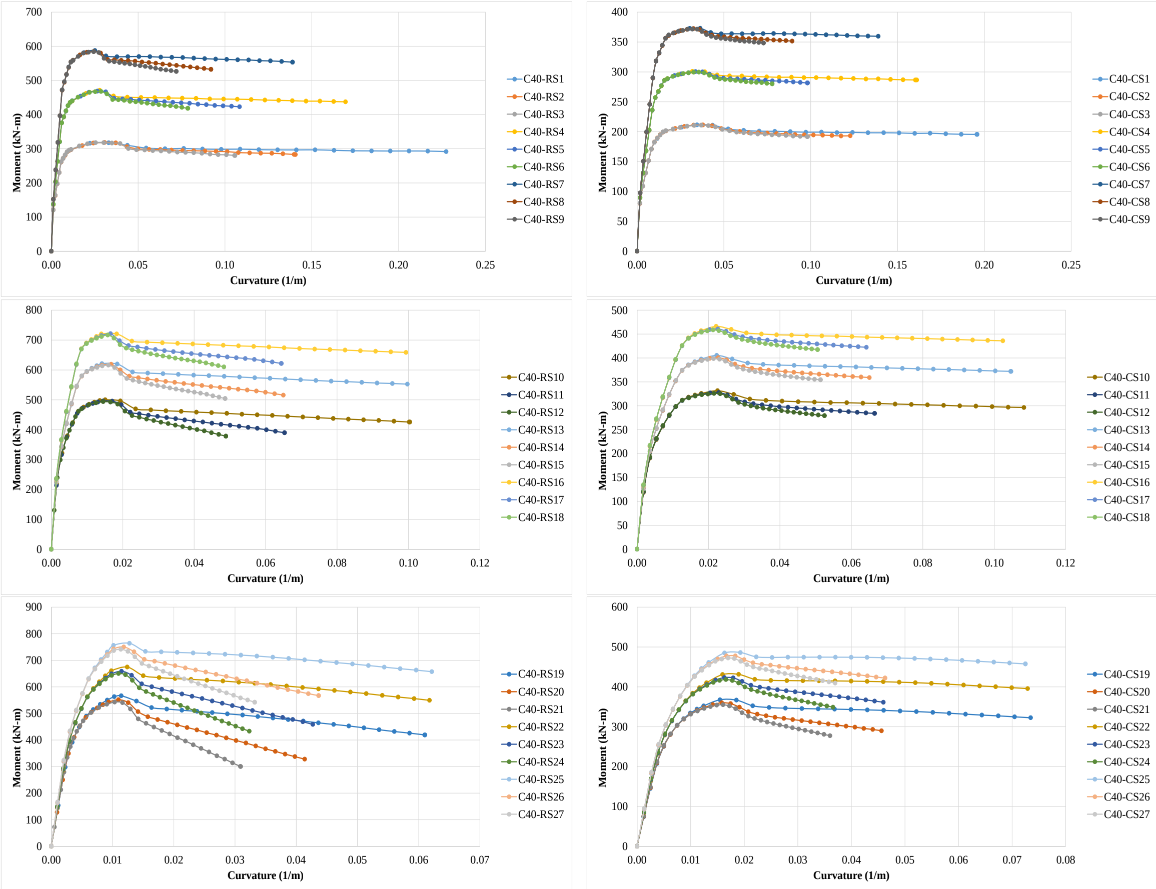

Figure 7. Moment-curvature relationships rectangular (left) and circular (right) sections for C40

Conclusion

In the study, cross sectional properties to design RC members are studied to identify behavior of RC rectangular and circular columns. The geometrical properties of RC cross sections whose moment-curvature relationships are given graphically are designed considering design properties of TEC 2007 and TS500. The moment-curvature relationship are determined according to the cross sectional analysis of RC columns by using XTRACT. The MC relationships are compared according to material class, longitudinal and transverse reinforcing ratios and the axial force of RC columns.

If the analysis results are compared, yielding and ultimate moment capacities of the sections increase when concrete material becomes more brittle. Moreover, the more ductile behavior for RC cross sections is observed due to increment of curvature ductility on RC rectangular and circular columns with the increase of transverse reinforcing ratio. Additionally, according to the analysis results are concluded that the increment of longitudinal reinforcing ratio affect the yielding and ultimate moment capacities of the members for each type of concrete material. With this increment the capacities increase while the cross sections of RC members become more brittle. By the way, the members having high compressive strength become more ductile as longitudinal reinforcing ratio increases when compared with the sections having low compressive strength. But curvature ductility have a balance between compressive concrete strength and longitudinal reinforcing ratio. More ductile behavior is determined for the members having low compressive strength by comparison with the members having high compressive strength as the longitudinal reinforcing ratio decreases. As a consequence of comparison, moment curvature relationship should be defined as a formulation according to the parameters which affect directly.

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