Determining Moment-Curvature Relationship of Reinforced Concrete Rectangular Shear Walls

Gokhan Dok, Hakan Ozturk, Aydin Demir

***Abstract*—**The behavior of reinforced concrete (RC) members is quite important in RC structures. When evaluating the performance of structures, the nonlinear properties are defined according to the cross sectional behavior of RC members. To be able to determine the behavior of RC members, its cross sectional behavior should be known well. The moment-curvature (MC) relationship is used to represent cross sectional behavior. The MC relationship of RC cross section can be best determined both experimentally and numerically. But, experimental study on RC members is very difficult. The aim of the study is to obtain the MC relationship of RC shear walls. Additionally, it is aimed to determine the parameters which affect MC relationship. While obtaining MC relationship of RC members, XTRACT which can represent robustly the MC relationship is used. Concrete quality, longitudinal and transverse reinforcing ratios, are selected as parameters which affect MC relationship. As a result of the study, curvature ductility and effective flexural stiffness are determined using this parameter. Effective flexural stiffness is compared with the values defined in design codes.

***Keywords*—**Moment-curvature, reinforced concrete, shear wall, numerical.

I. Introduction

IT is known that the shear walls are the most critical elements of any RC building under earthquake loads. Failure of one of shear walls could lead the building to collapse. Thus, behavior of the structures has to be known to design structures against earthquake loads. The behavior of RC structures is determined according to the behavior of their members. The behavior of RC members is evaluated with respect to the behavior and properties of the cross section. MC relationship is one of the best expressions to represent cross sectional behavior. Cross sectional behavior can be best determined by experimental studies. Experimental study is difficult and not practical for these entire RC shear walls. For this reason, some complicated numerical iteration methods are used to define MC relationship. In this study, XTRACT program using one of these iteration method is utilised to estimate the MC relationship.

In recent years, many engineering applications [1], [2] are used to formulate MC relationship and to determine parameters which can change MC relationship for RC members. There are several formulations to determine MC relationship [3], [4]. RC shear walls behave like columns under combined effect of bending moment and axial load [5], [6]. Moreover, some new approaches and formulations are developed with the contributions of these engineering applications [7,8]. Some researchers studied about a new approach to find MC relationship of RC circle columns and formulated their effective bending rigidity [9]. They also researched the parameters which affect this formula. The most crucial parameters affecting MC relationship are confinement, axial load level, section dimension and vertical and horizontal reinforcement. It is known that the best way is experimental study to determine parameters [10]. Moreover, in recent studies, it is tried to determine the parameters affecting curvature ductility of RC columns by applying pushover analysis which has to be calculated to evaluate performance and global ductility of RC structures [11]. Additionally, it is also researched in recent studies with MC curves considering asymmetrically reinforced cross-sections for RC beams [12].

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II. Moment and Curvature

The behavior of RC structural members can be understood by their MC relationships. These members can be subjected to bending or combination of bending and axial load. Strength, stiffness, and ductility characteristics of the cross sections can be determined by the MC relationship [13]-[15]. Curvature (C) is a geometrical parameter which represents deformation of a cross section under bending load. The derivative of the inclination of the tangent with respect to arc length (Fig. 1) is obtainable.

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

$$\phi = \frac{M}{EI} \qquad \text{EI: Flexural stiffness} \tag{2}$$

MC relationship can be specified experimentally and analytically. Because it is difficult to test RC members when the MC is needed, factual analytical methods are highly important. In the study, in order to obtain MC relationship for RC shear walls, XTRACT program is used instead of experimental study. MC relationships of RC shear walls are obtained by using a cross sectional analysis program [16]. It is an interactive program to analyze cross sections. The program can constitute MC relationship for concrete, steel, prestressed and composite structural cross sections. It can analyze input of any permissive cross section and any material input from the nonlinear material models. MC relationship of RC shear wall is derived from XTRACT, and its bilinearized curves are shown in Fig. 2.

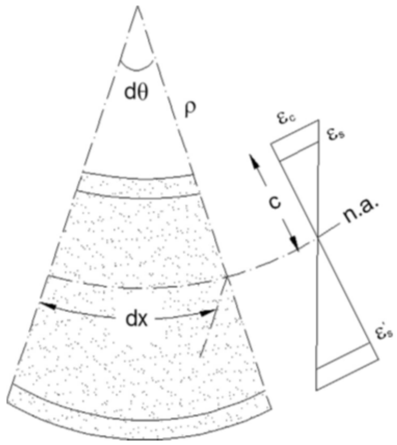

Fig. 1 MC relationship

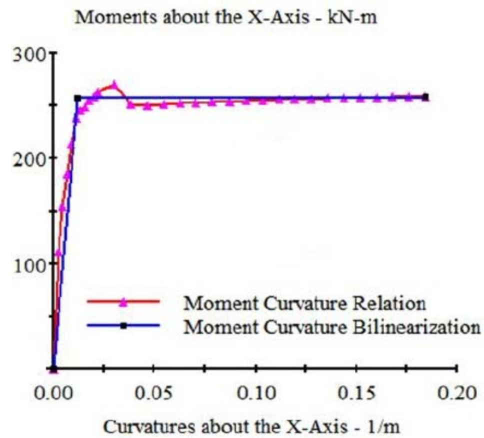

Fig. 2 MC bilinearization

III. Numerical Study

In the study, XTRACT section analysis programme was applied to evaluate the MC relationship of RC rectangular shear walls which have constant dimensions and different longitudinal and transverse reinforcing configurations. For this purpose, 60 rectangular RC shear walls cross sections are analyzed under constant axial load. The cross-sections of rectangular shear walls were composed and designed according to both Turkish Earthquake Code (TEC 2007) and Turkish design and construction code for RC structures [17], [18]. The dimensions of shear walls are chosen as 250 mm width and 1750 mm length and these values are constant in all cross-sectional analysis. The shear walls are designed as two parts which are end zones and web zones. End zones of shear walls are modelled according to the column design rules of TEC 2007. There different longitudinal reinforcement configurations for end zones are used as web reinforcements are chosen constant and ϕ12/250 mm. Five different type transverse configurations (ϕ8/100 mm) are used for both parts of RC shear walls. The cross-sectional details are given in Fig. 3. Concrete material behavior is modelled by employing the Mander approach [19]. Linear elastic-ideal elastoplastic (bilinear) stress-strain relationship is assumed for behavior of longitudinal and transverse reinforcements. Strain-hardening behavior is neglected for reinforcements. Four different compressive strengths (C20, C30, C40, C50) 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 Fig. 4 and Table I, respectively. The reinforcement configurations are given in Table II.

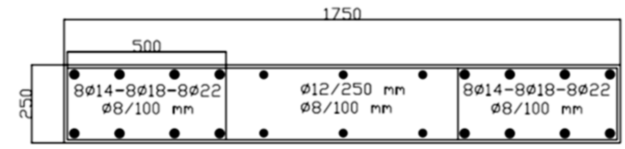

Fig. 3 Cross section of rectangular shear walls

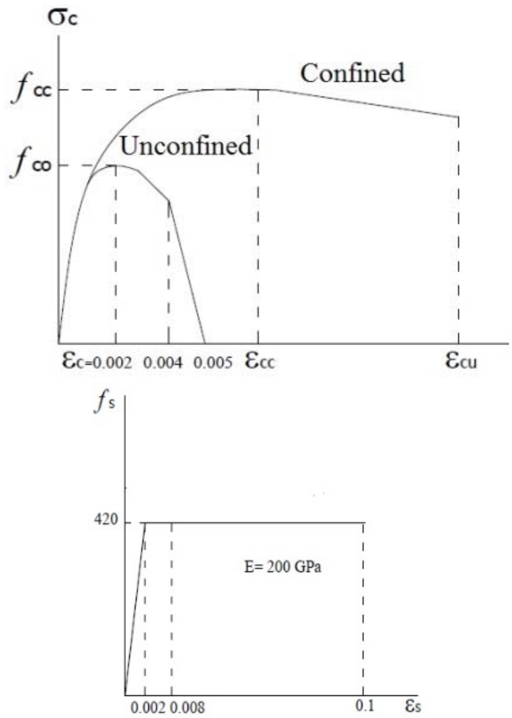

Fig. 4 Stress-strain relationship for materials

TABLE I
Strength of Materials

Concrete	Concrete Strength (MPa)	Longt.&Tran. Rein.	Longt. Rein. Strength (Mpa	Trans.Rein. Strength (MPa)
C20	20	420	420	420
C30	30			
C40	40			
C50	50			

In the study, according to the XTRACT section analysis, MC relationship changed with compressive concrete strength, longitudinal and transverse reinforcing ratio. These analyses are numbered between 1 and 15 for each material class and are given in Table III. In this study, 60 different cross sectional configurations are used to determine MC relationship of rectangular shear walls. Curvature ductility of each rectangular cross section shear wall gets 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 shear wall cross sections. Axial force value of shear walls is evaluated according to the codes which are shown in (3) and (4):

$$Nd_m \leq 0.5 f_{ck} A_c \quad \text{(TEC 2007)} \qquad (3)$$

$$Nd_m \leq 0.6 f_{ck} A_c \quad \text{(TS 500)} \qquad (4)$$

TABLE II
REINFORCEMENT CONFIGURATION OF CROSS SECTIONS

Concrete	Trans. Type	Longt. Rein.	Trans. Rein.	Web Longt. Rein Trans. Rein.
C20 C30 C40 C50	Single Hoop	8ϕ/14	ϕ8/100	ϕ12/250 ϕ8/100
		8ϕ/18		
		8ϕ/22		
	Single 1 Tie	8ϕ/14	ϕ8/100	ϕ12/250 ϕ8/100
		8ϕ/18		
		8ϕ/22		
	Single 2 Ties	8ϕ/14	ϕ8/100	ϕ12/250 ϕ8/100
		8ϕ/18		
		8ϕ/22		
	Double Hoop	8ϕ/14	ϕ8/100	ϕ12/250 ϕ8/100
		8ϕ/18		
		8ϕ/22		
	Triple Hoop	8ϕ/14	ϕ8/100	ϕ12/250 ϕ8/100
		8ϕ/18		
		8ϕ/22		

In all analyses, axial load is assumed to be constant and 1500 kN.

IV. RESULTS AND DISCUSSION

MC relationship of RC rectangular shear walls was determined by using XTRACT and it is defined as a bilinear curve with three parameters showed in Tables I and II. By using curvature parameters, yield curvature (ϕy) and ultimate curvature (ϕu) 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 Fig. 5, for C20, C30, C40, C50.

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

TABLE III
NUMBER OF ANALYSIS#

Concrete	Trans. Type	Longt. Rein.	Analysis #
C20 C30 C40 C50	Single Hoop	8ϕ/14	1
		8ϕ/18	2
		8ϕ/22	3
	Single 1 Tie	8ϕ/14	4
		8ϕ/18	5
		8ϕ/22	6
	Single 2 Ties	8ϕ/14	7
		8ϕ/18	8
		8ϕ/22	9
	Double Hoop	8ϕ/14	10
		8ϕ/18	11
		8ϕ/22	12
	Triple Hoop	8ϕ/14	13
		8ϕ/18	14
		8ϕ/22	15

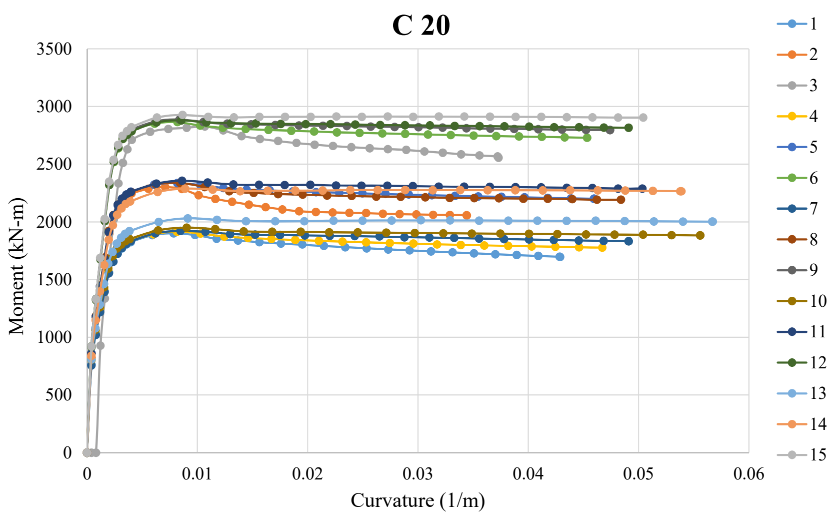

Fig. 5 (a) MC relationship for C20

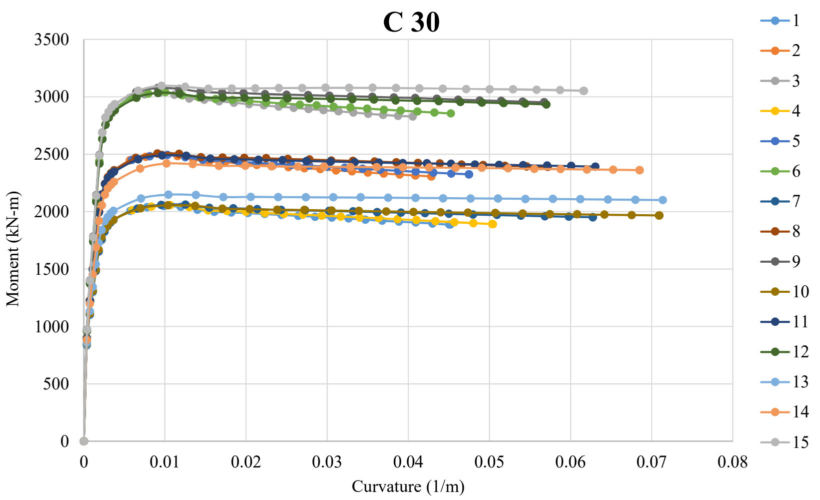

Fig. 5 (b) MC relationship for C30

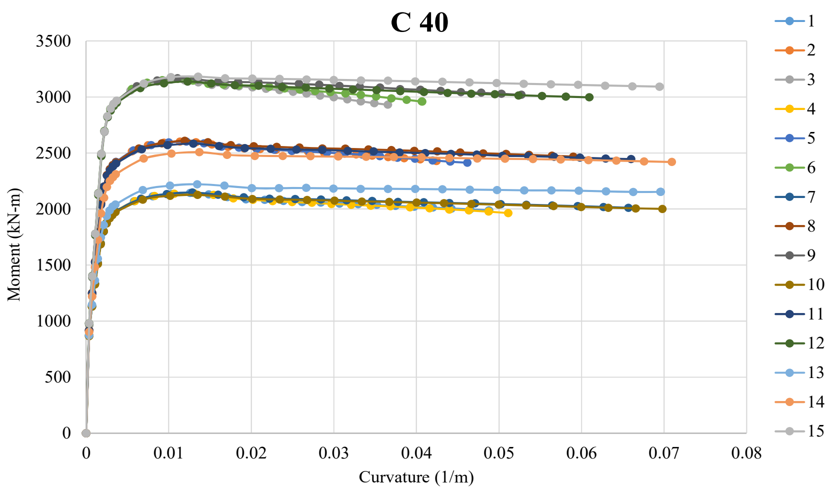

Fig. 5 (c) MC relationship for C40

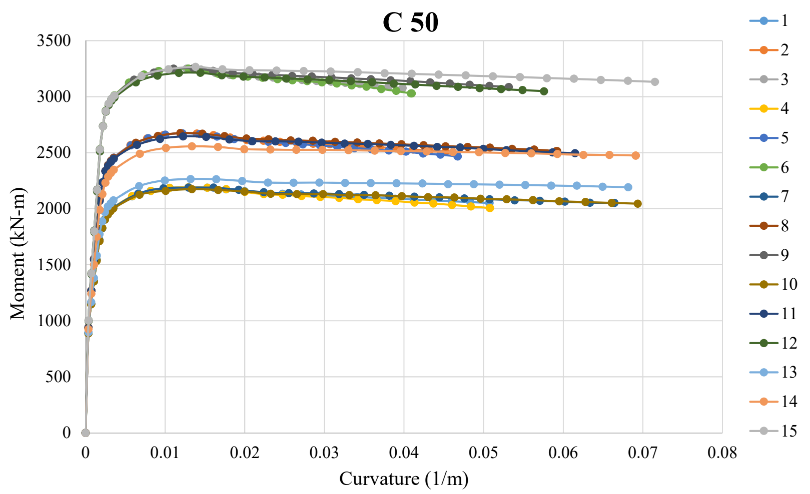

Fig. 5 (d) MC relationship for C50

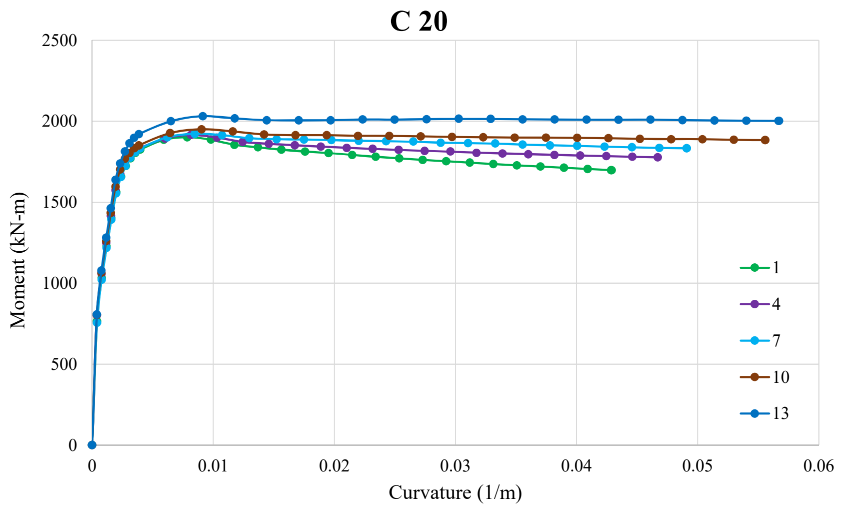

Fig. 6 (a) MC relationship with different transverse reinforcement type

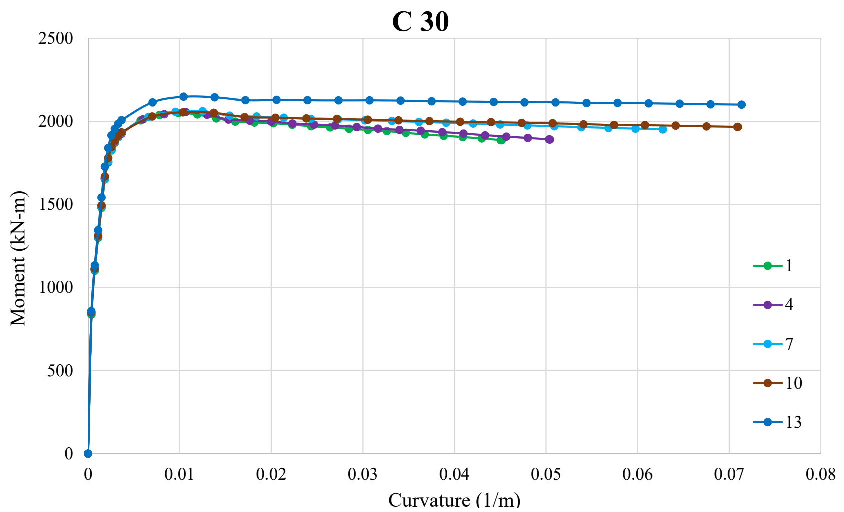

Fig. 6 (b) MC relationship with different transverse reinforcement type

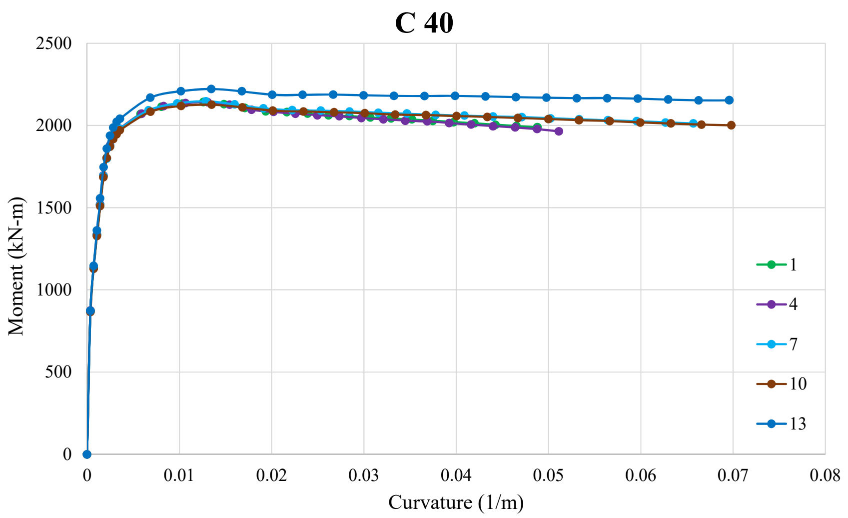

Fig. 6 (c) MC relationship with different transverse reinforcement type

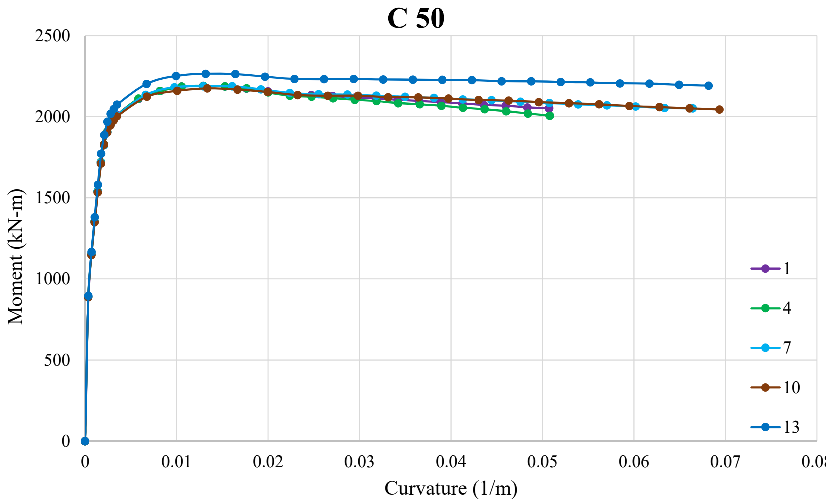

Fig. 6 (d) MC relationship with different transverse reinforcement type

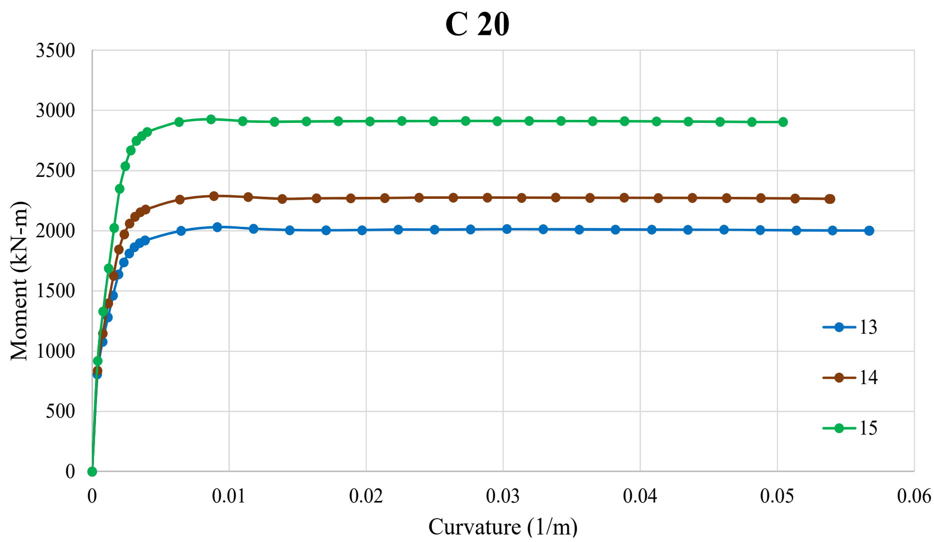

Fig. 7 (a) MC relationship with longitudinal reinforcement type

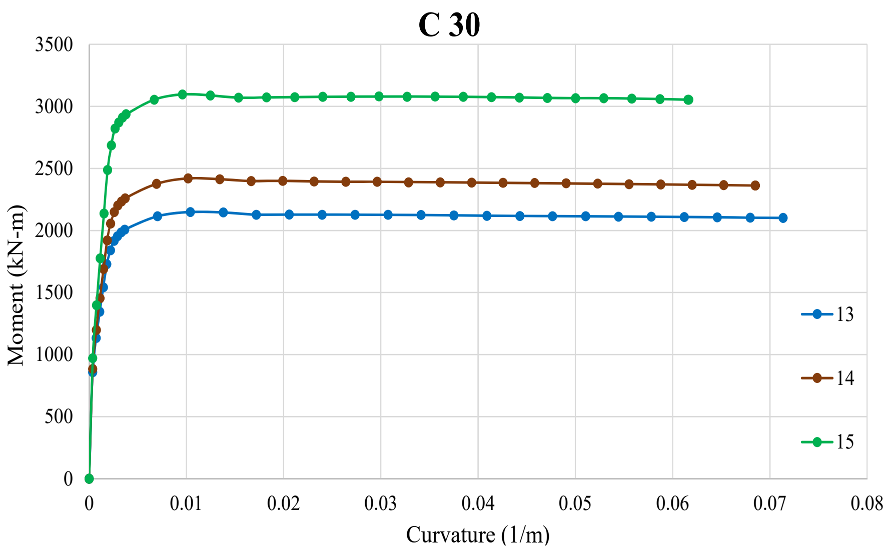

Fig. 7 (b) MC relationship with longitudinal reinforcement type

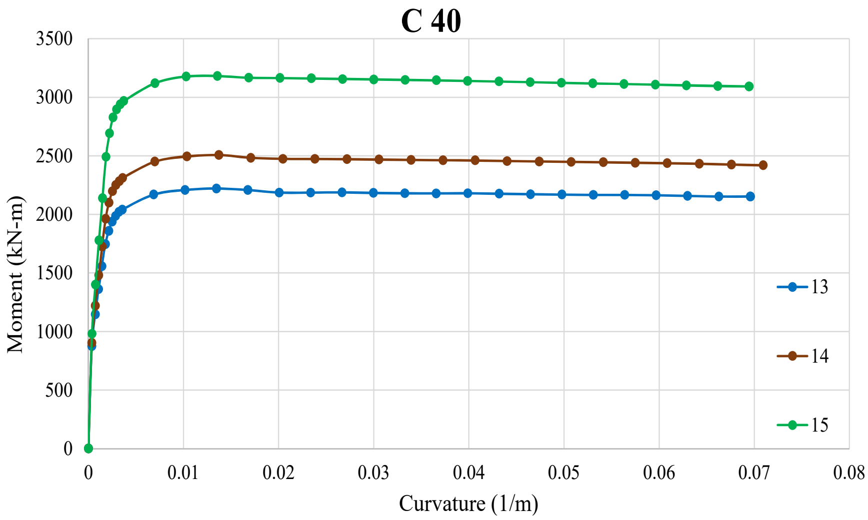

Fig. 7 (c) MC relationship with longitudinal reinforcement type

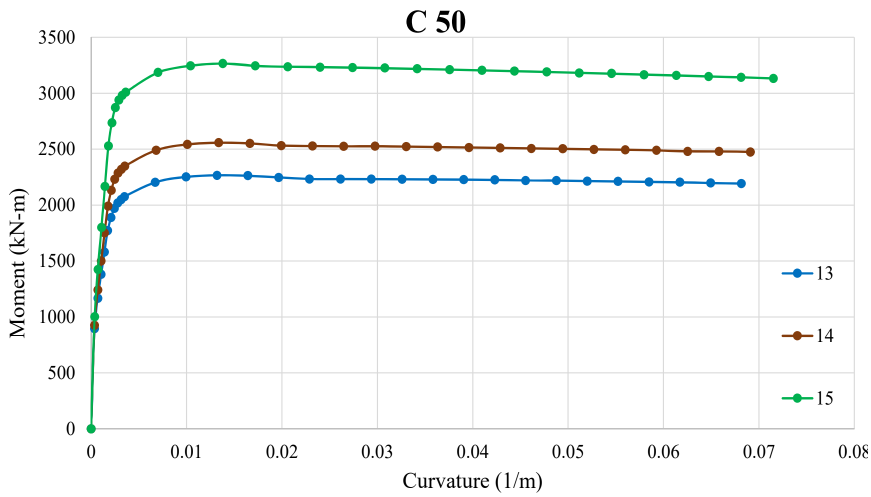

Fig. 7 (d) MC relationship with longitudinal reinforcement type

V. Conclusion

In the study, design parameters of RC members are investigated to determine behavior of RC rectangular shear walls. The cross sections of RC shear walls whose MC relationships are given graphically have constant dimensions. The sections designed according to TEC 2007 and TS 500 were analyzed by XTRACT to generate MC relationship. In the analysis material class, longitudinal and transverse reinforcing ratios are selected as comparison criteria, and the axial force of RC shear walls is assumed to be constant and 1500 kN.

If the analysis results are evaluated, an obvious increase in yielding and ultimate moment capacities of the sections is observed by increasing of compressive strength of concrete. Moreover, with the increase of transverse reinforcing ratio, the more ductile behavior is achieved due to increment of curvature ductility on RC rectangular shear walls. Additionally, the analysis results are deduced that yielding and ultimate moment capacities of the members increase with the increment of longitudinal reinforcing ratio for each type of concrete material. However, the curvature ductility of the members having low compressive strength decreases as longitudinal reinforcing ratio increases. But, reduction in ductility ratio of these members is not observed for the sections having high compressive strength. More ductile behavior is obtained for the members having high compressive strength in comparison with the members having low compressive strength.

References

[1] Caglar, N. and Garip, Z.S. (2013), "Neural network based model for seismic assessment of existing RC buildings", Comput. Concr., 12, 229-242.

[2] Caglar, N. (2009), "Neural network based approach for determining the shear strength of circular reinforced concrete columns", Constr. Build. Mater., 23, 3225-3232.

[3] Gunaratnam, D.J. and Gero, J.S. (2008), "Effect of representation on the performance of neural networks in structural engineering applications", Comput. Aided Civil Infrastruct. Eng., 9(2), 97–108.

[4] Pala, M., Caglar, N., Elmas, M., Cevik, A. and Saribiyik, M. (2008), "Dynamic soil-structure interaction analysis of buildings with neural networks", Constr. Build. Mater., 22(3), 330-342.

[5] Pala, M. (2006). "New formulation for distortional buckling stress". J.

Constr. Steel Res., 62, 716–722.
[6] Adeli, H. and Samant, A. (2000), "An adaptive conjugate gradient neural network–wavelet model for traffic incident detection", Comput. Aided Civil Infrastruct. Eng., 15 (4), 251–260.
[7] Bishop, C.M. (1995), Neural Networks for Pattern Recognition, Oxford University Press, Oxford, England.
[8] Kulkarni, A.D. (1994), "Artificial Neural Networks for Image Understanding", Van Nosrand Reinhold, NY, USA
[9] Caglar N., Demir A., Ozturk H., Akkaya A.(2015), "A simple formulation for effective flexural stiffness of circular reinforced concrete columns", Engineering Applications of Artificial Intelligence, 2015, 38(2015)79–87.
[10] Jadid, M.N. and Fairbairn D.R. (1996), "Neural-network applications in predicting moment-curvature parameters from experimental data", Eng. Appl. Artif. Intell., 9 (3), 309-319.
[11] Arslan, M.H. (2012), "Estimation of curvature and displacement ductility in reinforced concrete buildings", KSCE J. Civil Eng., 16 (5), 759-770.
[12] Petschke, T., Corres, H.A., Ezeberry, J.I., Pérez, A. and Recupero, A. (2013), "Expanding the classic moment-curvature relation by a new perspective onto its axial strain", Comput. Concr., An Int. J., 11 (6), 515-529.
[13] Dogangun, A. (2013), Design and Calculation of Reinforced Concrete Structures, Birsen Press, Istanbul, Turkey, ISBN: 978-975-511-310-X.
[14] Ersoy, U. and Ozcebe, G. (1998), "Moment-curvature relationship of confined concrete sections", IMO Technical Journal, December, Digest 98, 549-553.
[15] Ersoy, U., Ozcebe, G. and Tankut, T. (2008), Reinforced Concrete, Department of Civil Engineering, METU Press, Ankara, Turkey.
[16] XTRACT and User Manual, "Cross-sectional X structural analysis of components, Imbsen Software Systems, 9912 Business Park Drive", Suite 130 Sacramento, CA 95827.
[17] TEC (2007), Turkish Earthquake Code, Ankara, Turkey.
[18] TS 500 (2002), Requirements for Design and Construction of Reinforced Concrete Structures, Ankara, Turkey.
[19] Mander, J.B., Priestley, M.J.N. and Park, R. (1988), "Theoretical stress-strain model for confined concrete". J. Struct. Eng., 114(8), 1804-1826.