Computers and Concrete, *Vol. 14, No. 3 (2014) 279-297*
DOI: http://dx.doi.org/10.12989/cac.2014.14.3.279

Effects of confinement reinforcement and concrete strength on nonlinear behaviour of RC buildings

Burak Yön* and Yusuf Calayır

Civil Engineering Department, Fırat University, Elazığ, Turkey

(*Received April 2, 2014, Revised July 6, 2014, Accepted July 13, 2014*)

Abstract. This paper investigates the effects of confinement reinforcement and concrete strength on nonlinear behaviour of reinforced concrete buildings (RC). For numerical application, an eleven-storey and four bays reinforced concrete frame building is selected. Nonlinear incremental static (pushover) analyses of the building are performed according to various concrete strengths and whether appropriate confinement reinforcement, which defined in Turkish seismic code, exists or not at structural elements. In nonlinear analysis, distributed plastic hinge model is used. As a result of analyses, capacity curves of the frame building and moment-rotation curves at lower end sections of ground floor columns are determined. These results are compared with each other according to concrete strength and whether appropriate confinement reinforcement exists or not, respectively. According to results, it is seen that confinement reinforcement is important factor for increasing of building capacity and decreasing of rotations at structural elements.

Keywords: confinement reinforcement; concrete strength; distributed plastic hinge; nonlinear pushover analysis

1. Introduction

Earthquake is one of the most devastating natural hazards and caused collapses during history. Thousands of people dead and innumerable reinforced concrete buildings were collapsed and damaged seriously during the recent earthquakes such as 1999 Chi-Chi earthquake in Taiwan; 1999 Kocaeli 2003 Bingöl earthquakes in Turkey, 2008 Wenchuan earthquake in China and 2011 Van earthquakes in Turkey. Structural deficiencies, selection of improper structural system, poor workmanship and insufficient quality of materials can be considered as the most important reasons for severe damages. Also, another important reason of the damage is inappropriate confinement reinforcement (stirrups) at structural elements. During an earthquake shear forces increase especially at the ends of columns and beams, and beam-column joints. Confinement reinforcement prevents damages and collapses because it increases shear strength and axial load carrying capacity of structural elements. However, researchers indicated that inappropriate confinement reinforcement is one of the main reasons of damages during earthquakes (Adalıer and

∗Corresponding author, Ph.D.,E-mail: burakyon@gmail.com
[a]Yusuf Calayır, Professor, E-mail: ycalayir@firat.edu.tr

http://www.techno-press.org/?journal=cac&subpage=8 ISSN: 1598-8198 (Print), 1598-818X (Online)

(a)

(b)

(c)

(d)

(e)

Fig. 1 Damage at structural elements having insufficient stirrups and low concrete quality during Van earthquakes in 2011

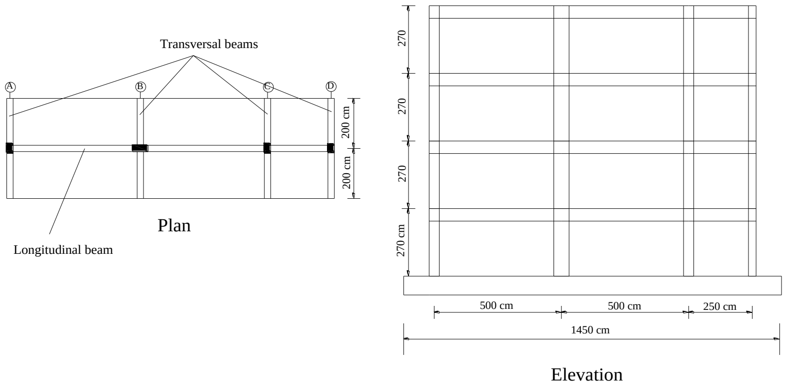


Fig. 2 Plan and evaluation of experimental setup building

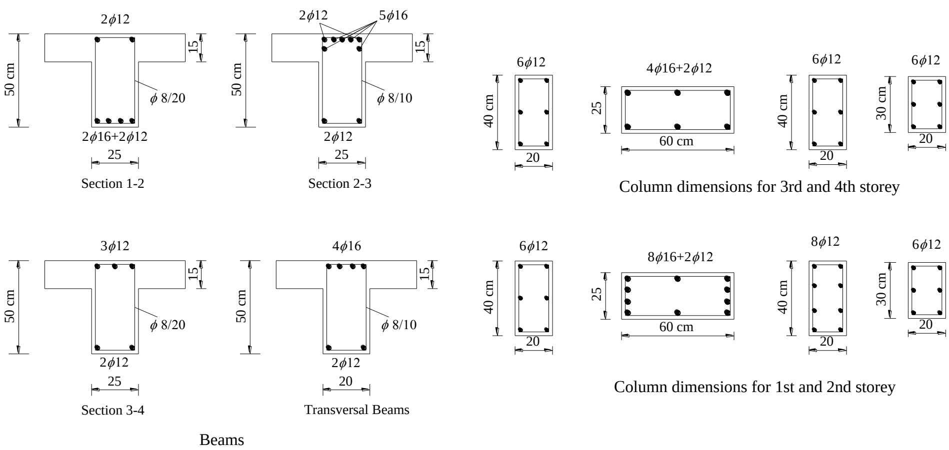


Fig. 3 Cross sections of structural elements of experimental setup building

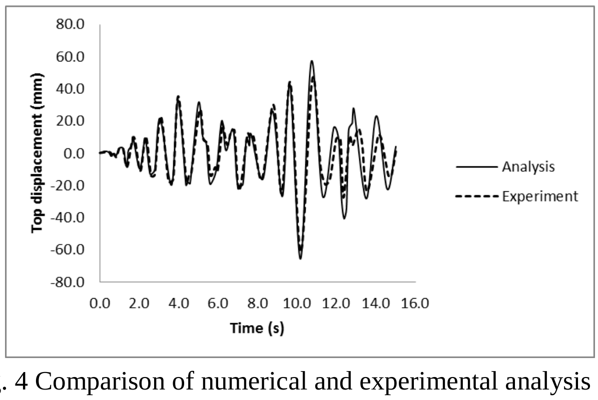


Fig. 4 Comparison of numerical and experimental analysis results

Aydıngün(2001), Sezen *et al*. (2003), Doğangün (2004), Ricci (2011), Calayır *et al*. (2012), Bayraktar *et al*. (2013), Ateş *et al*. (2013) and Yön *et al*. (2013). In addition to confinement reinforcement effect, concrete compressive strength is very important factor for seismic performance of a building. In Turkey, handmade concrete was generally used for construction of old buildings. Also, due to lack of using vibrator during concrete casting, homogeneous mixing had not been obtained. The current Turkish Seismic Code (TSC) requires that minimum characteristic compressive strength of concrete should not be less than 20 MPa for buildings. Fig. 1 shows damages at structural elements arose from using of insufficient stirrups and low concrete quality during Van earthquakes in 2011.

In this paper, the effects of confinement reinforcement and concrete strength on nonlinear behavior of reinforced concrete buildings are investigated. Nonlinear incremental static (pushover) analyses of a reinforced concrete frame building are performed according to concrete strength and whether appropriate confinement reinforcement exists or not.

Static pushover analysis which shows nonlinear static behavior of buildings subjected to lateral loads has been used in structural engineering due to its simplicity. This method is a practical procedure for estimating the structural capacity of buildings in the post-elastic range. Capacity curve of a building shows the relationship between the base shear force and the roof displacement. To obtain the capacity curves, lateral forces are increased monotonically until a certain level of deformation at the top of building is reached. (İnel and Özmen (2006), İnel *et al*. (2008), Chan and Zou (2004), Eslami and Ronagh (2012)).

In this study, distributed plastic hinge model is used for nonlinear modelling of structural elements. Taucer *et al*. (1991), Petrangeli (1999), Jeong and Elnashai (2005) validated the accuracy of this model by comparing with experimental test data. However, to validate this hinge approach and results, experimental analysis result of full scale, four stories, three bays, 2D reinforced concrete frame which designed according to gravity loads and a nominal lateral load of 8% of its weight was compared with numerical analysis result which obtained by using distributed hinge approach of the building. Loading, geometric characteristics and material properties of the experimental study are given by Pinho and Elnashai (2000), Varum (2003). Plan and elevation of the building together with cross sections of the structural elements are presented in Fig.2 and Fig.3, respectively.

The numerical analysis result was compared with the experimental result for top displacement of the building. This comparison is presented in Fig.4. It is seen from this figure, numerical analysis result of the building which is obtained by using distributed plastic hinge approach is similar to experimental result.

This hinge model has been used by many researchers. Mwafy and Elnashai (2001) made comparison of static pushover and dynamic collapse analysis in reinforced concrete buildings. They used distributed plastic hinge model in their study. Dides and Llera (2005) compared plasticity models which include fiber hinge model in dynamic analysis of buildings. Mwafy (2011) assessed seismic design response factors of concrete wall buildings. For this study, five reference structures with 20 to 60 stories were selected. Analyses of these structures were performed according to distributed plastic hinge modeling. Kenneth and Kalkan (2004) assessed the seismic deformation demands of multistory steel and concrete moment frames using non-linear procedures based on distributed plastic hinge assumption. Duan and Hueste (2012) investigated the earthquake behavior of a five story reinforced concrete building. The selected frame building had been designed according to the requirements of the Chinese seismic code. Kwon and Kim (2010) studied a reinforced concrete building which is damaged during the 2007 Pisco-Chincha earthquake. They performed nonlinear analysis of this building by considering distributed plastic hinge model. Hankok and Bommer (2007) investigated inelastic structural response using spectral matched records. Kadid *et al*. (2010) assessed behavior of reinforced concrete buildings under simultaneous ground motions considering distributed plastic hinge model. Thomos and Trezos (2006) generated a methodology to obtain pushover curves of reinforced concrete frames, taking into account the randomness of the basic variables. Sarno and Manfredi (2010) performed pushover and dynamic response history analyses for both constructed and retrofitted structures to investigate the efficiency of buckling restrained braces. Yön and Calayır (2013) performed pushover analysis of a reinforced concrete building using lumped and distributed plastic hinge models together with various lateral load patterns. Carvalho *et al*. (2013) made a comparison of various hinge model approaches by performing nonlinear static and dynamic analysis of a reinforced concrete building.

2. Distributed plastic hinge model

The distributed plastic hinge model accounts distributed plasticity along structural element. In this model, the structural element is divided in three types of fibers: some fibers are used for modeling of longitudinal steel reinforcing bars; some of fibers are used to define nonlinear behavior of confined concrete which consists of core concrete; and other fibers are defined for unconfined concrete which includes cover concrete. For each fiber, the stress/strain field is determined by using $\sigma - \varepsilon$ constitutive laws according to defined materials. Figs. 5 and 6 show distributed hinge modeling of a RC beam and typical distributed hinge model section of a RC element, respectively.

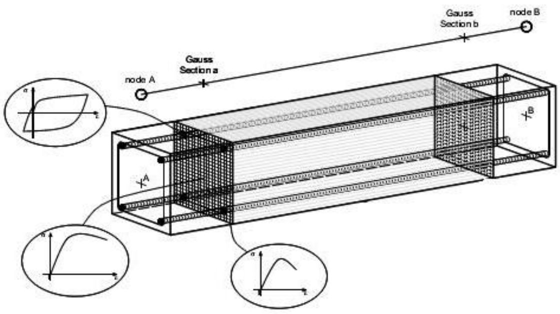


Fig. 5 Distributed hinge modeling of a reinforced concrete beam (adopted from SeismoStruct V6)

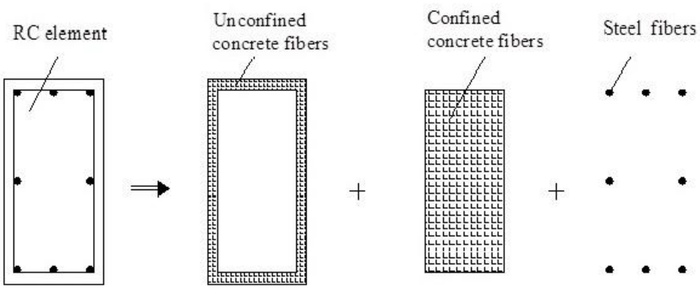


Fig. 6 Typical distributed hinge model of a RC element section

3. Numerical application

In this study, the effects of confinement reinforcement and concrete strength on nonlinear behaviour of reinforced concrete buildings are investigated. Nonlinear incremental static (pushover) analyses of a selected building are performed according to concrete strength and whether appropriate confinement reinforcement, exists or not in structural elements. An eleven-storey and four bays RC frame building is selected for numerical application. The total building height is 34.0 m and height of the1st storey is 4.0 m while the upper ones are 3.0 m. The first and last bays are 6.0 m and the second and third bays are 5.0 m. Also, it is assumed that, the selected building is located in high seismic intensity region (seismic zone 1 according to TSC) and has building importance coefficient of 1.0. In the seismic zone map of Turkey, the first seismic zone has 0.4g peak ground acceleration. To calculate the element forces and the stress–strain relationship for monitoring each section four Gauss integration points are selected. The elevation view of the building and typical element details are shown in Fig. 7.

Structural elements of the building are designed with appropriate and inappropriate confinement reinforcement according to TSC. Static pushover analyses of the building are performed by considering various concrete compressive strengths, which are C20, C25, C30 and C35. Distributed hinge model is used for nonlinear modelling of the structural elements. Capacity curves of the building and moment-rotation curves at lower end of ground floor columns are evaluated according to appropriate and inappropriate confinement reinforcement states and concrete strengths. SeismoStruct program, which can simulate the inelastic response of structural systems subjected to static and dynamic loads, are used for nonlinear analysis.

The current seismic codes include some requirements related to transverse reinforcement to provide confinement effect. According to TSC, these requirements for column and beam elements are given in Figs. 8 and 9, respectively (Dogangün 2013). In Fig. 8, h and b show large and small dimensions of column section, respectively. l_n is clear height of column, l_c confinement zone length, s_c spacing of transverse reinforcements in confinement zone of column and s_o spacing of transverse reinforcements in central zone of column.

In Fig. 9, $h_k$and$d$ indicate height and effective height of beam section, respectively.l_k is confinement zone length, $\emptyset_{min}$minimum longitudinal rebar diameter, $\emptyset_{max}$maximum longitudinal rebar diameters_k spacing of transverse reinforcements in confinement zone of beam, ands_o spacing of transverse reinforcements in central zone of beam. Also V_d shows design shear force and V_{cr} defines shear cracking resistance. Confinement parameters of the selected building are illustrated in Table 1. In this table S420 shows steel class where steel yield strength is 420 MPa.

Material models for steel and concrete are shown in Fig. 10. The bilinear elastic–plastic material model with kinematic strain-hardening is used for the steel. The concrete material is defined by the uniaxial confinement concrete model.

The confinement effect is taken into consideration using the Mander concrete model (Mander *et al*. 1988). Confinement factor which obtained by depending on concrete strength and whether appropriate confinement reinforcement exists or not are given in Table 2 for the structural elements. This factor which depends on the transverse and longitudinal reinforcement, concrete strength, and member dimensions shows the ratio of the confined concrete compressive strength to the unconfined concrete compressive strength.

Capacity curves of the building which are obtained according to appropriate and inappropriate confinement reinforcement with respect to TSC at structural elements for different concrete

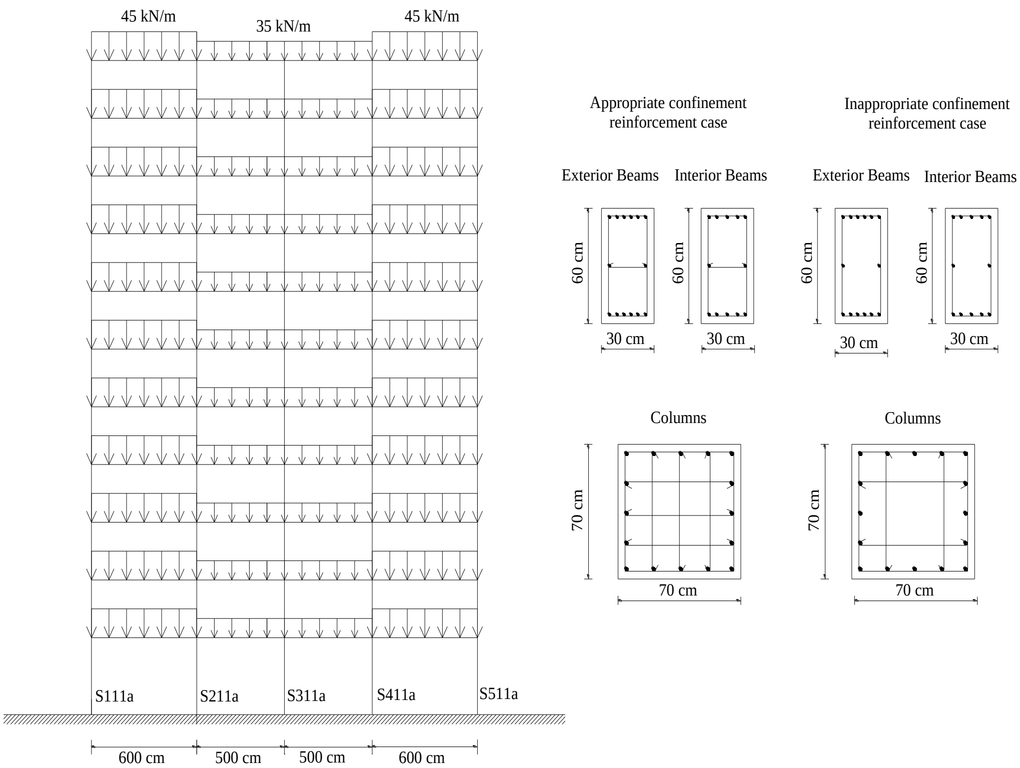


Fig. 7 The elevation view of the building and typical element details

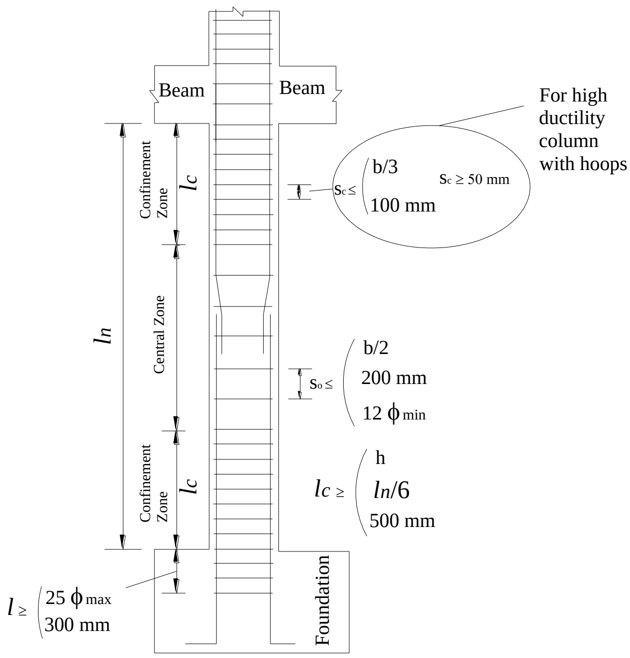


Fig. 8 Transverse reinforcement requirements for columns of high ductility level according to TSC

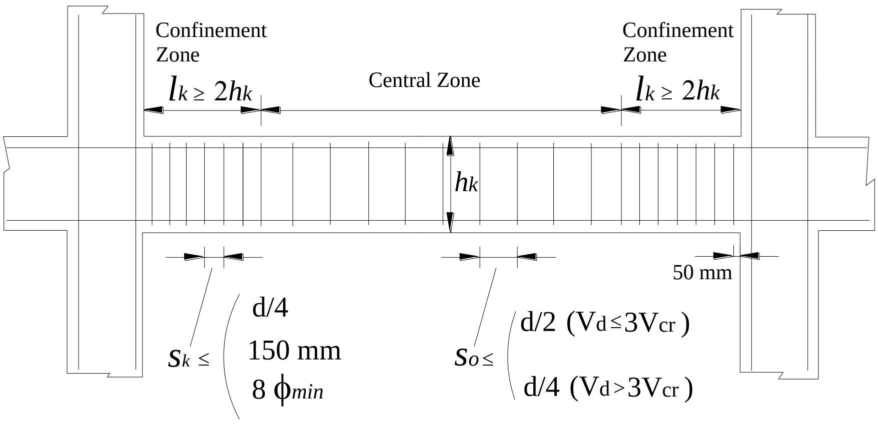
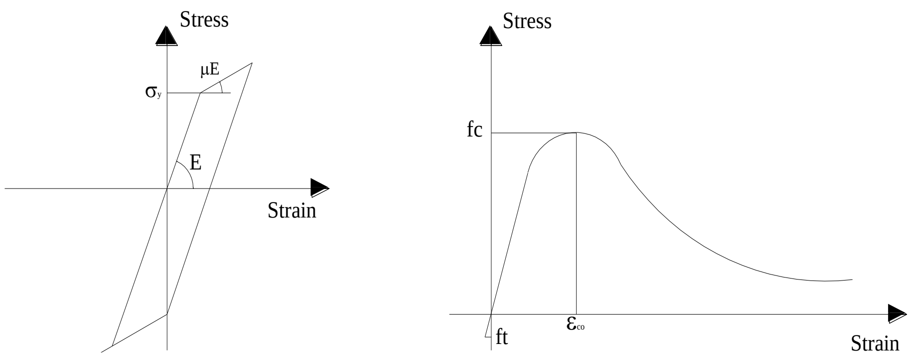


Fig. 9 Transverse reinforcement requirements for beams of high ductility level

Table 1 Confinement parameters of the selected building

	Transverse reinforcement spacing (cm) (appropriate to TSC)	Transverse reinforcement spacing (cm) (inappropriate to TSC)	Length of confinement zone (cm)
Confinement zone of column	10	20	70
Central zone of column	15	20	
Longitudinal reinforcement of column		16Ø 20	
Confinement zone of beam	10	25	120
Central zone of beam	20	25	
Longitudinal reinforcement of beam (exterior/interior)		6Ø 14/5Ø 14	
Web reinforcement		2×2Ø 12	
Diameter of Transverse reinforcement/reinforcement		Ø 8/S420	



a) Steel b) Concrete

Fig. 10 Material models for steel and concrete

Table 2 Confinement factors for the structural elements

Concrete Type	Column dimension (cm) 70/70				Beam dimension (cm) 30/60			
	Confinement zone of column		Central zone of column		Confinement zone of beam		Central zone of beam	
	Confinement compatible with TSC	Confinement incompatible with TSC	Confinement compatible with TSC	Confinement incompatible with TSC	Confinement compatible with TSC	Confinement incompatible with TSC	Confinement compatible with TSC	Confinement incompatible with TSC
C20	1.3657	1.0531	1.2387	1.0531	1.1769	1.0279	1.0592	1.0279
C25	1.2925	1.0387	1.1872	1.0387	1.1400	1.0216	1.0452	1.0216
C30	1.2593	1.0301	1.1604	1.0301	1.1187	1.0176	1.0367	1.0176
C35	1.2204	1.0245	1.1452	1.0245	1.1045	1.0149	1.0309	1.0149

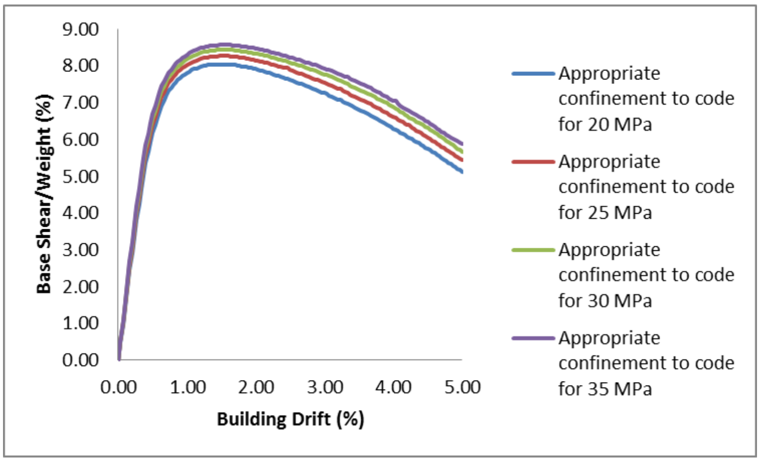


Fig. 11 Capacity curves of the building, in which structural elements have appropriate confinement reinforcement, for different concrete compressive strengths

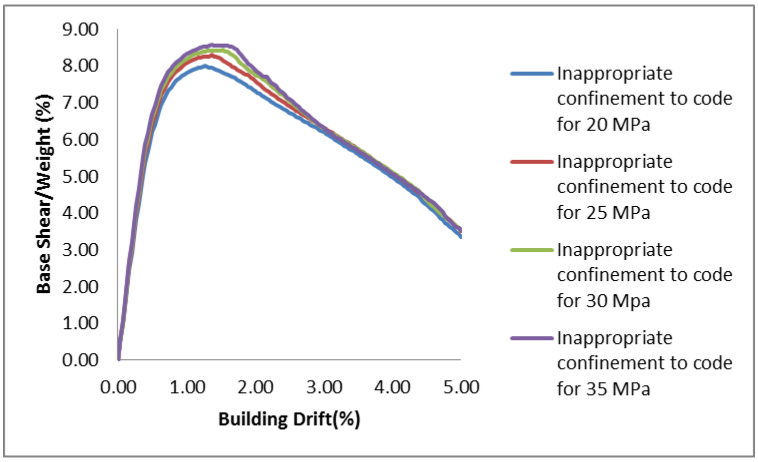


Fig. 12 Capacity curves of the building, in which structural elements have inappropriate confinement reinforcement, for different concrete compressive strengths

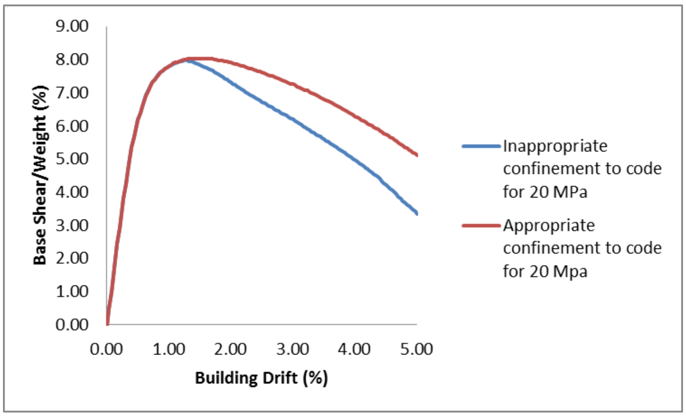


Fig. 13 Comparison of capacity curves of the building which has appropriate and in appropriate confinement reinforcement for concrete compressive strength of 20 MPa

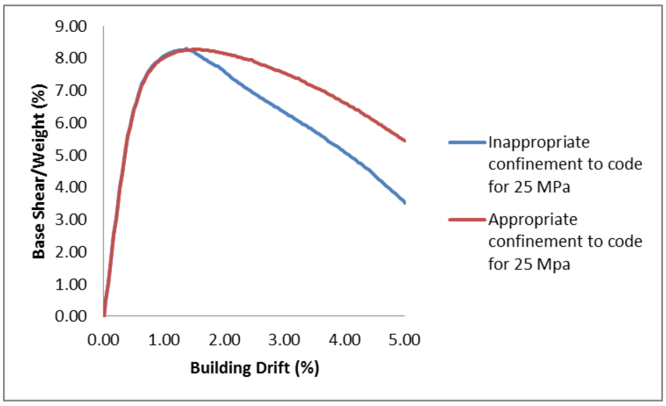


Fig. 14 Comparison of capacity curves of the building which has appropriate and inappropriateconfinement reinforcement for concrete compressive strength of 25 MPa

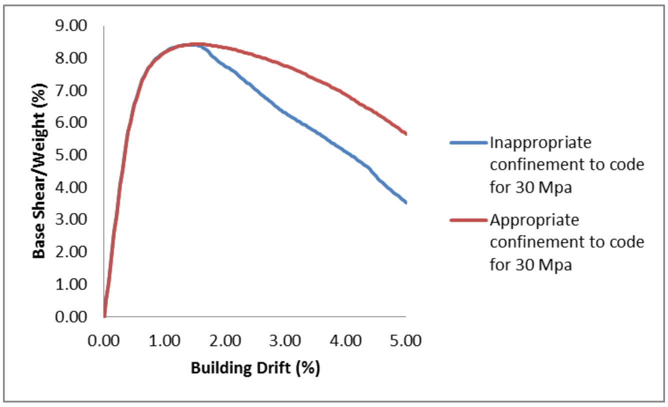


Fig. 15 Comparison of capacity curves of the building which has appropriate and inappropriate confinement reinforcement for concrete compressive strength of 30 MPa

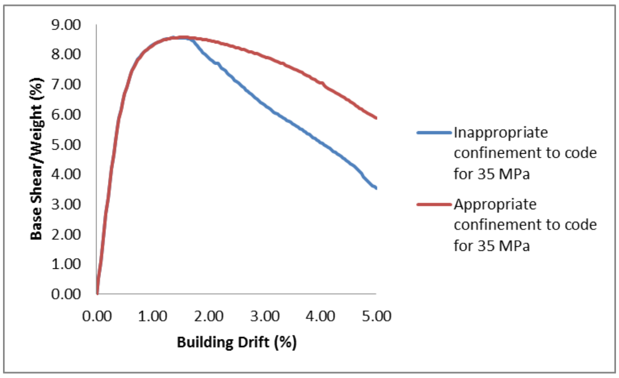
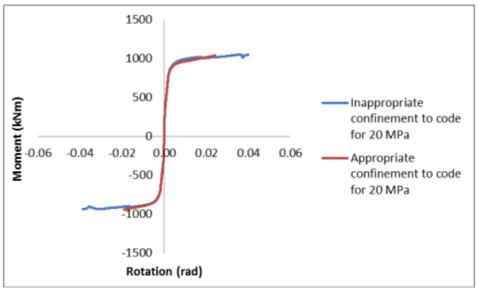
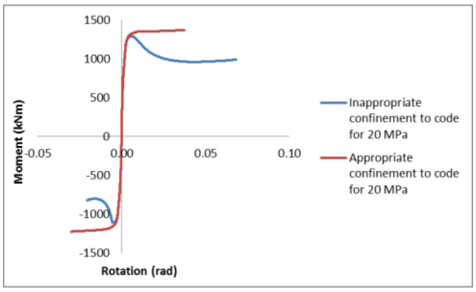


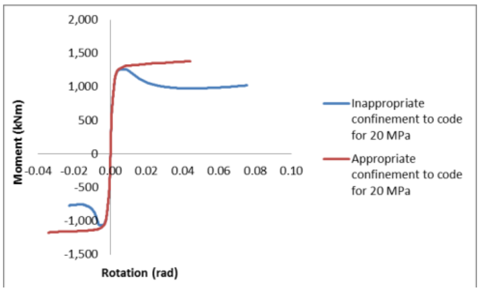
Fig. 16 Comparison of capacity curves of the building which has appropriate and inappropriate confinement reinforcement for concrete compressive strength of 35 MPa



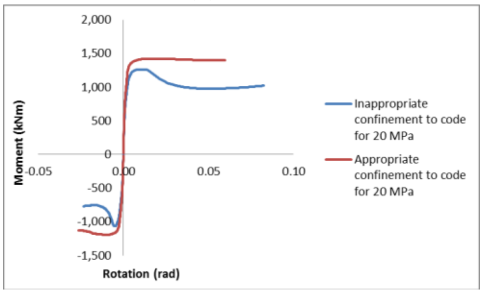
(a) S111a



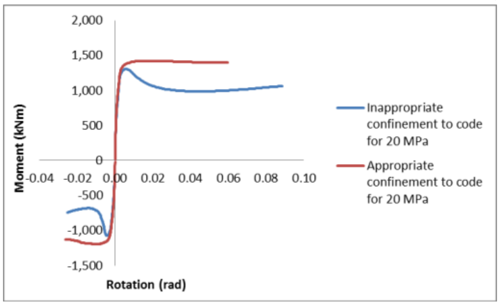
(b) S211a



(c) S311a

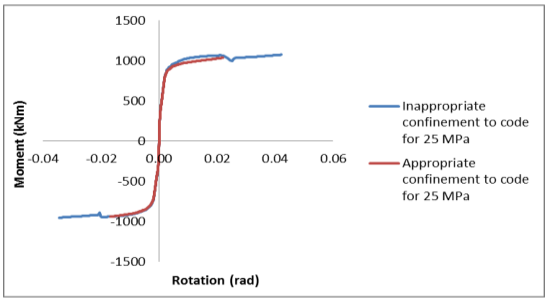


(d) S411a

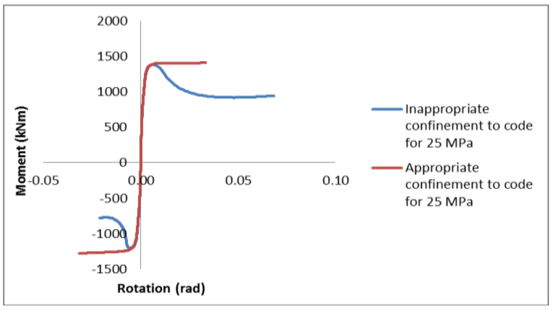


(e) S511a

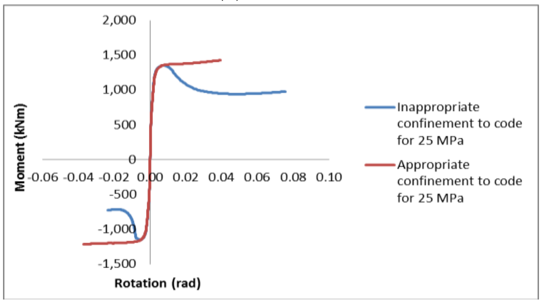
Fig. 17 Moment-rotation curves of lower end of ground floor columns named as S111a, S211a, S311a, S411a and S511a for concrete compressive strength of 20 MPa



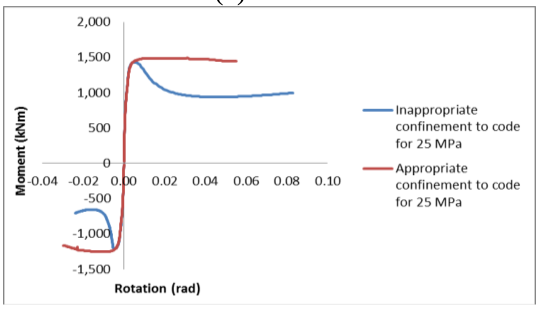
(a) S111a



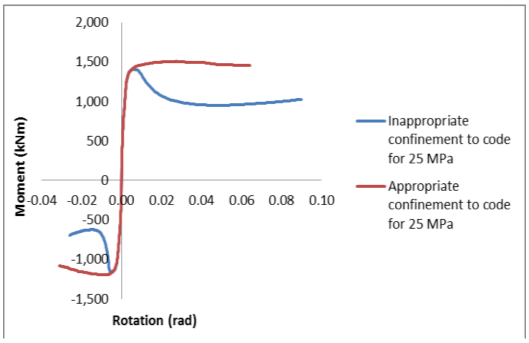
(b) S211a



(c) S311a

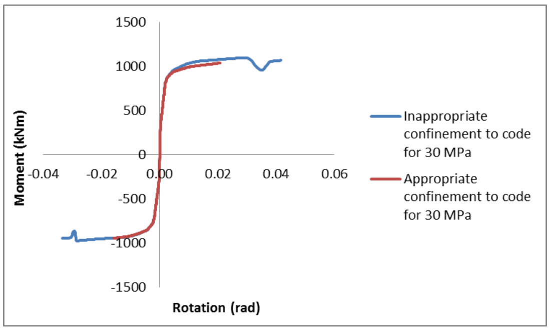


(d) S411a

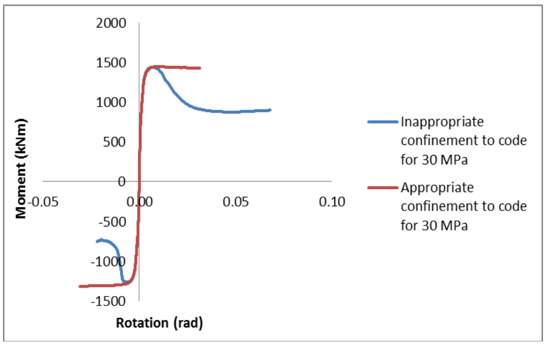


(e) S511a

Fig. 18 Moment-rotation curves of lower end of ground floor columns named as S111a, S211a, S311a, S411a and S511a for concrete compressive strength of 25 MPa

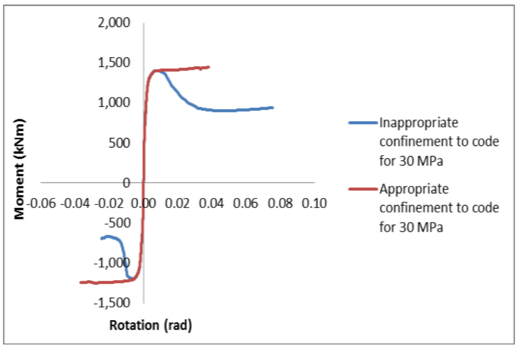


(a) S111a

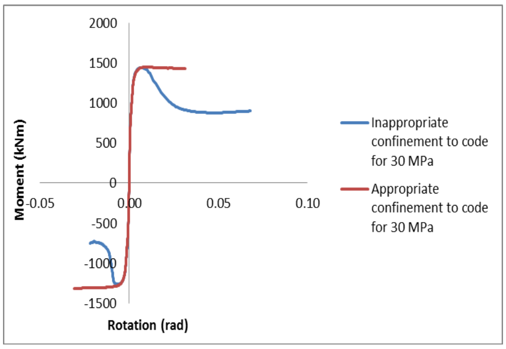


(b) S211a

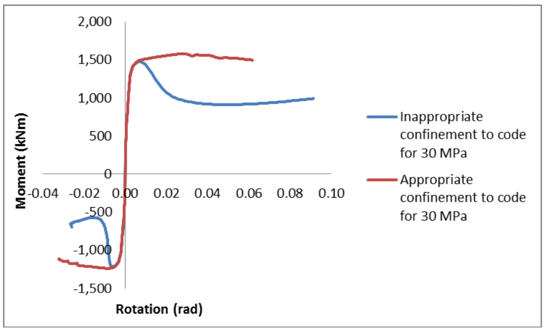
Fig. 19 Continued



(c) S311a

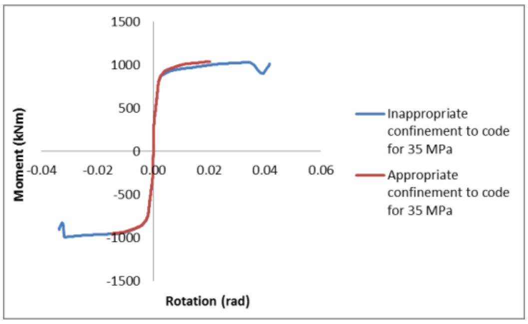


(d) S411a

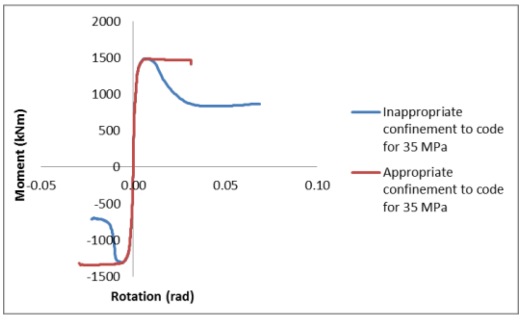


(e) S511a

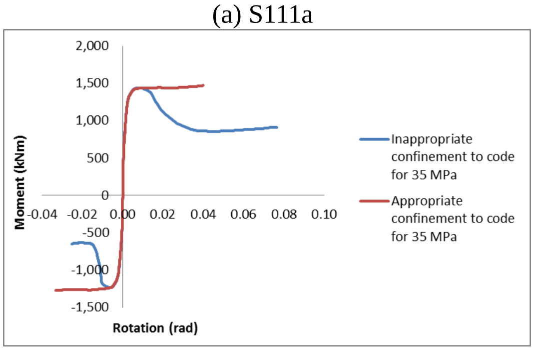
Fig. 19 Moment-rotation curves of lower end of ground floor columns named as S111a, S211a, S311a, S411a and S511a for concrete compressive strength of 30 MPa



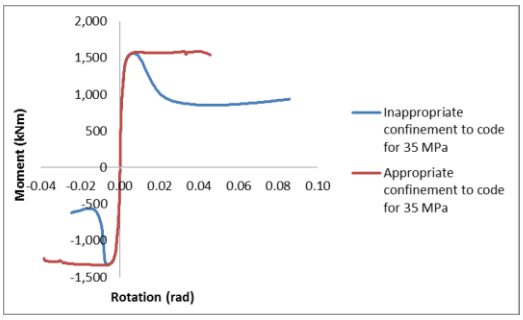
(a) S111a



(b) S211a

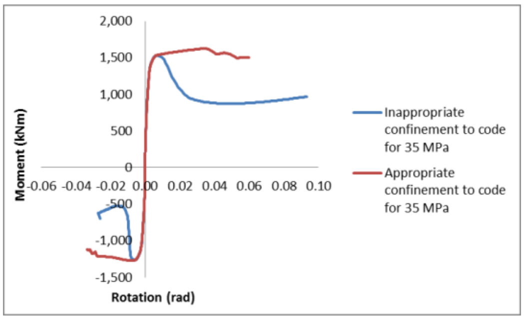


(c) S311a



(d) S411a

Fig. 20 Continued



(e) S511a

Fig. 20 Moment-rotation curves of lower end of ground floor columns named as S111a, S211a, S311a, S411a and S511a for concrete compressive strength of 35 MPa

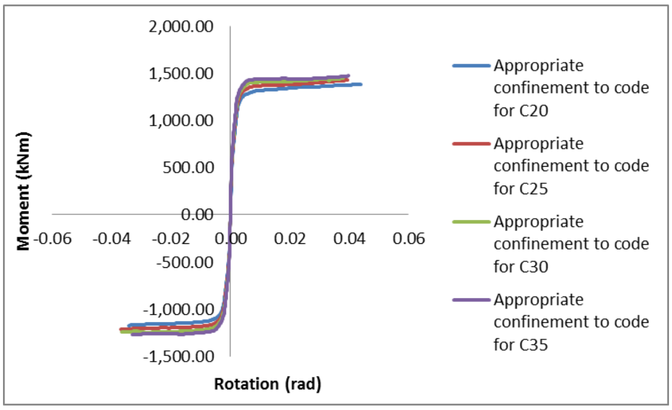


Fig. 21 Variation of moment-rotation curves with concrete compressive strength for the lower end of column S311a of the building in which structural elements have appropriate confinement reinforcement

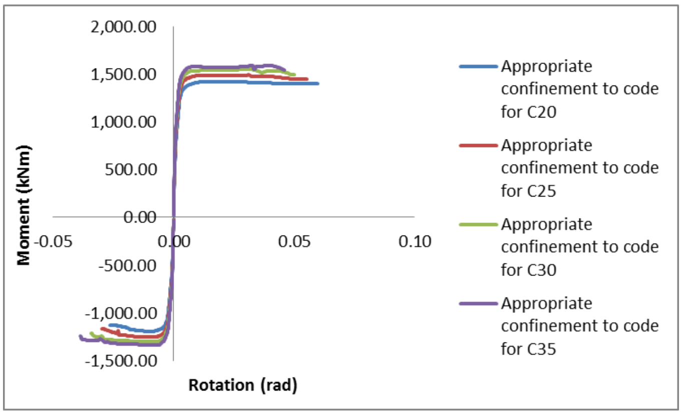


Fig. 22 Variation of moment-rotation curves with concrete compressive strength for the lower end of column S411a of the building in which structural elements have appropriate confinement reinforcement

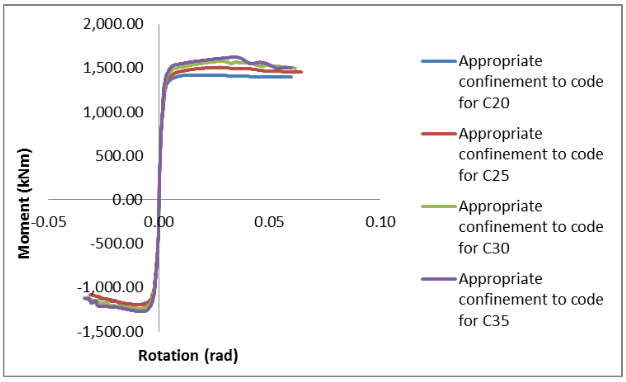


Fig. 23 Variation of moment-rotation curves with concrete compressive strength for the lower end of column S511a of the building in which structural elements have appropriate confinement reinforcement

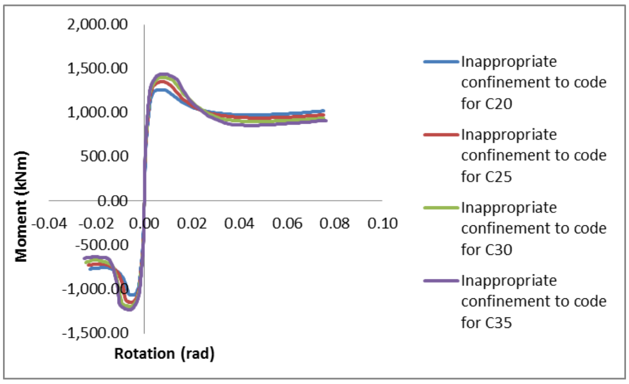


Fig. 24 Variation of moment-rotation curves with concrete compressive strength for the lower end of column S311a of the building in which structural elements have inappropriate confinement reinforcement

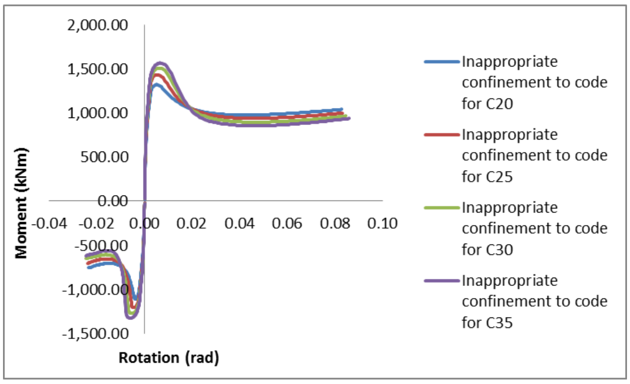


Fig. 25 Variation of moment-rotation curves with concrete compressive strength for the lower end of column S411a of the building in which structural elements have inappropriate confinement reinforcement

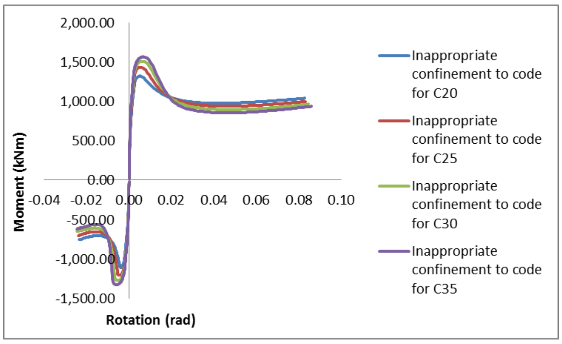


Fig. 26 Variation of moment-rotation curves with concrete compressive strength for the lower end of column S511a of the building in which structural elements have inappropriate confinement reinforcement

compressive strengths are shown in Figs.11-12, respectively. For these curves, the base shear is normalized with respect to the total seismic weight of the frame. The building drift BD is defined as the roof displacement $\Delta_R$normalized with respect to the total height of the frame H ($BD = \Delta_R/H$).

It is seen that from Figs.11 and 12, increasing of concrete compressive strength increases the building capacity. Increasing of the building capacity depending on concrete compressive strength for appropriate confinement reinforcement case is clearer than that of inappropriate confinement reinforcement case. However, in case of inappropriate confinement reinforcement, capacity curves of the building for all concrete class suddenly decrease after the base shear reaches to maximum value. Figs.13,14,15 and 16 show comparison of capacity curves of the building which has appropriate and inappropriate confinement reinforcement for concrete compressive strengths of 20, 25, 30, 35 MPa, respectively. It is seen from these figures that capacity curves are similar up to approximately 1.5% roof displacement for all concrete strengths. However, after this displacement level, capacity curves of the building are suddenly decreased, due to the building which has inappropriate confinement reinforcement shows non-ductile behavior.

Moment-rotation curves of lower end of ground floor columns which is named as S111a, S211a, S311a, S411a and S511a (see Fig. 7)for the selected building are shown in Figs. 17-20 at the same roof displacement case. These curves are drawn according to appropriate and inappropriate confinement reinforcement cases for different concrete compressive strengths.

As seen from Figs. 17-20, rotations at the ends of the columns having inappropriate confinement reinforcement are larger than those of the columns having appropriate confinement reinforcement for the same roof displacement case. Although increasing of rotation, post-elastic moments at the end of the columns having appropriate confinement reinforcement almost unchanged. However, the moments at the end of the columns which have inappropriate confinement reinforcement fall down suddenly with the increase in rotation, expect that of column S111a.

Figs.21-23 shows variations of moment-rotation curves with concrete compressive strength for the lower ends of columns (S311a, S411a and S511a) of the building in which structural elements have appropriate confinement reinforcement. As seen these figures, occurred rotations are close to each other. However, the moment values increase a little amount depending on increasing of concrete compressive strength. Figs. 24-26 shows variation of moment-rotation curves of the same column ends for inappropriate confinement reinforcement according to concrete compressive strength. It is seen from these figures, increasing of concrete compressive strength enhances moment value at the same rotation until maximum moment. However, the moment falls down suddenly after exceeding this point. Increasing of concrete compressive strength causes more decrease at these moments in case of inappropriate confinement reinforcement.

4. Conclusions

In this study, effects of confinement reinforcement and concrete strength on behaviour of reinforced concrete buildings are investigated. A reinforced concrete frame building which has eleven-story and four bays is selected for numerical application. Nonlinear incremental static (pushover) analyses of the building are performed according to various concrete strengths and whether appropriate confinement reinforcement which defined in Turkish seismic code, exists or not at structural elements. In the nonlinear analysis, distributed plastic hinge model is used. As a result of analysis, capacity curves of the building and moment-rotation curves at lower end sections of ground floor columns are determined. These results are compared with each other by depending on concrete strength and whether appropriate confinement reinforcement exists or not, respectively.

- It is seen from the results that increasing of concrete strength enhances the building capacity for appropriate and inappropriate confinement reinforcement cases. However, the capacity curves are similar up to approximately 1.5% roof displacement for various concrete strengths. Also, after this displacement level, capacity curves of the building which have inappropriate confinement reinforcement are decreased, suddenly.
- Rotations at the ends of the columns which have inappropriate confinement reinforcement are larger than those of the columns with appropriate confinement reinforcement for the same roof displacement case. Generally, although increasing of rotation, post-elastic moments at the end of the columns having appropriate confinement reinforcement almost unchanged. However, for inappropriate confinement case, they fall down suddenly with the increase in rotation.
- The columns' ends moments increase a little amount by depending on increasing of concrete compressive strength for appropriate and inappropriate confinement reinforcement cases. Increasing of concrete compressive strength increases moment value at the same rotation until reaching up to maximum moment. However, the moment falls down suddenly after exceeding this point for inappropriate confinement reinforcement case. Increasing of concrete compressive strength causes more decrease at these moments.

In the case of appropriate confinement reinforcement, the moment values increase a little with increasing of concrete compressive strength.

These results show that, confinement reinforcement is important factor for increasing of building capacity and decreasing of rotations at structural elements.

Acknowledgments

The authors gratefully thank to Seismosoft for providing free license for SeismoStruct software.

References

Adalıer, K. and Aydıngün, O. (2001), "Structural engineering aspects of the June 27, 1998 Adana–Ceyhan (Turkey) earthquake", *Eng. Struct.*, **23**, 343-355.

Ateş, Ş., Kahya, V., Yurdakul, M. and Adanur, S. (2013), "Damages on reinforced concrete buildings due to consecutive earthquakes in Van", *Soil Dyn. Earthq. Eng.* **53,** 109-118.

Bayraktar, A. Altunışık, A.C. and Pehlivan, M. (2013), "Performance and damages of reinforced concrete buildings during the October 23 and November 9, 2011 Van, Turkey, earthquakes", *Soil Dyn. Earthq. Eng.* **53,** 49-72.

Calayır, Y. Sayın, E. and Yön, B. (2012), "Performance of structures in the rural area during the March 8, 2010 Elazığ-Kovancılar earthquake", *Nat. Hazards*, **61**(2), 703-717.

Carvalho, G. Bento, R. and Bhatt, C. (2013), "Nonlinear static and dynamic analyses of reinforced concrete buildings – comparison of different modelling approaches", *Earthq. Struct.*, **4** (5), 451-470.

Chan, C.M. and Zou, X.K. (2004), "Elastic and inelastic drift performance optimization for reinforced concrete buildings under earthquake loads", *Earthq. Eng. Struct. Dyn.***33**, 929-950.

Dides, M.A. and Llera, J.C. (2005), "A comparative study of concentrated plasticity models in dynamic analysis of building structures", *Earthq. Eng. Struct. Dyn.*, **34**, 1005-1026.

Doğangün, A. (2004), "Performance of reinforced concrete buildings during the May 1, 2003 Bingöl earthquake in Turkey", *Eng. Struct.*, **26**(6), 841-856.

Doğangün, A. (2013), "Account and design of concrete structures", Birsen publishing house, İstanbul.Turkey (in Turkish).

Duan, H. and Hueste, M.B.D. (2012), "Seismic performance of a reinforced concrete frame building in China", *Eng.Struct.***41,** 77-89.

Eslami, A. and Ronagh, H.R. (2014), "Effect of elaborate plastic hinge definition on the pushover analysis of reinforced concrete buildings", *Struct. Des. Tall. Spec. Build.*, **23**(4), 254-271.

Hancock, J. and Bommer, J.J. (2007), "Using spectral matched records to explore the influence of strong-motion duration on inelastic structural response", *Soil Dyn. Earthq. Eng.*, **27,** 291-299.

İnel, M. and Özmen, H. B. (2006), "Effects of plastic hinge properties in nonlinear analysis of reinforced concrete buildings", *Eng.Struct.***28**, 1494-1502.

İnel, M., Özmen, H B. and Bilgin, H. (2008), "Re-evaluation of building damage during recent earthquakes in Turkey", *Eng.Struct.*, **30**, 412-427.

Jeong, S.H. and Elnashai, A.S. (2005), "Analytical assessment of an irregular RC frame for full-scale 3d pseudo-dynamic testing part i: analytical model verification", *J. Earth. Eng.*, **9**(1), 95-128.

Kadid, A., Yahiaoui, D. and Chebili, R. (2010), "Behaviour of reinforced concrete buildings under simultaneous horizontal and vertical ground motions", *Asian J. Civil Eng.*(Building and Housing*)*, **11**, 463-476.

Kenneth, S.K. and Kalkan, E. (2004), "Evaluation of seismic deformation demands using non-linear procedures in multistory steel and concrete moment frames", *ISET Journal of Earthq. Technol.*, **41**, 159-181.

Kwon, O.S. and Kim, E. (2010), "Case study: Analytical investigation on the failure of a two-story RC building damaged during the 2007 Pisco-Chincha earthquake", *Eng. Struct.*, **32,** 1876-1887.

Mander, J.B., Priestley, M.J.N. and Park, R. (1988), "Theoretical stress-strain model for confined concrete", *J. Struct. Eng.*, 1804-1826.

Mwafy, A.M. and Elnashai, A.S. (2001), "Static pushover versus dynamic collapse analysis of RC buildings", *Eng.Struct.*, **23,** 407-424.

Mwafy, A. (2011), "Assessment of seismic design response factors of concrete wall buildings", *Earthq. Eng. Eng. Vib.*, **10**, 115-127.

Petrangeli, M. (1999), "Fiber element for cyclic bending and shear of RC structures, II: Verification", *J. Eng. Mech.*, **125(**9), 1002-1009.

Pinho, R. and Elnashai, A.S. (2000), "Dynamic collapse testing of a full scale four storey RC frame", *ISET J.*

Earthq. Technol, **37**(4), 143-163.
Ricci, P., Luca, F.D. and Verderame, G.M. (2011), "6th April 2009 L'Aquila earthquake, Italy: reinforced concrete building performance", *Bull. Earthq. Eng.*, **9**, 285-305.
Sarno, L.D. and Manfredi, G. (2010), "Seismic retrofitting with buckling restrained braces: Application to an existing non-ductile RC framed building", *Soil Dyn. Earthq. Eng.*, **30**, 1279-1297.
Sezen, H., Whittaker, A.S., Elwood, K.J. and Mosalam, K.M. (2003), "Performance of reinforced concrete buildings during the August 17, 1999 Kocaeli, Turkey earthquake, and seismic design and construction practice in Turkey", *Eng. Struct.*, **25**(1), 103-114.
Taucer, F.F., Spacone, E. and Filippou, F.C. (1991), *A Fiber Beam-Column Element for Seismic Response Analysis of Reinforced Concrete Structures*, Report No. UCB/EERC-91/17, Earthquake Engineering Research Center, College of Engineering, University of California Berkeley.
Thomos, G.C. and Trezos, G.C. (2006), "Examination of the probabilistic response of reinforced concrete structures under static non-linear analysis", *Eng. Struct.*, **28**, 120-133.
SeismoStruct Version 6 available on www.seismosoft.com/en/SeismoStruct.aspx
Turkish Seismic Code 2007, Ankara, Turkey.
Varum, H. (2003), "Seismic assessment, strengthening and repair of existing buildings", Ph.D.Thesis, Department of Civil Engineering, University of Aveiro, Portugal.
Yön, B. Sayın, E. and Köksal, T.S. (2013), "Seismic response of buildings during the May 19, 2011 Simav, Turkey earthquake", *Eartq. Struct.*, **5**(3), 343-357.
Yön, B. and Calayır, Y. (2013), "Pushover analysis of a reinforced concrete building according to various hinge models", *2nd International Balkans Conference on Challenges of Civil Engineering*, *BCCCE*, Tirana, Albania 23-25May.

CC