Computers and Concrete, *Vol. 16, No. 2 (2015) 311-327*
DOI: http://dx.doi.org/10.12989/cac.2015.16.2.311

Implementation of bond-slip effects on behaviour of slabs in structures

S.S. Mousavi[a] and M. Dehestani[*]

Faculty of Civil Engineering, Babol Noshirvani University of Technology, Babol, Iran

(Received January 1, 2015, Revised July 11, 2015, Accepted July 25, 2015)

Abstract. Employing discrete elements for considering bond-slip effects in reinforced concrete structures is very time consuming. In this study, a new modified embedded element method is used to consider the bond-slip phenomenon in structural behavior of reinforced concrete structures. A comprehensive parametric study of RC slabs is performed to determine influence of different variables on structural behavior. The parametric study includes a set of simple models accompanied with complex models such as multi-storey buildings. The procedure includes the decrease in the effective stiffness of steel bar in the layered model. Validation of the proposed model with existing experimental results demonstrates that the model is capable of considering the bond-slip effects in embedded elements. Results demonstrate the significant effect of bond-slip on total behavior of structural members. Concrete characteristic strengths, steel yield stress, bar diameter, concrete coverage and reinforcement ratios are the parameters considered in the parametric study. Results revealed that the overall behavior of slab is significantly affected by bar diameter compared with other parameters. Variation of steel yield stress has insignificant impact in static response of RC slabs; however, its effect in cyclic behavior is important.

Keywords: modified embedded element; RC slab; parametric study; static loading; cyclic loading

1. Introduction

Structural behaviour of reinforced concrete (RC) slabs is a function of many parameters. Compressive strength of concrete, yield strength of reinforcing bar and the interfacial effects influence the bearing capacity and also ductility of a reinforced concrete slab. Bond strength between steel reinforcement and concrete plays a major role in determining failure displacement. Several factors can affect the bond behavior between reinforcement and surrounding concrete. Reinforcement diameters, compression strength of concrete and concrete coverage for reinforcing steel, are important factors that affect the interaction behavior between reinforcement and concrete in reinforced concrete slabs. In addition, different loading conditions such as flexural and lateral loadings affect the behaviour of RC slab. Understanding the influence of these parameters can lead

---

[*] Corresponding author, Assistant Professor, E-mail: dehestani@gmail.com
[a] Graduate student, E-mail: seyedsina.m@gmail.com

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

to predict the ultimate behavior of RC slab and have an optimal methodology for design consideration.

So far, many researches have been accomplished on the behavior of reinforced concrete slabs under different loading conditions. In these researches, the ultimate displacement and loading capacity of reinforced concrete slabs have been considered.

Ingerslev (1923) is a pioneering researcher who analyzed the behavior of the concrete slab. He has presented the classic yield line theory. The yield-line theory is a method for predicting the ultimate load-carrying capacity of slabs. In this field, Wood (1961) has presented the theoretical yield line load for slabs subjected to a uniformly distributed load.

In addition, Johansen and Johansen (1962) and Wood and Jones (1967) developed the yield line theory for different edge conditions. Bailey and Moore (2000) have investigated the structural behaviour of steel framed buildings withcomposite floor. They have presented the failure displacement of slab under fire condition. Yield stress and modulus of elasticity of reinforcement are the only parameters that have to be considered in their research for predicting failure displacement.

Bailey (2001) presented the new design method that allows the membrane action of a composite floor slab to be estimated when subjected to a fire. Membrane action is in-plane behavior of reinforced concrete slabs that can considerably enhance the load-carrying capacity compared to estimates obtained from classical yield line theory.

Elghazouli and Izzuddin (2004) have performed a parametric study with the use of new numerical analysis into the factors influencing the failure of lightly reinforced members. They have presented a direct relationship between the failure deflections and effective parameters. They have shown that the bond strength has considerable effect on failure displacement of a reinforced concrete slab.

Gilbert (2005) investigates the influence of both normal and low ductility reinforcement on the failure mode and ductility of RC slabs. In addition, Gilbert and Sakka (2007) have conducted experimental tests to determine the influence of reinforcement ductility on the response of RC slabs. They have confirmed that slabs with low ductility reinforcement fail in a brittle manner by fracture of the tensile reinforcement.

Shayanfar and Safiey (2008) developed an algorithmic procedure for producing the tension-stiffening curve of RC elements to be used in nonlinear finite element analysis of reinforced concrete structures with corroded reinforcements.

Cashell *et al.* (2010a, b, 2011) have investigated the failure conditions of reinforced concrete slabs. The importance of interaction effect in reinforced concrete slabs is shown in their researches. Dominguez *et al.* (2010) utilized a new kind of finite solid element for prediction of realistic behavior of reinforced concrete structures with bond-slip.

Chang *et al.* (2012) studied pullout behaviors of stiff fiber reinforced cementitious composites. They have reported that the embedded length and bond strength affect the load-loaded end displacement curves significantly.

In addition, so far, different methods have been employed for considering bond-slip effects in finite element analysis. Arslan and Durmuş (2014) employed a rule based Mamdani type fuzzy logic model for prediction of slippage for lightweight concretes. They have finally reported fuzzy logic as a practical method for predicting slippage at maximum tensile strength and slippage at rupture of structural lightweight concretes.

Recently, Golafshani *et al.* (2014) have used multi-gene genetic programming (MGP) technique for modeling the bond strength of ribbed steel bars in concrete. They have eventually concluded that MGP model predictions of the bond strength are more reliable than those obtaining from the existing building codes equations.

1.1 Research significance

In this study, a modified embedded model is presented and a parametric study is performed to provide a fundamental insight into performance of RC slabs under static and cyclic loading. In addition, concrete frames with RC slabs are modeled to determine bond-slip effects in macro analysis. Verification of the proposed new method is undertaken by comparison against selected experimental results to illustrate the accuracy of modeling.

Although the importance of interfacial effect between reinforcing bar and surrounding concrete has been considered in many previous works, it is essential to study the direct assessment of bond effect in structural behaviour of RC slabs. According to the simplicity of the proposed method, large complex composite structures such as multiple story building can be analyzed.

2. Description of the modified reinforcing bar model

The interfacial bond behavior of steel bars and surrounding concrete play a major role in structural behavior of RC members. Cashell *et al.* (2010a, b, 2011) have shown that the bond stress controls the failure displacement and strength capacity by enhancing the ductility of members. In addition, cracking pattern, strain localization in steel bar and energy dissipation of RC members in flexural condition are affected by the bond phenomena. Therefore, it is essential to consider the interfacial behavior in numerical investigation for proper and reliable results. There are two main techniques in finite element software to model steel bar in concrete structures. In an accurate model denoted by discreet element, steel bar and concrete bulk are modeled separately with two different elements and an interfacial layer is defined. The bond property can be assigned to interfacial layer. The second one is embedded element that consider perfect bond between steel bar and concrete. Although the discreet element is more accurate than the embedded technique, the convergence of the model is time-consuming and the procedure is not applicable for large systems. Thus, embedded element is usually used in the analysis of reinforced concrete members. In this study, a new efficient model introduced by Dehestani and Mousavi (2015) is employed to consider the bond effect in embedded method. The steel bar model is modified and the new elastic modulusis substituted with equivalent elastic modulus. The modified elastic modulus of steel reinforcing bar can be written as

$$E_s^* = \frac{f_y^*}{e_s + e_b} \tag{1}$$

Where f_y^* is the modified yield stress of steel bar which has presented by Belarbi and Hsu (1994). They have determined that the real yield strength of steel bar with surrounding concretecan be obtained from

$$\frac{f_y^*}{f_y} = 1 - 1.5\frac{\sqrt{n}}{r}\left(\frac{f_{cr}}{f_y}\right)^{1.5} \tag{2}$$

where r is the reinforcement ratio and f_{cr} represent the tensile cracking stress of concrete at cracking strain of about 8’ 10^{-5}·e_s is the strain of the steel bar corresponding to the stress of f_y^* in steel bar model and e_b is the effective bond strain of steel rebar which is obtained from

$$e_b = \frac{d}{l} \tag{3}$$

where d is the maximum slip of the steel bar. Wu and Zhao (2012) have presented a precise estimation of the maximum slip, which is obtained as follows

$$d = \frac{0.7315+K}{5.176+0.3333K} \tag{4}$$

where

$$K = K_{co} + 33K_{st} \tag{5}$$

$$K_{co} = \frac{C}{d_b} \tag{6}$$

$$K_{st} = \frac{A_{st1}}{CS_{st}} \tag{7}$$

C and d_b are concrete cover and bar diameter, respectively. A_{st1} is the area of one leg of the stirrup, C is the minimum concrete cover and S_{st} is the stirrup spacing.

There is no bond stress between concrete and rebar at the cracked section. When the bond strength disappears at a section, the strain and also the stress concentration occur. Concrete and steel bar have same strain at the middle point and hence, there is no slip at the middle point of the member. It can be deduced that the maximum slip is related to the half of the distance between two adjacent cracks. Thus, the transfer length l can be determined from

$$S_{r(min)} = 2l \tag{8}$$

where $S_{r(min)}$ is the length between two adjacent cracks, which is equivalent to the minimum crack spacing. The Eq. (9) shows the average spacing of flexural cracks given by CEB-FIP Model Code (1990).

$$S_{rm} = \frac{2}{3} \times \frac{d_b}{3.6\, r_{eff}} \tag{9}$$

Where r_{eff} is effective reinforcement ratio and can be obtained from:

$$r_{eff} = \frac{A_S}{A_{c,eff}} \tag{10}$$

where $A_{c,eff}$ is the effective concrete area in tension which is usually obtained by simplified approaches, such as those in Eurocode 2 (1991) or CEB-FIP Model Code 1990 [13]. For rectangular cross sections, it can be obtained from

$$A_{c,eff} = 2.5(h - d)b \tag{11}$$

where h is total depth of cross section, d is effective depth of cross section and b is width of cross section. Borosnyoi and Balazs (2005) have evaluated the ratio between the minimum and the average crack spacing between 0.67 and 0.77. Now, the minimum crack spacing can be obtained and eventually the transfer length is given by

$$l = \frac{0.67}{2} S_{rm} \tag{12}$$

The modified stress-strain relationship for steel is eventually constructed by considering the bond-slip effect. In the modified curve, the yield stress of steel bar is reduced according to Eq. (2) and the elastic modulus is replaced with modified elastic modulus given by Eq. (1).

In order to validate the proposed method, the response of the reinforced concrete slabs under monotonic loading is considered. A reinforced concrete slabs tested by Cashell *et al.* (2011) are selected for validating the embedded bond-slip model in finite element program. The specimen is a two-way concrete slab with area of 2250 *mm'* 1500 *mm* and depth of 60 mm subjected to a monotonic loading. The details of each validation specimens are given in Table 1.

The finite element software, ABAQUS is used for modeling of validation specimen. Isotropic plasticity condition is assumed for steel material. The density and Poisson's ratio were chosen as 7850 Kg/m^3 and 0.3, respectively. Concrete damaged plasticity (CDP) model is used to describe concrete behavior. CDP model consists of compressive and tensile behavior, defined separately in terms of plasticity and damage parameters. It assumes that the main two failure mechanisms are tensile cracking and compressive crushing of the concrete material (Hibbitt *et al.* 2004). Input parameters for CDP model are shown in Table 2.

Different models for stress-strain relationship of concrete are currently used in the analysis of reinforced concrete members. In this study, the monotonic envelope curve introduced by Park and Kent (1972) is used for stress-strain relation of concrete in compression. A straight-line can approximately relates stresses and strains of concrete in tension before cracking. Beyond the tensile strength of concrete, the model presented by Tamai (1988) is used for descending branch of stress-strain curve. The configuration of test for validation specimen is illustrated in Fig. 1.

A comparison between results shows that results of the numerical model with modified embedded element are in close agreement with those of experimental test. It should be noted that small differences between the results of the proposed model and the experimental results originate from many factors such as the self-weight of the loading arrangement and the stiffness of the loading arm of test machine.

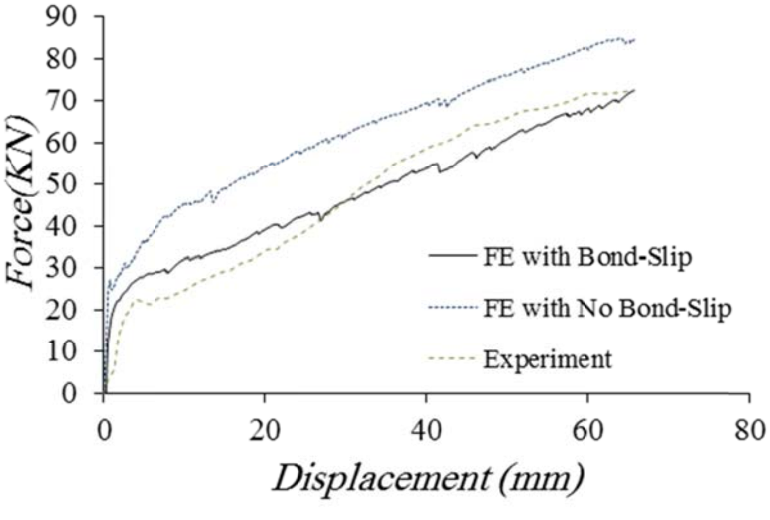


Fig. 1 Comparison of the new proposed method and experimental result

Table 1 Details of validation specimen

Specimen	r (%)	D (mm)	f_c' (Mpa)	f_{ct} (Mpa)	f_{sy} (Mpa)	e_{su}
R-F60-D6-A	$r_1 = r_2 = 0.24$	6	32	2.1	553	0.04

Table 2 Concrete damage plasticity (CDP) parameters

Dilation angle (y)	Flow potential ccentricity (Ò)	σ_{b0}/σ_{c0}	$\boldsymbol{K}_c$	Viscosity parameter (m)
30	0.1	1.16	0.666	0.00001

Table 3 Properties of control model

Specimen	r (%)	D (mm)	C (mm)	f_c' (Mpa)	f_{ct} (Mpa)	f_{sy} (Mpa)
Benchmark model	$r_1 = r_2 = 0.30$	8	30	30.0	2.0	400

3. Parametric study

The analytical simulation with new proposed method is used to study the importance of bond-slip phenomenon in RC slabs and also overall behavior of the structures. RC slabs are studied in micro and macro models under different types of loading. Monotonic and cyclic loadings are applied to RC slabs in micro models and effect of different parameters is investigated. The loading curves for monotonic and cyclic models are shown in Fig. 2. Multistory buildings are also considered in macro models.

3.1 Parametric study in micro modeling

3.1.1 Static loading

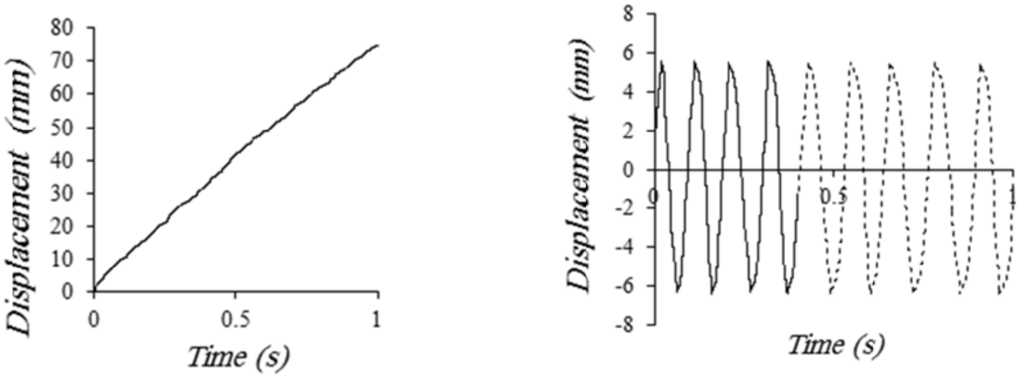
In order to determine the effective parameters, properties of the benchmark specimen with the same geometry of validation specimen (R-F60-D6-A) is used in several models. The models are varying with different coefficients of 0.75, 1.00, 1.25 and 1.50 relative to the key properties of benchmark specimen. Properties of benchmark model are shown in Table 3. Yield stress of steel, characteristic strength of concrete, diameter of reinforcing bar, concrete coverage of reinforcing bar and reinforcement ratio are the key parameters considered in this study.

Fig. 3 presents the load-displacement responses of slabs for various characteristic strengths of concrete, where the other properties are kept constant. As depicted in Fig. 3, 74 mm of pushing displacement is applied to structures and corresponding forces are measured. Results indicate that with 50 percent of increase in characteristic strengths of concrete, load capacity increases about 18 percent indicating an increase in static stiffness of slabs.

In order to investigate the influences of various parameters such as bar diameter, characteristic strength of concrete, yield stress of steel and reinforcement ratio on maximum mid-span deflection, 13 models have been constructed and analyzed. Load-displacement of each model with different values of parameters is obtained. To present the relative influence of parameters, overall results of models under base load (60 KN) are illustrated in Fig. 4. In order to facilitate the comparison between the results, the effective parameters and maximum deflection of the slab have been normalized to corresponding values of the benchmark specimen.

As shown in Fig. 4, 25 percent of increase in concrete characteristic strengths caused 14 percent of decrease in displacement of slabs. It is also shown that with 25 percent of increase in bar diameter, mid-span displacement decreases about 25 percent. For 25 percent of increase in steel yield stress, the mid-span deflection reduced about 9 percent. Also the mid-span deflection decreased about 11 percent when the reinforcement ratio increased 25 percent.

Results indicate that variation of the diameter of reinforcing bar has more significant effect on mid-span deflection of RC slab. Results also demonstrate that total behavior of the slab is not affected significantly by the variation of steel yield stress.



(a) Monotonic (b) Cyclic

Fig. 2 Types of displacement control tests in numerical study

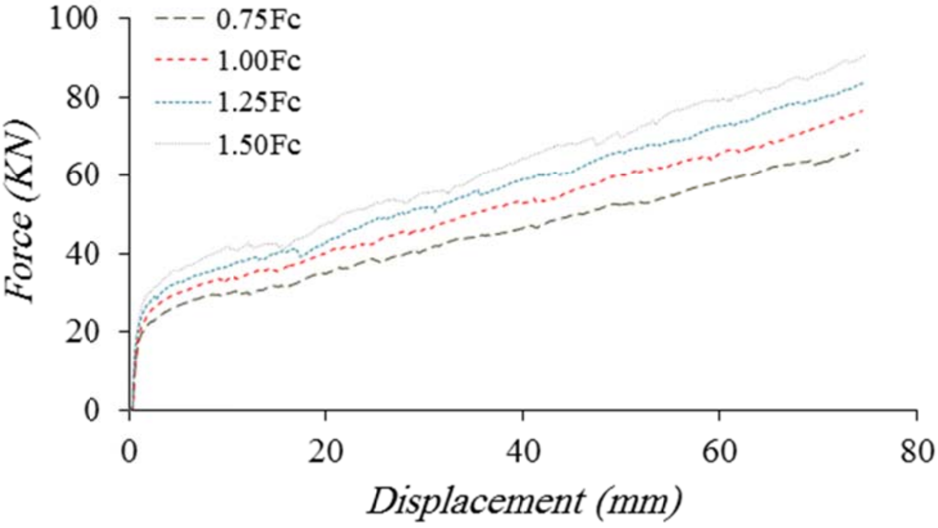


Fig. 3 Load-displacement responses for various characteristic strengths of concrete

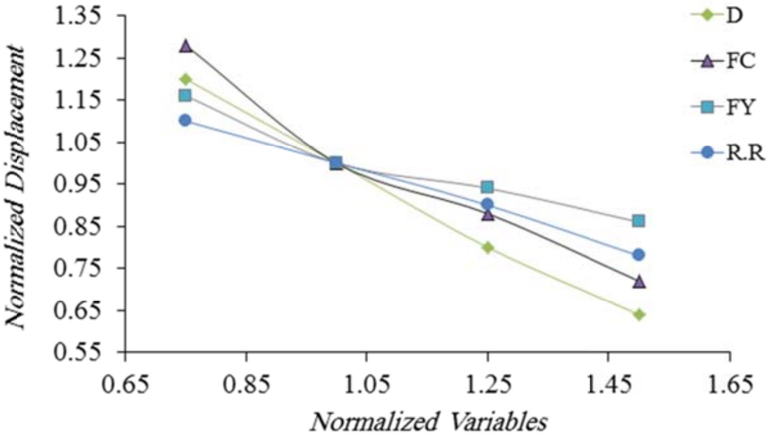


Fig. 4 Effects of various normalized parameters on deflection of the mid-span of the slab for static loading

3.1.2 Cyclic loading

To determine the cyclic behaviour of RC slabs, parametric study has been carried out. The proposed modified embedded method is also used to consider bond-slip effect in cyclic loading. Nine cycles of displacement (6 mm) were applied to the slabs. Coverage of steel bar from lower surface of slab, yield strength of steel bar, compression strength of concrete, diameter of rebar and reinforcement ratio are the parameters that are considered.

The hysteresis curves of slabs with different value of concrete coverage are shown in Fig. 5. The area within the curves for different coverage is insignificantly changed. As shown in Fig. 5, the energy absorption capability is approximately the same for different specimens. This has been shown in Fig. 6 where the total strain energy of slab is not affected significantly by the variation of concrete coverage.

The hysteresis curves of slab with different value of bar diameter are shown in Fig. 7. Responses indicate that the areas within the cycles are increased with the increase in bar diameter. By increasing the bar diameter, the ability to absorb energy is increased significantly.

Fig. 8 shows the important and effective role of bar diameter on cyclic behavior of slabs. Results indicate that with increase of 50 percent in bar diameter, the total strain energy increases about 55 percent.

As shown in Fig. 9, with increase in concrete characteristic strengths, the areas within the cycles curve increase. Hysteresis curves show that concrete characteristic strength has insignificant impact compared with bar diameter in cyclic behavior of slabs.

The total strain energy of slabs for various concrete characteristic strengths is illustrated in Fig. 10. With increase of 50 percent in concrete strength, energy absorption of slabs increases about 9 percent. However, the impact of concrete strength in cyclic loading is lower than that in static loading.

Effect of steel yield stress on hysteresis curve is presented in Fig 11. Increase in steel yield stresses is accompanied by significant increase in areas within the cycles. Results achieved in cyclic behavior are different from static conditions in which steel yield stress has insignificant impact.

Increase of 50 percent of steel yield stress caused about 29 percent of increase in the total strain energy of slabs. Significant influence of the steel yield stress is evident in Fig. 12.

Variation of hysteresis curve for different reinforcement ratios is shown in Fig. 13. The areas within the cycles for hysteresis curves do not changed considerably indicating small rate of dissipation of energy for various reinforcement ratios.

Fig. 14 presents the effect of reinforcement ratio on total dissipation energy of slab. Results indicate that with increase of 50 percent in bar diameter, the dissipation energy increased about 5 percent. Therefore, reinforcement ratio has insignificant impact on cyclic behavior of slabs.

Normalized total strain energy for various effective parameters such as concrete coverage, bar diameter, yield stress of steel, characteristic strength of concrete and reinforcement ratio is illustrated in Fig. 15. Results demonstrate that bar diameter has the most important impact on the cyclic behaviour of slabs with respect to other parameters. In addition, the concrete coverage of steel bars from lower surface of slab has negligible effect on dissipating energy. Responses indicate that the effect of steel yield stress on the cyclic behavior of slabs is of more importance than concrete characteristic strength.

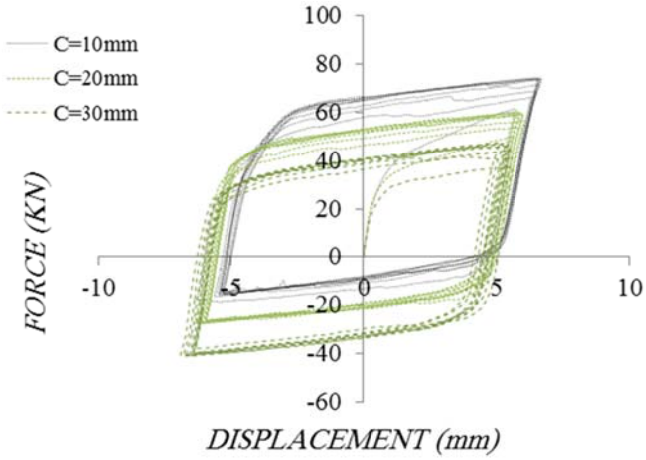


Fig. 5 Hysteresis curves of slab under cyclic loading for various concrete coverage

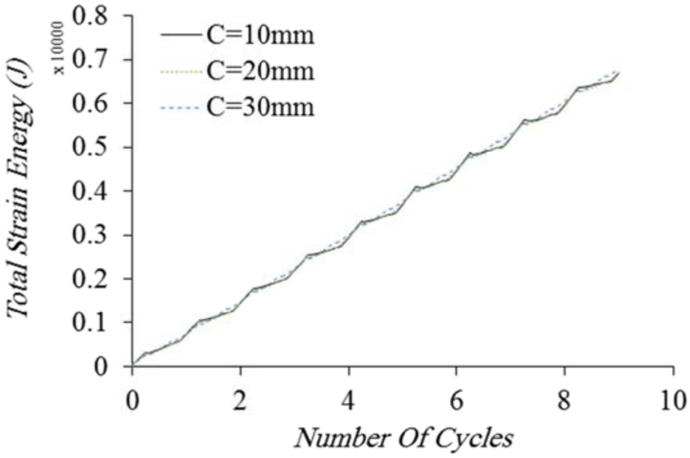


Fig. 6 Effect of concrete coverage on total strain energy in cyclic loading

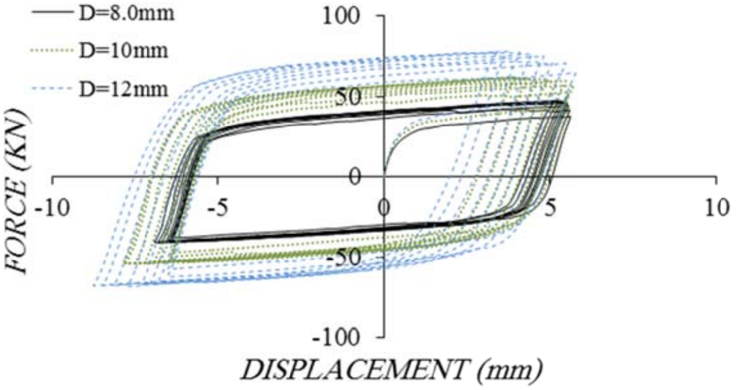


Fig. 7 Hysteresis curves of slab under cyclic loading for various bar diameters

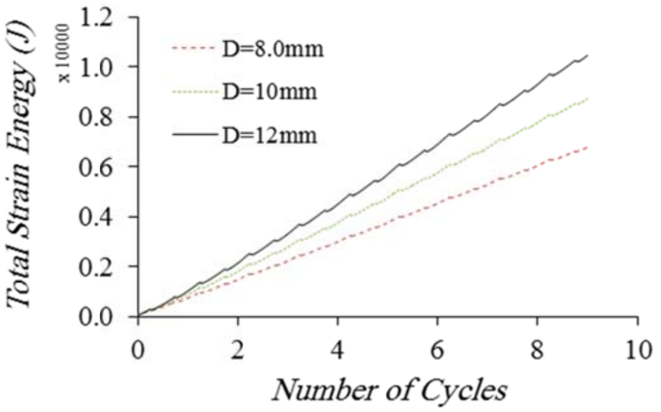


Fig. 8 Effect of bar diameter on total strain energy in cyclic loading

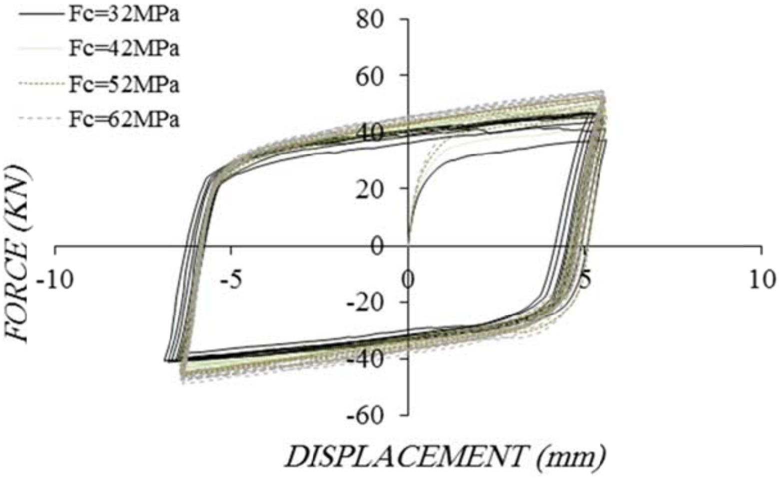


Fig. 9 Hysteresis curve of slab under cyclic loading for various concrete characteristic strengths

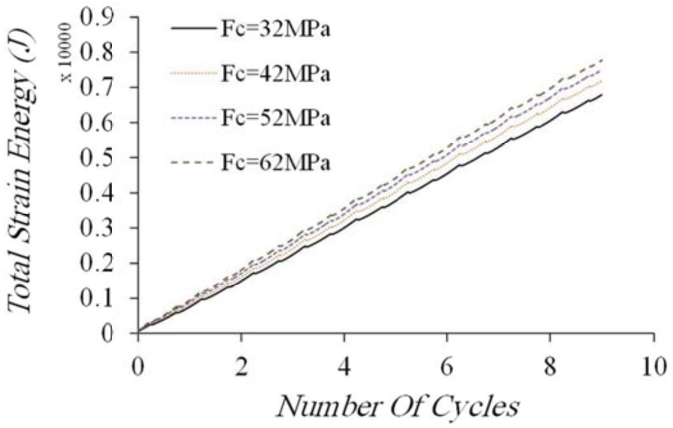


Fig. 10 Effect of concrete characteristic strength on total strain energy in cyclic loading

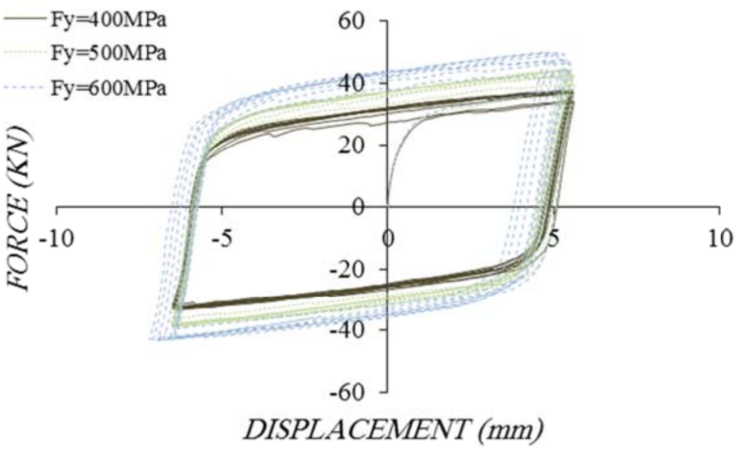


Fig. 11 Hysteresis curve of slab under cyclic loading for various yield stresses of steel

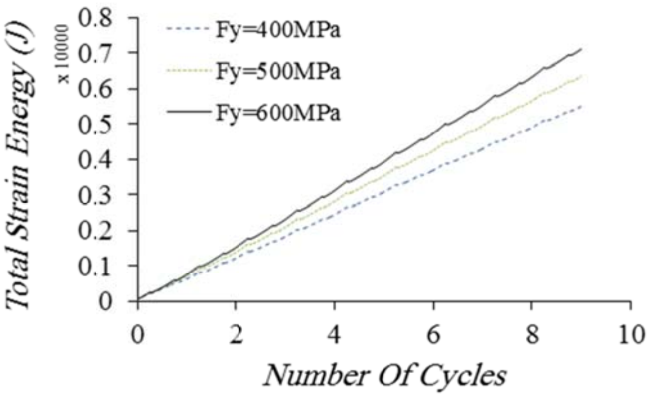


Fig. 12 Effect of steel yield stress on total strain energy in cyclic loading

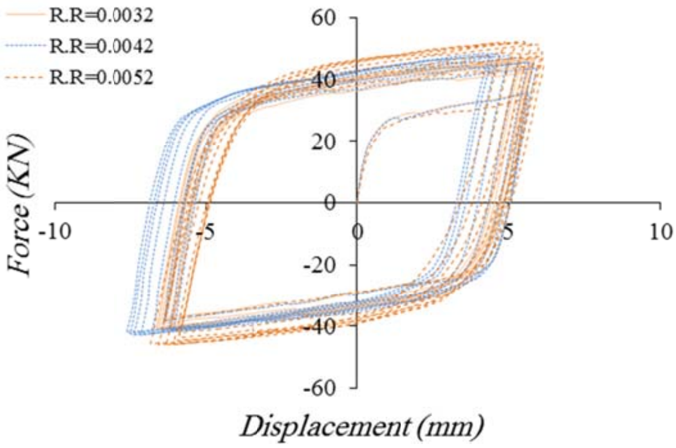


Fig. 13 Hysteresis curve of slab under cyclic loading for various reinforcement ratios

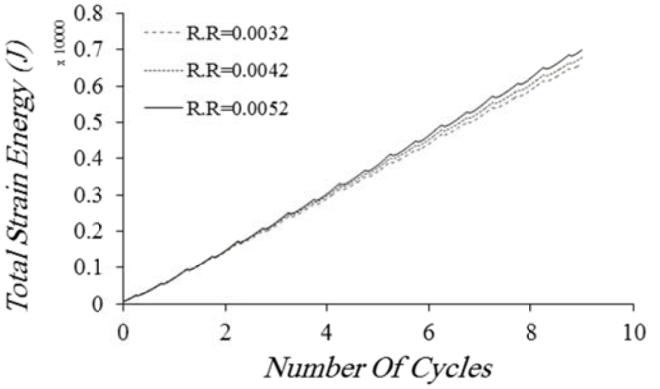


Fig. 14 Effect of reinforcement ratio on total strain energy in cyclic loading

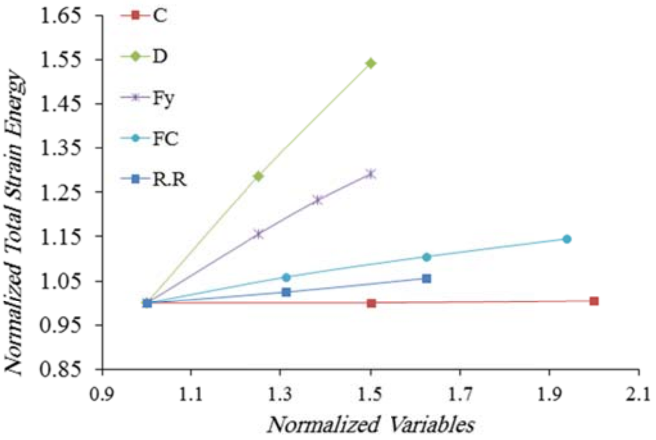
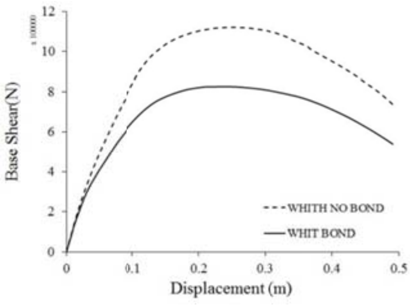
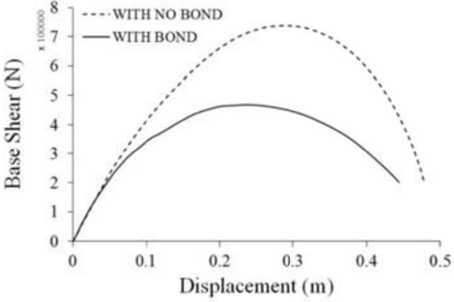


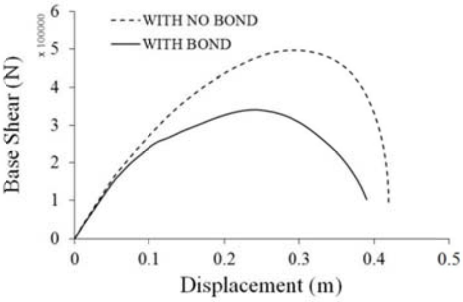
Fig. 15 Effects of various normalized variables on total strain energy in cyclic loading



(a) 3-story building



(b) 6-story building



(c) 9-story building

Fig. 16 Bond-slip effect in base shear of multistory building

3.2 Parametric study in macro modeling

The proposed modified embedded method is employed to perform the parametric study in macro modeling. It is expected that bond-slip consideration would affect the lateral stiffness of multistory buildings. Due to simplicity of the method, it is possible to investigate the influence of different effective parameters with considering bond-slip effects on the structural behavior of multi-story buildings. 3, 6 and 9 story buildings are modeled with and without bond-slip consideration. As shown in Fig. 16, the effect of bond-slip in base shear of buildings is remarkable. Results indicate that the maximum base shear of the building is decreased in model with bond-slip effect. The rate of decrease is about 35 percent of the maximum base shear in perfect bond (without slip) model.

The parametric study is performed in 3-story building. Steel yield stress, concrete characteristic strengths and bar diameter are variables that are considered. Fig. 17 presents the load-displacement of 3-story building for various concrete characteristic strengths. It is shown that with increase of

50 percent in concrete characteristic strengths, the maximum base shear of building increases to 2.2 percent.

Effect of steel yield stress on the load-displacement of 3-story building is illustrated in Fig. 18. Results show that 50 percent increase in steel yield stress is increased the maximum base shear 1.2 percent.

Fig. 19 shows the influence of bar diameter in response of 3-story building. The results indicate that increase of 50 percent for bar diameter caused a 3.7 percent increase in the maximum base shear of 3-story building.

Fig. 20 illustrates overall results of parametric study in this section. Results indicate that both concrete strength and steel yield stress have insignificant effects on the base shear. In addition, the reinforced concrete slabs has insignificant influence on the lateral stiffness of concrete frame of multistory buildings.

In fact, the lateral stiffness of building is dependent mostly on the stiffness of beams enclosing the slabs. In this study, the reduction of stiffness has been conducted on beams and slabs. No reduction has been implemented for columns. This is due to the fact that columns of building are bearing high compressive loads and therefore there is no need for bond-slip consideration for columns.

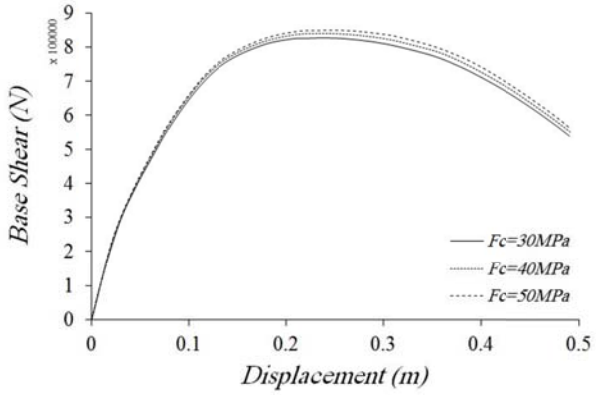


Fig. 17 Base Shear of 3-story building for various concrete characteristic strengths

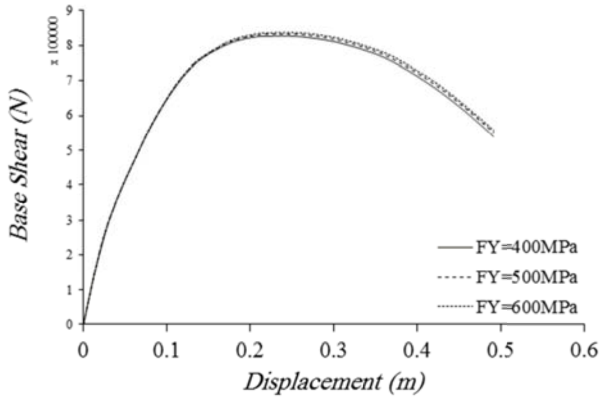


Fig. 18 Base Shear of 3-story building for various steel yield stresses

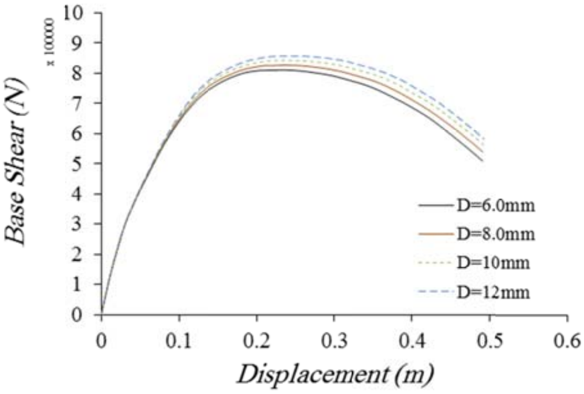


Fig. 19 Base Shear of 3-story building for various bar diameters

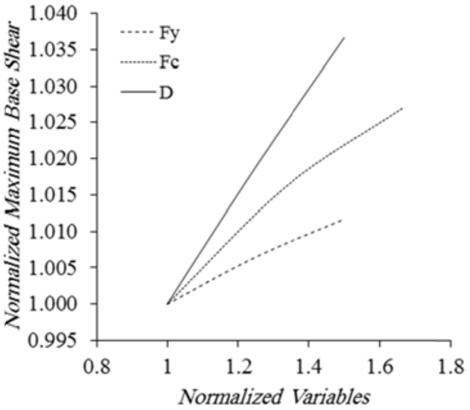


Fig. 20 Results of parametric study for structural behavior of 3-story building

4. Conclusions

A comprehensive study in behaviour of the RC slabs under different loading conditions has been carried out. A new modified embedded element is used to consider the bond-slip effects in numerical models.Various parameters such as concrete and steel properties, reinforcement ratio, bar diameter and concrete coverage have been studied. The following important concluding remarks were drawn eventually

- Results from macro study showed that considering bond-slip effect is very important and have significant effects on the response of multistory buildings.
- Results from the static study demonstrated that the bar diameter has more effect on the static behavior of RC slabs with respect to other parameters.
- Yield stress of steel has negligible impact on static behavior but its effect on cyclic behavior should be considered.
- Effect of concrete characteristic strength on the static behavior of RC member is considerable.

- Increase in stiffness of RC slabs is accompanied by increase in base shear of multistory building but the rate of increment is not significant. In fact it is mostly depends on properties of beams enclosing the slabs.
- Due to simplicity of the proposed modified embedded method, it can be used in complex composite structures such as multistory building to obtain reliable and precise results in finite element model.

Acknowledgments

Author would like to appreciate the faculty members of Civil Engineering Department of Babol University of Technology in Iran for their helpful assistances.

References

Arslan, M.E. and Durmuş, A. (2014), "Fuzzy logic approach for estimating bond behavior of lightweight concrete", *Comput. Concrete.*, **14**(3), 233-245

Bailey, C.G. (2001), "Membrane action of unrestrained lightly reinforced concrete slabs at large displacements", *Eng. Struct.*, **23**(5), 470-483.

Bailey, C.G. and Moore, D.B. (2000), "The structural behavior of steel frames with composite floor slabs subject to fire", *Struct. Eng.*, **78**(11), 19-27.

Belarbi, A. and Hsu, T.T. (1994), "Constitutive laws of concrete in tension and reinforcing bars stiffened by concrete", *ACI. Struct. J.*, **91**(4), 465-474.

Borosnyói, A. and Balázs, G.L. (2005), "Models for flexural cracking in concrete: the state of the art", *Struct. Concrete.*, **6**(2), 53-62.

Cashell, K.A., Elghazouli, A.Y. and Izzuddin, B.A. (2010a), "Experimental and analytical assessment of ductility in lightly reinforced concrete members", *Eng. Struct.*, **32**(9), 2729-2743.

Cashell, K.A., Elghazouli, A.Y. and Izzuddin, B.A. (2010b), "Ultimate behavior of idealized composite floor elements at ambient and elevated temperature", *Fire. Technol.*, **46**(1), 67-89.

Cashell, K.A., Elghazouli, A.Y. and Izzuddin, B.A. (2011), "Failure assessment of lightly reinforced floor slabs. I: Experimental investigation", *J. Struct. Eng. - ASCE.*, **137**(9), 977-988.

Chang, X., Chen, Y.J., Lin, H.X. and Zhang, Y.B. (2012), "Modeling of fiber pullout behaviors of stiff fiber reinforced cementitious composites", *Comput. Concrete.*, **9**(3), 171-178.

Comité euro-international du béton (1993), CEB-FIP Model Code 1990: *Design Code (No. 213-214). FIB-Féd. Int. du Béton.*

Dehestani, M. and Mousavi, S.S. (2015), "Modified steel bar model incorporating bond-slip effects for embedded element method", *Constr. Build. Mater.*, **81**, 284-290.

Domínguez, N., Fernández, M.A. and Ibrahimbegovic, A. (2010), "Enhanced solid element for modelling of reinforced concrete structures with bond-slip", *Comput. Concrete.*, **7**(4), 347-364.

Elghazouli, A.Y. and Izzuddin, B.A. (2004), "Failure of lightly reinforced concrete members under fire. II: Parametric studies and design considerations", *J. Struct. Eng. - ASCE.*, **130**(1), 18-31.

Eurocode 2 (1991), Design of Concrete Structures: Part 1: General Rules and Rules for Buildings, *European Committee for Standardization*.

Gilbert, R.I. (2005), "Strain localization and ductility of reinforced concrete slabs", *Proceedings of the Australian Structural Engineering Conference 2005*, Engineers Australia.

Gilbert, R.I. and Sakka, Z.I. (2007), "Effect of reinforcement type on the ductility of suspended reinforced concrete slabs", *J. Struct. Eng. - ASCE.*, **133**(6), 834-843.

Golafshani, E.M., Rahai, A. and Kebria, S.S.H. (2014), "Prediction of the bond strength of ribbed steel bars in concrete based on genetic programming", *Comput. Concrete.*, **14**(3), 327-359.

Hibbitt, D., Karlsson, B. and Sorensen, P. (2004), *ABAQUS Analysis User's Manual*, Pawtucket, USA.

Ingerslev, Å. (1923), "The strength of rectangular slabs", *J. Ins. Civil. Eng.*, **1**(1), 3-14.

Johansen, K.W. (1962), *Yield-Line Theory*, Cement and Concrete Association, London.

Park, R., Kent, D.C. and Sampson, R.A. (1972), "Reinforced concrete members with cyclic loading", *J. Struct. Div.*, **98**(7), 1341-1360.

Shayanfar, M.A. and Safiey, A. (2008), "A new approach for nonlinear finite element analysis of reinforced concrete structures with corroded reinforcements", *Comput. Concrete.*, **5**(2) 155-174.

Tamai, S. (1988), "Average stress-strain relationship in post yield range of steel bar in concrete", *Concrete. Lib. JSCE.*, **11**, 117-129.

Wood, R.H. (1961), *Plastic and Elastic Design of Slabs and Plates: with Particular Reference to Reinforced Concrete Floor Slabs*, Thames and Hudson.

Wood, R.H. and Jones, L.L. (1967), *Yield Line Analysis of Slabs*, Chatto & Windus and Thames & Hudson, London.

Wu, Y.F. and Zhao, X.M. (2012), "Unified bond stress-slip model for reinforced concrete", *J. Struct. Eng. - ASCE.*, **139**(11), 1951-1962.

CC