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Finite Element Analysis of RC Beams Include Bond Slip Effect

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***Abstract*—Load transition between reinforcement and surrounding concrete effect RC members' behavior in a great deal. But adherence is usually ignored in RC members' analyses which are performed using the FE method. In this study, the effects of bond slip on the analysis of RC members are examined. In the FE analyses, bond slip behavior between reinforcement and surrounding concrete simulated with spring elements. Bond slip relationship is identified experimentally using beam bending test suggested by RILEM. The results obtained from FE analyses are compared with the result of RC beam, tested experimentally.**

Keywords—*FEA, RC beam, bond slip, ANSYS*

I. Introduction

The behavior of RC members is based on the combined action of concrete and reinforcement. In the FE analyses; bond slip relationship is one of the most important parameter which should be added to modeling. Omitting bond-slip relationship in analyses can cause miscalculations of some critic results like load-deflection response, stress and strain [1-3].

Bond slip relationship to be used in the FE analyses can be obtained experimentally or numerically. So far the researchers, have used several methods of experiments like direct pull-out, beam anchorage and beam-column joint tests in order to define the adherence between reinforcement and surrounding concrete [4-6.] In the beams under the effect of bending, stress in reinforcement increases or decreases in parallel with moment change because of the adherence between reinforcement and surrounding concrete [7]. So, in the RC members under the effect of bending, in order to define the adherence between reinforcement and surrounding concrete, using beam bending test is more appropriate [8]. Up to now, some theoretical studies have been done and some researchers' have developed relationships giving bond slip relationship [9-11].

In the analyses of RC members, finite element method is commonly used. Because of the difficulty of including bond-slip relationships to the finite elements model; researchers usually consider that there is full adherence (perfect bond) between the reinforcement and surrounding concrete. But it is known that this consideration is valid only for areas which have low stress transition. Especially, in the areas where there are big stresses and cracks, reinforcement and concrete have different strains and bond-slip happen. When we examine the studies which were done using full adherence, according to the experimental studies; they reach bigger load carrying capacity and they perform more rigid behavior [1-3].

In this study, FE analyses of a RC beam which is tested experimentally are done. In the analyses bond-slip effect simulated with spring elements. Bond slip relationship of reinforcement and surrounding concrete obtained with beam bending test suggested by RILEM [12]. The results obtained from FE analyses are compared with the result of RC beam, tested experimentally.

II. Experimental Study

A. Beam details and test set up

The beam had a cross section of 150 mm x 300 mm and 2000 mm length (Fig. 1). The test set-up was designed to subject the simple supported beams to concentrated symmetrical four-point loading. Fig. 1 shows the loading and arrangements of the beam. Loading are done using a hydraulic jack with 300 kN capacity and displacement controlled. As shown in Fig. l, strains happened in longitudinal reinforcement during the experiment were measured using strain gauge sticked on longitudinal reinforcement in the lower surface of beam. Uniaxial compressive test were done on six standard cylinder specimens which were taken from the concrete while producing the beam and mean compressive strength was found 23.1 MPa. On the reinforcements which were used in the experiments standard tensile tests were done and average yield strength was found 496.2 and 512.7 MPa for ø8 and ø12 deformed reinforcements, respectively.

B. Investigation of bond slip relations

To used in analytical studies, bond slip relations between reinforcement and surrounding concrete under monotonic four-point flexural loading was investigated according to RILEM-FIB-CEB [12]. The properties of test specimen and experimental setup recommended by RILEM for beam bending test are shown in Fig. 2. Test specimen is consisted of two pieces of beams with 150x240 mm cross-section and 600 mm length. A steel joint is placed in the middle of beam space upper level in order to disappear the compression zone of concrete in the beam under bending effect and in order to find out the tensile strength which effect the reinforcement whose adherence was being examining. The slip in the reinforcement was measured using 0,001 mm sensitivity LVDT which were located on both ends of the beam.

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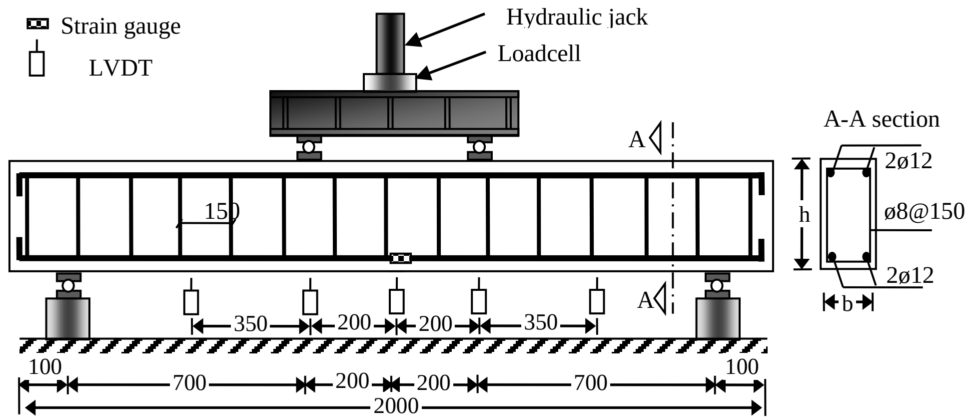

Figure 1. Beam details and test set up.

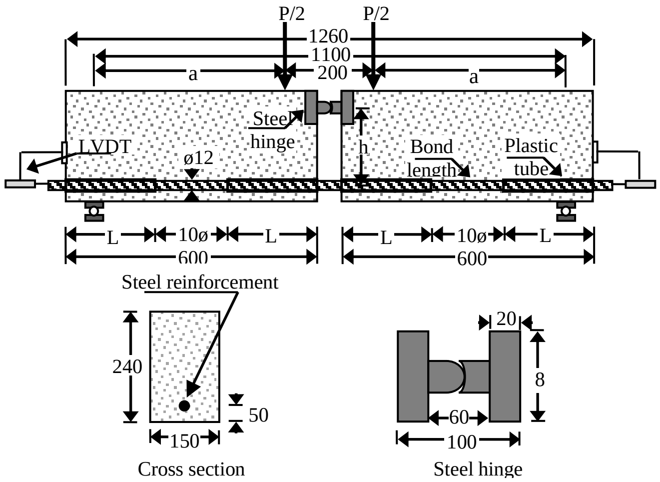

Figure 2. Beam bending test according to RILEM [24].

III. Analytical Study

Analyses of experimentally tested beam were done with ANSYS finite element software [13]. Material properties are defined by element type, material model and key options. Material models are the linear and nonlinear properties that define the elements behavior. Stress-strain relationship, modulus of elasticity, E, and poisson ratio, ν, for all elements defined according to experimental results. Eight node solid brick elements , Solid65, were used for three dimensional modeling of concrete which capable of cracking in tension and crushing in compression, plastic deformation, and creep, also, having three degrees of freedom at each node: transition in the nodal x, y and z directions. Stress strain diagram of concrete obtained experimentally was formed using multilinear isotropic hardening plasticity (Miso) which had Von Mises yielding criteria (Fig. 3(a)). Nonlinear behavior of concrete was modeled with Concrete (Conc) model. This model is used to simulate failure in brittle material and it is based on William Warnke failure criteria [14]. Failure surface can be defined using uniaxial tensile strength, f_{t}, and uniaxial crushing strength, f_{c}, values. In the analyses uniaxial tensile strength of concrete, which was found experimentally, was taken 1.7 MPa. Because of entering uniaxial crushing strength causes convergence mistakes, it was taken -1 and omitted out [15-16]. Two other important parameters to determine the nonlinear behavior of concrete are shear transfer coefficient for open and closed cracks were taken 0.3 and 0.7, respectively. The reinforcements stress strain diagrams obtained experimentally are formed using bilinear kinematical hardening plasticity (Bkin) model which based on Von Mises yield criteria (Fig. 3(b)). Reinforcements are modeled with one dimensional line elements (Link180) which has 2 nodes.

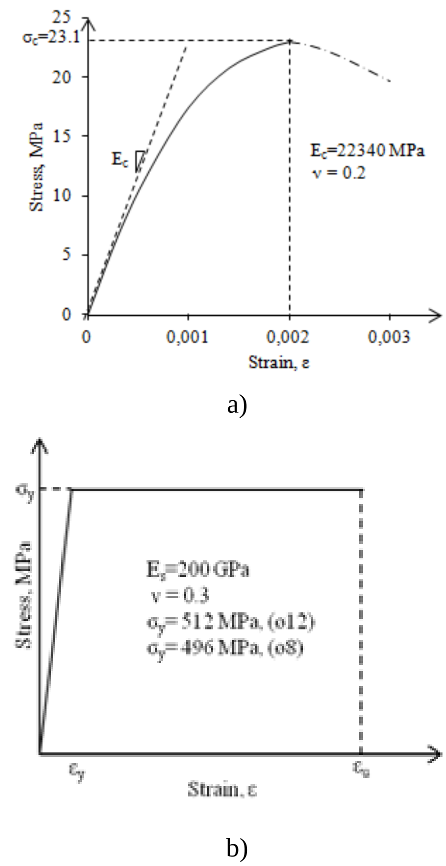

Figure 3. Stress strain curves for analytical models.

A. *Bond slip models*

Two different bond slip modeling methods were used in analytic models. The first one is full adherence (perfect bond) method which has the most common usage in literature because of easy modeling. In this method it is considered that there is full adherence between concrete and reinforcement. That's why, nods, belong to concrete and reinforcement, are combined and formed a common rigidity matrix. In the second method; bond slip relationship between the nods belong to concrete and reinforcement are modeled using spring elements (Combin39). The behavior of spring member are determined based on experimental studies explained in the previous part and are given in the Fig. 4.

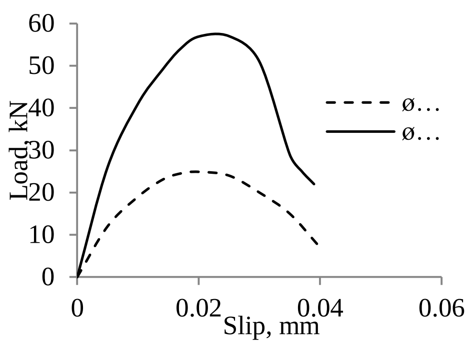

Figure 4. Stress strain curves for analytical models.

In the first model which named LN-PB (Line-Perfect Bond), the most common modeling method is used. Reinforcement modeling is done with line elements and it is considered that there is perfect bond between reinforcement and surrounding concrete (Fig. 5(a)). The second model, in which reinforcement is modeled with line elements is called LN-SPR (Line-Spring). In this model, to simulate adherence, spring elements are used between reinforcement and surrounding concrete and it is modeled according to experiment results (Fig. 5(b)).

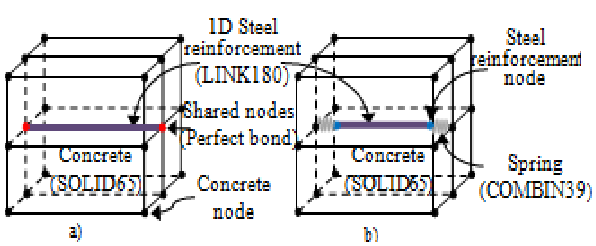

Figure 5. Reinforcement and bond-slip modeling details of a) LN-PB b)LN-SPR

By taking the advantage of the symmetry of the beam, a quarter of the full beam was used for finite element modeling (Fig. 6). This approach reduced computational time and computer disk space requirements significantly. Analysis was performed for each of the models and full Newton-Raphson method was used for the nonlinear analysis. As a result load deflection curves of beam and strain-deflection curves of longitudinal reinforcement were plotted for comparison with the experimental results.

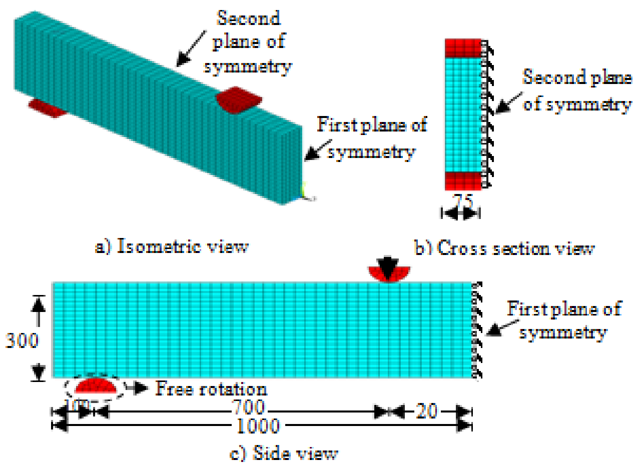

Figure 6. The developed FE model.

IV. Results and Discussions

Load deflection curves obtained from experimental and analytical studies were given in Fig. 7 and results were summarized in Table 1. In the experimental study, the first crack happened in 2,45 mm displacement with 23,51 kN load level. Initial stiffness of the curve was calculated as 9.59 kN/mm. When displacements increased, the cracks spreaded along the beam and in the 10.42 mm displacement with 90.31kN load level, yield happened in longitudinal reinforcement and crushing happened in the concrete. Since then, crack widths started increasing and curve started being horizontal. After beam reached in 29.57 mm displacement and 103.31 KN maximum load, and in 44.196 mm displacement, reinforcement had rupture and beam collapsed.

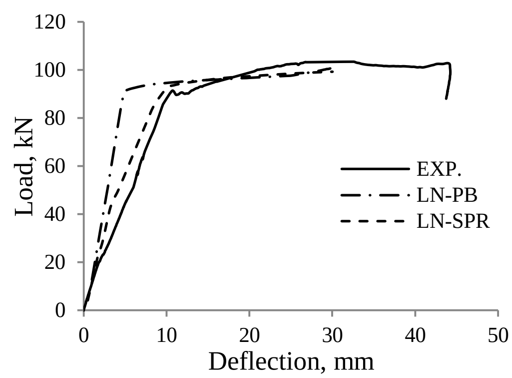

Figure 4. Stress strain curves for analytical models

In the analytic studies for LN-PB and LN-SPR models the initial stiffness was 15.12, 13.17 kN/mm, respectively. As seen in Fig. 7, until the yielding happened in longitudinal reinforcement, LN-PB behave more rigidly according to experimental results but LN-SPR, included bond slip effect, behave more similar to the experiments. In the LN-PB and

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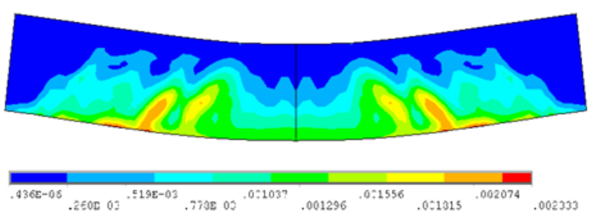
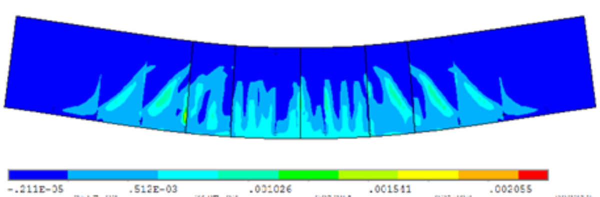
LN-SPR models when displacements were 5.13, 10.05 mm and loading were 91.46, 92.53, respectively, yielding happened in longitudinal reinforcement and crushing happened in concrete. According to these results loading values are very close to experimental results for all models. But in these loading levels, displacements obtained with difference 50.76% and 3.55% according to experimental results. After longitudinal reinforcement yielding, all analytical models curves had similar behaviors with experimental results. Maximum load values were 100.7, 99.24 kN for LN-PB and LN-SPR models and they were 2.5%, 3.93% and closer to experimental results

In the experimental study and in the FE models strains in longitudinal reinforcement were shown in Fig. 8. In the experiment member, in the regions where concrete tensile strength was exceeded cracks happened and adherence between reinforcement and surrounding concrete disappeared (Fig. 8(a)). That's why in these regions reinforcement and surrounding concrete had started different strains. In the LN-PB model when tensile strength in concrete exceeded, great strains happened (Fig. 8(b)). But because of perfect bond,

a) Test specimen



b) LN-PB



c) LN-SPR

Figure 8. Bond slip effect on strain distributions.

reinforcement and surrounding concrete went on strain together. So in the longitudinal reinforcement, some unrealistic strains happened. In the Fig. 9, strain curves happened in longitudinal reinforcement were given. In the longitudinal reinforcement, yielding happened in 10.42 mm in the experiment member but in models LN-PB it happened in 5.13 mm displacements. This clearly explained the reason of difference between load-deflection curves (Fig. 7). In the LN-SPR model which included bond slip relationships, strains were closer to experimental results (Fig. 8(c)). In these models, yielding in longitudinal reinforcement happened in 10.05 mm displacements (Fig. 9).

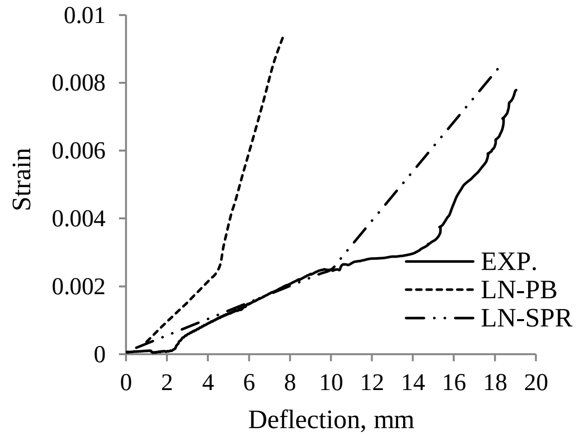


Figure 9. Strain deflection curves of longitudinal reinforcement.

V. Conclusion

In this study, bond slip effect in FE analyses of RC members were investigated and results were compared with experimental results. In FE analyses, because of the perfect bond assumption between reinforcement and surrounding concrete unrealistic strains occurs in longitudinal reinforcement after concrete cracked. This situation has greatly affected the load deflection relationship. Bond-slip relationship should be included to modeling with spring elements. ANSYS accurately predict the load deflection relations up to a point when compressive cracking becomes dominant.

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[Bond-slip relationship can be included to FEA with spring elements to simulate experimental behaviors of RC members]