13th International Congress on Civil Engineering, 9-11 May 2023
Iran University of Science and Technology, Tehran, Iran

A Study of Shear failure in beams and strengthening with bolted side plate (BSP)

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Abstract

For various reasons, reinforcement is inevitable. In this study, the method of strengthening reinforced concrete beams with bolted side plates (BSP) has been investigated. In order to validate the model, with the help of Abaqus finite element software, using the results of the laboratory model performed by Su et al. In 2010, the consistency of the software results was examined, which were acceptable. Then 14 different models were made in which the parameters: 1- Different width of reinforcement sheet 2- Different thickness of reinforcement sheet 3- Different angle of reinforcement sheet 4- Different length of reinforcement sheet were investigated. The results showed that by changing the sheet width from 75 mm to 300 mm, the beam resistance increases from about 160 KN to 240 KN (33%). Also, the change in the thickness of the steel sheet and the use of sheets with a thickness of 6 and 9 mm for the samples increased by 27% and 57 %. Sheets with 30, 45 and 60-degree angles were examined. The results showed that the smaller the angle of inclination of the sheet relative to the horizon, the more stress they can withstand in the sheets farther from the support.

Keywords: concrete beams, finite element method, steel sheets, strengthening, shear failure

1- INTRODUCTION

the method of strengthening reinforced concrete beams with bolted side plates (BSP) has a long history, although most researches on this method were focused on bending, and shear failure has been less investigated. In 2010, Siu investigated the effects of plastic hinges on partial interaction behavior of bolted side-plated beams, experimentally. The results revealed that the degree of partial interaction between RC beams and steel plates could be reduced by as much as 50% when the BSP beam proceeded from a linear to a non-linear stage in which plastic hinges have formed in critical sections. Consequently, the load-carrying capacity was reduced by up to 30% of the theoretical additional strength provided by the bolt–plate system. Li in 2013, in an experimental Study, tested a total of seven moderately reinforced BSP beams with different steel plate depths and various bolt spacings. In this study, the beams' behaviors were compared to the available test results for lightly reinforced BSP beams obtained by other researchers. The results show that moderately reinforced RC beams are more effective in increasing the flexural strength and ductility capacity using deeper steel plates than the use of a greater number of anchor bolts. In 2016, Li presented a new simplified flexural design procedure for BSP beams taking into account partial interaction. In this paper, an example is presented to illustrate the effectiveness of the optimized design method for BSP beams, considering the effect of partial interaction under realistic loading conditions. In 2018, Li developed a numerical model using the finite element method (FEM) software OpenSees to simulate the shear behavior of bolted side-plated (BSP) reinforced concrete (RC) beams. A parametric study was then conducted to reveal the variation of the shear performance with different factors, including the depth, thickness and yield strength of the bolted steel plates The accuracy of this theoretical model was then validated by comparing the prediction with the experimental and numerical results. Ketut Sudarsana in 2019 presented experimental results on the behavior of RC beams strengthening using full steel plates along the shear span fixed with bolts. Nine RC beams having dimension of 150x200x1500mm were tested to failure on simply supports with four point loadings setup. The beams were reinforced with tension rebars. The results show that the applications of steel plate and bolts as external reinforcement increase beam shear capacity, stiffness and delay the occurrence of first diagonal cracks. Beams strengthened with U-shape plates gave better performances than the beams with two pieces of L-shape plates due to better anchorages. Alasadi in 2020 investigated the flexural behavior of over-reinforced concrete beam enhancement by bolted-compression steel plate (BCSP) with normal reinforced concrete beams under laboratory experimental condition. Three beams developed with steel plates were tested until they failed in compression compared with one beam without a steel plate. The thicknesses of the steel plates used were 6 mm, 10 mm, and 15 mm. The beams were simply supported and loaded monotonically with two-point loads. The outcome of the experiment shows that the use of a steel plate can improve the failure modes of the beams and also increases the peak load and flexural stiffness. Karpiuk in presented experimental data on the bearing capacity of damaged reinforced concrete beams with the dimensions of 2000×200×100 mm, reinforced with prestressed metal casings. The authors of the article have developed a method and equipment for restoring and strengthening damaged reinforced concrete beams using a casing. The research results are presented in the form of experimental-statistical dependences of the bearing capacity of the support areas, deformability and crack resistance of the investigated elements on the ratio of the most significant design factors and external factors. ZhiZhang in 2022 in an experimental study aimed to investigate the flexural capacity of BSP beams with aluminum plates. The flexural strength, stiffness, and ductility of seven specimens with different plate thickness, plate height, bolts spacing, anchoring techniques, and prestressing were investigated. Compared with the reference RC beam, increasing the thickness of aluminum plates and reducing the spacing of bolts increased the bearing capacity and secant stiffness by 56% ∼ 66% and 33% ∼ 37%, and decreased the relative slips between aluminum plates and concrete, diminished the buckling in the compressive region of aluminum plates.

Considering the researched cases and paying attention to the fact that the research on the beams reinforced with the steel plate, which are prone to shear failure, has not been done so far, and it is necessary to investigate this issue and discuss it further.

2- NUMERICAL INVESTIGATION

We have used Abaqus finite element software to achieve the desired goals in the research. Concrete modeling is done with the well-known Concrete Damage Plasticity method (CDP). This model expresses the nonlinear behavior of concrete by using the concepts of isotropic damaged elastic and tensile and compressive plastic. The values of the parameters used in the damaged concrete plastic model are entered as follows.

Table 1. Values of parameters used in CDP model

Dilation Angle	Eccentricity	Fb_0/Fc_0	k	Viscosity parameter
36	0.1	1.16	0.667	0.5

Bilinear elastoplastic model has been used for steel modeling. The steel continues to the strain such as the yield stress (ε_y), linearly with the slope of Es and after that, linearly with a lower slope, until the point (ε_u). The modeling of concrete was carried out using the 3-dimensional elements of C3D8R continuous environment. The C3D8R element includes 8 nodes; each node has 3 degrees of freedom. Letter R seen in the name of the element represents the use of reduced integration., shell members are S4R type and for beam members are of type C3D8R. The loading of the beam enters the middle third of the beam. In the laboratory the control-displacement with slow load type is used. Because the static behavior of the concrete beam is intended, the load is applied slowly so that the dynamic components governing the problem are not activated. For this reason, we used non-linear static analysis in this research.

3- VALIDATION

In order to validate the finite element models, the reinforced beam model was first validated against results from an experimental study by …. The selected model is a concrete beam with a length of 3600 mm and cross-sectional dimensions of 225 x 350 mm. A lateral steel sheet with dimensions of 150 x 3600 and a thickness of 3 mm has been implemented to the beam for shear reinforcement. The compressive strength of the concrete used in the beam is 35 MPa. Figure 1 illustrates the specifications of this model. In modeling, due to loading symmetry, a half beam is modeled in software which is shown in figure 2. Figure 3 illustrates the result of the test.

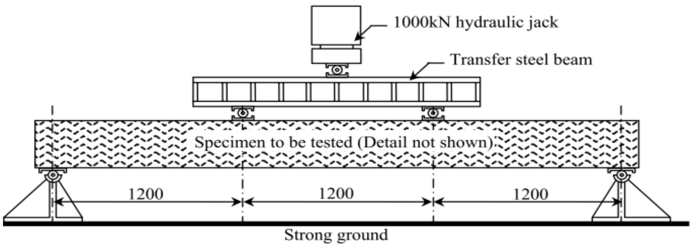

Figure 1. experimental model specifications

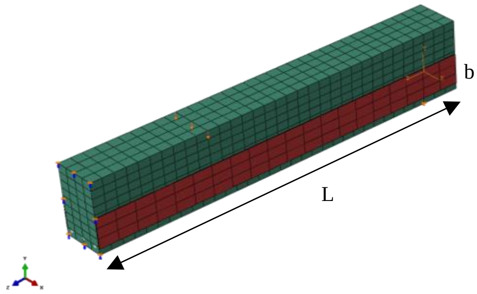

Figure 2. 3D model in the software.

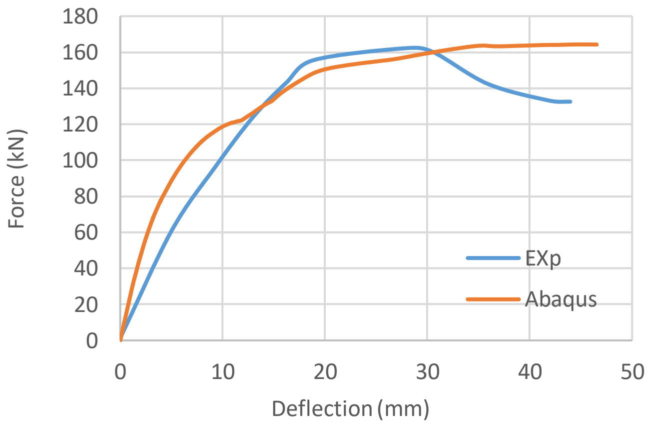

Figure 2. Validation results from the experimental model

The results obtained from the modeling confirmed the acceptability of the models developed by software.

4- SPECIMENS AND RESULTS

Table 2. illustrates the various parameters analyzed by this method, and the results will be represented in the following.

Table 2. specimens' specifications.

specimens	steel plate width (mm)	steel plate thickness (mm)	Steel plate length (mm)	Steel plate volume (cm^3)
Beam-b-75	75	3	1800	405
Beam-b-100	100	3	1800	540
Beam-b-200	200	3	1800	1080
Beam-b-300	300	3	1800	1620
Beam-t-3	75	3	1800	405
Beam-t-6	75	6	1800	810
Beam-t-9	75	9	1800	1215
Beam-SP-400	350	6	400	840
Beam-SP-800	350	6	800	1680
Beam-SP-1200	350	6	1200	2520
Beam-SP-1600	350	6	1600	3360
Beam-SP-800	350	6	800	1680
Beam-SP-1600-t3	350	3	1600	1680
Beam-SP-1200-t4	350	4	1200	1680
Beam-400-t12	350	12	400	1680

4-1- EFFECTS OF THE WIDTH OF REINFORCING PLATE

Figure (4) shows the load-displacement curves of the specimens. As can be seen, after passing through the linear region, a limited drop occurs, showing that cracks have been taken place in the beam. After that, the resistance of the side plate is added to the system. With the addition of this mechanism, the resistance of the sample increases again. Finally, by increasing the tension in the sheet and decreasing its hardness, the resistance value of the sample decreases.

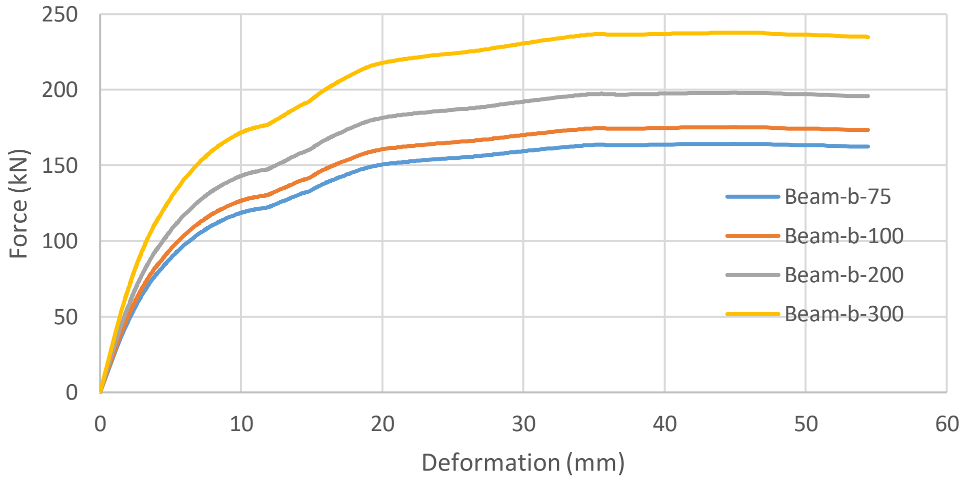

Figure 4. Load-deflection diagram of specimens

4-2- EFFECTS OF THE THICKNESS OF REINFORCING PLATE

It can be seen that the effect of the thickness of the plate has a considerable effect on the load capacity of the specimens. However, by increasing the thickness to a large amount, the stress in the steel decreases and the stress in the concrete increases, leading to premature failure in the concrete. On the other hand, increasing the thickness by 3 times increases the load capacity by just 57%, which may not be economically viable.

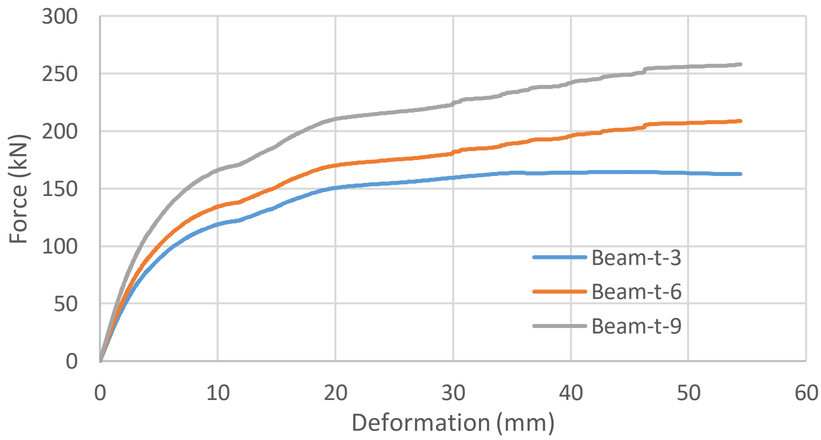

Figure 5. Load-deflection diagram of specimens with different plate thickness

4-3- EFFECTS OF THE LENGTH OF REINFORCING PLATE

In the specimen with a length of 400 mm plate, due to the fact that the length of the plate is short, the behavior of the beam with the reinforcement plate is more like the beam without reinforcement. But after adding the length of the reinforcement sheet, the behavior of the specimen is hardening. It shows that in the lengths of 800 to 1600 mm, the plate plays an effective role in bearing the beam.

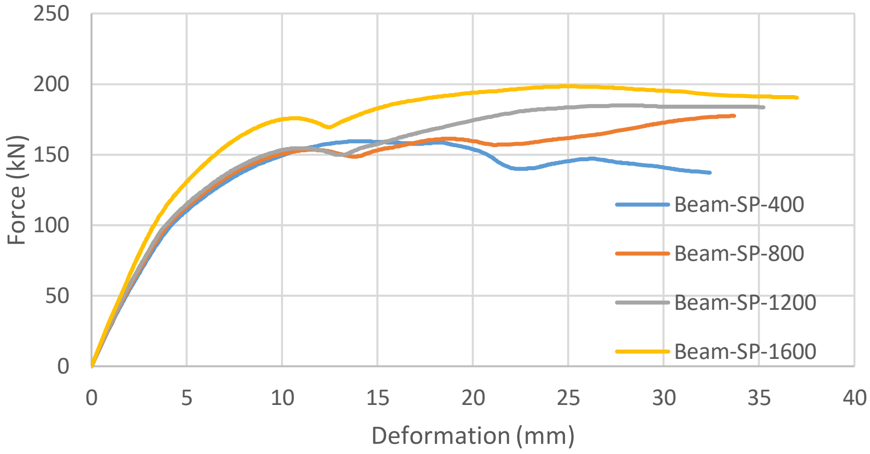

Figure 5. **Load-deflection diagram of specimens** with different plate length

4-4- PLATES WITH EQUAL VOLUME

Comparing the specimens of this part with the specimen without reinforcement (whiteout plate) in all reinforcement cases, we see a noticeable increase in the strength of the beam. It can be said that the resistance of the Beam-400-t12 has a higher resistance than other samples at a displacement of 10 mm, but with the continued loading of the sample, it suddenly drops, which can be due to the shortness and insufficient coverage of the beam by Steel plate. In general, the Beam-SP-800 sample behaves better than the other specimens, which can be concluded that for the same volume of reinforcement plate, reinforcing the beam with a sheet 800 mm long and 6 mm thick is the best choice.

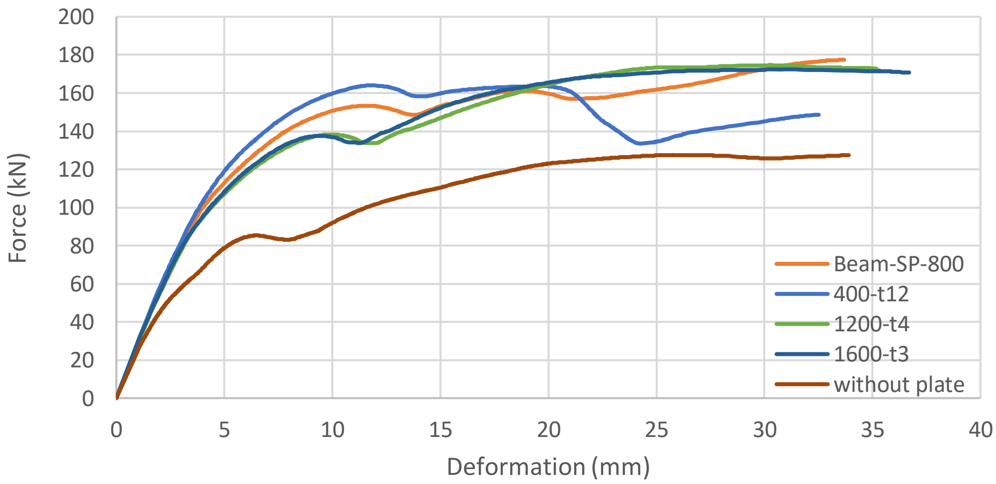

Figure 5. Load-deflection diagram of specimens with the same volume

5- CONCLUSIONS

specimens	steel plate width-b (mm)	steel plate thickness-t (mm)	Steel plate length-l (mm)	Plate volume (cm^3)	Ultimate stress (MPa)
Beam without plate	-	-	-	-	123
Beam-b-75-t-9- l-1800	75	9	1800	1215	257.92

Beam-b-75-t-6- l-1800	75	6	1800	810	208.67
Beam-b-75-t-3-l-1800	75	3	1800	405	164.32
Beam-b-100-t-3-l-1800	100	3	1800	540	172.54
Beam-b-200-t-3- l-1800	200	3	1800	1080	198.13
Beam-b-300-t-3- l-1800	300	3	1800	1620	219.92
Beam-b-350-t-6- l-400	350	6	400	840	159.40
Beam-b-350-t-6- l-800	350	6	800	1680	177.43
Beam-b-350-t-6- l-1200	350	6	1200	2520	184.76
Beam-b-350-t-6- l-1600	350	6	1600	3360	198.36
Beam-b-350-t-3- l-1600	350	3	1600	1680	172.34
Beam-b-350-t-4- l-1200	350	4	1200	1680	174.617
Beam-b-350-t-12- l-400	350	12	400	1680	164.02

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6- REFERENCES