Behavior of Reinforcement Concrete Beams Using Steel Strips as a Shear Reinforcements

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Abstract

An experimental and theoretical study on reinforced concrete beams using steel strip plates as a shear reinforcement instead of stirrups bars is presented in this paper. Five specimens with same dimensions and properties were used in this study. One of them has regular ties as shear reinforcements and is used as a reference beam. Other specimens used steel plates as shear reinforcements with an equivalent area of the regular ties of the reference beam. Four thicknesses of plates were used, 1mm, 2mm, 3mm, and 4mm. The experimental results showed a good agreement in term of the ultimate load within the range of 99.86 – 113.33 % of the ultimate load of the reference beam. The steel strips work as a regular tie to control the cracks (number and width). The analytical result showed that there is a good agreement between the numerical results and the experimental results in the term.

Keywords: Crack width, Finite element, Reinforced concrete, Shear reinforcement, Steel plates.

INTRODUCTION

Reinforced concrete (RC) beams should have acceptable shear reinforcement to prevent sudden and brittle failure after formation of the diagonal cracks, and also to keep the crack width within the acceptable level (Daou & Ghanem, 2003). Surviving RC beams with shear deficiencies ultimately need strengthening. Deficiencies may occur due to different factors such as insufficient shear reinforcement, reduction in steel area due to corrosion, increased service load, and design defects (Khalifa, Tumialan, Nanni, & Belarb, 1999). The purpose of shear reinforcement is to prevent failure in shear, and to increase beam ductility and subsequently, the likelihood of sudden failure will be reduced.

The type of shear reinforcements on RC beams has been studied by many researchers. (Abdul Hamid, 2005) showed experimentally that the use of additional horizontal and independent bent-up bars increased the RC beam resistance against shear forces compared to conventional shear reinforcement system. (Al-Nasra & Asha, 2013) investigated four different types of shear reinforcement that can be used in RC beams; traditional stirrups, welded swimmer bars, bolted swimmer bars, and u-link bolted swimmer bars. A swimmer bar is a small inclined bar with its both ends bent horizontally for a short distance. Their results showed an improvement in shear strength of RC beams by using swimmer bars in general. (Aziz & Yaseen, 2013) investigated the effect of type and position of stirrups of high-strength RC deep beams on the ultimate shear capacity. Three types of shear reinforcements were used; vertical stirrups, horizontal stirrups, and inclined stirrups. The results indicated that ductility and ultimate load capacity were improved by using vertical with horizontal stirrups and vertical with inclined stirrups. (Sinaei, Shariati, Abna, Aghaei, & Shariati, 2012) used ABAQUS program to model the behavior of reinforced concrete (RC) beams. In the finite element model, they used concrete damaged plasticity approach where this model can help to confirm the theoretical calculations as well as to provide a valuable supplement to the laboratory investigations of behavior. For validation, a reinforced concrete beam was modeled that had been experimentally tested and reported in previous experimental research. This is followed by a comparison of the finite element with the experimental results for the RC beam element. Their study was compared the numerical results with experimental data for the reinforced concrete beam subjected to flexural loading. The results indicate that the displacement, tensile strain for the main reinforcement, compressive strain for concrete and crack patterns obtained from the finite element model (FEM) were well matched with the experimental results. (Sihua, Ze, & Li, 2015) used the nonlinear analysis of a reinforced concrete beam was based on the finite element analysis software ABAQUS. Plasticity model of concrete damage was employed for simply supported reinforced concrete beam analysis. Their results of the experimentation and the ABAQUS analysis were compared in a diagram, accordingly, reasons of the result difference between the two methods were discussed, which can be a useful reference for the further study of the nonlinear analysis of reinforced concrete.

(Tejaswini & Rama Raju, 2015) presented a study to compare experimental results with the ABAQUS results. Initially, they investigated laboratory tests on a beam of 1200 × 200 ×100 mm of M30 grade concrete for plain, under, balanced, over reinforced sections. Finite Element Analysis (FEA) had also been performed using ABAQUS for the model geometry considered in the experimental study. Their numerical results from the FEA were compared with the experimental results which showed that good agreement between the results.
The main goal of this study is confined to study the effect of using steel strips as a shear reinforcement instead of steel bar stirrups. The use of this type of reinforcement decreases the crack width, a number of cracks, and cracks spacing. Therefore, it will lead to maintain the confinement of the concrete core of section and increase the ultimate strength of RC beam.

EXPERIMENTAL PROGRAM

Experimental program was mainly designed to study the effect of using steel strip plates as shear reinforcements in RC beams in shear zone instead of regular steel bar stirrups. A total of five RC beams were constructed with same materials and geometry. The total length is 1200 mm with 150 × 150 mm cross-sectional dimensions as shown in Figure 1. All beams were cured for 28 days under field conditions. The longitudinal and shear reinforcement for reference concrete beams and other beams that have the same shear reinforcement of strip stirrups are shown in Figure 2. RC beams were casted and tested at the laboratories of civil engineering in AL-Qadisiyah University.

Materials Properties

In this research, Portland cement (Type V) was used, Crushed limestone with a (5-19) mm size and specific gravity of 2.60 was used as coarse aggregate according to Iraqi standards specifications (IQS) NO. 45 / 1984. Natural sand from the Al Najaf sea region was used, zone 2 according to IQS:45 1984 with 2.87 fineness modulus. Volumetric mixing ratio of (1:2:4) with water/cement ratio (w/c) = 0.45 was adopted. The average compressive strength of the concrete mix for 7 and 28- days were 18.6 and 20.4 MPa, respectively using 150 × 150 × 150 mm cube tests.

Steel reinforcement (bars and plates)

All beams were reinforced with 2012 mm as main reinforcement. The shear reinforcement used for reference beam B0 was a regular ties (Ø 10 @ 109 mm), while other beams (B1, B2, B3, and B4) were reinforced by steel plates with different thicknesses 1 mm, 2 mm, 3 mm, and 4 mm, respectively as shown in Figure 1 and Figure 2. The number of plates used as ties was equal to the number of regular ties of reference beam B0 and have the same arrangement and length. From the equivalence between regular ties area and steel plate area the width of steel plate (w) was calculated as follow:

\[(A_t \cdot f_{fy}) = (A_p \cdot f_{yp})\] plate

\[A_p = w \times t\]

\[A_t = \text{area of ties}\]

\[A_p = \text{area of steel plate}\]

\[w = \text{width of steel plate}\]

\[t = \text{thickness of steel plate}\]

Sample of each type of using bars and plates was tested by universal testing machine (UTM). The experimental stress-strain relationship for the steel plate with 1 mm thick is shown in Figure 3 and the test results of the steel plates and bars were listed in Table 1.

TESTING PROCEDURE

All RC beams were tested under three points flexural using a 200-kN-capacity hydraulic actuator with a loading rate of 0.05 mm/sec as shown in Figure 4. All beams were monotonically loaded until a significant drop in the load was observed. A 3 mm thick steel plate were used at mid span to ensure a uniform loading distribution. A dial gauge was attached to bottom mid-span to record the displacement. A hand-held microscope crack meter with an ±0.02 accuracy was used to measure the cracks width at each loading stage and failure.

ABAQUS MODELLING

The nonlinearity of RC structures is divided into three types: material nonlinearity, geometric nonlinearity, and boundary conditions nonlinearity. Material nonlinearity refers to the elastic properties as the linear phase and to the plastic properties as the nonlinear phase analysis of steel and concrete materials. In ABAQUS, the linear stage can be defined by the elastic modulus and Poisson's ratio of concrete and steel materials. In nonlinear stage, it is different since the plastic stage of stress-strain relationship for steel reinforcement must be defined. However, for concrete plastic stage, there are three models can be employed; concrete smeared cracking, concrete damaged plasticity and cracking model for concrete in ABAQUS/Explicit (Sihua, Ze, & Li, 2015). The plasticity model of concrete damage was used in this research and it has a good convergence. The change of boundary conditions (the contact between the members was included) in the analysis process produces a boundary nonlinearity problems. Frictional contact between the steel and concrete in ABAQUS was achieved by using embedded technology. The simulation of a RC members requires an accurate model of the structural elements. A sketch of each part was created separately with ABAQUS, using a 3D solid element in “modeling space” using deformable type for concrete beam as shown in Figure 5. An 8-node solid element as shown in Figure 6 with each node has three degrees of freedom (translations in the nodal x, y, and z directions) was utilized. The element has the ability to define the plastic deformation, cracking in three orthogonal directions, and crushing. A steel plate was used in the model with perfect bond with the surrounding concrete in loading and supports regions to avoid the stress concentrations around the loading and support points (Sinaei, Shariati, Abna, Aghaei, & Shariati, 2012). All reinforcements were modeled using truss elements. The reinforcements were connected to the surrounding concrete using embedded region constraint in ABAQUS, which allows each node in the reinforcement element to connect properly to the nearest concrete node. This type of bond does not include
the slip between the reinforcements and concrete nodes. However, the bond-slip effect was partly considered through the definition of the concrete tension softening.

RESULTS AND DISCUSSION

In order to carry out the analysis and comparison between FEA and experimental test results conveniently, the load in ABAQUS was applied incrementally, the result was calculated, and the data of mid-span deflection and drawing the graphs were gathered. Deflection was measured at midspan at the center of the bottom face of the concrete beam. Figure 7 shows the load-deflection curve of the reference RC beam for both the experimental and numerical data. In general, the load-deflection curve for the beam from the numerical results showed an excellent agreement with the experimental data. A comparison FEA results of the RC beams with the steel strips as a shear reinforced with those observed in the laboratory were shown in Figure 8 to Figure 11. It can be seen from these figures that good agreements between the experimental results and FEA results.

Table 2 shows the experimental and numerical results of five RC beams under concentrated load at mid span. Maximum crack width at failure was measured and listed in this table. As can be seen from this table, the experimental and numerical data of mid-span deflection and drawing the graphs were gathered. Deflection was measured at midspan at the center of the bottom face of the concrete beam. Figure 7 shows the load-deflection curve of the reference RC beam for both the experimental and numerical data. In general, the load-deflection curve for the beam from the numerical results showed an excellent agreement with the experimental data. A comparison FEA results of the RC beams with the steel strips as a shear reinforced with those observed in the laboratory were shown in Figure 8 to Figure 11. It can be seen from these figures that good agreements between the experimental results and FEA results.

Table 2 shows the experimental and numerical results of five RC beams under concentrated load at mid span. Maximum crack width at failure was measured and listed in this table. It is clear from experimental results inducted in Table (3) and Figure 8 to Figure 11 that the RC beams that reinforced in shear zone by steel strips have a good agreement with reference beam B0 that reinforced in shear zone by regular ties, as shown in Figure 12. Good agreement was achieved between the experimental and FEA results with differences not exceeded to 3%. The RC beams B1, B2, B3, and B4 with thickness of 1mm, 2mm, 3mm, and 4mm, respectively provided about 106.7%, 99.86%, 100.1%, and 113.33% of ultimate load from the reference RC beam B0 (with regular ties), respectively. Test results showed that the behavior of all the RC beams were quite the same because using the same equivalent shear area. It can be seen that FEA by ABAQUS can be basically consistent with the experimental test results, but there were some differences between the values calculated by the analysis and the test. The reason may be to the fact that finite element simulations was assumed to have a uniform, isotropic and the same contact form between cells. However, the constitution of actual concrete is very complex. The Complicated action between concrete components cannot be easily replaced by unified form. Moreover, the bond between concrete and reinforced steel in FEA is represented using the embedded technology to simplify the modeling process. However, it cannot be achieved with the increased load of RC and changing nature of the friction moment, especially reinforced slip simulation. This can easily lead to distorted results.

CRACK PATTERN

The general failure modes of all RC beams were represented by cracks development. Cracks in the concrete beams are formed generally in regions where the tensile stresses exist and exceed the specified tensile strength of concrete. During the loading process, several micro flexural cracks appeared early at mid span in the all tested beams. These cracks were extended and widened as the load increased. Cracks were observed in the beams, which resulted from flexural tensile stresses in the region of the beam cross-section below the neutral axis for positive bending moment. Comparison of the concrete crack patterns from the FEA results with those observed in the laboratory is shown in Figure 13.

In general, flexural cracks occurred early at mid span. When the applied loads increased, vertical flexural cracks spread horizontally from the mid span to the support. At a higher load level, diagonal tensile cracks appeared. Increasing the applied loads induced additional diagonal and flexural cracks. Shortage of cracks may be due to a decreased in the net spacing between the stirrups (steel strips), which meaning that increasing in confinement of concrete due to increasing width of steel strips. There was a good agreement between the FEA and the experimental data for the concrete crack patterns. From experimental tests, it can be noticed that the maximum crack width and number of cracks decreased as the strip width increased, as shown in Table 2. As can be seen from this table, the first crack load was decreased as the strip width increased. Also at the failure showed the deformation of steel strips, especially for the strips, which are thickness of 2 mm and 1 mm clearly and this may be explained that the steel strips suffer from axial and bending stresses.

CONCLUSIONS

In this paper, experimental test and nonlinear FEA of rectangular RC beams that use steel strips instead of bar strips were investigated. Based on the present results, the following conclusions may be drawn:

1. The steel strips could be used to enhance the shear capacity of RC beams.
2. Using steel strips as stirrups showed a good agreement with reference beam up to 99.86 – 113.33 % of ultimate load.
3. The steel strips can control the cracks width and reduce the length and number of cracks as a regular tie.
4. The comparison between the FEA and the experimental test results gave a good agreement in terms of ultimate load, failure mode, and crack pattern.
5. Increasing the width of the steel strips reduces the number and width of the cracks.
6. Some steel strips could suffer from deformations especially steel strips with thickness 1mm, and 2mm.
Table 1: Properties and dimensions of bars and steel plates

<table>
<thead>
<tr>
<th>Material type</th>
<th>f_y (MPa)</th>
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<tbody>
<tr>
<td>Ø 10 bar</td>
<td>446</td>
</tr>
<tr>
<td>Ø 12 bar</td>
<td>526</td>
</tr>
<tr>
<td>Plate (t=1 mm)</td>
<td>480</td>
</tr>
<tr>
<td>Plate (t=2 mm)</td>
<td>302</td>
</tr>
<tr>
<td>Plate (t=3 mm)</td>
<td>266</td>
</tr>
<tr>
<td>Plate (t=4 mm)</td>
<td>328</td>
</tr>
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</table>

Table 2: Experimental and Finite element results of RC beams

<table>
<thead>
<tr>
<th>Beam No.</th>
<th>Thick. of Strips t_s (mm)</th>
<th>Dimension of Strip w × d (mm)</th>
<th>Cracking load P_c (kN)</th>
<th>Exp. Ultimate load P_uexp (kN)</th>
<th>Num. Ultimate load P_uhn (kN)</th>
<th>Rate in ultimate load respect to B0 (Ref.) (%)</th>
<th>P_uhn/P_uexp (%)</th>
<th>Obser. Max. crack width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B0 (Ref.)</td>
<td>-</td>
<td>-</td>
<td>25.2</td>
<td>53.63</td>
<td>54.89</td>
<td>100</td>
<td>102.35</td>
<td>0.92</td>
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<tr>
<td>B1</td>
<td>1.0</td>
<td>73×110</td>
<td>19.8</td>
<td>57.20</td>
<td>58.33</td>
<td>106.7</td>
<td>101.97</td>
<td>0.68</td>
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<tr>
<td>B2</td>
<td>2.0</td>
<td>58×110</td>
<td>23.6</td>
<td>53.56</td>
<td>54.96</td>
<td>99.86</td>
<td>102.61</td>
<td>0.72</td>
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<tr>
<td>B3</td>
<td>3.0</td>
<td>44×110</td>
<td>24.8</td>
<td>53.70</td>
<td>54.55</td>
<td>100.10</td>
<td>101.58</td>
<td>0.78</td>
</tr>
<tr>
<td>B4</td>
<td>4.0</td>
<td>27×110</td>
<td>26.8</td>
<td>60.28</td>
<td>61.35</td>
<td>113.33</td>
<td>101.77</td>
<td>0.84</td>
</tr>
</tbody>
</table>
Figure 1: Geometrical and reinforcement details of concrete beams

Figure 2: Bars and steel plates used in RC tested beams

Figure 3: Experimental stress-strain relationship of steel plate with thickness 1 mm

Figure 4: Simply supported RC Beams under test

Figure 5: Assembly of Parts (concrete members, main reinforcement, strip stirrups)
Figure 6: FEM mesh for concrete and reinforcement

Figure 7: Load-deflection response for reference beam (B0)

Figure 8: Load-deflection response for RC beam (B1)

Figure 9: Load-deflection response for RC beam (B2)

Figure 10: Load-deflection response for RC beam (B3)
Figure 11: Load-deflection response for RC beam (B4)

Figure 12: Experimental results of RC beams

<table>
<thead>
<tr>
<th>Beam No.</th>
<th>Experimental Test</th>
<th>ABAQUS Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>B0</td>
<td><img src="image" alt="Experimental Test Image" /></td>
<td><img src="image" alt="ABAQUS Models Image" /></td>
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<tr>
<td>B1</td>
<td><img src="image" alt="Experimental Test Image" /></td>
<td><img src="image" alt="ABAQUS Models Image" /></td>
</tr>
<tr>
<td>B2</td>
<td><img src="image" alt="Experimental Test Image" /></td>
<td><img src="image" alt="ABAQUS Models Image" /></td>
</tr>
<tr>
<td>B3</td>
<td><img src="image" alt="Experimental Test Image" /></td>
<td><img src="image" alt="ABAQUS Models Image" /></td>
</tr>
<tr>
<td>B4</td>
<td><img src="image" alt="Experimental Test Image" /></td>
<td><img src="image" alt="ABAQUS Models Image" /></td>
</tr>
</tbody>
</table>

Figure 13: Crack Pattern of experimental tests and FEM at failure
REFERENCES


