Interaction between Theory and Practice in Civil Engineering and Construction
Edited by Komurlu, R., Gurgun, A. P., Singh, A., and Yazdani, S.

ISBN: 978-0-9960437-2-4

THE EFFECT OF REINFORCING ARRANGEMENT ON THE BEHAVIOR OF REINFORCED CONCRETE FLANGED DEEP BEAMS WITH WEB OPENINGS

ABBAS HILO ALI

Iraqi Ministry of Water Resource, Baghdad, Iraq

The objective of the work is to investigate the structural *behavior* of reinforced concrete flanged deep beams with web openings under repeated loading through experimental tests which were carried out on simply supported T- beams , subject to two point loads. This work deals with the results of experimental work with three test specimens with square opening 25% of web depth at mid high through critical shear path. The effect of steel reinforcement arrangement for web opening is investigated. The experimental tests of sections under repeated loading showed that reinforcement of web opening increased the cracking and ultimate loads. It is observed that reinforcement for opening reduced the deflection and the crack width. The inclined reinforcement results are better than orthogonal.

Keywords: Reinforced concrete, Web reinforcement, Repeated loads, Flange.

1 INTRODUCTION

Reinforced concrete deep beams are widely used in many structural engineering applications, such as, transfer girders piles cap, offshore structures (caisson), shear wall, wall footings, floor diaphragms, and complex foundation system. When the span to depth ratio of simply supported beam is less than 2, or less than 2.5 for any span of a continuous beam, then these beams are considered as deep beams (Park and Paulay 1975).The ACI Building Code 318-08 Deep beams are members loaded on one face and supported on the opposite face so that compression struts can develop between the loads and the supports, and have either:

- Clear spans, l_n, equal to or less than four times the overall member depth; or
- Regions with concentrated loads within twice the member depth from the face of the support.

Deep Beams are structural element loaded as beams but having a large depth/thickness ratio and a shear span/depth ration not exceeding 2 for concentrated load and 4 for distributed load, where the shear span is the clear span of the beam for distributed load. In many instances reinforced concrete slab together with the beams behave as a T section, stronger compression zone provided by flanges in T section generally precludes shear compression failure in T beams and as a result has shear strength higher than the shear strength of rectangular sections (Hawy 2005).

1.1 Behavior of Deep Beams

Deep beams differ from the common flexural members in that they behave as two-dimensional rather than one-dimensional members and are subjected to a two-dimensional state of stress. This difference in *behavior* is mainly attributed to the significant effects of vertical normal stresses and shear deformations in these members (Kani 1969). In deep beams the stress distribution with depth is nonlinear even at the elastic stage (Subedi 1986). The strength of deep beams is usually controlled by shear, rather than flexure, provided that normal amount of longitudinal reinforcement are adequately used. The main parameters governing the deep beam *behavior* are the span/depth ratio, shear span/depth ratio, slenderness (depth/thickness) ratio, main and web reinforcement, and the loading and supporting condition (ACI 2008).

1.2 Effects of Web Opening

Maximum crack width at failure will be greater when the opening center is located at the center of the shear zone than at any other position. So location of the opening center at this point is undoubtedly the maximum damaging situation in the web region. The strength of the beam increases when the opening is located away from what can be called the loaded quadrant to the unloaded quadrant and vice-versa. The location of the web opening is therefore a major factor influencing the strength of the beam. It should be remembered that the deflection in deep beams are substantially influenced by shear and, as such, location of the opening in the region of high shear and intercepting the critical path is understandable. The openings should invariably be provided with some loop reinforcement in their periphery to avoid possible stress concentration. The web reinforcement controls crack widths and deflection. Of all types of web reinforcement, the inclined type placed perpendicular to the plane of rupture (critical diagonal crack) has been found to be the most effective arrangement. The next practical and effective type is the horizontal web steel which with nominal vertical web steel may further increase the effectiveness of the beam and so its strength. It was observed that in beams with web openings, horizontal web reinforcement distributed equally on either side of the opening location showed better results (Kong 2002).

2 EXPERIMENTAL TEST PROGRAM

2.1 Materials

All materials used in experimental investigations are available in local market, which include cement, natural gravel, natural silica sand, water, and deformed reinforcement bars. All materials are tested according to Iraqi specifications.

2.2 Concrete Mix

The quantities of cement, fine aggregate and course aggregate based on dry weights were as follows: (Cement 1:Sand 1.5:Gravel 3) Water/ cement ration (W/C ratio= 0.55) The mix was designed to give a compressive strength of about 30 N/mm2 at age of 28 days and slump of about 80 mm. The same concrete mix was used throughout the whole investigation. Tilting drum mixer was used; mixing was carried out according to BS 1881.

2.3 Testing the Properties of Concrete

During the casting of each group of beams, three (150 x150x150) mm cubes and three (100 x 200) mm cylinders were made. The cube compressive and splitting tensile strength were obtained by testing three cubes and three cylinders according to BS 1881.

2.4 Description of Tested Deep Beams

TB#1 is designed according to CIRIA Guide 2 (1977), which is summarized in Table 1, gives 4-ø10 mm for main reinforcement, ø6 at 150 mm for vertical web reinforcement and ø6 at 200 mm for horizontal web reinforcement. All beams have length of 1300 mm , depth of 400 mm, flange width of 300 mm, flange thickness of 60 mm , web thickness of 120 mm and the distance between the supports center / center are 1000 mm, with web square opening (100 x 100) mm (Figure 1). In this study, Two type of reinforcing arrangement for web opening used in this study, orthogonal for TB#2 and inclined for TB#3, by using same bar diameter all changes above were with same main reinforcement at TB#1.

Table 1. Details of reinforcement for specimens.

I	specimen Symbol	Main reinforcing	Web reinforcing Vertical	Web reinforcing Horizontal	Flange reinforcing	Opening reinforcing	Loading type
1	TB#1	4 ø 10 mm	ø 6@150 mm	ø 6@200 mm	ø 6@200 mm	None	repeated
2	TB#2	4 ø 10 mm	ø 6@150 mm	ø 6@200 mm	ø 6@200 mm	ø 6 Orthogonally	repeated
3	TB#3	4 ø 10 mm	ø 6@150 mm	ø 6@200 mm	ø 6@200 mm	ø 6 Inclined	repeated

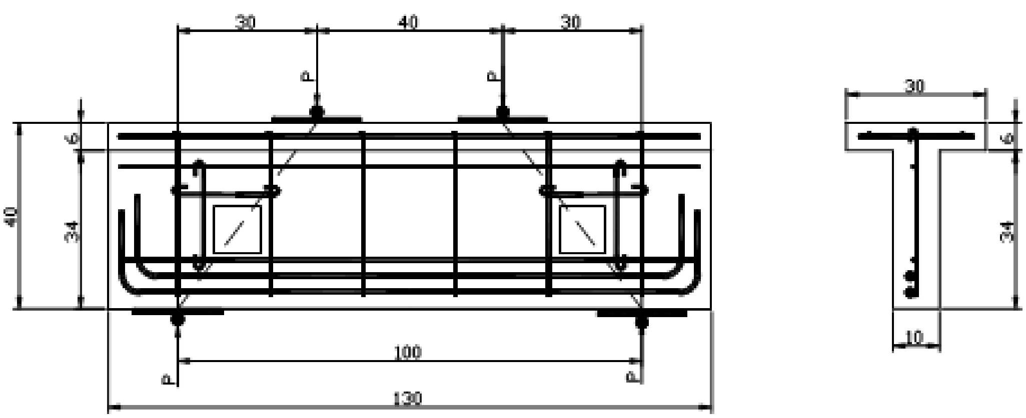

Figure 1. Description of tested specimens.

2.5 Fabrication and Casting of Beams

Timber forms with plywood face were used in casing beams, the interior face of forms were coated with oil prior casting and before the reinforcement cage was placed in position, plastic spacers were used to maintain the concrete covers, the concrete mix was then placed in layers and each layer compacted by means of Poker vibrator, the top surface of the beam was finished level by a hand trowel. After the mold is stripped, the beams were cured for seven day after casting by using damp canvas.

2.6 Testing Equipment and Instrumentations

Below is a list of equipment and instrumentations used during experimental work:

- Machine of load applying: Torsee Universal Testing Machine with a capacity of 2000 kN was used to apply the load**.**
- Electrical strain gauges: TML strain gauges.
- Data Acquisition System: The data acquisition system used in this study includes personal laptop computer, strain indicator which has 16 channels named Data Taker (data logger) DT85 – Australian made 2010.
- Measurement of deflection: The mid-span deflection of each beam was measured by using dial gauge with magnetic base. The accuracy of the dial gauge was 0.01 mm.
- Micro-Crack reader: Width of concrete cracks was monitored using hand microscope of accuracy 0.02 mm per division.

2.7 Test Procedure

- **Loading for first crack**: Loading initiated from zero with slow rate about 1 kN and recorded the data readings for strains and deflection until detected the first crack,. Then loading was stopped to measure the values of crack width by crack detector device and the load value. If that crack was diagonal crack then item 2 below performing, if not the loading continue until detecting the first diagonal crack.
- **Loading repeating**: When detecting the first diagonal crack, some cycles of loading and unloading performed during this stage for minimum five times, the loading and unloading performed in gradual increment and decrement in a suitable rate. During these individual steps, deflections, strains, crack width readings were recorded. If specimen did not, the loading increased by (25 kN), some cycles were performed about five times. If specimen did not, the loading increased by (25 kN), some cycles were performed for about five times. If specimen did not failed, the loading increased by (25 kN), some cycles were performed of about five times. If specimen did not failed, the loading increased by (25 kN), some cycles performed about five times, If specimen did not failed in this step the test continued to failure.

- **Loading to failure**: When the loading was increased to next loading step some specimens were fail and a test terminated when the total load applied on the specimens was started to drop off.

3 TEST RESULTS AND DISCUSSION

The test results can be seen on Figure 2 and Table 2.

3.1 Effect on Cracking and Ultimate Load

It is observed that cracking load for beam with web opening reinforcement arranged orthogonally TB#2 and arranged inclined TB#3 was increased by about 50% than without open reinforcement TB#1, but it was equal for TB#2 and TB#3.Ultimate load was increased by 14% for TB#2 and 48% for TB#3 than ultimate load for TB#1, and the ultimate load for TB#3 was more than for TB#2 by 26%.

Table 2. Experimental cracking load and ultimate loads for the tested specimens.

Specimen symbol	Cracking Load V_{cr} (kN)	Ultimate Load V_u (kN)	V_{cr} / V_u
TB#1	20	74	0.27
TB#2	30	87.5	0.34
TB#3	30	110	0.27

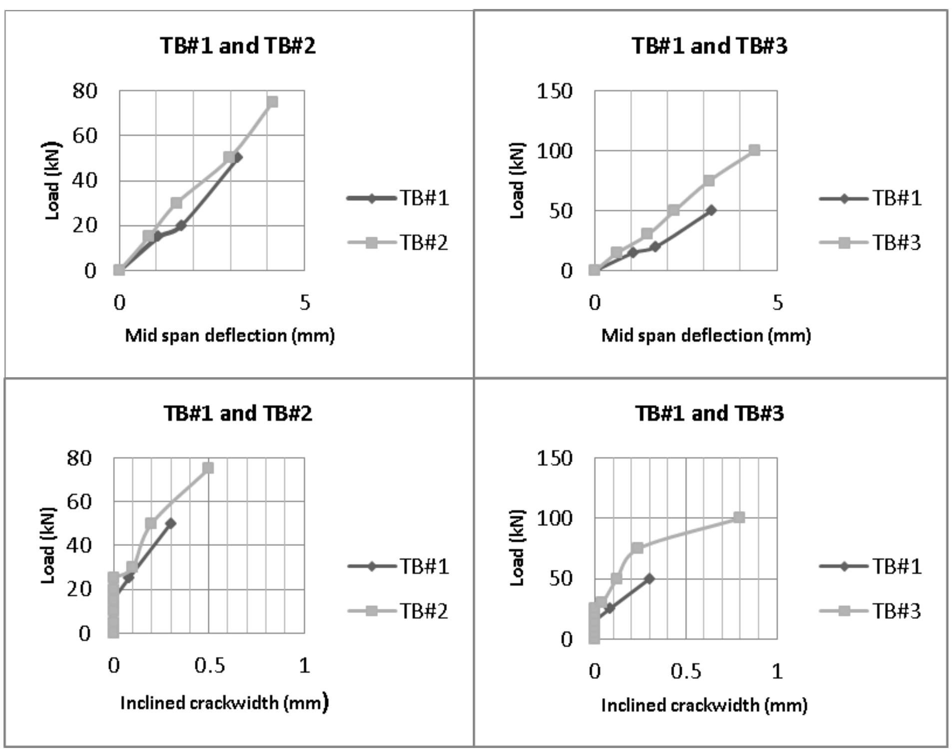

Figure 2. Charts of test results.

3.2 Effect on deflection

It is observed that reinforcing for opening was reduced the deflection, and the inclined reinforcing was gave better result than orthogonally web opening reinforcing under repeated loading.

3.3 Effect on Crack Width

It is observed that reinforcing for opening was reduced the crack width, and the inclined reinforcing gave better result than orthogonally reinforcing under repeated load.

3.4 Web opening Reinforcement Strain

Two electrical strain gauges were installed on web opening reinforcement bars for specimen TB#2, one on horizontal web opening reinforcement under web opening point number 5 and one on vertical web opening reinforcement near web opening point number 6, it is observed that the stain at these point was very close until inclined cracking, and after inclined cracking the values were varied, in stage of loading repeated on cracking load stage, the strain in vertical web reinforcement was higher, but when loading reached about 70% of cracking load stage the strain in horizontal web reinforcement was increased more than vertical until load reached to ultimate loading the strain in vertical web reinforcement return to be higher than in horizontal bars. One electrical strain gauge was installed on inclined web opening reinforcement point number 4 in specimen TB#3 top of opening it is observed that the strain at point 4 was increased more than strain in points (5 and 6) in TB#2 after inclined cracking.

4 CONCLUSIONS

The experimental tests of sections under repeated loading showed that reinforcement of web opening increased the cracking and ultimate loads and reduced the deflection and the crack width. The inclined reinforcement results are better than orthogonal.

References

ACI 318-08, *Building Code Requirements for Structural Concrete (318-08) and Commentary (318-08)*, American Concrete Institute, Detroit, 2008.

Construction Industry Research and Information Association (CIRIA), CIRIA Guide 2, London, 1977.

Park, R. and Paulay, T., *Reinforced Concrete Structures*, John Wily and sons, 1975.

Kong, F. K., *Reinforced Concrete Deep Beams*, Taylor and Francis Inc., 2002.

Kani, G. N. J., *A Rational Theory for the Function of Web Reinforcement*, ACI Journal, Vol.66, No.3, Mar., 1969.

Subedi, N. K., et al., *Reinforced Concrete Deep Beams _ Some Test Results*, Magazine of Concrete Research, Vol. 38, No. 137, Dec. 1986.