Engineering and Technology Journal Vol. 38, Part A (2020), No. 04, Pages 605-613

Engineering and Technology Journal
Journal homepage: engtechjournal.org

Strut Confinement of Simply Supports Deep Beam Using Strut Reinforcement

Eyad K. Sayhood[a*], Khudayer N. Abdullah[b], Sarah J. Kazem[c]

[a] Civil Engineering Department, University of Technology, Baghdad; Iraq.
dr_eyad_alhachamee@yahoo.com

[b] Civil Engineering Department, University of Technology, Baghdad, Iraq. 40024@uochnology.edu.iq

[c] Civil Engineering Department, University of Technology, Baghdad, Iraq. Sarahjawad.sj@yahoo.com

*Corresponding author.

Submitted: 28/03/2019 Accepted: 24/08/2019 Published: 25/04/2020

K E Y W O R D S

Deep beam, Strut confinement, Strut reinforcement.

A B S T R A C T

This study investigates the effect of confining the Strut region of the deep beam by using Struts Reinforcement; which consists of four main bars enclosed by stirrups. Six specimens were tested for investigating the behavior of deep beams including; ultimate load, mid-span deflection, crack pattern, first shear and first flexure cracks, concrete surface strain and mode of failure. The specimens were tested under two symmetrical points load with and of 1 and compressive strength of 38 MPa. The main parameters were: first one the diameter of the main bars of Strut Reinforcement (8, 10, 12 mm) with constant spacing of stirrups equal to 80 while the other parameter was varied spacing of stirrups of strut reinforcement (120, 100, and 80 mm) with constant main bars diameter of 8 mm. The test results showed that the Strut confinement generally increased the ultimate load from 750 kN to 1250 kN and the ductility of the beam, confined shear cracks and strain surface across the strut and shear area and turned failures mode from shear failure to flexure. The increase in the diameter of the main bars enhanced the behavior of the beam more than the stirrups number.

How to cite this article: E. K. Sayhood, K. N. Abdullah and S. J. Kazem, “Strut confinement of simply supports deep beam using strut reinforcement”, Engineering and Technology Journal, Vol. 38, Part A, No. 04, pp. 605-613, 2020.
DOI: https://doi.org/10.30684/etj.v38i4A.117

1. Introduction

The deep beam is the structure that has a large depth compared with clear span (Ln) that measured from face to face of the supports. According to ACI 318 M-14 [1] code; The deep beam is a member with clear span ≤ 4d and the concentrated load located within the area ≤2h measured from the face of the support. There are many applications for deep beam in building fields, it can be used as transfer-girder in bridges or high multi-story building, foundation beam and deep grid walls in offshore

structure … etc. The assumption of the plain section remain plane after bending that valid for shallow beam doesn't valid for deep beam and the strain distributed in non- linear way over the depth of the deep beam under loading [1‹2], thus deep beam is defined as a type of discontinuity region and usually controlled by shear rather than flexure due to the geometrical proportion of the deep beam. Because of the action of internal forces on the deep beam the strength of deep beam, usually greater than that predicted using the method of the shallow beam [3], as a result, the prediction of strength of deep beam must be based on nonlinear analysis [2].
The mechanism of load transfers from point load to the support is defined as load path conception where the force transmitted directly to the support through compression-strut [4] Figure 1 shows Strut and Tie model based on load-path conception.

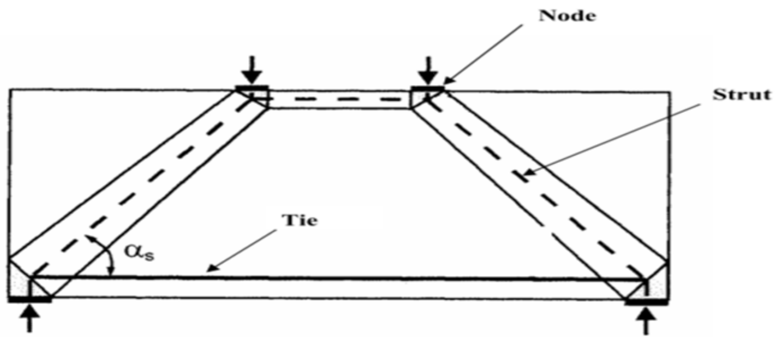


Figure 1: Strut and tie model of the deep beam [5]

Many types of research interested in studying the behavior of deep beam, investigating the effect of different factors on deep beams, strengthening and predicting its ultimate strength. A considerable increase in ultimate strength due to the increase of shear span to depth ratio was investigated by Smith and Ventosiotis [3]. The effect of vertical and horizontal reinforcement of deep beam were studied by Aguilar and Matamoros [6]. Park and Kuchma [7] used the strut and tie model to estimate the shear strength of the reinforced deep beam and provided a consistent rule for cracked reinforced concrete and formulation of secant stiffness using considering the strain compatibility.
Ashour and Yang [8] predicted the shear strength of the deep beam using struts and tie model based on cracks band theory. AL-Bayati [9] studied behaviors of the reinforced deep beam that cast from lightweight porcelanite aggregate and the effect of increasing compressive strength, shear span to depth ratio and vertical and horizontal reinforcement.

2. Experimental Program

Six deep beams were tested under two symmetrical point load. The specimen dimensions were (400 mm depth, 200 mm width, and 1500 mm length). The beams were made from NC (normal concrete) with compressive strength equal to 38 MPa. The reinforcement of the deep beams consists of three tension bars its diameter equal to 16 mm and skin reinforcement of 6 mm diameter distributed on spacing equal to 80 mm and 70 mm for both vertical and horizontal respectively Figure 2.
The shear span to depth ratio (a/d) was equal to 1 and the clear span was 1080 mm. Control beam C-B1 cast without any confinement and other beams cast with strut reinforcement extended along the region of the strut. The strut reinforcement consists of four main bars and enclosed by stirrups Figure 3 (a and b). Three beams (B2, B3, and B4) were confined by strut reinforcement consists of 4 main bars of 8 mm diameter, and stirrups of 6 mm diameter with varied spacing (80 mm, 100 mm, and 120mm) for beam (B2, B3, B4) respectively. Beams (B5 and B6) were confined with strut reinforcement consists of 4 main bars of varying diameters (10 and 12 mm) for beams (B5 and B6) respectively and stirrups of diameter 6 mm of constant spacing 80 mm. Table 1 illustrates the details of strut reinforcement confined beams.

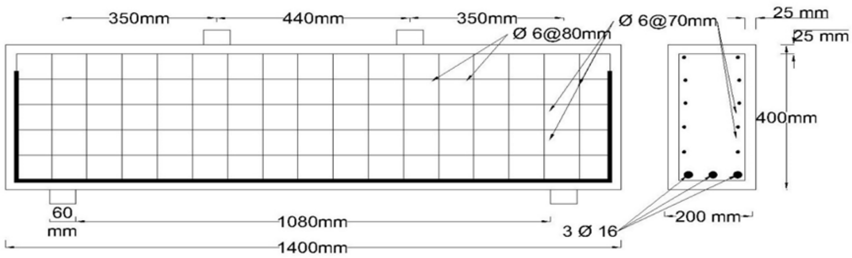


Figure 2: Reinforcement details of deep beam

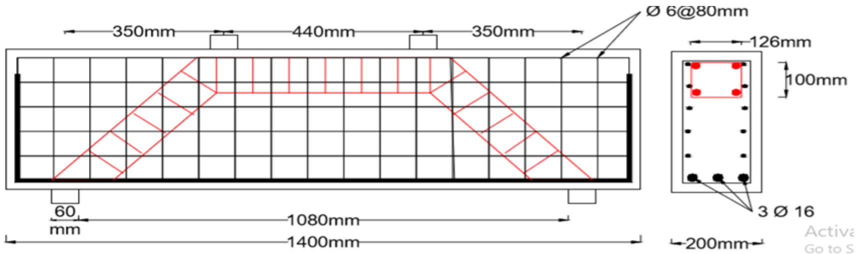


Figure 3 a: Strut reinforcement along the compression-strut of Deep-beams

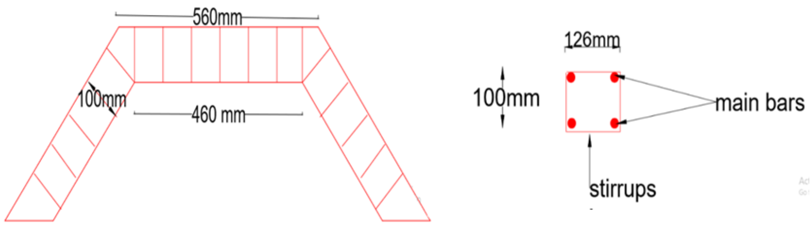


Figure 3 b: Strut-reinforcement details

Table 1: Detail of strut reinforcement of confined beam

BEAM	C-B1	B2	B3	B4	B5	B6
Main bars	NONE	4 Ø 8	4 Ø8	4 Ø 8	4 Ø 10	4Ø 12
Stirrups	NONE	Ø6@120	Ø6@100	Ø6@ 80	Ø6@80	Ø6@80

3. Materials

I. Cement

Ordinary Portland cement type 1 was used in this study. It is provided by the AL-MASS company for cement manufacturing in ALsulaymania/Iraq. The cement was tested in the national center for construction laboratories/laboratory Baghdad. The test results complied with the Iraqi specification IQS NO.5/1984 [10].

II. Coarse Aggregate

The maximum size of crushed gravel that used in normal concrete is 12 mm. The test result of the grading of coarse aggregate agreed with the Iraqi Specification No.45/1984 [11]. The test was done at the national center for construction and researches.

III. Fine Aggregate

Natural sand was used to produce normal concrete as fine aggregate that available in the AL-Ukhaidher region in Iraq. The test results of sieve analysis and physical properties were complied with the Iraqi Standard No.45/1984 [11] and were done in the national center of construction and researches.

IV. Steel Reinforcement

The test procedures of tensile steel bars were conducted according to the (ASTM-A370-14 [12]). The results of the test were agreed with ASTM-A615 [13] for grade 60 and were done in the University of Technology.

4. Mix Proportions

Mix proportion of normal concrete where designed to produce the target fc' that equal to 38 MPa. Table 2 shows the mix proportions of the materials.

5. Casting Procedures

Mixing procedure is conducted at the laboratory of civil engineering Dept. in the university of technology, using 2 mixers of a drum capacity about o.1 m^3, where the proportions of materials divided into two halves mixed by the two mixers. After preparation of the materials by taking the weight of each material, coarse aggregate was added with sand and mixed for a few minutes, after that cement added then and mixed until good workability is obtained. Fresh concrete poured to the previously prepared mold, cleaned, oiled and setting vertically the steel reinforcement cages were placed inside the mold and fixed using a 25 mm spacer.
Control specimens consist of (six cylinders of 100×200 mm and prisms of 100×100×400 mm) also cast with each specimen to investigate mechanical properties of concrete. The beams specimens were cast, cured and covered with canvas and sparkled with water while controlled specimens were cured inside the water tank.


Plate 1: Mixing procedure of concrete and casting of the beams

6. Results

The results of this study included the results of the control specimens and the beams.

I. Results of Hardened Concrete Test

Many tests are conducted to investigate the mechanical properties of concrete.

a. Compressive Strength *fc'*

The test was conducted by testing three cylinders of a dimension (100×200) mm and according to the (ASTM-C39/C39M-03) [14] then calculating the average of these cylinders. The tests were conducted using a digital machine from (CONTROL) group of max. capacity equal 4000 kN, at the age of 28 days from casting and the average result is illustrated in Table 3.

b. Splitting Tensile Strength(*fct*)

The splitting test was conducted using three cylinders having a dimension of (100×200) mm according to the (ASTM C496/C496M -11) [15] on the same digital machine of compressive strength, at the age of 28 days and the results illustrated in Table 3.

Table 3: Compressive strength and splitting-tensile strength of concrete

Concrete	Compressive strength *fc*' MPa	Tensile strength *fct* MPa
NC	38.24	3.4

II. Results of Deep Beams

The tests were conducted in the structural laboratory of the civil engineering Dept. of the University of Technology by using AVERY machine. The test included reporting of the ultimate load, mid-span deflection, crack pattern, mode of failure and concrete surface strain.

a. Mode of failure and crack pattern

The control beam C-B1 failed by shear by the propagation of the diagonal cracks with a clear appearance of some flexure cracks. The diagonal cracks were initiated from the bottom of the beam near the support and extend diagonally towards the loading plate with increasing load. The flexure crack was initiated from the bottom of the beam at mid-span and extend upward with increased load. For the control beam C-B1, the shear crack appeared first and after a while flexure cracks, were initiated. As the load increased, shear cracks extended and propagated diagonally upward and penetrated the compression zone. This was companied by the crushing of concrete under the loading plate. With the confinement of the strut reinforcement and with the increasing of its main bars diameter and stirrups number, the shear area of the beams had great confinement against shear stresses and crack width، so that، the shear cracks initiated later were limited in width and its propagation were retarded. The failure of these confined beams was by the propagation of flexure cracks where the failure of those beams was in flexure. Strut reinforcement turned the failure mode from shear to flexure. With the increasing of stirrups and main bar diameters in strut reinforcement, the flexure cracks propagate more and penetrate the compression zone at mid-span with the crushing of concrete in this area. The increase in the diameters of main bars of strut reinforcement gives more effect and confinement to the strut and shear region. Table 4 illustrates the first cracks of shear and flexure details and mode of failure. Plate (2-7) show the mode of failure and crack pattern of the beam (C-B1, B2, B3, B4, B5, and B6) respectively.

b. Ultimate Load

Ultimate load capacity for the control beam(C-B1) was 750 kN. it's obvious from the results of the test which is illustrated in (Table 4) that strut confinement generally increased the ultimate load capacity for the confined deep beams from 750 kN to 1250 kN and this increase due to the great support of the shear and the strut region provided by (Strut reinforcement). The increase in the stirrups number in strut defined by decreasing of its spacing (120, 100, and 80) with constant main bars diameters of 8 mm increased the ultimate load to (1050, 1080, and 1100 kN) respectively, while increasing the diameter of the main bars (8, 10, 12 mm) with constant stirrups spacing of 80 mm increased the ultimate load to (1100, 1200, and 1250 kN) respectively. The diameter of the bars is more effective in increasing the ultimate load of confined beams.

c. Load – deflection response

From Figure 4, it is obvious that the deep beam without any confinement show linear behavior of deflection at the early stages of loading. While the confined beams are generally more ductile and the load-deflection curve shows more toughness. It is obvious that deflection in the earlier age of loading decreased with the increasing of the stirrups and more with the increasing of bars diameter, this is because of the decrease in shear crack propagation. The Figure shows that strut reinforcement confinement increased the ultimate deflection with increasing strut reinforcement stirrups and main bar diameter. The ductility of the confined beam showed great enhancement that made the beams carried more deflection before got failed.

d. Surface Strain of Concrete

The test result of the concrete surface strain of the five deep beam shows that the strain at mid-span increased at confining deep beam compared to the control beam C-B1 due to the increased cracks width and propagation of flexure cracks on confined deep beam and the strain at shear span decreased compared to the control beam C-B1 due to the confining of the strut region produced by the strut reinforcement.

Plate 2: Cracks pattern of beam C-B1

Plate 3: Cracks pattern of beam B2

Plate 4: Cracks pattern of beam B3

Plate 5: Cracks pattern of beam B4

Plate 6: Cracks pattern of beam B5

Plate 7: Cracks pattern of beam B6

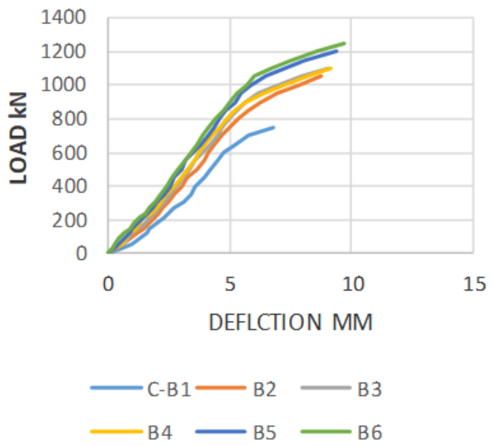
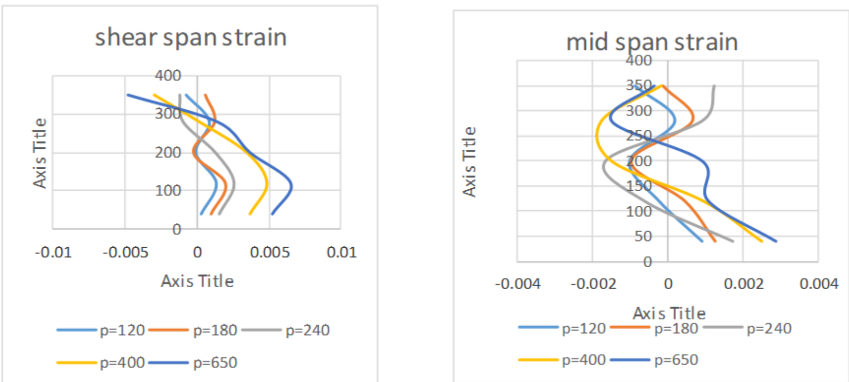


Figure 4: (Load-deflection)-curves of deep beams specimens

Table 4: The results of specimens' test

Beam	First Shear crack stage		First Flexure crack stage		Ultimate stage		Pcr (s)/Pu	Pcr (f)/Pu	Mode of failure
	Pcr (s) (kN)	Δv (s) (mm)	Pcr (f) (kN)	Δv(f) (mm)	Pu kN	Δv u mm			
C-B1	210	2.3	270	2.7	750	6.8	0.28	0.36	Shear-compression
B2	250	2.2	240	2.1	1050	8.8	0.23	0.23	flexure
B3	350	2.55	250	2.05	1080	9.1	0.31	0.28	flexure
B4	330	2.3	240	1.8	1100	9.2	0.3	0.21	flexure
B5	350	2.3	280	1.89	1200	9.4	0.29	0.23	flexure
B6	400	2.4	260	1.65	1250	9.7	0.32	0.2	flexure



a b

Figure 5: Concrete surface strain of beam a. C-B1 at mid span, b. C-B1 at shear span

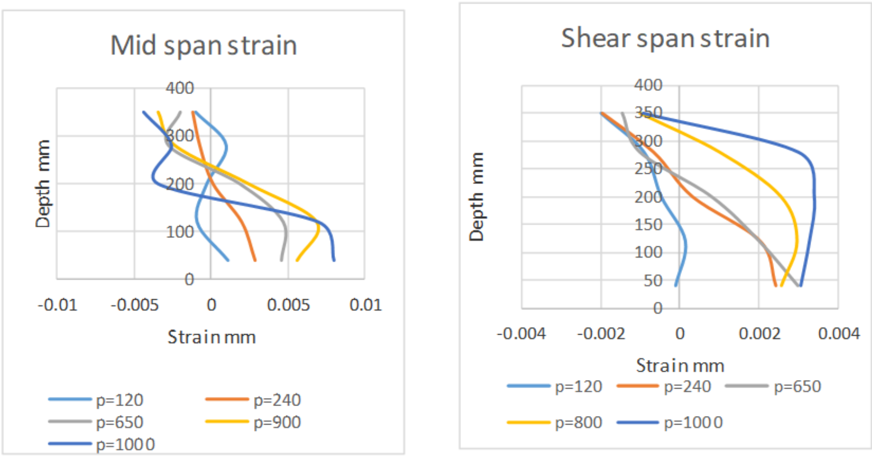


Figure 6: concrete-surface-strain beam with strut reinforcement confinement (B2)

7. Conclusions

1. The confinement of the strut by reinforcement generally increased the ultimate load (from 750 kN to 1250kN), decreased deflection at the earlier age of loading by about 28.75 % while the ultimate deflection increased by about 42.64 %.
2. The confinement of the strut by reinforcement changed the failure mode of deep beams from shear with some flexure cracks to the pure flexure mode of failure.
3. Strut Reinforcement confined shear cracks propagation, stresses, and strain at the strut region.
4. Increasing the stirrups number (120 mm to 80 mm spacing) of strut reinforcement with a constant diameter of main bars, increased ultimate load (1050 kN to 1100 kN), the deflection decreased and the ultimate deflection increased.
5. Increasing the diameter of the bar of the strut reinforcement from (8 mm to 12 mm), with constant space of stirrups distribution (of 80 mm) rising load capacity from (1100 to 1250 kN), decreased the early load deflection and increased the ultimate deflection. This effect gives the best result rather than the effect of stirrups number.
6. The surface strain of concrete at mid-span of confined beams increased compared to the control beam C-B1 this is because of the propagation of flexure cracks, while the strain at shear span decreased due to the confinement of shear cracks and its propagation at shear span due to the confining of strut produced by strut reinforcement.

References

[1] ACI committee-318, “Building code requirements for structural concrete (ACI 318M-14) and commentary,” American Concrete Institute, Farmington Hills, 2014.

[2] P. Nagarajan, T.M.M. Pillai and N. Ganesan, “Design of simply supported deep beams using IS 456: 2000 and strut and tie method,” Institution of Engineering Journal (India), Part CV, Civil Engineering Division, vol. 88, pp.38-43. 2007.

[3] K.N. Smith, and A.S. Vantosiotis, “Shear strength of deep beam,” ACI Structural Journal, Vol.79, No.3, pp. 429-437, 1982.

[4] F. K. Kong, “Reinforced concrete deep beams,” Taylor and Francis Book, Inc, Van No strand Reinhold, New York, 299 pp. 2002.

[5] D. H. Sanders, “Verification and implementation of strut-and-tie model in LRFD bridge design specifications,” AASHTO, Highway Subcommittee on Bridge and Structures. 2007.

[6] G. Aguilar, A.B. Matamoros, G. Parra-Montesinos, Ramírez, J.A. and Wight, J.K., “Experimental evaluation of design procedures for shear strength of deep reinforced concrete beam,” American Concrete Institute. 2002.

[7] J.W. Park, and D. Kuchma, “Strut - and - tie model analysis for strength prediction of deep beams,” ACI Structural Journal, 104, 6, p.657. 2007.

[8] K.H. Yang, and A. F. Ashour, “Strut and tie-model based on cracks band theory for deep beam,” Journal of Structural Engineering, 137, 10, pp.1030-1038, 2010.

[9] N. A. J. Al-Bayati, "Behavior of porcelanites reinforced concrete deep beams," (Ph.D. Thesis), Building and Construction Department, University of Technology, Baghdad, Iraq, 298 pp. 2012.

[10] IQS No. "Portland cement," Central Agency for Standardization and Quality Control, Planning Council, Baghdad, IRAQ, (in Arabic). 5/1984.

[11] IQS No. "Aggregate from natural sources for concrete," Central Agency for Standardization and Quality Control, Planning Council, Baghdad, IRAQ. 45/1984.

[12] ASTM A370-14, "Standard test methods and definitions for mechanical testing of steel products," ASTM International, West Conshohocken," PA, 2014.

[13] ASTM A615/A615M − 15, "Standard specification for deformed and plain carbon-steel bars for concrete reinforcement," Vol. 01.04, 2015.

[14] ASTM C39/C39M-03, "Standard test method for compressive strength of cylindrical concrete specimens," ASTM International, West Conshohocken, PA, 2003.

[15] ASTM C496/C496M -11, "Standard test method for splitting tensile strength of cylindrical concrete specimens," ASTM International, West Conshohocken, PA, 2011.