"Verification the shear reinforcement distribution across the web of reinforced concrete deep beams "

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The purpose of the numerical analysis presented in this study was to evaluate the benefit of increase the spacing transvers stirrups across web of beams subjected to behaivour shear Where the variable in this study exceeded paragraph (9.9.4.3) stipulated by (ACI 318R-19) by increasing the transverse spacing across web from (d/5) to (d/4). In order to accomplish this goal, thirty three full-scale simply supported reinforced concrete deep beams under the effect of symmetrical concentrated two-point load. Where performed using finite element method (ABAQUS / CAE 2019) all specimens were tested with an (a/d) ratio of 0.84 as well the dimensions of all beams are (360 × 1300 × 3200) mm. classified into three groups. The first group included (11) deep beam samples of normal strength concrete with $f_c^{'}$=30Mpa and without steel fiber. The second group included (11) samples of high strength concrete with $f_c^{'}$=45Mpa and steel fiber ratio (0.75%), while the third group included (11) samples of reactive powder concrete with $f_c^{'}$=76.3Mpa and steel fiber ratio (1.5%), to study the effect of: increase the transvers spacing across web (S_{wt}) on the first cracking load and ultimate load, load vertical mid-span deflection, distribution stresses on stirrups, Absorbed energy, and Shear ductility. Based on the results of the numerical analysis, it was observed that closely spaced stirrups across a beam's web (d/5) did not provide a discernable benefit to the shear capacity or serviceability performance. Where a strong convergence of results was observed between the transversely spaced across web (d/5) beams and the transversely spaced across web (d/4) beams

Keywords: Deep Beam, Shear, Stirrups, Steel fiber.

1. Introduction

\Shear behavior was simulated for 33 deep beam specimens using the ABAQUS program under a symmetrical concentrated two-point load. The reinforcement design for each model was the same, except that the distance between stirrups was made greater as the number of stirrups was decreased. The load continues to increase until the specimen fails,

and thus the behavior of the deep beam specimens with shear behaviour can be seen, and this failure leads to the appearance of inclined cracks. All data are included in tables with the excel program and presented as charts, all results are discussed in this paper.

Using the same reinforcement ratio, this study compared the effects of placing stirrups concentrated near the member face (two legs) with those placed evenly over the web (four legs), proving the validity of the research conducted by Robin Tuchscherer (2011) [1]. Beams measuring 21 by 44 inches (530 by 1120 millimeters) and designed with shear-span-to-depth relation of 1.84were subjected to tetrad tests. A beam with a shear width to-depth relation of 1.85 and a cross section measuring 36 by 48 inches (910 by 1220 millimeters) was subjected to two tests. Specimens' strength and utility were evaluated against one another. The effectiveness of 0.2% and 0.3% reinforcing ratios in vertical webs was studied. The shear capacity and service-level behavior of 36-inch (930-mm) broad specimens were minimally changed by spreading the stirrup legs across the web. The effect of stirrups was found to be much smaller when compared to the more conservative ACI 318-08 STM regulations.

Specifically, ACI 318-08, AASHTO LRFD (2008), and FIP (1999) to quote from the supporting commentary to ACI 318-08 [2] Section R11.5.7: Large beams with extensive flexural reinforcement's shear behavior can be improved by reducing stirrup leg transverse spacing across the section. The Commentary of the ACI 318-08 standards' sectional shear design section makes this recommendation. The main body of the guideline does not provide a transverse spacing restriction for web reinforcement.

According to FIP (1999) [3]. No segment's transverse spacing (the distance between stirrup legs) should overdo the lesser of the subsequent values indicated in Section6.4.3.1:

$S_{wt} \leq z \leq 400mm$ (16in) at the critical point, anywhere z is internal moment arm. Stirrup spacing throughout the web must be kept to a minimum for the concrete to resist shear as efficiently as feasible:

$S_{wt} \leq z/5 \leq 200mm\ (8in)$ Beam sections that resist sectional shear, or B-Regions, must be designed to meet this criterion. In the bottomless beam section of standard, the clause is not mentioned.

The AASHTO LRFD (2008) [4] requirements penalize a deep beam if stirrups are not distributed across the web, unlike the ACI 318-08 and the FIP (1999). Article 5.6.3 if stirrups are not evenly distributed over web, the effective width of a strut frame interested in an internal tie of a two-panel STM is lowered. Distance between consecutive vertical web reinforcements must be less than 6d b, where d b is diameter of the primary longitudinal tension reinforcement, according to AASHTO requirements see Figure (1-1). this is only needed for deep beams in shear and strut-and-tie types with multiple panels. In the code's section addressing sectional shear, however, no such requirement is made. With the stronger impact that stirrups have on resisting sectional shear stresses, this phenomena doesn't make sense. In conclusion, there is no agreement on a maximum transverse spacing for web reinforcement at the present time. There has been a dearth of studies examining this problem in the past. This paper's major motivation was, thus, to add to the existing literature on the impact of dispersing web reinforcement. Objects characterized by deep beam shear behavior are of interest. Studies are summarized here:

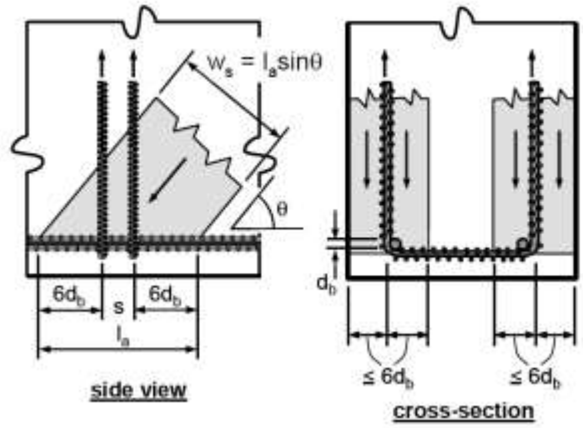

Figure (1-1): An Anchored Strut is a Necessity According to the AASHTO LRFD (2008) [4]

Leonhardt and Walther (1961) [5] evaluated 10 samples with web widths between 30 and 5 cm (12 and 2 in.). Stirrups made from 6 mm smooth wire were placed at 11 cm intervals on all specimens for reinforcement (No. 2 stirrups at

4 in.). The average height of the samples was 30 cm (12 in.). In this experiment, four specimens were loaded with a localized stress using shear span-to-height relation of 3.5. It was determined that a length-to-height ratio of 10 would produce most reliable results by testing six identically loaded specimens. When the breadth of the specimen was enlarged, the shear stress at failure was found to be lower. Leonhardt and Walther found that a shear-region oblique strut behaves like a beam supported at the stirrup legs (1-2). Adding intermediate "supports" increases the beam's shear capacity (i.e. intermediary stirrup legs). The study's authors concluded that the minimum distance between stirrups across a web should be 20 centimeters (8 inches) for beams subject to severe shear loads and 40 centimeters (16 inches) for beams subject to mild shear stresses. The suggestions made by Leonhardt and Walther are probably included in the FIP (1999) suggestions (1961). This paper employs Leonhardt and Walther's oblique strut theory to describe vertical web reinforcement transverse spacing in terms of beam depth.

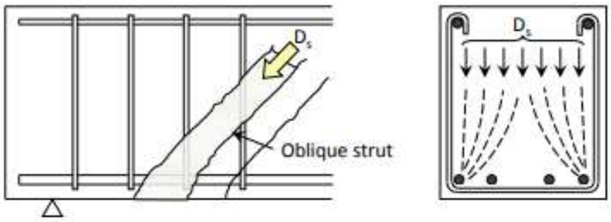

Figure (1-2): Sideways Strut with Stirrup Legs in a Vertical Position (Leonhardt and Walther, 1961) [5]

Four beams of varied widths and stirrup distributions were tested to failure by Hsuing and Frantz (1985) [6]. Table1: Beam Specifications (1-1). A shear span towards depth ratio of 3.0 was used for all of the tests. With a ratio of 0.2% in the vertical web reinforcement, each beam was incredibly strong. The researchers concluded that neither the web width nor the distribution of stirrups had a significant impact on a specimen's relative shear strength. Hsuing and Frantz tested 18 in. (460 mm) broad beams. Table shows the performance of specimens with stirrups set at 16 in. (410 mm) or d across the web (1-1). So, increasing the transverse spacing of the vertical web reinforcement had no influence on shear capabilities.

Table (1-1): Past Research Examining the Effect of Multiple Stirrups (1 in = 25. 4mm, 1 kip = 4.45 kN, 1 ksi = 6.89 MPa)

Beam I.D.	b_w, in.	d in.	a/d ratio	ρ_v	Transverse Spacing across Web, S_{wt}	S_{wt}/d	f'_c psi	V_{test} Kip	$\frac{V_{test}}{f'_c b_w d}$	$\frac{V_{test}}{\sqrt{f'_c} b_w d}$
Hsuing and Frantz (1985)										
A	6	16.5	3.0	0.0022	4.3"	0.3	6200	24.8	0.04	3.2
B	12	16.5	3.0	0.0020	10.3"	0.6	6200	45.0	0.04	2.9
C	18	16.5	3.0	0.0022	16.3"	1.0	6200	76.2	0.04	3.3
D	18	16.5	3.0	0.0022	5 spa.@3.3"	0.2	6200	78.2	0.04	3.3
Anderson and Ramirez (1989)										
W1	16	13.75	2.65	0.0039	12.6"	0.9	4230	103.4	0.11	7.2
W2	16	13.75	2.65	0.0039	2.8"/7"/2.8"	0.2 to 0.5	4670	123.4	0.12	8.2
W3	16	13.75	2.65	0.0039	12.6"	0.9	4690	113.4	0.11	7.5
W4	16	13.75	2.65	0.0039	7"/7"	0.5	4900	131.4	0.12	8.5

Anderson and Ramirez (1989) [7] analyzed the results of stirrup distribution on four 16-inch (410-millimeter) wide samples. Each sample was rated based on a standard ratio of shear span toward depth of 2.65. Individually beam contained 0.4% reinforcement in the form of vertical web reinforcement. More details on beams are listed in the table (1-1) when stirrups were disseminated over the web, the inner longitudinal bars received more strains, indicating that the interior longitudinal bars are better utilized when the transverse reinforcement is dispersed across the web. Large beams with many longitudinal bars benefited from stirrups placed transversely across the web, according to the study's authors. Stirrups placed at 0.9d across the web, on the other hand, did as well as those placed at 0.5d for specimens. Table (1-1). When the transverse arrangement of vertical web reinforcement was raised to 0.9d, the specimens' shear capabilities did not decrease. Reinforcing a beam's web doesn't improve its shear capacity, according to current studies. Prior research on this topic, however, has shown contradictory findings with relation to a deep beam zone. To learn more about this topic and to fill up the existing data, a research approach identical to the one detailed in this report was implemented.

[8] Previous study shows that a direct-strut (one-panel model) is the main load-carrying mechanism for constructions with an aspect

ratio of 2 or 2.5. Current research [9] shows that direct struts are the major load transfer method for 1.85 aspect ratio specimens. Theoretical and experimental data supports using a single-panel truss to mimic a deep beam (a/d 2).

2. Research program

The initial element of the study program consists of validating the suggested model with experimental data from the literature. Parametric analysis is the focus of the second section.

2.1. Model Validation

A benchmark test was done on one of Hong et al. [10]'s deep beams (Beam SS-1) to examine the selected concrete model's capacity to research reinforced concrete deep beams' tensile and compressive behavior. This test verified deep beam shear strength.

First, we'll go over the fundamental steps of a finite element analysis, and then we'll dive into how to build a finite element model in ABAQUS. Furthermore, by explaining and identifying their essential characteristics, plasticity constitutive models used to describe concrete and reinforcement in numerical simulations are addressed, as well as contact algorithms used to model the interaction between two entities. Other numerical aspects that are required for impact analysis simulation are also presented.

For the purpose of comparing this test to previous experimental findings, it was developed. In their research, Hong et al. [10] instruments were utilized in order to measure the midspan deflections as well as the loads of beams that were simply supported. In Figure (2-1), we see the beam's cross section and the loading arrangement used for the test. The concrete beam mesh was created using an 8-node solid element with one integration point. A 2-node linear 3D truss element in a truss structure modeled steel rebars. Figure (2-2) shows the validated mesh.

The load-deflection response of investigated beam is shown in Figure (2-3) and compared to the experimental data obtained by Hong et al. [10]. In good arrangement with actual consequences, the modeled response confirms the chosen model's capacity to represent the entire beam's behavior up to failure. As well as investigating concrete's response under complex stress situations, such as that of reinforced concrete deep beams, the model's conclusions can be utilized to validate and direct experimental investigations.

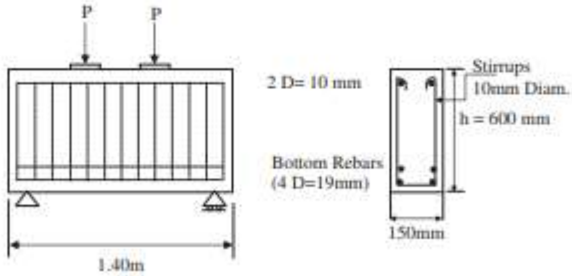

Figure (2-1): Beam SS-1's cross section and loading arrangement [10].

Figure (2-2): for Beam SS-1, the Applied Mesh.

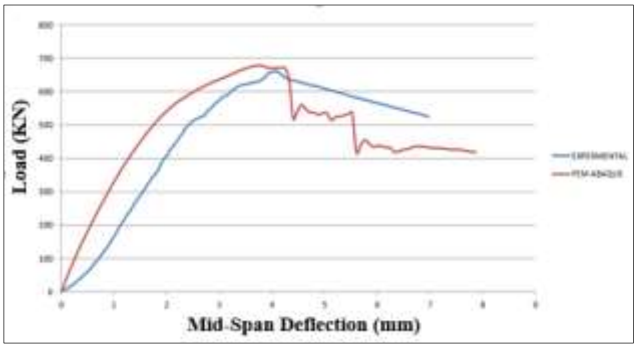

Figure (2-3): Analysis of the applicable material model's response to a load versus the corresponding deflection obtained experimentally.

2.2. Parametric study

Parametric study was carried out to investigate the effect of different design parameters on the shear capacity of RC deep beams.

The design parameters are: Reducing the number of vertical stirrups by distributing them over distances greater than the distance mentioned in ACI code-318-19, which is equal to d/5 and concrete compressive strength (30, 45 and 76.3MPa) As well as adding different percentages of steel fiber (0.75% and 1.4%).

3. Numerical analysis

3.1. Beam Testing Results and Descriptions

To assure the development of tied-arch action in the deep beam, 33 models were examined in the ABAQUS program with vertical and horizontal shear reinforcement, total length (L=3200mm), center to center (L=3000mm), clear span (Ln=2800mm), cross-section (3601300) mm, and a/h=1/1.3. (ACICode318-19).

Each and every specimen was evaluated when subjected to the two-point concentrated loads along the leading edge and longitudinal tension reinforcement in the form of five distorted bars with a 25 mm diameter was used to prevent flexure failure and promote shear instead. Compressive reinforcing bars (2 x 25 mm) were employed to secure the stirrups and prevent the compression zone from failing suddenly and crushing everything in its path. Vertical and horizontal shear reinforcement (12mm @200 mm c/c) was installed in all beams. As may be seen in the figure, the concrete was encased completely (3-1).

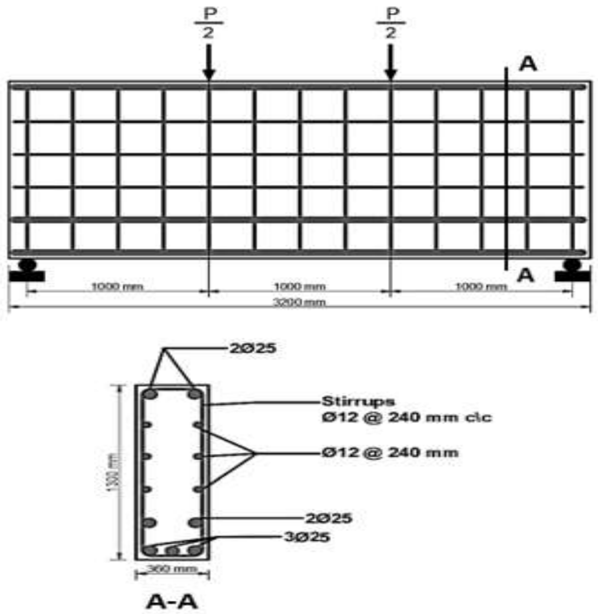

Figure (3-1): specimen's details (not to scale)

3.2. Materials' Physicochemical Characteristics

A material-behavior model is associated with each component (material properties). The finite element model (FEM) parameters used in this analysis are summarized in Table (3-1).

Table (3-1): Settings for the finite element method (FEM) applied to deep beams

Concrete				
Concrete Parameter	Definition	Deep Beams		
		Group No.1	Group No.2	Group No.3
		NSC without steel fiber	HSC with 0.75% steel fiber	RPC with 1.4% steel fiber
f_c	Compressive Strength (N/mm2)	30**	45*	76.3*
f_{SP}	Splitting Strength (N/mm2)	3.34**	5.4*	6*
υ**	Poisson Ratio	0.15	0.15	0.15
E_c***	Young Modulus (N/mm2)	30588	34545	35110
Reinforcing Steel				
Reinforcing Steel Parameter	Definition		Bar Diameter	
			12mm	25mm
E_s**	Young Modulus (N/mm^2)		200000	200000
f_y*	Stress of Yielding (N/mm^2)		395	395
υs**	Poisson Ratio		0.3	0.3
A	Cross Section area (mm^2)		113.097	490.874
Steel Plate				
E_s**	Young Modulus (N/mm^2)		200000	
υs**	Poisson Ratio		0.3	

*** Where: (f_y) from Hong et al. [10], (f'_C=45Mpa and f'_{SP}=5.4Mpa) from Muhanad Shakir Mahdi [11], and (f'_C=76.3Mpa and f'_{SP}=6Mpa) from Hussein Khaleel Ibrahim [12]**

Note: if the compressive strength was measured based on the test of a standard 100 or 150-mm cube, then it was converted to the equivalent 6-inch cylinder strength according to the conversion factors in FIP (1999) [3].

**** Assumed**

*****Calculated as per Euro Code.**

4. Results and discussions

4.1. Load–deflection response

The load deflection curves (at mid-distance) for all the beams are shown in Figures (4-1) to (4-

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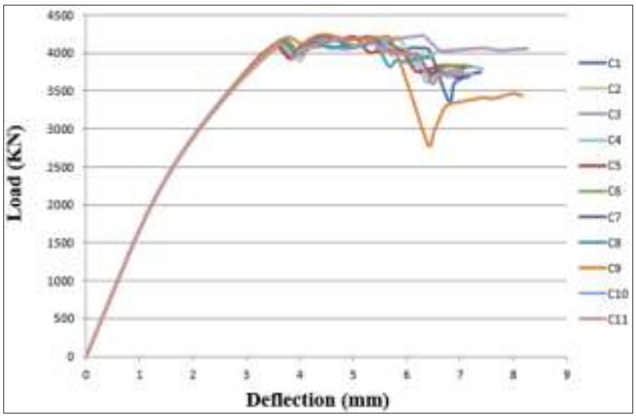
3), and these curves began with the same total beam stiffness up to the crushing force since the strengths of the concrete were almost identical. Then, its stiffness decreases with the increase in



the applied load due to crack propagation which leads to an increase in its deflection in the medium range. The stiffness of the total beam can be indicated by the relationship of the load inclination and deflection.

three groups (G-1, G-2, and G-3) Includes Increasing the spacing between the vertical stirrups by (10mm) for each model from (200mm) up to (300mm), as evidenced by the payload deflection curves, where the stirrups show an improvement in the overall girder rigidity and its bearing capacity.

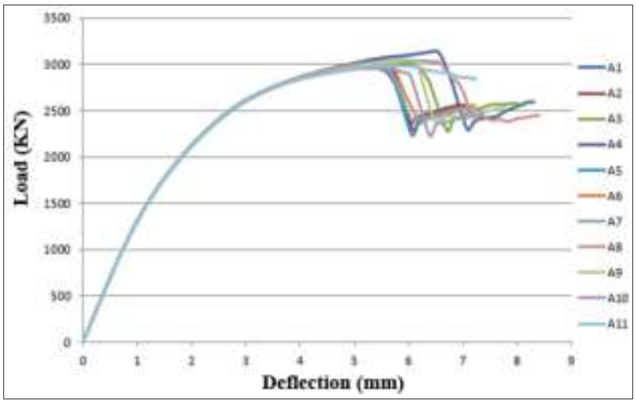


Figure (4-1): Beam bending due to vertical load deflection (G-1)

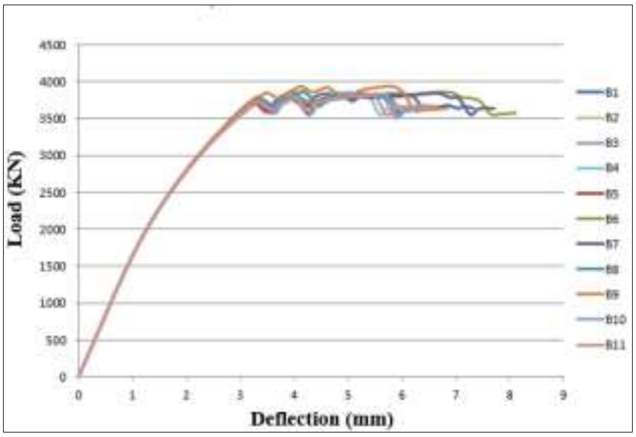


Figure (4-2): vertical beam deflection under load (G-2)

Figure (4-3): Load-vertical deflection of the beams (G-3)

4.2. First Crack and Ultimate Loads

Tables (4-1) to (4-3) summarizes the results of first crack load, ultimate load capacity, mid span deflection at failure where Table (4-6) shows that as (S_{wt}) was lowered, the ($\frac{Pcr}{Pu}$) for models (A1 to A4) decreased while as the (S_{wt}) is increased, the ($\frac{Pcr}{Pu}$) decreases for models (A6 to A11).

The ($\frac{Pcr}{Pu}$) for models (B1 to B4) is shown to decrease as a function of (S_{wt}) in Table (4-7) whilst the value of ($\frac{Pcr}{Pu}$) for models (B6 to B11) decreased as the value of (S_{wt}) increased.

As can be seen in Table (4-8), the ($\frac{Pcr}{Pu}$) of models (C1 to C4) decreased as the (S_{wt}) decreased however the ($\frac{Pcr}{Pu}$) for models (C6 to C11) increased with increasing the (S_{wt}).

Table (4-1): FEM Result of the deep beams for first group

Models Name	Transverse Spacing across Web S_{wt} (mm)	First Crack load (kN) P_{cr}	Ultimate Load (kN) P_u	$\frac{P_{cr}}{P_u} \times 100\%$
A1	200	1005.12	3135.59	32.05%
A2	210	1004.61	2984.16	33.66%
A3	220	1005.17	3037.44	33.09%
A4	230	1004.76	2978.43	33.73%
A5	240	1005.09	2965.13	33.89%
A6	250	1004.92	3005.03	33.44%
A7	260	1005.32	2987.79	33.64%
A8	270	1004.39	3046.85	32.96%
A9	280	1004.79	3048.15	32.96%
A10	290	1004.16	2962.58	33.88%
A11	300	1004.42	2997.77	33.5%

Table (4-2): FEM Result of the deep beams for second group

Models Name	Transverse Spacing across Web S_{wt} (mm)	First Crack load (kN) P_{cr}	Ultimate Load (kN) P_u	$\frac{P_{cr}}{P_u} \times 100\%$
B1	200	1495.06	3861.58	38.71%
B2	210	1494.55	3827.49	39.04%
B3	220	1495.13	3830.5	39.03%
B4	230	1495.08	3867.8	38.65%
B5	240	1494.72	3827.59	39.05%
B6	250	1494.87	3855.49	38.77%
B7	260	1495.27	3846.78	38.87%
B8	270	1494.39	3855.51	38.76%
B9	280	1494.81	3934.31	38%
B10	290	1494.14	3826.34	39.04%
B11	300	1494.42	3828.64	39.03%

Table (4-3): FEM Result of the deep beams for third group

Models Name	Transverse Spacing across Web S_{wt} (mm)	First Crack load (kN) P_{cr}	Ultimate Load (kN) P_u	$\frac{P_{cr}}{P_u} \times 100\%$
C1	200	1508.42	4217.8	35.76%
C2	210	1507.9	4215.06	35.77%
C3	220	1508.51	4224.18	35.71%
C4	230	1508.06	4207.78	35.84%
C5	240	1508.43	4196.38	35.94%
C6	250	1508.25	4105.64	36.73%
C7	260	1508.67	4106.89	36.73%
C8	270	1507.74	4162.68	36.22%
C9	280	1508.17	4145.22	36.38%
C10	290	1507.5	4178.44	36.07%
C11	300	1507.79	4182.01	36.05%

4.3. Absorbed energy

Ductility is a structural attribute that is influenced by fracture and is dependent on the size of the structure element (Bozorah, 2004) [13]. Ductility is determined by the fracture. According to Mohammed Hassani's research (2012) [14], absorbed energy (AE) is a metric that may be used to quantify the ductility of a structure. Consideration of the region below the load-deflection curve is one method that might be used to compute it. The values of the absorbed energy for the tested beams are illustrated in Figures (4-4) to (4-6) where the more there is an increase in the values of the absorbed energy, the more ductile the beam will behave. It was possible to deduce from Figures aforementioned that all of the beams, in contrast to the control beam, where the variation in the ratios of energy absorbed is extremely minimal from one another, and that the distance between stirrups does not significantly impact the deep beam ductility.

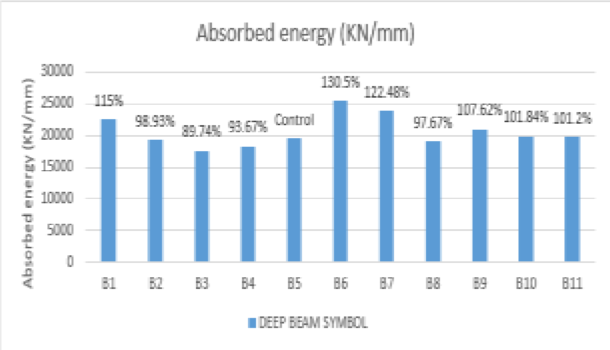


Figure (4-4): Absorbed energy for first group of deep beam

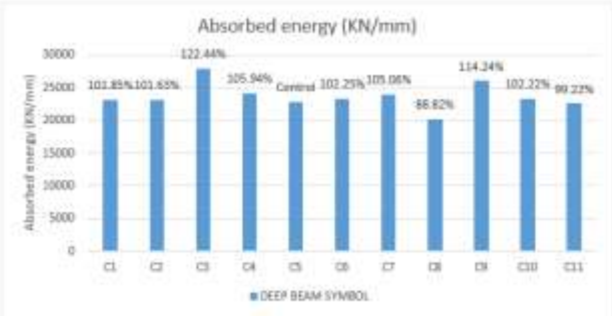


Figure (4-5): Absorbed energy for second group of deep beam

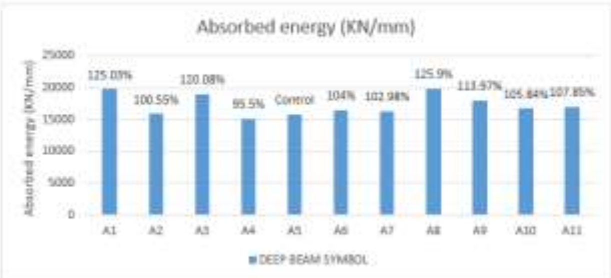


Figure (4-6): Absorbed energy for third group of deep beam

4.4. Shear ductility

In spite of the fact that design provisions classify deep-beam failure as brittle, deep beams can sometimes demonstrate a degree of ductility when the right conditions are met.

Shear ductility is defined as the ratio of Ac/Au, where Au is the area under the load deflection curve up to ultimate load and Ac is the area under the load deflection curve for a beam up to its complete collapse (G. Appa Rao* & K. Kunal, 2007) [15], as shown in the Tables (4-4) to (4-6) understand the ductility of beams failing in shear.

Table (4-4): Shear Ductility Index for first group

Beam specimen	Transverse Spacing across Web S_{wr} (mm)	Au (mm^2)	Ac (mm^2)	Au/Ac %
		Group (G-1)		
A1	200mm	15305.93	19776.25	77.4
A2	210mm	11258.24	15904.23	70.78
A3	220mm	13034.42	18992.56	68.63
A4	230mm	11652.69	15107.48	77.13
A5	240mm	11196.03	15816.57	70.78
A6	250mm	12589.41	16449.25	76.53
A7	260mm	12159.28	16288.32	74.65
A8	270mm	13911.52	19913.66	69.86
A9	280mm	13909.26	18026.66	77.16
A10	290mm	12561.29	16741.5	75.03
A11	300mm	13014.31	17059.08	76.29

Table (4-5): Shear Ductility Index for second group

Beam specimen	Transverse Spacing across Web S_{wr} (mm)	Au (mm^2)	Ac (mm^2)	Au/Ac %
		Group (G-2)		
B1	200mm	10912.67	22501.61	48.5
B2	210mm	14997.4	19277.97	77.8
B3	220mm	15558.21	17485.99	88.97
B4	230mm	11570.84	18251.93	63.4
B5	240mm	15273.76	19485.22	78.38
B6	250mm	21109.34	25428.48	83
B7	260mm	20221.94	23865.5	84.73
B8	270mm	11664.17	19031.4	61.29
B9	280mm	17871.23	20970.57	85.22
B10	290mm	16388.79	19844.41	82.58
B11	300mm	16421.69	19719.35	83.27

Table (4-6): Shear Ductility Index for third group

Beam specimen	Transverse Spacing across Web S_{wt} (mm)	An (mm^2)	Ac (mm^2)	An/Ac %
Group (G-3)				
C1	200mm	13422.42	23227.74	57.78
C2	210mm	19095.63	23178.92	82.38
C3	220mm	21141.77	27923.78	75.7
C4	230mm	16958.22	24161.25	70.18
C5	240mm	15773.7	22805.9	69.16
C6	250mm	16604.54	23320.34	71.2
C7	260mm	16643.5	23960.84	69.46
C8	270mm	10288.22	20258	50.78
C9	280mm	13406.42	26054.74	51.45
C10	290mm	14613.81	23313.78	62.68
C11	300mm	14599.72	22630.01	64.5

5. Summary and conclusions

Based on the inclusive consequences from the finite element analysis, the following main conclusions are obtained:

1. By comparative numerical analysis of the deflection, first crack, and ultimate load data of models with web reinforcement with different transverse spacing ranging from d/6 to d/4 (note that the model having d/5 transverse spacing is a deep beam control), it can be concluded that The serviceability performance of packets with d/6 and d/5 transverse spacing is equivalent to those with d/4 transverse spacing.
2. Including the 11 models that are a part of each combination, there are a total of 33 models, all of which have deep beam specimens that have failed due to concrete cracks .The load-carrying capacity of the specimen depended on the consistency of the mixtures used, as the 1.4% steel fiber RPC mixture had the highest load-carrying capacity, followed by the 0.75% steel fiber HSC mixture, the last of which was the NSC mixture. It is important to highlight that the increased cross-sectional spacing across the web did not have a negative impact on the service performance of the samples used in this study.
3. The results showed that the difference in the distance between the apply load and the nearest stirrup within the shear span (a) causes a difference in the distribution of maximum stress on the stirrups within this zone, which indicates that this variable needs further research in the future.
4. The use data of HSC and RPC in deep beam improved the shear behavior.
5. The addition of steel fiber in different ratios has enhanced the response of the deep beam to the effect of shear behavior.

Conflict of Interest

The authors reaffirm that there is no conflict of interest with the publishing of this article.

Abbreviations

FEM	Finite element method
SFCR	Steel Fiber reinforced concrete
NSC	Normal Strength concrete
HSC	High Strength Concrete
RPC	Reactive Powder Concrete
RC	Reinforced Concrete
Swt	Transverse Spacing across Web

4. References

1. Robin Tuchscherer, (2011), "Distribution of Stirrups across Web of Deep Beams" BS from the University of Wisconsin-Milwaukee; and his MS 5 and PhD from the University of Texas at Austin.
2. ACI Committee 318-08, "Building Code Requirements for Reinforced Concrete (ACI 318-08)", American Concrete Institute, Farmington Hills, MI, 2008.
3. FIP Recommendations, "Practical Design of Structural Concrete", Federation Internationale de la Precontrainte, FIP Commission 3, September 1999, 113 pp.
4. AASHTO LRFD, 2008 Interim Revisions, "Bridge Design Specifications", 4th Edition, 2007, American Association of State Highway and Transportation Officials, Washington, D.C., 2008.
5. Leonhardt, F. and Walther, R., translation by Amerongen, C. V., "The Stuttgardt Shear Tests", 1961, from Beton und Stahlbeton,

Vol. 56, No. 12, 1961 and Vol. 57, No. 2, 3, 6, 7, and 8, 1962, Translation No. 111, Cement and Concrete Association, London, 1964, 138 pp.

6. Hsuing, W. and Frantz, G. C., "Transverse Stirrup Spacing in R/C Beam," ASCE Journal of Structural Engineering, Vol. 11, No. 2, February 1985, pp. 353-362.
7. Anderson, N. S. and Ramirez, J. A., "Detailing of Stirrup Reinforcement", ACI Structural Journal, Vol. 86, No. 5, September-October, 1989, pp. 507-515.
8. Collins, M.P. and Mitchell, D., "Prestressed Concrete Structures", Response Publications, 7 Toronto and Montreal, 1997.
9. Birrcher, D. B.; Tuchscherer, R. G.; Huizinga, M. R.; Bayrak, O.; Wood, S. L.; Jirsa, J. 11 O.; "Strength and Serviceability Design of Reinforced Concrete Deep Beams", Report No. 12 0-5253-1, Center for Transportation Research, University of Texas at Austin, Austin, TX, 13 April 2009, 376 pp.
10. S. Hong, D. Kim, S. Kim, N. Hong, "Shear strength of reinforced concrete deep beams with end anchorage failure", ACI Struct. J. 99 (1) (2002) 12–22.
11. Muhanad Shakir Mahdi, "Torsional Behavior of Reinforced Self-Compacted Concrete Deep Beams With Longitudinal Opening", Faculty of Engineering, Mustansiriyah University, (2021).
12. Hussein Khaleel Ibrahim, "PERFORMANCE OF REINFORCED HIGH STRENGTH CONCRETE CIRCULAR COLUMNS PARTIALLY STRENGTHENED WITH STEEL FIBERS", College of Engineering of Al-Nahrain University, (2021).
13. o Buyukozturk, "Ductility and Deflection, Lect. Mech. Des. Concr. Struct. (Ductility Deflection)", Massachusetts Institute of Technology, (2004)
14. M. Mohammadhassani, M.Z. Jumaat, M. Jameel, H. Badiee, A.M.S. Arumugam "Ductility and performance assessment of high strength self-compacting concrete (HSSCC) deep beams: an experimental investigation" Nucl. Eng. Des. (2012), 10.1016/j.nucengdes.2012.05.005
15. G. Appa Rao*, K. Kunal & R. Eligehausen, "Shear strength of RC deep beams" *Indian Institute of Technology Madras, Chennai-600 036, India & University of Stuttgart, 70569 Stuttgart, Germany, 2007.