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SHEAR CAPACITY OF SELF COMPACTING CONCRETE DEEP BEAM UNDER CONSTRAINED AXIAL LOADS

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Abstract: The main objective of this paper is to study the shear capacity of SCC reinforced concrete deep beams subjected to axial load. Seven simply supported deep beams casted by using SCC mix with steel fibers and tested. All these beams have dimensions of 1300mm length, 350mm high, and 150mm width and have been subjected to constant axial force with value (100) kN and then subjected to two point loads. The variables of this work are (shear span/depth (a/d), vertical shear reinforcement (ρ_v), and horizontal shear reinforcement (ρ_h) to study their effects on first crack and ultimate loads , and mid span deflection.

Keywords: *Deep Beams, Shear Strength, SCC With Steel Fibers, Axial Load*.

تأثير تسليح منطقة القص على مقاومة القص للعتبات العميقه ذات الخلطه الخرسانيه ذاتية الرص والمقيده باحمال محورية

الخلاصة: ان الهدف الرئيسي من هذا البحث هو دراسة تصرف العتبات الخرسانيه العميقه للقص ذاتية الرص والمقيده محوريا. سبعة عتبات خرسانيه بسيطة الاسناد استعملت فيها الخطه الخرسانيه ذاتية الرص و الالياف الحديديه تم صبها وفحصها. جميع العتبات ذات الابعاد 1300مم طول العتبه، 350 مم ارتفاع العتبه، 150مم عرض العتبه وجميع العتبات سلط عليها احمال محوريه ثانيه بقيمة 100 كيلو نيوتن مع حملين مركزين. المتغيرات المستعمله في هذا البحث هي (مسافة القص/ عمق العتبه)، نسبة التسليح الافقي، نسبة التسليح العمودي لدراسه تأثير هذه المتغيرات على احمال التشقق واحمال العظمى و الهطول في منتصف العتبات.

1. Introduction

Self Compacting Concrete (SCC) is a type of concrete removes entrapped air in concrete without vibration to perform homogeneity, for that it is not need compaction, because it be compacted and leveled under its self weight. Also it characterized by workability and ability to fill formwork under its own weight and high resistance to segregation and bleeding . SCC is the best choice that used in section with difficulties to casting and vibration, and section with steel dense, especially deep beams [1,2].

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Fibers are used to provide higher toughness, long term durability, and to modify the flow properties of fresh concrete, arrest the crack growth if the modulus of elasticity of the fibres is more than the concrete, help to carry the load that leads to increase the tensile strength of concrete, also reduce creep and shrinkage of concrete, and used to improve the toughness and flexural strength [3, 4].

Deep beams are structural members loaded on one face and supported on the opposite face. Also, it is a beam with clear span (ℓ) to depth (d) ratio ℓ/d ≤4, and short shear span (a) that mean has shear span to depth ratio a/d ≤2, and the minimum ratio of reinforcement according to AASHTO that deep beam must contain amount of reinforcement equivalent to 0.3% of cross sectional area in both vertical and horizontal directions [5]. The behavior of deep beam is characterized by the elastic flexural stress distribution is nonlinear, the shear deformations become significant when compared to pure flexure, and at the ultimate limit state the shape of concrete compressive stress block is not parabolic shape because of larger ratio of d/ℓ[6]. The shear is controlling the strength of deep beam more than the flexure because it proportions. The shear strength of deep beam is greater than that predicted using expression develop for slender beam, because of their ability to redistribute internal forces before failure and to develop mechanism of force transfer completely different from normal beam [8,7].The deep beam is used in Transfer girders, buildings with large span without using columns, constructions with very long span halls, pile caps, foundation walls, etc [5,7,9].

The shear is the most important factor in many kinds of concrete members , its unbalance vertical force acting on the left or right of the section. When there is a change in the bending moment in the span, the shearing force acts on the beam and equal to the variation in the bending moment. The types of shear force are vertical and horizontal ones. The horizontal shear force appears on beam when it is subjected to bending stresses, while the vertical shear force appears when it is subjected to zero bending stresses. When shear plane due to temperature deformation or presence of tension force caused by restrained shrinkage, the crack will occur in the shear plane before any shear force is applied**.** Shear reinforcement is provided through the stirrups to take the shear to which the structure is subjected, and to stop the development of the diagonal tension cracking. These stirrups are perpendicular to longitudinal reinforcement and therefore they oriented vertically in horizontal beam [3,4,10]**.**

2. Experimental Program

The experimental program was achieved to investigate the shear capacity of simply supported deep beams tested constrained with axial load using SCC. Seven beams were designed to fail in shear and had the same dimensions were (150×350 1300) mm, and same amount of bottom flexural reinforcement. All these beams were tested with clear span equal 1100 mm which is less than four time of the height of the tested beam. In this study, three parameters were studied: shear span/ effective depth (a/d), vertical and horizontal reinforcement (ρ_v) and (ρ_h) respectively. All beams subjected to axial load 100kN and then subjected to two points symmetric loading, the tested beams were used to study the effect of each parameters on the failure load. The reason of chosen these parameters was their importance in studying of SCC deep beams behavior. The amount of flexural reinforcements for all seven beams were 3Φ20 (ρ=0.02123, when ρ is the flexural reinforcement ratio). The specimens were divided into three groups (A, B, C,) according to (a/d), ρ_v , and ρ_h. The first group A consisted of three deep beams (B1, B2, B3) were reinforced with vertical shear reinforcement of Φ4 mm @ 100 mm center to center (c/c) , and horizontal reinforcement 2Φ4 @ 90 mm (c/c), but their (a/d) values were differed as (1.2, 1,0.8). The second group B consisted of three deep beams (B1,B6, B7) were reinforced with horizontal shear reinforcement 2Φ4 mm @ 90 mm (c/c) , (a/d) =1.2, V_f =1, but their differed in vertical reinforcement as: B6 without vertical reinforcement, while B7 reinforced vertical reinforcement with Φ4 mm @ 200 mm (c/c). The third group C consisted of three deep beams (B1, B4, B5) were differed in horizontal reinforcement as: B4 reinforced with 2Φ4 mm @ 135(c/c) mm, and B5 reinforced with 2Φ4 mm @ 270 mm(c/c). For all tested beams the depth (d) =296mm.

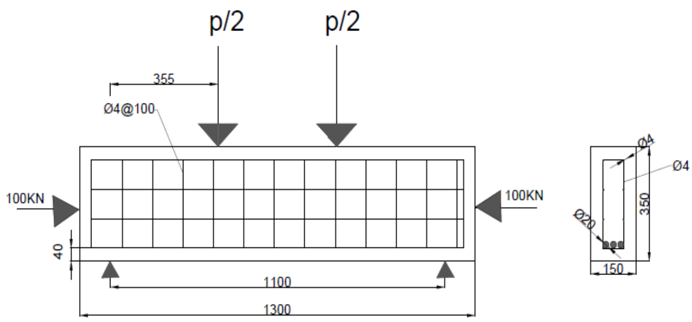

Figure1. Beams (1)

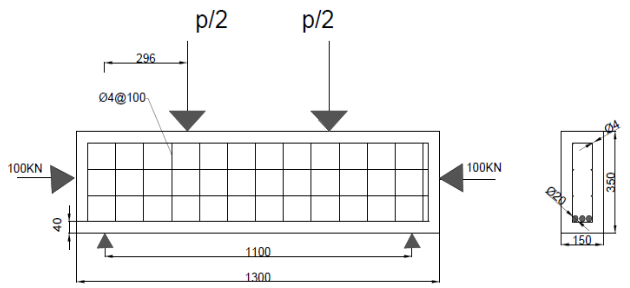

Figure 2. Beam 2

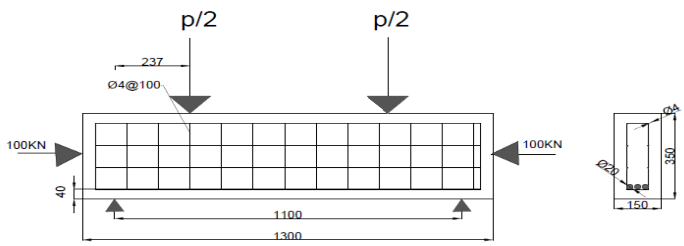

Figure3. Beam 3

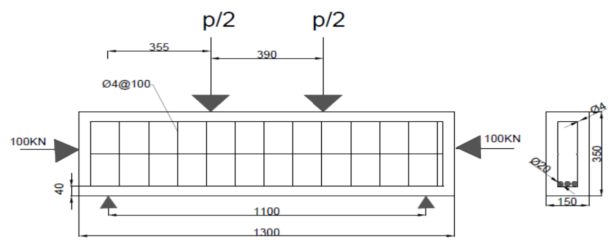

Figure 4. Beam 4

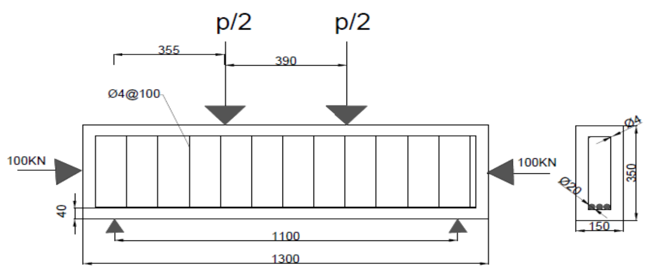

Figure5. Beam5

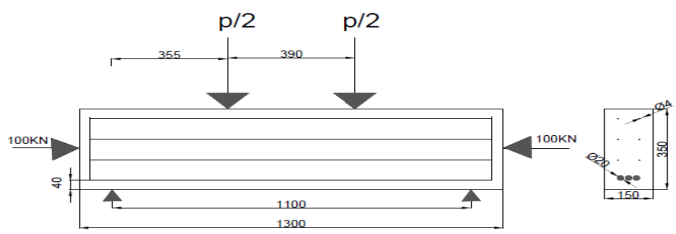

Figure6.Beam6

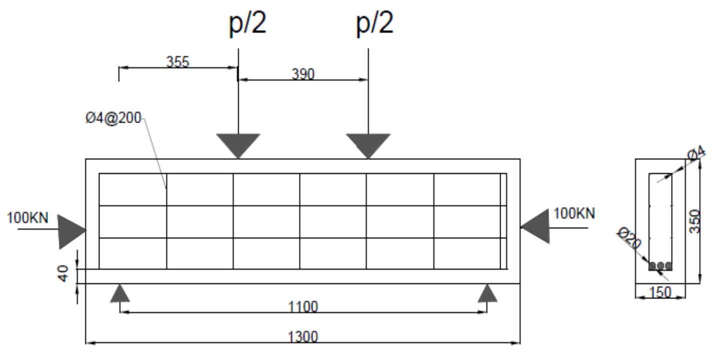

Figure7. Beam 7.

3. Components Used to Produce Self Compacting Concrete

In producing SCC, the used materials are: a higher proportion of ultrafine materials, chemical admixtures, and superplastisizer. Cement, aggregate, admixture, and filler . These materials must be evaluated according to strength, fineness, and combination with each other [11].

- Ordinary portland cement was used in the concrete mix of the present work . Tables (1,2) show the chemical compositions and physical properties of cement tested by Iraqi National Center for Construction Laboratories and Researches in Baghdad.

Table (1) Chemical Composition of the used Cement

No.	Chemical composition	Weight%	Iraqi Specifications No.5/1984[13]
1	SiO_2	22.35	-
2	CaO	63.25	-
3	MgO	1.96	5
4	Al2o3	4.4	-
5	Fe_2O_3	4.16	-
6	SO_3	2.21	2.8 (Max)
7	C_3S	45.75	-
8	C_2S	29.65	-
9	C_3A	4.63	-
10	C_4AF	12.65	-
11	Loss on Ignition (L.O.I)	1.24	4 (Max)
12	Insoluble Residue (IR)	0.2	1.5 (Max)
13	Lime Saturation Factor	0.87	0.66-1.02

(2) Physical Properties of the Cement

No	Physical Properties	Test Results	Iraqi Specification No. 5/1984 [13]
1	pecific surface area (blain method),cm^2/g	2800	
2	Setting time(Yicale's method)		
	Initial setting, hrs:min	1:28	00:45 Min
	Final setting, hrs: min	3:14	10:00 Max
3	Compressive strength(MPA)		
	3days	22.7	15Min
	7days	28	21Min

- Natural sand was used in the concrete mix of the present work. Table (3) shows the physical properties of the sand.

Table (3) Physical Properties of Sand

Physical properties	Test results	Limit of Iraqi specifications No.45/1984[14]
Specific Gravity	2.63	-
Absorption	0.65%	-
Sulfate Content	0.34%	0.5% (Max)

- Crushed gravel was used in the concrete mix of this work to improve the concrete strength with particles size between (5-12) mm. Table (4) shows the physical properties of gravel.

Table (4) Physical Properties of Gravel

Physical Properties	Test Results	Limits of Iraqi Specifications No.45/1984 [14]
Specific gravity	2.61	-
Absorption	0.71%	-
Sulfate content	0.081%	0.1% (Max)

- Chemical admixtures added to the concrete mixture before or during mixing related to cement mass. PC 260 was the type of SP that used in this work. Table (5) shows the technical properties of SP 260.

Table (5) Technical Properties of Hyperplast PC260

Form	Viscous Liquid
Color	Light yellow liquid
Freezing point	$-7^{O}C$
Specific gravity	1.1+/- 0.02
Transport	Non-flammable
Labeling	Not classified as hazardous material

* These data were listed from catalogue of manufacture

- The fillers are added in concrete as a part of total cement volume. The limestone was that used in this work. Table (6) shows chemical compositions of limestone.

Table (6) Chemical Properties of Limestone

Oxide Composition	% by Weight
CaO	54.1
MgO	0.13
SiO_2	1.38
Fe_2O_3	0.12
Al_2O_3	0.72
SO_3	0.21
Loss on Ignition (LI)	42.56

- Drinkable water was used for both mix and curing in this study.
- Steel fibers with hook ends were used in this work. Table (7) shows the properties of Steel Fibers.

Table (7) Properties of Used Steel Fibers

Relative Density	7860 kg/m^3
Yield strength	1130 MPa
Modulus of elasticity	10^3 MPa×200
Strain at portion limit	10^{-6}×5650
Poisson's ratio	0.28
Average length	50 mm
Nominal diameter	O.5 mm
Aspect ratio	100

* These properties were listed from catalogue of manufacture

- Deformed steel reinforcement was used to reinforce the beams. The nominal reinforcements diameter of 20 mm were used in tension zone, while 4 mm diameter reinforcement were used in the compression zone. For stirrups the reinforcement with diameter 4mm were used. Also, adding the hook bars to lift the beams for curing and testing. Table (8) shows specification and tensile test results of Steel Bar.

Table (8) Specification and Tensile Test Results of Steel Bar

Nominal Diameter (mm)	Yield Stress (MPa)	Ultimate Strength (MPa)	Elongation %	Vartion in Diameter %
4	698	867	-	2.7
20	491	777	11.24	-
المواصفه المعتمده م.ق.ع 1999 /2091(الحد الادنى)	400	600	9	-

4. Mixing and curing Procedure

The laboratory mixing procedure that followed in this work outlined by Emborg[11] and modified by Aljabri [12]. The total time of mixing procedure was 6 mins.
The Table (9) shows the quantities by weight of materials that used in the concrete mix:

Table (9) Quantities by Weight of Materials That Used in This Work

Mixes	Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Limestone (kg/m^3)	Super Plasticizer (l/m^3)	Steel Fiber (kg/m^3)	Water (l/m^3)
SCC-1	500	850	950	75	14	78.6	170

5. Test Measurements and Instrumentation

Steel frame with two plates as upper and lower bases that connected by four rods, used in this test to compress the beam after subjected the beam to the axial load, to achieve the requirements of axial load test. The two plates were used with dimensions (350×300×20) mm, and the rods with diameter 25mm and length 1600mm.

The iron frame is bound unless the upper plate to be ready for testing. The specimen is put inside the iron frame, then lifted by crane and placed vertically on the testing machine to apply to axial load with magnitude 100kN as a first stage of loading, then bound the upper plate after that, the crane is used to place the beam horizontally onto two supports, the beam has been labeled, and locate the two load arms at upper face of beam The second stage of loading by applied two point loads at increments of 100kN until failure.The universal testing machine with maximum capacity 3000 kN available at Structural Laboratory of Engineering College of Al-Mustansiriyah University, was used to test all the seven deep beams**.** One mechanical dial gauge was used to measure the deflection at the center of each beam with accuracy 0.01mm.

Plate (1) Load Measurement Machine

Plate (2) Steel Frame

Plate (3) Beam Applied to Axial Load

Plate (4) Beam Applied to Two Point Loa

3. Hardened Properties of Self Compacting Concrete

The mechanical properties of SCC are tested after curing age 28 days. Table (10) shows the test results of mechanical properties. These properties are concrete compressive strength f'_c, splitting tensile strength f_t, modulus of rapture f_r, modulus of elasticity E_c .

Table (10) Test Results of Mechanical Properties for Hardened Self Compacting Concrete.

Mixes	f'_c (MPa)	f_{cu} (MPa)	f'_c/f_{cu}	f_t (MPa)	f_r (MPa)	E_c (MPa)
SCC-1	54	63.8	0.846	6.8	8.6	34827.58

4. Behavior of Self Compacting Concrete Deep Beams

Seven SCC deep beams are subjected to 100kN axial load, and then subjected to two point loads. In general, after application of loads, at low load levels, all tested beams behaved in elastic manner, when the load was increased, exactly at loading level between (22-36) % from the ultimate load, the first shear cracks were appeared near the support, and after that some inclined cracks grow between the supports and the position of the two point loads, except B1 where some of flexural perpendicular cracks were appeared in the zone of maximum bending moment with diagonal shear crack between the support and the load position. Also, crushing of concrete at support zone was appeared in beams (4, 6) because of the high compressive stress appeared at this zone. With increasing the load, the inclined shear cracks grow and the width was increased, and other inclined cracks were appeared till the load reached to the ultimate level. All the results of first crack load (P_{cr}), ultimate load (P_u), all the variables, the mode of failure, and the division of the groups are summarized in Table (11).

Table (11) Test Results of Tested Deep Beams

Groups	Beam No.	a/d	ρ_v%	ρ_h%	V_f %	P_u (kN)	P_{cr} (kN)	Variable Consider	Mode of Shear Failure
A	B1	1.2	0.168	0.1682	1	838	265	Beams with different a/d ratios	Diagonal splitting mode
	B2	1	0.168	0.1682	1	1040	375		Diagonal splitting mode
	B3	0.8	0.168	0.1682	1	1350	470		Diagonal splitting mode
B	B1	1.2	0.168	0.1682	1	838	265	Beams with different ρ_v ratios	Diagonal splitting mode
	B6	1.2	0	0.1682	1	720	233		Diagonal splitting mode with crushing at support zone
	B7	1.2	0.084	0.1682	1	790	248		Diagonal splitting mode
C	B1	1.2	0.168	0.1682	1	838	265	Beams with different ρ_h ratios	Diagonal splitting mode
	B4	1.2	0.168	0.1242	1	795	246		Diagonal splitting mode
	B5	1.2	0.168	0.00621	1	690	220		Diagonal splitting mode

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C	B1	1.2	0.168	0.1682	1	838	265	Beams with different ρ_h ratios	Diagonal splitting mode
	B4	1.2	0.168	0.1242	1	795	246		Diagonal splitting mode
	B5	1.2	0.168	0.00621	1	690	220		Diagonal splitting mode

The Plates below from (5) to (11) show the tested deep beams with the pattern of cracks at ultimate loads.

Plate 5. Crack Pattern of Beam 1

Plate 6 .Crack Pattern of Beam 2

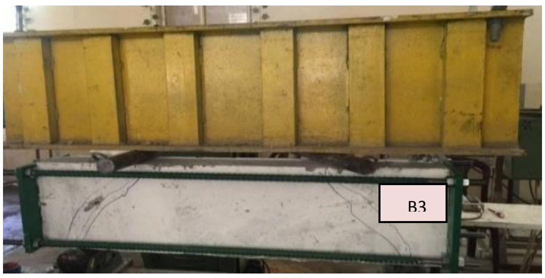

Plate 7. Crack Pattern of Beam 3

Plate 8. Crack Pattern of Beam 4

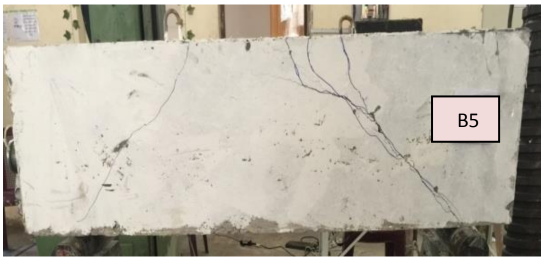

Plate 9. Crack Pattern of Beam 5

Plate 10. Crack Pattern of Beam 6

Plate 11. Crack Pattern of Beam 7.

4.1. Group A: Effect of (a/d) Ratio

From the results of the Table (12) it is obtained when (a/d) ratio decreases from 1.2 to 1 the first cracking and ultimate loads increase about 41.51% and 24.1% respectively. Also, when a/d decreases from 1.2 to 0.8 the first cracking and ultimate loads increase about 77.63% and 61.1% respectively, so when decreasing (a/d) ratio the strength of the beam increases, because when increasing the shear span that's increases the tension stress because of increasing the bending moment (M). The effect of (a/d) value on the load- mid span deflection of the beams is illustrating by the curve that shown in the Figure (1). When (a/d) is decreasing from 1.2 to 1 and 0.8, that decreasing the deflection values at corresponding load because of increasing the shear span that increasing the bending moment (M) and decreasing the moment of inertia (I) lead to decrease the rigidity of flexural zone because of high flexural stress.

Table (12) Effect of (a/d) on the First Shear Cracking and Ultimate Loads

Beam No.	a/d	V_f%	ρ_v %	ρ_h %	P_{cr} (kN)	P_u (kN)	% Increasing of Shear Cracking Load According to B1	% Increasing of Ultimate Load According to B1
B1	1.2	1	0.168	0.1682	265	838	-	-
B2	1	1	0.168	0.1682	375	1040	41.5	24.1
B3	0.8	1	0.168	0.1682	470	1350	77.4	61.1

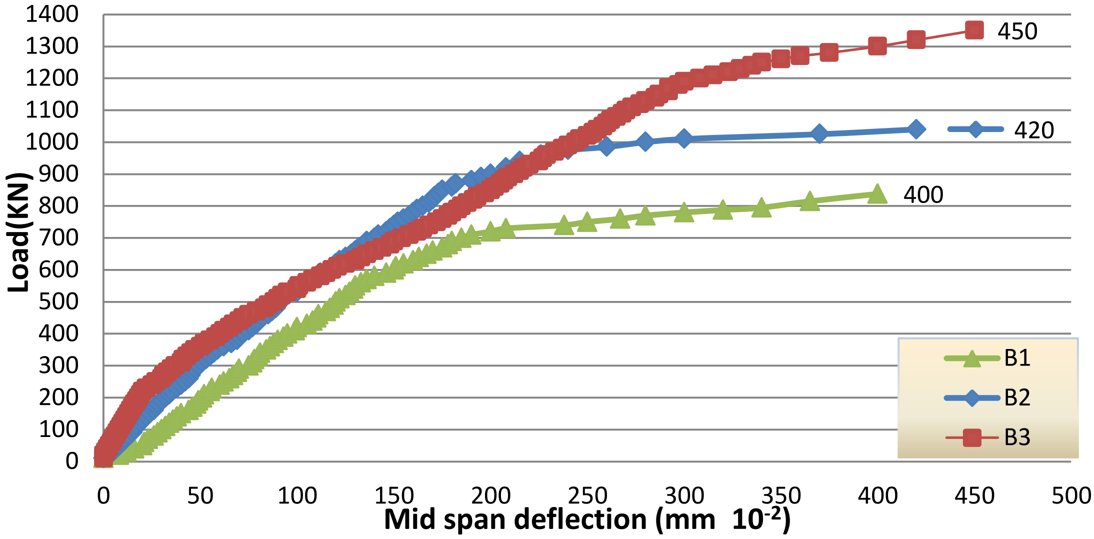

Figure1. Effect (a/d) on Load Mid-Span Deflection.

The effect of (a/d) on the first shear cracking and ultimate loads is compared with results of Akram[15] and Hulail[7]:

- Akram[15], when the (a/d) decreases from 1.2 to 1and 0.8,the increasing in P_{cr} and P_u were (38.9, 11.9)% and (72.2,42.5)% respectively.

- Hulail[7], the increasing in P_{cr} and P_u were (32, 31) %, (23.5, 30.4) %, (33.3, 20.43) % when (a/d) decreases from 1 to 0.6 and V_f (0, 0.4, 0.8) respectively.

Notice that the clearly effect of axial load in increasing both of cracking and ultimate loads when comparing with results of Akram and Hulail.

4.2. Group B: Effect of Vertical Reinforcement ρ_v

The Table (13) illustrates the effect of ρ_v on both of P_{cr} and P_u magnitudes. When increasing the percentage of ρ_v from 0 % to 0.084% that leads to increase P_{cr} about 18.75%, and P_u about 9.7%. Also, when increasing the percentage of ρ_v from 0% to 0.168% that increasing P_{cr} about 65.63% , and P_u about 16.93% because of presence of vertical reinforcement increasing the shear capacity by resisting the diagonal stress that's leads to delay the failure. The effect of the change of ρ_v ratio according to load-mid span deflection is shown in the Figure (2). The Figure appears that the increasing of ρ_v ratio leads to decrease the deflection values in the beam at corresponding loads.

Table (13) Effect of Vertical Reinforcement Ratio on First Shear Cracking and Ultimate Loads

Beam No.	a/d	V_f %	ρ_v %	ρ_h %	P_{cr} (kN)	P_u (kN)	% Increasing of Shear Cracking Load According to B6	% Increasing of Ultimate Load According to B6
B6	1.2	1	0	0.1682	233	720	-	-
B7	1.2	1	0.084	0.1682	248	790	6.4	9.7
B1	1.2	1	0.168	0.1682	265	838	13.7	16.4

The clearly effect of axial load on the results of beams according to the V_f content compare with results of Hulail. The increasing of both first cracking and ultimate loads when (a/d) equal to 0.6 and the V_f increasing from 0% to 0.4% and 0.8 % are (27.3, 6.2) % and (69.7, 15.5) % . When (a/d) equal to 1 the increasing are (36, 6.8) % and (68, 25.7) % respectively .

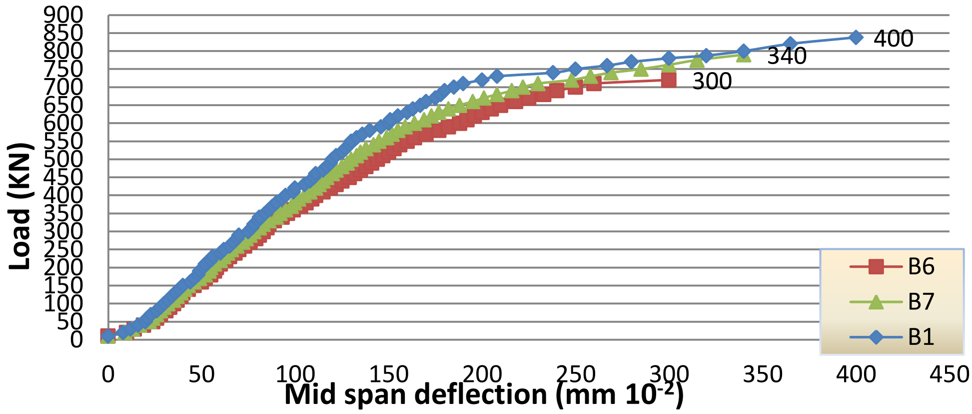

Figure 2. Effect ρ_v on Load Mid-Span Deflection.

4.3. Group C: Effect of Horizontal Reinforcement ρ_h

The Table (14) illustrates the effect of effect of ρ_h on the magnitude for both of P_{cr} and P_u. When increasing the percentage of ρ_h from 0.00621% to 0.1242% leads to increase the P_{cr} about 21.21%, and P_u about 15.22%. When increasing the percentage of ρ_h from 0.00621% to 0.168% increasing the P_{cr} about 60.6% , and the P_u about 21.45% .The effect of increasing ρ_h on percentage of P_{cr} value is higher than the percentage of P_u. The effect of change ρ_h ratio on the load- mid span deflection is illustrated by curves in the Figure (3). It's appears that the increasing of ρ_h ratio in the beam leads to decrease the deflection of beam at every stage of loadings.

Table (14) Effect of Horizontal Reinforcement Ratio on First Shear Cracking and Ultimate Loads

Beam No.	a/d	V_f %	ρ_v %	ρ_h %	P_{cr} (kN)	P_u (kN)	% Increasing of Shear Cracking Load According to B5	% Increasing of Ultimate Load According to B5
B5	1.2	1	0.168	0.00621	220	690	-	-
B4	1.2	1	0.168	0.1242	246	795	11.8	15.2
B1	1.2	1	0.168	0.1682	265	838	20.5	21.5

The results of increasing cracking and ultimate loads according to the effect of ρ_v are compared with Akram and Hulail:
-Akram [15], the increasing in P_{cr} and P_u are (5.9, 11.7) % respectively, when ρ_v increases from (0 to 0.168) %.
-Hulail [7], when ρ_v increases from (0.25 to 0.57) % the increasing are (9.1, 10.3) % for (a/d) equal to 0.6 and (8, 14.9) % when (a/d) equal to 1 respectively.
So, the effect of axial load on the increasing of cracking and ultimate loads is higher on the beams than un subjected to axial load

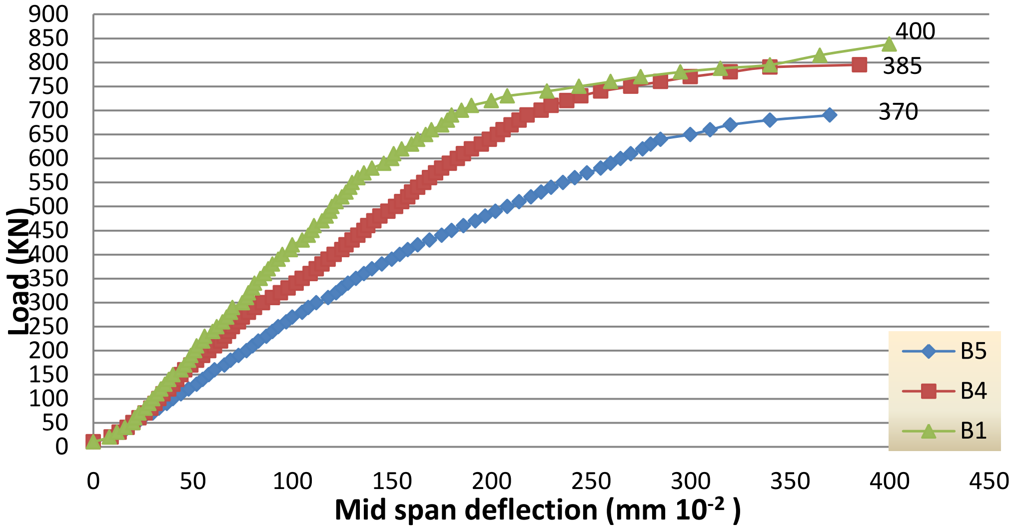

Figure3.Effect ρ_h on Load Mid-Span Deflection.

5. Conclusions

The following conclusions are obtained from the experimental work about SCC deep beams subjected to axial load:

1- The effect of axial load on the beams is very significant by improving the strength and capacity of concrete to resist the applied load and that's leads to increasing the value of P_{cr} and P_u.

2- The mid-span deflection decreasing when increasing the strength of the beam by decreasing (a/d) ratio and increasing ρ_v, and ρ_h ratios.

3- The effect of axial load on the beam by increasing the rigidity of concrete and that's contribute to decrease the mid span deflection.

4- When decrease (a/d) ratio from 1.2 to 1and 0.8, that's increasing the first cracking and ultimate loads about (41.5,77.4) % and (24,6) % respectively for SCC deep beams subjected to axial load because of increasing the shear span that's increases the tension stress because of increasing the bending moment (M).

5- Increasing vertical and horizontal web reinforcements ratios lead to increase the first crack and ultimate loads because of presence of vertical and horizontal reinforcement increasing the shear capacity by resisting the diagonal stress that's leads to delay the failure. When increasing the ρ_v from 0% to 0.084% and 0.168% increase the P_{cr} percentages as (18.7, 65.6) %, and P_u percentages as (9.7, 16.4) % respectively. Also, when increasing the ρ_h from 0.00621% to 0.1242% and 0.1682% increases the P_{cr} percentages as (21.2, 60.6) respectively and increases the P_u percentages as (15.2, 21.5) % respectively.

6- The effect of ρ_h on the first crack and ultimate loads is more significant than the ρ_v by increasing P_{cr} and P_u percentages as (60.6, 21.5) % and (12.7, 16.4) % when increasing ρ_h and ρ_v from 0% to 0.168% respectively.

7- All the beams failed with diagonal splitting mode with crushing at support zone for some beams.

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