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SUGGESTED EQUATIONS FOR MECHANICAL PROPERTIES OF SELF COMPACTING CONCRETE STRENGHTENED WITH STEEL FIBERS AND EFFECT OF SUCH FIBERS ON SHEAR CAPACITY OF SIMPLY SUPPORTED DEEP BEAMS UNDER AXIAL LOADS

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Abstract: Deep beams are structural elements that commonly design for bridges, girders, foundation walls, pile caps and others. Also, using Self Compacting Concrete (SCC) mix for deep beam is a suitable choice for deep beams because of reinforcement congestion therein. The main objective of this work is to study the shear capacity of SCC reinforced concrete deep beams subjected to axial load, so that both of experimental and analytical works are done. The experimental work consists four simply supported deep beams casted by using SCC mix with steel fibers and tested. All these beams have dimensions 1300mm length, 350mm high, 150mm width and have been subjected to axial force with (100) kN value and then subjected to two-point loads. The variables of this work are vertical and horizontal shear reinforcement and steel fibers ratio in order to study their effects on first crack load and ultimate load and mid span deflection. From the experimental results obtained all the tested beams failed by diagonal splitting mode with some crushing at support zones (in some beams). The second part is the analytical study of this research, including presents proposed equations to estimate the mechanical properties as: compressive strength $f`_{cf}$, splitting tensile strength f_{tf}, modulus of rapture f_{rf}, and modulus of elasticity E_{cf} of fibrous SCC.

Keywords: *Deep Beam, SCC With Steel Fiber, Axial Load, Shear Strength*

المعادلات المقترحه للخواص الميكانيكية للخرسانة ذاتية الرص و المقواة بالالياف الحديدية وتأثير هذه الالياف على تحمل القص للعتبات الخرسانيه العميقة بسيطة الاسناد تحت تأثير الاحمال المحورية

الخلاصة: العتبات العميقه هي عناصر انشائيه شائعة تصميميا تستعمل في الجسور، الاسس ، العوارض وغيرها. العتبات العميقه تكون كثيفة التسليح لذلك يفضل يجب أن تستعمل فيها الخلطه الخرسانيه ذاتية الرص. ان الهدف الرئيسي من هذا البحث هو دراسة تصرف العتبات العميقه لمقاومة القص والمعرضه للاحمال المحورية. يتكون هذا البحث من جزء عملي وجزء نظري، في الجانب العملي تم صب وفحص أربع عتبات عميقه بسيطة الاسناد بأستعمال الخلطة الخرسانية ذاتية الرص والمزودة بألياف حديدية. جميع هذه العتبات متماثلة الأبعاد حيث طول العتبه 1300مم والعمق 350 مم والعرض 150مم وجميعها تعرضت لى أحمال محورية بقيمة 100 كيلو

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نيوتن وبعدها سلط عليها حملين جانبيين. المتغيرات المدروسة في هذا البحث نسبة تسليح القص الافقي والعامودي، و نسبة الألياف الحديدية ودراسة تأثير هذه المتغيرات على قيم مقاومة حمل التشقق والمقاومة القصوى والهطول الوسطي للعتبات. من نتائج الفحص المختبري للنماذج، جميع هذه العتبات قد فشلت بالانشطار القطري مع تهشم بعض أجزاء الخرسانه في منطقة الأسناد للعتبات. الجزء الاخر من البحث هو الجزء النظري الذي يتضمن اقتراح معادلات لحساب الخصائص الميكانيكيه مثل: مقاومة الانضغاط، مقاومة الشد، معامل الانشطار، معامل المرونة للخلطات الخرسانية الليفية ذاتية الرص.

1. Introduction

Deep beam 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[1], and it is the durable choice in design of: transfer girder, water tanks, foundation walls, etc [2-4]. Two dimensional elasticity solutions of deep beams provided perfect descriptions of its behavior before cracking but after cracking the major redistribution of stress happen and the beam capacity must be predicted by inelastic analysis [4].

The shear is controlling the strength of deep beam more than the flexure because it proportions [3,5]. Deep beam is a heavy reinforced member, and to solve this problems the best choice is using SCC to fill all the mold, specially the narrow places between the congested reinforcements [2,6] . SCC is a type of concrete not need compaction, because it be compacted and leveled under it's self weight remove entrapped air characterized by workability, ability to fill formwork under it's own weight, high resistance to segregation and bleeding [7,8], also the advantages of SCC are better bond strength, improved durability, faster construction times, easy for placing and others[3,7-9], using hooked steel fibers in the mixture participate to carry the load that leads to increase the tensile strength of concrete and reduce creep, shrinkage of concrete, also used to improve the toughness and flexural strength[10]. Shear force is the most important in many kinds of concrete members, 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 [10]**.** Shear reinforcement is provided as 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 for that oriented vertically in horizontal beam [11]**.**

This is mostly true when strength dependents on more than one load effect like axial load [1], it is a force applied along the line of an axial and being perpendicular to the cross section of the beam. Compression and tension forces are the types of axial force depending on direction, and the act of the axial force may be through the centroid of the beam producing uniform stress then called the load concentric loading.

2. Components Used to Produce Self Compacting Concrete

In SCC, the important materials used are: a higher proportion of ultrafine materials, chemical admixtures, and superplastisizer. Cement, aggregate, admixture, and filler such materials must be evaluated according to strength, fineness, and combination with each other [12]. The components that used in SCC must be good for the mixture, and not contain any harmful components to the workability, quality, and durability of SCC, or cause corrosion of steel reinforcement [13]. These components are:

- Ordinary portland cement was used in the concrete mix of the present work should satisfies the requirements of concrete as strength, durability[13], with chemical and physical properties as Tables (1) and (2).

Table (1) Chemical Composition and Main Compounds of the Cement

No	Chemical composition	Weight%	Iraqi Specifications No.5/1984[18]
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

Table (2) Physical Properties of the Cement

No	Physical Properties	Test Results	Iraqi Specification No. 5/1984 [18]
1	Specific 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, , to produce SCC can be used a good grading for sand with fineness modulus between (2.7-3), particle or angularity shape are suitable factors, and crushed or rounded sands[12 and 13].

Table (3) Physical Properties of Sand

Physical properties	Test results	Limit of Iraqi specifications No.45/1984[19]
Specific Gravity	2.63	-
Absorption	0.65%	-
Sulfate Content	0.34%	0.5% (Max)

- Crushed gravel was used in the concrete mix of present work to improve the strength of structure because of the interlocking of the angular particles with particles size between (5-12) mm [13].

Table (4) Physical Properties of Gravel

Physical Properties	Test Results	Limits of Iraqi Specifications No.45/1984 [19]
Specific gravity	2.61	-
Absorption	0.71%	-
Sulfate content	0.081%	0.1% (Max)

- The most important admixture used in SCC is super plasticizer (SP) [14], PC 260 was the type of SP that used in this work.

Table (5) Technical Properties of Hyperplast PC260

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

* These data were listed from catalogue of manufacture

- Limestone powder is the most important type of fine filler [15], Alghubra were the traditional name of limestone that used in this work.

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

- Tap water was used for both mix and curing in this study.

-Steel fibers with hook ends were used in this work to improve mechanical properties as ductility, impact , and to increased compressive strength, tensile strength, resist to fatigue, and shear strength of concrete [11 and 13].

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	0.5 mm
Aspect ratio	100

-Deformed steel reinforcement was used to reinforce the beams. The nominal reinforcement diameter of 20 mm was used in tension zone, while 4mm diameter reinforcements were used in compression zone and for stirrups.

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

Nominal Diameter (mm)	Yield Stress (MPa)	Ultimate Strength (MPa)	Elongation%	Vartion in Diameter %
4	698	867	-	2.7
20	491	777	11.24	-

3. Mix Design

The laboratory mixing procedure that followed in this work outlined by Emborg [16] and modified by Aljabri [17]. Total time of mixing procedure was 6 mins, and the procedure was stated in this following:

1-Added the fine aggregate (sand) to the mixer and mixed for 60 sec with 1/3 quantity of water.
2- Added the cement and limestone to the mixer and mixed for another 60 sec with 1/3 quantity of water.
3- Added the coarse aggregate (gravel) to the mixture with the last 1/3 quantity of water and 1/3 dosage of PC260, and mixing for 90 sec, and then left the mixer for 30 sec to rest.
4- After that, the 2/3 dosage of PC260 added with the steel fibers to the mixer and mixing for 120 sec to achieve good and homogeneous distribution of steel fibers.
5- The mixture discharged, tested and casting.

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 Fibers (kg/m^3)	Water (l/m^3)
SCC-0	500	850	950	75	14	0	170
SCC-0.5	500	850	950	75	14	39.3	170
SCC-1	500	850	950	75	14	78.6	170

4. Experimental Program

The experimental program was achieved to investigate the shear capacity of simply supported deep beams tested under axial load using SCC. Four beams were designed to fail in shear and had the same dimensions were (150×350 1300) mm with overall length 1100mm, and same amount of bottom flexural reinforcement. All these beams were tested with clear span equal 1100 mm less than four time of the height of the tested beam. In this study two parameters were count: both vertical and horizontal reinforcement (ρ_v) and (ρ_h), and steel fibers content (V_f). All beams are 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 amount of flexural reinforcements for all beams were 3Ø20 (ρ=0.02123, when ρ is the flexural reinforcement ratio). The specimens were divided into two groups (A, B) according to ρ_v , ρ_h , and V_f . The group A consisted of three deep beams (B1, B2, B3) were reinforced with vertical shear reinforcement of Ø4 mm @ 100 mm (c/c), and horizontal reinforcement 2Ø4mm @ 90 (c/c) mm, and (a/d) =1.2, but their V_f differed as (1, 0 and 0.5) %. The group B consisted of two deep beams (B1, B4) where (B4) without vertical and horizontal reinforcement.

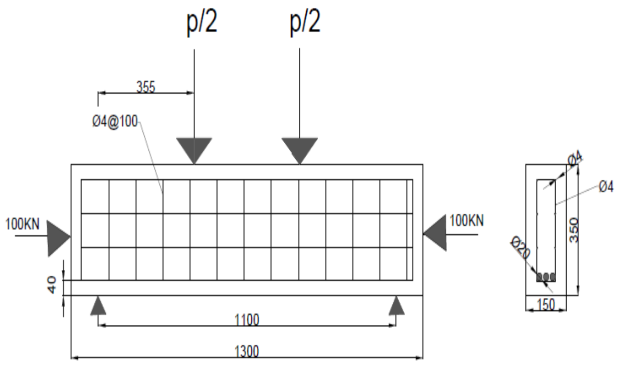

Figure (1) Beams (1-3)

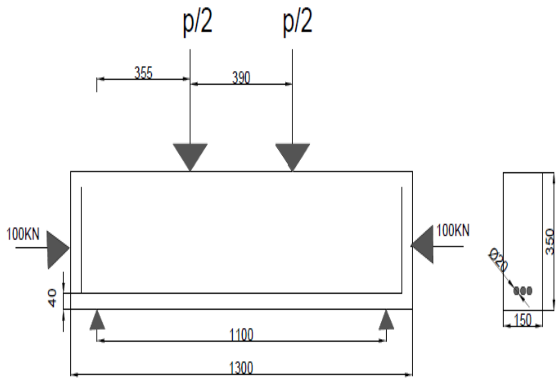

Figure (2) Beam 4

5. Test Measurements and Instrumentation

- One mechanical dial gauge was used to measure the deflection at the center of each beam with accuracy of 0.01mm.
- A universal testing machine with maximum capacity 3000 kN available in Structural Laboratory of Engineering College of Mustansiriyah University was used to test all the deep beams.
- Steel frame with two plates as upper and lower bases that connected by four rods were used in this test to compress the beam after subjected the beam to the axial load for achieving the requirements of axial load test. The two plates were used with dimensions of (350×300×20) mm, and the rods with 25mm diameter and 1600mm length.
-Four deep beams were tested at Structural Laboratory of Al-Mustansiriyah University/ Engineering College. All the beams were painted with white color to observe the cracks patterns and first crack easily. The iron frame was bound unless the upper plate to be ready for testing. The specimen was put inside the iron frame, and then placed vertically on the testing machine to be subjected to axial load with magnitude of 100kN as a first stage of loading, then bound the upper plate. After that, the specimen placed horizontally onto two supports, the beam was labeled, subjected to two load arms at upper face of beam, the dial gauge at the middle of beam were positioned. The second stage of loading presented by applied two point loads at increments of 100kN until failure. At each stage of loading the concrete strain and deflection were recorded. When the first crack appeared, the corresponding load was recorded. Finally, the positions of all cracks were marked on the beams and was recorded at any load stage occurred.

6. Hardened Properties of Self Compacting Concrete

The mechanical properties of SCC are tested after curing for 28 days. Table (10) shows the test results of the mechanical properties. These properties are concrete compressive strength f'_c , splitting tensile strength f_t , modulus of rapture f_r and modulus of elasticity E_c. All the results that presented in this table are the average of three specimens.

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-0	49	59.6	0.822	4.8	5.4	33657.91
SCC-0.5	49.7	61	0.814	5.3	6.6	34069.23
SCC-1	54	63.8	0.846	6.8	8.6	34827.58

7. Fresh Self Compacting Concrete Properties

To ensure the mix is SCC mix, the fresh properties results must be in the range of the limitations. Trail mix was done on the mix that presented by Akram[20] with same modification in mix properties as previously detailed. In this study two tests as T_{50} slump flow test and slump flow test, V-funnel test and V-funnel at T_{5min} test are done Material Libratory of Mustansiriyah University/ Engineering Faculty. Table (11) illustrates the results of these tests and compared the results with limitations of EFNARC [21] and ACI-237 [22].

Table (11) Tests Results of Fresh Properties for Self Compacting Concrete

Tests	T_{50} Slump Flow (sec)	Slump Flow (mm)	V-Funnel (sec)	V-Funnel at T_{5min} (sec)
SCC-0	4	710	8	10
SCC-0.5	4.5	680	9	11
SCC-1	5	650	10	12
EFNARC Limitations	2-5	650-800	8-12	+3
ACI-237 limitations	2-5	450-760	-	-

8. Behavior of Self Compacting Concrete Deep Beams

Four 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 the tested beams behaved as an elastic manner. Where no visible cracks and the deflection was slight at mid span of the beam because the stress at this stage was still small and the strength of the beam could resist the applied load. When the load was increased, exactly at loading level between (22-36) % from the ultimate load, the first shear cracks were visible 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 appeared in the zone of maximum bending moment with diagonal shear crack between the support and the load position. So, all the beams failed with diagonal splitting mode. Also, crushing of concrete at support zone appeared in beams (B_2, B_3) because of the high compressive stress acting at this zone. 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 (12).

Table (12) 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 V_f ratios	Diagonal splitting mode
	B2	1.2	0.168	0.1682	0	550	141		Diagonal splitting mode with crushing at support zone
	B3	1.2	0.168	0.1682	0.5	735	195		Diagonal splitting mode with crushing at support zone
B	B1	1.2	0.168	0.1682	1	838	265	Beams with and without ρ_v and ρ_h	Diagonal splitting mode
	B4	1.2	0	0	1	580	175		Diagonal splitting mode

Plate (1) Crack Pattern of Beam1

Plate (2) Crack Pattern of Beam2

Plate (3) Crack Pattern of Beam3

Plate (4) Crack Pattern of Beam4

8.1. Group A: Effect of Steel Fibers Content

For the V_f ratio of 0.5% B_3 the P_{cr} and P_u increasing about 25.81% and 18.5 % when compared with the reference specimen B_2 respectively. Also, for the V_f ratio of 1% B_1 the P_{cr} and P_u increasing about 70.97% and 35.16% respectively. This increasing of P_{cr} ratios because of increasing the strength of the beam increase and the serviceability . The curve below shows that, the graduating the V_f ratio from 0% to 0.5% and 1% leads to decrease in the deflection values of the beam at corresponding load because of the presence of V_f .

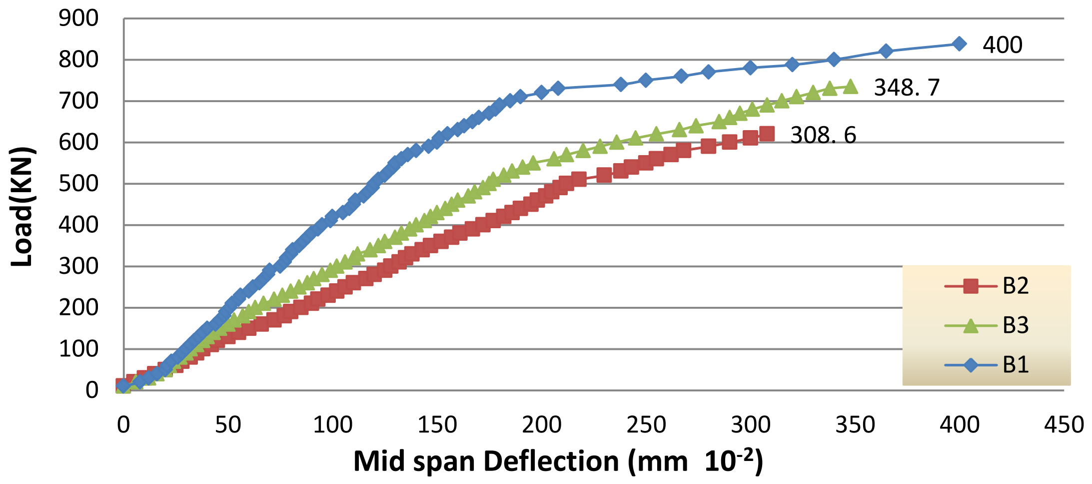

Figure (1) Effect of V_f on Load-Mid Span Deflection

8.2. Group B: Effect of Vertical and Horizontal Reinforcement

When adding both vertical and horizontal reinforcements, the P_{cr} and P_u increased about 51.43% and 44.5 % respectively. The presence both of vertical and horizontal reinforcements increased the P_{cr} more than P_u values because of increasing the strength of the beam. The Figure (2) illustrates the difference of load - mid span deflection according to the absence and presence of vertical and horizontal reinforcements in the beam. When the vertical and horizontal reinforcements were absent that lead to increasing the deflection in every stage of loadings because of decreasing the capacity of the beam .

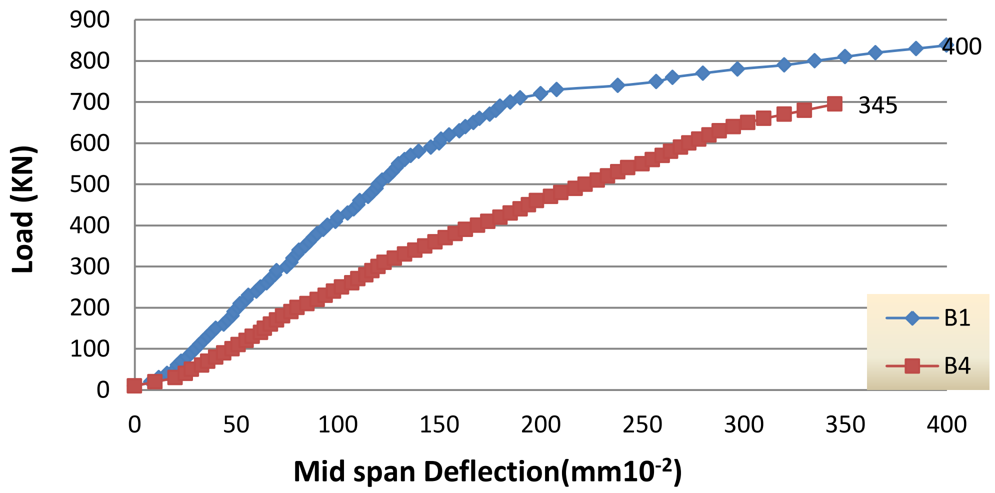

Figure (2) Effect of ρ_v and ρ_h on Load-Mid Span Deflection

9. Regression Analysis

The aim of regression analysis is to evaluate the expression relating the standard variables to one or more other variables which are named predictor variables. The predictor variable is a variable whose variation is believe to cause or agree with variation in the variable. Regression analysis is defined as an important statistical method is used to derive the proposal equation by using **Data Fit Software Version 9 of Oakdale Engineering Computer Program**. The proposed equations given in this research to predict the initial value of mechanical properties . The proposal equations are listed in this Table (13):

Table (13) the Proposal Equations

No.	Proposal Eq.	μ	SD	COV%	R^2
1	$f`_{cf} = 1.15\ f`_{cn}\ F^{0.085}$	1.0025	0.03063	3.0555	0.98
2	$f`_{cf} = f`_{cn} + 5.01V_f$	0.9925	0.036606	3.69	0.97
3	$f_{tf} = 0.74 f_{cf}^{0.5} F^{1.87}$	0.979275	0.1065	10.87	0.91
4	$f_{tf} = 0.32\ f_{cf}^{0.76}\ V_f^{0.24}$	1.003833	0.067681	6.7	0.93
5	$f_{rf} = 6.11\ f`_{cf}^{0.1}\ F^{0.24}$	1.00033	0.0879	8.787	0.75
6	$f_{rf} = 3.46\ f`_{cf}^{0.21}\ V_f^{0.25}$	1.001325	0.08372	8.372	0.69
7	$E_{cf} = 4756\ f`_{cf}^{0.5}\ F^{0.4}$	0.996075	0.03973	4	0.91
8	$E_{cf} = 4605\ f`_{cf}^{0.5}$	0.993367	0.045124	4.55	0.90

10. Conclusions

The following conclusions are obtained from the experimental and analytical 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 cracking load (P_{cr}) and ultimate load (P_u). Also, increasing the rigidity of concrete that's contributes to decrease the mid span deflection.

2- The diagonal splitting mode of failure is dominant regardless of shear reinforcement presence and steel fibers ratio.

3- Presence of vertical (ρ_v) and horizontal (ρ_h) web reinforcements ratios lead to increase the first crack and ultimate loads because of increasing the strength and capacity of the beam, when using the both ρ_v and ρ_h of 0.168% lead to increase the P_{cr} and P_u about 51.43% and 52.4% respectively in compression to nonreinforcement beam.

4- The effect of steel fibers (V_f) content is more than the presence of steel reinforcement on the beam behavior. By improving the concrete rigidity that's increasing the P_{cr} and P_u values because of the presence of V_f improving the mechanical properties of beam and increasing the capacity of the tension zone that's leads to increase the moment of inertia of tension zone (I) that's increasing the rigidity of the beam and decreasing the deflection values.

5- The mid-span deflection decreases when increasing the strength of the beam by increasing V_f, ρ_v, and ρ_h ratios. Also, the effect of V_f on the deflection is higher than the steel reinforcement ratio on the maximum values.

6- The proposal equations predict to estimate the mechanical properties give closer results to experimental results of presented work and other researchers works [3,20] , The preferred proposal equations are:

-For compressive strength, the prefer equation is $f`_{cf} = f`_{cn} + 5.01\ V_f$, with R^2=0.97.

-For splitting tensile strength, the proposal equation is $f_{tf} = 0.74 f_{cf}^{0.5} F^{1.87}$, with R^2=0.91.

-For modulus of rapture, $f_{rf} = 6.11\ f`_{cf}^{0.1}\ F^{0.24}$ is the suitable equation, with R^2=0.75.

-For modulus of elasticity, the best equation is $E_{cf} = 4605\ f`_{cf}^{0.5}$, with R^2=0.9.

11. Abbreviations

SCC Self Compacting Concrete
ρv Vertical reinforcement
ρh Horizontal reinforcement
$f'c$ Ultimate compressive strength
f_t Splitting tensile strength
f_r Modulus of rupture
E_c Modulus of elasticity of concrete
l Clear span between faces of two supports
d Depth of deep beam
l/d (length/depth) ratio
a Shear span from center of support to center of point load
a/d (shear span/depth) ratio
Vf Steel fiber content
Pu Ultimate load
Pcr First cracking load

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