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EXPERIMENTAL COMPARISON BETWEEN FLEXURAL CRACKS BEHAVIOR OF SELF-COMPACTING CONCRETE AND NORMAL CONCRETE BEAMS

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Abstract: Eight reinforced concrete rectangular beams were designed and tested to study the effect of using self-compacting concrete (SCC) and normal concrete (NC) on the flexural cracking behavior under two concentrated load. All beams have the same longitudinal and vertical steel ratio and gross section area of (15000) mm^2. The tested beams were divided into two groups; the first group consists of four self-compacting concrete beams (SCC) while the second group consists of four normal strength concrete (NSC). Each group was divided into two series according to clear span to effective depth ratio (ln/d), each series includes of two compressive strength (f_c'). It was found that the beams which made from SCC was more stiffer as compared with the beam which made from NCC with same of the clear span to effective depth ratio, longitudinal steel ratio, vertical steel ratio and relative compressive strength. The first crack in the SCC beams about 26.95% from the ultimate load while the first crack in the NSC beams about 20% from the ultimate load, the ACI 318-08 equation is conservative as compared with the experimental study, the max crack width of SCC beams is lesser than the NC beams, the number of crack in SCC beams is lesser than the NC beams, the Z factor value in different exposure in ACI formula is more conservative than obtained from experimental study, the experimental cracking moment of SCC beams are greater than the experimental cracking of NSC. As compared with theoretical cracking moment predicated from cracking moment predicated from ACI formula, the maximum crack width of SCC increased about 20.833%, 26.16% when the clear span to the effective depth ratio (ln/d) increase from 8.4 to 10 at compressive strength (f_c') 23.81 and 17.9 MPa respectively while the maximum crack width of NSC increased about 8.1%, 11.42% when the clear span to the effective depth ratio (ln/d) increase from 8.4 to 10 at compressive strength (f_c') 22.41 and 16.2 MPa respectively and the ultimate load capacity of SCC increased about 9.433%, 14.285% when the compressive strength (f_c') increased from (17.9) to (23.81) MPa at clear span to effective depth ratio (ln/d) (8.4),(10) respectively while the maximum crack width of NSC increased about 2.56%,5.714% when the compressive strength (f_c') increased from (16.2) to (22.41) MPa at clear span to effective depth ratio (ln/d) (8.4),(10) respectively.

Keywords: *Cracking load, cracking moment, crack width, self-compacted concrete beam*

مقارنة عملية لتصرف تشققات الانحناء للعتبات الخرسانة الذاتية الرص والخرسانة الاعتيادية

الخلاصة: يتناول البحث دراسة تأثير ثمان عتبات خرسانية مسلحة ذات مقطع مستطيلة الشكل وبأبعاد (100mm x 150mm) صممت وفحصت لدراسة تأثير استخدام الخرسانة الذاتية الرص والخرسانة الاعتيادية على تصرف تشققات الانثناء تحت تأثير حملين مركزين جميع العتبات تحوي على نفس الحديد الطولي والحديد العمودي وذات مساحة مقطع 15000 ملم2 .قسمت العتبات المفحوصة الى مجموعتين المجموعة الأولى تحتوي على اربع عتبات ذاتية الرص بينما المجموعة الثانية تتكون من اربع عتبات ذات خرسانة اعتيادية. كل مجموعة قسمت الى متواليتين حسب نسبة الفضاء الى العمق الفعال. كل متوالية تتكون من اربع عتبات كل عتبتين منها ذات نفس مقاومة الانضغاط تقريبا وتبين ان العتبات الذاتية الرص اكثر قساوة بالمقارنة مع العتبات ذات الخرسانة الاعتيادية على الرغم من كون نسبة الفضاء الصافي الى العمق الفعال ونسبة الحديد الطولي والعمودي ومقاومة الانضغاط متساوية. التشقق الأول في الخرسانة الذاتية

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الرص تقريبا 26,95% من الحمل الأقصى بينما التشقق الأول في الخرسانة الاعتيادية حوالي 20% من الحمل الأقصى للعتبات. باستخدام المدونة الامريكية (ACI 318-08)وجد بأنها متحفظة مقارنة مع النتائج المستحصلة من الجانب العملي. عرض التشقق الأكبر للعتبات الخرسانية الذاتية الرص اقل منها في العتبات ذات الخرسانة الاعتيادية وقيمة معامل Z حسب قاعدة (ACI) اكثر تحفظ من النتائج المستحصلة من النتائج العملية وعزم التشققات التجريبي للعتبات الخرسانية الذاتية الرص اكبرمنها في العتبات ذات الخرسانة الاعتيادية بالمقارنة مع عزم التشقق النظري المستحصل من قاعة (ACI) وعرض اكبر تشقق للعتبات الذاتية الرص يزداد حوالي 20,833% و 26,16% عند نسبة طول صافي الى عمق فعال يتغير من 8,4 الى 10 وذات مقاومة انضغاط 23,81 و 17,9 (Mpa) على التوالي بينما عرض التشقق الأكبر لعتبة ذات خرسانة اعتيادية يزداد حوالي 8,1% و 11,42% عند نسبة طول صافي الى عمق فعال يتغير من 8,4 الى 10 عندما تكون مقاومة الانضغاط 22,41 و16,2 $(M\text{pa})$ على التوالي وسعة التحمل القصوى لعتبات ذات خرسانة ذاتية الرص تزداد حوالي 9,433% و 14,285% عندما تكون مقاومة الانضغاط تزداد من 17,9 الى 23,81 (Mpa) عندما تكون نسبة طول صافي الى عمق فعال 8.9 و 10 على التوالي بينما عرض التشقق الأكبر للخرسانة الاعتيادية يزداد حوالي 2,56% و 5,714 عندما مقاومة الانضغاط تزداد من 16.2 الى 22,41 (Mpa) عندما تكون نسبة طول صافي الى عمق فعال 8.9 و 10 على التوالي.

1. Introduction

Cracking of concrete structures due to bending or tension has usually great significance on structural behavior. Structural cracks can influence both serviceability and durability of structural members. From the serviceability point of view, the reduction of stiffness and increase of deformations, the possible water leakage through the cracks and the aesthetical concerns can be mentioned. From the durability point of view, the possible attack of steel corrosion and the reduced service life of structures can be in focus [1], the occurrence of cracks in reinforced concrete structures is inevitable because of the low tensile strength of concrete. Cracks form when the tensile stress in concrete exceeds its tensile strength.

Cracking in reinforced concrete structures has a major- influence on structural performance, including tensile and bending stiffness, energy absorption capacity ductility, and corrosion resistance of reinforcement cracking at the service load should not extend to such a limit that it spoils the appearance of the structure or leads to excessive deformation of the members. This may be achieved by specifying an allowable limit on crack width values. In order to assure satisfactory performance of the structure even under a service loads, an important limit state i.e., the limit state of serviceability (cracking) is introduced into the limit state design procedure. This limit state is assumed to be satisfied if crack widths in a concrete member are within a maximum allowable limit while the need for a crack limit state has been universally agreed on; the formulae for predicting the crack width extensively vary in the various codes of practice. Inspection of crack width prediction procedures proposed by various investigators indicates that each formula contains a different set of variables.

A literature review also suggests that there is no general agreement among various investigators. On the relative significance of different variables affecting the crack width, despite the large number of experimental work carried out during the past few decades. Taking all the parameters into account in a single experimental program is not normally feasible due to the large number of variables involved, and the interdependency of some of the variables. [2]

2. Causes of cracking

There are several reasons for cracking in concrete. Cracks can be formed both in fresh concrete (before setting of cement paste) and in hardened concrete. As concrete sets, plastic cracking may occur during the first few hours after casting. There are two types of plastic cracking: plastic shrinkage cracking (commonly in slabs) and plastic settlement cracking (in deep members). Both types of plastic cracking are associated with bleeding of concrete.

In hardened concrete cracks can be formed from loads (flexure, tension, shear, torsion bond, etc.) or from imposed deformations (shrinkage, thermal movements, etc.).[3]

3. Research significance

Concrete has been used in the construction industry for centuries. Many modification and developments have been made to improve the performance of concrete, especially in term of strength and workability. Engineers have found new technology of concrete called self-compacting concrete.

The main objective of the work described in this study is to investigate and to get more information and more understanding about the crack behavior of self-compacting concrete beams and compared with the normal strength concrete beams (NSC) under flexural load.

4. Tested program

4.1. Description of specimens:

The tested beams were divided into two groups according to the concrete type to SCC and NCC, each group was divided in two series according to clear span to effective depth ratio increase from 8.4 to 10. The rectangular -section has overall dimensions of 150 mm (total depth) and the width of the section is (100) mm.

The longitudinal deformed steel reinforcement consists of two bars of 8 mm nominal diameter at the bottom and two plane bars of 4 mm nominal diameter at the top. The internal steel stirrups are 4 mm in nominal diameter spaced of 66 mm center to center as shown in Fig.(1), and the total description of the beams which used in this study are listed in Table (1).

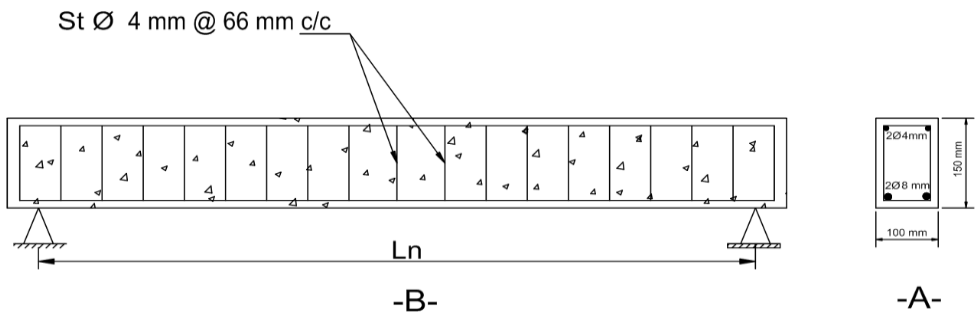

Fig. (1) Details of specimens all dimensions in mm: (A) cross-section; (B) Elevation.

Table (1): Total description of the tested beams

Group	Beam	Comp. strength (f_c') MPa	Clear span (ln)mm	Effective depth (d)mm	Clear span to effective depth ratio (ln/d)
Self-compacted concrete	A10	23.8	1120	132	8.48
	A11	23.8	1320	132	10
	C10	17.9	1120	132	8.48
	C11	17.9	1320	132	10
Normal strength concrete	B10	22.41	1120	132	8.48
	B11	22.41	1320	132	10
	D10	16.2	1120	132	8.48
	D11	16.2	1320	132	10

4.2. *Materials*

General description and specification of materials used in the tested beams are listed below; tests are made in the National Center for Constriction Laboratories and Research

- Cement: Ordinary Portland cement type I produced at northern cement factory (Tasluja-Baizian) is used throughout this investigation which conforms to the Iraqi specification No. 5/1984[4], Tables (2) and (3) show the chemical and physical properties of the used cement.
- Fine Aggregate: Al- Ukaider natural sand is used. This complies with the Iraqi Standard Specification No.45/1984,[5] zone (2).The specific gravity, sulfate contents(SO_3) and absorption of the used sand were 2.66,0.4%,1.7% respectively.
- Coarse Aggregate: Crushed gravels maximum size 14 mm from Al-Niba'ee area are used. This complies with the Iraqi Standard Specification No.45/1984, [5] the specific gravity, sulfate contents (SO_3) and absorption of the used gravel were 2.65, 0.07%, 0.57% respectively.
- Water: Ordinary potable water is used throughout this work for both mixing and curing of concrete.
- Steel Reinforcement: Deformed longitudinal steel bars with nominal diameter of 8mm and 4mm were used in this study. Reinforcement were tested to determine the yield stress of 8mm and 4mm they were 397.88 and 596.83MPa respectively
- Limestone Powder: A fine limestone powder (locally named as Al-Gubra) of northern origin with fineness (3100 cm^2/ gm) has been used as a filler for concrete production for many years. It has been found to increase workability and early strength, as well as to reduce the required compaction energy. The increased strength is found particularly when the powder is finer than the Portland cement [6]. The cement in SCC mixes is generally partially replaced by fillers like lime stone powder in order to improve certain properties such as;
    - Avoiding excessive heat generation.
    - Enhancing fluidity and cohesiveness.
    - Enhancing segregation resistance.

- Increasing the amount of powder (cement +filler), so it becomes more economical than using cement alone.

- Super plasticizer [7]: To produce SCC, a super plasticizer known as (High Water Reducing Agent) based on polycarboxylic ether is used; it has the trade mark Glenium 51. Glenium 51 is free from chlorides and complies with ASTM C494-99, types A and F. It is compatible with all Portland cements that meet recognized international standards. Table (4) shows the typical properties of Glenium 51.

Table (2): Chemical Composition of Cement

Compound Composition	Chemical Composition	Percent	Limit of Iraqi specification No.5/1984[4]
Lime	CaO	61.67	-
Silica	SiO2	20.69	-
Alumina	Al2 O3	5.20	-
Iron Oxide	Fe2 O3	4.61	-
Magnesia	MgO	2.43	< 5
Sulfate	SO3	2.21	< 2.8
Loss on Ignition	L.O.I.	3.31	< 4
Insoluble Residue	I.R.	0.5	< 1.5

Table (3): Physical Properties of the Cement Used in this Work.

Physical properties	Test Results	Limit of Iraqi specification No.5/1984[4]
Specific Surface area (Blaine Method , cm2/gm)	3043	≥ 2300.0
Setting time (Vicats Method)		
Initial Setting time, hrs. : min	174	45 min>
Final Setting time, hrs. : min	3:54	≤ 10:00 hr
Compressive strength of mortar		
2 days (MPa)	21.61	≥ 15
7 days (MPa)	30.75	≥ 23

Table (4): Typical properties of Glenium 51 [7]

No.	Main action	Concrete super plasticizer
1	Color	Light brown
2	pH. Value	6.6
3	Form	Viscous liquid
4	Subsidiary effect	Hardening
5	Relative density	1.1 at 20°C
6	Viscosity	128 ± 30 cps at 20°C
7	Transport	Not classified as dangerous
8	Labeling	No hazard label required

4.3. *Concrete mix*

Mix proportioning is more critical for SCC than for NSC and HSC. Many trials are carried out on mixes incorporating super plasticizer by increasing the dosage of the admixture gradually, adjusting the w/c ratio to ensure the self-compact ability [8]. Table (5) indicates the mix proportion of SCC and NSC mixes. For each concrete mix, three standard cube specimens (150×150×150) mm are taken, they were tested at 28 days of age, the test result of fresh concrete properties are shown in Table (6) these results are within the acceptable criteria for SCC given by ACI committee-363 [9] and indicate excellent deformability without blocking.

Table (5): mix design of SCC and NSC mixes by weight

Group	Type of concrete	comp. strength of cube (f_{cu}) MPa	comp. strength of cylinder (f_c') MPa	W/C Ratio	Mix proportions (kg/m^3)					lit /m^3	
					Cement	Limestone powder (lsp)	Total powder	Sand	Gravel	Water	Glenium 51
A	(SCC)	29	23.8	0.37	250	250	500	739	870	185	6
B	(NSC)	27.34	22.42	0.5	400	----	400	728	1092	200	---
C	(SCC)	21.83	17.9	0.36	300	200	500	758	890	180	6
D	(NSC)	19.756	16.2	0.7	317	----	317	720	1136	222	---

Table (6): Results of testing fresh SCC property in experimental work

Mix symbol	Slump flow (mm)	T50 Sec.	L-box (H2/H1)	T20 Sec.	T40 Sec.
A	738	5	0.89	1.65	3.35
C	745	4.5	0.9	1.18	3.01
Acceptance criteria for Self-compacting concrete (SCC) [10]					
NO.	Method	Unit	Typical range of values		
			Minimum		Maximum
1	Slump flow	mm	650		800
2	T50	Sec	2		5
3	L-Box	(H2/H1)	0.8		1

5. Test procedure of beams

All the beams were white washed in order to aid the observation of the crack development during the testing. Beams were tested under gradually increasing load up to failure under two point symmetric top loading in universal-Testing machine (MFL systems) at the structural laboratory of the college of the engineering, Al-Mustansiriyah university as shown in Fig.(2). The tested beams were simply supported at ends over an effective span of (50 mm) the distance between the two point loads at the third of the clear span length. A dial gauge of (0.01 mm) accuracy with (30 mm) capacity was fixed at the middle of the bottom of the beam to measure the mid span deflection; the test set-up is shown in Fig. (3). Loading procedure was started by the application of single point load from the testing machine to the upper midpoint of the loading bridge. The single load was then divided equally between the two point loads that were transferred to the concrete beam through two (Φ 30 mm) steel bars loaded at the end of the bridge. Beam specimens were placed at the testing machine and adjusted so that the centerline, supports, point loads and dial gauge was fixed at the correct and proper location. Loading was applied in small increments of (5 kN).At each load stage the deflection readings at the mid span was recorded. The loading increments were applied until failure.

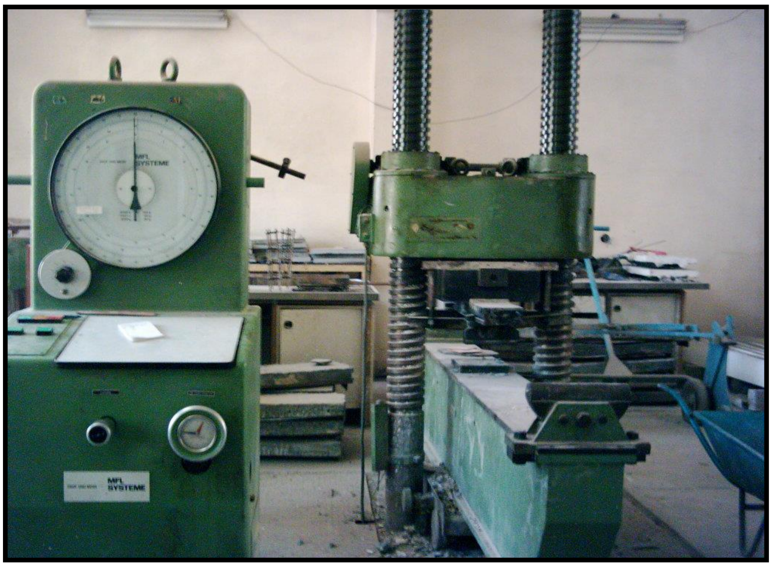

Fig. (2) Test Machine

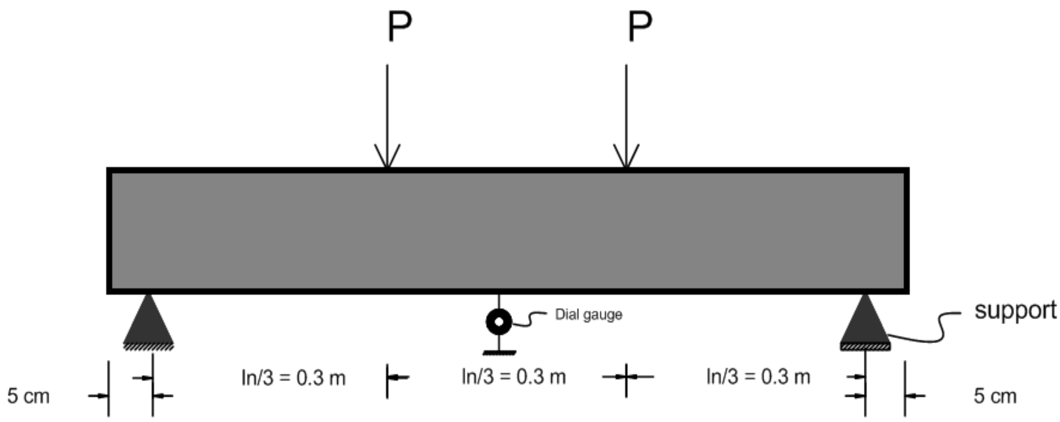

Fig. (3) Schematic diagram of test set-up

6. Crack of beam in Code provisions

Prior to 1999, flexural crack control requirements in ACI were based on the so-called Z-factor method developed be Gergely and Lutz [11]. Their work was based on extensive statistical analysis techniques on experimental data from several researchers. The equation proposed by the early version of ACI 318-95 [12] took the following form

$$W_{crack\ max} = 11 \times 10^{-6} \beta f_s \sqrt[3]{d_c A_0} \quad (1)$$

Where:

β= (h-x)/ (d-x) is the ratio of distance between neutral axis and extreme tension face to distance between neutral axis and centroid of reinforcing steel β= 1.20 in beams may be used to compare the crack widths obtained in flexure and axial tension. A_o = the area of concrete surrounding each reinforcing bar = A_e/nb, A_e = the effective area of concrete in tension, A_e can be defined as the area of concrete having the full width of the beam and having the same centroid of the main reinforcement; A_e = 2 dcb, nb = the number of tension reinforcing bars. dc = the distance measured from the centroid of tensile steel to the extreme tensioned fiber.

The flexural crack width expression in the above equation with (h-x)/(d-x)= 1.2 is used in ACI 318-95 in the following form

$$Z = f_s \sqrt[3]{d_c A_0} \quad (2)$$

A maximum value of z = 30645 N/mm is permitted for interior exposure, corresponding to a limiting crack width of 0.4 mm. ACI 318-95 also limits the value of z to 25392 N/mm for exterior exposure, corresponding to a crack width of 0.3 mm When structures are subjected to very aggressive exposure or designed to be watertight, ACI committee 350565limits the value of z to 17000 N/mm corresponding to a crack width of 0.20 mm. ACI 318-05 [13], ACI 318-08[14] proposed the following equation for crack control

$$S = (380(280/f_s) - 2.5\ c \leq 300(280/f_s) \quad (3)$$

Where

S= maximum spacing of reinforcement closest to the tension face, mm c = least distance from surface of reinforcement to tension face, mm

However the equation does not make a distinction between interior and exterior exposure, i.e. the exposure conditions dependence was eliminated. Also, the equation is indirectly tied to a crack width equals to 0.4 mm. The value of fs at service load shall be computed on the basis of service moment ACI permits the use of fs = 0.6 fy

7. Results and discussion

All the result show that the SCC beams gave higher performance than NSC, this can be assumed that SCC beam flexural cracking strength probably caused good bond between the reinforcement and concrete this occurrence may possible be explained by SCC having greater fill capacity, which enables them to cover the reinforcement entirely without need of vibrato while control process depends on the vibration to be compacted perfectly. The greater filling capacity of SCC and its smaller amount of bleeding also reduced the occurrence of voids between the reinforcement and the concrete [15].

7.1. Load –deflection curves

All beams showed typical structural behavior in flexure. Vertical flexural cracks were observed in the constant moment region and final failure occurs due to crushing of the compression concrete. Figs. (4). show that the beams which made from SCC was stiffer as compared with the beam which made from NCC with the same of the clear Span to effective depth ratio and almost the same compressive strength.

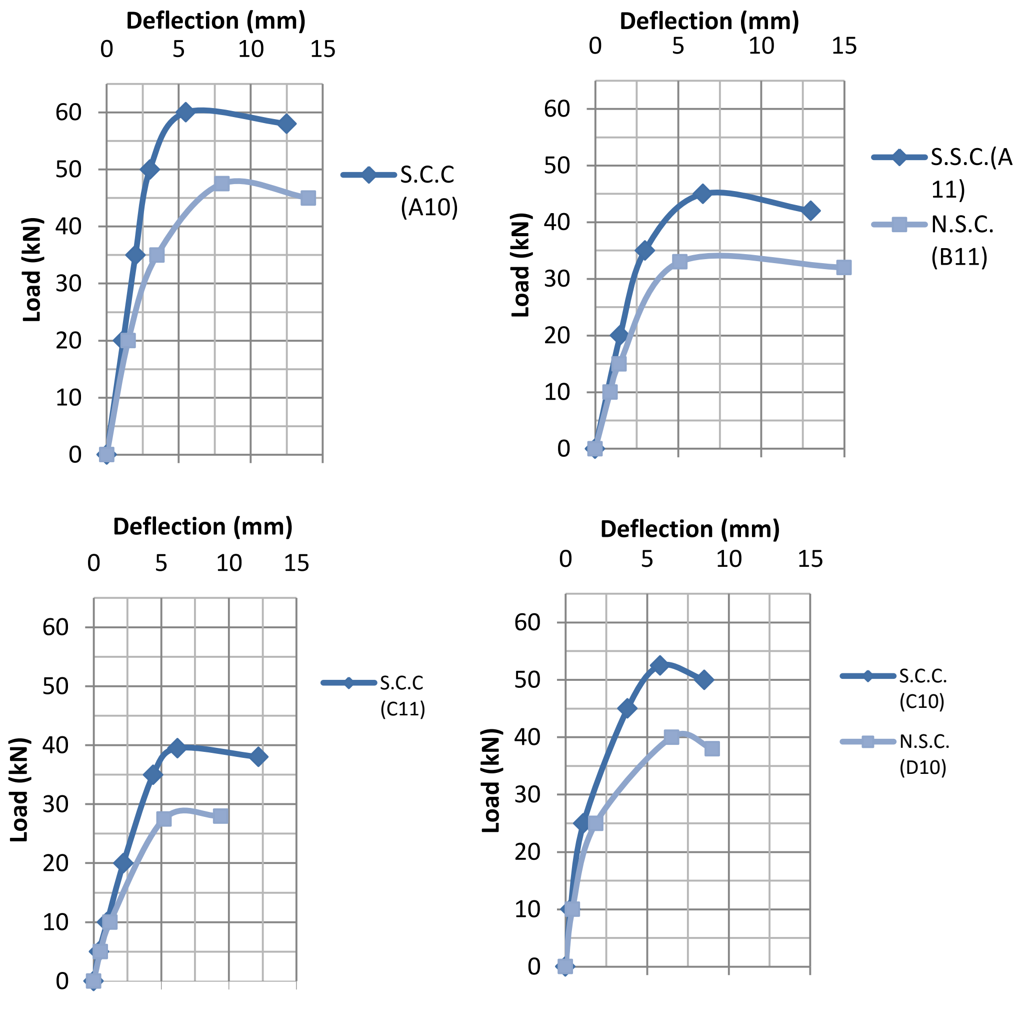

Fig.(4) load – deflection curve for SCC and NSC beams

7.2. Crack width

The crack width are presented in Table (7) which its compare the predicted crack width according to ACI 318 under service load with the experimental value .it was observed that the ACI 318 equation is conservative as compared with the experimental study and also observed that the maximum crack width of SCC beams is lesser than the NC beams as seen in Fig. 5.

7.3. Number of Crack

The number of crack between two point load is predicted in Table (7) and Fig.6. show that the number of crack in SCC beams is lesser than the NC beams and also show that Z factor value in different exposure in ACI formula is more conservative than obtained in experimental study as shown in Table (8)

Table (7) comparison of Crack width with ACI equation

Beams	Number of crack	W crack Experimental	W crack From ACI	Wcrack ACI/Wcrack EXP
A10	20	0.058	0.13487	2.325345
B10	23	0.080	0.13487	1.685875
C10	16	0.053	0.13487	2.544717
D10	21	0.078	0.13487	1.729103
A11	16	0.048	0.13487	2.809792
B11	19	0.074	0.13487	1.822568
C11	13	0.042	0.13487	3.21119
D11	17	0.070	0.13487	1.926714

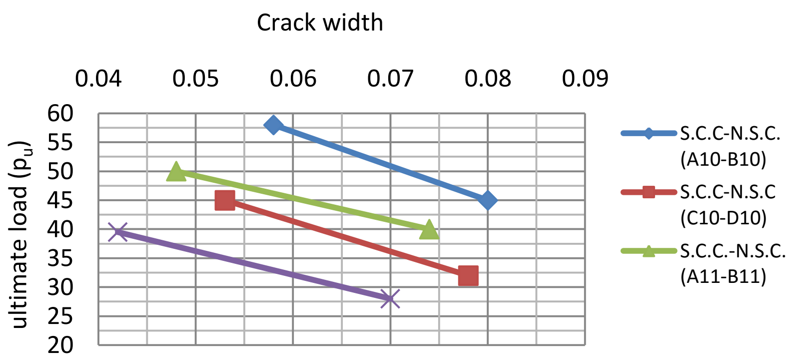

Fig.(5) Ultimate load versus cracking width for SCC and NSC beams

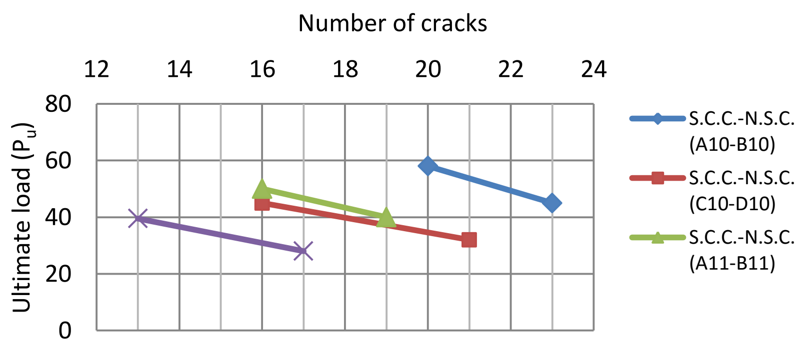

Fig.(6) Ultimate load versus number of cracks for SCC and NSC beams

Table (8) comparison of Z factor at different exposer of ACI limits with experimental study

Beams	Interior exposer				exposer External				Very aggressive			
	ZEXP N/mm	ZACI N/mm	Wcrack Exp.	Wcrack ACI	Z_{EXP} N/mm	Z_{ACI} N/mm	W_{crack} Exp.	W_{crack} ACI	Z_{EXP} N/mm	Z_{ACI} N/mm	W_{crack} Exp.	W_{crack} ACI
A_{10}	1027.43	30645	0.058	0.4	1027.43	25392	0.058	0.3	1027.43	17000	0.058	0.2
B_{10}	1027.43	30645	0.080	0.4	1027.43	25392	0.080	0.3	1027.43	17000	0.080	0.2
C_{10}	1027.43	30645	0.053	0.4	1027.43	25392	0.053	0.3	1027.43	17000	0.053	0.2
D_{10}	1027.43	30645	0.078	0.4	1027.43	25392	0.078	0.3	1027.43	17000	0.078	0.2
A_{11}	1027.43	30645	0.048	0.4	1027.43	25392	0.048	0.3	1027.43	17000	0.048	0.2
B_{11}	1027.43	30645	0.074	0.4	1027.43	25392	0.074	0.3	1027.43	17000	0.074	0.2
C_{11}	1027.43	30645	0.042	0.4	1027.43	25392	0.042	0.3	1027.43	17000	0.042	0.2
D_{11}	1027.43	30645	0.070	0.4	1027.43	25392	0.070	0.3	1027.43	17000	0.070	0.2

7.4. Compressive strength

The compressive strength (f_c') has slight influence on the maximum crack width for both SCC beams and NSC beams. Table (9) and Fig. 7. Show the influence of compressive strength (f_c') on the maximum crack width.

It was found that the ultimate load capacity of SCC increased about 9.433%, 14.285% when the compressive strength (f_c') increased from (17.9) to (23.81) MPa at clear span to effective depth ratio (ln/d) (8.4),(10) respectively while the maximum crack width of NSC increased about 2.56%,5.714% when the compressive strength (f_c') increased from (16.2) to (22.41) MPa at clear span to effective depth ratio (ln/d) (8.4),(10) respectively.

Table (9) effect of compressive strength (f_c') on the Max. Crack width

Group	Beam name	(ln/d)	Comp. strength (f_c')	Max. crack width Experimental	Cracking load(Pcr) kN	Ultimate load (PU) kN	Percentage of increased %
SCC	C_{10}	8.4	17.9	0.053	12.5	45	---
SCC	A_{10}		23.81	0.058	15	58	9.433
SCC	C_{11}	10	17.9	0.042	11.5	39.5	----
SCC	A_{11}		23.81	0.048	12.5	50	14.285
NSC	D_{10}	8.4	16.2	0.078	7	32	---
NSC	B_{10}		22.41	0.080	7.5	45	2.56
NSC	D_{11}	10	16.2	0.070	7.5	28	----
NSC	B_{11}		22.41	0.074	8	40	5.714

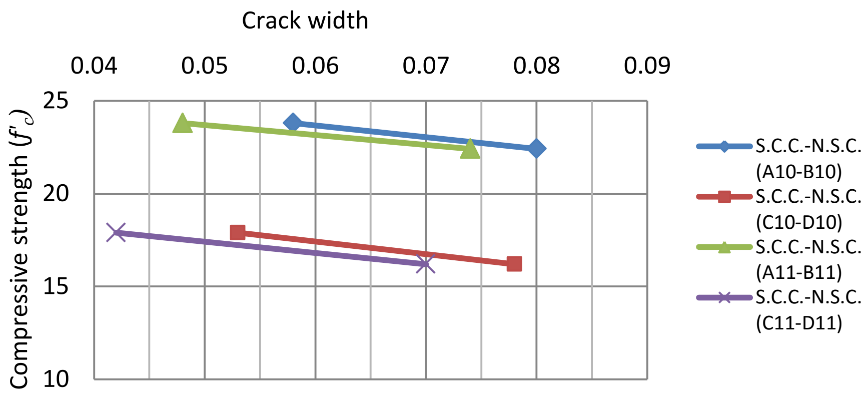

Fig.(7) compressive strength (f'_c) *versus* cracking width for SCC and NSC beams

6.5. Cracking moment

The experimental cracking moment ($M_{cr\ exp}$) and the theoretical cracking moment ($M_{cr\ th}$) of the beam is determinate using the formula as recommended by ACI318M-08[14] was listed in Table (10).it was observed that the experimental cracking moment of SCC beams are greater than the experimental cracking of NSC as compared with theoretical cracking moment predicated from cracking moment predicated from ACI formula.

Table (10) comparisons of cracking moment and ultimate moment results

Beam	Exp. Cracking moment (Mcr) kN.m	Theo.Cracking moment (Mcr) kN.m	(Mcr exp/Mcr th)%
A10	3.05	1.13	2.69
B10	1.52	1.1	1.38
C10	3.0	1.13	2.65
D10	1.68	1.1	1.53
A11	2.54	0.98	2.60
B11	1.62	0.93	1.73
C11	2.76	0.98	2.08
D11	1.8	0.93	1.93

6.6. Clear span to effective depth ratio

The clear span to effective depth ratio (ln/d) has influence on the maximum crack width for both SCC beams and NSC beams. Table (11) and Fig.8. show the influence of clear span to effective depth ratio (ln/d) on the maximum crack width. It was found that the maximum crack width of SCC increased about 20.833%, 26.16% when the clear span to the effective depth ratio (ln/d) increased from 8.4 to 10 at compressive strength (f_c') 23.81 and 17.9 MPa respectively while the maximum crack width of NSC increased about 8.1%, 11.42% when the clear span to the effective depth ratio (ln/d) increase from 8.4 to 10 at compressive strength (f_c') 22.41 and 16.2 MPa respectively.

Table (11) effect of clear span to effective depth ratio (ln/d) on the Max. Crack width.

Group	Beam name	Comp. strength (f_c')	Clear span to effective depth ratio (ln/d)	Max. crack width Experimental	Percentage of increased %
SCC	C_{10}	23.81	8.4	0.048	----
SCC	A_{10}		8.4	0.050	20.833
SCC	C_{11}	17.9	10	0.042	----
SCC	A_{11}		10	0.053	26.190
NSC	D_{10}	22.41	8.4	0.074	----
NSC	B_{10}		8.4	0.080	8.100
NSC	D_{11}	16.2	10	0.070	----
NSC	B_{11}		10	0.078	11.428

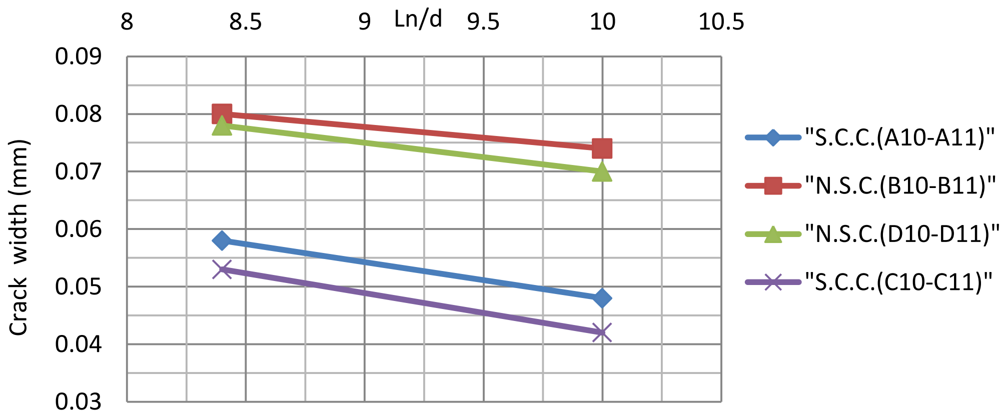

Fig.(8) Cracking load versus clear span to depth ratio (ln/d) for SCC and NSC beams

6.7. Cracking load

The cracking loads are presented in table (12) and the crack pattern for all tested specimens are shown in photograph in Fig. (9). For all beams, the first crack loads recorded by the testing machine of the beams.

It was found that the first crack in the SCC beams about 26.95% from the ultimate load while the first crack in the NSC beams about 20% from the ultimate load. Also it was noted that the first crack appear between two point load for SCC and NSC beams. The crack forming on the surface of beams was mostly vertical, suggesting failure in flexure. The first cracking load of the SCC and NSC was illustrated in Table (12).

Table (12) comparisons of cracking load and ultimate load results

Beam	Cracking load (Pcr) kN	Ultimate load (PU) kN	(Pcr/Pu) %
A10	15	58	25.86
B10	7.5	45	16.66
C10	12.5	45	27.77
D10	7	32	21.87
A11	12.5	50	25.0
B11	8	40	16.0
C11	11.5	39.5	29.11
D11	7.5	28	26.78

Fig. (9) Crack pattern for tested beams.

8. Conclusions

Based on the experimental results of this investigation for evaluation of maximum crack width, number of crack, cracking load and cracking moment of SCC and NC beams the following conclusions are drawn:

- The beams which made from SCC was more stiffer as compared with the beam which made from NCC with same of the clear span to effective depth ratio, longitudinal steel ratio, vertical steel ratio and relative compressive strength.
- The first crack in the SCC beams about 26.95% from the ultimate load while the first crack in the NSC beams about 20% from the ultimate load.
- The ACI 318 equation is conservative as compared with the experimental study.
- The max crack width of SCC beams is lesser than the NC beams.
- The number of crack in SCC beams is lesser than the NC beams.
- The Z factor value in different exposure in ACI formula is more conservative than obtain in experimental study.
- The experimental cracking moment of SCC beams are greater than the experimental cracking of NSC as compared with theoretical cracking moment predicated from cracking moment predicated from ACI formula.
- The maximum crack width of SCC increased about 20.833%, 26.16% when the clear span to the effective depth ratio (ln/d) decreed from 8.4 to 10 at compressive strength (f_c') 23.81 and 17.9 MPa respectively while the maximum crack width of NSC increased about 8.1%, 11.42% when the clear span to the effective depth ratio (ln/d) decreed from 8.4 to 10 at compressive strength (f_c') 22.41 and 16.2 MPa respectively.
- The ultimate load capacity of SCC increased about 9.433%, 14.285% when the compressive strength (f_c') increased from (17.9) to (23.81) MPa at clear span to effective depth ratio (ln/d) (8.4),(10) respectively while the maximum crack width of NSC increased about 2.56%,5.714% when the compressive strength (f_c') increased from (16.2) to (22.41) MPa at clear span to effective depth ratio (ln/d) (8.4),(10) respectively.

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