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Original Paper

Flexural behavior of self-compacted reinforced concrete beams

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Abstract

Eight reinforced concrete rectangular beams were designed and tested to study the effect of using self-compacted concrete (SCC) on the flexural behavior under two concentrated load. All beams have the same longitudinal and vertical steel ratio and gross section area of (150000) mm^2. The tested beams were divided into two groups; the first group consist of four (SCC) beams while the second group consist 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 consist of two compressive strength (f_c'). It was found that the ultimate and cracking moment capacity predicted from ACI318M-08 is conservative prediction than experimental result for both SCC beams and NSC beams, the beams which made from SCC were 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 experimental ultimate moment capacity and cracking moment predicted from SCC beams were greater than the ultimate moment capacity predicted from NSC beams, , the ultimate load capacity of SCC increased about 28.89%, 25% when the clear span to the effective depth ratio (ln/d) decreased from 10 to 8.4 at compressive strength (f_c') 23.81 and 17.9 MPa respectively while the ultimate load capacity of NSC increased about 26.3%, 21.21% when the clear span to the effective depth ratio (ln/d) decreed from 10 to 8.4 at compressive strength (f_c') 22.41 and 16.2 MPa respectively, and the ultimate load capacity of SCC increased about 10%, 12.5% 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 ultimate load capacity of NSC increased about 14.28%, 15.15% 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: flexural strength, self-compacted concrete beams, normal strength concrete, cracking moment, ultimate and nominal moment.

Introduction

Self-Compacted concrete (SCC), is a new kind of high performance concrete (HPC) with very effective deformability and segregation resistance. The main advantage of SCC is; a flowing concrete without segregation and bleeding, capable of filling spaces in dense reinforcement or inaccessible voids without hindrance or blockage. The composition of SCC should be designed in order not to separate and not to excessively bleed.

Concretestrengthdevelopmentisdeterminednot onlybythewater-to-cementratio, but also by the content and specification of mix materials (Bin Muda, 2009).

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

Tested program:

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

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according to overall length1220, and 1440 mm long. 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 diameter at the bottom and two plane bars of 4 mm diameter at the top. The internal steel stirrups are 4 mm in 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).

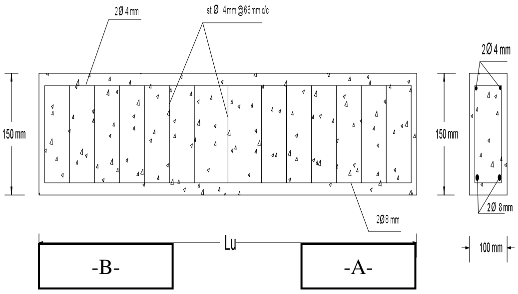

Fig. (1): Details of specimens all dimensions in mm: (A) cross-section; (B) Elevation.

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

Table. (1): Total description of the tested beams.

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-Bazian) is used throughout this investigation which conforms to the Iraqi specification No. 5/1984(1984), Tables (2) and (3) show the chemical and physical properties of the used cement.
- Fine Aggregate: Al-Ukhaider natural sand is used. This complies with the Iraqi Standard Specification No.45/1984,) المواصفة العراقية رقم ٤٥ لسنة ١٩٤٨) zone (2).The specific gravity, sulfate contents(SO3) and absorption of the used sand were 2.66,0.4%,1.7% respectively.
- Coarse Aggregate: Crushed gravels maximum size 14 mm from Al-Nibaee area are used in this study. This complies with the Iraqi Standard Specification No.45/1984, [3] the specific gravity, sulfate contents (SO3) and absorption of the used gravel were 2.65, 0.07%, 0.57% respectively.
- Water: Ordinary potable water was 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 was tested to determine the yield stress of 8mm and 4mm they were 397.88 and 596.83 MPa receptively.
- Limestone Powder: A fine limestone powder (locally named as Al-Gubra) of northern origin with fineness (3100 cm²/ gm) it 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 [2004]. 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 segregation resistance.
➢ Enhancing fluidity and cohesiveness.
➢ Increasing the amount of powder (cement +filler), so it becomes more economical than using cement alone.

- Superplasticizer [2002]: To produce SCC, a superplasticizer 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, 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.

Compound Composition	Chemical Composition	Percent	Limit of Iraqi specification No.5/1984[2]
Lime	CaO	61.67	-
Silica	SiO_2	20.69	-
Alumina	Al_2O_3	5.20	-
Iron Oxide	Fe_2O_3	4.61	-
Magnesia	MgO	2.43	< 5
Sulfate	SO_3	2.21	< 2.8
Loss on Ignition	L.O.I.	3.31	< 4
Insoluble Residue	I.R.	0.5	< 1.5
Lime Saturation Factor	L.S.F	0.90	0.66 – 1.02
Main Compounds (Bogue's Equation) Percentage by Weight of Cement			
Tricalcium Silicate	C_3S	38.55	
Dicalcium Silicate	C_2S	33.15	
Tricalcium Aluminate	C_3A	7.12	
Tetracalcium Alumina Ferrite	C_4AF	10.73	

Table. (2): Chemical Composition of Cement.

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

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

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

Table (4): Typical properties of Glenium 51 [2002].

Mix proportioning is more critical for SCC than for NSC and HSC. Many trials are carried out on mixes incorporating superplasticizer by increasing the dosage of the admixture gradually, adjusting the w/c ratio to ensure the self-compact ability (Al-Jadiri, 2008). 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 [1998] and indicate excellent deformability without blocking.

Group	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	23.8	0.37	250	250	500	739	870	185	6
B	22.42	0.5	400	----	400	728	1092	200	---
C	17.9	0.36	300	200	500	758	890	180	6
D	16.2	0.7	317	----	317	720	1136	222	---

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

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-compacted concrete (SCC) [2005]

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

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

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-Mustansiriya 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): Tested Machine.

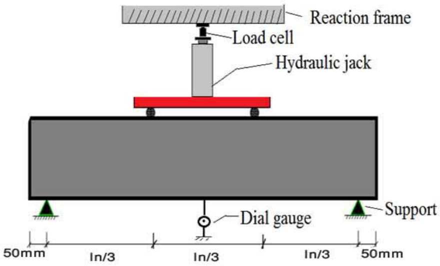

Fig. (3): Schematic diagram of test set-up

Flexural strength of beam in Code provisions:

In the design of rectangular section with tension reinforcement only as shown in Fig. (4), the condition of equilibrium are:

1-Force equilibrium

$C=T$ ------------------- (1)

$0.85f_cba=A_sf_y=\rho bdf_y$

$a=A_sf_y/0.85fcb=\rho df_y/0.85f_c$

2- Moment equilibrium

$M_n=(CorT)(d-a/2)$-------------------------(2)

$M_n=\rho bdf_y(d-0.5\rho df_y/0.85f_c)$

$M_n=\rho bd^2f_y(1-0.59\rho f_y/f_c)$

Where: C = Compression force, T = tensile force, b = width of section, d = effective depth, A_S= area of longitudinal steel bar, M_n= nominal moment.

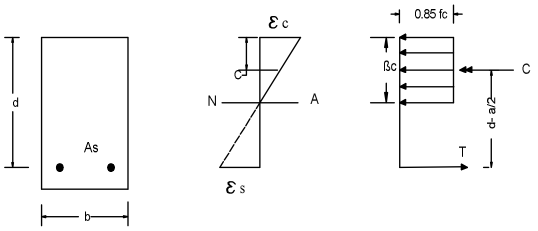

Fig. (4): strain and equivalent stress distributed in rectangular section.

Results and discussion:

All the result show that the SCC beams was gave higher performance than NSC ,this can be assumed that SCC is effective in increasing the beam flexural strength probably caused by good bond between the reinforcement and concrete this occurrence may possible be explained by SCC having grater 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 (Bin MUDA, 2009). as shown below.

General observation:

All beams showed typical structural behavior in flexure. Vertical flexural cracks were observed in the constant moment region and final failure occurs due to crashing of the compression concrete. Figs (5),(6),(7) and (8) show that the beams which made from SCC were more stiffer as compared with the beam which made from NSC with same of the clear span to effective depth ratio, longitudinal steel ratio, vertical steel ratio and relative compressive strength.

Bending moment:

A comparison between the experimental ultimate moment (M_{uexp}) and theoretical design moment (M_{nth}) show in Table (7). It was found that the ultimate moment capacity predicted from SCC beams were greater than the ultimate moment capacity predicted from NSC beams and the ultimate moment capacity predicted from ACI318M-08 were more conservative than the nominal moment capacity predicted from SSC and NSC beams also provided adequate load factor against failure.

cracking moment:

The experimental cracking moment (M_{crexp}) and the theoretical cracking moment (M_{crth}) of the beam is determinate using the formula as recommended by ACI318M-08[2008] were listed in Table (8).

$Mcr_{th}=(f_r\times I_g)/y_t$ ……………. (3).

Where:f_r =modulus of rupture of concrete (MPa);I_g=second moment of inertia of gross area ignoring reinforcement and y_t = distance from the extreme tensile fiber to the neutral axis. 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 ACI formula.

clear span to effective depth ratio:

The clear span to effective depth ratio (ln/d) has significant influence on the ultimate load capacity for both SCC beams and NSC beams. Table (9) shows the influence of clear span to effective depth ratio (ln/d) on the ultimate load capacity. It was found that the ultimate load capacity of SCC increased about 28.89%, 25% when the clear span to the effective depth ratio (ln/d) decreed from10 to 8.4 at compressive strength (f'_c) 23.81 and 17.9 MPa respectively while the ultimate load capacity of NSC increased about 26.3%, 21.21% when the clear span to the effective depth ratio (ln/d) decreed from10 to 8.4 at compressive strength (f'_c) 22.41 and 16.2 MPa respectively.

Compressive strength:

The compressive strength (f'_c) has slight influence on the ultimate load capacity for both SCC beams and NSC beams. Table (10) shows the influence of compressive strength (f'_c) on the ultimate load capacity. It was found that the ultimate load capacity of SCC increased about 10%, 12.5% 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 ultimate load capacity of NSC increased about 14.28%, 15.15% 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.

Failure mode:

All of the tested beams failed in flexure with crushing of concrete in the compression zone at the failure stage after the development of flexural cracks. The failure mode and crack pattern of the tested beams are presented in Fig. (9), the first visible crack formed between the locations of the two point loads in the region of the maximum moment. Therefore, as the load was increased more cracks started to form up to failure occurred (Arivalagan, 2012).

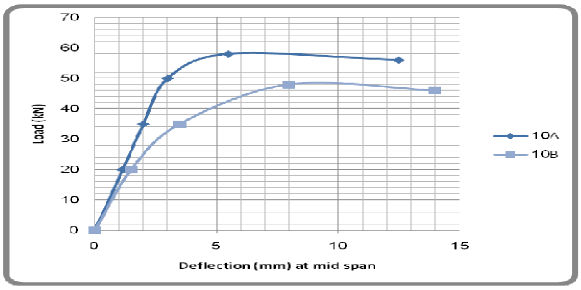

Fig. (5): Load –deflection curve for SCC and NSC-beams.

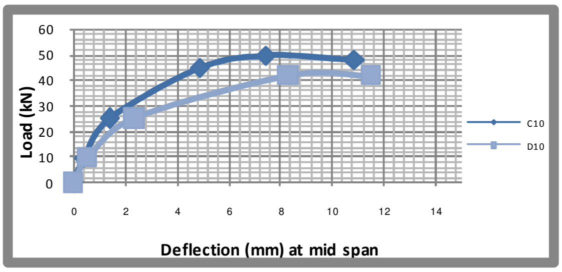

Fig. (6): Load –deflection curve for SCC and NSC-beam.

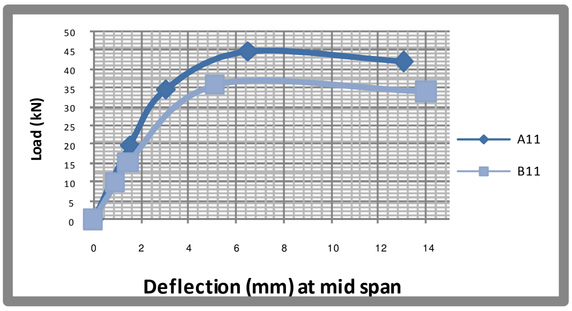

Fig. (7): Load –deflection curve for SCC and NSC-beam.

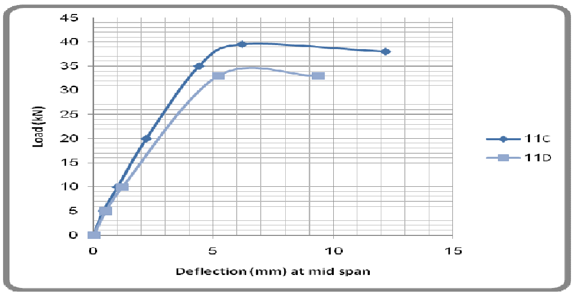

Fig. (8): Load –deflection curve for SCC and NSC-beam.

Beam	Clear span to effective depth ratio (ln/d)	Comp. strength (f'_c) MPa	Ultimate moment capacity (M_ukN.m)exp.	Nominal moment capacity (M_nkN.m) ACI	$M_u$exp/M_nACI ratio %
A10	8.48	23.81	10.825	4.80	2.25
B10	8.48	22.41	8.96	4.77	1.87
C10	8.48	17.90	9.33	4.67	1.98
D10	8.48	16.20	7.84	4.61	1.7
A11	10	23.81	10.05	4.80	2.09
B11	10	22.41	8.485	4.77	1.77
C11	10	17.90	8.933	4.67	1.912
D11	10	16.20	7.368	4.61	1.61

Table. (7): comparisons of tested results.

Beam	Exp. Cracking moment (Mcr)kN.m	Theo.Cracking moment (Mcr)kN.m	(M_{crexp}/M_{crth}) %
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

Table (8) comparisons of cracking moment and ultimate moment results.

Group	Comp.strength (f_c')	Clear span to effective depth ratio (ln/d)	Ultimate load capacity	Percentage of increased %
SCC	23.81	10	45	----
		8.4	58	28.88
	17.9	10	40	----
		8.4	50	25.0
NSC	22.41	10	38	----
		8.4	48	26.3
	16.2	10	33	----
		8.4	42	27.27

Table (9) effect of clear span to effective depth ratio (ln/d) on the percentage increased in the ultimate load capacity.

Group	Clear span to effective depth ratio (ln/d)	Comp.strength (f_c')	Ultimate load capacity	Percentage of increased %
SCC	8.4	17.9	50	---
		23.81	58	10
	10	17.9	40	----
		23.81	45	12.5
NSC	8.4	16.2	42	---
		22.41	48	14.28
	10	16.2	33	----
		22.41	38	15.15

Table. (10): effect of compressive strength (f_c') on the percentage increased in the ultimate load capacity.

Conclusions:

Based on the tested results of this experimental investigation for evaluation of flexural behavior of SCC beams, the following conclusions are drawn:

- Nominal moment predicated from ACI 318M-08 is conservative prediction than the experimental values for the SCC –beams and NSC beams.
- The beams which made from SCC were more stiffer as compared with the beam which made from NSC with same of the clear span to effective depth ratio, longitudinal steel ratio, vertical steel ratio and relative compressive strength.
- The ultimate moment capacity predicted from SCC beams were greater than the ultimate moment capacity predicted from NSC beams.
- The experimental cracking moment of SCC beams are greater than the experimental cracking of NSC
- The ultimate load capacity of SCC increased about 28.89%, 25% when the clear span to the effective depth ratio (ln/d) decreed from 8.4 to 10 at compressive strength (fc) 23.81 and 17.9 MPa respectively
- The ultimate load capacity of NSC increased about 14.28%, 15.15% when the compressive strength (fc) increased from (16.2) to (22.41) MPa at clear span to

effective depth ratio (ln/d) (8.4), (10) respectively.

- The ultimate load capacity of SCC increased about 10%, 12.5% when the compressive strength (fc) increased from (17.9) to (23.81) MPa at clear span to effective depth ratio (ln/d) (8.4), (10) respectively
- The ultimate load capacity of NSC increased about 14.28%, 15.15% 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.

Fig. (9) Crack pattern for tested beams.

References:

- ACI Committee 363 “Guide to Quality Control and Testing of High Strength Concrete (ACI- 363, 2R-98)”, American Concrete Institute, Detroit, (1998).

Al-Jadiri, R.S.F., "A Method for Proportioning Self-Compacting Concrete" M.Sc. Thesis, Al-Mustansiriya University, (2008).

Arivalagan, S. (2012). “Engineering Performance of concrete beams reinforced with GFRP Bars and stainless steel”, Global Journal of Research in Engineering civil and Structural Engineering Vol.12 Issue 1 Version 1 January

- Baseline Report for the Aggregate and Concrete Industries in Europe", ECO-SERVE Network, Cluster 3: Aggregate and Concrete Production, June (2004), 68 PP".

Bin MUDA, M.F. (2009). "The Properties and Flexural Behavior OF self-Compacting Concrete Using Rice Husk Ash and Admixture", M.Sc. Thesis, University of Technology. Malaysia,

- Committee 318" Building Code Requirements for Structural Concrete and Commentary (ACI 318M-08)/ ACI 318 RM-02)", American Concrete Institute, Detroit, (2008).
- "Glenium 51", Degussa construction chemicals. 06/MBT-Me Revised 06/ (2002).
- Krieg, W. (2003). "Self-Compacting Concrete: Definition, Development, and Applications", A technical Paper Presented in the Meeting of the ACI, Saudi Arbia Chapter, Eastern Province, October,
- "The European Guidelines for Self-Compacting Concrete Specification", production and use, May (2005), www.efca.info or www.efnarc. org, pp.68.
- المواصفة العراقية رقم ٥ "الاسمنت البورتلاندي، الجهاز المركزي للتقييس والسيطرة النوعية" بغداد ١٩٨٤,ص٨
- المواصفة العراقية رقم ٤٥ لسنة (١٩٨٤) (ركام المصادر الطبيعية المستعملة في الخرسانة والبناء، ص (٥-٢٠)

الملخص العربى

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ثمانية عتبات خرسانية مستطيلة الشكل صممت وفحصت لدراسة تأثير الخرسانة ذاتية الرص على سلوك الانحناء تحت تأثير حملين مركزين. جميع العتبات تحوي على نسبة حديد طولية وعمودية واحدة وعلى مساحة مقطع عرضي هي(١٥٠٠٠) ملم^{٢}. العتبات المفحوصة قسمت إلى مجموعتين المجموعة الأولى تحوي على أربعة عتبات خرسانية ذاتية الرص بينما المجموعة الثانية تحوي على أربعة عتبات خرسانية اعتيادية. كل مجموعة قسمت إلى متواليتين حسب نسبة الفضاء الصافي إلى العمق الفعال كل متوالية تحوي على مقاومتين للانضغاط.وجد من خلال نتائج الفحص بان عزم التشقق وعزم الانحناء الأقصى المستحصلة باستخدام المدونة الأمريكية (318M-08) متحفظة مقارنة مع النتائج المستحصلة من الجانب العملي. كما وجد أن تصرف العتبات الخرسانية ذاتية الرص يكون أقسى من سلوك العتبات الخرسانية الاعتيادية تحت نفس الظروف مثل نسبة الفضاء الصافي العمق الفعال ونسبة الحديد الطولي والعمودي وتقريبا نفس مقاومة الانضغاط، كما وجد أن عزمي الانحناء الأقصى والتشقق للعتبات الخرسانية الذاتية الرص اكبر من العتبات الخرسانية الاعتيادية، وكذلك إن القيمة الحمل الأعظم للعتبات الخرسانية الذاتية الرص يزداد بمقدار (٢٨.٨٩%) و (٢٥%) عندما تقل نسبة الفضاء الصافي العمق الفعال (ln/d) من (١٠) إلى (٨.٤) بمقاومة انضغاط (٢٣.٨١) نت/ملم^{٢} و(١٧.٩) نت/ملم^{٢} على التوالي، بينما القيمة الأعظم للعتبات الخرسانية الاعتيادية يزداد بمقدار (٢٦.٦٣%) و (٢١.٢١%) عندما تقل نسبة الفضاء الصافي العمق الفعال من (١٠) إلى (٨.٤) بمقاومة انضغاط (٢٢.٤١) نت/ملم^{٢} و (١٦.٢٠) نت/ملم^{٢} على التوالي، وكذلك أن القيمة الحمل الأعظم للعتبات الخرسانية الذاتية الرص يزداد بمقدار (١٠%) و (١٢.٥%) وعندما تزداد مقاومة الانضغاط من (١٧.٩) ت/ملم^{٢} إلى (٢٣.٨١) ت/ملم^{٢} بنسبة الطول الصافي إلى العمق الفعال من (٨.٤) و (١٠) على التوالي، بينما قيمة الحمل الأعظم للعتبات الخرسانية الاعتيادية يزداد بمقدار (١٤.٢٨%) و (١٥.١٥%) عندما تزداد مقاومة الانضغاط من (١٦.٢)ت/ملم^{٢} إلى (٢٢.٤١) ت/ملم^{٢} بنسبة الطول الصافي إلى العمق الفعال من (٨.٤) و (١٠) على التوالي.