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Research paper



Behavior of The RC Slab-Beam System Using Self Compacting Concrete

Nameer A. Alwash[1*], Fatimah H. Naser Al-Mamoori[2]

[1]College of Engineering, Civil Department, University of Babylon
[2]College of Water Resources Engineering, Hydraulic Structures Department, University of AL-Qasim Green
**Corresponding author E-mail:namer_alwash@yahoo.com*

Abstract

The present study includes an experimental investigation of the behavior of square reinforced concrete slabs. These slabs are with and without edge beams under uniformly distributed load with corner supports using two types of self compacting concrete (SCC), the first type of SCC incorporated limestone filler and the other was without filler, the results obtained are compared with those obtained from conventional concrete (CC).

The experimental program consists of testing nine square slab samples. Three of these slab samples are flat in shape with panel dimensions of 1050×1050×50 mm depth. The others three slab samples are of the same outer dimensions with surrounding edge beams of depth to slab thickness equal 100/50 and 100 mm width. The last three slab samples are similar to the former slab-beam systems but with increasing the depth of edge beams by 50%.

In general, for a specified flat plate panel, the ultimate load carrying capacity can be increased, if the panel is restricted by four surrounding beams. The slab-beam samples with surrounding beams of depth to slab thickness equal to 3 showed greater ultimate load capacity by about 79.37%, 52% and 97.82% when compared with the corresponding flat slabs samples produced using CC, SCC with and without filler, respectively.

Keywords: *Flat slab, flexural behavior, slab-beam system, self-compacting concrete, uniform load.*

1. Introduction

Slabs are the most important parts of the structural constructions. Beams are also important parts of reinforced concrete structures which resist the applied loads and distribute them to the columns or supports. Usually, in the design and construction, the slabs are support by beams and the beams supporting by columns. This may be called as Slab–Beam Systems which is widely used in both multi-story buildings and bridges. (1). The beams reduce the available net clear ceiling height. Hence in offices, public halls and warehouses sometimes beams are eliminated and slabs are directly supported by columns. This types of construction is aesthetically appealing also. These slabs that are directly supported by columns are named Flat Slabs.

Research and experimental data have been achieved on the behavior and properties of reinforced concrete as a material, and also on reinforced concrete structures. This helps engineers to understand wider the reinforced concrete behavior and the factors that have influence on such behavior and encourage them in construction field to increase the use of reinforced concrete as a construction material for different forms and shapes of structures. Most of the structures nowadays are made of reinforced concrete elements. It is because of the reasons of their strength, durability, adaptability and because the materials are economical (2).

Recently, the design of modern RC buildings has become more sophisticated. The structures designed forms have become increasingly intricate and congested reinforced. At the time of lack of skilled labor, especially in construction sites. Moreover, there is a requirement to economize in time of construction and moulds dead load and also to remove problems associated with vibration. Therefore, the SCC used as an innovative construction material which will have many possibilities and outlooks (3).

2. Objective of Research

The objectives of this research are to investigate some of fresh and hardened properties of SCC with/without filler and compare them with the properties of CC using same aggregate content at optimal W/C ratio to saving costs. The second objective is to study the structural behavior of R/C two-way flat slabs and slab with edge beams (slab-beam systems). Also, study the effect of increasing the depth of edge beams by 50% using SCC with and without filler in comparison with CC.

3. Samples Identification

In order to produce the slab samples, three mixes were used, (M1 is SCC with 24% limestone filler (L), M2 is SCC without filler and M3 is CC) which have the same aggregate content and the same cost with optimal W/C ratio to study the structural behavior of reinforced flat slabs and slab–beam systems producing by these types of concrete.

Flat slab (A) denotes by (Series-A) : A-M1, A-M2, and A-M3 while, slab–beam systems which have edge beams of depth 100 mm (B) (edge beams of depth to slab thickness equal 2), denotes as (Series-B) : B-M1, B-M2, and B-M3. Besides, slabs with edge

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beams of depth 150 mm (C) (edge beams of depth to slab thickness equal 3), denotes as (Series-C) : C-M1, C-M2, and C-M3.

4. Description of the Slab Samples

4.1. Details of Reinforced Concrete Flat Slab Samples

Three flat slab samples of (1050×1050×50) mm were casted. These slab samples denoted as series (A) : A-M1, A-M2, and A-M3 with steel ratio of (0.00387). The reinforcement of Turkish production are uniformly spaced and placed in two orthogonal directions according to the limited distances of (100) mm in addition to provided corner reinforcement as shown in Figure (1).

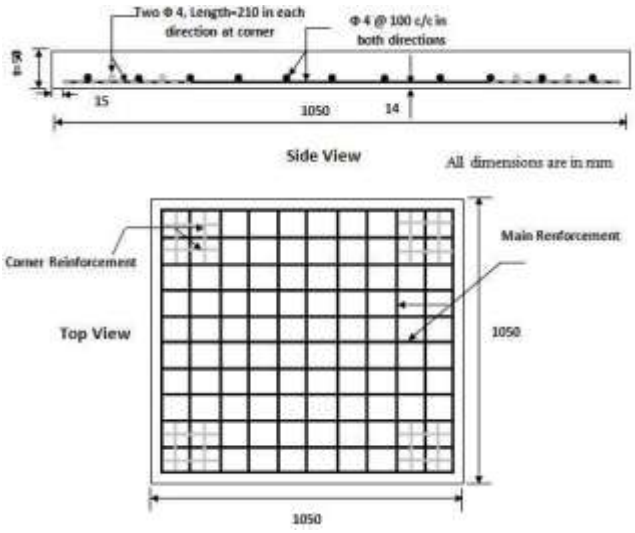


Fig. 1: Details of reinforcement of the flat slab samples (Series-A)

The clear cover for sides is taken (15 mm). The clear span after supporting is (850 mm). Figure (1) shows the details of reinforcement.

4.2. Description of the Slab-Beam Samples

All of the slab-beam samples are single square panels having a slab size of (850×850×50) mm (have the same depth in flat slabs) and surrounding beams of cross-section (100×100) mm. For series (B) (slab-beam samples with surrounding edge beams of depth to slab thickness equal 2): B-M1, B-M2, and B-M3 and (100×150) mm for series (C) (slab-beam samples with surrounding edge beams of depth to slab thickness equal 3): C-M1, C-M2, and C-M3. The slab samples are reinforced as shown in Figure (2).

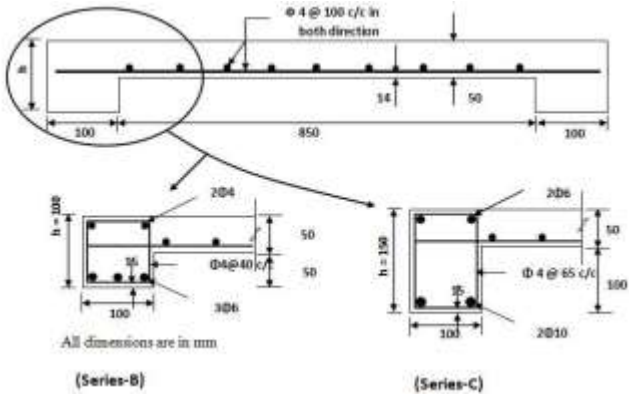


Fig. 2: Details of reinforcement of the slab-beam systems

The arrangement of slab reinforcement gives the same steel ratios for flat slab samples in the two orthogonal directions (0.00387). The slabs is supported by reinforced concrete beams a long all edges that are cast monolithically with it. The steel ratio for main reinforcement of the surrounding beams is kept constant for beams in series B and C. Shear reinforcement are also provided for the beams to satisfy the shear strength requirement as given by Sec. 11.5 of the (ACI-Code 318-2014) (4). Figure (2) shows the details of reinforcement. All samples are supported and subjected to the applied load under the same manner as in flat slabs.

5. Material Properties and Proportions of Mixes

In this work, the cement ordinary portland cement named as (Tasluja-Bazian) is used. The cement is tested according to the Iraqi standard No.5/1984 (5), for the chemical analysis and for the physical properties. Natural sand within zone 2 from (Al-Akaidur) region were used in this work after satisfied to the requirements of the limits of the Iraqi Specification No.45/1984 (6). Rounded coarse aggregate of maximum aggregate size 14 mm from Al-Nebai quarry are used. The results of physical and chemical tests compliance to the Iraqi Specification No.45/1984 (6). Limestone powder within the size of particle less than 0.125 mm is used as filler material in order to development the workability and the density of the SCC. Glenium 51 used in this work as a chemical admixture in order to get the highest performance and durability. For both mixing and curing in this research, tap water is used.

The mix proportions of SCC are designed according to The European Guidelines for Self-Compacting Concrete (EFNARC (2005) Mix Design Method for SCC (7). The CC is designed depended on the American Method of Mix Proportions Selection (ACI Committee 211.1-91) (8). The details of the mixes are given in Table (1).

Table 1: Mix proportion

Materials	Mix Symbol		
	M1	M2	M3
Cement (Kg/m3)	315	415	565
Limestone Filler (Kg/m3)	100	-	-
Sand (Kg/m3)	750	750	750
Gravel MAS 9.5mm (Kg/m3)	765	765	765
SP (l/ m3)	5.4	4	-
Water (l/ m3)	165	170	228
W/P ratio	0.39	0.41	-
W/C ratio	0.52	0.41	0.40

The mix design of SCC must conforms the criteria on passability, filling ability and segregation resistance. Therefore, many trial mixes are performed by exact weighing and the materials proportions are modified to satisfy a satisfactory self-compact ability by evaluation of the fresh concrete tests (Slump Flow and T50 cm, L-Box, V-Funnel and U-Box Tests). Also, the mix design for CC must satisfy the slump test as shown in Figure (3).

6. Mixing, Casting, Curing and Concrete Testing of Specimens

After testing of fresh properties of concrete, all molds of slab and concrete hardened properties were casted with concrete and cured according to the ASTM C192/C192M-05 (9) as shown in Figure (3). In the state of hardened concrete, various destructive testing for concrete hardened properties at twenty eight days are performed. The destructive tests includes cylinder (fc') and cube compressive strength (fcu), flexural strength (fr), splitting tensile strength (fct) and modulus of elasticity (Ec) from stress–strain relationship; according to the ASTM C39/C39M-05 (10) and BS 1881-part 116-02 (11), ASTM C78-02 (12), ASTM C496/C496M-04 (13) and ASTM C469-02 (14); respectively. All the processes done in

structural laboratory at the Civil Engineering Department of the Babylon University as shown in Figure (3).



Fig. 3: Fresh concrete testing, casting, curing and concrete testing of specimens

7.Test Setup of Slab Samples

All of the simply supported slab samples on four columns from stiff steel at their corners only are loaded up to failure under uniformly distributed load (UDL) as shown in Figure (4); using by a box of steel plate of thickness 2 mm with inside dimensions (depth 100 mm and same surface area of slab except area of corner supporting) is used to hold the sand to be placed over the slab as a part of the uniformly distributed load.

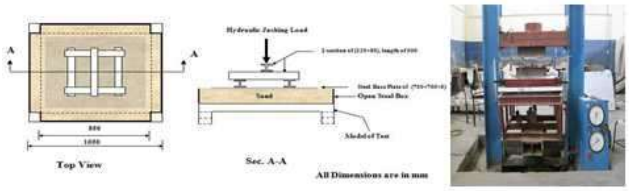


Fig. 4**:** Loading system for test slab samples under uniform load

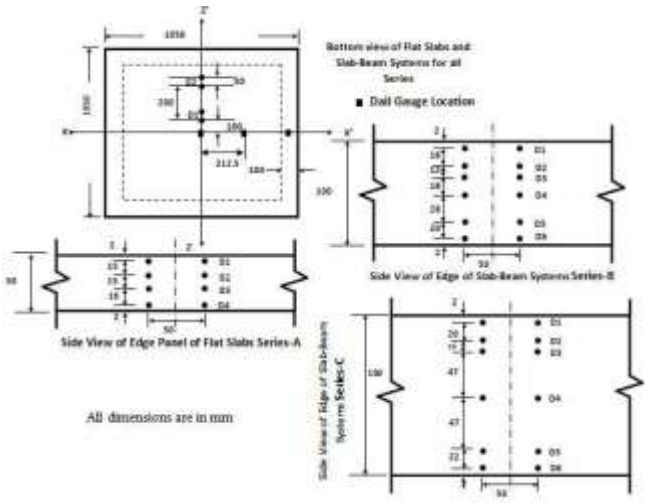


Fig. 5: Configuration of demec points

The box coated on the inner surfaces by a sheet of nylon to reduce any possible friction. The applied load of a hydraulic machine which transmitted the load to four points using a loading base which consisted of five steel members with I-section of (120×80) mm and length of 500 mm. Two of these members were parallel and the other welded perpendicularly upon them. The parallel steel members were connected fixed over a steel plate of (750×750×5) mm by welding. This steel loading base transmitted the load to the 100 mm layer of sand used between the loading base and the slab specimen. Cracking behavior, load-deflection and strain were studied. Figure (5) shows the arrangement of demec discs used to measured strains.

8. Experimental Results

8.1 Fresh Concrete Results

The results of fresh properties of each mix are analyzed and compared with the standards limits, to ensure that the mixes satisfy the requirements of SCC. Table (2) indicates that the results are within the limits.

Table 2: Results of workability tests of the SCC

Method		Mix Symbol		Limitations (7)
		M1	M2	
Slump Flow	(D) mm	735	710	650 – 800
	(T50 cm) sec.	3.4	3.6	2 – 5
V-Funnel	(Tv) sec.	6.7	8.5	6 – 12
	Time increase, (Tv 5 min.) sec.	1.5	1.8	+ 0-3
L-Box (BR = H2/H1) /		0.89	0.83	0.8 – 1.0
U-Box (ΔH = H2-H1) mm		8	11	0 – 30

The concrete mix which incorporated only with chemical admixture G51 (M2) is qualified for SCC, while the mix which contains 24% L (M1) shows better workability and consistency as noted in Table (7); this is due to the limestone filler which enhanced the fresh properties; this can be explained by the high packing ability of limestone in granular skeleton of cement paste results in higher volume of continuous phase of paste which reduces the friction at the aggregate-paste interface and provides sufficient lubrication for flow-ability (15).

8.2 Results of Concrete Mechanical Properties

All of the hardened concrete properties at the age of 28 days for various specimens are presented in Table (3). The results of (M1, M2 and M3) shown in Table (3) state that the mechanical properties for conventional concrete (M3) is the higher among them and this may be attributed to the fact that M3 contains higher cement content than M1 and M2. Moreover, the cement direct effect on concrete could be explained by the fact that the cement paste is the acting part in the concrete and the concrete strength depends on the paste cohesion and its adhesion to the aggregate particles, the statement is in agreement with the previous work which conducted by (Jianxin and Holger-2002) (16) whereas, the mechanical properties for M1 is lower than that for M2 because of the existence of limestone filler in M1 replacement of cement which is not contributed significantly to developing the compressive strength as stated by (Gaimster and Dixon-2003) (17).

Table 3: Hardened properties for all of concrete mixes

Sample Symbol	Mechanical Property				
	f_{cu} (MPa)	$f_{c'}$ (MPa)	f_r (MPa)	f_{ct} (MPa)	E_c (GPa)
A-M1	32.98	26.52	3.12	2.63	22.9

B-M1	35.96	27.01	3.52	2.87	24.1
C-M1	35.37	28.10	3.71	2.91	24.2
Average	34.77	27.21	3.45	2.80	23.7
A-M2	37.60	29.93	3.83	3.11	24.8
B-M2	38.86	30.35	4.24	3.51	24.8
C -M2	38.22	30.14	4.01	3.27	26
Average	38.22	30.14	4.02	3.29	25.2
A-M3	45.88	36.59	5.38	4.13	29.6
B-M3	39.97	32.91	4.66	3.77	26
C-M3	42.94	33.11	4.75	3.94	27.7
Average	42.93	34.20	4.93	3.94	27.8

The precrack stage from stress-strain curve for all mixes is plotted in Figure (6) which shows obviously, that the ascending portion of the compressive stress–strain curve becomes steeper and more linear as the compressive strength increases.

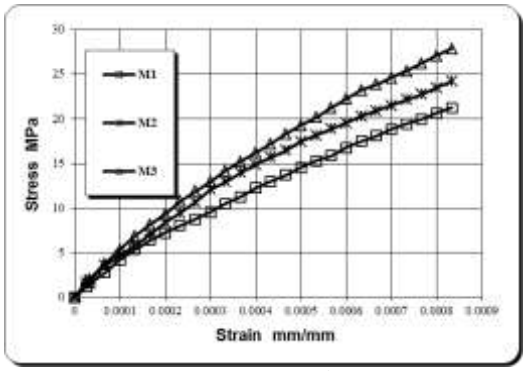


Fig. 6: Stress-strain curve for all mixes

It is obvious from the above figure that the behavior of SCC (M1 and M2) in current study is different from CC (M3) in terms of stress-strain curve behavior in spite of same coarse aggregate content because the higher paste content in CC also, M1 is different from M2. This simple difference in behavior between them is in the same way in pervious mechanical properties.

8.3 Experimental Results of Slab Samples

Table (4) presented the loads of the first cracking (Wcr), the ultimate failure loads (Wu), deflections and the modes of failure for all samples of slabs that studied.

Table 4: Results of Cracks, Deflection at Ultimate Load and Failure Mode for each Slab

Specimen	Load kN/m^2		(Wcr / Wu)%	Deflection mm			Failure Mode
	Wcr	Wu		Central	Quarter	Edge Beam	
A-M1	12.5	57.5	21.74	29.81	22.2	10.54*	Punching shear
A-M2	14	64.2	21.80	28.88	22.1	9.92*	Punching shear
A-M3	18	82.5	21.82	28	21.92	9.82*	Punching shear
B-M1	20.3	79.4	25.56	24.89	15.52	7.31	Shear in edge beams
B-M2	25	88	28.41	25.06	14.81	6.44	Shear in edge beams
B-M3	31	98	31.63	24.77	14.37	5.96	Shear in edge beams
C-M1	33.25	87.4	38.04	14.2	7.3	4.79	Shear in edge beams
C-M2	42	127	33.07	17.96	9.43	6.23	Flexure in slab
C-M3	49	148	33.11	16.58	9.83	7.5	Flexure in slab

* At the edge of flat slab at the same location for edge beam in slab-beam system.

8.3.1 Cracking Behavior

The visible first crack load of all the samples varied from (21.74%) to (38.04%) of the experimental average ultimate loads. The rest of cracks commenced later with increasing load.

In samples Series-A, A-M3 showed higher first cracking loads when compared with A-M1 and A-M2. All samples in Series-A, the cracks appear firstly near the supports. As expected, for Series-B and Series-C, B-M3 and C-M3 gave higher value in first cracking in comparison with other samples for each series. In C-M2, shear cracks in edge beams and flexural crack in tension face of slab were occurred at same load level (42 kN/m^2). Only in C-M1 and B-M1 cracks take place firstly in slab tension face while in other slab-beam system samples, the cracks of shear are visible in edge beams. The samples of Series-B show significant enhancement in first cracking loads because of the presence of the edge beams, slabs samples B-M1, B-M2 and B-M3 show an increase in first cracking load of 62.4%, 78.57% and 72.22%, respectively, when compared with the flat slabs A-M1, A-M2 and A-M3, respectively.

Slab samples of Series-C show the best behavior that gave an increase in first cracking load more than Series-A. By the same way C-M1, C-M2 and C-M3 increase in first cracking load by 166%, 200% and 172.22%, respectively in comparison with the slab samples A-M1, A-M2 and A-M3. This is expected due to the bigger depth of edge beams. The cracks development mechanism is often the same for all slab samples of each series. The pattern of cracks at failure for each series as shown in Figures (7).

Expected difference is observed in width of cracks between the samples for each series. These differences depend on ultimate capacity for each sample, the sample A-M2 is flat slab, therefore the first crack occurred at a lower load than slab-beam system of samples B-M2 and C-M2 which have high ultimate capacity that delay appearance of first crack and the increasing of the width of crack with increasing load in comparison with flat slab. The relation between crack and load width for the three series is shown in Figures (8)

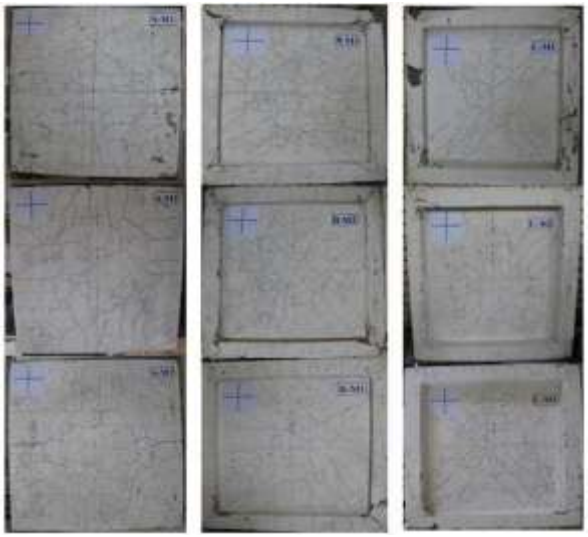


Fig. 7: Bottom view of cracks pattern at failure for all slabs models

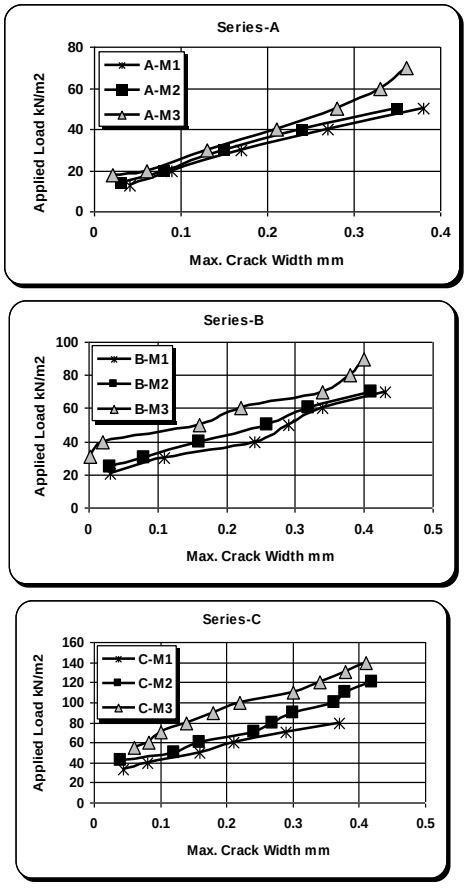


Fig. 8: Crack width versus applied load for all series

8.3.2 Deflection Versus Load Curves

The values of deflections, ultimate loads and modes of failure for all samples of slab are listed in Table (4). The experimental structural behavior of slab sample are presented by their deflection versus load as shown in Figures (9-a-b-c).

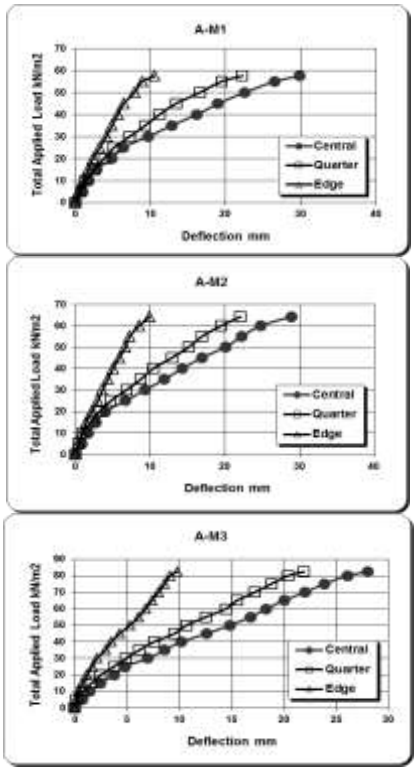


Fig. 9-a: Deflection versus load for Series-A

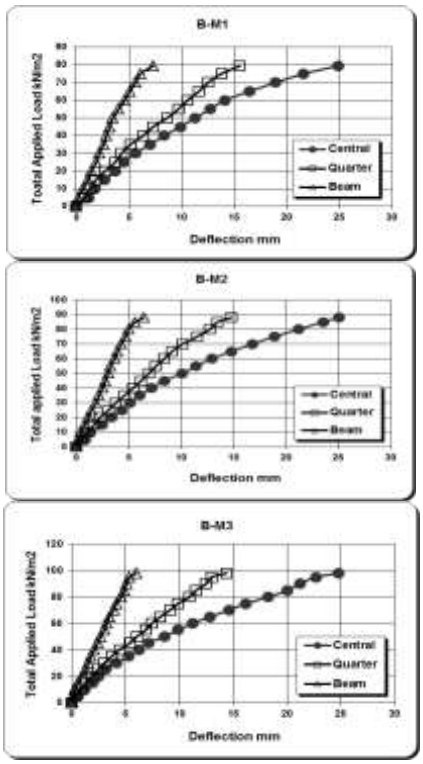


Fig. 9-b: Deflection versus load for Series-B

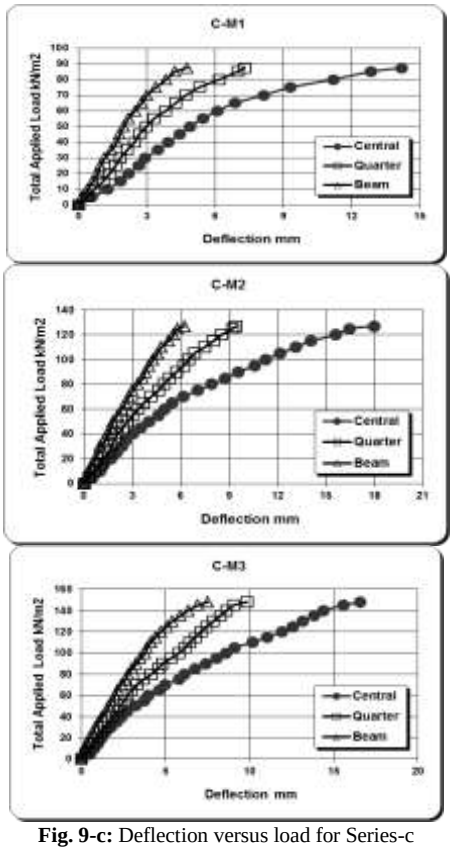


Fig. 9-c: Deflection versus load for Series-c

The change in the initial slope of the deflection-load curves for all samples started between (12.5-49) kN/m^2. This change in slope indicated the load of first cracking. After that, all samples acting in a rather certain manner. For the slab sample A-M1, the ultimate load for this slab is 57.5 kN/m^2, the ultimate load is increased in A-M2 by only 11.65%. whereas, the ultimate load of A-M3 is higher than that of the reinforced concrete slabs A-M1 and A-M2 by 43.48% and 28.50%, respectively; this is due to the difference in the mechanical properties between the mixes as discussed

previously reflected on the ultimate loads and corresponding deflections. The same behavior is found in Series-B and Series-C.
For the slab samples B-M1, B-M2 and B-M3 which are slabs with edge beams, the increase in ultimate load capacity were about 38.09%, 37.07% and 18.79% when compared with the corresponding flat slab samples A-M1, A-M2 and A-M3. This is due to the presence of edge beams that increase load capacity. This is reflected in the corresponding deflections as stated in Table (4) in central, quarter and edge beam in comparison with the same location of edge flat slab. Also, the slab samples in Series-C which are slabs with edge beams have an increase in the depth of edge beams by 50% from Series-B, and as a result the ultimate load capacity is more than in Series-B. The increase in ultimate load capacity is by 52%, 97.82% and 79.39% for C-M1, C-M2 and C-M3, respectively in comparison with flat slab samples A-M1, A-M2 and A-M3.

8.3.2 Concrete Strain

As a comparison between the three mixes (M1, M2 and M3) for each series, the strain results are plotted for selected loading level during the loading stages along half one principal axis of symmetry and reflected on the other half in the bottom face of the tested slab samples, as shown in Figures (10). Naturally, there are variations in strain value for three series that follow other parameters such as ultimate load capacity for each series.

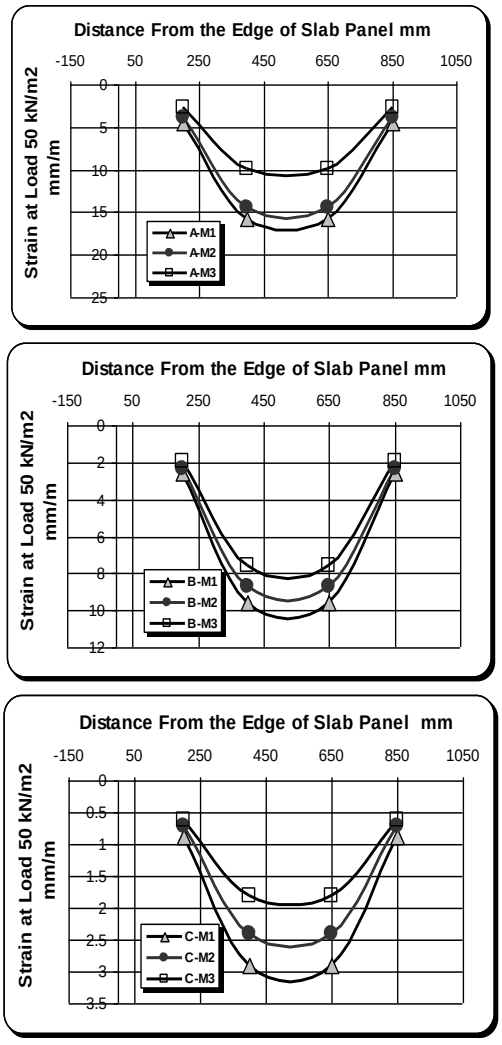


Fig. 10: Tensile Strain Versus Distance in the Bottom Face of Slab Samples at Load 50 kN/m2

In edge beam and side edge of flat slab, the neutral axis depth can be seen obviously fluctuate with the increasing in load capacity as shown in Figure (11) as example. In tension zone it can be said at load 25 kN/m2 and 40 kN/m2 that the strain distribution was nearly linear and became nonlinear in following successive loads because of cracking whilst in the compression zone its remained almost linear. On the other hand, the presence of edge beams reduces the concrete strain.

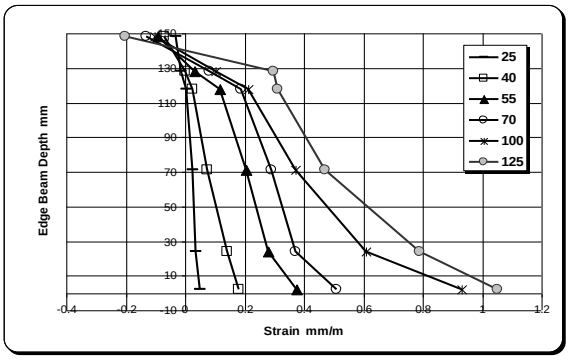


Fig. 11: Strain Distribution in Central Section for Edge Beam of (C-M2)

9. Conclusions

1- SCC incorporated filler has better fresh properties than SCC without filler but, has a lesser concrete strength because filler does not contribute significantly to the development compressive strength.
2- At the same cost, SCC gave strength less than CC by amount in the range (11.36% – 69.34%) for the considered mixes. In other meaning, to arrive the same strength; the SCC material costs will be higher than the equivalent material costs of a CC, But, when SCC is reasonable used, the reduction of costs because of shorter performed time, good productivity, and in many cases such as reduction of noise during casting, good working conditions, the ability of expanding the placing times and the excellent surface quality without surface defects or any blowholes, may result in more better prices of the final product.
3- For a specified flat plate panel, the ultimate load carrying capacity can be increased, if the panel is strengthened by edge beams in the four sides. The slab-beam samples with surrounding edge beams of depth to slab thickness equal 2 has greater ultimate load capacity by about 38.09%, 37.07% and 18.79% when compared with the corresponding flat slabs samples produced by using CC, SCC with and without filler, respectively.
4- The increasing in depth of edge beams by 50%; led to increase the ultimate load capacity by about 51% and 44% when compared with the corresponding slabs samples produced by using CC, SCC without filler, respectively.

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