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Feasibility of using self-compacting concrete in civil engineering applications

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ABSTRACT

This research aimed to investigate the feasibility of using self-compacting concrete in civil engineering applications as a producing a precast hollow unit. The behavior of the hollow sections cast with self-compacted concrete beneath line-load was evaluated. An experimental work was carried out and a finite element model with ANSYS (version 15) was adopted. A total of fourteen hollow beams were cast and tested. The most variables taken into thought were; the types of reinforcement (reinforced steel bar and steel wire meshes), the types of steel wire meshes (expanded and welded steel wire mesh), number of layers of steel meshes (one layer and two layers), cross section thickness of concrete (40 mm and 60mm), concrete cover thickness (15mm and 20 mm) and also the shapes of cross section (square or circular). Special attention to initial cracking load, ultimate load, deflection, cracking pattern, energy absorption and ductility index were investigated. Good agreement was found compared with the experimental results. Out of this research; this paper presents applications of self-compacted concrete for casting skinny structural hollow members. These members can be used as precast units within the construction of the tunnel to decrease the problems in highway roads due to the difficulty of using crossing bridges particularly for kids and old people which are very useful for developing countries with great economic advantages.

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1. Introduction

Self-compacting concrete (SCC) is new particular concrete recommended for all several applications particularly in extremely reinforced concrete members like bridge decks or abutments tunnel linings tubing segments, wherever it is difficult to vibrate the concrete, dams, underground structures, composite structures, or may be for traditional engineering structures (Klug and Holschemacher, 2003). There are several factors effects on the workability of self-compacted concrete like the sort of construction, the chosen placement and consolidation methods, the shape of the form-work and also the nature of the reinforcement (Khayat et al., 1997). The absence of the vibration is decreasing the pressure; the modified consistency dose will increase the loads

(Abdel Hady, 2003). To create SCC fascinating for the application especially as a prepared ready mix concrete, the value of the manufacturing SCC compared to traditional concrete should be reduced (Proske and Graubner, 2002). The characteristic of SCC to flow free segregation into formwork without the requirement for vibration affects absolutely the distribution of the concrete strength even in massive concrete members (Khayat et al., 1997; Vanhove et al., 2001). Pereira-de-Oliveira et al. (2013) studied the porousness of SCC with recycled aggregate incorporation. Sara et al. (2017) presented a literature review on the behavior of self-compacting concrete at fresh state with fine and coarse recycled aggregates. They concluded that SCC with recycled aggregates is of great relevance to society that rationalized the negative effects on the atmosphere. Olga et al. (2016) were

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carried out an experimental program on SCC-type mixtures pump ability to spot the most parameters for pumping quality control. Results discovered that also when the cast in situ procedure is correctly performed; it will have an effect on each the early age performance and also the hardened properties of the SCC-type mixtures. Habib et al. (2016) evaluated the performance of various self-consolidating concrete (SCC) mixtures in a full-scale reinforced concrete beams. The result of combine of mix design and the stability of the SCC on the flowability and passing ability of the concrete cast within the vertical and horizontal directions along the beams are evaluated. The first application of SCC was during a building in June 1990, and so it absolutely was employed in several applications like the towers of a pre-stressed cable-stayed bridge in 1991. In 1992, a special type of lightweight SCC was used in the main girder of a cable-stayed bridge. Since then the utilization of SCC in actual structures has bit by bit increased with the aim that SCC are going to be the normal form of concrete. SCC is applied in precast plants, wherever special conditions are available (Skarendahi, 1998). A typical application of SCC is that the two anchorages of Akashi–Kaikyo Bridge opened in April 1998 a suspension bridge with the longest span in the world (1,991meters). A new construction system that makes full use of the performance of SCC, the concrete was mixed at the lot of batch plant beside the site and was the pumped out of the plant. The utilization of SCC shortened the anchorage construction period by 20% from 2.5 to 2 years (Ouchi, 2000). Manikandanet et al. (2015) presented the flexural behavior of hollow core sandwich beams with completely different core shape, by using expanded polystyrene foam within the tension zone of beams. The results showed associate improvement within the behavior of hollow core sandwich beams compared with conventional solid beams. Djamaluddin et al. (2014) conducted an experimental study on fully removed concrete in the tensile zone. They studied the effect of removed concrete on the flexural mechanical action between tension stress and compression stress of the concrete beam section because the flexural capacity of the beam decreases. Kocher et al. (2002) presented a theoretical study of sandwich structures with polymer frame reinforced with hollow core using simple analytical models that describe the contribution to the stability of the structure in hollow at the core. Shirai and Ohama (1990) used polymer-modified mortar rather than ordinary cement mortar to improve the flexural behavior and impact resistance of ferrocement. Yogendran (1987) studied the effect of silica fume in the properties of high-strength concrete. He concluded that the optimum percentage of silica 15% as a replacement of cement content at the water-cement ratio of 0.34.

2. Research Significance

This paper introduces a new effective and economic technique for constructing tunnel using permanent precast units casting with SCC. The objectives of the experimental program described within this research were (i) studying the behavior of reinforced thin hollow beams

cast with SCC under line-load as in Fig. (1). (ii) Studying the effect of the type of reinforcement, type and number of layers of steel wire meshes, the shape of the cross section, thickness of concrete cover and cross-sectional. (iii) Evaluating the economic assessment of thin hollow sections as precast tunnel units. Theoretical analysis will be conducted by ANSYS 15 as a finite element package to verify the results of the experimental program.

3. Experimental Program

To evaluate the aim of this study, fourteen reinforced hollow beams were conducted. 1500 mm in length is for the tested sections. A square cross section has a dimension 400 mm×400 mm. A circular cross section has a diameter 400 mm. 60 mm and 40 mm were the cross-sectional thickness for reinforced by steel bars and steel wire meshes, respectively. The geometrical and reinforcement details of the tested beams are shown in Table 1 and Fig. 1. Fig. 2 shows the test set-up. The test specimens were painted with white paint to clarify the visual cracks during the testing. To measure the deflection, demec points were placed during loading. I beam 15 with 2 m in length was used for line load. The subsequent code was used for the sample designation: the first letter defines shaped cross section (Q for the square cross section and C for the circular cross section) the second letter S defines the steel reinforcement. The letter W is for welded steel wire mesh. The letter (ex) is for expanded wire mesh. Letter V defines the cover concrete which is equal 15 mm. The letter r defines the stirrups used with the steel wire mesh. The number 1 is for one layer steel wire mesh also the number 2 is for two layers steel wire mesh.

4. Material Properties

Ordinary Portland cement type I (CEMI 42.5N) according to the requirements of E.S.S. 4756-11, 2009 with a specific gravity of 3.15 and a specific surface area (Blaine fineness) 3700 cm²/gm. was used. Locally produced identified Silica Fume (S.F.) was delivered in 25-Kg sacks according to the manufacturer; the powder had an average particle size of 0.1 micrometers, specific surface area 170000 cm²/gm. and specific gravity of 2.2. Natural siliceous sand was used as fine aggregate throughout the current research. The fine aggregates used was obtained from Suez zone with 2.62 specific gravity, 2.67 fineness modulus and absorption percentage of 0.79%. Coarse aggregate (dolomite) with a nominal size of 10 mm was used; with a specific gravity 2.64 and absorption value of 1.8%. Viscocrete 5930 L as high range water reducer (HRWR) complies with ASTM C494 Type A & F was used. Expanded metal wire mesh and welded steel wire mesh were used as reinforcement. The geometric properties of these meshes accommodates of ACI 549.1R-97, as shown in Fig. 3 and Table 2. Tensile tests on welded steel wire mesh and expanded metal wire mesh were carried out. The proof stress for welded steel wire meshes and expanded metal wire meshes were 315 and 210 N/mm², respectively. The ultimate

tensile strength for welded steel wire meshes and expanded metal wire meshes were 600 and 315 N/mm², respectively. Mild steel rebar (nominal diameters 8 mm) was used as main reinforcement with yield and ultimate

tensile strength of 292 and 455 N/mm², respectively. Mild steel rebar was used for stirrups (nominal diameters 6 mm) with yield and ultimate tensile strength of 254 and 390 N/mm², respectively.

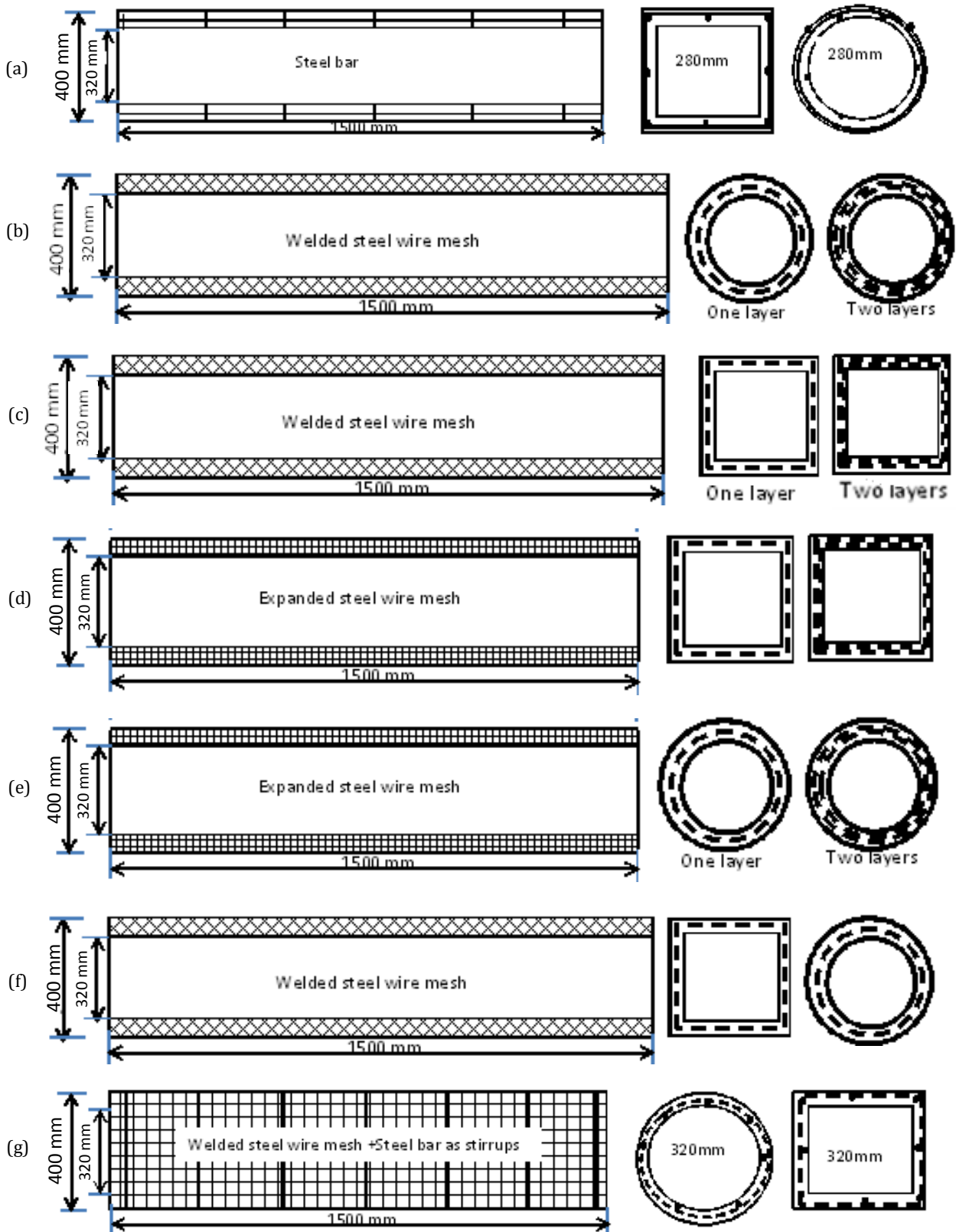
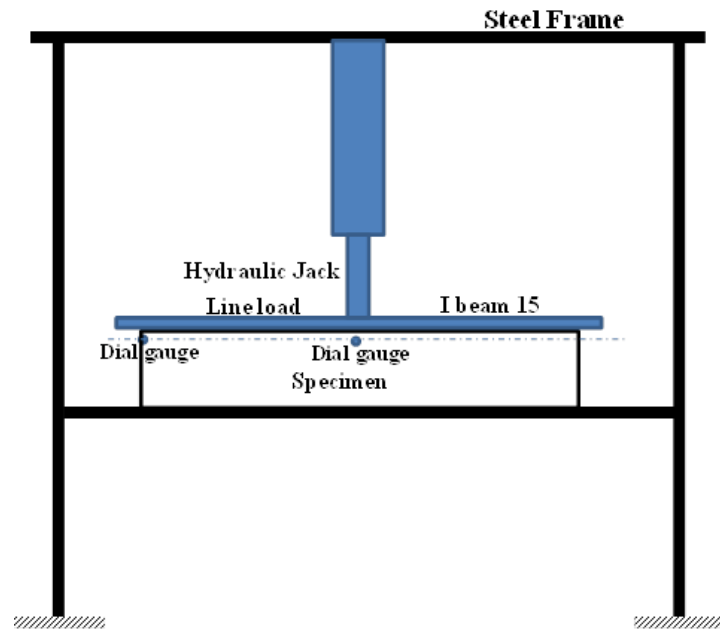
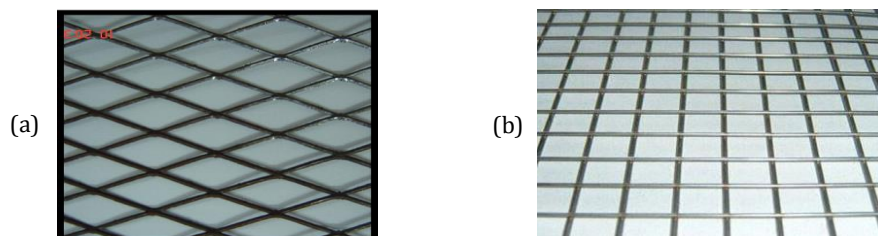


Fig. 1. Geometrical and reinforcement details of the tested hollow beams: (a) QS and CS; (b) C1W and C2W; (c) Q1W and Q2W; (d) Q1ex and Q2ex; (e) C1ex and C2ex; (f) Q1wv and C1wv; (g) Q1wr and C1wr.

Table 1. Details of the tested specimens.

Designation of Beam	Reinforcing Wire Mesh			Steel Reinforcement		Thickness (mm)	Length (mm)	Concrete cover (mm)	Total weight of steel (kg)
	Type	No. of layers	V_f %	Longitudinal	Stirrups				
QS	-	-	-	Φ 8/ 15 cm	ϕ 6/20 cm	60			6
CS	-	-	-	Φ 8/ 15 cm	ϕ 6/20 cm				5.8
Q1w	welded	1	5.2	-	-				1.2
C1w	mesh	1	5.4	-	-				1.15
Q1ex	expanded	1	6.3	-	-			20	1.25
C1ex	mesh	1	6.5	-	-				1.2
Q2w	welded	2	10.4	-	-	40	1500		2.4
C2w	mesh	2	10.8	-	-				2.3
Q2ex	expanded	2	12.6	-	-				2.5
C2ex	mesh	2	13	-	-				2.4
Q1wv		1	5.2	-	-			15	1.2
C1wv	welded	1	5.4	-	-				1.15
Q1wr	mesh	1	10.2	-	ϕ 6/20 cm			20	2.97
C1wr		1	10.4	-	ϕ 6/20 cm				2.92

* V_f : Volume fraction of wire mesh

**Fig. 2.** Test set-up.**Fig. 3.** Types of steel mesh: (a) Expanded steel wire mesh; (b) Welded steel wire mesh.**Table 2.** Geometric properties of the steel meshes.

Mesh Type	Mesh Opening (mm)		Dimension of Strands (mm)	Diameter (mm)		Grid Size (mm)	Weight (kg/m ²)
	Long Way	Short Way		Width	Thickness		
Square welded wire fabric	25	25	1.2	0.7	1.4	25x25	2.5
Expanded (metal) mesh	12.7	12.7	2.40	1.25	1.25	12.7x12.7	3

5. Casting and Testing Procedures

Square specimens placed into molds with the longitudinal axis being vertical. Concrete was poured gently in one layer up to the highest edge, minimizing entrapped air wherever the smoothness of the formed surfaces is important, the concrete spaded along the molds or gently tapped on the perimeters of the molds

with a mallet. Molds maintained vertical throughout and once inserting till concrete hardens. For circular specimens, centrifugal force casting (rotating machine) with the same mix design was used (Table 3). The specimens were kept in molds for three days once casting and expose to 100°C. Afterward that the specimens were immersed in clean water till taken out for testing.

Table 3. Mix proportions (kg/m³).

Cement	Sand	Dolomite	VEA	S.F.	Water	F_{cu} (N/mm ²), 28 days
400	1036	850	8	20	140	44

VEA: ViscoCrete-5930 L S.F.: Silica fume F_{cu} : compressive strength

6. Results and Discussion

6.1. Effect of shape of cross section

Fig. 4 shows the effect of the shape of the cross-section for the tested beam with different types of reinforcement. It is noticed that the loads for the beams with square cross sections was higher than that of circular cross sectional. This due to value of the moment of inertia of square section is bigger than the circular section. Fig.4(a) illustrates the effect of the shape of the cross section for the beams reinforced with steel reinforcement. The initial cracking load and ultimate load was 35 and 110 kN for square cross section. 32 and 100 kN was the initial and ultimate load for the circular cross section. 75 and 70 kN was the failure load for square and circular cross section. The initial cracking load and ultimate load for the square cross-sectional were higher than that of circular sections by 9% and 10%, respectively. The same results were recorded for the beams with steel wire mesh as illustrate in Figs. (b, c). The initial cracking load and ultimate load was 19 and 65 kN for square cross section. 18 and 60 kN was the initial and ultimate load for the circular cross section reinforced with welded steel wire mesh. 50.3 and 46.3 kN was the failure load for square and circular cross section reinforced with welded steel wire mesh. 16, 55 and 41.4 kN was the initial cracking, ultimate and failure load for the square cross section reinforced with expanded steel wire mesh while 15, 50 and 41.6 were being the initial cracking, ultimate and failure load respectively for the circular cross section reinforced with expanded steel wire mesh. The initial cracking load and ultimate load increased by 6% and 8%, respectively for the square cross-sectional compared with the circular cross sectional of the beam reinforced with welded steel wire meshes. Also; 7% and 10% increasing in the initial cracking load and ultimate load for the square cross sections compared with the circular cross section for the beams reinforced with expanded steel wire mesh.

6.2. Effect of number of mesh layers

The effect of numbers of steel wire mesh layer was shown in Figs. 5 and 6. As the number of steel wire mesh were increasing, the initial cracking, ultimate load and energy absorptions increase for all types of steel wire mesh and the shape of cross section.

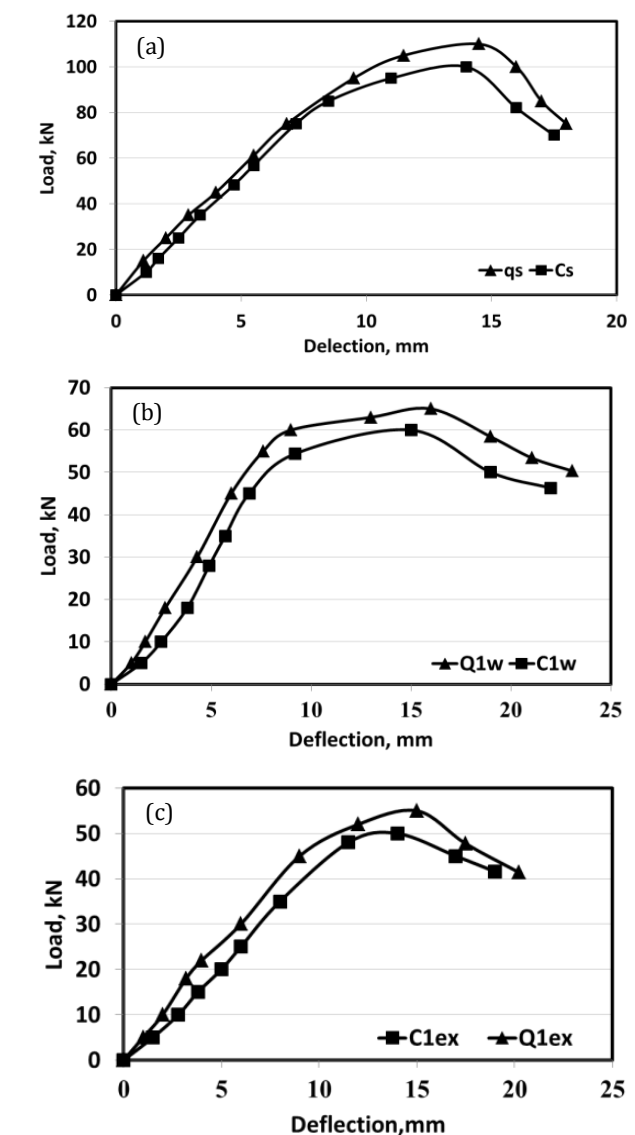


Fig. 4. Effect of shape of cross section: (a) Control specimens; (b) Specimens reinforced with welded wire mesh; (c) Specimens reinforced with expanded wire mesh.

For the beams with square cross sectional and reinforced with one layer welded steel wire mesh 19, 65 kN for initial and ultimate load. Also the energy absorption

was 1040 kN.mm. 22.8 and 80 kN were resulted for two layer in addition to 1500 kN.mm for energy absorption. The initial cracking load, ultimate load and energy absorption increased by 20%, 23% and 44% for the two mesh layers compared with one mesh layers, respectively. For the beams with circular cross sectional and reinforced with one layer welded steel wire mesh 18, 60 kN for initial and ultimate load. Also the energy absorption was 1190 kN.mm. 23.5 and 84 kN were resulted for two layer in addition to 1600 kN.mm for energy absorption. An increasing by 31%, 40% and 34% for the beam reinforced with two layer welded steel wire mesh compared with one layer welded steel wire mesh for with the circular cross sectional. For the beams with square cross sectional and reinforced with one layer expanded steel wire mesh, 16, 55 kN for initial and ultimate load. Also the energy absorption was 980 kN.mm. 23.3 and 70 kN were resulted for two layer in addition to 1150 kN.mm for energy absorption. The initial cracking load, ultimate load and energy absorption increased by 45%, 27% and 17% for the two mesh layers compared with one mesh layers, respectively. For the beams with circular cross sectional and reinforced with one layer expanded steel wire mesh 15, 50 kN for initial and ultimate load. Also the energy absorption was 1010 kN.mm. 21.4 and 75 kN were resulted for two layer in addition to 1210 kN.mm for energy absorption. An increasing by 43%, 50% and 20% for the beam with the circular cross sectional as illustrated in Fig. 6.

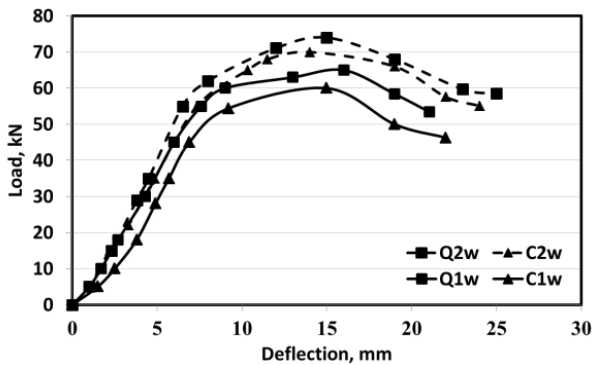


Fig. 5. Effect of number of layer for sections reinforced with welded wire mesh.

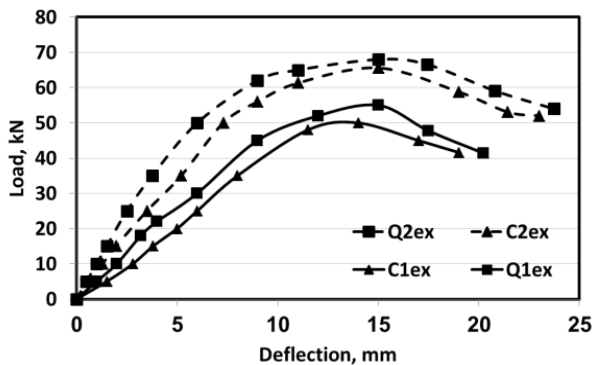


Fig. 6. Effect of number of layer for sections reinforced with expanded wire mesh.

6.3. Effect of type of reinforcement

Figs. 7 and 8 show the effect of types of reinforcement on the behavior of the tested beams with different of cross section. From these figures, the loads for conventional reinforcement were the highest compared with the two types of steel wire meshes. In addition to the loads for the beams reinforced with welded steel wire mesh are higher than that for beams reinforced with expanded steel wire mesh. However the energy absorption for the beams reinforces with steel wire meshes is higher than that reinforced with convention reinforcement. Fig. 7 illustrates the effect of type of reinforcement for square cross section. It is clear that; 35 and 110 kN were the initial cracking and ultimate load, respectively for the beam reinforced with conventional reinforcement. 19 and 22.8 kN was the initial cracking load for one layer and two layers welded steel wire mesh, respectively. The ultimate load was 65 and 80 kN for one layer and two layers respectively. For the square section with expanded wire mesh 16 and 23.3 kN was the initial cracking load for one layer and two layers expanded steel wire mesh, respectively. The ultimate load was 55 and 70 kN for one layer and two layers; respectively. A decreasing in the initial cracking and ultimate load by average 48 and 45% for welded and expanded steel wire meshes reinforcement compared with conventional reinforcement for the beams with square cross section. The increase in the initial cracking load was reduced to 33% for the two layers of reinforcement in both welded and expanded wire mesh. In addition to the increases in the ultimate load was reduce to 62% and 36% for welded and expanded wire mesh as illustrated in Fig. 7. On the opposed side the energy absorbed was decreased by 7 and 13% for the beams reinforced with one layers of welded and expanded steel wire meshes compared with conventional reinforcement as illustrated in Fig. 7. In addition to the energy absorption for the beams reinforced with two layers welded and expanded steel wire mesh increased by 33% and 2% compared with that conventional reinforced steel. An improvement in the initial cracking load and ultimate load by 15% for the one layers expanded wire mesh compared with one layer of welded steel wire. Also, an improvement in the initial cracking load and ultimate load by -3% and 12.5% for the two layers welded wire mesh compared with two layers of expended steel wire mesh. The same results were noticed for the beams with circular cross section as illustrated in Fig. 8. The initial cracking load, ultimate load and energy absorption were 18 kN, 60kN and 1190 kN.mm for one layer welded wire mesh. Also, 23.5 kN, 84 kN and 1600 kN.mm for initial cracking load, ultimate load and energy absorption for two welded steel wire mesh. The initial cracking load, ultimate load and energy absorption were 15 kN, 50kN and 1010 kN.mm for one layer expanded wire mesh. Also, 21.4 kN, 75kN and 1210 kN.mm for initial cracking load, ultimate load and energy absorption for two expanded steel wire mesh. A decreasing in the initial cracking and ultimate load by an average 48% and 45% for one layer of welded and expanded steel wire meshes reinforcement compared with the conventional reinforcement for the beams with circular

cross section. The energy absorbed was increased by 5% for the beams reinforced with one layers of welded steel wire meshes compared with conventional reinforcement. While a decreasing was noticed in the energy absorption by 2% for one layer expanded wire mesh compared with conventional reinforcement. The variation in the initial cracking load was reducing to 26% and 33% for two layers welded and expanded wire mesh compared with conventional reinforcement. Also the variation of ultimate load was reducing to 19% and 33% were for two layers welded and expanded wire mesh compared with conventional reinforcement. The energy absorbed was increased by 42% and 7% for the beams reinforced with two layers of welded and expanded steel wire meshes compared with conventional reinforcement. The initial cracking load, ultimate load and energy absorption was increases by 16%, 23% and 15% for one layer welded steel wire mesh compared with expanded steel wire mesh. Also, an improvement in the initial cracking load, ultimate load and energy absorption by 9%, 6% and 24% for the two layers of welded steel wire mesh compared with expanded steel wire mesh.

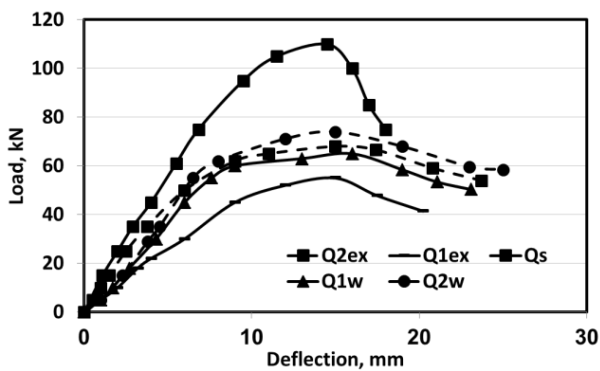


Fig. 7. Effect of types of reinforcement for square sections.

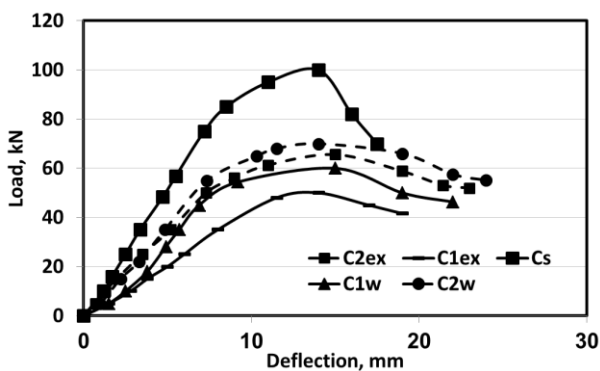


Fig. 8. Effect of types of reinforcement for square sections.

6.4. Effect of concrete cover

Fig. 9 shows the effect of concrete cover thickness for the beams with square cross section and reinforced with one layer welded steel wire mesh on the behavior of the tested beams. The initial cracking load, ultimate load and energy absorption was 19 kN, 65 kN and 1040 kN.mm, respectively for the specimen Q1w. While the initial

cracking load, ultimate load and energy absorption was 18 kN, 67.5 kN and 1300 kN.mm respectively for specimens Q1wv. Decreasing the concrete cover thickness by 25% decreasing the initial cracking load by 5%; however increasing the ultimate load and energy absorption by 3.8% and 25%, respectively. For the beams with circular cross section, the initial cracking load, ultimate load and energy absorption was 18 kN, 60 kN and 1190 kN.mm, respectively for the specimen C1w. The initial cracking load, ultimate load and energy absorption was 16 kN, 62 kN and 1400 kN.mm respectively for specimens C1wv. The initial cracking load decreased by 11%; however increasing the ultimate load and energy absorption by 3% and 17% respectively as illustrated in Fig. 10.

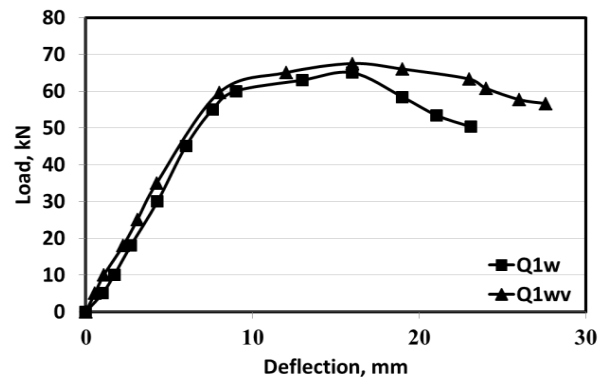


Fig. 9. Effect of concrete cover for square section.

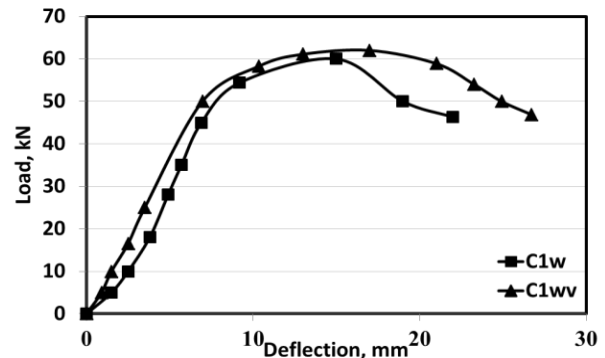


Fig. 10. Effect of concrete cover for circular section.

6.5. Effect of using steel bar as additional stirrups

The effect of using steel bar as additional stirrups on the behavior of the tested beams with one layer welded steel wire mesh was shown in Figs. 11 and 12. The use of stirrups resulted in the movement of the initial cracking load from the edges to the middle direction, in addition to delay the appearance of the initial cracking load. The initial cracking load, ultimate load and energy absorption was 19 kN, 65 kN and 1040 kN.mm, respectively for the specimen Q1w. While the initial cracking loads, ultimate load and energy absorption was 17.5 kN, 66 kN and 1430 kN.mm respectively for specimens Q1wr. The initial cracking load, ultimate load and energy absorption was 18 kN, 60 kN and 1190 kN.mm, respectively for the specimen C1w. While the initial cracking loads, ultimate

load and energy absorption was 15 kN, 61 kN and 1480 kN.mm respectively for specimens C1wr. The initial cracking and ultimate load increased by -8% and 1.5% compared with the beams without stirrups for the tested beams with square and circular cross section. Also, the ratio of initial cracking load to ultimate load were 27% and 25% for the square and circular cross section the ratio of initial cracking load to ultimate load was changed by 2% and 5% for the square and circular cross section compared with the tested beams without steel stirrups.

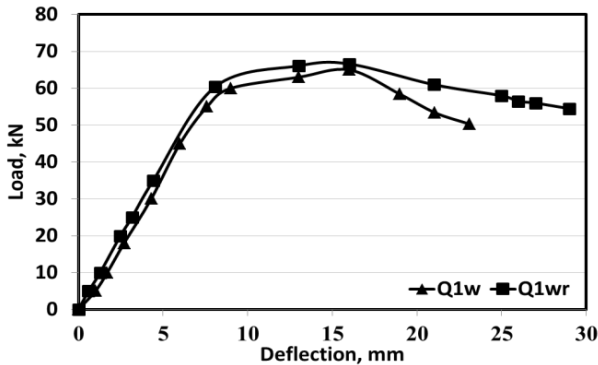


Fig. 11. Effect of using steel stirrups for square section.

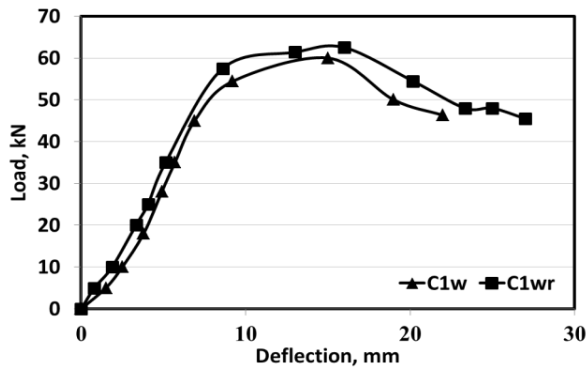


Fig. 12. Effect of using steel stirrups for circular section.

6.6. Ductility index and energy absorption

The test results are listed in Table 4. The table shows the obtained experimental results for each specimen as well as the ductility ratio, and energy absorption properties. Ductility ratio is defined here as the ratio between the mid-span deflections at ultimate load to that at the first crack load (Δ_u/Δ_y), while the energy absorption is defined as the area under the load-deflection curve. Computer program (BASIC language) was used to calculate the area under curve by integrated the equation of the load-deflection curve for each beam specimens as follow:

$$\text{Energy absorbed} = \int_0^{\Delta_u} f(\Delta)d\Delta;$$

where: $f(\Delta)$ is the equation of load-deflection curve; Δ_u is the mid-span deflection at failure load.

The value of ductility index and energy absorption for all beams is presented in Table 4. It was observed the ductility behavior of circular hollow beams is better than of square beams. As the beams reinforced with wire meshes had ductility ratio more than with steel reinforcement due to the elongation of steel wire mesh is bigger than mild steel. The ductility ratio for the test specimens ranged from 3.0 to 4.06. The energy absorption of tested beams reinforced with steel wire meshes was higher than that with steel reinforcement due to increase the area under load deflection curve. Ductility index and energy absorption increased as the number of layers of steel wire meshes were increasing. This illustrates the effect of the stiffness of the beams.

6.7. Crack pattern

Cracking patterns for all the tested beams were illustrated in Fig. 13. All tested beams were un-cracked beam for the initial stages of loading. When the applied load reached to the rupture strength of the concrete on the specimen, the concrete started to crack up to the failure pattern in the all tested beams.

Table 4. Test results for the hollow beams.

Beam code	First crack load (kN)	Ultimate load (kN)	Deflection (mm)		Ductility index	Energy absorption (kN.mm)
			Δ_y	Δ_u		
Qs	35	110	4.7	15	3.14	1130
Cs	32	100	4.9	15.5	3.125	1000
Q1w	19	65	4.7	16	3.42	1040
C1w	18	60	4.2	14	3.33	1190
Q1ex	16	55	4.3	14.5	3.43	980
C1ex	15	50	4	13.5	3.33	1010
Q2w	22.8	74	3.3	11.5	3.5	1500
C2w	23.50	70	3.1	11	3.52	1600
Q2ex	23.30	68	4	12	3	1150
C2ex	21.40	65.5	3.6	12.5	3.5	1210
Q1wv	18	67.5	4	15	3.75	1300
C1wv	16	62	3.6	14	3.875	1400
Q1wr	17.50	66	3.55	13.5	3.77	1430
C1wr	15	61	3.7	15	4.06	1480



Fig. 13. Cracking pattern of tested beams.

7. Finite Element Model

A finite element package (ANSYS version 15), was used to simulate the behavior of hollow beams. Two types of elements were used; SOLID65 and LINK8. Fig. 14 shows the SOLID65 as 3-D reinforced concrete solid.

Link 8 (Fig. 15) was defined by two nodes, the cross-sectional area, an initial strain, and the material properties. The steel wire meshes was defined by the volume fraction, initial strain and the material properties. Table 5 and Figs. 16 to 19 show some theoretical results for the ANSYS program.

Table 5. Comparison between theoretical and experimental results for first crack and ultimate loads.

Beam code	First crack load (kN)		Ultimate load (kN)	
	P_{theor}	$P_{exp./ P_{theor}}$	P_{theor}	$P_{exp./ P_{theor}}$
Qs	35	1.00	108	1.02
Cs	33	1.06	99	1.01
Q1w	20	0.95	65	1.00
C1w	19.5	0.92	62	0.97
Q1ex	15.5	1.03	55.5	0.99
C1ex	14	1.07	49	1.02
Q2w	22	1.04	78	0.95
C2w	25	0.94	72	0.97
Q2ex	24	1.04	70.7	0.96
C2ex	22	0.97	70.8	0.93
Q1wv	18	1.00	68.89	0.98
C1wv	15.8	1.01	62.6	0.99
Q1wr	17	1.03	64.68	1.02
C1wr	15.3	0.98	62.8	0.97
Average = 1.003		Average = 0.98		
S.D.= 0.0637		S.D.= 0.0284		

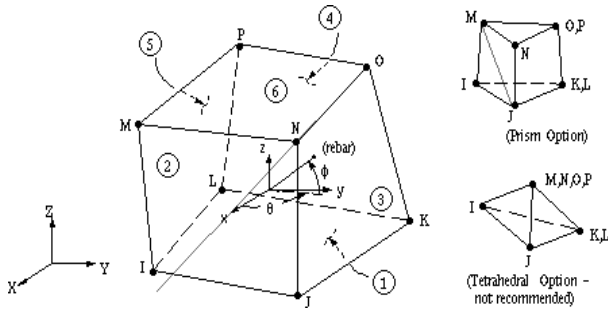


Fig. 14. SOLID65 3-D reinforced concrete solid.

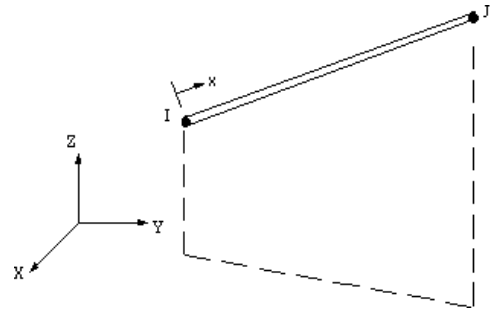


Fig. 15. LINK8 3-D spar.

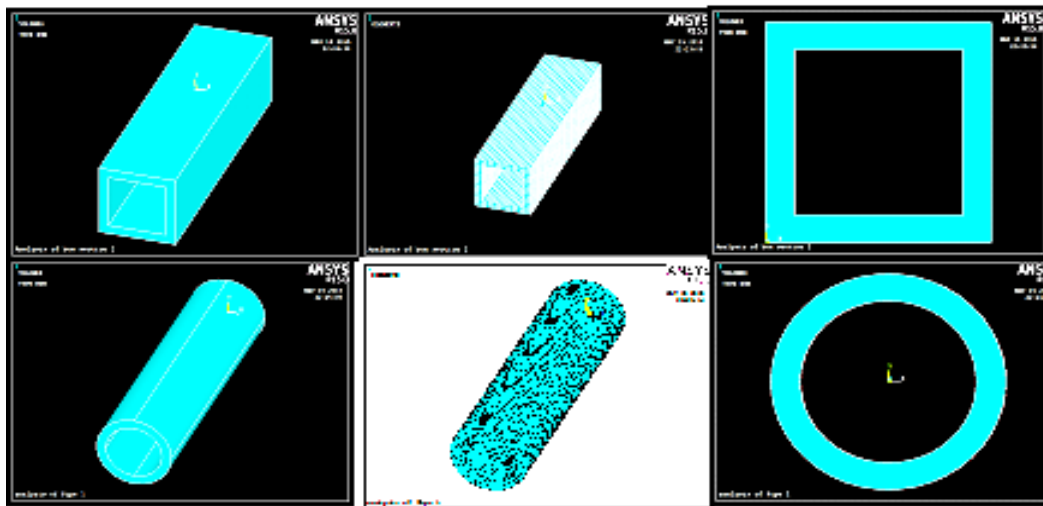


Fig. 16. Configuration of the tested hollow beams.

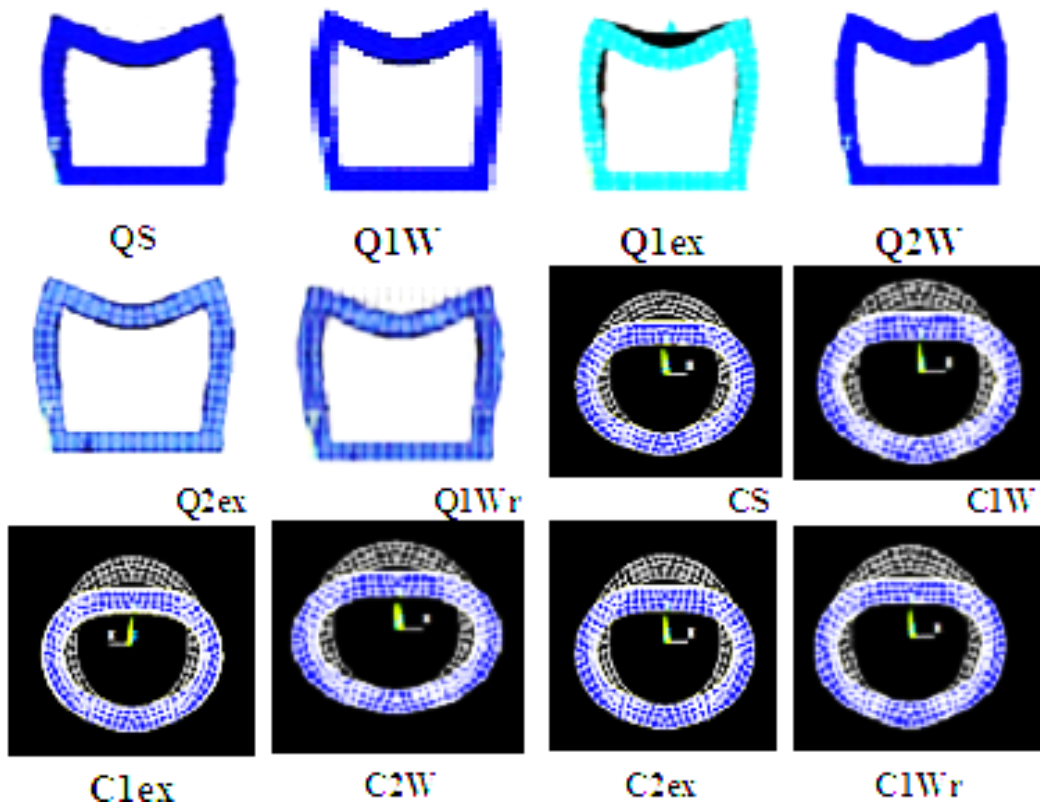


Fig. 17. Displacement of tested specimens.

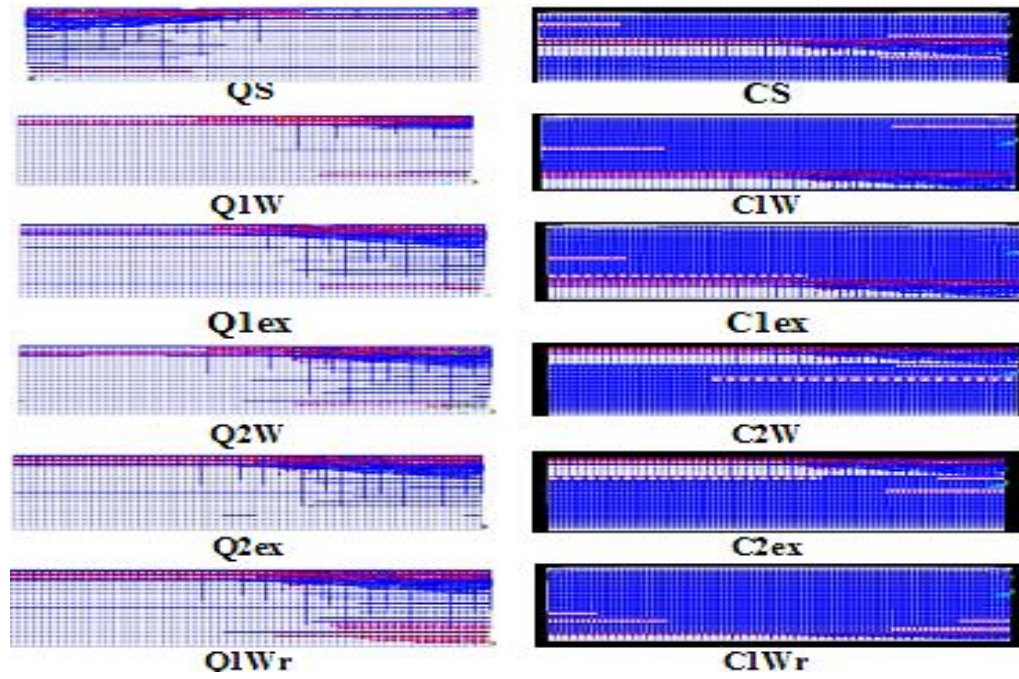


Fig. 18. Crack patterns of tested specimens.

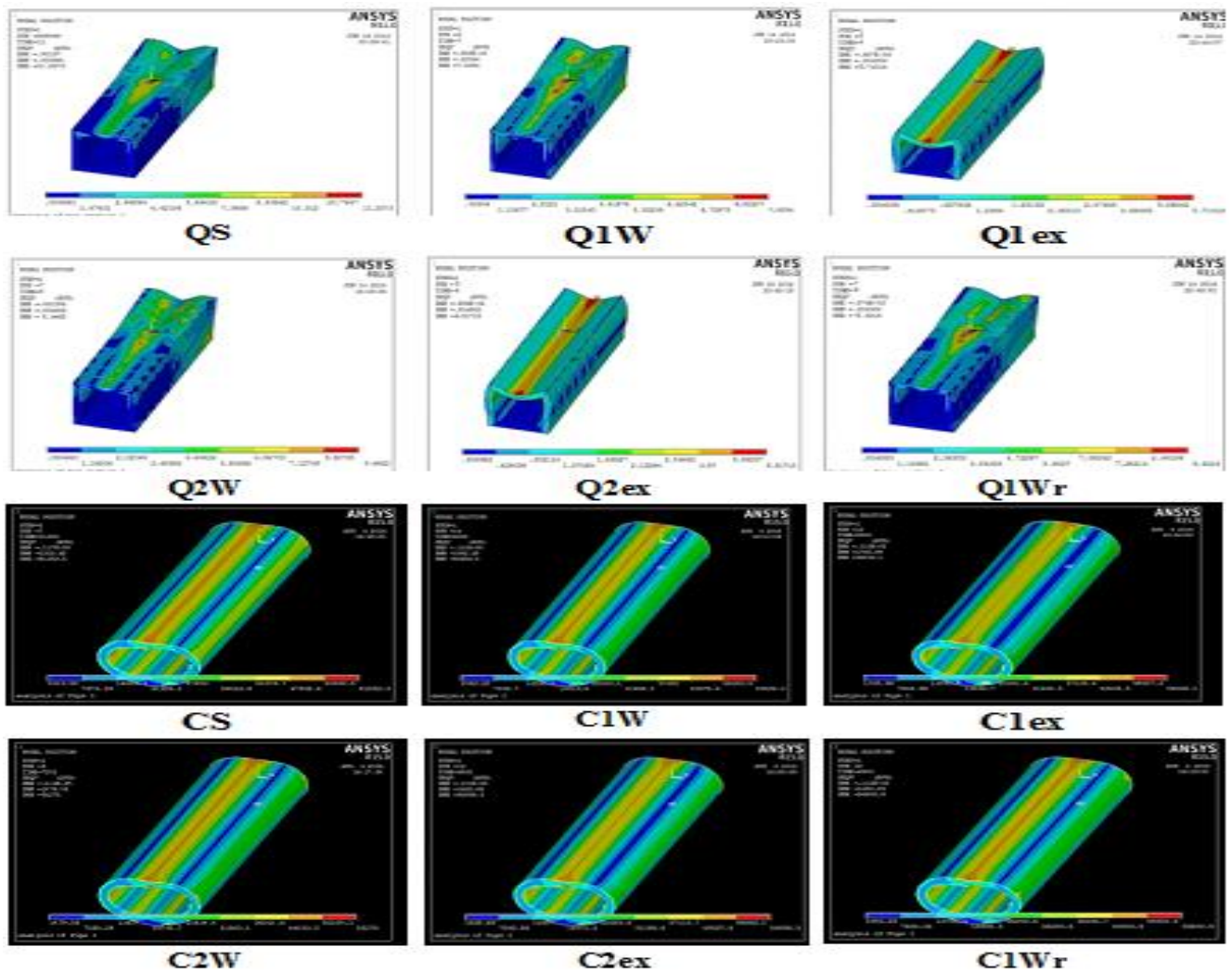


Fig. 19. Von Mises stress distribution for tested hollow beams.

8. Economic Assessment of Thin Section as Permanent Precast Units

As one of the applications, using self-compacted concrete, particularly in cast thin hollow sections. These sections cast as permanent precast units for construction tunnels. This way can offer save time in casting on the site and provide the cost of creating an alternate road. The cost comparison of thin hollow beam shown in Table 6. Tables 7 and 8 show the time-table for the conventional construction of the tunnel and the suggested method. Table 7 shows the stages of tunneling through traditional methods. This methods starting from digging the road which entails a leak and searching through an alternative to the work of converting it to traffic. It may require the expropriation of some land to increase the

efficiency of the project. The preparing the chopping, wrenches, preparation for casting, and finally the tunnel ceiling not less than 18th week. Table 8 shows the time-table the proposed method for all the preparation, casting and post casting stages which are carried out in the factory away from the site. This method allows regular traffic without stopping at any time. Fig. 20 shows the main point of suggested method of installation of the pre-cast pieces in the site, which cast in the factory and quoted for the site. In suggested method, first step is digging the lane so that we can use the other parts of the lane. Moreover, we do not need to work alternative roads or cut off the road. The connection between the two pieces will connect only with the presence of a left lane for the road. When preparing for the third piece the right lane will open.

Table 6. Cost comparison of thin hollow beam.

code	Volume, m3	Concrete, kg/unit					Reinforcement					Total cost, L.E.
		cement	sand	Dolomite	Silica fume	HRWR	Cost	No. of layers	Area, m2	L.E./ m2	No. of bars L.E./ bar	
Qs	0.144	55	122	98	6	1.1	150	-	-	-	8 63	213
Cs	0.052	20	44.3	35.3	2	0.4	65	-	-	-	-	128
Q1w	0.096	36.8	81.8	65	4	0.74	86	1	2.4	16.8	-	102.5
C1w	0.038	15	32.4	25.8	1.6	0.3	40	1	1.875	13.125	-	53.125
Q1ex	0.096	36.8	81.8	65	4	0.74	86	1	2.4	16.8	-	119.6
C1ex	0.038	15	32.4	25.8	1.6	0.3	40	1	1.875	13.125	-	66.25
Q2w	0.096	36.8	81.8	65	4	0.74	86	2	4.8	33.6	1.5	119.6
C2w	0.038	15	32.4	25.8	1.6	0.3	40	2	3.75	26.25	1.5	66.25
Q2ex	0.096	36.8	81.8	65	4	0.74	86	2	4.8	33.6	1.5	119.6
C2ex	0.038	15	32.4	25.8	1.6	0.3	40	2	3.75	26.25	1.5	66.25
Q1wv	0.096	36.8	81.8	65	4	0.74	86	1	2.4	16.8	-	102.5
C1wv	0.038	15	32.4	25.8	1.6	0.3	40	1	1.875	13.125	-	53.125
Q1wr	0.096	36.8	81.8	65	4	0.74	86	1	2.4	16.8	2 20	122.8
C1wr	0.038	15	32.4	25.8	1.6	0.3	40	1	1.875	13.125	2 20	73.125

Note: The currency unit is the Egyptian pound (L.E), the date for the price calculation at January 2017.

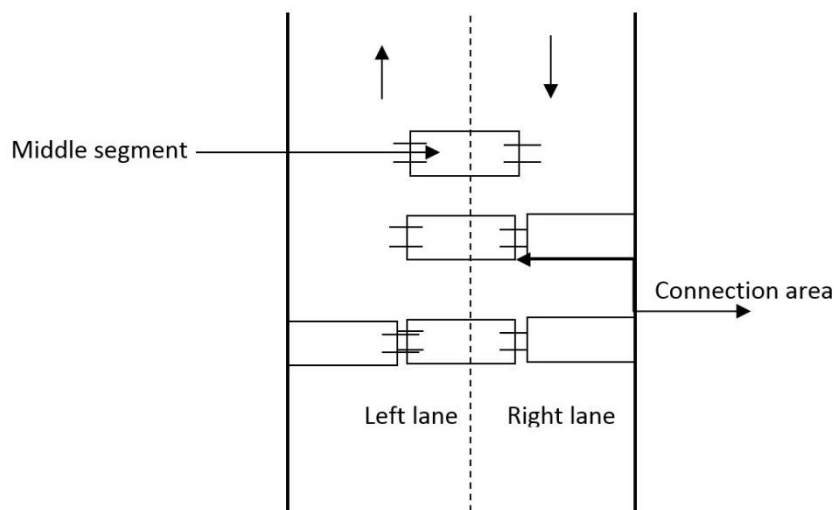


Fig. 20. Geometric shape for suggestion method.

Table 7. Time-table for conventional method.

code	1 st week	2 nd week	3 rd week	4 th week	5 th week	6 th week	7 th week	8 th week	9 th week	10 th week	11 th week	12 th week	13 th week	14 th week	15 th week	16 th week	17 th week	18 th week	
Mobilization	█																		
Cutting asphalt		█																	
Excavation			█																
Fixing floor form work				█															
Fixing floor steel					█														
Casting floor						█													
Fixing walls form work							█												
Fixing walls steel								█											
Casting walls									█										
Fixing roof scaffolding										█									
Putting roof form work											█								
Fixing roof steel												█							
Casting roof													█						
Removing scaffolding														█					
Removing shuttering															█				
curing						█	█	█	█	█	█	█	█	█	█	█	█	█	
Painting inside tunnel																		█	
Fixing asphalt																			█

Table 8. Time table for suggested method.

code	First week	2 nd week	3 rd week
Excavation +putting middle segment	█		
Right segment+casting overlap connection		█	
Left segment+casting overlap connection			█
covering		█	█

9. Conclusions

The following conclusions could be drawn from the results of the paper carried out to evaluate the behavior of thin hollow beams casting with self-compacting concrete:

- The initial cracking load for square cross section reinforced with conventional reinforcement, welded steel wire mesh and expanded steel wire mesh, increased by 9%, 6% and 7%, respectively compared with circular cross section.

- The ultimate load for square cross section reinforced with conventional reinforcement, welded steel wire mesh and expanded steel wire mesh, increased by 10%, 8% and 10%, respectively compared with circular cross section.
- Using welded steel wire mesh, the initial cracking load, ultimate load and energy absorption increased by 20%, 23% and 44% for the beam reinforced with two mesh layers compared with one mesh layers, respectively for square cross section. Also, the initial cracking load, ultimate load and energy absorption increased by 31%, 40% and 34%, respectively for the

beam reinforced with two layer steel wire mesh compared with one layer steel wire mesh for with the circular cross sectional.

- Using expanded steel wire mesh, the initial cracking load, ultimate load and energy absorption increased by 45%, 27% and 17% for the two layers compared with one mesh layers, respectively. Also, the initial cracking load, ultimate load and energy absorption increased by 43%, 50% and 20%, respectively for the beam reinforced with two layer steel wire mesh compared with one layer steel wire mesh for with the circular cross sectional
- A decreasing in the initial cracking and ultimate load by average 48 and 45% for one layer welded and expanded steel wire meshes reinforcement compared with conventional reinforcement for the beams with square and circular cross section.
- An increasing in the initial cracking load, ultimate load and energy absorption by 16%, 23% and 15% for circular cross sectional reinforced with one layer welded steel wire mesh compared with expanded steel wire mesh and by 9%, 6% and 24%, respectively for the two layers of welded steel wire mesh compared with expanded steel wire mesh.
- An improvement in the initial cracking load and ultimate load by 15% for the beam with square cross sectional reinforced with one layers expanded wire mesh compared with one layer of welded steel wire and by -3% and 12.5% for the two layers welded wire mesh compared with two layers of expended steel wire mesh.
- An increasing in the energy absorption by 5% for the beams reinforced with one layers of welded steel wire meshes compared with conventional reinforcement. While a decreasing was noticed in the energy absorption by 2% for one layer expanded wire mesh compared with conventional reinforcement.
- Using stirrups of mild steel bars with one layer welded wire mesh leads to increase the number of cracks and consequently increase the ultimate load by 1.5% in than that obtained when using only one layer without rings which lead to increase construction age. Moreover, the ratio of initial cracking load to ultimate load was 27% and 25% for the square and circular cross section, respectively.
- Decreasing the concrete cover thickness by 25%, the ultimate load and energy absorption increased by an average 3.8% and 25%, respectively for square cross section and 3% and 17% for circular cross section.
- Good agreement was found compared with the experimental results.
- Suggestion method in fixing precast tunnel cheaper and save time three times and six times respectively than ordinary method.
- These results clarify that there the increase in the ultimate load is 2.5% at slight increasing in the total cost.

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Study on partial replacement of groundnut shell ash with cement

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ABSTRACT

Concrete plays a prominent role in the construction industry. In the present scenario, there is a shortage of this material so there is a need to find alternatives to replace it in the concrete. In order to overcome this situation; many waste products which are available freely like a paper waste, red mud, rice husk and plastic waste can be used. Among all of these, Ground nut shell ash is one of the good waste materials available from the oil industry. It can be used widely for the replacement of cement. The ground net shell contains CaO , SiO_2 , Al_2O_3 , and Fe_2O_3 . This experimental investigation was carried out to evaluate the strength of concrete, in which cement was replaced with ground nut shell ash for cubes, cylinders, and Prisms with different percentages which vary from 0% to 30% at an interval of 5% were performed. Concrete was batched by weight on adopting a ratio of 1:2:4 with water–cement ratio of 0.6. Concrete cubes of 150*150*150 mm in dimensions, cylinders of 150*300 mm in dimensions and 100*150 mm prisms are used. These Cubes, cylinders, and prisms were tested for 7, 14 and 28 days for compression, flexural and split tensile strengths. It is observed that 10% replacement of ground nut shell ash shown the highest strength values when compared with other percentages and for 15% replacement of ground nut shell ash the compressive and split tensile strength obtained the highest strength rather than other flexural strength.

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1. Introduction

The explicitly in use of concrete, and its adaptability to environmental conditions make concrete suitable for applications in almost all civil engineering and building structures (Mtallib and Ibrahim, 2009). To save energy and to earn carbon credit is very much essential for the improvement of mankind. To produce tons of cement we use earth resources like limestone, clay, and chalk etc. During manufacturing of Cement, an equal amount of carbon-dioxide is released into the atmosphere which is harmful for both environment and human. Energy plays an important role in the period of developing countries like India, China, Cuba, and Egypt etc. By earning carbon credit by using agriculture waste (ground nut) for Building Materials like cement, both the energy & environment can be saved. Concrete consists of cement, aggregates (generally coarse aggregates made of gravel, crushed stone, and limestone, plus fine aggregates such

as sand from the river), water, and/or admixtures. Concrete is made by mixing of Cement, water, coarse and fine aggregates and admixtures (if required). By mixing; this objective concrete gives strength and durability. Concrete is presently one of the most popular materials used in construction and civil engineering works. When reinforced with steel, concrete has a higher capacity for carrying loads. Most of the cement used in construction work is ordinary Portland cement. Portland cement is manufactured by mixing naturally occurring substances containing chemical composition.

Therefore the utilization of groundnut shell ash reduces the environmental problem. In recent days, the natural pozzolanas materials use as partial replacement for cement has increased strength and durability. Literature and various research papers are available which have mentioned about the various advantages in the use of pozzolans in concrete production. At present, issues related to environmental conservation have gained

importance; hence the utilization of these waste materials that are available in our environment is now necessary. Apart from these materials, for replacement, many fresh materials are also been used as replacement materials in the recent construction works. Some of the replacement materials are red mud, paper waste, hypo sludge, industrial waste etc. These replacement materials are been used in case of high strength concrete too. In this study, Groundnut shell Ash (GNSA) is used as a partial replacement of cement. Groundnut shell is the form of fuel used in sweet manufacturing units and the oil mills. The groundnut shell after being used as fuel generates ash which can be used as a replacement material for cement, the disposal of which is the major hassle. Thereby results in the decrease in waste to be disposed of and also there is the effective usage of the waste that is generated.

With the use of groundnut shell ash in concrete the cost will decrease and also it reduces the environmental pollution and saves the energy. GNSA has better pozzolanic property. It contains some chemical composition also. The pozzolanic activity of ash increases with an increase of time. The addition of GNSA in cement concrete may reduce drying shrinkage, water absorption, but increases the setting time. Increases of setting time are due to slow reactivity of GNSA.

The presence of GNSA may block the existing pore structure of concrete and thereby increase its strength and impermeability. The main object is to find a solution to reduce the environmental pollution due to cement manufacturing by using GNSA.

2. Mix Proportioning

Concrete mix design for M15 grade in this experiment was designed as per the guidelines specified in I.S. 10262-1982. Design stipulations are shown below.

2.1. Design stipulations

- Characteristic compressive strength = 15 N/mm² (Required in the field at 28 days)
- Maximum size of aggregate = 20 mm (angular)
- Degree of workability = 0.80
- Degree of quality control = Good
- Type of exposure = Mild
- Type of vibration = Vibration

2.2. Test data for materials

- Type of cement or grade of cement- OPC 53 grade
- Specific gravity of cement = 3.12
- Specific gravity of coarse aggregates = 2.527
- Specific gravity of fine aggregates = 2.62

2.3. Design of concrete mix

- Target mean strength (f_c') =
 $F_{ck} + 1.65(s) = 15 + 1.65(3.5) = 20.775 \text{ N/mm}^2$
- Water cement ratio = 0.6
- Water content = 186 litres

- Cement content per m³ of concrete = 310 kg
- Percentage of entrapped air = 2%
- Fine aggregates required = 620 kg/m³
- Coarse aggregate required = 1240 kg/m³

Table 1 shows the mix proportions of plain concrete mix.

Table 1. Mix ratio for plain cement concrete.

Cement	Fine aggregates	Coarse aggregates	W/C ratio
310	620	1240	186
1	2	4	0.6

3. Materials

The materials used in this study were ground nut shell ash (GNSA), ordinary Portland cement (OPC 53 grade), sand as fine aggregates, chippings as coarse aggregates (20 mm size), and water. Wooden moulds were used for cubes, cylinders and for the prism. The ground nut shells were taken from a farm in Srikakulam in India state.

3.1. Cement

Ordinary Portland cement available in the market of grade 53 was used in the project. Care has been taken to see that the procumbent made from a single batch is stored in airtight containers to prevent it from being affected by the atmospheric moisture and humidity. Cement was subjected to some physical tests in accordance with BS 4550 (1978) such as compressive strength, specific gravity, setting time etc. the details of tests are given in Table 2.

3.2. Fine aggregates

Fine aggregates is an available river sand. Sand is used as fine aggregates in this project. The sand is free from clay, silt, and organic impurities. Sand was tested for various properties like specific gravity, bulk density, fineness modulus, partial size etc. and in according with IS 2386-1963. These test results are given in the Table 3.

3.3. Coarse aggregates

Machine crushed angular granite metal of 20 mm nominal size from the local source was used as coarse aggregates. It is free from impurities such as dust, clay, and organic matter etc., it was tested with different properties as shown below in Table 4.

3.4. Groundnut shell ash

The shells were sun dried and then ground using rice milling machine to reduce its size to a size conforming to coarse aggregates as specified in BS 882 (1992). The ash was obtained by burning of ground nut shells on an iron sheet or iron tin in an open air under normal temperature

(650°C). After burning of ground nut shell, ash will generate. This ash was cooled and after used to sieve

through British standard sieve of 75 microns. GNSA consists some chemical properties as shown in Table 5.

Table 2. Properties of cement.

S. no.	Properties	Test results	Requirement as per IS:12269-1987
1.	Fineness, m ² /kg	245	225 minimum
2.	Setting time		
	Initial (minutes)	50	Not less than 30
	Final (minutes)	180	Not more than 600
3.	Specific gravity	3.15	-----
4.	Soundness, mm	7	10 maximum
5.	Compressive strength, MPa		
	3 days	30	27
	7 days	39	37
	28 days	55	53

Table 3. Properties of fine aggregates.

S. no.	Property	Test result
1.	Specific gravity	2.52
2.	Fineness modulus	6.104
3.	Mean particle size	0.1-0.2µm
4.	Partial size	Spherical

Table 4. Properties of coarse aggregates.

S. no.	Property	Test result
1.	Specific gravity	2.56
2.	Fineness modulus	2.385
3.	Mean particle size	0.1-0.2µm
4.	Particle size	Angular

Table 5. Chemical composition of GNSA.

Constituent	Percentage composition GNSA (%)
Silica (SiO ₂)	16.3
Ferrous Oxide (Fe ₂ O ₃)	1.7
Calcium Oxide (CaO)	8.69
Aluminium Oxide (Al ₂ O ₃)	6
Magnesium Oxide (MgO)	7
Sodium Oxide (Na ₂ O ₃)	10
Potassium Oxide (K ₂ O)	16
Sulphite (SO ₃ ²⁻)	6.3

3.5. Water

The locally available portable water accepted for local construction was used in the experimental investigation after testing. The pH value should not be less than 6. The water is portable; it therefore satisfies the specification requirement for water according to BS 3148 (1980).

3.6. Concrete cubes productions

The mix proportion used for this work was 1:2:4 (M15 grade). The proportions of cement to ash in the concrete were 100:0%, 95:5%, 90:10%,85:15%,80:20%,75:25% and 70:30%, respectively. The concrete materials cement, sand, chippings, and ground nut shell ash were mixed by hand with a water/cement ratio of 0.6 by weight. The materials were mixed together thoroughly by string to form a uniform mass.

The moulds were cleaned with engine oil or grease to prevent the development of the bond between the mould and concrete. The freshly prepared mixed concrete was taken into mould. Each mould was filled with three layers of concrete and each layer was rammed 25 times with tamping rod. Then the concrete cubes and cylinders in the moulds were left in the open air 24 hours. For each of the cement: ash proportion, 3 cubes, 3 cylinders and 3 prisms were cast. Therefore a total 72 cubes, 72 cylinders and 72 prisms were produced for testing. Removing of the concrete cubes and cylinders from the moulds was carefully done after 24 hours of the concrete setting. Curing of the concrete cubes was done by complete immersion in a pond or tank filled with tap water only for periods of 7, 14 and 28 days respectively.

3.7. Batching information for cubes and cylinders cast

Table 6 shows the mix proportions of different mix used in this study.

4. Testing of Specimens

4.1. Compressive strength test

Before crushing, cubes were brought out of the water and kept it for about 1-2 hours for water to dry off. They were brought and then then taken to the crushing machine in according with BS 1881 (1983). Cubes get cracks due to failure in their strength as a result of the load applied to the cubes by the crushing machine; the

load on the cubes was applied at a constant rate of stress equal to 0.2 N/mm² per second. The strength was recorded to the nearest 0.2 N/mm². The compressive

strength is calculated as $F_{ck}=P/A$; where, F_{ck} is compressive strength, P is ultimate load (N) and A is the loaded area (mm²).

Table 6. Percentage replacement with different proportions of materials.

Percentage of GNSA	GNSA (kg)	Cement (kg)	Sand (kg)	Granite (kg)	Water (litre)	Water/Cement ratio
0%	0	39.177	78.399	156.798	23.506	0.6
5%	1.953	36.918	78.399	156.798	22.321	0.6
10%	3.915	35.254	78.399	156.798	21.153	0.6
15%	5.557	33.232	78.399	156.798	19.935	0.6
20%	7.835	31.34	78.399	156.798	18.798	0.6
25%	9.72	29.358	78.399	156.798	17.61	0.6
30%	11.708	27.328	78.399	156.798	16.426	0.6
35%	13.775	25.39	78.399	156.798	15.26	0.6

4.2. Split tensile strength test

After the specimen had been cured for 7, 14 and 28 days in the water tank, the specimens were taken out from water and allowed dry for 1-2 hours. This test was carried out by placing the specimens horizontally between the loading surface of a testing machine and the load is applied until the cylinder gets failure.

Split tensile strength test was calculated as $=2P/\pi DL$.

4.3. Flexural strength test

Flexural strength is also called bend strength. Flexural strength specimen is in rectangular shape. After the specimen had been cured for 7, 14 and 28 days in the water tank, the specimens were taken out from water and allowed dry for 1-2 hours. This test is carried out by placing the specimens under a load in a three point bending or four-point bending. Flexural strength test was calculated as:

For three point bending is $\sigma = 3FL/2bd^2$;

For four point bending strength $\sigma = 3FL/4bd^2$;

where, F is the load, L is the length of the support span, B is width, D is the thickness.

4.4. Slump test

Slump test was carried out to determine the workability of the concrete mix prepared in the lab during the progress of the work. This test was carried out in different percentages to check the uniform quality of concrete during mixing. Generally, this test used to find the workability which indicates water- cement ratio but there are various factors including properties of materials, mixing, methods, admixtures etc. also affect the slump value. The slump cone was placed on a flat non-porous surface and held down by foot. The mould was then filled in three layers. Each layer was compacted. After the third layer had been tamped, the slump cone was immediately removed by raising it vertically. The height of the slump

cone was determined by taking measurement from the top of the slump cone to the top of the concrete. The slump was measured as the difference between the height of the cone and the height of the slump concrete.

5. Results and Discussions

5.1. Compressive strength

The results of the compressive strength test carried out are shown in the Fig. 1 below. It shows that compressive strength increases with the increase of cubes curing and decreases when the percentage of ground nut shells ash increases. At 0% ash and 100% cement that served as the control, compressive strength increases from 13.65 N/mm² at 7 days to 17.35 N/mm² at 28 days.

Compressive strength of 90:10% cement /ash increases from 15.6 N/mm² at 7 days to 23.15 N/mm² at 28 days. The compressive strength for 35% ash replacement were 5.9 N/mm², 7.52 N/mm² and 8.92 N/mm² for 7, 14, and 28 days, respectively

According to BS 8110, a grade 15 concrete of 1:2:4 without any mixing with cement should have acquired strength of 13.65 N/mm² within 7 days of wet curing; 17.35 N/mm² within 28 days. Based on the result obtained from this reported work, OPC/GASH of 90:10% would be suitable for concrete. The results shows that their strength improves with time since pozzolanas react more slowly than cement due to variation in their constituent's composition.

The pattern of this study was similar to Alabandan et al. (2006), Sideris and Sarva (2001), Sengul et al. (2005); they reported that cement blended with pozzolanas would produce 65 to 95 % strength of OPC concrete in 28 days. As previously described by Bengtsson and Whilken (1986), Nwofor and Sule (2012); a percentage replacement of 10% with GSA will be adequate for good concrete work.

5.2. Split tensile strength

The result below shows that split tensile strength for the 100:0% cement/ground nut shell ash is 1.8 N/mm², 2.1 N/mm² and 2.7 N/mm² for 7, 14 and 28 days, respectively while it was for 90:10% cement/ground nut shell ash is 2 N/mm², 2.6N/mm² and 3 N/mm² for 7, 14 and 28 days. The result shows that 10% of ground nut ash replacement gives the better result when compared to other replacement. The split tensile strength increase as the age of the concrete increase as shown in Fig. 2.

5.3. Flexural strength

The result below shows that flexural strength for the 100:0% cement/ground nut shell ash is 6.00 N/mm², 6.5

N/mm² and 7.5N/mm² for 7, 14 and 28 days, respectively while it was for 85:15% cement/ground nut shell ash is 6.2N/mm², 6.9N/mm² and 7.5 N/mm² for 7, 14 and 28 days.

The result in Fig. 3 show that 15% of ground nut ash replacement gives the better result when compared to other replacement.

5.4. Slump Test

Slump test is used to find the improper mixed batch. It measures the consistency of fresh concrete before its set.

The inner portion of the mould and its base should be moistened at the beginning of every test. The slump value is indicated in Fig. 4.

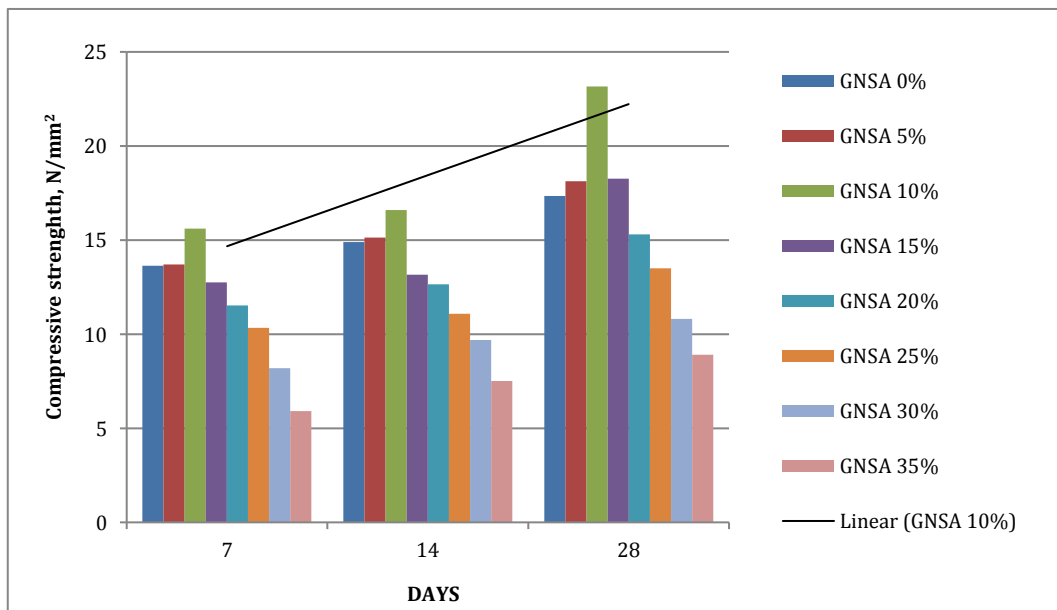


Fig. 1. Compressive strength for all percentages.

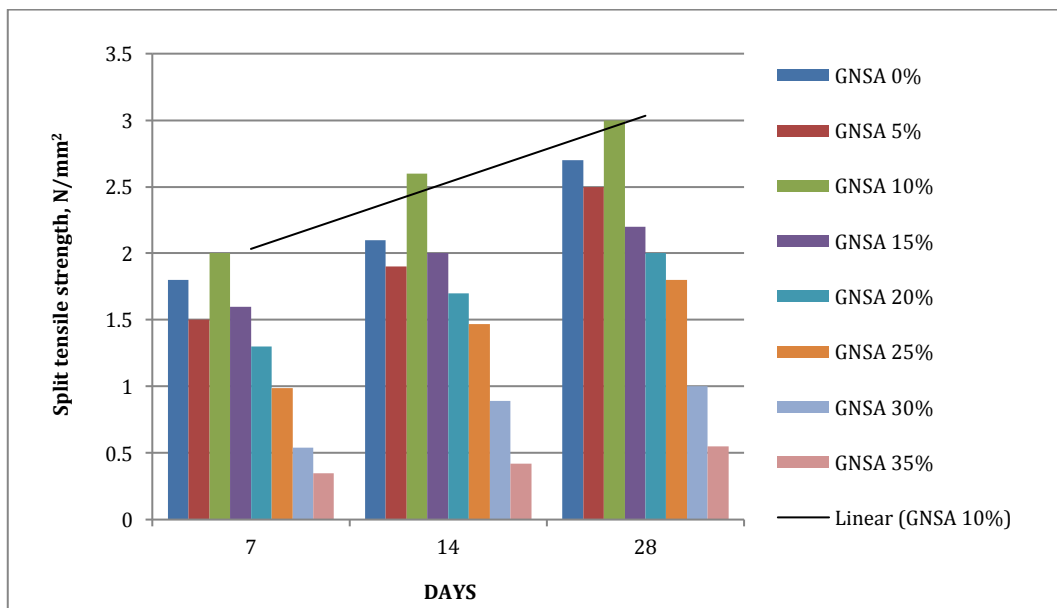


Fig. 2. Split tensile strength for all percentage replacement.

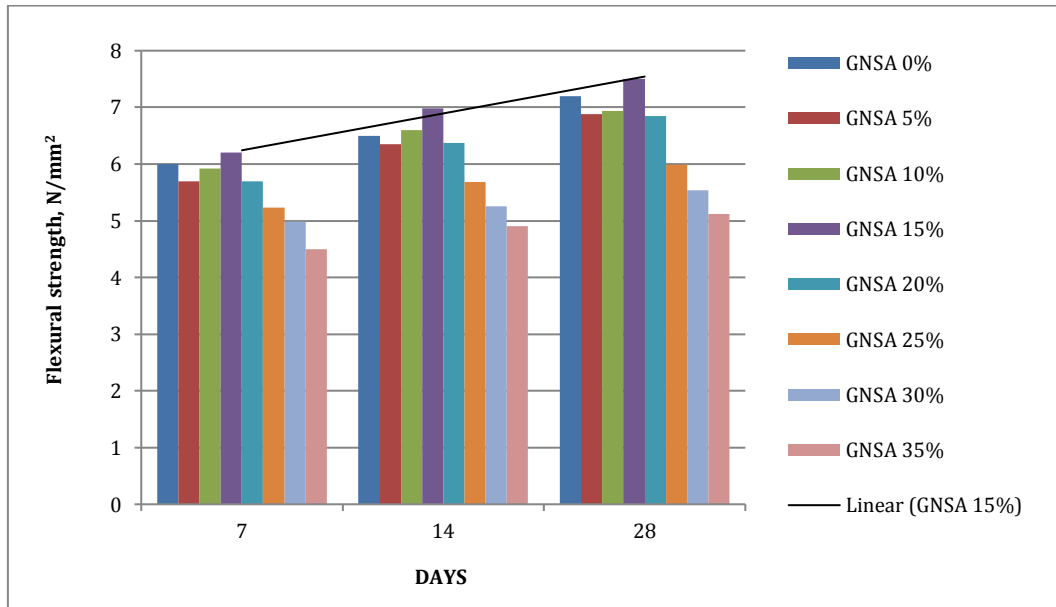


Fig. 3. Flexural strength for all percentages.

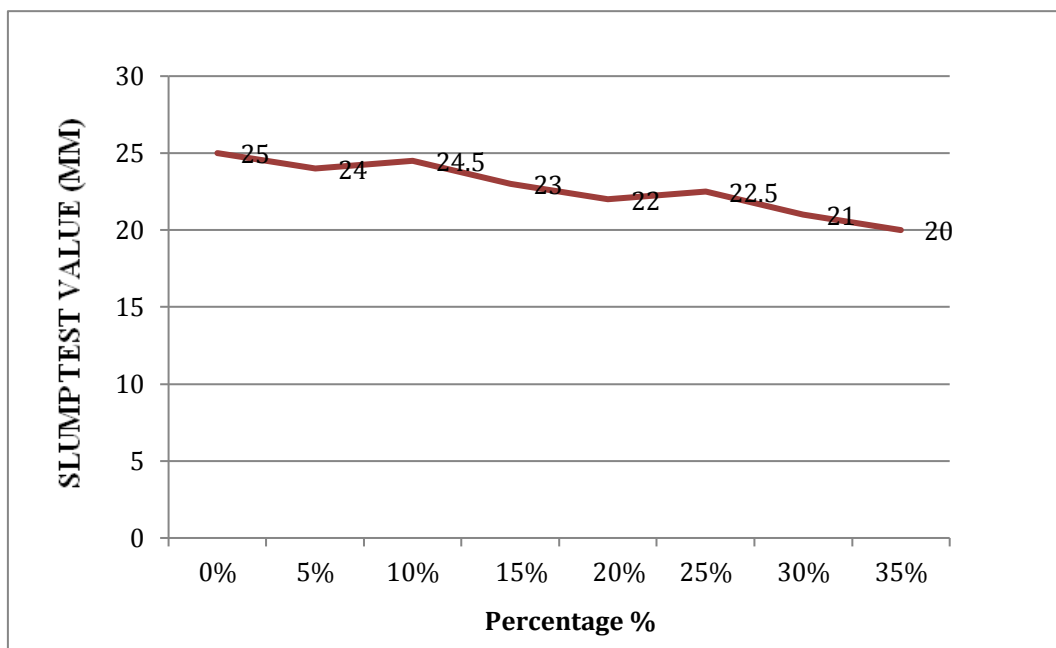


Fig. 4. Slump test values for different percentages.

6. Conclusions

Based on experimental investigations by considering the compressive strength, split tensile strength and flexural strength of concrete, the following observations are made:

- The compressive strength of concrete is increases when the replacement of Cement with groundnut shell ash up to 10% replaces by weight of Cement.
- The split tensile strength of concrete is increases when the replacement of Cement with groundnut shell ash up to 10% replaces by weight of Cement
- The flexural strength of concrete is increases when the replacement of Cement with groundnut shell ash up to 15% replaces by weight of Cement.
- When W/C ratio is increased respectively, compressive strength, spilt tensile strength and flexural strength of concrete is increased.
- Groundnut shell ash is a better innovative supplementary cementations' construction material which is used in concrete, so it can save the agriculture waste disposal costs and produce a greener concrete for construction.
- This research concludes that groundnut shell ash can be innovative supplementary cementations' Construction Material in Concrete but judicious decisions are to be taken by engineers.

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Challenge Journal

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Case Study

Effectiveness of crack repairing measures in Tabuk City, Saudi Arabia

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ABSTRACT

Concrete cracking and defect patterns can often indicate its causes. In this research paper, detailed description of cracks types, causes, and proper solutions is identified. The main objective of the paper is to measure the response of specialists about the probability of certain cracks causes and solutions, and to evaluate the effect of using epoxy materials in repairing concrete cracks. The present study shows that about 50% of responders indicated that cracks due to steel corrosion represent between 10-20% of building cracks. And about 80% of the responders indicated that crack due to load increasing is rarely occurred in the site. The interviewed specialists ensured that using epoxy materials are effective in solving most cracks' problems. The experimental work results show that the flexural strength of epoxy repaired samples exceeded that of original samples. And the increase in flexural strength is inversely proportioned with sample depth.

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1. Introduction

Some types of cracking indicate a structural issue, when others do not indicate any type of issue other than normal weathering. The age of the cracks should be determined before assuming any solution (Roger, 2014). There are many different causes of cracks, which can lead to different types of cracking patterns (Gwalior, 2004; Fowler, 2008). Each type of cracking pattern can be associated with a likely cause. Some cracks are a result of wear, while others are related to design or construction defects (Roberts, 2016). When a structure is overloaded to the extent not covered in safety factors, concrete may be damaged or fail. Overloading may be in shear, flexure, or tension, or may be a result of fatigue or cyclic loading. Each of these has a different cracking pattern to look for (Kashyzadeh and Kesheh, 2012).

Causes of cracks are different; some are related to corrosion in the reinforcing steel, others are occurred from freeze/thaw effects, others related to concrete shrinkage, and causes related to workmanship (Thagunna, 2014; Nama et al., 2015). Friedman conducted a study to identify the main causes of cracks in poured concrete and the proper methods to repair it (Friedman, 2007).

Several studies searched for cracks solutions. The solutions varied from preventive to curative ones. Kishor and Namesh (2014) set different measures to control cracks in structure starting from identification and inspection.

Some studies tested the effect of adding repair materials to cracks. An old study showed that the flexural strength of cracked concrete specimens repaired by epoxy injections became larger than that of the original concrete specimen (Kleinschrodt, 1989). The study of Kunieda (2001) performed experimental work for evaluating flexural failure behavior of concrete beams repaired by crack injection techniques. Four samples were prepared at different sizes. The study results showed that flexural strength of repaired samples is larger than original sample. Another study was conducted to evaluate the performance of epoxy injection repair process by preparing test samples. The study found that using low viscosity epoxy is effective in sample with cracks width <math><1/16</math> inch. They found that medium viscosity epoxy is suitable for repairing cracked slabs (NAHB Research Center, 2002).

This study aims to measure specialist's response about crack's causes and solutions. And to test the effect of using epoxy materials in repairing cracks.

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2. Concrete Crack Causes

Cracks could cause major damage to any building. It is very important to study causes of such cracks and to know the ideal methods to deal with them. As known soil and footing settlement is the major cause of cracks in buildings. Other main causes of concrete cracking are described below:

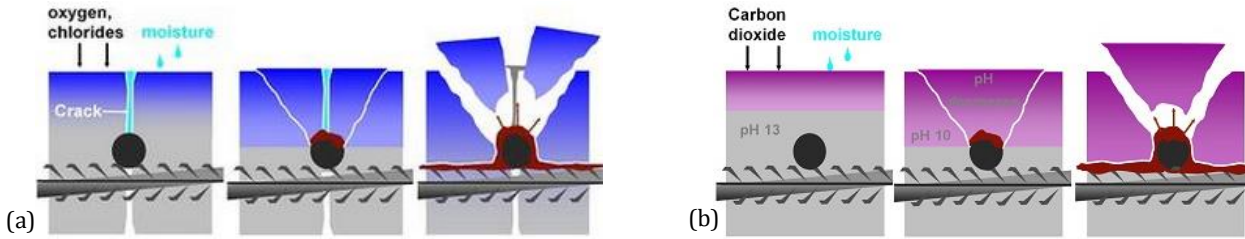


Fig. 1. (a) Corrosion due to chloride; (b) Corrosion due to carbonation.

2. Concrete shrinkage: Shrinkage in concrete could be either initial or plastic. Initial Shrinkage is normally occurs in all building materials or components that are cement based. Shrinkage of concrete and mortar occurs only at the time of manufacture, when the moisture used in the process of manufacture dries out. Plastic shrinkage occurred in freshly placed concrete. Sometimes cracks occur on the surface before concrete has set when there is relatively high amount of bleeding.
3. Concrete creep: This type of cracks normally occurred when buildings subjected to sustained load.
4. Vegetation Growth: Roots of a tree generally spread horizontally on all sides to the extent of height of the tree above the ground and when the trees are located in the vicinity of a wall, they can cause cracks in walls due to expansive action of roots growing under the foundation.
5. Sulphate attack: Soluble sulphates which are sometimes present in soil or ground water reacts with cement in the presence of moisture and form products which occupies much larger volume than the original constituents.
6. Alkali-aggregate reaction: Cement contains some alkalis. These alkalis react with certain siliceous mineral constituents of aggregate and cause expansion, cracking and disintegration of concrete.
7. Poor structural design/construction practices.

3. Study Analysis

The study aims to measure the response of specialists about the probability of certain cracks causes, and to identify the proper solutions for each cause from the responder’s opinions based on a questionnaire distributed to them. The questionnaire was divided into two parts. The first part is related to different causes of building cracks. The second part introduces their opinions about the appropriate solutions for each cause. The questionnaires were distributed in the several engineering design and consultation offices in the city.

1. Concrete reinforcement corrosion: concrete provides good protection to steel. This protection depends upon the quality of concrete, depth of concrete cover, and workmanship. When the reinforcement steel gets corroded, it increases in volume with setting up of internal stress in the concrete. There are two major causes of corrosion in the reinforcing steel: chloride penetration and carbonation (Fig. 1).

The following equation was used to estimate number of interviewed specialists (since standard deviation is not known).

$$N = p * q * \left(\frac{z_{\alpha/2}}{d}\right)^2, \tag{1}$$

where: p is the proportion of interviewed specialists who suggested solving cracks with epoxy; q is the proportion of interviewed specialists who suggested solving cracks with other than epoxy.

To have the largest sample size; (p) is considered as 0.5. Confidence level is considered as 90% so $Z_{\alpha/2}$ equal to 1.645 and permitted error (d) as ± 0.1 , the sample size was found as 70 specialists.

4. Observations

The statistics from the observed data show their response about the cracks causes include: concrete shrinkage, steel corrosion, sulfate salts, increasing load, inadequate steel, defects in concrete, displacement in columns, stress on concrete, column overload, increasing in tile dimension, and bending strain. Their responses were measured on a subject scale with the probability of certain cracks causes’ occurring. The study statistics and observations are shown in Table 1.

Table 1. Cracks due to concrete shrinkage.

Responders Answer	Occurrence Percentage
29%	Less than 10%
34 %	10 -20%
30%	20 – 50%
7 %	More than 50%

From Table 1, it is appeared that the opinions of responders varied about percentage of crack occurrence due to concrete shrinkage. This may indicate that such

crack appear in many concrete structures. Fig. 2 below show that about 50% of responders indicated that crack occurrence due to corrosion of steel represent between 10-20% of building cracks.

Table 2 below showed that about 80% of the responders indicate that cracks occurrence due to increasing load is rarely occurred in the site.

Fig. 3 below showed that the opinions of responders vary about percentage of crack occurrence due to inadequate steel. This may indicate that such crack appear in many concrete structures.

Table 3 below showed that interviewers respond were not clear regarding the presence of defective materials in concrete as a cause of cracks. This may indicate that such cause is related to the material used in concrete in each region.

The interviewers were asked about the best solution for the above mentioned cracks causes. Their response is restricted in using special epoxy materials to solve the cracks problems. They mentioned that method is widely used because it is cost-effective since it does not need to replace the existing structure. While they indicated several preventive solutions as summarized below (it is important to know that these are the opinions of the interviewed specialists).

1. Use sulfate-resistant cement with clean raw materials and clean water is the best solution to avoid cracks due to concrete sulfate salts.
2. Good compaction of concrete, concrete water treatment, and hydration for a period not less than 7 days

is the best solution to avoid cracks due to concrete shrinkage.

3. Removing all impurities and clean the steel from rusting with isolate epoxy is the best solution for cracks due to steel corrosion.
4. Following design standards (loads, steel, and stirrups) is the best solution to avoid cracks due to design problem (increasing load or increasing slab dimension, column overload).

Table 2. Cracks due to increasing loads.

Responders Answer	Occurrence Percentage
41%	Less than 10%
39%	10 – 20%
14%	20 – 50%
6%	More than 50%

Table 3. Cracks due to the presence of defective materials in concrete.

Responders Answer	Occurrence percentage
38%	Less than 10%
33%	10 – 20%
26%	20 – 50%
3%	More than 50%

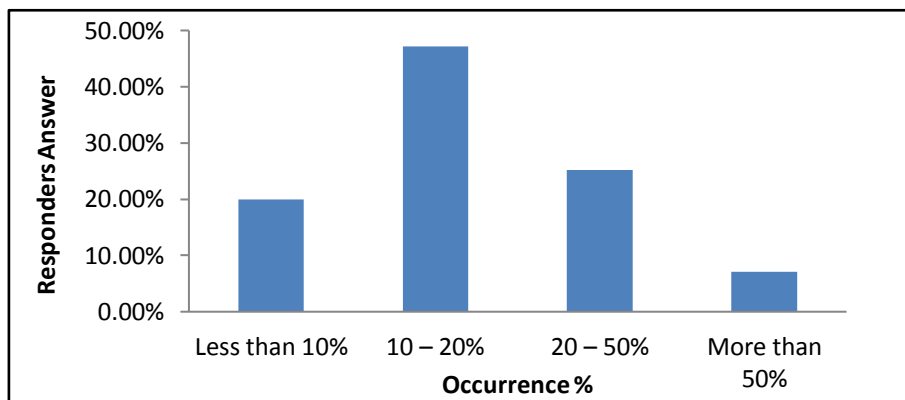


Fig. 2. Cracks due to steel corrosion.

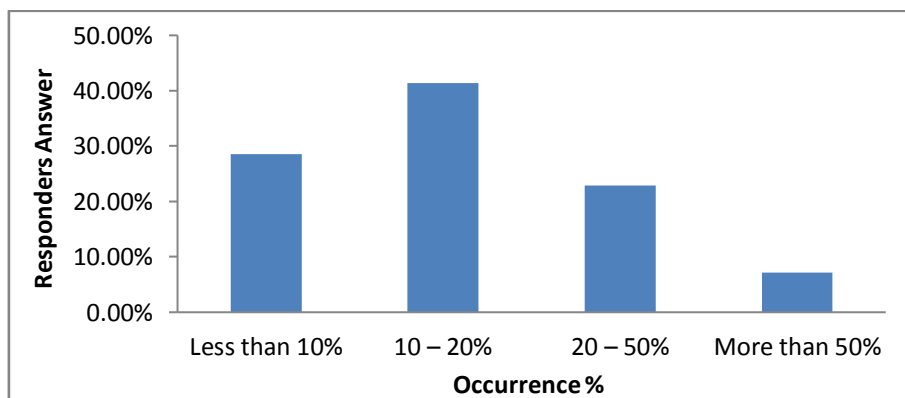


Fig. 3. Cracks due to increased shear stress (inadequate steel).

5. Experimental Work

Crack injection is a common technique for repairing damaged concrete structures. Several methods were used in testing and analyzing repair schemes. An ordi-

nary concrete mixture was prepared with 0.45 water cement ratio and 15mm maximum aggregate size. Four concrete samples were prepared having 10cm and 20cm depth. A surface crack was made approximate 2mm width with 1/10 depth of each sample as shown in Fig. 4.

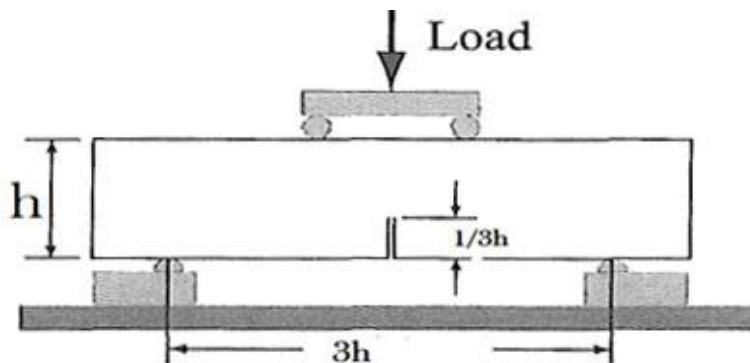


Fig. 4. Test setup for concrete samples.

Other two samples were cured using (Concure WB) crack repairing epoxy. This type of epoxy is based on a low viscosity wax emulsion. It applied to retain moisture in concrete for effective curing to reduce permeability, avoid surface cracks, reduce shrinkage, and improve durability. The use of Concure WB complies with BS 8110, ASTM C309 and ASSHTO M148. Concure WB was applied to the surface of the concrete samples immediately after de-molding. Samples were tested at 7 days concrete age. The test results of flexural strength are summarized in Table 4.

Table 4. Flexural strength test results (kg/cm²).

Increased Percentage	Repaired Samples	Original Samples	Sample Depth (cm)
3.6	98.5	95	10
1.3	101.8	100.5	20

It is appeared from table that the flexural strength of repaired samples exceeded that of original samples. It also appeared that the increase in flexural strength between original and repaired samples is inversely proportioned with sample depth. As discussed above, most of the experiments found that using epoxy injection is valuable in cracks curing. This conclusion is complying with other old studies' results, and with the responder's solution to repair cracks in building.

6. Conclusions

Building stability may be affected by serious types of cracks. Due to construction faults and other unavoidable reasons, different type of cracks starts to appear on various building. Some types of cracks need attention as they are structurally hazardous. In this paper, the response of specialists about the probability of certain types of cracks was measured. The study results showed that about 50% of responders indicated that cracks due

to steel corrosion represent between 10-20% of building cracks. It is also appeared that about 80% of the responders indicate that crack due to load increasing is rarely occurred in the site.

Several solutions for cracks were suggested with different assumed preventative measures such as using sulfate-resistant cement, good compaction of concrete, steel cleaning, and following design standards. Such measures will help construction companies, consultant, and designers to avoid cracking problems. It is concluded that the causes of crack can be controlled if proper consideration is given to construction material and technique to be used. The experimental work on cracks was compatible with the study observations. It found that using epoxy is suitable for repairing cracked elements. And that the flexural strength of repaired samples exceeded that of original samples.

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