PROPERTIES AND STRUCTURAL BEHAVIOR

OF Reinforced Concrete Slabs

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ABSTRACT

The main objective of this research is to investigate the properties of fresh and hardened made from local materials as well as its structural behavior. The experimental program consisted of casting and testing of Totally three RC slab specimens with cross-sectional dimension of (800X800 X95) mmwere tested. thesis investigated the influence of type of concrete (NC) and compressive strength (30, 50 and 62 MPa) were designed to fail in punching shear of slabs and on the punching shear of slabs geometrically similar slabs .Results shows the punching shear capacity of the slabs increase with increasing of compressive strength . However, for slabs failed in punching shear, NC slabs having f_c' of about 32, 48 and 62 Mpa exhibited 9.3%, 15.5% and 25% higher flexural cracking load respectively.

Keywords: Ultimate Loads, Compressive Strength ,Deflection, .

1.Introduction

Concrete slabs are considered to be an important structural elements in reinforced concrete structures because they support the structure and transfer the loads to the columns or walls , so any failure or damage occurs in the slab may cause a partial failure of the structure . Differences between the hardened properties of normal concrete may be attributed to the modified mix composition as mentioned before, the better microstructure and homogeneity . The properties of NC concrete in hardened state and also the possible differences in comparison with common concrete are described in the following articles .The type and properties of filler play an important role in the development of strength with time [1,2,3], but there are some researchers indicated that the strength development of SCC and NC over a period of time is also similar[4,5]. The punching shear strength in a flat slab depends on the slab geometry, loaded area, slab thickness, concrete strength and amount of reinforcement (either flexural or punching shear reinforcement). The transferred moments between the slab and the column, the slab particularities (e.g.: openings), and the position of the column (centre, edge or corner) influence the punching shear force as well [3]. Generally the compressive strength of concrete has a large influence on the punching shear strength and behavior of flat slabs; the punching shear strength value specified in different codes vary with concrete compressive strength f_c' and is usually expressed in terms of $(f_c')^n$. In **ACI 318 -11 Code** [4] the punching shear strength is expressed as proportional to $(f_c')^{1/2}$. However in **CEB-FIP MC1990** [5] and **Eurocode 2-2004** [6] punching shear strength is assumed to be proportional to $(f_c')^{1/3}$. Moreover, as the concrete strength increases beyond (40-50 MPa), most current approaches become less conservative and even unsafe in some cases [7].This is partly because for high strength concrete, the relation between the shear resistance of a member and the strength of concrete depends upon the characteristic of the aggregate [5]. **Aziz (2010)** [8] experimental results showed that, as compressive strength of self compacting concrete (SCC) increases from 32 to 68 MPa the punching shear strength improves by 35 % and this leads to allow for higher forces to be transferred through the slab-column connection.**Aziz and Fadhil (2011)** [9] investigated experimentally the punching shear and flexural strengths of reinforced SCC concrete flat plate slabs made with Non-Rectangular (triangular and trapezoidal) shaped. It was deducted that the cracking load depends essentially on concrete strength and not on slab configuration, but the ultimate capacity depends on both, concrete strength and shape of slab. The main targets of the present investigation to assess the effect of mix proportions by using locally available materials on the hardened concrete properties (compressive strength, splitting strength, flexural strength, modulus of elasticity) of NC. To assess the effect of the difference in compressive strength on structural behavior (punching shear in slabs) of NC to compare between them at different levels of compressive strength (30, 50, and 62) MPa.

2. Experimental Program of Structural Behavior

Experimental program of structural behavior consists of casting and testing 3 specimens slabs failed in punching shear . Each of 3 specimens (NC) made with concrete mixes having cylinder compressive strength about 30, 50 and 62 MPa respectively. The mix proportions and hardened properties of these mixes are shown in Tables (1) and (2) respectively. In the other words, the main parameters in this study are type and compressive strength of concrete

Table (1): Mix proportion of NC.

Concrete type	Mix symbol	Cement (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	SP/C %by wt.
NC	NC30	350	181	700	1155	-
	NC50	450	175	675	1115	0.20
	NC62	550	159	660	1085	0.65

Table (2): Properties of hardened NC at 28 days.

Concrete type	Mix symbol	Compressive strength(MPa)		Fr (MPa)	ft (MPa)	Ec (GPa)
		Cube 150x150 Fcu	Cylinder 150x300 f_c'			
NC	NC30	39.8	32.2	4.44	٣,١٠	32.262
	NC50	56.2	48.3	5.59	3.88	35.311
	NC62	70.8	62.9	7.58	5.67	37.00

3. Casting, Curing and Test Set-up of Slabs Failed in Punching Shear

The variable was investigated in this study to show their effects on the punching shear strength of the slabs. These variable was concrete compression strength (30,50 and 62) MPa. Table (3) illustrates the properties of all the tested slabs.

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In order to study the influence of the test variables on the punching shear strength of the square slabs, three slabs were cast and tested. All the slabs were square of dimensions (800×800 × 95) mm and simply supported along the four edges with a clear span of 700 mm in each direction. A square steel column with dimensions (75×75) mm was used to apply the load in center of the slab, and the corners of the slab were carefully clamped to prevent any possibility of slab uplift. These requirements were found important which ensured a punching failure type occurring in the slab when the central load was applied. The reinforcement used were 10mm diameter deformed bars placed at a spacing of (110 mm c/c) in two directions with 760mm length, placed at the bottom face of the slab with a concrete cover of 20 mm, as shown in the Fig.(1). All molds were cleaned and their internal surfaces were oiled to prevent adhesion to concrete after hardening. Before placing concrete in the mold, reinforcement was placed near the bottom face of the slab's mold. NC was placed in the mold in three equal layers. Each layer was compacted by using electrical vibrating table for two minutes to ensure removing the entrapped air as much as possible. The specimen was then removed from the vibrating table. the concrete was poured directly into one edge of the formwork from wheelbarrow and allowed to flow along in all directions of the formwork Fig. (2). Top surface of all slabs was well finished using a steel trowel so that the upper surface of the wooden block was kept level with the concrete surface. The slabs were covered with a damp canvas and Nylon sheets to prevent moisture loss and after 7 days from casting, the specimen was demolded and placed in the lab without any curing until the time of testing.

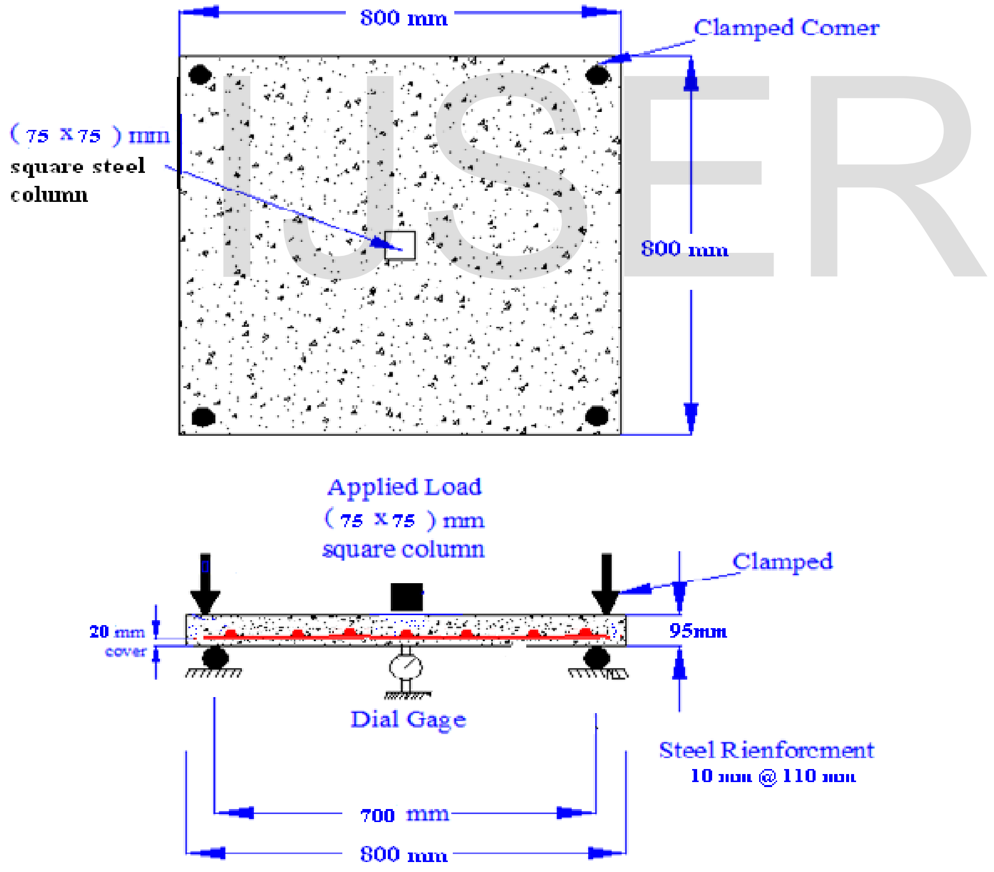

Figure (1): Details of the slab specimen.

Before the testing day, the slab was cleaned and painted with white paint on both surfaces, to achieve clear visibility of cracks during testing. The slab was labeled and carefully placed along the edges on simple supports. The point load was applied at the center of the top surface of the slab and the dial gauge was positioned under the center of the bottom surface of the slab, so that a precise set-up of the testing equipment was achieved.

A special supporting frame was manufactured and used inside the testing machine, as shown in Fig.(3) to provide the required span of the slab. This supporting frame was made using four steel beams welded and arranged to form a square shape. Each of these four steel beams had a 25 mm dia. steel bars are welded on its top face to provide a simple support for the slab edge.

All slabs were tested using a hydraulic universal testing machine (Torsee's Universal Testing machine with a capacity of 2000 kN) as shown inFig.(4). The load was applied gradually in increments of 10 kN.This amount of incremental loading allowed sufficient number of loads and corresponding deflections to be taken during the test which gave a good picture for the structural behavior of the slab. The load at first crack as well as the ultimate punching shear load with their corresponding deflections at the slab center were observed and recorded.

Fig. (2): Casting of slabs.

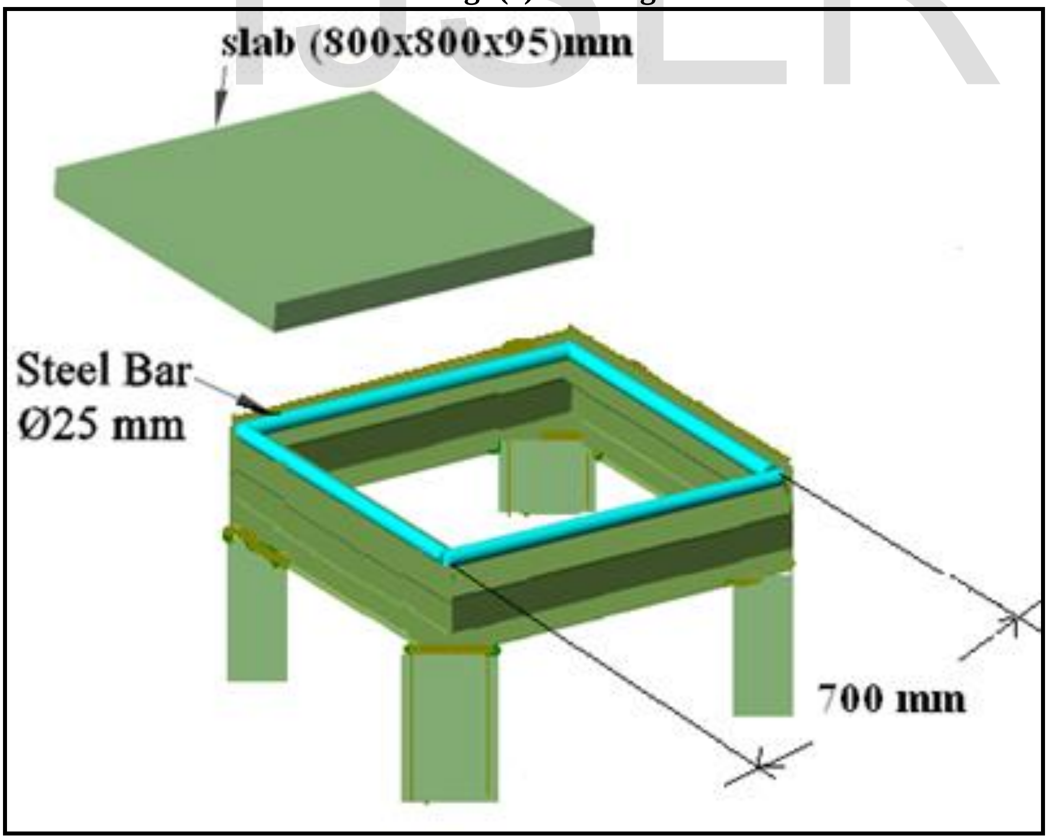

Figure (3): Supporting slab frame.

Fig. (4): Test set-up of slabs.

4. MATERIALS

4.1 Cement

Ordinary Portland cement manufactured by falcon cement, used in this study. The physical properties and the chemical analysis test results for the cement used are given in tables (3) and (4) respectively. They comply with the Iraqi specification number (5/1984) [10].

Table (3) :Physical properties of cement.

Physical property*	Test results	Limit of I.Q.S No. 5/1984
Specific surface area (Blaine method), m2/kg	315	230 (Min.)
Setting time (Vicat apparatus), hr:min Initial Final	2:20 4:30	00:45 (Min.) 10:00 (Max.)
Compressive strength (70.7mm cube), MPa 3-day 7-day	17 26	15 (Min.) 23 (Min.)

* construction materials laboratory of the College of Engineering , Basrah University.

Table (4): Chemical analysis and main compounds of cement .

Chemical analysis*	Percentage, by weight	Limit of I.Q.S No.5/1984
(CaO)	62.83	
(SiO_2)	20.5	
(Al_2O_3)	6.36	
(Fe_2O_3)	3.4	
(MgO)	4.47	5.00 (Max.)
(SO_3)	2.00	2.80 (Max.)
(K_2O)	0.61	

(Na2O)	0.23	
(L.O.I)	0.73	4.00 (Max.)
(I.R)	0.58	1.50 (Max.)
(L.S.F)	0.91	0.66-1.02
Main compounds (Bogues equations)		
C3S	40.9	
C2S	27.91	
C3A	11.18	
C4AF	10.35	

*Chemical testing laboratory in the College of Engineering University of Basrah

4.2Fine Aggregate (Sand)

Natural sand from Zubair area in Basrah city was used as fine aggregate for concrete mixes in this study. The fine aggregate was sieved at sieve size (4.75mm) to separate the aggregate particle of diameter greater than (4.75mm). The sand was then washed and cleaned with water several times, later it was spread out and left to dry in air, after which it was ready for use. The grading test results of the fine aggregate is shown in table (5). The obtained results indicated that the fine aggregate grading and the sulfate content were within the limits of Iraqi specification No. 45/1984 [11]. Table (6) shows the properties of sand used which include the specific gravity, sulfate content, absorption, and bulk density(of the fine aggregate).

Table (5): Grading of fine aggregate.

No.	Sieve size (mm)	Passing (%) fine aggregate	Passing (%) Iraqi specification 45/1984 for zone No.(2)
1	4.75	100	90-100
2	2.36	78	75-100
3	1.18	64	55-90
4	0.6	48	35-59
5	0.3	20	8-30
6	0.15	2	0-10

Table (6): Properties of the fine aggregate.

Physical properties*	Test results	Iraqi specification. 45/1984 for zone No.(2)
Specific gravity	2.65	-
Sulfate content	0.3 %	Not more than 0.5%
Absorption	1 %	-
Bulk density(kg/m3)	1560	-

*Physical testing laboratory in the College of Engineering University of Basrah

4.3 Coarse Aggregate(Gravel):

Crushed gravel of maximum size (10 mm) from Jabal Sanam region in Basrah city is used. Table (7) shows the grading of this aggregate, which conforms to the Iraqi specification No.45/1984[11].Table (8) shows the properties of the coarse aggregate.

Table (7): Grading of coarse aggregate

Sieve Size (mm)	%Passing by weight	Limits of the Iraqi specification No.45/1984
20	100	100-95
14	82	-
10	41	30-60
5	2	0-10
2.36	1	-

Table (8): Properties of coarse aggregate

Physical properties	Test result	Limit of Iraqi specification No.45/1984
Specific gravity	2.60	-
Sulfate content	0.0 61%	0.1% (max)
Absorption	0.75%	-

*Physical testing laboratory in the College of Engineering University of Basrah

4.4 Water

Tap water was used in this work for both making and curing the specimens.

4.5 Steel Reinforcement

Ukrainian steel reinforcing deformed bars of 12and 20 mm diameter were used for the longitudinal reinforcement and 10 mm diameter deformed bars were used for stirrups. Three tensile specimens of each size of bars were tested. Test results indicated that the bars conformed to the ASTM A615/A615M-04b[12]. The properties of reinforcing bars are presented in table (9).

Table (9):Properties of reinforcing bars.

Bar size (mm)	Test results		
	Yield stress (N/mm2)	Ultimate Strength (N/mm2)	Elongation (%)
10	500	650	14

4.6 High Range Water Reducing Admixture (Superplasticizer S.P.)

A high performance concrete superplasticizer (also named High Range Water Reduction Agent HRWRA) based on polycarboxylic technology, which is known commercially as Glenium 51, is used in this study.Glenium 51 has been primarily developed for applications in the premixed and precast concrete industries where the highest durability and performance is required. Glenium 51 is free from chlorides and complies with ASTM C494 type a[13]. Table (10) shows the properties of Glenium 51.

Table (10): Properties of Glenium51.

Form	Viscous Liquid
Commercial name	Glenium 51
Chemical composition	Sulphonated melamine and naphthaline formaldehyde condensates
Subsidiary effect	Increased early and ultimate compressive strength
Form	Viscous liquid
Color	Light brown
Relative density	1.1 gm/cm3at 20 oC
pH	6.6
Viscosity	128 ± 30 cps @ 20º C
Transport	Not classified as dangerous
Labeling	No hazard label required
Chloride content	None

5. Test Procedure

All tests were carried out initially under the condition of load control of 10 kN increments, which was then reduced to 5kN close to the ultimate load. The same test procedure was followed for all beams. Also, to insure good seating of the beams and to overcome any problems that may appear during loading process, the beams were subjected to small loading before the test was started. Then the load was applied step-by-step to the beam at rate of 10 kN per step. At the end of each loading step, observations and measurements were recorded for the midspan deflection, strain gage readings, crack width, and crack development and propagation on the beam surface. The cracks were outlined by a thick marker pen. Also the first crack load was recorded. The positions of the visual cracks the loads, at which they are formed, were recorded. Figure (3) shows the test procedure.

6.Slabs Designed to Fail in Punching Shear

This includes the experimental evaluation of the punching shear capacity of three conventional concrete slabs(NC30, NC50, NC62). The main variables considered in these slabs was: compressive strength of concrete. For each slab, the first cracking and ultimate load capacity are presented in Table (11). The size and angle of the failure zone and crack pattern were investigated.

6.1 General Behavior of Slabs under Loading

The general behavior (crack pattern and failure mechanism) of NC slabs was all nearly identical, When the load was applied to the slab specimen, the first visible crack (bending cracks) was observed at the tension face of the tested slab at load level equal to (23.5-27.7)% of the ultimate load. In all slabs, cracking on the tensile face began near the center and radiated towards the edges (semi- random phenomena). As the load was increased the cracking propagated to the opposite face. At higher loads, the already formed cracks get widened while new cracks started to form. The new formed cracks were roughly semi-circular or elliptical in shape and occurred in the tension surface of the slab. Failure of the slab occurred when the cone of failure radiating outward from the point of load application pushed up through the slab body (brittle failure with limited warning). At failure, the slab was no longer capable of taking additional load.No cracks were observed in the compression face of any slab, except those which were observed around the loaded area at failure, which were almost the same as that of the loading plate dimensions. Figures (5) to (7) show the crack pattern in the top and bottom faces of all tested slabs.

Table (11): Deflection characteristics at first crack and ultimate loads of NC slabs.

Slab	First cracking load, P_{cr}. (kN)	Ultimate load, P_u. (kN)	Deflection at P_{cr} (mm)	Deflection at P_u (mm)	P_{cr}/P_u %
NC30	32	124.0	0.65	5.7	25.8
NC50	36	130.0	0.59	5.8	27.7
NC62	40	170.0	0.7	6	23.5

Figure (5): Punching shear failure and crack patterns of slab NC30.

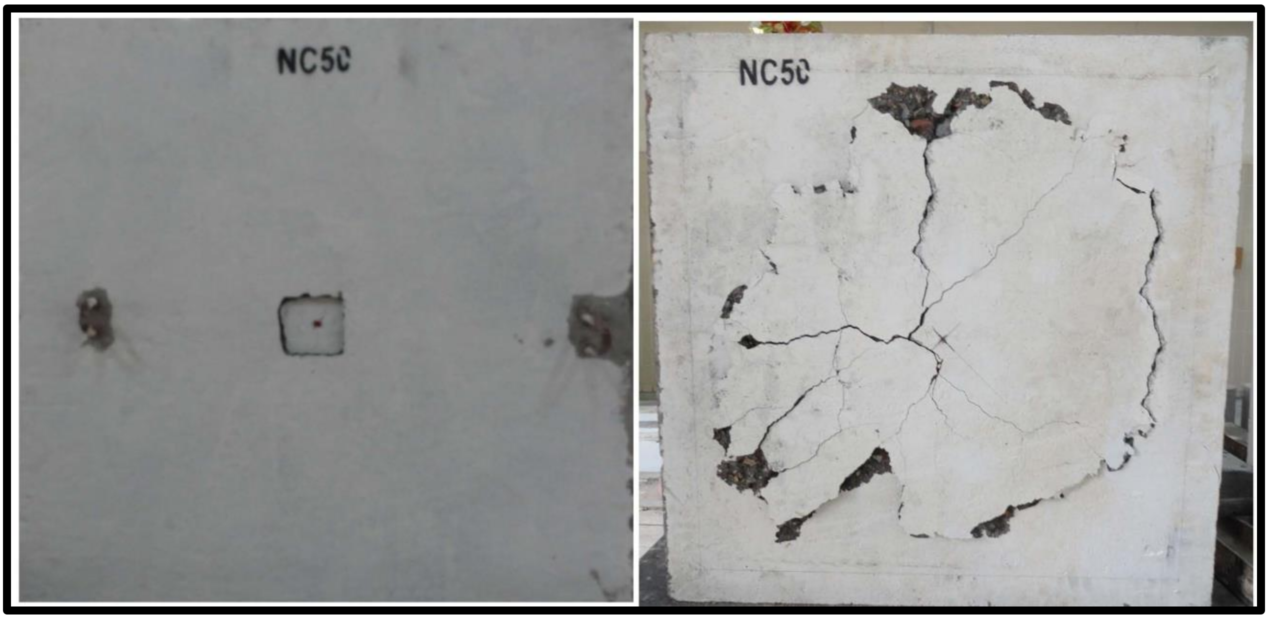

Figure (6): Punching shear failure and crack patterns of slab NC50.

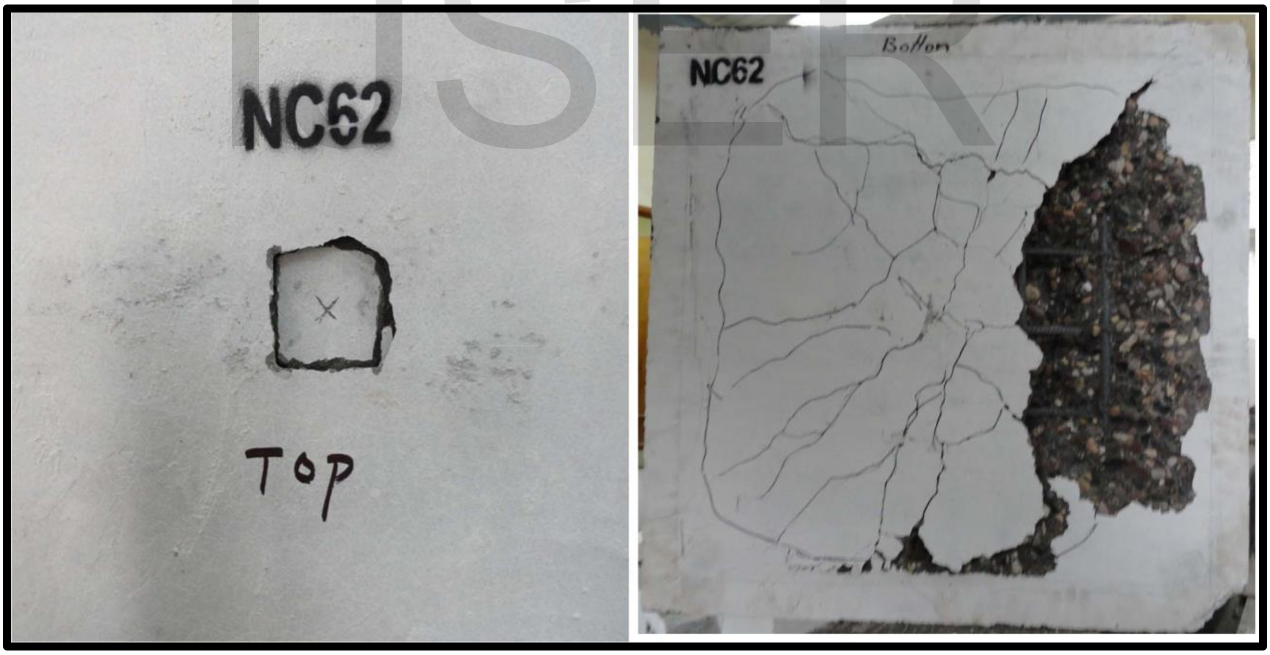

Figure (7): Punching shear failure and crack patterns of slab NC62.

<u>**6.2 Cracking and Ultimate Load**</u>

The experimentally obtained first cracking load and ultimate load have shown that an increase with increasing of fc' in the both types of concrete (NC), the observed first cracking load of all tested slabs was approximately (27.7 %) of the ultimate load, as shown in Table (11). In NC group, slab (NC50) exhibited (12.5%) higher first cracking load than slab (NC 30), slab (NC62) showed (25%) higher first cracking load than slab (NC30). The ultimate load of slabs (NC50) and (NC62) was higher than that of slab (NC30) by 4.8% and 37%, respectively. While the increasing in the ultimate load was19%, 21.5%, and 11.25% respectively.

6.3 Load-deflection Response

Figure (8) traces typical experimental load-deflection characteristics of all slabs. In the first stages of loading, the deflection of NC. But, beyond the first cracking load, the deflection of NC slabs was approximately similar with the increment in load. As expected, the slabs were capable of undergoing a significant amount of deformation prior to failure, which approximately equals to (L/116, L/92, L/78, L/122, L/120, and L/117) for slabs (NC30), (NC50), and (NC62), respectively(where L is clear span of the slab). The increase in compressive strength (fc') leads to decrease in deflection values at each stage of loading, this can be justified from the relatively large deflection of the lower compressive strength concrete as shown in Fig.(8).

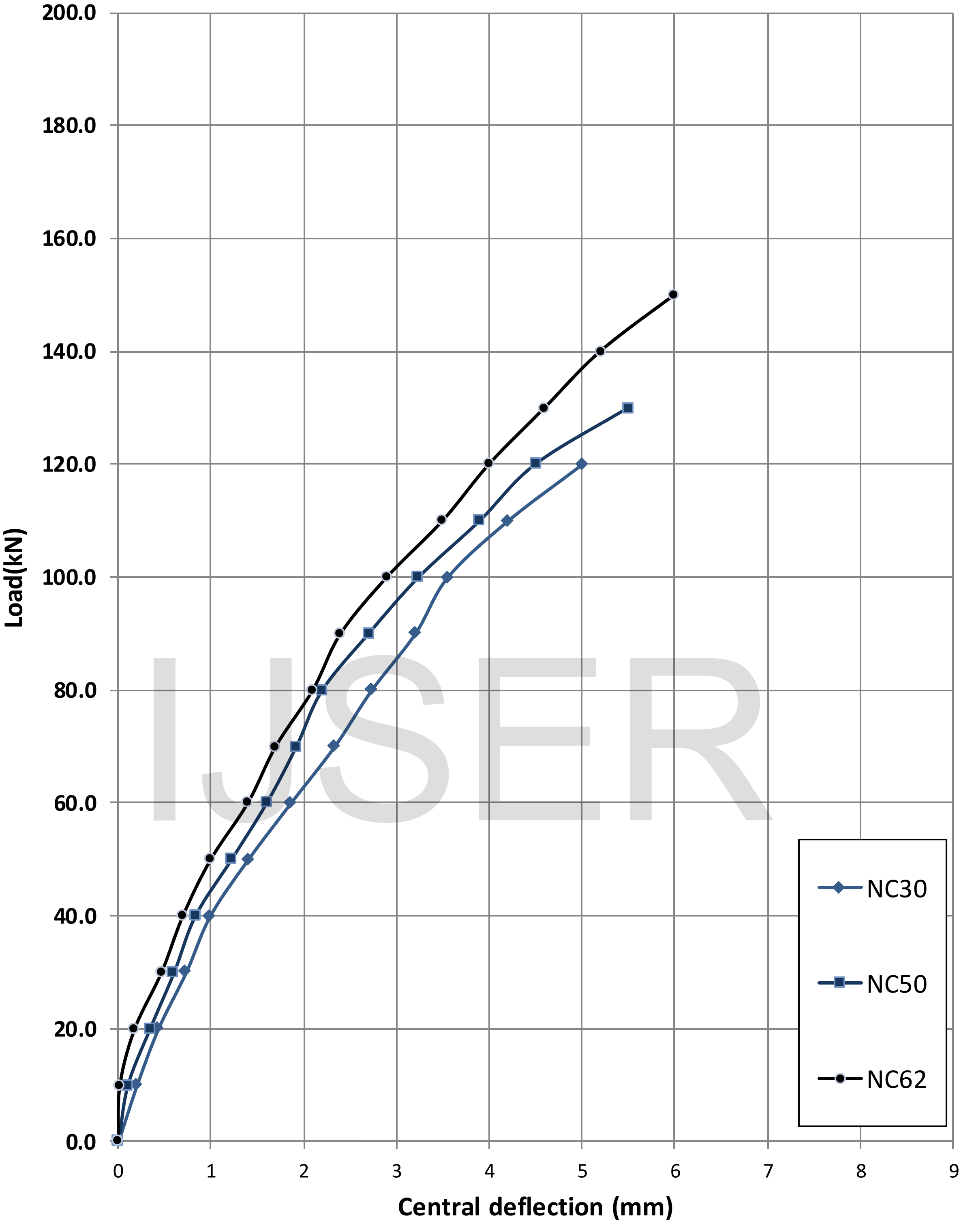

Figure (8): Comparison of load - central deflection curves for all slabs.

7. CONCLUSIONS

The following conclusions can be drawn on the basis of

present study:

1. It was found the increase in percentage of compressive strength from 30 ,50and 62 for slabs concrete at 28 days to the causes increases in the in compressive strength, flexural strength, splitting and modulus of elasticity .

2. The increase in percentage of compressive strength leads to better punching shear performance..

3. With the increase in percentage of compressive strength the ultimate deflection was found to be decreased.

4.For slabs failed in punching shear, NC slabs having fc' of about 30, 50 and 62 Mpa exhibited flexural cracking load NC slabs 9.3%, 15.5% and 25% respectively. For the ultimate load, NC slabs having fc' of about 32, 48 and 62Mpa exhibited 19%, 21.5% and 11.25% respectively.

5.The ACI 318M-11Code under-estimates moment capacity of slabs failed in shear, while for slabs, the ratio of measured to predicted punching shear strength was 1.72 for NC respectively.

6.The Eurocode 2-2004 was conservative in shear strength prediction for slabs, , the ratio of measured to predicted punching shear strength was 1.45 for NC respectively.

7.The BS8110-1997 was conservative in shear strength prediction for slabs made with NC the ratio of measured to predicted punching shear strength was 1.8 for NC respectively.

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