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FLEXURAL BEHAVIOR OF LIGHTWEIGHT AGGREGATE CONCRETE ONE-WAY SLABS

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ABSTRACT

The lightweight aggregate concrete had become a wide spectrum use at civil structures nowadays. The main aim of this research is towards evaluating the efficiency of lightweight aggregate in the structural behavior of reinforced concrete slabs. A three-dimensional finite element model suitable for the analysis of lightweight concrete one-way slabs (LWC) was used through this study. This analysis has been adopted by using the finite element principles with a system computer program (ANSYS V.17.2). The ordinary reinforced concrete and LWC slabs were modeled by 8-node isoparametric brick elements, while the steel reinforcing bars were modeled as axial members (bar elements) connecting opposite nodes in the brick elements with a full interaction assumption. In the present study, some important factors were studied by using numerical model to investigate their effect on the behavior of LWC one-way slabs. The parameters that considered were: (1) Type of lightweight aggregate (crushed brick and porcelenite); (2) Effect of different slab thickness; and (3) loading types applied. Results explained the ultimate load increasing by (17.33 %) for crushed brick concrete and decreased by (27%) for porcelenite concrete when compared with normal concrete. Using crushed brick as lightweight aggregate gives more toughness than porcelenite aggregates.

Key words: Lightweight, One-Way Slabs, Porcelenite, Crushed Brick.

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1. INTRODUCTION

Lightweight concrete is typically lighter than regular concrete by about 25-35%. Using modern design methods, lightweight concrete has been manufactured with high resistance. However, the lightweight concrete casting and finishing requires specialized attention to ensure the final product's compatibility with the design requirements and specifications. **Al-Khaiat (1997)**.

Qusai (1995) investigated properties of lightweight concrete made from local porcelenite aggregate. This study was conducted to investigate the possibility of using porcelenite rocks, widely distributed in western desert of Iraq (Trifawi desert), in the production of LWC comply with the requirements of standards specifications. A series of trial mixes experiments, which can be used as a basis for mix design of porcelecnite aggregate concrete. These relationships demonstrate the relatively higher demands of cement and water contents for this type of concrete to attain the desired workability and compressive strength.

In 1996, **Lai** produced lightweight concrete by replacing 10% of the coarse aggregate with expanded polystyrene. Practical tests have shown that modern concrete has a similar bearing strength to conventional concrete. Although the beam has been significantly skewed with polystyrene more than the corresponding beams with normal weight concrete due to the low elasticity of polystyrene.

Thiyab (2017) produced lightweight concrete using rubber tire residues. The research included a study of the effect of these residues on the properties of hardened concrete. The rubberized rubber tires replaced a percentage of the coarse aggregate. The mix was modified using Styrene Butadiene (SBR) rubber to increase the mechanical properties and durability values. The mixture can be considered as 10%, 20% and 30% as a lightweight structural structure (exceeding 17 MPa). Other mixtures can be used to produce lightweight blocks used in partitions.

In the present work, the structural behavior of lightweight reinforced concrete one way slabs using different to aggregates of locally waste materials, different slab thickness, with different applied loads are studied.

2. FINITE ELEMENT REPRESENTATION OF LWC SLABS

Finite element method has been used as a general method of stress and deformation analysis. A three dimensional solid element is an alternative way to finite element representation of the structures. These elements that are used in ANSYS program are shown in Table (1), **ANSYS (17.2)**.

Table (1): Finite element representation of structural components

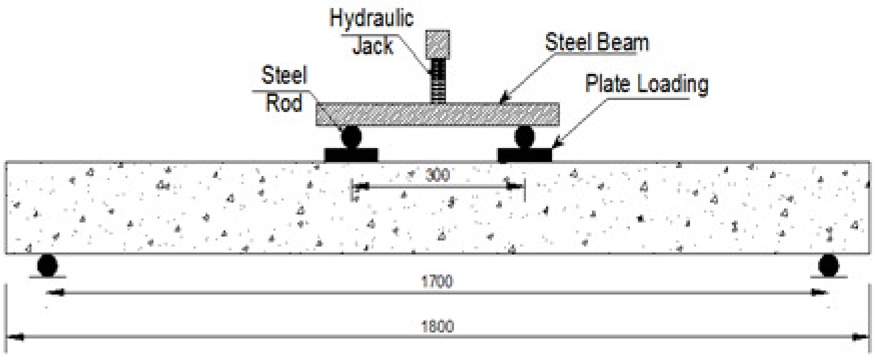
Structural component	Element designation in ANSYS
Concrete	Solid 65
Steel reinforcement	Link 180
Steel plates (at loading and supporting)	Solid 185

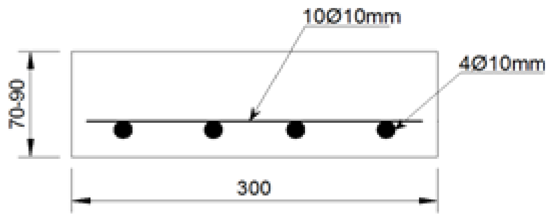
3. VERIFICATION EXAMPLES

This finite element analysis (FEA) calibration study includes modeling a concrete slab with the dimensions and properties corresponding to solid slab tested by **Abdullah (2017)**. All tested slabs were (300*1800) mm and (70 to 90) mm thickness. The yield strength of steel reinforcement is 420 MPa, and was designed to obtain a flexural failure. The overall dimensions and details of the tested slabs are shown in Figure (1). The effective span of the slabs was (1700) mm. The target of the comparison is to ensure that the elements, material properties and convergence criteria are adequate to model the response of the member and make sure that the simulation process is correct. The specimen details are indicated in Table (2).

Table (2) The specimen details.

Slab code	Longitudinal steel	Transverse steel	Thickness of slab (mm)	Compressive strength (MPa)
SN1	4Φ10mm	10Φ10mm	70	29.2
SN2	4Φ10mm	10Φ10mm	80	28.1
SN3	4Φ10mm	10Φ10mm	90	28.2





Cross Section

Figure (1): Test setup by **Abdullah (2017)**.

The mid span load was represented in the finite element model by 96 equivalent nodal forces of the slab, as shown in Figures (2 and 3).

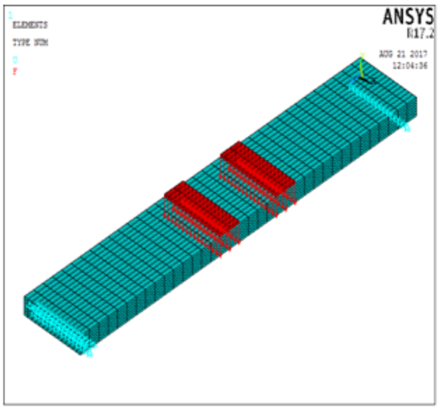


Figure (2) Finite elements mesh and load simulation for beams used in ANSYS program

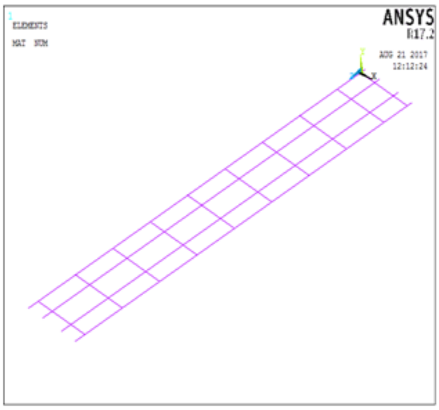


Figure (3) Internal reinforcement arrangement of tested concrete slabs.

Figures (4, 5, and 6) show the relationship between load and deflection at mid-span of slabs, for both the experimental tests and the numerical analyses. The analytical ultimate deflection and ultimate applied load are detected quite well compared with that experimentally observed for slabs (SN1, SN2, SN3) respectively. It is obvious for the Figures (6, 7, and 8) that is a good correlation between the two behavior experimental and the proposed theoretical one.

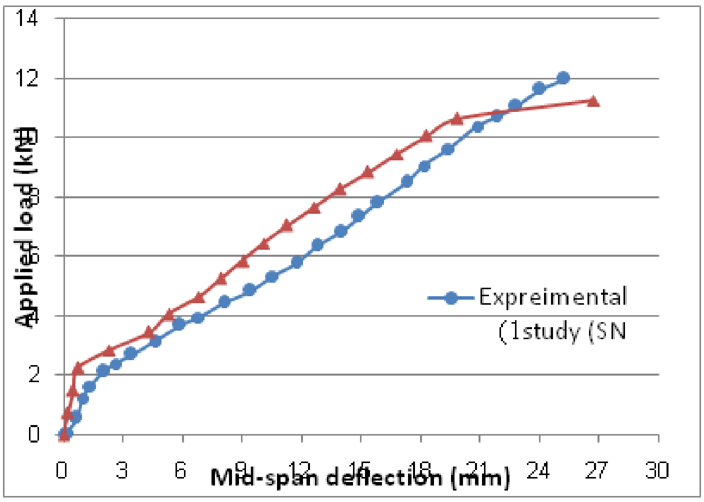


Figure (4): Load-deflection curve for normal concrete slab (SN1).

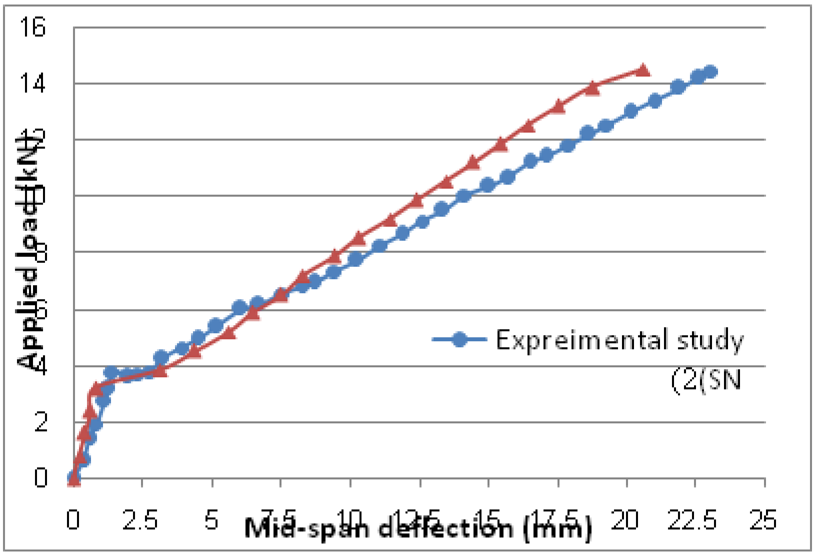


Figure (5): Load-deflection curve for normal concrete slab (SN2).

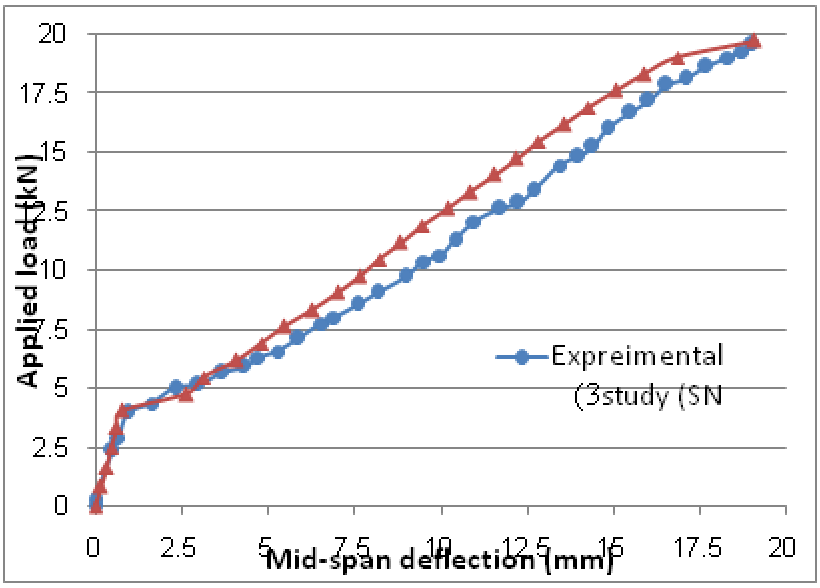


Figure (6): Load-deflection curve for normal concrete slab (SN3).

5. 5. THE PARAMETRIC STUDIES AND RESULTS

The results and data calculated from the structural test of the reinforced concrete slabs including the maximum loading capacity, toughness and ductility, with the compressive strength of each mix are established have also. Table (3) show the type of loadings applied as well, the thickness and properties of concrete slabs used through the present study were found.

6. STRUCTURAL TEST RESULTS

The structural slabs test were intended to load each slab to failure on two points loads test as fabricated experimentally by **Abdullah (2017)** with fabrication shown in Fig.(1), as well as the specimens with one point and distributed loads as described in Table (3). The deflection of the mid span were measured through the numerical analysis. These readings established Load-Deflection diagrams for each slab to help finding the maximum loading capacity and initial cracking load for each slab as shown in Table (4), As well as knowledge of the increase or improvement in ductility and toughness.

Table (3) Variables parameters studied in this research

Specimens symbols	Type of concrete	Type of course aggregate	Thickness (mm)	Type of loading	Compressive strength fc' (MPa)
SN1	Normal	Normal	70	Two point	29.2
SN2			80	Two point	28.1
SN3			90	Two point	28.2
SN4			70	One point	29.2
SN5			70	Distributed	
SB1	LW	Crushed Brick	70	Two point	37.3
SB2			80	Two point	
SB3			90	Two point	
SB4			70	One point	
SB5			70	Distributed	
SP1	LW	Porcileniate	70	Two point	17.82
SP2		Porcileniate	80	Two point	
SP3		Porcileniate	90	Two point	
SP4		Porcileniate	70	One point	
SP5		Porcileniate	70	Distributed	

Table (4) Structural reinforced concrete slabs

Symbol	Ultimate load Pu (kN)			Ultimate deflection (mm)			Initial cracking load (kN)
	Exp.	Num.	Exp. / Num.	Exp.	Num.	Exp. / Num.	
SN1	11.97	11.25	1.064	25.4	26.7	0.951	3.0
SN2	14.45	14.534	0.994	23.07	20.62	1.12	3.86
SN3	19.56	19.76	0.989	19.02	19.1	0.995	4.76
SN4	-------	10.65	-------	-------	23.59	-------	2.1
SN5	-------	19	-------	-------	25.14	-------	4.0
SB1	-------	13.2	-------	-------	25.4	-------	3.0
SB2	-------	16.53	-------	-------	21.63	-------	3.66
SB3	-------	19.17	-------	-------	18.53	-------	4.26
SB4	-------	11.25	-------	-------	24.95	-------	3.0
SB5	-------	23.45	-------	-------	31.93	-------	4.88
SP1	-------	8.25	-------	-------	24.33	-------	2.25
SP2	-------	11.6	-------	-------	23.39	-------	2.6
SP3	-------	16.78	-------	-------	25.16	-------	3.22
SP4	-------	6.9	-------	-------	23.31	-------	1.5
SP5	-------	13.75	-------	-------	28.01	-------	3.75

6.1. Effect of lightweight aggregate types

To investigate the effect of lightweight aggregate types on the behavior of one-way RC slab, three types of lightweight aggregate used in this study as shown following:

- Normal aggregate concrete testes by **Abdullah (2017).**
- Porcelenite aggregate concrete tested by **Qusai (1995).**
- Crushed brick aggregate concrete tested by **Nasser (2015**).

Previous studies have shown that the amount of modulus of elasticity decreased to 55% compared with normal concrete when using porcelenite aggregate (compression cylinder test), so that, strain at top fiber of concrete will be reached to ultimate strain at lower stresses and this led to decreasing ultimate load. Results explained the ultimate load increasing by (17.33 %) for crushed brick concrete and decreased by (27%) for porcelenite concrete when compared with normal concrete, and this increase was due to improved mechanical properties using crushed brick and silica fume. The behavior of load-deflection curves were described at Figure (9). These results indicates that using crushed brick, as lightweight aggregate was very effective in improving the toughness of the tested slabs. In addition, the change of the type of aggregate from normal to the crushed brick did not affect on the cracking load, but when using porcelenite aggregate instead of normal aggregate leads to a decrease in the cracking load to (33%) due to weak resistance of this type of aggregate.

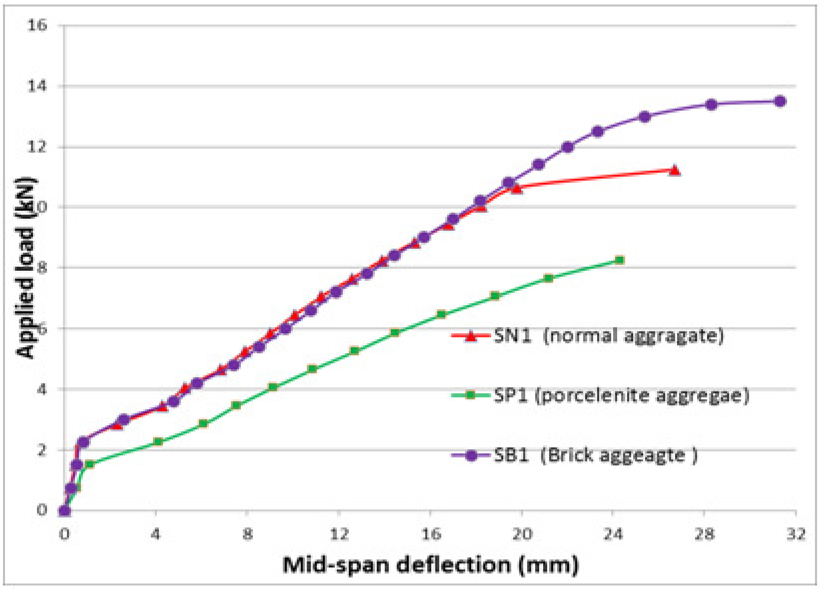


Figure (7): Load-deflection curve for slab with variables aggregate types.

6.2. Effect of slab thicknesses

For the same amount of the applied load, the decrease in the slab thickness generates a smaller moment within the shear span, this increases the flexural stresses, and in turn causes an increase in the tensile stresses on the effective-depth. In conjunction with shear stresses within shear-span, this leads to increase the principal tensile stresses, and this in turn reduces the diagonal cracking load. Three different slab thicknesses were used in LWC slabs tested to know their effect on the load-deflection curves. These values were (70, 80 and 90) mm. Figures (8, 9 and 10) show the behavior of load-deflection curves, from which it can be seen that as the slab thickness increase, the ultimate load increases by (75.64%, 97.4% and 42%) for normal concrete, porcelenite concrete and crushed brick concrete respectively. Figure (11) shows the ultimate loads with variable thicknesses of concrete. The ductility of the slabs has been significantly affected with the change in thickness of these slabs, and through the load-deflection curves, we notice that increasing the thickness of the normal concrete slabs and crushed brick concrete slabs leads to a decrease in ductility, but in the case of porcelenite concrete slabs, increasing the thickness of the slab leads to improved toughness. The results showed that increasing of the slab thicknesses leads to an increase in the first cracking load for all types of concrete, the increase was by (58.7%, 42.84% and 42%) for normal concrete, porcelenite concrete and crushed brick concrete respectively when the change thickness from (70 to 90mm).

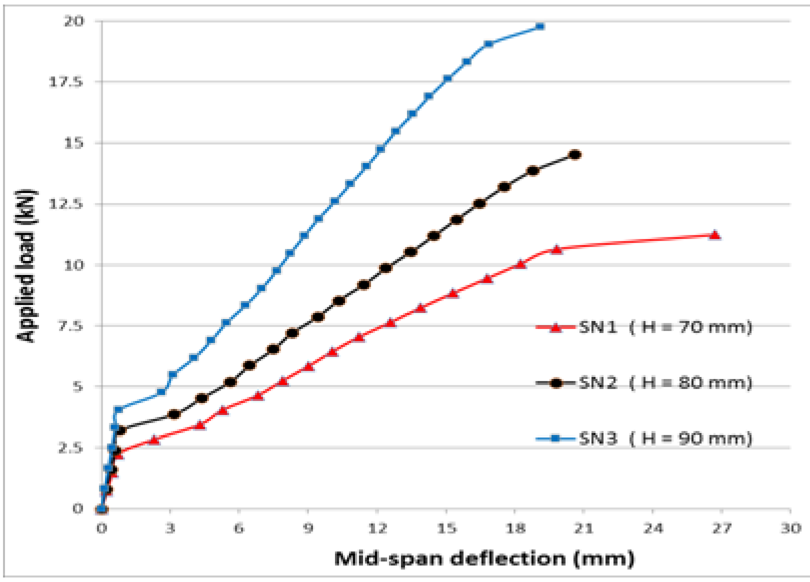


Figure (8): Effect of different thickness on Load-deflection curve for normal concrete slabs.

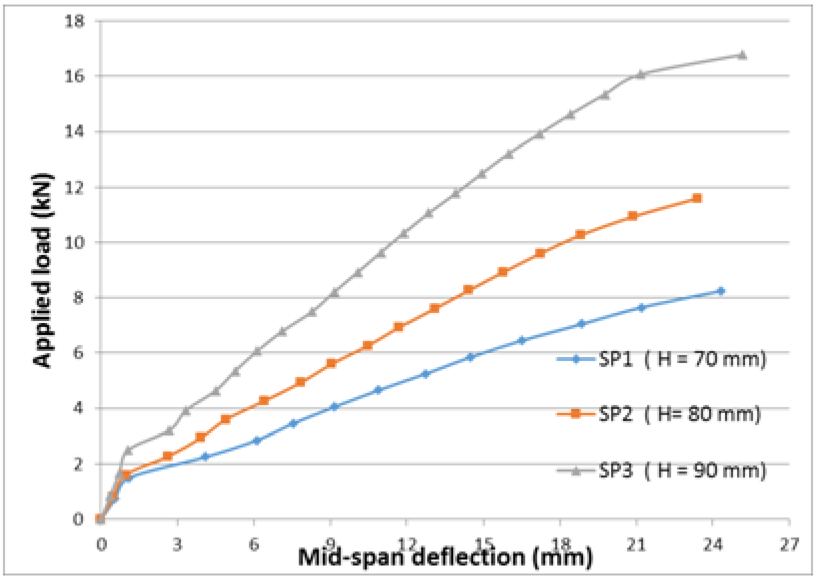


Figure (9): Effect of different thickness on Load-deflection curve porcelenite aggregate concrete slabs.

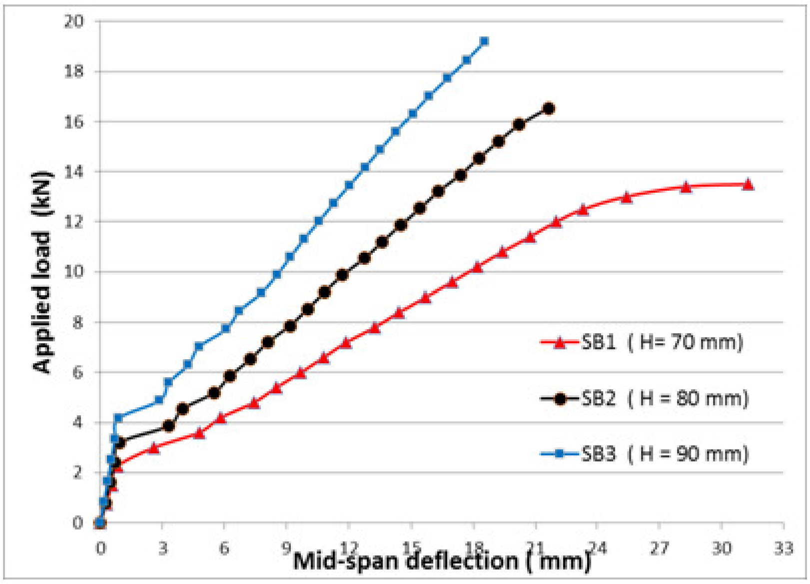


Figure (10): Effect of different thickness on Load-deflection curve crushed brick concrete slabs.

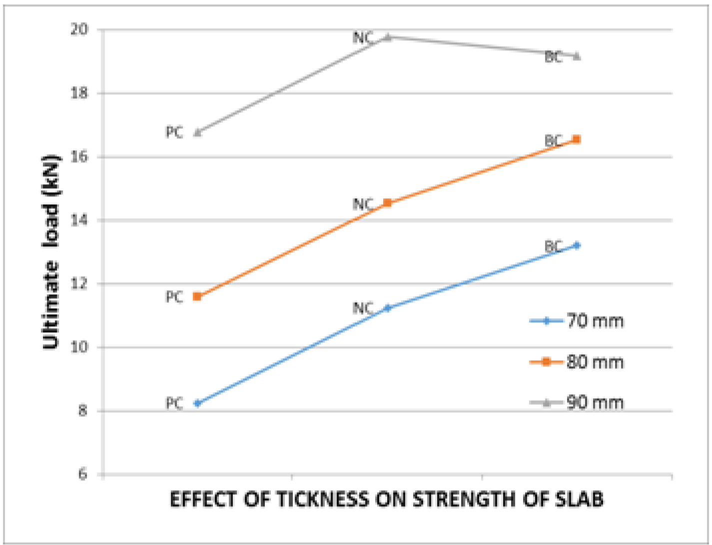


Figure (11): Effect of slab thickness on ultimate loads with variable concrete types.

6.3. Effect of loading types

To study the effect of the load types on the behavior of the LWC slab. The following cases are considered:

- The original case (two-point load).
- The second case (one point load).
- The third case (distributed load).

It is clear from the result shown in Figures (12 to 14) that the toughness of all aggregate concrete slabs tested in the present study improved with the change of loading type form one point load to distributed load with the same thickness of slabs, and this obvious from load-deflection curves. Figures (12, 13 & 14) show flexural behavior of the R.C slabs. The capacity of ultimate load and initial cracking loads increases by (78.4%, 99.27% and 108.5%), (90.4%, 66.67% and 62.67%) for (normal concrete, porcelenate concrete and crushed brick concrete) slabs respectively.

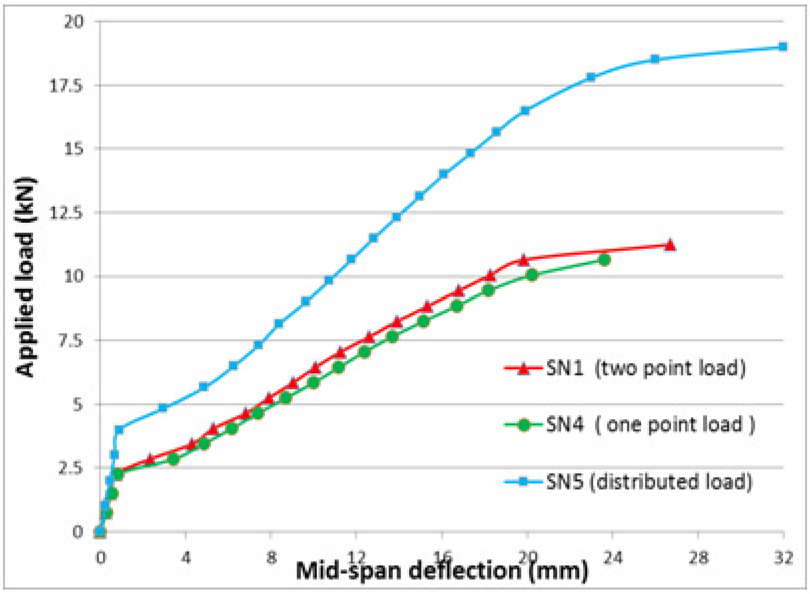


Figure (12): Load-deflection curve for normal concrete slab with variables loading types.

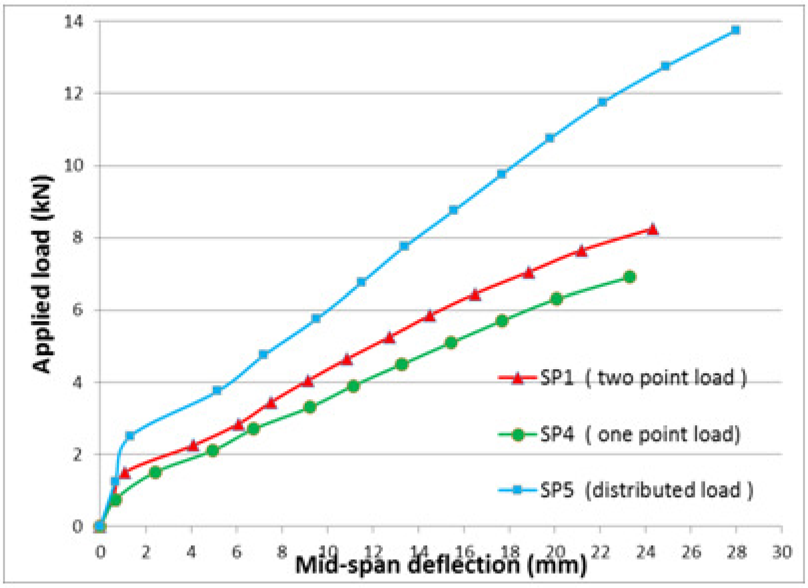


Figure (13): Load-deflection curve for porcelenite aggregate concrete slab with variables loading types.

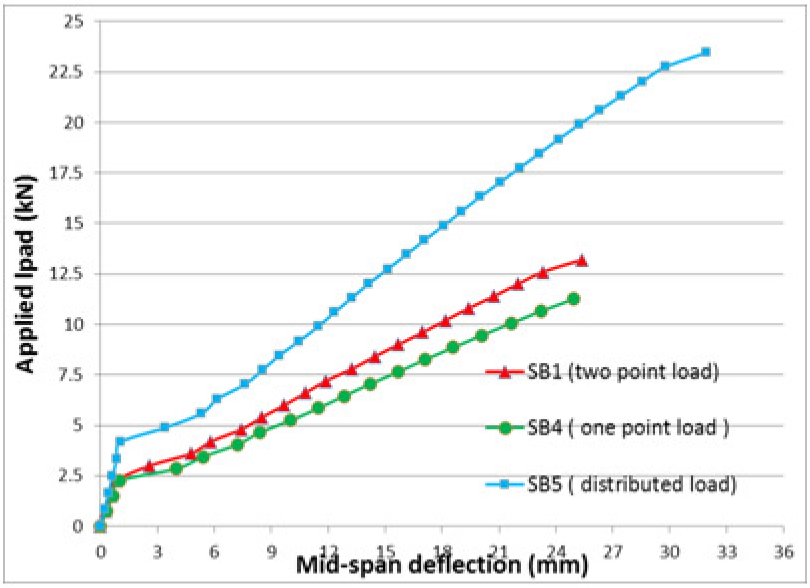
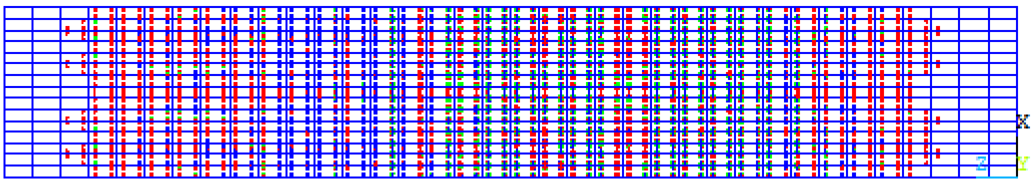


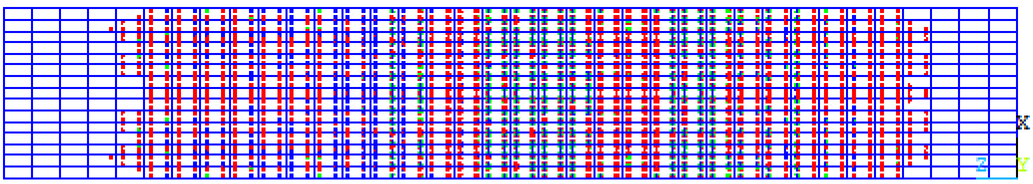
Figure (14): Load-deflection curve for crushed brick aggregate concrete slab with variables loading types.

7.4. Crack Patterns

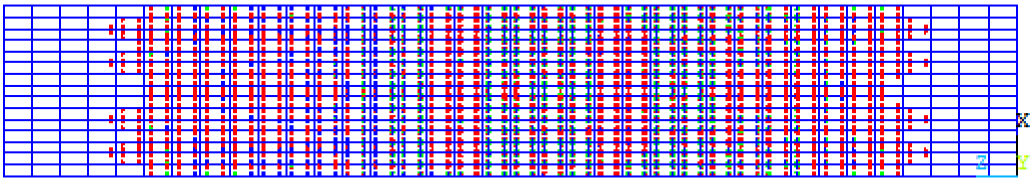
The numerical-model painted the cracks at all stages of loading. Cracking-patterns in the beams was obtained using the Crack/Crushing plot option in ANSYS (V.17.2). According to ANSYS program, the first crack which represents slight crack is symbolized by a red circle outline at an integration point, the second crack which represents moderate crack is symbolized by a green circle outline, and the third crack which represents failure crack is symbolized by a blue circle outline. Figure (15) shows the crack-patterns at ultimate load by ANSYS model.



SN1



SB1



SP1

Figure (15): Typical Crack patterns of 70mm concrete slabs with two points loads.

CONCLUSIONS

- Numerical finite element analysis which presented in this-study by using the computer program (ANSYS V.17.2) were in good agreement with experimental load-deflection curves from the previous research throughout the entire range of behavior.
- Flexural capacity of the crushed brick aggregate slab increased by 17.33% when compared with normal concrete slab of two-point loading applied of 70mm slab thickness.
- The slab made of crushed brick concrete has better structural behavior than normal and porcelenite aggregates concrete slabs.
- The ultimate load decreased with a maximum value of 26.66% when replacing normal by porcelenite aggregates of 70mm slab thickness.
- The best behavior of R.C slabs were registered for specimens applied to the ultimate load with a high percentage capacity increment of (78.4%, 99.27% and 100.82%) and the cracking load increased by (91%, 63% and 150%) for (normal concrete, porcelenite, and crushed brick concrete) slabs respectively tested under distrusted loads compared with the point loads.
- Slab thickness has a considerable effect on the ultimate flexural strength, initial cracking load and deflection at mid-span of slabs. The increase of slab thickness from (70 to 90 mm) leads to increase in the ultimate flexural strength by (78.4%, 99.27% and 100.82%), the cracking load increased by (59%) for normal concrete, (42%) for crushed brick concrete and (44%) for porcelenate concrete. Mid-span deflection decreases to (64%, 62.3% and 52.6%) for (normal concrete, porcelenate concrete and crushed brick concrete) slabs respectively.

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NOTATION

E_s	Modulus of Elasticity of Steel
f_c'	Uniaxial Compressive Strength of Concrete (Cylinder Test)
f_y	Yield strength of steel bar.
ε	Strain , σ Stress