VOL. 11, NO. 15, AUGUST 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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NUMERICAL ANALYSIS OF REINFORCED CONCRETE HOLLOW-CORE SLABS

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ABSTRACT

A longitudinal voids through the one way reinforced concrete slabs are very important for utility services and for structural purposes by reducing the own weight of the structure. These types of slabs were analyze numerically by using nonlinear solution of a finite element program ANSYS with dimensions (2.05m) length, (0.6m) width and (250mm) thickness. Three sizes of circulars cores are used with core diameter (150, 100 and 75mm) by reducing in self-weight of slab (23.5%, 15.7% and 8.8%) respectively. The modelling of the materials, the concrete slabs, steel reinforcement bars and steel plates for loading and supports were done then meshing it before solution. The analysis results are compared with the solid slabs types under the same conditions. Some of parameters are studied such as the ratio of shear span (a) to effective depth (d) (a/d), size of cores, shape of core, type of loading and effective of top steel reinforcement. It was founded that reducing the self-weight of concrete caused reducing in ultimate capacity of slabs by (20.6%, 13% and 3.8%) compared with solid slab with core diameter (150, 100 and 75mm) respectively. The ultimate capacity of the slab reduces with increasing the ratio (a/d). Using the square shape of the holes reduces the cracking load and ultimate capacity by about (13.5%) with increasing the deflection by (39.5%).

Keywords: numerical, hollow-core, one way, reinforced concrete slab, finite element, ANSYS.

INTRODUCTION

Reinforced concrete slabs are the most common structural elements, and it becomes one of the most important building elements which are widely used in many types of engineering structures. The precast or cast-in situ reinforced concrete slabs can be reduce its own weight by removing the ineffective concrete or by reducing the cross sections using pre-stressing reinforcement.

Various studies at past was done on reinforced concrete elements for reducing the self-weight of the structures. For economical purposes, the lightweight materials which are used inside reinforced concrete element can be replaced by air (cores) and using it as a ducts for mechanical and electrical requirements. Not all the internal concrete can be replaced by air (cores), the concrete at top provided the compression zone and in the tension zone to bond with reinforcement for flexural resistance also the aggregate interlock is important for provided shear resistance.

Generally, the one way normal R.C slab can be do in three forms of slabs: solid slabs, ribbed slabs and hollow-core slabs. Hollow core floors represent a special kind of floor totally made of concrete lightened by leaving longitudinal voids (cores) of suitable size to create webs to reduce weight, costs, as fire resistance and for electrical and mechanical purposes. Primarily, hollow core elements are used as floor or roof deck systems and also have applications as wall panels, sound barriers, spandrel members and bridge deck units.

Reinforced concrete hollow-core slab is made with cores in one direction with the following points:

a) Cross section of hollow-core slab was defined as continuous of I-section parts and designed as a one way ribbed slab with top and bottom flanges.
b) Conventional span length up to 7m and width of each panel up to 2.4m.
c) Assumed moderately thick Plate (thickness to span ratio $\left(\frac{h}{l} = \left(\frac{1}{10} - \frac{1}{5}\right)\right)$).
d) Limitations of cross section according ACI-318M-14 code [1]:

- $b_w \geq 100$mm
- $h_w \leq 3.5\, b_w$
- $s \leq 800$mm
- $h_f \geq s/2$, $h_f \geq 50$mm
- $b_f = b_w$ + dia. of core
- b_w : width of web
- h_w : height of web(diameter of core)
- s : spacing between ribs (s=zero in hollow-core slab)
- h_f : height of flange top or bottom
- b_f : width of flange

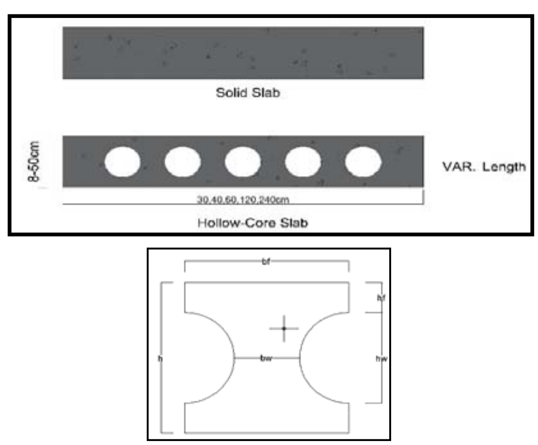

Figure-1. Dimensions of cross section of hollow-core slab.

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LITERATURE REVIEW

Helén Broo, Karin Lundgren (2002), [2] Presented calculation method for shear and torsion in hollow core slabs adds stresses from various influences without considering deformations and compatibility, the softening of cracking concrete, or restraint at the boundaries, and is therefore most likely conservative. Finite element analyses were carried out of individual hollow core units, subjected to different combinations of shear and torsion. Pre-stressed hollow core units of two thicknesses, 200 mm and 400 mm, were tested both with and without eccentric loading. The analyses were made with various levels of detailing, using the finite element program DIANA 7.2. The slab was modelled with beam elements and concrete was modelled using non-linear fracture mechanics in a smeared rotating crack model

P.C.J. Hoogenboom (2005), [3] presented a procedure for the finite element analysis of hollow-core slab floors, which may be necessary in case of large floor opening. This procedure was planned to develop a computer program for this analysis as a design tool. Formulas for homogenization of the floor properties are presented. Finite element modelling is discussed. Formulas for calculating stress recovery are presented by the section moments and section forces in critical points of a floor. These stresses are checked against the material strength at critical locations of the floor. It was conclude that the large openings in hollow-core slab floors can be possible without extra beams or columns.

Chang *et al* (2008), [4] presented a simple computational method to be used in design and modeling the structural behavior of hollow core concrete slabs in fires. The proposed model consisted of a grillage system using beam elements to include the thermal expansion in both directions and to simulate the vertical cracking in the flanges, with the topping concrete modeled using shell elements. The new model can predict the fire performance of hollow core slabs well, on the condition that no shear failure or significant shear displacements are present

Aseel Sabah Mahdi, (2011) [5] carried out nonlinear analysis of reinforced concrete hollow core slabs by finite element method using plate bending elements and beam elements to model the structure. The basic idea was to separate the hollow core slab into two main components. Hollow plates representing the upper and lower flanges and stiffening beams representing the vertical webs between the voids. A computer program that will be modified for analyzing various reinforced and pre-stressed concrete hollow core slabs and the finite element solutions were compared with the available experimental results to demonstrate the potential of the computational nonlinear model

Lara Kawai *et al.*, (2014) [6] carried out theoretical and numerical study on human induced vibrations in hollow core slabs. Initially, a review of the dynamic loads induced by humans in activities such as walking was shown as well as acceptance criteria for human comfort. Then a parametric study on vibration sensitivity of typical structural configurations of hollow core slabs cores was developed through numerical simulations with the finite element method.

The various methods that were expressly developed for the analysis of cellular or voided slab, together with those existing general methods that can also be used for the analysis of these elements [7]:

a) Orthotropic Plate Theory
b) Sandwich Plate Method
c) Frame and Grillage Method
d) Folded Plate Method
e) Discrete Beam Method
f) Finite Element Method (FEM)

NUMERICAL ANALYSIS OF SLABS

The finite element method is a numerical procedure that can be applied to obtain solutions to a variety of engineering problems in which any structure can be replaced by a finite number of elements interconnected at a finite number of nodal points.

ANSYS (**AN**alysis **SYS**tem) is a comprehensive general-purpose finite element computer program that contains over 100,000 lines of code and more than 180 different elements. It is capable of performing static, dynamic, heat transfer, fluid flow, and electromagnetism analysis. It can be used in many engineering fields, including structures, aerospace, electronics, and nuclear problems [8].

A nonlinear finite element analysis has been carried out to analyze a solid and hollow-core slabs with some of parameters study. The analysis was performed by using ANSYS release (15.0) computer program by subprogram ANSYS Parametric Design Language (APDL) for structural analysis problems.

A typical ANSYS analysis has four major steps:

a) Definition the properties of the used material and elements.
b) Configuration the model.
c) Applying the loads and boundary conditions before the solution.
d) Reviewing the results.

Details of slabs

All slabs are of (2050mm) length, (600mm) width and, (250mm) thickness. The span length is (1750mm) and resting on simply supports at their ends. The actual dimensions with slab geometry and details of loading were present at Figure-2 to Figure-4.

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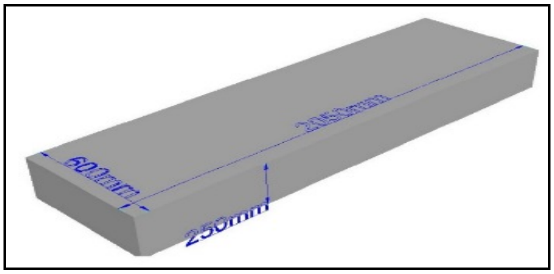

Figure-2. Dimensions of slab.

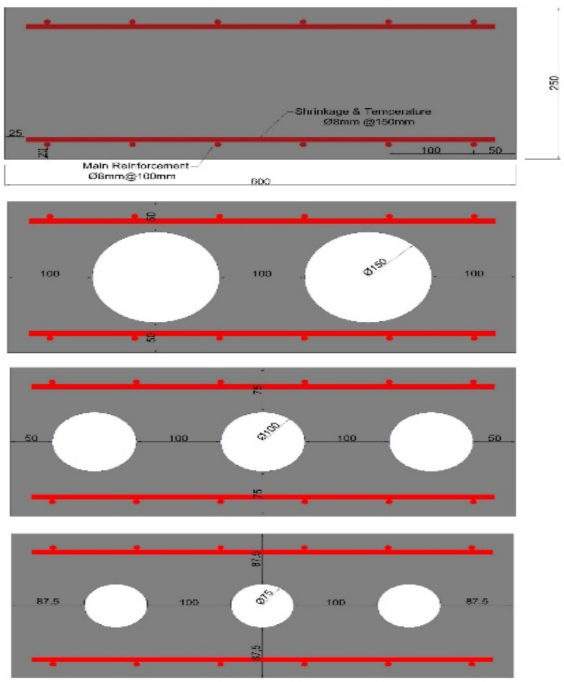

Figure-3. Details of cross sections of slabs.

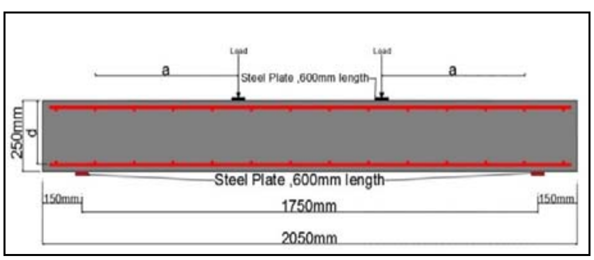

Figure-4. Details of loading.

Model generation

The main purpose of finite element analysis is to recreate mathematically. Any model must comprise all the nodes, elements, boundary conditions, material properties, real constants, and all other features which are used to represent the physical system of the model. In ANSYS terminology, the term model generation usually takes on the narrower meaning of creating the nodes and elements that represent the space volume of the actual system. Thus, a model generation in this discussion will mean all process of describing the geometric configuration of the model's nodes and elements [8].

Types of element

The following elements described below are to be used for modeling of solid and hollow-core slab:

SOLID65) Element: this element was used to model the concrete and it has eight nodes with three degrees of freedom at each node – translations in the nodal x, y, and z directions [8].

(LINK180) Element: Modeling of reinforcing steel in finite elements is much simpler than the modeling of concrete. A Link180 element was used to model steel reinforcement. This element is a 3D spar element and it has two nodes with three degrees of freedom – translations in the nodal x, y, and z directions [8].

(SOLID185) Element: An eight node solid element was used for modeling steel plate's supports. The element is defined with eight nodes having three degrees of freedom at each node translations in x, y and z directions [8].

Steel plates were added at support and point of loading locations in the finite element models (as in the actual slabs) to provide a more even stress distribution over the support and point of loading areas. An elastic modulus equal to 2000000 MPa and Poisson's ratio of 0.3 were used for the plates. The steel plates were assumed to be linear elastic materials.

(PLANE182) Element: PLANE182 element was used for 2-D modeling of solid structures. It was used for the area plane around the circular shape of slab cores only. The element can be used as either a plane element (plane stress, plane strain or generalized plane strain) or an axisymmetric element. It is defined by four nodes having two degrees of freedom at each node: translations in the nodal x and y directions.

The finite element models adopted in this study have a number of parameters which can be classified into three categories as shown in Table-1:

a) Concrete property parameters.

b) Steel reinforcement property parameters.

c) Steel plate property parameters.

Table-1. Materials properties.

Material model number	Element type	Materials properties		
1	SOLID65	Linear Isotropic		
		EX	29385.5 MPa	
		PRXY	0.2	
		Multi-linear Isotropic		
		Point No.	Strain	Stress (MPa)
		Point 1	0.00039	11.43
		Point 2	0.001	25.6
		Point 3	0.0015	33.1
		Point 4	0.002	36.9
		Point 5	0.0026	38.1
		Concrete Properties		
		Open S.T. Coef. (βo)	0.8	
		Closed S.T. Coef (βc)	0.95	
		Uniaxial Cracking Stress	3.40	
		Uniaxial Crushing Stress	38.1	
		Biaxial Crushing Stress	0	
		Hydrostatic P...	0	
2	LINK180 (Discrete)	Linear Isotropic		
		EX	199100 MPa	
		PRXY	0.3	
		Bilinear Isotropic		
		Yield Stress	578MPa	
		Tang Mod	1991MPa	
3	SOLID185	Linear Isotropic		
		EX	2000000MPa	
		PRXY	0.3	

Modeling of the solid and hollow-core slabs

The concrete model that represent the slabs with and without longitudinal hollow-cores are formulated by drawing areas at plan(x-y) in the first step and subtract the cores areas and then extrudes them in (z-direction) to form the volume of the slabs as shown in Figure-5. In the present study, the net from longitudinal and transverse steel reinforcement bars which formed the reinforcement model was created through line element between nodes of each adjacent concrete solid element (discrete model), so the two materials shared the same nodes.

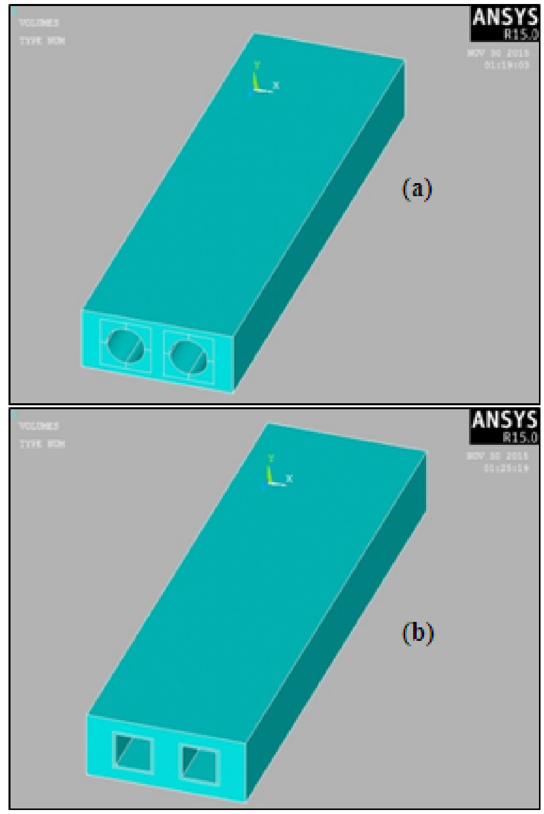

Figure-5. Modeling of hollow-core slab (a) Circular core (dia.150mm), (b) Square core (133x133mm).

Meshing process

A convergence of results is obtained when an adequate number of elements are used in a model. This is practically achieved when an increase in the mesh density has a negligible effect on the results. Therefore, in this finite element modeling study a convergence study was carried out on reinforced concrete slab (solid type) to determine an appropriate mesh density.

Three types of mesh of reinforced concrete slab (solid type) are used to find the best mesh size (2460, 19680 and 157440 elements) for element's size as (50, 25, 12.5mm) respectively as shown in Figure-6.

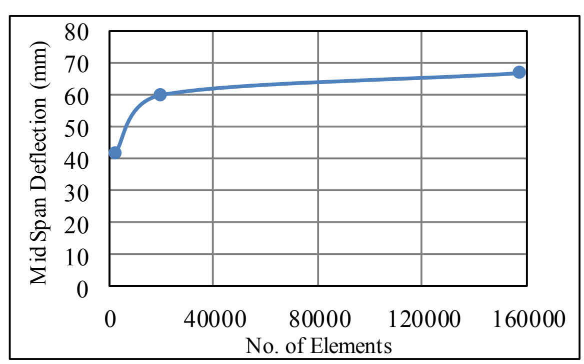

Figure-6. Convergence of results study.

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It can be concluded from Figure-6 that the difference can be neglected when the number of elements increased from (19680) to (157440), therefore the (19680) model with mesh size (25mm) was adopted in the analysis of all slabs.

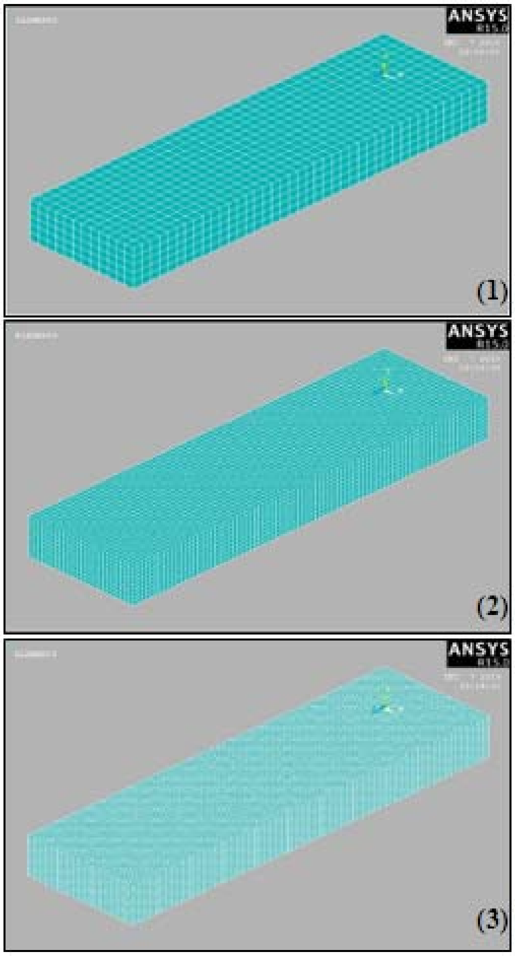

Figure-7. Selecting mesh density of sizes (50, 25 and12.5mm), respectively.

The meshing of concrete solid slab was done directly as a cubic elements by **(SOLID65)** while the meshing of hollow-core slab with circular and square core shape need fine mesh for the area around the core opening in a way so that **(SOLID65)** element can be used for all slabs. The only way to do that is by drawing symmetrizes four squares area to form a square area greater than the radius or the dimension of the core opening then drawing circle or square at the center of theses square areas and subtract it to form the circular or square shape of core opening. The areas were limited between the out square area and voided circular or middle square shape will be meshed using concentrated meshes by **(PLANE182)** element then extrude it to be a volume and then meshing it with **(SOLID65)** element as shown in Figure-7 and Figure-8.

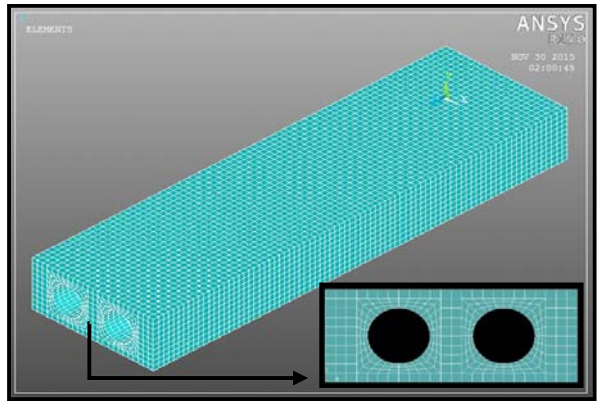

Figure-8. Mesh of hollow-core slab (150mm Dia).

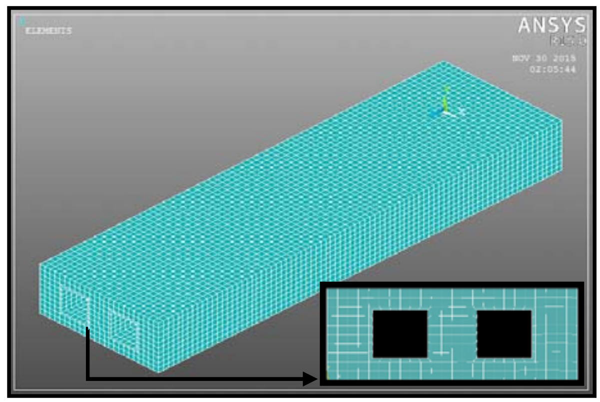

Figure-9. Mesh of hollow-core slab (130x130mm).

The mesh of reinforcement was not needed because individual elements were created by using **(LINK180)** element that passes through the nodes of the concrete elements.

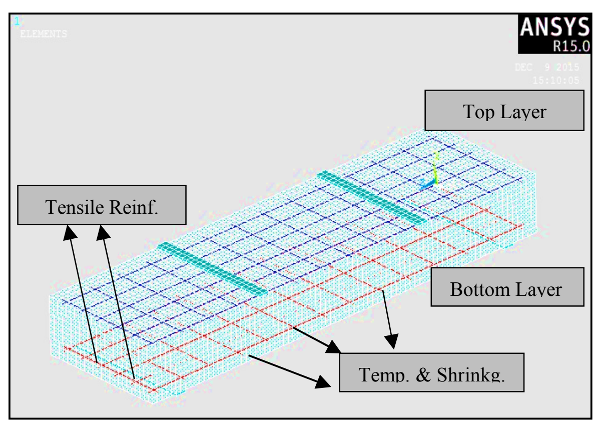

Figure-10. Layers of reinforcement steel.

Loading and boundary conditions

The loading and support dimensions were (50 x 600) mm. Two steel plates of (10mm) thickness are modeled using **(SOLID185)** elements, were added at the support and two steel plates at loading locations with the same size of concrete mesh in order to avoid stress

ISSN 1819-6608
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concentration problems. This will provide a more even stress distribution over the support area [Figure-10)].

The **(SOLID185)** elements which are used to model steel plates at supports have three degrees of freedom UX, UY and UZ. These degrees of freedom at the bottom face of these plates are restrained with a single line of supports which placed under the centerline of the steel plate to allow rotation of the plate below the concrete slab with the required positions as a simply support to simulate the real boundary conditions as shown in (Figure-11). The right steel plate was restrained in Z-direction (U_Z=0) and the left steel plate was restrained in X and Y direction (U_X=0, U_Y=0).

The external loads was applied on two steel plates over the surface of concrete slabs with the required locations. These loads were applied in the form of concentrated loads on all top nodes of plates (75node per plate) as a ($\frac{P/2}{75}$) for each node as shown in Figure-12 to simulate the real loads which adopted in the experimental work.

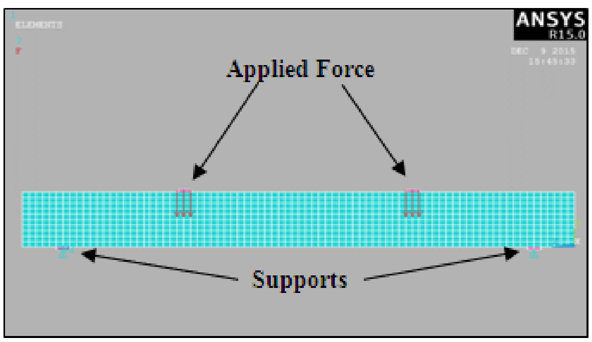

Figure-11. Applied loads and boundary conditions (Side View).

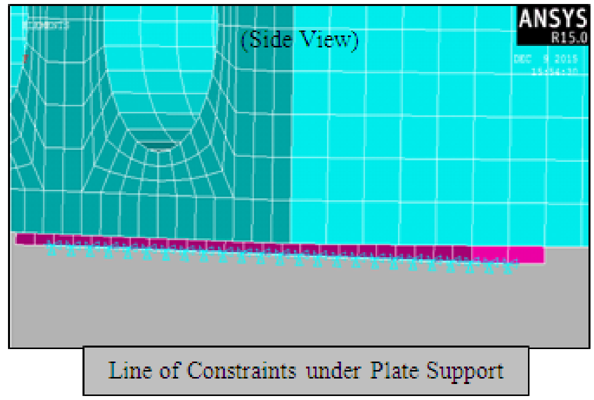

Figure-12. Constraints of plate supports.

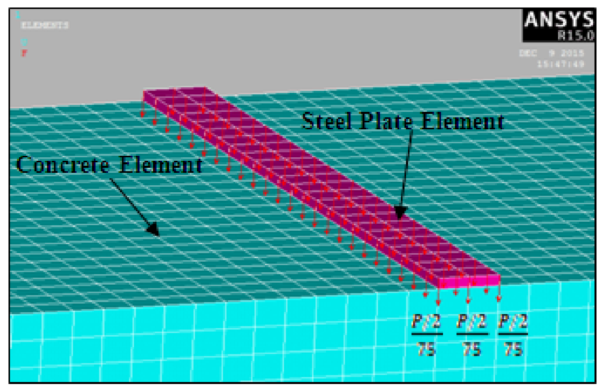

Figure-13. Distribution of applied load on nodes.

Analysis termination criterion

The application of the loads up to failure was done incrementally as required by the Modified Newton-Raphson method. Therefore, the total applied load is divided into a series of load increments (load step). Within each load step, maximum of (200) iterations were permitted.

At certain stages in the analysis, load step size was varied from large (at points of linearity in the response) to small (when cracking and steel yielding occurred). In all cases, convergence was achieved before reaching the maximum (200) iteration.

The failure of the models is defined when the solution for a minimum load increment does not convergence (convergence fails). The program then gives a message specifying that the models have a significantly large deflection (rigid body motion).

ANALYSIS RESULTS

The results of the nonlinear finite element analysis by ANSYS program were presented for all solid and hollow-core reinforced concrete slabs.

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Table-2. Results of Finite Element Analysis.

Slab type	Slab no.	$\frac{a}{d}$	Ultimate load (kN) (P_u)	Ultimate deflection (mm) (Δ_u)
Solid	Slab-1	2	310.60	60.43
	Slab-2	2.5	243.21	52.95
	Slab-3	3	210.19	33.02
Hollow-Core 150mm	Slab-4	2	288.28	49.69
	Slab-5	2.5	193.00	67.91
	Slab-6	3	160.690	69.87
Hollow-Core 100mm	Slab-7	2.5	211.50	62.92
Hollow-Core 75mm	Slab-8	2.5	234.00	53.50

Load-deflection plots

The deflection (vertical displacement) in Y-direction (UY) are obtained at the center of mid span and under the load of the bottom face of the slab. Deflection contour of finite element analyzed slabs due to the applied loading is shown in Figure-13 to Figure-15.

In this result, verification is done in order to check the validity and accuracy of the finite element procedure. The load versus deflection plots obtained from the numerical and the experimental results data are presented for comparison in Figure-16 to Figure-19.

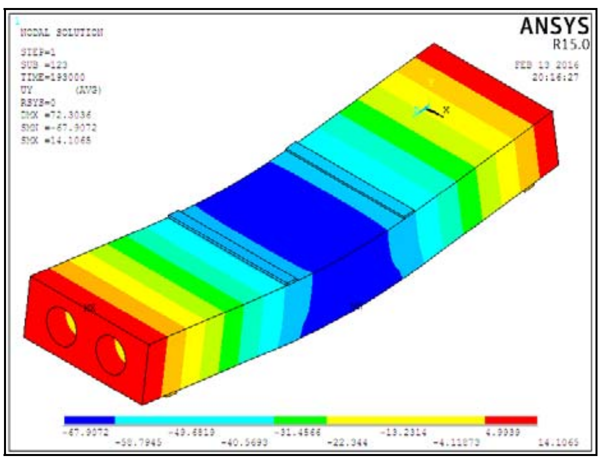

Figure-14. Deflection contours (U_Y) of hollow-core slab (150mm), at load ultimate (a/d=2.5), (Slab-5).

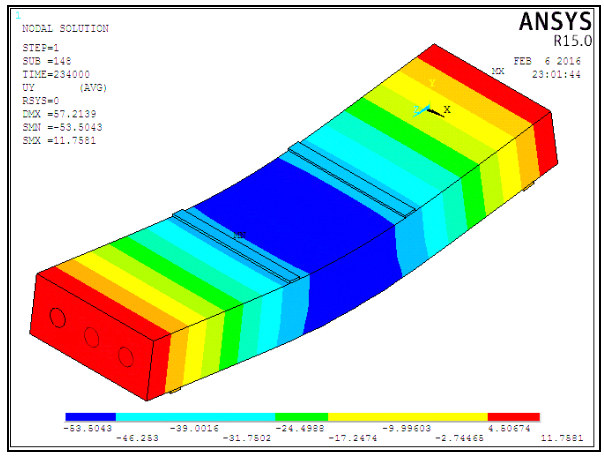

Figure-15. Deflection contours (U_Y) of hollow-core slab (100mm), at load ultimate (a/d=2.5), (Slab-7).

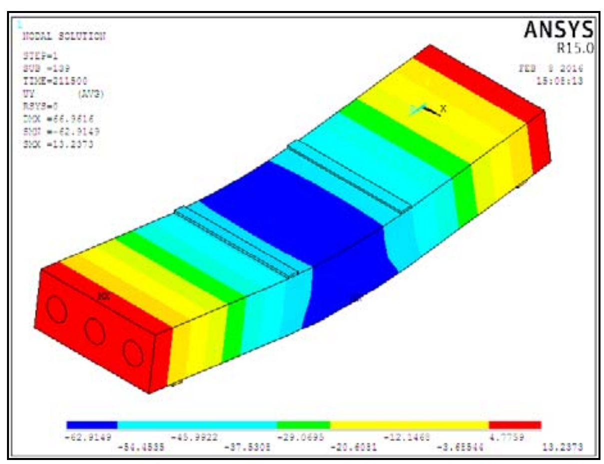

Figure-16. Deflection contours (U_Y) of hollow-core slab (75mm), at load ultimate (a/d=2.5), (Slab-8).

The accuracy of the finite element models is determined by comparing with the experimental results

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and the ultimate loads obtained from numerical models are in excellent agreement with the corresponding values from the experimentally results. The numerical results show that greater ultimate load with smaller deflection at the ultimate load stage as compared to experimentally results with max variation 7.49% in ultimate load and 6.10% in deflection.

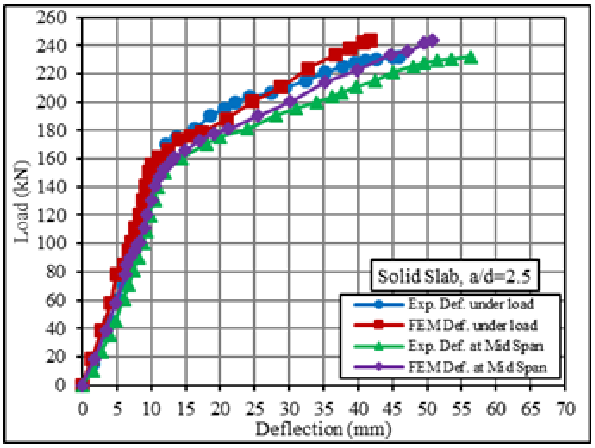

Figure-17. Load-deflection relationship for solid slab (SS) with (a/d 2.5).

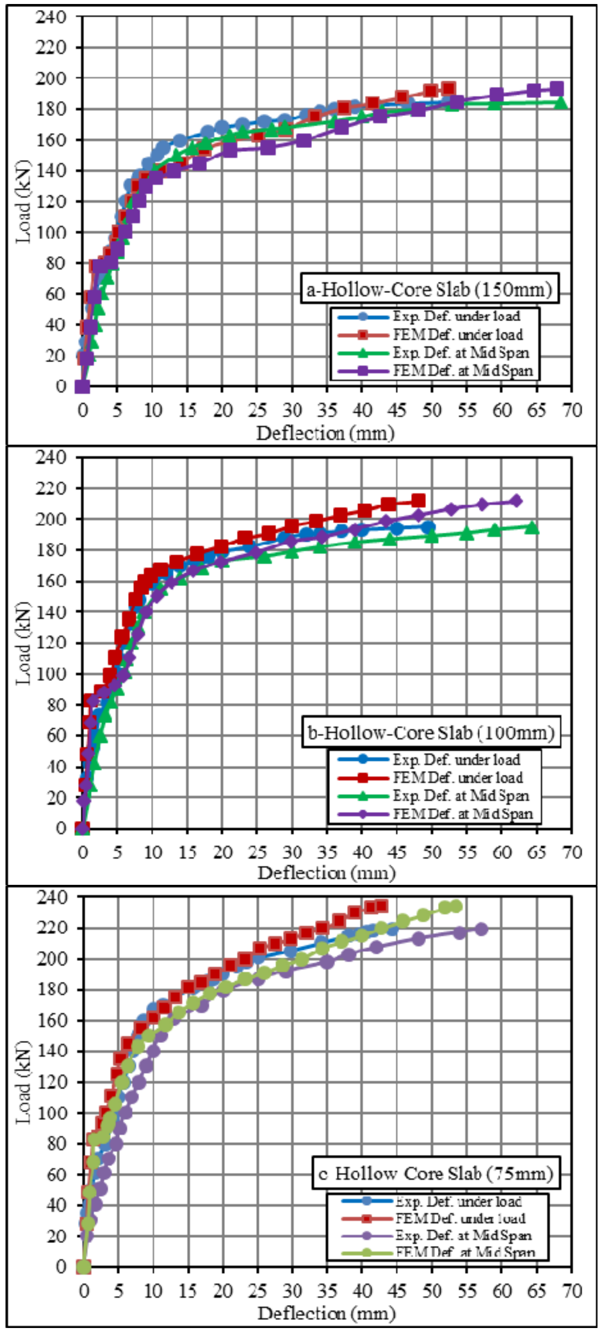

Figure-18. Load-deflection relationship for hollow-core Slab (CCS) with (a/d=2.5) and Core Diameter (a)150mm, (b)100mm, (c)75mm.

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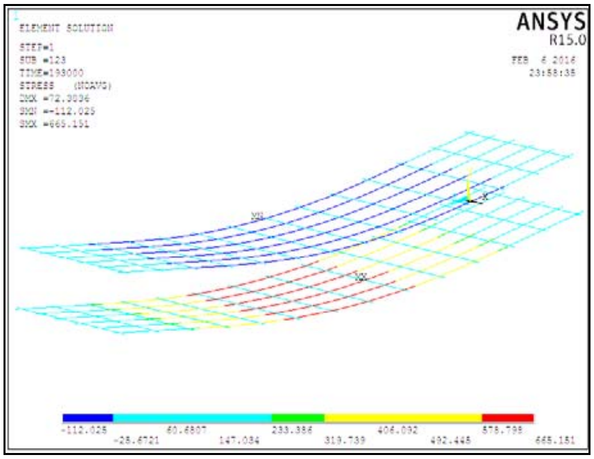


Figure-19. Stresses in longitudinal steel of hollow-core slab (CCS), (150mm) with (a/d=2.5) at ultimate load.

Stress in tested slabs

The variation of normal stresses in steel reinforcement is shown in Figure-18 and Figure-20. In these Figures, it is obvious that the maximum tensile stress of steel reinforcement at mid span of the bottom reinforcement fiber while the top fiber of reinforcement being in compression stress.

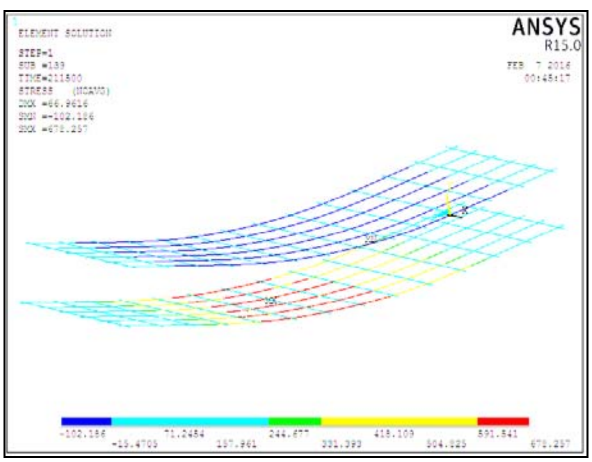


Figure-20. Stresses in longitudinal steel of hollow-core slab (CCS), (100mm) with (a/d=2.5) at ultimate load.

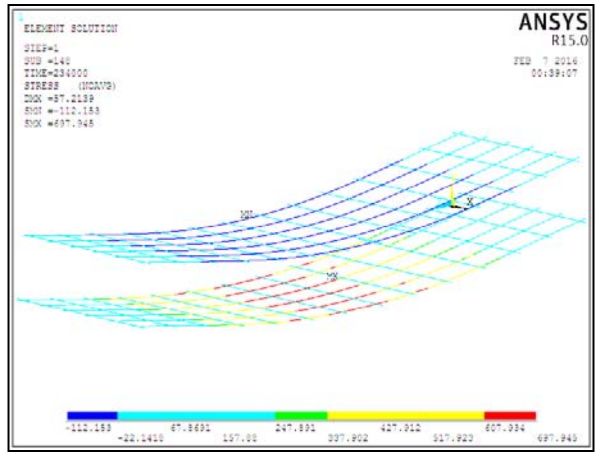
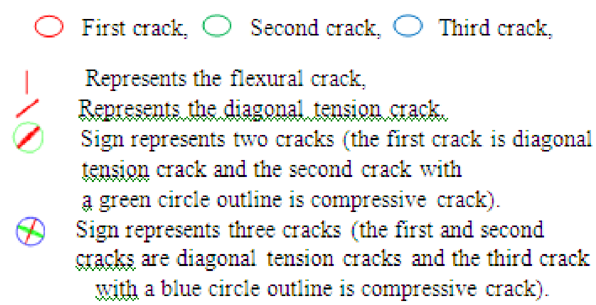


Figure-21. Stresses in longitudinal steel of hollow-core slab (CCS), (75mm) with (a/d=2.5) at ultimate load.

Crack patterns

ANSYS computer program displays circles at locations of cracking or crushing in concrete elements. Figure-21 shows the location of cracks and crushed integration points along the solid and hollow-core slabs with core diameter (150, 100 and 75) respectively. ANSYS explain the cracks signs as follow:



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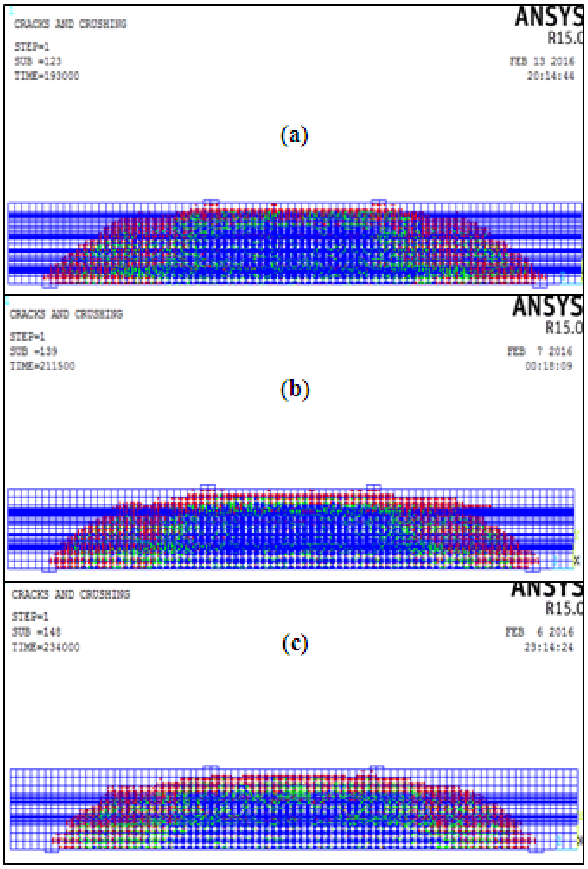

Figure-22. Crack pattern carried out by ANSYS program under (a/d=2,5) (a)Hollow-core slab(150mm), (b) Hollow-core slab(100mm), and (c) Hollow-core slab(75mm) at Ultimate load.

Parametric study

The parameters that may affect the behavior of the hollow-core reinforced concrete slabs under the same conditions are studied here in:

a) Effect of (a/d) ratio

The analyzing of reinforced concrete solid and hollow-core slab with core diameter (150mm) is carried out with different values of shear span distance to effective depth ratio (a/d). Three values of (a/d) are used as (2, 2.5 and 3) and the results are shown in Figure-22 and Figure-23. It is note that the increasing of this ratio the ultimate load decreases with decrease the deflection for solid slab while in hollow-core slab the ultimate load decrease with increasing the deflection when increasing (a/d) ratio.

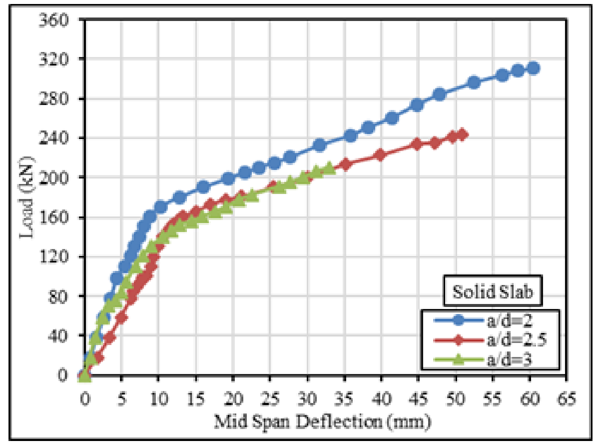

Figure-23. Load-deflection relationship of solid slabs with variation of (a/d) ratio.

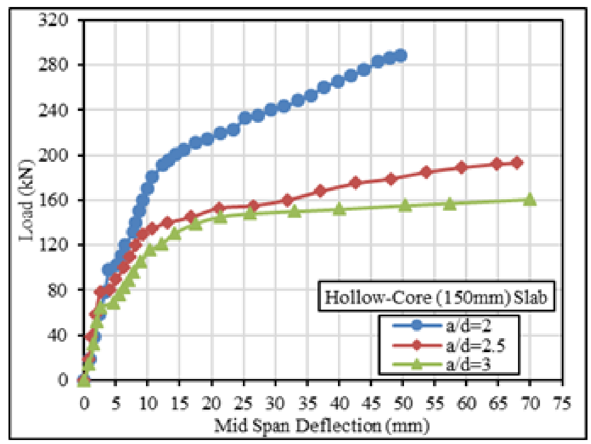

Figure-24. Load-deflection relationship of hollow-core slab (Core Diameter 150mm) with variation of (a/d) ratio.

b) Effect of core shape

Studying the effect of core shape on the behavior of hollow-core slab is carried out. Two shape with same core area as a circular shape with core diameter (150mm) and square shape with dimensions (133x133mm). The obtained results refer that the ultimate load and deflection of hollow-core slab with circular core is greater than that with square shape this is may be due to stress concentration effect at the square shape corners. The analysis results are compare with solid slab as shown in Figure-24.

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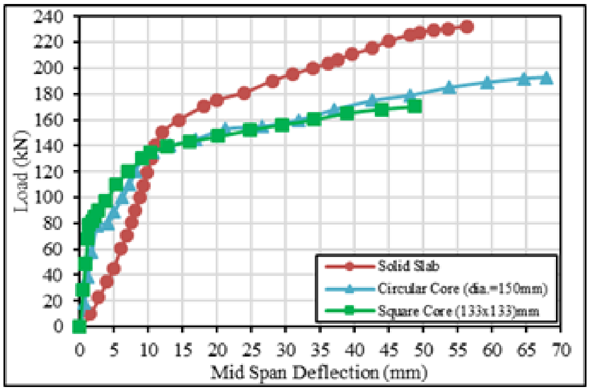

Figure-25. Effect of core shape of hollow-core slab.

c) Effect of core size

The hollow core slabs having circular core shapes and square core shapes were analyzed with equivalent areas of three sizes for each core shape under same loading and support conditions. The circular shape types were presented and analyzed previously while the equivalent square core shapes having dimensions (133x133mm, 89x89mm and 66x66mm) are shown in Figure-25 It is observed that increasing core size will decrease the ultimate load regardless of core shape. But the deflection increase with increasing the size of circular shape while it decreases with increasing the dimension of square shape as shown in Figure-26 and Figure-27.

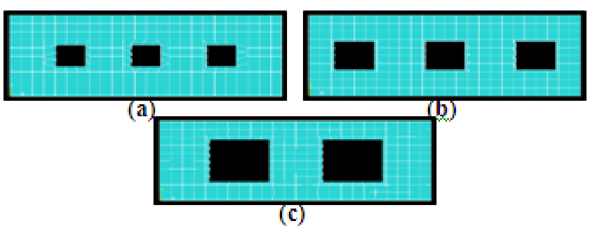

Figure-26. Sizes of square shapes of cores (a) 66x66mm, (b) 87x87mm and (c) 133x133mm

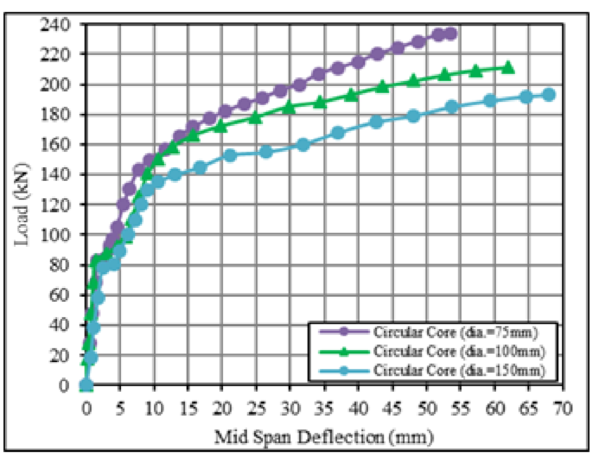

Figure-27. Load-deflection relationship for hollow-core slab with circular core shapes.

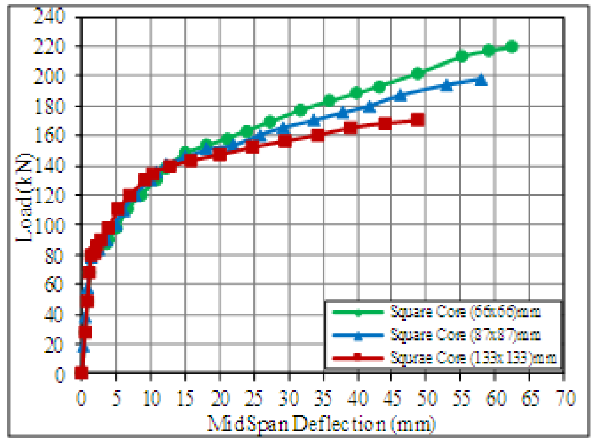

Figure-28. Load-deflection relationship for hollow-core slab with square core shapes.

The selection of optimum core diameter presents in Figure-28 by comparison the core diameter with reduction of weight and reduction of strength. The curves are intersect in optimum core diameter (93mm) in which the reduction in weight equal the reduction in strength.

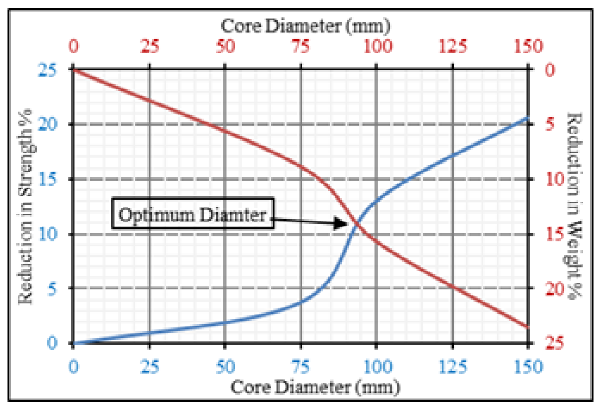

Figure-29. Variation of core diameter with reduction of weight and strength.

d) Effect of compressive strength of concrete

The reinforced concrete hollow-core slab having core diameter (150mm) under (a/d) equal 2.5 was selected to study the influence of the grade of concrete on the behavior of load-deflection curve. It has been reanalyzed using different values of concrete compressive strength as (25, 38, and 45) MPa respectively (This means increasing the stiffness of concrete) as shown in Figure-29. As the compressive strength increases the stiffness increase and the cracking and ultimate loads increase.

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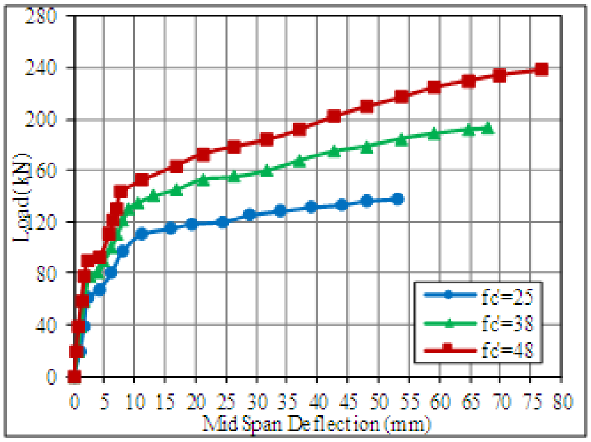

Figure-30. Effect of concrete compressive strength on the hollow-core slab.

e) Effect of loading type

The reinforced concrete hollow-core slab with circular core (diameter 150mm) was analyzed under uniform load on all surface nodes of the concrete elements by ANSYS program. The analysis results compared with the results of the same slab under two point loads with the ratio (a/d=2.5). The results indicate that the ultimate total load of this slab was increased from (193kN) for two point loads to (347kN) under uniform load type with decreasing in deflection by about (28.5%) as shown in Figure-30.

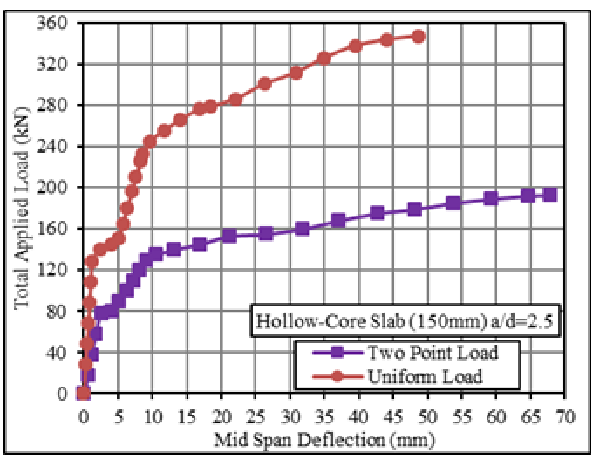

Figure-31. Effect of loading type of hollow-core slab.

f) Effect of top layer of reinforcement

Figure-31 shows the effect of using top steel reinforcement with bottom one. The hollow-core slab with core diameter (150mm) under two point loading with (a/d) equal 2.5 was analyzed first with top and bottom reinforcement as presented before then analyzing the same slab with removing the top reinforcement. It was noted that the ultimate load capacity of the slab will decreased by about 28% with removing the top reinforcement. This is may be due to the existence of top reinforcement will distribute the stresses around the core and prevent crushing.

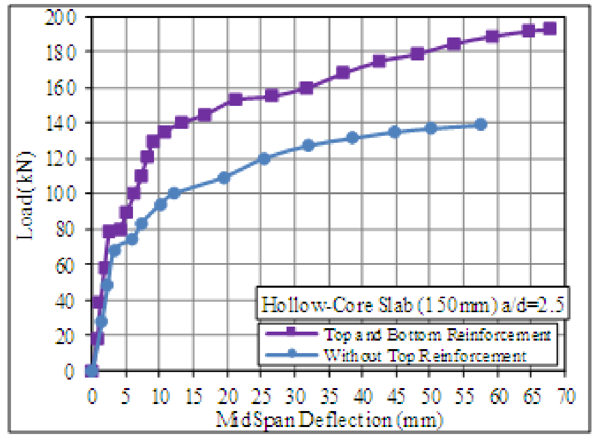

Figure-32. Effect of removing top fiber of steel reinforcement of hollow-core slab.

CONCLUSIONS

Based on the analysis results of the numerical investigations of the solid and hollow-core slabs, the following conclusions can be drawn:

a) The presence of longitudinal hollow cores inside the reinforced concrete slabs reduce the cracking and ultimate strength depended on the size and shape of cores.

b) Reducing the own weight of the moderate thick reinforced concrete slabs by about 23.6% with longitudinal hollow cores (dia. =150mm) lead to reduce the ultimate strength by about 20.645% while reducing the weight by about 15.71% with hollow cores (dia. =100mm) lead to reduce the ultimate strength by about 13.038% and reducing the weight by about 8.84% with hollow cores (dia. =75mm) lead to reduce the ultimate strength by about 3.787%.

c) Increasing the ratio (a/d) from 2 to 3 lead to reduce the ultimate strength by about 32% in solid slab with decreasing the deflection by 45%. While 44% reduction in ultimate load fore hollow-core slab with increasing the deflection by 40.6% due to reducing the stiffness of slab with removing the concrete volume of hollow cores.

d) In hollow-core reinforced concrete slab, the circular core shape have cracking and ultimate strength greater than the square shape by about 13.4% and increasing in deflection by about 39.5%. The increase in core size for circular core shape caused a reduction in ultimate strength with increasing the deflections while increasing the core size in square core shape cause a reduction in ultimate strength with reducing deflections.

e) It was found that when the compressive strength of the concrete increases from (38MPa) to (48MPa), the

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ultimate strength increase by 23.6% and when the compressive strength decrease from (38MPa) to (25MPa), the ultimate strength reduce to about 28.7%.

f) It was found that the ultimate strength of the hollow-core slab increases by about 80% for the case of uniform load and a reduction in deflection by (28.5%) compared to two point loads with (a/d) equal 2.5.

g) It was found that removing the top steel reinforcement in hollow-core slab reduces the ultimate strength by about 28% due to crushing failure of top flange of concrete so that it is recommended to use this layer prevent this failure.

h) Results of comparison between experimental and finite element results show that the difference range was (4.71-7.49) % in ultimate load and (0.69-6.10) % in deflection.

i) It is recommended that the optimum core diameter in hollow-core slab is (93mm) because of that the reduction in weight and strength are equal. In addition, reducing the core diameter will increase the ribs and that cause increasing in strength of the slab.

j) It is recommended to use circular core shape instead of square shape in order to obtained more strength for the same hole area.

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