International Journal of Engineering & Technology, 7 (4.20) (2018) 438-442

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Effect of the Rib Depth to the Overall Beam Depth Ratio in the Lightweight One-Way Ribbed Slabs

Taif A. Abdulkareem[1], Ashraf A. Alfeehan*[2]

[1]College of Engineering-Mustansiriyah University, Baghdad-Iraq
[2]College of Engineering-Mustansiriyah University, Baghdad-Iraq
**Corresponding author E-mail: drce_ashrafalfeehan@uomustansiriyah.edu.iq*

Abstract

The ribbed slabs provide a lighter and stiffer slab than an equivalent traditional slab with minimizing the total volume of the materials. Four one-way lightweight concrete panels, including one flat and three ribbed panels were cast and tested under two-point load as simply supported up to the failure. The main investigated variable is a ratio of the rib depth (d) to the overall beam depth (h). All the panels have the same concrete volume and the same steel reinforcement ratio. Also, the width of the rib is equal to the slab thickness as a constraint condition in all the panels. Data were recorded at the loading stages to determine the load capacity and the deflection. A nonlinear finite element analysis carried out by using ANSYS-15 software program to analyze the panels and to verify the results. Increase the (d/h) ratio improved the structural behavior by increase the carrying load capacity and reduces the deflection to a certain limit. Compatibility results have been obtained between the numerical and experimental work.

***Keywords**: ANSYS, lightweight, micro-reinforcement, ribbed slab, load-deflection.*

1. Introduction

In civil engineering construction, the objective of using or selecting any material is to make full use of its properties in order to get the best performance for the formed structure. The merits of a material are based on factors such as availability, structural strength, durability and workability. As it is difficult to find a material which possesses all these properties to the desired level, therefore, the engineer's problem consists of an optimization involving different materials and methods of construction [1].

The one way ribbed floor systems consist of a series of parallel reinforced concrete tee beams framing into reinforced concrete girders with a whole depth greater than the solid slab depth. The systems of the ribbed slab are more economical for buildings where the spans are relatively large and the superimposed loads are small, such as in hotels, schools and hospitals. Many researchers focus on removing the ineffective area of the slab cross-section near the neutral axis to reduce the slab weight. The removal area may affect the behavior of the slab although it is ineffective in resistance to the flexural stresses. **De Oliveira** et al, carried out an investigation on eight ribbed slab panels to find out the sharing of a slab portion in resisting the shearing stresses. The total depth of the panel is 300mm with various thicknesses of the flange. The results showed that the significant contribution for the flange is in resisting the shearing stresses. The flexural steel strain was proportionally with increasing of the flange depth that gives more ductility. Increase the width of the panels did not lead to a significant increase in the ultimate load [2]. **Abdulwahab and Khalil** tested eight (0.25 scale) waffle slabs with different rib depth and rib spacing. The test plan was designed to inspect the effect of the depth and the spacing of the ribs on the strength and flexural rigidity of the waffle slabs. Two solid slabs were also included; the first has the same total slab depth as in the first group to study the torsional and flexural influences, and the second to investigate the equivalent thickness assumption. The same values of the failure loads are expected approximately because the concrete in a tension zone is not affected. The reduction in self-weight was about 16% by increasing 20% in the ultimate failure load by increasing the depth of the ribs in the waffle slab system [3]. **Olawale and Ayodele** used twenty model samples for solid and waffle slabs. The samples divided into two groups, included ten samples for each group. The first group were with small dimensions supported on all four sides, while the second group were with large dimensions supported on the two short sides. It was observed that the waffle slabs possess a flexural rigidity higher than the solid slabs. This shows the benefit of the waffle slabs in comparison with the solid slabs by supporting the heavier loads over a long span without needing to increase the depth [4].

Lightweight concretes (LWC) are significant materials in the construction industry due to the economic and the practical advantages [5]. The low evident specific gravity due to the porosity represents the fundamental characteristic of (LWC). In a construction of the concrete buildings, the self-weight represents very large parts of the design loads, therefore there is an important advantage in reducing the concrete density. Besides, (LWC) reduces the cost of formwork, steel and increases its output [6,7]. The normal concrete density is considered ranging between 2240 kg/ m^3 and 2480 kg/ m^3, while the (LWC) has a density not exceeding 1920 kg/ m^3 [8]. In this work, the authors attempted to find the optimum cross-section by studying the effect of the ratio of the rib depth to the overall beam depth (d/h) in the lightweight ribbed slabs. Two conditions were taken into consideration in this study. The first is that the rib width is equal to the slab thickness and the second is that the concrete cross-section and the steel reinforcement areas are the same in the flat and the ribbed panels.

2. Experimental program

The experimental program consists of pouring and testing of four slab specimens; one slab specimen is considered as a reference slab (flat slab). The panel coding and the slab thickness are shown in Table 1. The length and the width of each panel are (1150) and (450) mm respectively. The details of the panel section are shown in Figure 1. The concrete volume and the reinforcement ratio are the same in all the panels. The ribbed slab specimens designed according to ACI-318M-14 [9].

Table 1: Panel Coding and Slab Thickness

No. of Specimen	Panel Coding*	Depth of the Rib (mm)	Overall Beam Depth (mm)	Ratio (d/h)
1	FS	0	100	0
2	RS1	37.5	117.5	0.319
3	RS2	64	134	0.477
4	RS3	100	160	0.625

*F: Flat, RS: Ribbed, S: Slab

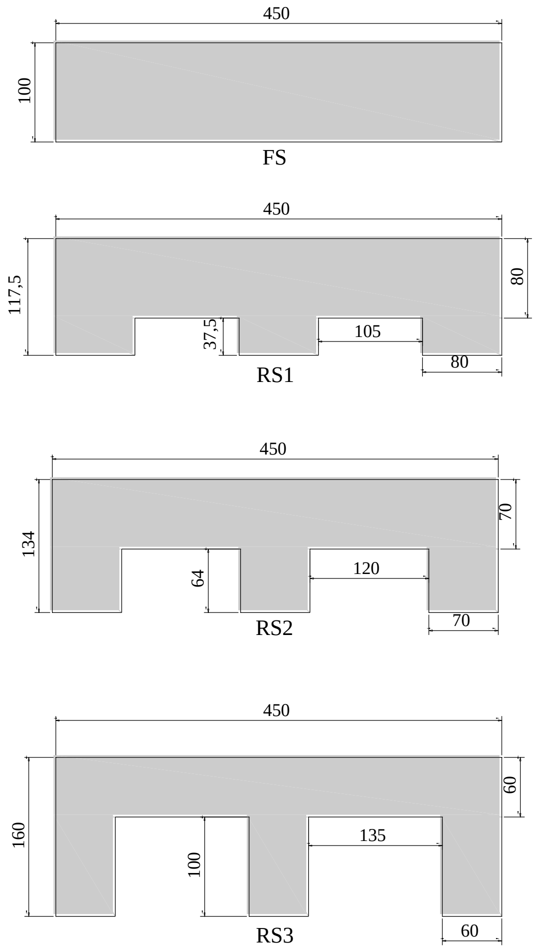

Fig.1: Sections of the panels (All Dimensions in mm)

The used materials and concrete mix proportions are presented in Table (2). The reinforcing steel was a multi-layered bi-directional of a micro-reinforcement with a diameter of (1.55mm) and clear spacing (10mm) in each direction according to ASTM A 1008 Ductile steel. This type of steel which also called MicroMat system provides both structural strengthening and hardening capabilities. The resulting of high-performance composite section has an extremely high energy absorption, ductility characteristics similar to steel and very high flexural, shear, and compressive strengths [10]. The details of the reinforcement are illustrated in Figures 2 and 3.

Table 2: Lightweight Concrete Mix

Material	Quantity kg/ m^3
Cement (ordinary Portland cement Type I)	800
Sand (pass from sieve 600µm)	800
Silica Fume (8 % of wt. of Cement)	64
Limestone (95% pass through sieve 90µmm)	320
w/c (33% of wt. of cement)	264
Superplasticizer liter/m^3 (6 % of Cementitious Materials)	52
Aluminum powder (0.2 % of wt. of cement)	1.6

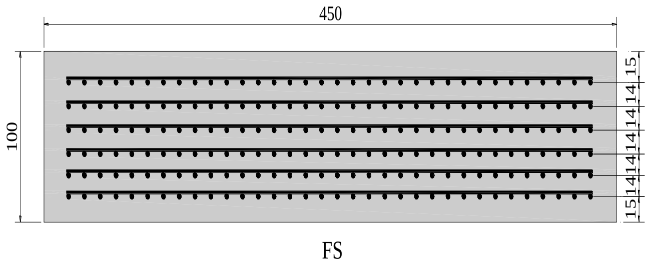

Fig. 2: Micro-reinforcement of (FS) (All Dimensions in mm)

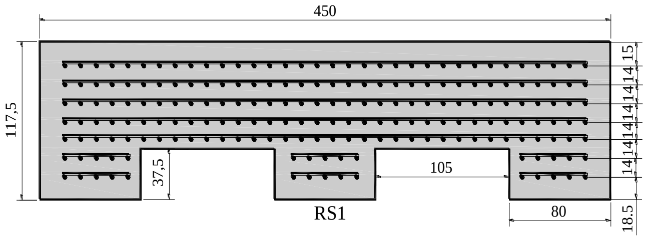

Fig. 3: Micro-reinforcement of (RS1) (All Dimensions in mm)

The panels tested under two-point loads as simply supported up to the failure as shown in plate 1.

Plate 1: Test of the ribbed slab panel

3. Numerical work

Numerical analysis has been carried out by a nonlinear finite element program for all the experimental tested slabs. The analysis performed by the finite element software ANSYS (Version 15) [11]. The elements for the panel components are presented in Table 3. The total number of the elements used in the numerical analysis was about 63678. The real constants are needed for representing the element geometric properties such as thickness, cross-sectional area, initial strain and other values. Also, the material properties are needed to represent the characteristics which depend on the mechanical properties tests such as modulus of elasticity, Poisson's ratio and density.

Table 3: Characteristics of the Selected Elements

Panel Components	Element Type	Element Characteristics
Concrete	Solid65	Defined by eight nodes and the isotropic material properties.

Reinforcing Bars	Link180	Defined by two nodes, the cross-sectional area, an initial strain, and the material properties.
Steel plate	Solid45	Defined by eight nodes and the orthotropic material properties.

Only a quarter of the panel considered by symmetrical boundary conditions and loading. The supported nodes constrained to move in the three directions (Ux =Uy= Uz=0). The test carried out by taking a quarter of the panel because the full specimen takes a long time. The planes of symmetry and the finite element mesh are shown in Figure 4. The micro-reinforcement modeled by the element link 180. The details of the micro-reinforcement are shown in Figure 5.

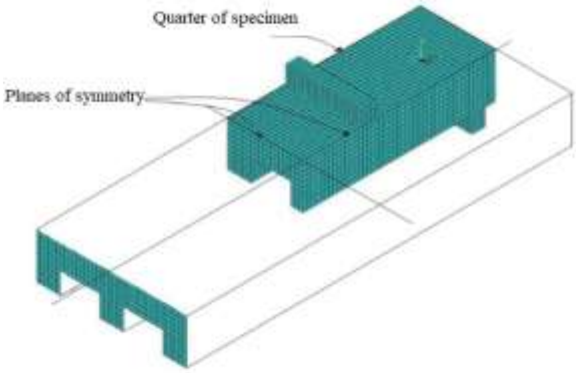

Fig. 4: Planes of symmetry

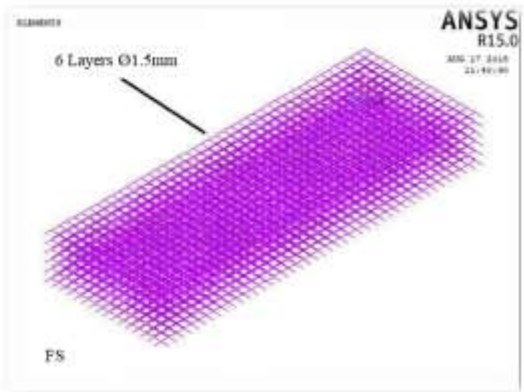

Fig. 5: Micro-reinforcement for quarter flat panel

4. Results and Discussion

During the experimental work, general behavior, mode of failure, cracking load, ultimate load, for each panel specimen were observed. The test results are recorded, summarized and given in Table 4. The first cracks of all specimens occurred at mid-span with increasing rate gradually as the load increased. Cracks appeared on each side of the specimen until the failure. Plate 2 shows the failure modes and the cracks pattern of the tested panels. At the early stage of loading, the first cracks appear at bottom of mid-span in the tension zone. When the load increases, these cracks become wider and going up, as well other cracks which will develop in the similar zone. Additional loading made the cracks to spread and extend faster. Some of the cracks reach the compression zone until the failure occurs at ultimate load capacity.

Plate 2: Failure Modes and Cracks Pattern

4.1. Load-deflection relationship

The type of the cross-section of the panel has a great effect on the ultimate load capacities and deflection values. The flat panel has the same volume of concrete and reinforcement of the ribbed panel. By comparing the flat slab panel (FS) of (d/h) equals zero with the ribbed slab panel (RS1) of (d/h) equals 0.319, the ultimate load capacity of the ribbed panel (RS1) increases by (26.35%) and the ultimate deflection decreases by (6.1%). When the (d/h) ratio equals 0.477, the ultimate load capacity of the ribbed panel (RS2) increases by (30.23%) while the ultimate deflection decreases by (13.58%). By increasing the ratio of (d/h) to 0.625 in (RS3), the ultimate load capacity increases by (37.2%) while the ultimate deflection decreases by (22.22%) by comparison to the flat panel (FS). The increase in ultimate capacity is due to the increasing of the section stiffness by conversion the panel section from a flat to a ribbed section. The load-deflection relationship in Figure 6 shows an improvement in the ductility properties with increasing the (d/h) ratio when the width of the rib equals to the slab thickness. When the ratio (d/h) increases in the ribbed panels RS1 and RS2 from 0.319 to 0.477, the percentage of increase in ultimate load capacity reduces from 26.3% to 3%, while the percentage of decreasing in ultimate deflection rises from 6.1% to 7.8%. But, when the ratio (d/h) increases in the ribbed panels RS2 and RS3 from 0.477 to 0.625, the percentage of increase in ultimate load capacity rises from 3% to 5.3%, while the percentage of decreasing in ultimate deflection reduces from 7.8% to 4.3%. This means that the increase of the (d/h) ratio improves the structural behavior by increase the carrying load capacity and reduce the deflection up to a certain limit. By increasing the (d/h) ratio beyond this limit, the performance of the section begins to decline. The ribbed panel (RS3) which gave the highest ultimate load and lowest deflection represents the better section near the optimum design of the ribbed slab.

Table 4: First and Ultimate Cracking Results

Coding	First Cracking Load (P_{cr}) kN	Deflection at Cracking Load (Δ_{cr}) mm	Ultimate Load (Pu) kN	% of Difference in Ultimate Load	Ultimate Deflection (Δ_u) mm	% of Difference in Ultimate Deflection
FS	15	1.55	64.5	0	8.1	0
RS1	16	1.5	81.5	+26.3	7.6	-6.1
RS2	21.5	1.9	84	+3	7	-7.8
RS3	22.5	1.77	88.5	+5.3	6.7	-4.3

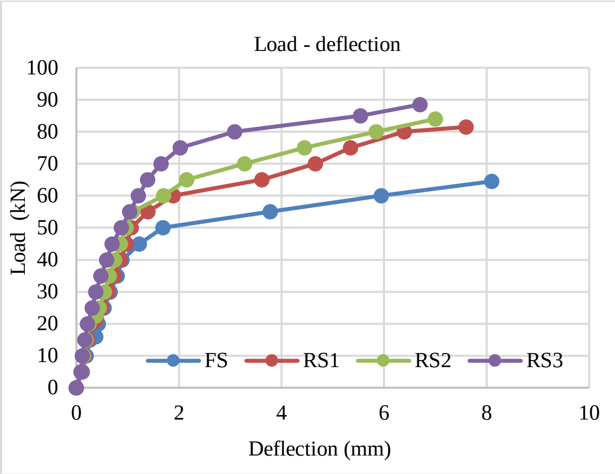

Fig. 6: Load-deflection curves of the panels

4.2. Comparison of numerical and experimental results

The experimental and numerical results of the ultimate load capacity with the corresponding displacements are shown in the Table 5. The numerical load-deflection response for the panel specimens are plotted and presented in Figures 7 to 10. Also, the deflected profiles (deflection contour) of the finite element models are shown in the Figures 11 and 12. The results of the maximum deflection and the ultimate load of specimens from the finite element analysis referred a good agreement with the results from the experimental test of specimens. The difference between experimental work and numerical analysis was about (4%) in the ultimate load (Pu) and (8%) in the ultimate deflection (Δu). These ratios are seemed to be reasonable and accepted. The failure loads obtained from the numerical analyses were higher by about (3%~6 %) than the values from the experimental results. This may be due to the ideal conditions of the concrete homogeneity assumed in the numerical solution and/or due the smooth rate of loading .

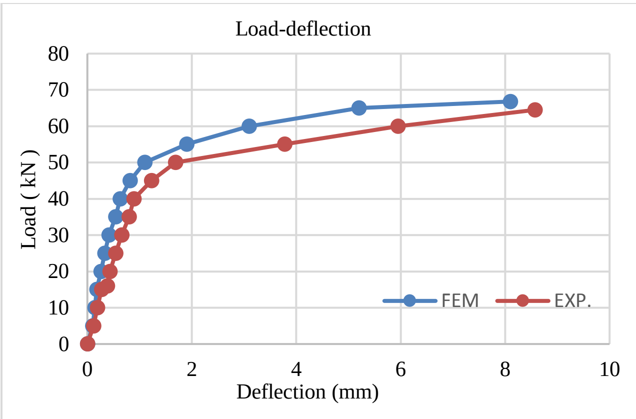

Fig. 7: Load-deflection curve comparison of FS

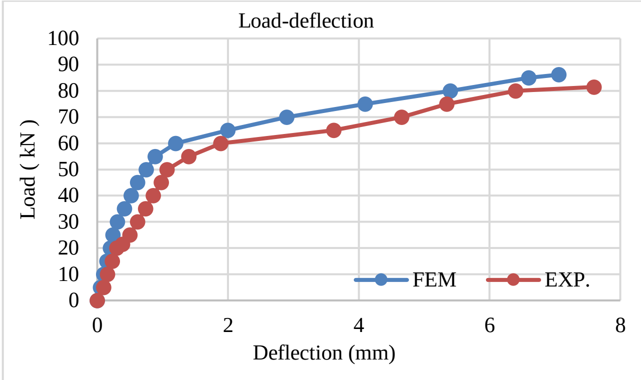

Fig. 8: Load-deflection curve comparison of RS1

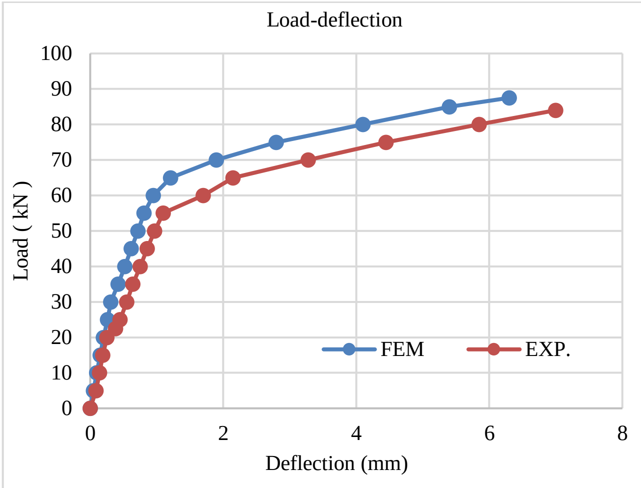

Fig. 9: Load-deflection curve comparison of RS2

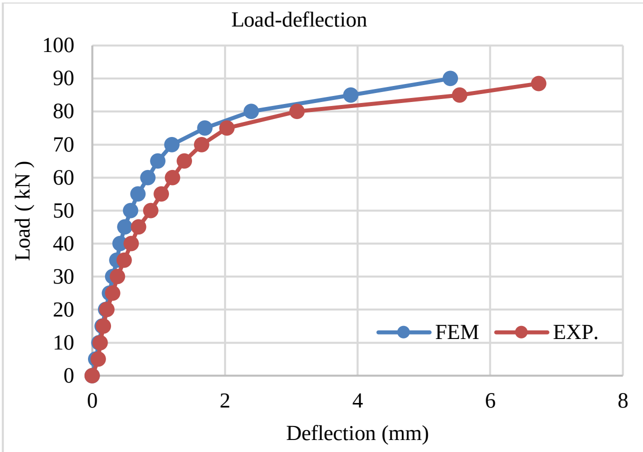

Fig. 10: Load-deflection curve comparison of RS3

Table 5: Numerical and Experimental Results

Coding	Experimental Results		Numerical Results		Load Correction Factor	Deflection Correction Factor
	Pu (kN)	Δu (mm)	Pu (kN)	Δu (mm)	PuN/ PuE	ΔuN/ ΔuE
FS	64.5	8.1	66.6	7.61	1.033	0.94
RS1	81.5	7.6	86.2	7.06	1.058	0.93
RS2	84	7	87.5	6.3	1.042	0.90
RS3	88.5	6.7	93.8	6.09	1.06	0.91
Average					1.048	0.92

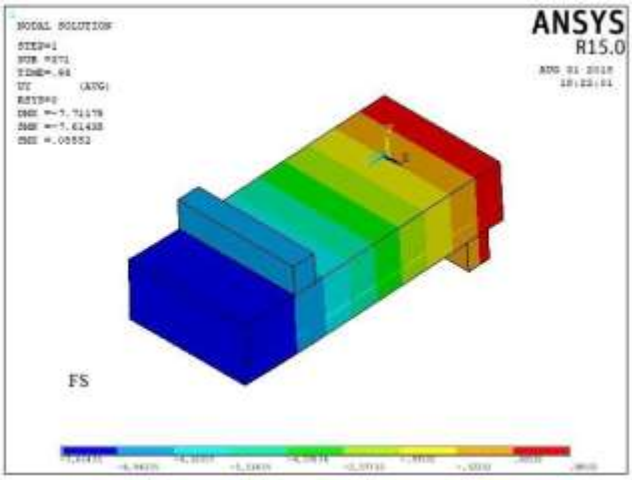

Fig. 11: Deflection contour of FEM analysis for FS

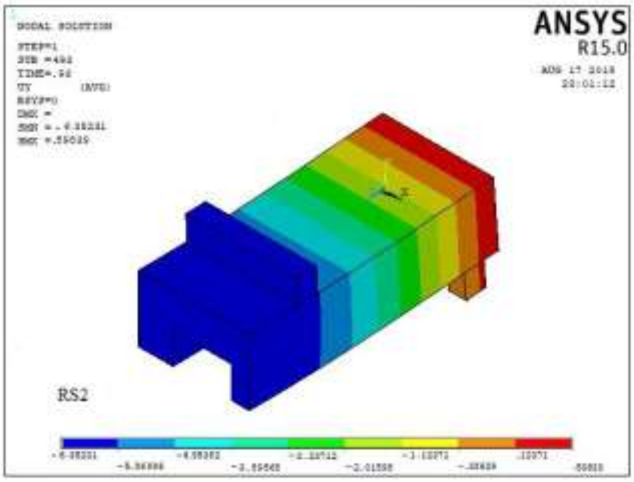

Fig. 12: Deflection contour of FEM analysis for RS2

5. Conclusions

Based on the experimental and numerical results, the following main conclusions were obtained:

1. Chang of the cross-section type from a flat panel to a ribbed panel with the same concrete volume and the same reinforcement ratio, causes an improvement of the load carrying capacity and reduce the observed deflection.
2. The increasing ratio of (d/h), with the equality condition of the rib width and the slab thickness, plays a significant role to increase the flexural stiffness and enhances the structural performance of the panel.
3. The better ratio of (d/h) was (0.625) which near to the optimum ratio, due to the highest ultimate load and lowest deflection.
4. The adopted three-dimensional finite element model is suitable to expect the behavior of concrete ribbed panels.
5. The numerical and experimental results for the tested panels showed a compatible acceptance throughout the entire range of their behavior.
6. The failure loads from the experimental results were lower about (3~6) % than the loads from the numerical analyses.

Acknowledgement

The authors would like to thank the Mustansiriyah University - College of engineering in Baghdad - Iraq, for the support of this work.

References

[1] Yam, L.C.P., "*Design of Composite Steel-Concrete Structures*", Surry University Press, London, (1981), 168 p.
[2] De Oliveira, W. M. Souza., and T. R. G. Caetano, "Shear Strength of Reinforced Concrete One-way Ribbed Slabs.", *Ibracon structures and materials journal*, Vol.4, Issue 5, (2014).
[3] Abdul-Wahab, H. M., and M. H. Khalil, "Rigidity and Strength of Orthotropic Reinforced Concrete Waffle Slabs.", *Journal of structural engineering*, Vol.126, Issue 2, (2000), pp. 219-227.
[4] Olawale, A. J and A. G. Ayodele, "A Comparative Study on the Flexural Behaviour of Waffle and Solid Slab Models When Subjected to Point Load" *Journal of civil engineering and architecture*, Vol.4, Issue 5, (2014).
[5] Skoyles, E.R., Bardhan-Roy, K., "A Comparative Study of Economics of "Lightweight Structural Concrete Floor Slabs in Building", *The international journal of lightweight concrete*, Vol.1, No.1, (1979), pp.9-27.
[6] Ali, M. A., "The Possibility of Produce Self Compacted Polystyrene Concrete", *Journal of engineering and development*, Vol. 16, No.4, (2012), pp. 1-15.
[7] Slate, F. O., Nilson, A. H., and Martinez, S., "Mechanical Properties of High-Strength Lightweight Concrete", *ACI Journal*, Vol. 83, No. 4, (1986), pp. 606-613.
[8] ACI Committee 213R-03, *"Guide for Structure Lightweight-Aggregate Concrete"*, American Concrete Institute, USA, (2003), pp.1-37.
[9] ACI Committee 318, *"Building Code Requirements for Structural Concrete (ACI 318-M14)"*, American Concrete Institute, USA, (2014).
[10] Structural Technologies *"DUCON® Micro-Reinforced Concrete Armoring System*, http://www.structuraltechnologies.com.au.
[11] ANSYS, *"ANSYS Help"*, version 15.0, Copyright (2013).