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PUNCHING SHEAR ANALYSIS OF STRUCTURAL LIGHTWEIGHT FOAMED CONCRETE FLAT SLABS WHEN EXPOSED TO FIRE

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ملخص البحث:

هذا البحث يهدف الي عمل تحليلا لسلوك الخرسانة الخفيفة الوزن نظريا من خلال استخدام حبيبات البوليسترين كحل بديل جزئي لخفض وزن وحدة الخرسانة الجافة من ٢٣ كيلو نيوتن/ متر٣ إلى 1.82 كيلو نيوتن / متر٣ تحت تأثير الحمل المركزي و الامركزي عند تعرضها للحريق من عدمه.

البرنامج النظري يتكون من مجموعتين من البلاطة اللاكمرية المسلحة من الخرسانة خفيفة الوزن. المجموعة الاولي تحتوي علي ثلاثة بلاطات الاولي و الثانية تحتوي على نسبة حديد 0.7% الاولى تم إختبارها تحت تأثير حمل مركزي و الثانية تحت تأثير حمل لامركزي بنسبة e/t=0.5 و الثالثة تحتوي على نسبة حديد 4.0%. أما المجموعة الثانية تم إختبار هذه البلاطات تحت تأثير تعرضها للحريق بدرجة مئوية 60 لمدة ساعة. ابعاد جميع البلاطات 150*1750*1750 مم (عرض * طول *ارتفاع)علي التوالي.

وتم عمل الدراسة البارامترية عن طريق عمل النماذج باستخدام احد البرامج للعناصر غير الخطية (ANSYS-15.0) التي اشتملت علي عدد ستة عشر بلاطة لاكمرية مسلحة من الخرسانية خفيفة الوزن تحت تأثير الأحمال المركزية و اللامركزية عند تعرضها للحريق، واظهرت النتائج ان زيادة نسبة لامركزية الحمل (e/t=0.5, 0.75 و 1.0) على البلاطات اللاكمرية المسلحة من الخرسانة خفيفة الوزن أدى ذلك إلى إنخفاض في حمل الانهيار بمتوسط (11.59%, 30.19%, 44.19% بالتتالي) و إنخفاض في الهبوط الأقصى المقابل لحمل الانهيار بمتوسط (23.44%, 28.43%, 34.16% بالتتالي).

Abstract

Reinforced concrete flat slab is used in a wide range of applications. In addition, reduction of the weight of the concrete used increases the advantages of the flat slab. The main objective of this work is to study the performance of structurally reinforced foam concrete flat slab exposed to fire under eccentric and concentric loads. The numerical specimens included six tested square slabs with typical dimensions of 150 mm thickness, 1750 mm total length and the column cross section was 200 × 200 mm at the center of the slab to verification the experimental specimens that presented by Riad and Shoeib [1]. The density of the used lightweight polystyrene foam concrete was 1820 kg/m^3. The crack patterns, load–deflection curves, steel strains and deflection during the fire were investigated by software analysis_(ANSYS-15.0). As an additional comparative investigation, of the slabs to enhance the understanding of the mechanics by (ANSYS-15.0). The results showed that maximum load of the tested slab with foam concrete were reduced compared to those of normal concrete. From the analysis of the results, it was found that the fire caused a reduction in the ultimate loads in the case of tested foam concrete slabs compared to that of normal-weight concrete slab. And also, the deformation of slabs foam concrete slab during the fire was increased comparing with normal-weight concrete slabs. In a theoretical study, the Proposal reduction factors of compressive strength during the fire for Foamed Concrete was done.

Keywords: Lightweight concrete, Foam concrete, Flat slab, Fire condition.

1-INTRODUCTION

Lightweight concrete (LWC) has been used in construction since the eighteenth century. It is very important in decreasing the cost of reinforced concrete (RC) structures. The weight and type of coarse aggregate and the ratio between fine and coarse aggregate are the main parameters used to reduce the density of concrete (less than 1800 kg/m^3) [1–4]. Foam with different forms is used in the construction field and can be used in the mixed material of concrete. Its application depends on its density [5–6]. There are many studies on the used foam in reinforcement concrete structural element [7–15]. The use of foam to produce lightweight concrete in construction may become more widespread than traditional lightweight concrete because the manufacturing foam can be available in different countries.

M. Tech Scholar et al. 2014 [7] investigated two foam concrete mixtures produced with and without sand, and attempts have been made to select the proportions of foam concrete mix for the target plastic density of 1900 kg/m^3. They concluded that the mixed proportion of foam concrete used in this research could not be used for structural purposes because the 28-day compressive strength of the foam concrete is less than 17.0 MPa. A.A. Hilal, N.H. et al. [8] presented an experimental study on the enhancement of pre-formed foam concrete with densities from 1300 to 1900 kg/m^3 using two types of additives (silica fume and fly ash) together with a water reducer agent. The results showed that the additives improved the pore structure, increased the strength, reduced the water absorption, and slightly increased the thermal conductivity of foam concrete. Wan Ibrahim M. H et al. [9], investigated the effects of polyolefin fibers at a relatively low volume fraction (0.0%, 0.20%, 0.40%, and 0.60%) on the compressive and flexural properties of foam concrete with density ranging from 1300 to 1600 kg/m^3. The test results showed that polyolefin fibers only slightly improved the compressive strength and flexural strength of the foam concrete by 4.3% and 9.3%, respectively.

Lee, Yee et al. (2017) [10] tested RC slabs and beams made of lightweight foamed mortar with density ranging from 1700 to 1800 kg/m^3. The produced compressive strength was equal to 20 MPa. The results showed that reinforced lightweight foamed mortar beams caused a reduction in the maximum load from 8.0% to 34.0% compared with normal-weight RC with the same reinforcement configuration.

There are many works [16–18] that have studied the behavior of flat slabs exposed to fire; however, the behavior of polystyrene foam concrete exposed to fire has not been studied before. From the previous review, we found that, by using different additives and various fibers, the foam concrete can be successfully used in RC structures. The structural polystyrene foam concrete slabs can be used to replace hollow block slabs and thermally isolated layers.

The main task of this paper is to study the efficiency of structural lightweight polystyrene foam concrete flat slabs under different parameters when exposed to fire.

2-Numerical Program

2-1-Numerical Specimens and Parameters

The numerical specimens included six tested RC square slabs with typical dimensions of 150 mm thickness and 1750 mm length. The clear span was equal to 1650 mm. The RC column is square with 200 mm in the case of the concentric load. In the case of an eccentric load, the column was extended above the slab compression face by 200 mm for all tested specimens. The typical concrete specimen's dimensions and reinforcement details are shown in Figure 1 as the experimental specimens that presented by Riad and Shoeib [1].

The main parameters in this work are the effect of the percentage of tension steel reinforcement (0.40% and 0.70%) and type of vertical loads (concentric or eccentric) on the performance of flat slab when exposed to fire. Six specimens with polystyrene foam concrete slab were tested.

The eleven tested specimens were divided into two groups, as follows. The first group comprised three specimens, which were used to study the effect of load types and the main steel ratios on the behavior of light-weight concrete. The second group, with three specimens, examined the effect of fire on the behavior of light-weight concrete. The slabs were first loaded to 30% of the ultimate load from the control test slabs as service existing load for slab in building. At this load, the slabs were exposed to fire to reach 500 °C for one hour. Then, the loading of the slabs was continued up to the ultimate load after cooling by air. Table (1) summarizes the difference between the analytical model and the experimental results

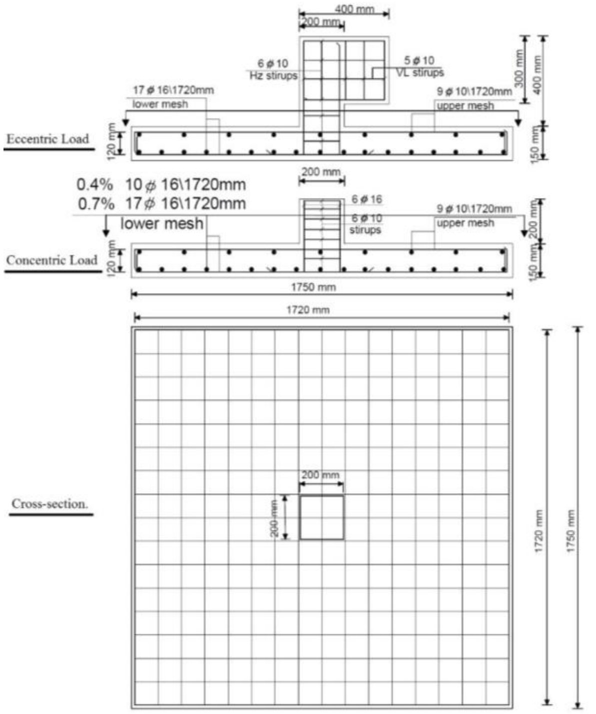


Figure (1): Typical dimensions and RFT for tested specimens

Table (1): Verification of the Analytical Model and tested specimens of Riad and Shoeib [1].

Group	**Specimen**	**Specimens Code**	**Failure Load (kN)**			**Deflection at Edge of Column (mm)**		
			Experimental	**Analytical**	**% Diff.**	**Experimental**	**Analytical**	**% Diff.**
G1	S6	LACH	430	459.7	6.9	17.72	16.04	-9.48
	S7	LAEH	367	406.4	10.73	11.4	12.28	7.71
	S11	LACU	343	376.6	9.8	15.5	14.55	-6.13
G2	S8	LFCH	332	341.33	3	19.75	19.44	-1.57
	S9	LFEH	238	272.24	14.38	14.33	13.23	-7.68
	S10	LFCU	278	286.7	3.13	15.9	15.95	0.5

L* lightweight concrete, A* without fire, F* exposed to fire, C* under concentric load, E* under eccentric load, U* 0.4% rft from gross area of slab, H* 0.7% rft from gross area of slab.

2-2-Modeling Slabs by ANSYS-15.0

This section elaborates elements types, real constant, material properties, numerical concepts, boundary conditions and analysis types so as process together with load stepping.

2-2-1-Elements Types

The following elements are elaborated here, as follows:

2-2-1-1-Concrete Element

Their used two version of concrete element; the first version was solid 70 to modeling a thermal element slab and the second version was solid 65 to modeling a structural element slab.

A thermal version of the model was used to calculate the temperature profile in the concrete slab; a structural version of the model then read the temperature profile to calculate stresses.

Their use at high temperatures creates thermal stresses. Temperature distribution data of thermal analysis is required in the coupled field analysis finally to obtain and analyze thermal stresses. It is, therefore proposed to take up a heat conduction problem using finite element method to obtain temperature distribution data of a reinforced concrete slab at high temperatures.

The distributions of thermal elastic stress components were then calculated by switching the solid 70 thermal element to solid 65 structural element.

2-2-1-1-1-Structural Concrete Element and Thermal Concrete Element

Solid65 geometry has an element of solid 8-node. It is used to simulate the concrete element. It is special for 3-D modeling for solid concrete elements with or without reinforcing bars. The element allows the presence of three different reinforcing materials. It has 3 freedom degrees at each node (i.e. translation in nodal x-y-z directions). It is capable of plastic-deformation, cracking in 3-orthogonal-direction, and crushing. The geometry is presented in Figure (2). A three-dimensional 8-nodded tetrahedral element having thermal degree-of-freedom (element type solid70 in ANSYS 15.0) is chosen for heat conduction problem as shown in Figure (3)

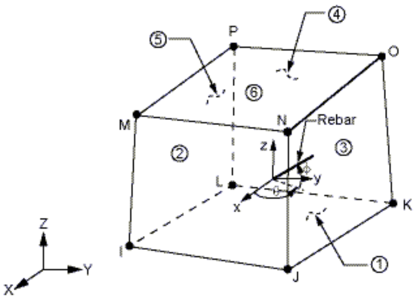


Figure (2): Structural Element Solid65.

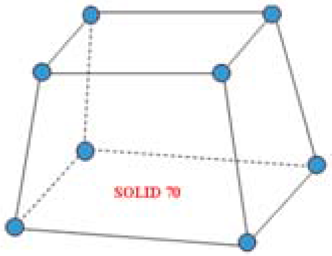


Figure (3): Thermal Element Solid70.

2-2-1-2-Steel Reinforcement Element

For discrete model, aLink180 is used to simulate steel reinforcement. For this element, 2 nodes are needed, each with 3 freedom degrees (i.e. translation in x-y-z directions). It is proficient in plastic-deformation. Its geometry and node position are as presented in Figure (4). Accordingly, a discrete model was chosen to be applied in this study.

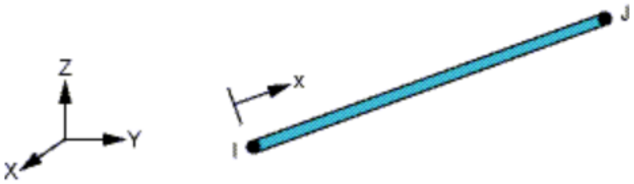


Figure (4): Link180 in ANSYS-15.0.

2-2-1-3-Lead Plates and Supports

Solid185 has eight nodes with three freedom degrees, at each node (i.e. translation in x-y-z directions). It is plastic and hyper-elastic. It allows for stress-stiffening and creep so as large deflection together with large strain. It is formulated to simulate deformation of incompressible elasto-plastic materials and incompressible hyper-elastic materials. Its geometry and position is presented in Figure (5).

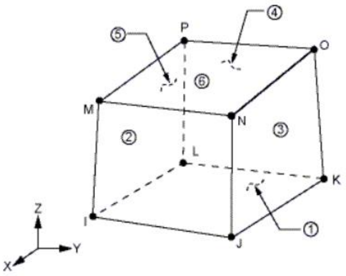


Figure (5): Solid 185 in ANSYS-15.0.

2-2-4-Loads and Boundary Conditions

Displacement boundary conditions constrain the model to reach a unique solution. They are applied at supports and loadings exist in order to ensure that model acts similar to experimental slab. The slab is modeled as a simply supported, which it has constrained in the UY. Two nodes in X-direction are constrained in the UX and another two nodes in Y-direction UY. The displacement is applied at the column head based on its position. The displacement applied at a single node on upper plate. The support and the displacement applied are presented in Figure (6).

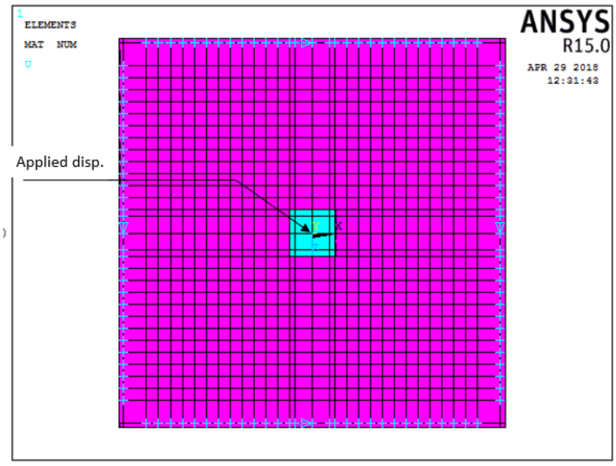


Figure (6): Support Condition and Applied Displacement**.**

3-Verification of the Analytical Model

3-1-Crack Patterns and Load-Deflection Curves

Figure (7) presents the propagation of cracks of the slab just before failure using finite element model and actual failure shape, which is very close. This indicated a good agreement between finite element and experimental one. As shown in Figures (8), (9), and (10), the numerical models gave load versus mid span deflection in good agreement with the experimental one.

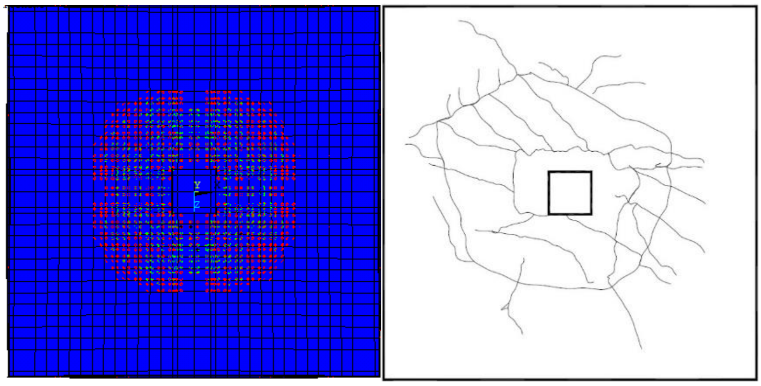


Figure (7): Experimental Failure Compared to Cracks Propagation before Failure from Finite Element Model for Slab S6 (LACH).

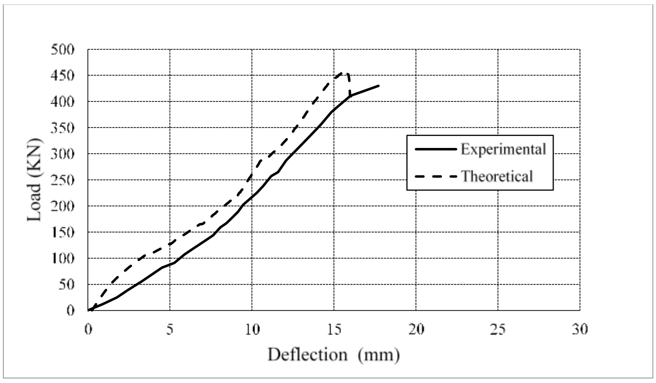


Figure (8): Load-Deflection Relationship for Slab S6 (LACH).

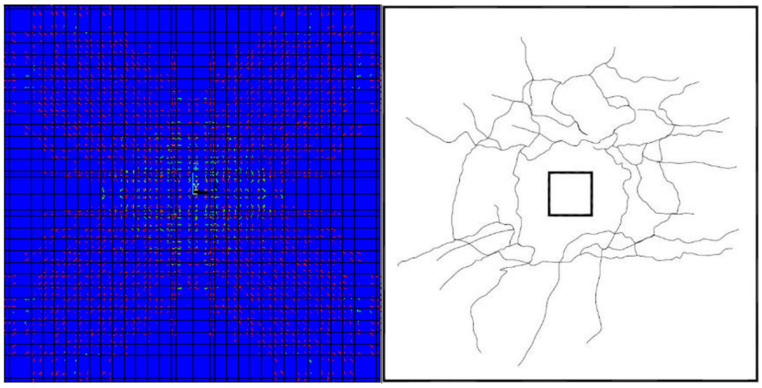


Figure (9): Experimental Failure Compared to Cracks Propagation before Failure from Finite Element Model for Slab S8 (LFCH).

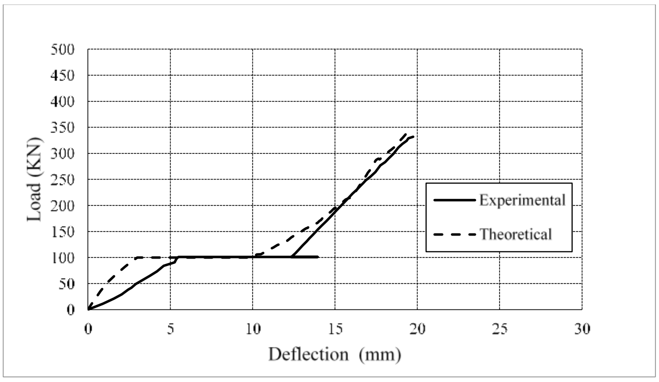


Figure (10): Load-Deflection Relationship for Slab S8 (LFCH).

4-Parametric Study

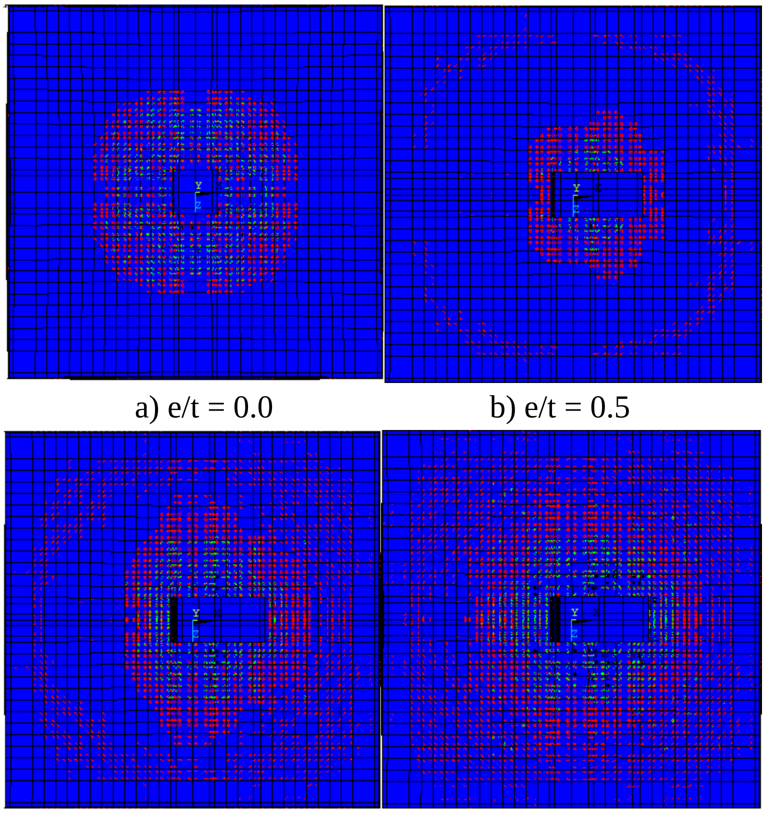
A parametric study including thirty-two square reinforced LWC slabs under concentric and eccentric loads. This parametric study database investigates the influence of the different parameters on reinforced LWC, such as percentage of the main reinforcement steel and fire condition.

the non-linear finite element results of the parametric study database are presented and the significance of each parameter on the slabs failure mechanism is elaborated. The parametric study database is presented in Table (2).

Table (2): Parametric Study Database of Slabs.

Group	Specimens	Specimens code	Type of concrete	Heating Temp (C°).	Eccentricity Ratio (e\t)	Main RFT %	Flexure RFT
G1	1	LACH	LWC	Non	No	H	17 Ø 16
	2	LAE$_1$H			0.5		17 Ø 16
	3	LAE$_2$H			0.75		17 Ø 16
	4	LAE$_3$H			1.0		17 Ø 16
	5	LACU			No	U	10 Ø 16
	6	LAE$_1$U			0.5		10 Ø 16
	7	LAE$_2$U			0.75		10 Ø 16
	8	LAE$_3$U			1.0		10 Ø 16
G2	9	LFCH	LWC	500°	No	H	17 Ø 16
	10	LFE$_1$H			0.5		17 Ø 16
	11	LFE$_2$H			0.75		17 Ø 16
	12	LFE$_3$H			1.0		17 Ø 16
	13	LFCU			No	U	10 Ø 16
	14	LFE$_1$U			0.5		10 Ø 16
	15	LFE$_2$U			0.75		10 Ø 16
	6	LFE$_3$U			1.0		10 Ø 16

L* lightweight concrete, A* without fire, F* exposed to fire, C* under concentric load
E$_1$*, E$_2$* and E$_3$* under eccentric load (e/t) =0.5, 0.75 and 1.0 respectively.
U* 0.4% rft from gross area of slab, H* 0.7% rft from gross area of slab.



a) e/t = 0.0 b) e/t = 0.5

c) e/t = 0.75 d) e/t = 1.0

Figure (11): Cracks Propagation before Failure from Finite Element Model.

In case of, study the behaviour of lightweight RC flat slabs with RFT percentages equal to 0.7% and 0.4% when applying the concentric and changing eccentric vertical load e/t= 0.5, 0.75 and 1.0.

In case of high RFT percentage equal to 0.7%, the effect of applying the concentric and the changing eccentric vertical load LAE1H, LAE2H and LAE3H with e/t= 0.5, 0.75 and 1.0 respectively on the behaviour of lightweight RC flat slabs was noted as the following.

It is clear from Figures (12) and (13), when applying the eccentric vertical load LAE1H, LAE2H and LAE3H with e/t= 0.5, 0.75 and 1.0 respectively on the tested specimens with high RFT%, that the ultimate load decreased compared to concentric control specimen (LACH) by percentage 11.59%, 30.19% and 44.15% respectively, and the deflection corresponding to the ultimate load decreased with percentage 23.44%, 28.43% and 34.16% respectively. It noted also that, the stiffness of these tested specimens increased by increasing the eccentric vertical load, although the stiffness of the eccentric specimen with e/t= 1.0 becomes similar to concentric control specimen, as shown in Figure (6-75).

In case of usual RFT percentage equal to 0.4%, the effect of applying the concentric and the changing eccentric vertical load LAE1U, LAE2U and LAE3U with e/t= 0.5, 0.75 and 1.0 respectively on the behaviour of lightweight RC flat slab was noted as the following.

It is clear from Figures (14) and (15), when applying the eccentric vertical load LAE1U, LAE2U and LAE3U with e/t= 0.5, 0.75 and 1.0 respectively on the tested specimens with usual RFT%, that the ultimate load decreased compared to concentric control specimen (LACU) by percentage 15.10%, 31.40% and 47.27% respectively, and the deflection corresponding to the ultimate load decreased with percentage 10.65%, 17.73% and 24.74% respectively. It noted also that, the stiffness of these tested specimens increased by increasing the eccentric vertical load, although the eccentric specimen with e/t= 0.5 have the same stiffness of concentric control specimen, as shown in Figure (6-76).

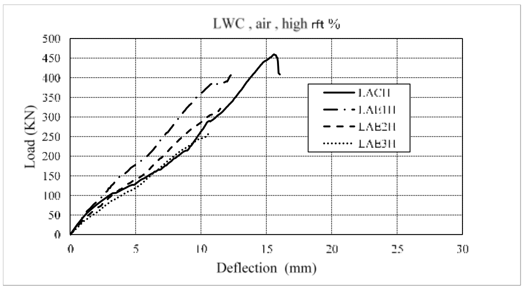


Figure (12): Effect of e/t Ratio on the Load-Deflection Curves for LWC with High RFT %.

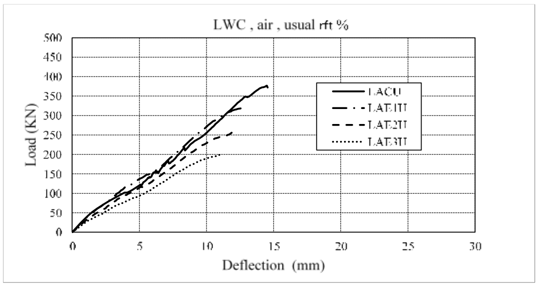


Figure (13): Effect of e/t Ratio on the Load-Deflection Curves for LWC with Usual RFT %.

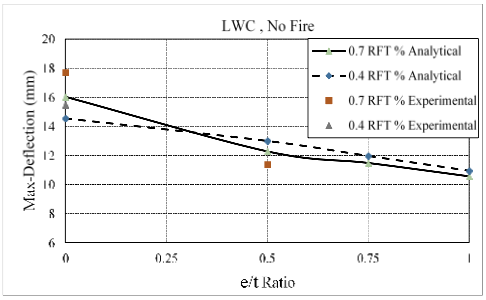


Figure (14): Effect of e/t Ratio on the Ultimate Load for LWC.

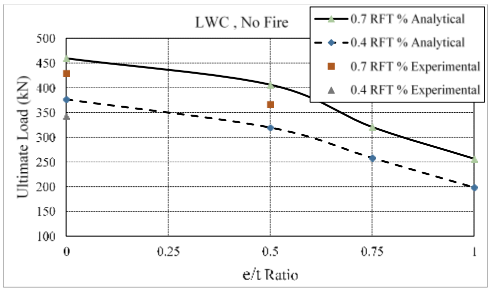


Figure (15): Effect of e/t Ratio on the Maximum Deflection for LWC.

In case of, study the behaviour of lightweight RC flat slabs were exposed to fire with RFT percentages equal to 0.7% and 0.4% when applying the concentric and changing eccentric vertical load e/t= 0.5, 0.75 and 1.0.

In case of high RFT percentage equal to 0.7%, the effect of applying the concentric and the changing eccentric vertical load LFE$_1$H, LFE$_2$H and LFE$_3$H with e/t= 0.5, 0.75 and 1.0 respectively on the behaviour of lightweight RC flat slabs were exposed to fire was noted as the following.

It is clear from Figures (16) and (17), when applying the eccentric vertical load LFE$_1$H, LFE$_2$H and LFE$_3$H with e/t= 0.5, 0.75 and 1.0 respectively on the tested specimens were exposed to fire with high RFT%, that the ultimate load decreased compared to concentric control specimen (LFCH) by percentage 20.24%, 44.10% and 61.58% respectively, and the deflection corresponding to the ultimate load decreased with percentage 31.94%, 33.28% and 38.58% respectively. It noted also that, the stiffness of these tested specimens increased by increasing the eccentric vertical load, although the stiffness of the eccentric specimen with e/t= 1.0 becomes similar to concentric control specimen.

In case of usual RFT percentage equal to 0.4%, the effect of applying the concentric and the changing eccentric vertical load LFE$_1$U, LFE$_2$U and LFE$_3$U with e/t= 0.5, 0.75 and 1.0 respectively on the behaviour of lightweight RC flat slabs were exposed to fire was noted as the following.

It is clear from Figures (18), (19) and (20), when applying the eccentric vertical load LFE$_1$U, LFE$_2$U and LFE$_3$U with e/t= 0.5, 0.75 and 1.0 respectively on the tested specimens were exposed to fire with usual RFT%, that the ultimate load decreased compared to concentric control specimen (LFCU) by percentage 27.76%, 55.94% and 63.20% respectively, and the deflection corresponding to the ultimate load decreased with percentage 26.96%, 32.79% and 34.29% respectively. It is noted also that, the stiffness of these tested specimens increased by increasing the eccentric vertical load, although the eccentric specimen with e/t= 0.5 have the same stiffness of concentric control specimen.

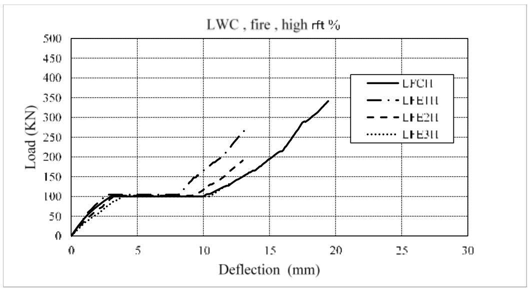


Figure (16): Effect of e/t Ratio on the Load-Deflection Curves for LWC with High RFT % when Exposed to Fire.

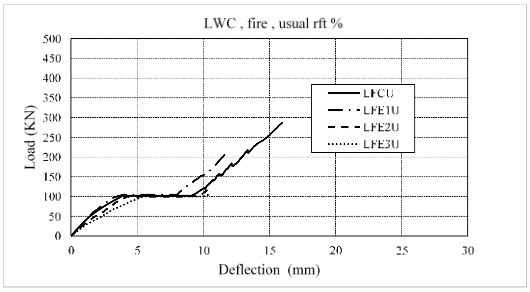


Figure (17): Effect of e/t Ratio on the Load-Deflection Curves for LWC with Usual RFT % when Exposed to Fire.

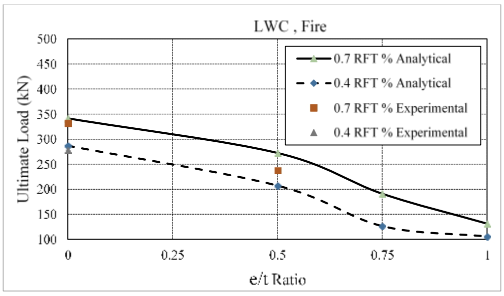


Figure (18): Effect of e/t Ratio on the Ultimate Load for LWC when Exposed to Fire.

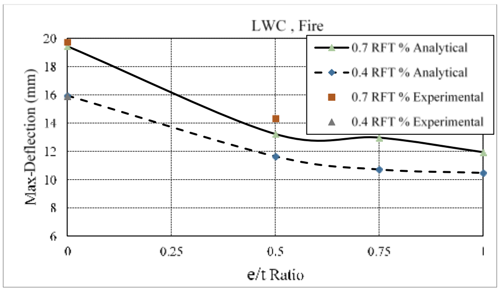


Figure (19): Effect of e/t Ratio on the Maximum Deflection for LWC when Exposed to Fire.

From Figure (6-83), we notice that, by increasing e/t Ratio to 0.5, 0.75 and 1.0, the deflection during fire process at constant load for LWC specimens with high RFT % equal to 0.7% decreases compared to control specimen (LFCH) by average percentage 16.5%. Moreover, in case of usual RFT % equal to 0.4%, the deflection during fire process at constant load decreases compared to control specimen (LFCU) by average percentage 13.3%.

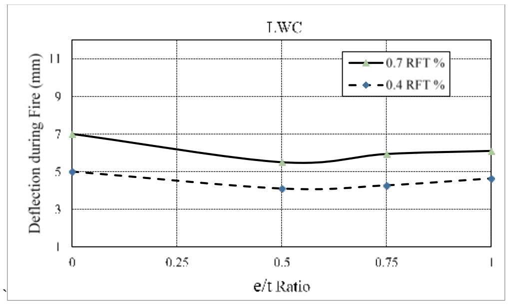


Figure (20): Effect of e/t Ratio on the Deflection during Fire Process for LWC.

5-CONCLUSION

By studying the behavior of structural lightweight foam concrete flat slabs when exposed to fire, we found that:

1. By applying the eccentric vertical load with e/t= 0.5, 0.75 and 1.0 on the LWC tested specimens with high RFT%, the ultimate load decreased compared to concentric control specimen (LACH) by percentage 11.59%, 30.19% and 44.15% respectively, and the deflection corresponding to the ultimate load decreased with percentage 23.44%, 28.43% and 34.16% respectively.
2. By applying the eccentric vertical load with e/t= 0.5, 0.75 and 1.0 on the LWC tested specimens with usual RFT%, the ultimate load decreased compared to concentric control specimen (LACU) by percentage 15.10%, 31.40% and 47.27% respectively, and the deflection corresponding to the ultimate load decreased with percentage 10.65%, 17.73% and 24.74% respectively.

3. By applying the eccentric vertical load with e/t= 0.5, 0.75 and 1.0 on the LWC tested specimens were exposed to fire with high RFT%, the ultimate load decreased compared to concentric control specimen (LFCH) by percentage 20.24%, 44.10% and 61.58% respectively, and the deflection corresponding to the ultimate load decreased with percentage 31.94%, 33.28% and 38.58% respectively, while the deflection during fire process at constant load decreases by average percentage 16.5%.
4. By applying the eccentric vertical load with e/t= 0.5, 0.75 and 1.0 on the LWC tested specimens were exposed to fire with usual RFT%, the ultimate load decreased compared to concentric control specimen (LFCU) by percentage 27.76%, 55.94% and 63.20% respectively, and the deflection corresponding to the ultimate load decreased with percentage 26.96%, 32.79% and 34.29% respectively, while the deflection during fire process at constant load decreases by average percentage 13.3%.
5. Further analytical investigate the effect of cooling in the analytical model slabs.

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