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Theoretical Study for Punching Behavior of Light Weight Concrete Slabs

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ملخص البحث

هذا البحث هو دراسة نظرية لسلوك البلاطات الخرسانية خفيفة الوزن تحت تاثير احمال الاختراق. تشمل الدراسة اثنى عشر بلاطه من الخرسانة التقليدية تم تنفيذها باستخدام طريقة العناصر المحددة (Finite Element Method) لعمل نماذج على برنامج "Ansys 14" مقسمة على مرحلتين ، المرحلة الأولى هي نماذج محاكاه لبلاطات من الخرسانة التقليدية منفذة معمليا ومختبرة سابقا للتحقق من دقة محاكاة النموذج الحاسوبى بمقارنة نتائجه مع النتائج المعملية ، المرحلة الثانية هي نماذج مناظرة لبلاطات من الخرسانة خفيفة الوزن وبنفس خواصها ولكن باستخدام الخرسانة التقليدية التي تم التحقق من نتائجها في المرحلة الأولى. هذه النماذج جميعها تم اختبارها حتى الكسر تجت تاثير احمال الاختراق المركزة من خلال برنامج الانسيس حيث وجد ان هناك تقارب بشكل جيد في نتائج اختبار نماذج المرحلة الأولى – نماذج المحاكاه- عند مقارنتها بالنتائج المعملية لنفس العينات مما يبين دقة وفاعلية النماذج المقترحة لاستخدامها في المرحلة الثانية. تم دراسة مدى تاثير عدة عوامل مثل وزن وحدة الحجوم للخرسانة وسمك البلاطة ومساحة التحميل وحديد التسليح ضد اجهادات القص على قيمة تحمل البلاطات لاجهادات الاختراق. يشتمل هذا البحث على عرض شامل لجميع الخطوات والتجارب والنتائج التي تم التوصل اليها حيث تم الحصول على قيمة اقصى حمل اختراق لكل نموذج بلاطة من النماذج التي تم اختبارها من خلال برنامج الانسيس وبناء عليه تم حساب قيمة معامل انخفاض حمل الاختراق (λ) للبلاطات الخرسانية خفيفة الوزن.
ان الهدف الرئيسى لهذه الرسالة هو استنباط معادلة تربط بين معامل الانخفاض (λ) ووزن وحدة الحجوم للخرسانة وقد تم تحقيق ذلك باستخدام النتائج التي تم التوصل اليها ثم مقارنة هذه المعادلة مع مثيلاتها في الاكواد الأخرى.

Abstract

This paper presents a Theoretical Study for Punching Behavior of Light Weight Concrete Slabs. Twelve normal weight concrete finite element models were developed by “Ansys 14” and divided into two systems. The First system are models developed to simulate control specimens for verifying the used material parameters and the second system are models developed by using (NWC) parameters verified from the first system to represent the (LWC) physical model with the same properties. These models were tested to failure under concentrated punching loads through the program. The results of the first system show good agreement with experimental and the program results. Thus, the proposal models in the first system have sufficient accuracy to be used in the second system. The concrete unit weight, slab’s thickness, shear reinforcement, and loaded plate area were the test parameters. A comprehensive presentation of the programmatic procedure, testes and results are given in this paper. The punching shear loads were obtained from the test results of all finite element models (FEM) and then the punching strength reduction factor (λ) is calculated for each case study. The main objective of this research is to find a relation between the reduction strength factor (λ) and the unit weight of concrete which was developed using mathematical regression techniques and compared with the available equations in other codes.

Keywords: LWC Slabs, Punching Shear behavior, Ansys program, Punching reduction factor (λ).

1. INTRODUCTION

Lightweight concrete has extreme importance in construction industry. Most of the current concrete research focuses on high-performance concrete, by which is meant a cost effective material that satisfies demanding performance requirements, including durability. Lightweight concrete (LWC) is very important to the construction industry due to its cost effective and highly advantages. Structural lightweight concrete mixtures can be designed to achieve similar strengths as normal weight concrete; the same is true for other mechanical and durability performance requirements. Structural lightweight concrete provides a more efficient strength-to-weight ratio in structural elements. In most cases, the marginally higher cost of lightweight concrete is offset by the size reduction of structural elements, less reinforcing steel and reduced volume of concrete, resulting in lower overall cost.

The primary advantage of using LWC is to reduce the dead load of the concrete structure, which allows the structural designer to reduce the size of carrying columns, footings and other load bearing elements. The use of lightweight aggregate concrete in a structure is usually predicated on lower overall costs. While lightweight concrete may cost more than normal weight concrete, the structure may cost less as a result of reduced dead weight and lower foundation costs. This is the basic reason, in most cases, for using structural lightweight concrete. Economy then depends on attaining a proper balance among cost of concrete per unit volume, unit weight, and structural properties.

Normal weight concrete may be the least in cost per unit volume, but will be heavier; resulting in greater dead loads, increased sizes in many sections, and therefore may require more concrete and reinforcing steel.

Lightweight foamed concrete is a new kind of Lightweight concrete, which combines the advantages of normal density concrete, cellular concrete and self-compacting concrete through partially replacing the normal weight aggregates with polystyrene foam, hence, leading to concrete's unit weight reduction while maintaining adequate strength. One of the most important elements in RC structures which can be produced from lightweight foamed concrete are the slabs.

2. LITERATURE REVIEW

The history of lightweight concrete (LWC) dates back to over 3000 years ago. LWC has been successfully used since the ancient Roman times and it has gained its popularity due to its lower density and superior thermal insulation properties. The usage of lightweight materials, such as pumice-stone, comes far away back since the Romans, when they mixed these aggregates with binders made of volcanic ashes and lime to get a concrete with low density.

Among various types of lightweight aggregates (LWA) used nowadays, synthetic LWAs such as Leca (Denmark), Liapor (Germany) Liaver (Germany) and Poraver (Germany), produced in special industrial processes, are widely used in LWC because of their properties (e.g. low density, low water absorption, high strength). More environmental and economic benefits can be achieved if waste materials can be used to replace the fine lightweight aggregate.

Concrete Compressive strength levels required by the construction industry for the usual design strengths can be obtained economically with the structural lightweight concrete (Shideler 1957; Hanson 1964; Holm

1980a). The modulus of elasticity of concrete depends on the relative amounts of paste and aggregate and the modulus of each constituent (LaRue 1946; Pauw 1960). Normal-weight concrete has a higher (Ec) because the moduli of sand, stone, and gravel are greater than the moduli of lightweight aggregates.

Reinforced concrete slabs supported on columns were initially developed in the United States of America and Europe in the beginning of the 20th century. Their designs typically included large mushroom-shaped column capitals to facilitate the local introduction of forces from the slab to the column. In the 1950s, flat slabs without capitals started to become prevalent because of their simplicity, both for construction and for use. One way shear is rate of change of bending moment. It's typically called beam shear. Two way shear is punching shear, it's also called flat slab shear. Punching shear is a type of failure of reinforced concrete slabs subjected to high localized forces. In flat slab structures this occurs at column support points. The failure is due to shear. This type of failure is catastrophic because no visible signs are shown prior to failure. Punching shear failure disasters have occurred several times in the past decade.

The design of slab-column framed systems often meets two main challenges, unacceptable deflections and punching shear failures around columns. Deflection-related problems in flat slabs are often eliminated by applying prestressing to the slab. However, connection punching shear failures are still of concern in the design of slab-column framed systems, particularly when located in regions of moderate to high seismicity because of the combination of gravity- and earthquake-induced shear stresses and deformations. Punching shear failures occur suddenly, without warning and therefore, they need to be prevented.

3. Research Program

3.1 Literature Experimental case studies

A complete parametric study were carried out and the parameters were investigated in this study; namely, the concrete type, the slab thickness, the amount of shear reinforcement and the loaded plate area. The study contains literature experimental case studies besides FEM models developed by the author. The experimental cases studied of this research were divided into two groups based on its source as follows:

Group (1) After "Ahmed Ali Mohamed Ali 2010 ": The thesis consists of Seven (7) LWC slabs (spec. L1-L7) and one (1) NWC control slab (spec. N2).

Group (2) After "K.S. YOUM, et al. 2014":The thesis consists of three (3) LWC slabs (spec. LA-LD) and one (1) NWC control slab (spec. NR).

3.2 Details of "ANSYS 14" Models

"ANSYS 14" FEM were developed as follows:

Stage (I), two FEM (spec. N2, NR) to simulate the two (NWC) control specimens. Material parameters of these models were adjusted to match the experimental results.

Stage (II), contains (10) (FEM), (7) models (spec. N(L1)- N(L7)) to simulate the equivalent (NWC) specimens of the 1st group and (3) models (spec. N(LA)- N(LD)) to simulate those of the 2nd group.

Tables 3.1 & 3.2 show the details of both tested specimens literature experimental case studies spec. & FEM models spec.

Table 3.1 Summary of group (2) Specimens data

Specimen		Loaded Area (cm2)	Slab thickness cm	Shear RFT	Concrete Comp. strength fcu (t/m2)
LWC	NWC				
LA	**N(LA)**	900 = 30 x 30	20	-	4650
LB	**N(LB)**	900 = 30 x 30	28	-	5837.5
LD	**N(LD)**	900 = 30 x 30	20	-	4275
NR	NR	900 = 30 x 30	20	-	5075

Table 3.2 Summary of group (1) Specimens data

Specimen		Loaded Area (cm2)	Slab thickness cm	Shear RFT	Concrete Comp. strength fcu (t/m2)
LWC	NWC				
L1	**N(L1)**	100 = (10 x 10)	10	-	2500
L2	**N(L2)**	100 = (10 x 10)	6	-	2500
L3	**N(L3)**	100 = (10 x 10)	14	-	2500
L4	**N(L4)**	100 = (10 x 10)	10	Studs 20 cm	2500
L5	**N(L5)**	100 = (10 x 10)	10	Studs 30 cm	2500
L6	**N(L6)**	200 = (14.14 x 14.14)	10	-	2500
L7	**N(L7)**	400 = (20 x 20)	10	-	2500
N2	N2	100 = (10 x 10)	10	-	2500

4. Program Results and Discussions

This article presents and discusses the results of the research program:

- First, Punching load of failure is presented for each of (LWC) physical model and corresponding (NWC) FEM of groups (1) & (2).
- Punching strength reduction factor (λ) for each case study was calculated by dividing the punching capacity of the (NWC) FEM by its corresponding capacity of (LWC) physical model.
- Finally, a relation between Punching strength reduction factor (λ) and (LWC) density was developed using mathematical regression techniques.

4.1 Case Studies Results and Punching strength reduction factor (λ)

Table 4.1 summarizes the ultimate punching loads of both physical and FEM models of group (1). It can be noted that the average value of the reduction factor (λ) for (LWC) Specimens is about (0.85).

Table 4.1 Summary of ultimate punching loads of group (1) Specimens

Physical Model - LWC			FEM model - NWC		Reduction Factor
LWC Slab	Concrete density ɣc (kg/m3)	Ult. Punching Load Ps (ton)	NWC Slab	Ult. Punching Load Ps (ton)	λ
L1	1916.65	11	N(L1)	12.50	0.88
L2	1916.65	5	N(L2)	6.41	0.78
L3	1916.65	17.5	N(L3)	20.77	0.84
L4	1916.65	12.5	N(L4)	14.27	0.88
L5	1916.65	13	N(L5)	14.87	0.87
L6	1916.65	11.5	N(L6)	14.30	0.80
L7	1916.65	15.5	N(L7)	17.11	0.91
N2	2380	12.5	N2	12.50	1.00

Table 4.2 summarizes the ultimate punching loads of both physical and FEM models group (2). Values of reduction factor (λ) for (LWC) Specimens are shown in table .

Table 4.2 Summary of ultimate punching loads of group (2) Specimens

Physical Model - LWC			FEM model - NWC		Reduction Factor
LWC Slab	**Concrete density γc (kg/m3)**	**Ult. Punching Load Ps (ton)**	**NWC Slab**	**Ult. Punching Load Ps (ton)**	λ
LA	1807	55.2	N(LA)	72.63	0.760
LB	2059	92.9	N(LB)	101.53	0.915
LD	1847	62.63	N(LD)	78.29	0.800
NR	2335	67.04	NR	67.04	1.000

4.2 Relation between Punching Reduction Factor (λ) and (LWC) density

The main objective of this research is to find a relation between Punching strength reduction factor (λ) and the unit weight of concrete.

Fig.(4.1) is a graphical representation for the research goal.

$$\boldsymbol{\lambda = 1.1 - (5.45\, \gamma_c^{-4.7}\,)}$$

where γc is the unit weight of concrete

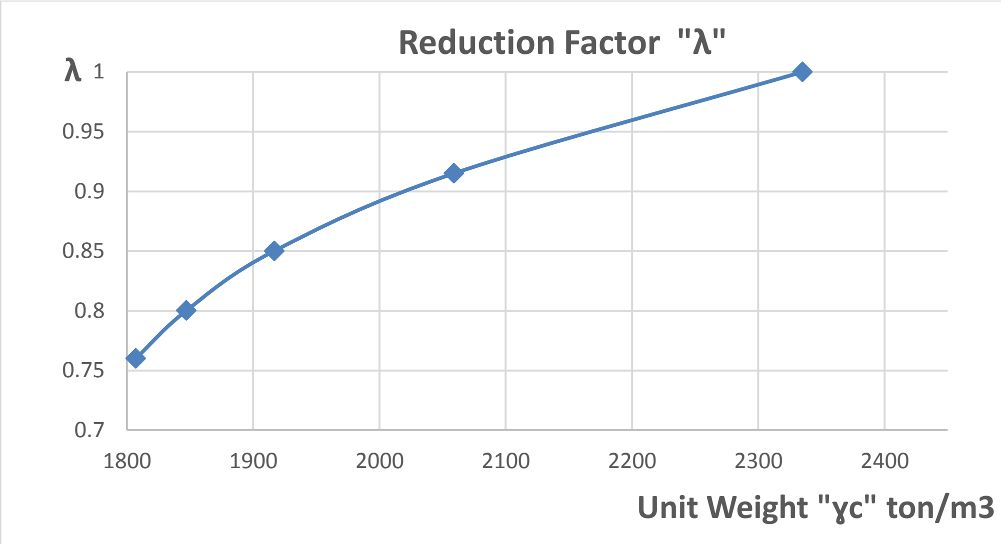

Fig. 4.1 λ - γ_c curve

5. Code Predictions

In this section, Punching strength reduction factor (λ) was determined according to ACI 318M-14 as follows:

The value of (λ) shall be based on the composition of the aggregate in the concrete mixture in accordance with the next table.

Modification factor λ

Concrete	Composition of aggregates	λ
All-lightweight	Fine: ASTM C330M Coarse: ASTM C330M	0.75
Lightweight, fine blend	Fine: Combination of ASTM C330M and C33M Coarse: ASTM C330M	0.75 to 0.85[1]
Sand-lightweight	Fine: ASTM C33M Coarse: ASTM C330M	0.85
Sand-lightweight, coarse blend	Fine: ASTM C33M Coarse: Combination of ASTM C330M and C33M	0.85 to 1[2]
Normalweight	Fine: ASTM C33M Coarse: ASTM C33M	1

[1]Linear interpolation from 0.75 to 0.85 is permitted based on the absolute volume of normalweight fine aggregate as a fraction of the total absolute volume of fine aggregate.

[2]Linear interpolation from 0.85 to 1 is permitted based on the absolute volume of normalweight coarse aggregate as a fraction of the total absolute volume of coarse aggregate.

The relation between Punching strength reduction factor (λ) and the unit weight of concrete according to ACI 318M-14 is as follows:

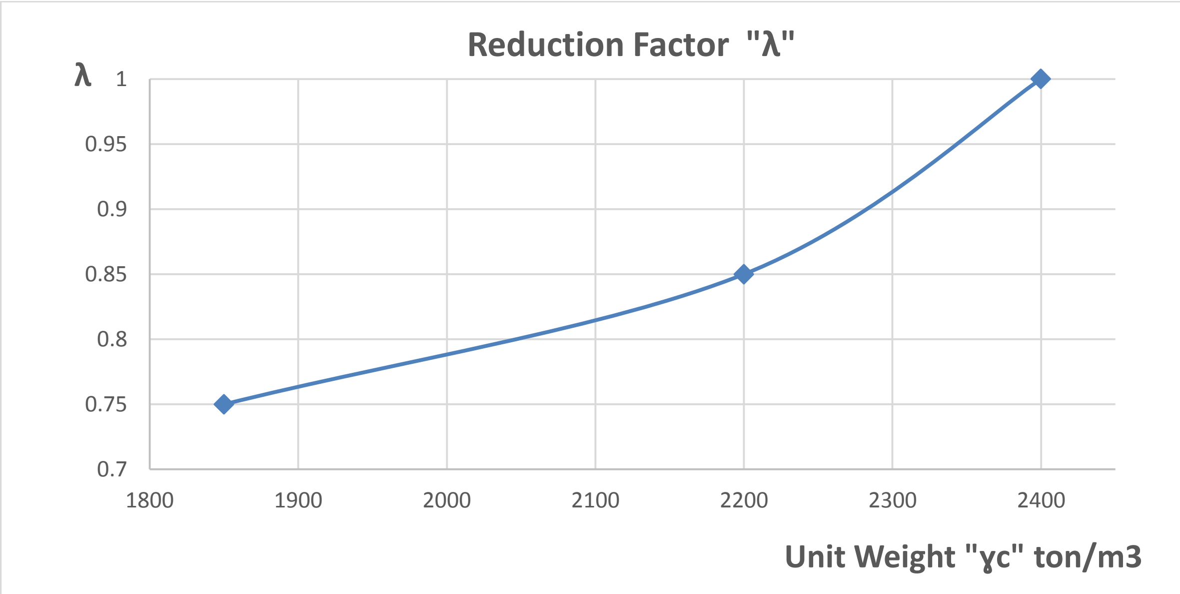

Fig. 5.1 λ - γ_c **curve**

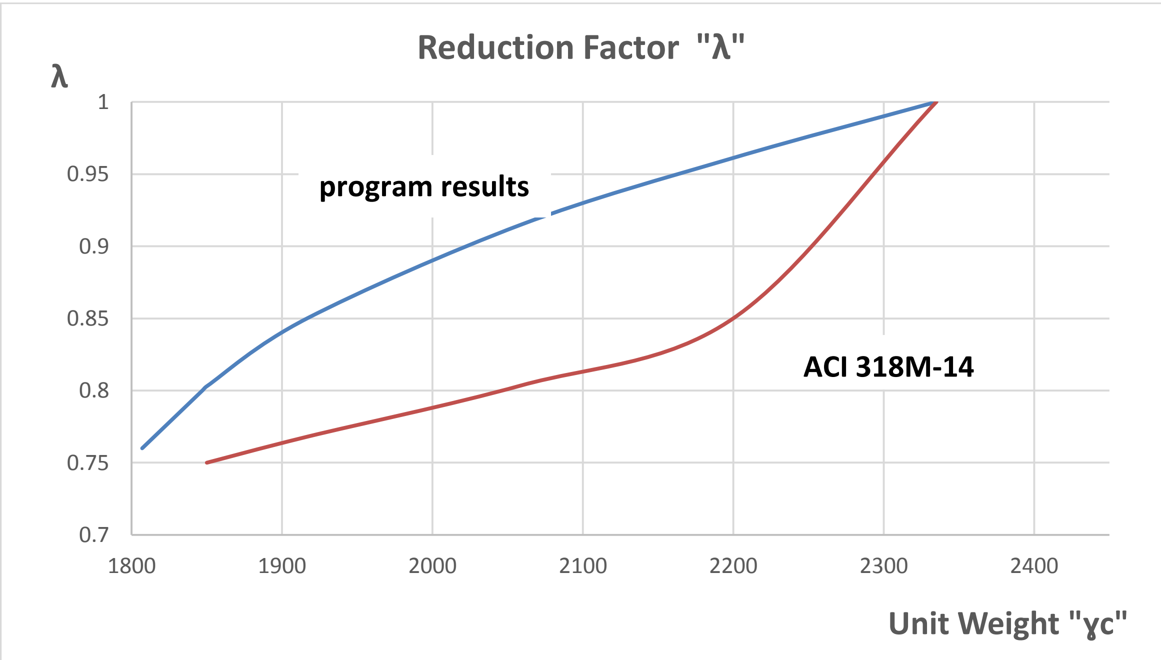

Fig. 5.2 λ - γ_c **curve**

6. Conclusions

The main objective of this research is to find a relation between Punching strength reduction factor (λ) and the unit weight of concrete. It was found that the factor (λ) increases with increasing the unit weight of concrete. this illustrates the nonlinear relation between the factor (λ) and the unit weight of concrete.

The comparison between the graphical representation from the research results that the values of (λ) for lightweight concrete is high in case of the research results than of ACI 318M-14. Thus the punching strength for sections made from lightweight concrete is higher and the dimension size for concrete sections becomes smaller. Therefore, this improvement in the values of punching strength reduction factor (λ) suggests Lightweight concrete (LWC) to be more cost effective in construction industry.

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