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STRUCTURAL PERFORMANCE OF COMPOSITE REINFORCED CONCRETE BUBBLED ONE WAY SLABS

A Thesis Submitted to Council of College of Engineering, University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

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COMMITTEE DECISION

We certify that we have read the thesis entitled "Structural performance of composite reinforced concrete bubbled one way slab" and we have examined the student (Ibrahim Abbas Ali) in its content and what is related with it, and in our opinion it is adequate as a thesis for the Degree of Master of Science in Civil Engineering.

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بسم الله الرحمن الرحيم

﴿ وَيَسْأَلُونَكَ عَنِ الرُّوحِ قُلِ الرُّوحُ مِنْ أَمْرِ رَبِّي وَمَا أُوتِيتُم مِّنَ الْعِلْمِ إِلَّا قَلِيلًا ﴾

صدق الله العظيم

مــن ســورة الاسراء – آيـــة85

Dedication

To My Family
With Love and Respect

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Structural Performance of Composite Reinforced Concrete Bubbled One Way Slab

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Abstract

Slab is very important structural member and usually take high percentage of total weight of building therefore, many attempts have been conducted in order to reduce the dead weight of slabs and most of these researches focus on the traditional reinforced concrete slabs and composite reinforced concrete slabs while there are no researches conducted on reducing self-weight of composite slabs with plastic bubbles.

The composite one-way slab with plastic bubbles (One-Way Composite bubbled slab system) is a developed type of slabs in which used recycled plastic bubbles in one way composite slab in order to reduce the self-weight of slab. This study presents experimental investigation to study the structural performance of composite reinforced concrete bubbled one way slabs, where twelve specimens of composite one-way slabs with dimensions (1850mm x 500mm x110mm) have been evaluated.

All the composite slabs specimens divided into four groups according to presence or absence of shear connectors, also depending on presence or absence of plastic bubbles and diameter of plastic bubbles (70mm and 86mm). Each group consists of three specimens of composite slabs which are different in geometry of profile steel sheet (trapezoidal shape, triangle shape and T-shape). The composite slabs specimens tested under two-point load to obtain the ultimate load capacity, vertical deflection response, slip between steel sheet and concrete, strain development in concrete and steel sheet, toughness index and energy absorption.

The test results show that other types of geometries of profile steel sheets can be used such as (T-shape and Triangle shape) instead of the trapezoidal shape (traditional shape). These types have better results in term of the ultimate load and structural behavior. The adding shear connectors to the composite slabs with (Trapezoidal shape and Triangle shape) increase the ultimate load capacity by (22.2% and 17.8%) respectively and decrease deflection as compared with the same load while effect of adding shear connectors to the composite slab with T-shape is very little or can be neglected.

It has been found that the composite bubbled slabs, (with diameter 70mm) give an ultimate load close to composite slabs without bubbles, except the composite bubbled slab with a trapezoidal shape shows a decrease in the ultimate load by (10.9%). Increasing the diameter of bubbles from 70mm to 86mm leads to increasing the ultimate load capacity of composite slabs with trapezoidal and triangle shapes by (10.2% and 18.1%) respectively, and decreasing the ultimate load of T-shape by (6.2%).

The proposed one-way composite bubbled slab consider sustainable section and has important contribution to construct environmentally friendly buildings where the sustainability analysis shows that the CO_2 emission and embodied energy can be reduced up to 13.8% and the raw material by about (6.75% to 14%) by using the composite bubbled slab.

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List of Symbols

Symbol	Definition
$f_{yp.d}$	Design value of the yield strength of profile steel sheet
A_P	Cross sectional area of profile steel sheet
f_{cd}	Cylinder Compressive strength
N_c	Design value of the compressive normal force in the concrete flange
Δ_u	Deflection at ultimate load
Δ_y	Deflection at yield load
μ	Degree of shear connection; coefficient
b	width of slab
b_0	Effective width of rib
c_p	Critical perimeter for punching shear
d_g	Maximum size of aggregate
d_p	Effective depth
E	Elastic modulus of elasticity
e	Distance from the centroidal axis of profiled steel sheeting to the extreme fibre of the composite slab in tension
e_p	Distance from the plastic neutral axis of profiled steel sheeting to the extreme fibre of the composite slab in tension
ε_u	Strain at ultimate load
ε_y	Strain at yield load
fc'	Cylinder Compressive strength
f_{cu}	Cube Compressive strength
f_r	Flexural Strength
F_{sp}	Splitting Tensile Strength
h_c	Thickness of concrete above the sheeting
k	Empirical value of friction between concrete and sheet
L_s	Shear span of length
m	Empirical value of Mechanical interlocking between concrete and sheet
$M_{pl,Rd}$	Design resistance to sagging bending
M_{pr}	Reduced plastic resistance moment of the profiled steel sheeting
N_{ac}	the compressive force in sheeting
M_{pa}	Design value of the plastic resistance moment of the effective cross-section of the steel sheet
$N_{c,f}$	Design value of the compressive normal force in the concrete flange with full shear connection
N_p	Tensile force in sheeting

P_{cr}	Crack load
P_{Fs}	First slip load
P_u	Ultimate load
P_y	Yield load
$V_{l,Rd}$	The longitudinal shear resistance
υ_{min}	Shear strength of the concrete
$V_{p,Rd}$	Resistance composite slab to punching shear
V_{Rd}	design vertical shear resistance
X_{Pl}	Distance between the plastic neutral axis and the extreme fibre of the concrete slab in compression
z	lever arm; dimension; co-ordinate
γ_c	Partial factor for concrete
γ_{Vs}	Factor for shear resistance of a composite slab
τ_v	The longitudinal shear strength

List of Abbreviations

Abbreviation	Definition
ASTM	American Society for Testing and Material
ALCORN	New Zealand Specific Coefficients of Embodied Energy and Embodied CO2 Produced by Andrew Alcorn (2003)
BREEAM	Building Research Establishment and Environmental Assessment Method
BS	British Standard
CO_2	Di oxide carbon
LEED	Leadership in Energy and Environmental Design
LSP	Limestone Powder
N.A	Neutral Axis
SCC	Self-compacted concrete
RC	Reinforced Concrete
ECC	Engineered Cementitious Composite
AISI	American Iron and Steel Institute

CHAPTER ONE

INTRODUCTION

1.1 General

In concrete construction, the slab is a very important structural member to make a space and usually the slab consume a large amount of concrete and its construction takes much time because of the time of construction is strongly influence by the time that is consumed to construct the floors, therefore much time can be saved if the concrete is cast on permanent steel formwork, this formwork will act before casting as a platform for construction whereas after casting the profile steel sheet acts as a permanent formwork to support the weight of wet concrete, then and after the concrete is hardened the steel sheet will act as a tensile reinforcement**(Chug, et al, 2011)**. See Figure (1-1).

Figure (1-1) Composite Slab Construction, Showing the Steel Sheet Placed on Steel Frame (Lysaght)

The composite slab system offers a wide range of advantages in buildings, such as **(Penza 2010, Rackham et al. 2009 and Johnson 1994)**:

- **Speed of Construction:** More time can be saved if the slabs are cast on steel sheets which acts first as formwork and then when concrete hardened acts as reinforcement for slab. One team of workers can instilled about 400 m^2 of profile steel sheet per one day depending on the size and shape of the building footprint**.**
- **Safe Method of Construction:** The composite slab with a steel sheet can provide a safe working platform and acts as a safe floor to protect workers below from falling objects**.**
- **Weight Reduction:** The composite slab is stiffer and stronger than many other decking slab systems, therefore, using less thickness compared with other floors system and that leads to reduce concrete volume**.**
- **Transport Saving:** The steel sheet is light and is delivered in pre-cut lengths that are tightly packed into bundles. The one truck can transport in excess of 1000m^2 of decking. Therefore, a smaller number of deliveries are required when compared to other forms of construction.
- **Sustainability:** The profile steel sheet has the ability to be re-used or recycled repeatedly without reducing its properties, so this makes composite construction a sustainable solution. At least 94% of all steel construction products can be either re-used or recycled from the demolition of a building.
- **Structural stability:** The profile steel sheet can help to resist lateral the load due to torsional buckling and wind during construction by acting as a diaphragm which transfer the lateral load to the wall and columns, also acts as a restraint for the beams.
- **Easy installation of services:** Cable trays and pipes can be hung from hangers that are attached via using special dovetail recesses rolled into the decking profile, thereby facilitating the installation of services such as electricity, telephone and information technology network cabling.

The main disadvantage of composite slabs can be summarized as follows:-

1- It is very temperature sensitive and expands and contracts with temperature change.
2- High fabrication and assembly costs.
3- The profile steel sheet should be protection against corrosion.
4- The composite slabs are subjected to vibration during their use.

The weight of concrete is very high due to its high density compared with its strength. Therefore, any attempt to reduce the weight of the slab is considered an effective solution to get light weight of RC building. This allows to reduce weights of beams, columns and foundation. Since 1900s, many attempts were made to reduce the weight of RC slabs by removing the ineffective concrete of the slab to reduce in self-weight and give high structure performance such as: **(Salman, 2012)**:

- Precast beam and block slab.
- Hollow core slab.
- Waffle slab.
- Ribbed slab
- Cobiax slab

1.2 Bubbled Reinforced Concrete Slabs

A bubbled reinforced concrete slab is an innovative slab system which was invented by Jorgen Breuing in 1990s in Denmark. It allows to reduction of unnecessary dead load through the introduction of recycled spherical plastic void formers into the concrete slab. By reducing the weight of the slab, it allows to wider spans among columns as well as minimizes the beams and columns. Figure (1-2) shows a section in the bubbled RC slab.

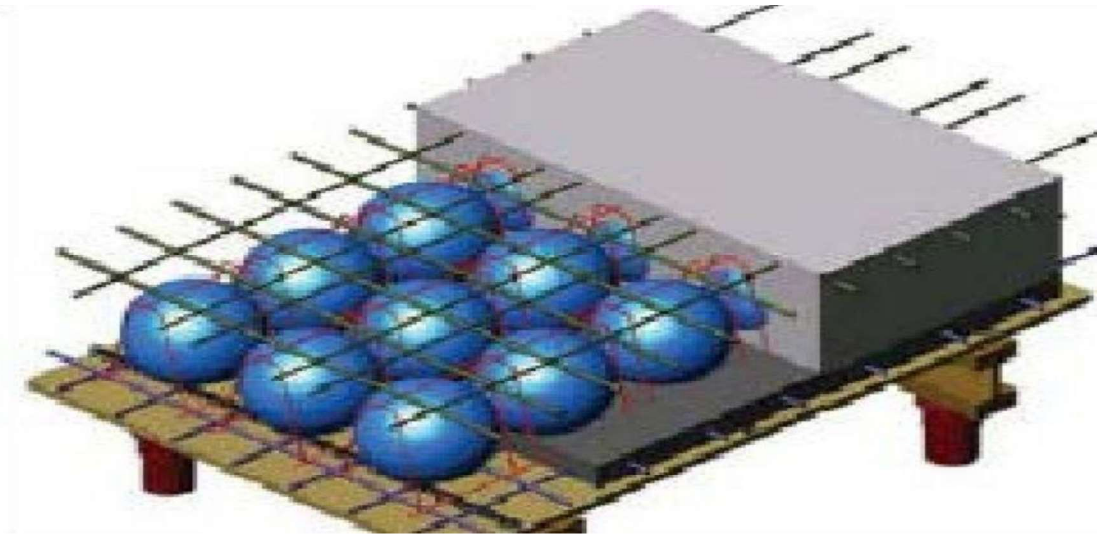


Figure (1-2) Section in RC Slab (John, 2015)

The geometry of bubbled RC slab consists of two layers of meshes and voids. The voids are made in the middle of the cross section where concrete has less function and affection while maintaining solid sections in top and bottom where high stresses can exist. Figure (2-3) shows the geometry of bubbled RC slab **(Ali, 2014)**

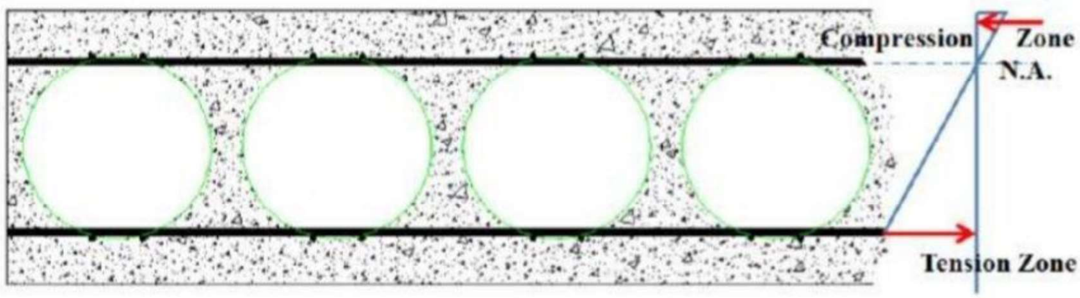


Figure (1-3) Geometry of Bubbled RC Slab (Ali, 2014)

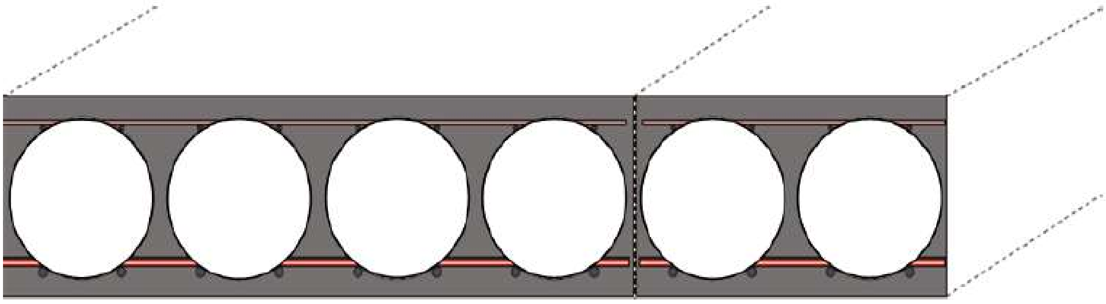
Generally, there are three types of bubbled RC slabs which are classified according to the type of construction: reinforcement modules (simple type), the filigree elements (semi-precast type), and finished planks (precast type). Figure (1-4) shows types of bubbled RC slabs. The bubble-deck system has many advantages in building design and during construction including: **(Fuchs, 2009)**:

1. Reducing the self-weight of the slab.
2. Reducing the time consuming for construction.

3. Bubble-deck system consumes less amount of concrete and that lead to reducing an amount of CO_2 emissions.
4. Providing sound and thermal insulator.
5. Saving total cost of construction.

(a) Type-A- Simple Bubbled Slab (Bubble-Deck, 2003)

(b) Type-B-Filigree Elements (Semi-Precast Type)



(c) Type-C- Finished Planks (Precast Type)

Figure (1-4) Types of bubbled RC slabs

The bubbled slab is removes the ineffective concrete from the inside of the slab while keeps the overall height of the slab for comparable utility in most applications. The modulus of section and stiffness are approximately equivalent to the solid slab but they have lesser self-weight than that of the slab. **(Midkiff, 2013)**. The composite slab which consists of profile steel sheet and concrete, the ineffective concrete in the ribs are usually neglected in design for flexural, so if some concrete is removed from the ribs and replaced by spherical plastic bubbles will get a new type section named "composite bubbled slab". This section will has such advantages as:

1. Reducing total weight of the structure.
2. Saving the total time of construction.
3. Saving cost. Since the composite bubbled slab is stiff, the total thickness is less. More clearly, using plastic bubbles lessens the total material and that lead to reduce the total cost
4. Less amount of materials (cement, sand, aggregate and water) are needed to be transported to the construction location.
5. Reducing the emission of CO_2, consumption of energy transportation and natural resources depletion.
6. Reducing the impacts of nature resource consumption, lessening CO2 emission and optimizing the use of available material.
7. Providing thermal and sound insulation

1.3 Proposed Applications of the One Way Composite Bubbled Slab

The composite bubbled slab can be used in different types of steel structure:

- Multi-storey car parker.
- Industrial buildings.
- Office buildings.
- Commercial buildings.
- Hospitals.
- Housing.

1.4 Research Significance

The composite slab is a very important member. However, there is a few research carried out to study the structural performance of the composite slab with different geometries of profile steel sheets. As well as the slab consumes large amount of concrete and there is not any attempts to reduce self-weight of the composite slabs with recycled plastic bubbles.

1.5 Aim and Objectives of Research

This research is conducted in order to investigate experimentally the structural behavior and the sustainable benefit of the one-way composite bubbled slab with plastic spheres bubbles. The main objectives of this study are:

1. To investigate the performance of the profile steel sheet as a permanent formwork and observe ease flow of SCC and ease casting.
2. To evaluate the strength and behavior of the composite slab with using different types of geometry from the profile steel sheet.
3. To study the effect of adding shear connectors (headed stud) to the profile steel sheet on the strength and behavior of the composite slab.
4. To investigate strength, behavior and the stainable benefit of using plastic spheres bubbles in one-way composite slab.
5. To investigate the effect of increasing diameter plastic sphere bubbles on strength and sustainable benefit of one-way composite slab.

1.6 Layout of the Thesis

This study is presented in five chapters, as shown below:

- Chapter one presents a general introduction about the composite slab with recycle plastic spheres bubbles, application, scope and objectives of study.
- Chapter two presents on introduction, background and the design of composite slab as well as types of plastic bubbled slabs. In addition,

this chapter presents some previous researches with experimental studies that were carried out for both composite slabs and bubbled slabs.

- Chapter three offers the properties of the materials which are used in the experimental work of this study, casting and test procedures of control specimens and specimens of composite slabs.
- Chapter four reviews the experimental result and their discussion.
- Chapter five introduces the conclusions obtained from this study and recommendations for further work.