Ministry of Higher Education
and Scientific Research
University of Diyala
College of Engineering

STRENGTH AND BEHAVIOR OF BUBBLED REINFORCED CONCRETE ONE WAY SLAB

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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Date: / / 2018

DEDICATION

To my parents
With love and gratitude

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Eternal praise and thanks are due to Almighty Allah for His continuous infinite graces of which this thesis is a little one.

*My deep respect and gratitude go readily to my supervisors: Prof. **Dr. Amer M. Ibrahim** and **Asst. Prof. Dr. Murtada A. Ismael** who embodied their loyalty and meticulous care in reading just to weed out in accuracies without their help this study would have remained just a thread of an idea.*

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2018

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ABSTRUCT

Reinforced concrete slab with plastic voids (Bubbled-Deck system) is a new type of slabs which has two-dimensional arrangement of voids within the slab that is developed to decrease the slab self-weight while maintaining approximately the same load carrying capacity as compared with the solid slabs. Plastic voided slabs have the ability to reduce concrete amount by about 30 percent and this reduction is so important in terms of cost saving and enhancement the structural performance.

In this thesis experimental and theoretical investigation is carried out to study the strength and behaviour of bubbled reinforced concrete one-way slabs. The experimental program consists of testing fifteen one-way slabs with dimensions of 1850mm×460mm×110mm. One of the tested slabs is a solid slab (without balls) is used as a reference, the remaining fourteen bubbled slabs (with spherical and elliptical balls) are divided into three groups according to construction type (simple type, filigree type and filigree type with longitudinal joint). The parameters of the experimental work include: shape of the balls (spherical or elliptical), clear spacing between balls in the cross section (25mm or 70mm), type of concrete (NSCC or HSCC) and the presence of lateral shear reinforcement (steel cage or shear key).

The experimental results showed that the simple bubbled slabs containing spherical and elliptical balls have about 81% to 96% of the ultimate load of

solid slab and an increase in the deflection at ultimate load by 7.8% to 21%, at the same time the first crack load decreases by about 6.7% to 16% as compared to solid slab. Also, the results showed that the presence of steel cage in filigree bubbled slabs results in increase the ultimate load by 69% and 50% as compared with that without steel cage. Furthermore, the results reveals that the use of lateral reinforcement (shear key) in filigree bubbled slabs with longitudinal joint increases the ultimate load by about 61% and 37%, at the same time the ultimate deflection increases by about 77% and 63%.

On the other hand, the results showed that the calculated amount of input raw materials of the bubbled slab show a reduction in the input raw materials up to 16% so that the cost reduced by about 8% from the total cost of solid slab. Also, Sustainability analysis proves that the (CO_2 emission and energy consumption) can be reduced by about (5% and 10%) by using the bubbled slabs, so the use of bubbled slab has important contribution to construct the environmentally friendly buildings.

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LIST OF SYMBOLS

Symbol	Definition
Ø	Reduction factor
P_Y	Yield load
Δ_y	Deflection at yield load
P_u	Ultimate load
Δ_u	Deflection at ultimate load
ε_{cr}	Strain at crack load
ε_y	Strain at yield load
ε_u	Strain at ultimate load
P_{cr}	Crack load
P_s	Slide load
λ	Vertical diameter to horizontal one
μ	Friction factor
c	Cohesion factor
A_{cv}	Area of concrete considered to be engaged in interface shear transfer
P_c	Permanent net compressive force
f'_c	Cylinder Compressive strength
K_1	Fraction of concrete strength available to resist interface shear
K_2	Limiting interface shear resistance
L_{vi}	Interface length
f_{cu}	Cube Compressive strength
f_{ct}	Splitting Tensile Strength
f_r	Flexural Strength
E	Elastic modulus of elasticity
I_v	Moment of inertia for void part
I_s	Moment of inertia for solid part
h	Total thickness of slab
r	radius of spherical ball
a	Vertical radius of elliptical ball
c	Horizontal radius of elliptical ball
D	Ball diameter
L	Span length
d	Effective depth
$ØV_{nh}$	factored nominal horizontal shear strength
V_u	Vertical shear force
b_v	Width of the contact surface
V_{ni}	Nominal inter face shear strength

LIST OF ABBREVIATIONS

Abbreviation	Definition
ACI	American Concrete Institutes
ASHTO	American Association of State Highway
ASTM	American Society for Testing and Material
BD	Bubble-Deck
BREEAM	Building Research Establishment and Environmental Assessment Method
BS	British Standard
CO_2	Di oxide carbon
DIN	German Standard
FR	Fire Resistance
HSCC	High Strength Self-Compacted Concrete
HPSCA	High Performance Superplasticizer Concrete Admixture
I	Moment of Inertia
LEED	Leadership in Energy and Environmental Design
LRFD	Load Resistance Factor Design
LSP	Limestone Powder
NSCC	Normal Strength Self-Compacted Concrete
N.A	Neutral Axis
RC	Reinforced Concrete
SCC	Self-compacted concrete

CHAPTER ONE

INTRODUCTION

1.1 General

The slab is one of the most important structural member in making a space, and is one of the largest members in consuming concrete **(Chung, et al., 2011)**. The first design limitation in designing a reinforced concrete slab is the span between columns. When designing large spans between the columns, the use of very thick slabs and/ or support beams are often required. This leads to increasing the dead weight of the structure when using large amounts of concrete. Heavy structures are less resistant to seismically forces than the light ones, due to the existence of a larger dead load which often increases the magnitude of inertia forces. Incorporating support beams also contribute to larger floor-to-floor heights, which in turn increase the costs of finish materials **(Midkiff, 2013).**

For decades, many attempts have been made to create biaxial hollow slabs for the sake of reducing the weight. Many tries used a less heavy material like expanded polystyrene which is laid between the bottom and top of reinforcement, such as waffle slabs/ grid ones. Only waffle slabs have certain use in the market, but its use is very limited because of reduced resistances towards shear, local punching and fire **(Joseph, 2016).**

The so called "Bubble-Deck System", invented by Jorgen Breuing in nineties, is used for eliminating the weight of the slab. This system uses spherical balls made of recycled industrial plastic in order to create air voids while providing strength through the arch action as it is shown in Plate (1-1). These bubbles are able to decrease the dead weight up to 35% and increase the capacity to nearly 100% with the same thickness. Reducing the dead load makes the long-term response more economical to building, while offsetting increases the deflection of the slab **(Lai, 2010)**.

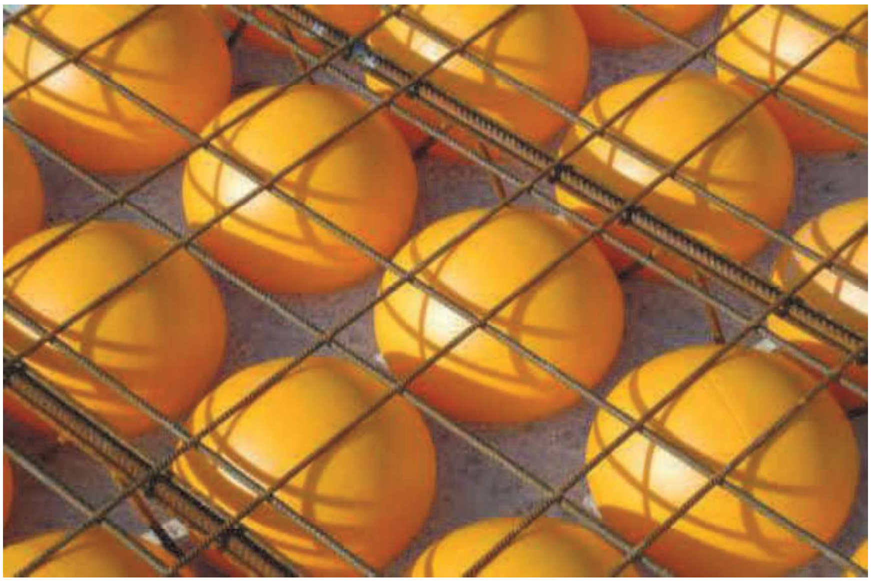

Plate (1-1) Bubble-Deck system (Bubble-deck, 2006)

One of the methods used for lessening harm to the environment is by adopting a sustainable element in constructing activities **(Fuchs, 2009)**. Bubbled reinforced concrete slab systems contribute to achieve Building Research Establishment and Environmental Assessment Method (henceforth BREEAM) targets. BREEAM, the first commercially available environmental assessment tool to building, is established in UK and the use of these systems qualify Leadership in Energy and Environmental Design (henceforth LEED) points. LEED is the leadership in energy and environmental design green building rating systems developed and adopted in US **(Klein, 2006)**. The Bubble-Deck system offers a wide range of advantages in building design and during constructing, such as **(Fuchs, 2009)**:

1. Reducing the self-weight of the slab by about 30 to 50%, bubble slab which reduces the concrete usage in columns, walls and foundations by about 20%.

2. A bubbled slab uses less concrete than solid concrete slab systems do, 1kg of plastic replaces more than 100kg of concrete. This leads to reducing CO_2 emissions in the atmosphere of the manufacturing process. Besides, it meets sustainability goal through the use of recycled plastic balls.
3. Reducing consumption of energy in production, transportation and carrying out.
4. Lessening the total cost of building construction by about 8 to10%.
5. Enhancing structural efficiency.
6. Decreasing the time of construction.
7. Green technology.
8. Providing sound and thermal insulator.

1.2 Application of Bubble-Deck Slab

The bubbled slab system has been used in many buildings in Holland, Germany, United States, and Denmark. The followings are some examples of these systems:

- **La Bahn Hockey Arena**

La Bahn is an arena for the hockey team of the University of Wisconsn at United States. After consulting a company of Bubble-Deck, the designer's team suggests using a Bubbled-Deck system for the walkway. Filigree panels are placed within two days after delivery to the location. It includes the plastic ball, the main reinforcement and the bottom layer of concrete. After one week, the top layer of concrete is completed. Using a bubble-deck in walkway reduces the construction time and cost by about 25000$. The plate (1-2) shows construction of the arena **(Midkiff, 2013)**.

Plate (1-2) Construction of La Bahn hockey arena (Midkiff, 2013)

- **Millennium Tower**

Millennium Tower is one of the first high rise building using Bubble-Deck in Holland, 35 stories (25000m^2) and 140m height. In 2000 the Tower is completed as shown in Plate (1-3) **(Bubble-Deck, 2008)**.

Plate (1-3) Millennium tower (Bubble-Deck, 2008)

1.3 Research Objectives

At recent years, the use of a Bubbled-Deck system increases significantly in the buildings in which the self-weight of their slabs is wanted to be decreased. This makes researchers examine the structural behavior of these slab systems. Therefore, this study investigates the bubbled slab behavior in order to find out their structural efficiency.

The objectives of this study are to investigate theoretically and experimentally the strength and behavior of bubbled slabs and compare them with the solid slab. Additionally, the benefit of sustainability resulting from using recycled plastic balls placed inside slabs core is to be studied knowing that these balls act as an element reducing the input raw material quantities, CO_2 emission and energy consumption.

1.4 Research Justifications

In the past, many studies were carried out about the Bubble-Deck system but most of them mainly focused on the behavior of two-way bubbled slabs. While the studies regarding the structural behavior of one-way bubbled slabs are little and not comprehensive.

1.5 Methodology and Limitation of Thesis

The experimental program of this study includes casting, testing of one solid slab and other fourteen bubbled slabs. The researcher ends up with discussing the results in terms of ultimate load, load-deflection relationship, steel tensile strain, concrete compressive strain, crack pattern and mode of failure. The experimental work consists of many variables such as:

1. The main variable (types of constructions) are:
   - i. A simple bubbled slab
   - ii. A filigree bubbled slab

iii. A filigree bubbled slab with longitudinal joint.

2. The secondary variables are:
   i. Shape of balls (spherical or elliptical)
   ii. The clear spacing between balls (25mm or 70mm)
   iii. Type of concrete (Normal Strength Self-Compacted Concrete NSCC or High Strength Self-Compacted Concrete HSCC).
   iv. Presence of shear reinforcement (steel cage or shear key).

1.6 Layout of the Study

- Chapter one presents a general introduction about the Bubbled slab and its application in buildings. It also describes the aims of the study.

- Chapter two displays an introduction to sustainability. It also covers some types of plastic voided slab systems, structural properties of the bubbled slab and briefly reviews some previous studies carried out in the field of bubbled slabs (experimental and numerical studies).

- Chapter three explains the experimental program and properties of the materials used. Details of the tested slabs, concrete mix and test set up are also described.

- Chapter four analyses and discusses the experimental data of the tested slabs.

- Chapter five presents some conclusions and offers some suggestions for future studies.