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Structural Behavior of Reinforced Concrete Deep Beams with Longitudinal Holes

A Thesis Submitted to the 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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بسم الله الرحمن الرحيم

قَالُواْ سُبْحَانَكَ لاَ عِلْمَ لَنَا إِلاَّ مَا عَلَّمْتَنَا
إِنَّكَ أَنتَ الْعَلِيمُ الْحَكِيمُ

صدق الله العلي العظيم

سورة البقرة
(الاية 32)

Dedication

To …

God, The greatest truth in my life.

My father, my heartbeat.

My mother, the sight of my eyes.

My brothers, who supported me.

My honorable teachers who taught and rewarded us their knowledge.

Everyone, who wishes me success in my life,

I dedicate this humble work

abbas

Acknowledgments

"In the Name of Allah, the Most beneficent, the Most Merciful"

First praise be to "Allah" who gave me the strength and health to work and enable me to finish this work.

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Appreciation and thanks are also extended to the all staff of department of Civil engineering, and the staff of Structural Engineering Laboratory.

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Finally, I would like to express my love and respect to my mother, my family, My brother, no word can express my gratitude to them.

Abbas H. Abdulabbas

Structural Behavior of Reinforced Concrete Deep Beams With Longitudinal Holes

Abstract

Deep beams made of reinforced concrete with a hollow core feature longitudinal openings along the length of their span and have many advantages. The longitudinal openings in the hollow reinforced concrete beams reduce the quantity of concrete used, lowering dead loads and construction costs while allowing for a longer span. Additionally, these hollows are used to pass mechanical and electrical services. Due to the decreased CO_2 emissions, concrete abatement aids in the sustainability process.

The current study includes an experimental investigation of the structural behavior of hollow reinforced concrete deep beams. The experimental program included casting and testing sixteen reinforced concrete deep beams with dimensions of 1400 mm length, 150 mm width, and 320 mm total depth. The shear span is 375 mm and the clear span is 1060 mm. Fifteen of the samples had longitudinal hollows with a reference solid sample. The variables studied are the number of longitudinal hollows (one to three), the size of the hollows (25 mm to 50 mm), the depth of the hollow (76 mm to 200 mm), the geometric shape of the hollow (circular, rhombic, rectangular), and the inclination of the longitudinal hollow (0% to 8.86%) to their effects on the structural behavior of hollow reinforced concrete deep beams.

Experimental results showed that the use of hollows with numbers from one to three reduces the first crack load for flexural by 17.33% to 22.66% and reduces the first crack load for diagonal by 10.71% to 14.28%, as well as the ultimate strength decreased between 8. 12% and 20.1%, and the use of hollows with diameters from 25 to 50 mm reduces the load of the first crack for flexural by 2.66% to 22.66%, and the load of the first crack for diagonal decreased by 2.14% to 14.28% as well as The ultimate

strength decreased between 2.8% to 20.2%.

When using hollows with depth variations from 76 mm to 200 mm, the first crack load for flexural is reduced by 17.33% to 1.33%, the first crack diagonal load is reduced by 10.71% to 1.42%, and the ultimate load strength is between 8. 12% to 13.45%. In addition, the load of the first crack to flexural decreased by 2.67% to 8%, and the load of the first crack for diagonal decreased by 3.56% to 10%, as for the ultimate load resistance it decreased by 6.72% to 11.76% at using the longitudinal hollows of the circular, rhombic and rectangular shape, respectively. Also, the presence of hollow with a slope from 0% to 8.86% reduces the load of the first crack for flexural by 2.67% to 6.67% and reduces the load of the crack slit for diagonal by 3.57% to 7.14%, and the last decrease of the ultimate load resistance is reduced By 6.72% to 11.20%.

It was reported that the stiffness factor decreased by 25.51to 56.22% when using one to three hollows, respectively, while the stiffness factor decreased by 8.45% to 56.22% when using hollows with a diameter of 25 mm to 50 mm respectively. While changing the depths of the hollow from 76 mm to 200 mm leads to a reduction in the stiffness factor of 25.51% to 21.72%, respectively. While a decrease of 18.95% to 30.55% was reported when using circular, rhombic, and rectangular hollows, respectively. A slope of 0% to 8.86% reduces the stiffness factor by 18.95% to 30%, respectively.

Using hollow reinforced concrete deep beams will lower the weight of the raw materials to 13.8% % saving up to 13.8 % in costs. Furthermore, reduced the embedded energy and CO_2 emission by about 13.82%.

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LIST OF ABBREVIATIONS

Abbreviation	Description
ANSYS	Analysis System
CFRP	Carbon Fiber Reinforced Polymer
CVA	Concrete Volume Abatement
PVC	Poly Vinyl Chloride
HRCDB	Hollow Reinforced Concrete Deep Beam
HRCB	Hollow Reinforced Concrete Beam
Agg.	aggregate
a/h	Shear Span to Overall Depth Ratio
L_n/h	Clear Span to Overall Depth Ratio
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BS	British Standard
c/c	Center to Center Clear Span, mm
RC	Reinforced Concrete
STM	Strut and Tie Model
I.Q.S	Iraqi Standard Specification
Vol.	Volume

LIST OF SYMBOLS

Symbol	Description
N.A	Neutral Axis ,mm
Δu	Deflection at ultimate load ,mm
Ln	Clear span ,mm
a	Shear span ,mm
d	Effective depth ,mm
E	Modulus of elasticity ,Mpa
fc'	cylinder Compressive strength ,mm
fct	Splitting Tensile strength, Mpa
fcu	Cube Compressive strength, Mpa
h	total depth of beam ,mm
L	Span length ,mm
P_{fcr}	Flexural Crack load, kN
P_{scr}	Diagonal Crack load, kN
Pu	Ultimate load, Kn
A_h	Area of secondary horizontal reinforcement, mm^2
A_v	Area of secondary vertical reinforcement, mm^2
b	Width of cross section of ring deep beam ,mm
j_d	Moment arm, mm
L_b	Length of load bearing block, mm
P_n	Nominal applied load, kN
$\emptyset st$	Diameter of bar for shear reinforcement, mm
w_{sb}	Width of strut at support nodal zone , mm
w_{st}	Width of strut at load nodal zone, mm
α_1, α_2	Inclination angle of reinforcement to the axis of the ring deep beam, degree
β_c	Confinement modification factor for struts and nodes
β_n	Nodal zone coefficient
β_s	Factor to account for the cracking effect and confining reinforcement on
ϕ	Diameter of bar, mm
θ	Angle of inclination of the diagonal compressive stress and the failure plane with the ring deep beam longitudinal axis in right side, degree
f_{yh}	Yield stress of secondary vertical reinforcement, MPa

f_{yv}	Yield stress of secondary horizontal reinforcement, MPa
F_n	The capacity of STM members, kN
S_h	Spacing of secondary horizontal reinforcement, mm
S_v	Spacing of secondary vertical reinforcement, mm
V_n	Nominal strength, kN
Ømain	Diameter of bar for main reinforcement, mm
f_y	Yield stress , MPa

CHAPTER ONE
INTRODUCTION

1.1 General

The self-weight of the structural members constitutes a large part of the design loads when designing the concrete members, so there are great efforts to reduce the self-weight of the concrete members, which reduces the design loads and the size of the foundations (Joy and Rajeev 2014; Bernardo, 2019).

The laying of longitudinal pipes to create hollow core structural members is one of the common methods at the present time to remove an amount of concrete and reduce the self-weight of the structural members (Parthiban and Neelamegam 2017; Abtan and AbdulJabbar 2019).

There are many advantages when using the hollow-core reinforced concrete beam compared to solid beams (Nimnim., 1993; Hemzah and Hassan., 2020; El Maaddawy and Sherif,2009) such as :

1. Economically in terms of costs due to the low amount of concrete used.
2. It is used to pass several types of services (sewage, mechanical, electrical and communications...etc.) and to protect these services from external environmental conditions.
3. Construction is quick for hollow beams due to the decrease in the amount of concrete in them.
4. As a result of reducing the amount of concrete used in the construction of beams, CO_2 emissions are reduced, so it is an environmentally friendly measure.

In construction work, reinforced concrete deep beams are commonly used in high-rise buildings (Figure (1.1)), which are commonly used in bunkers, Transfer girders, pile caps (Figure (1.2)), and many other applications (Chin, et 2015; El-barbary 2015; Abdul-Razzaq and Farhood 2019).

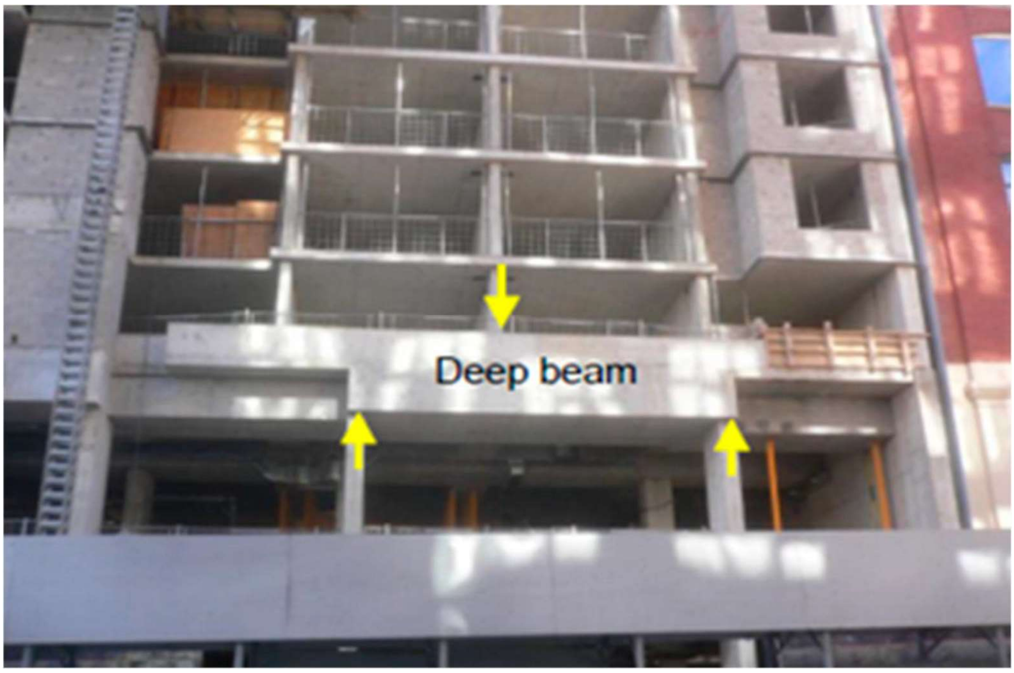

Figure (1.1) Deep Beam in a multi-story building (El-barbary 2015)

Figure (1.2) Column footing (deep beam) supported by two piles (Hasan 2016)

In modern construction, openings in deep beams are often used, especially in tall buildings to allow the passage of various services (Hanoon et al., 2017; Nair,2015; Hassan et al., 2019). This poses a challenge because the stress distribution is non-linear as a result of the generation of the D-regions along the deep beams, so it is difficult to locate the neutral axis. (Niranjan and Patil2012; Senthil and Singh 2018; Abdul-Razzaq and Jebur 2017).

1.2 Deep Beams Requirements According to ACI – Code

The American Concrete Institute Code (ACI), (ACI 318-19) describes deep beam as:

Deep beams are members that are loaded on one face and supported on the opposite face such that strut-like compression elements can develop between the loads and supports and that satisfy (a) or (b):

a) Clear spans (Ln), less than or equal to 4 times the whole member depth.;

b) Concentrated loads exist within a distance of 2h from the face (h) of the support.

1.3 Modes of Failure of Reinforced Concrete Deep Beams

In general, the structural behavior of RC deep beams is affected by many factors, including the conditions of deep beams (clear span/total depth ratio (L/h) and shear/depth ratio (a/h)), loading and location of load, strength of concrete, amount of tensile steel, inclusion of other materials Such as fiber...etc.(Subedi, et al., 1986). The mode failure of RC deep beam can be summarized as follows:

1. Flexural failure: When there is a low amount of reinforcement in the tensile zone and a large a/h ratio which causes decreased load capacity and increase in the deflection, the failure will be in the reinforcing steel produced in the maximum moment area as shown in Figure (1.3).

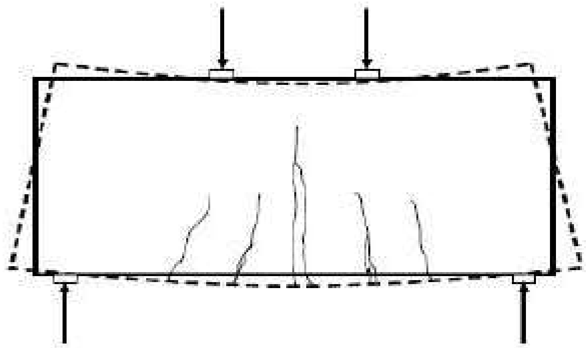

Figure (1.3): Flexural failure[1] of deep beam (Subedi et al., 1986)

2. Flexural-shear failure: When the tensile area is reinforced with enough steel reinforcement and the improvements of the inclined diagonal cracks are headed by flexural cracks at the maximum moment zone, the main cracks will produce the failure. It is the cracks spreading from the support area to the bearing area (loading area) that cause the failure as shown in Figure (1.4).

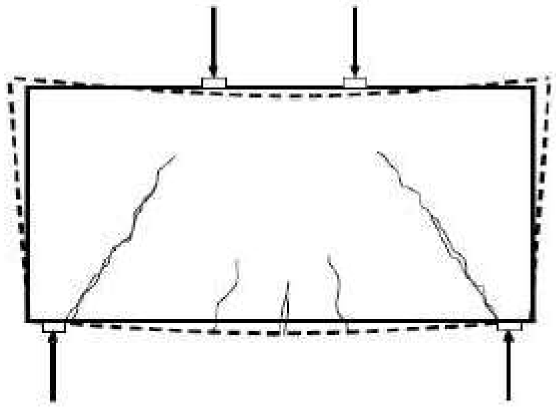

Figure (1.4): Flexural-shear failure[1] of deep beam (Subedi et al., 1986)

3. Diagonal splitting failure: This type of failure occurs when the diagonal terminal crack extends between the load and the support and propagates outward from the middle band as shown in Figure (1.4).

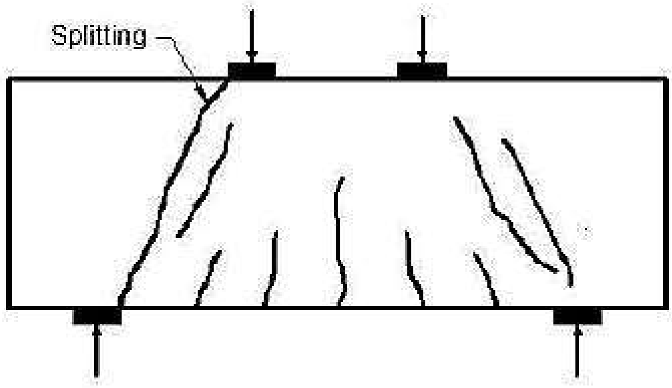

Figure (1.5): Diagonal splitting failure of deep beam (Kong et al.,1970)

4. Diagonal compression failure: This type of failure arises. A diagonal crack develops around the line connecting the support and the load. As a result of the increase in the applied loads, another crack develops that is tilted and closer to the support zone than the first crack and increases in development upwards with the increase in the load. Which leads to the demolition of concrete parts between the first and second cracks, causing the final failure, which forms support between the bearing points and the support as shown in Figure (1.6).

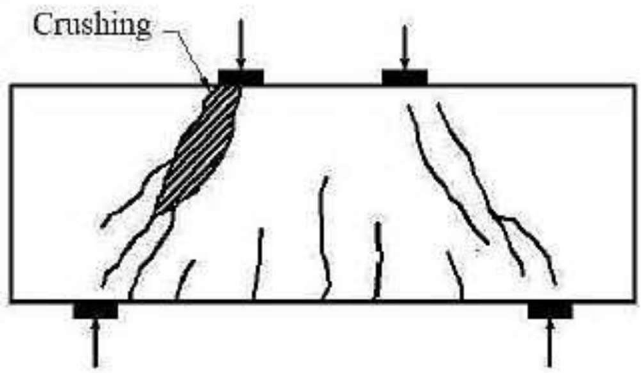

Figure (1.6): Diagonal compression failure of deep beam (Kong et al., 1970)

5. Bearing failure: This failure occurs when there is an increase in pressures in the zone of supports or zone of load; see crack No.1 in Figure (1-6).

6. Bond failure (Anchorage failure): This type of failure takes place about the beam ends, where high flexural bond stresses can combine with high local bond stresses as shown by crack No.2 in Figure (1-5). To avoid bond failures, the longitudinal reinforcement may be anchored by a plate or through the embedment of straight bars, headed bars, or hooked bars ACI 318M-19 (R23.2.6). A standard hook can be used, as defined by ACI 318M-19 (25.3.1), contains a bend of 90-degree with 12 times the diameter of the bar behind the bend as extension. The hook must be positioned at that point where the bars are fully developed. Strut and Tie Model (STM) states that the longitudinal tension reinforcement of the tie could be fully developed at compression- compression- tension (CCT) vertical face at every support node. Bearing and anchorage failure in deep beam is shown in Figure (1.7).

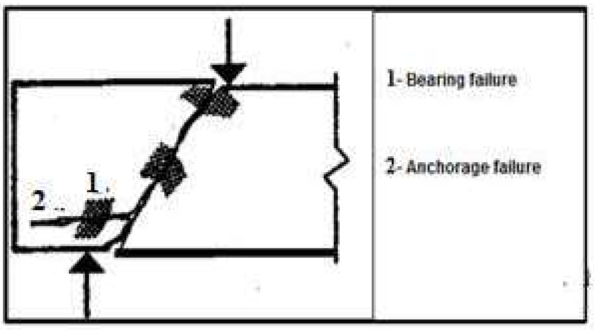

Figure (1.7): Bearing and Anchorage failures in deep beam (Kong et al., 1970)

1.4 Importance of the Study

In fact, deep beams are very heavy members that consume concrete quantities, so attempts have been made to reduce the weight of the beam and the quantities of concrete used, and one of these methods is the use of longitudinal hollows in deep beams. Also, proper implementation of HRCB is a very governing issue in civil engineering projects for both strength and serviceability requirements. The collection of reliable empirical results about HRCB is very useful for comparing its performance with conventional reinforced concrete beams.

Consequently, scientific authors and structural designers still have motivations to understand and quantify the structural behavior of HRCB, in this way, this study attempts to improve the knowledge about this field through the implementation of an experimental investigation on a hollow-core concrete deep beam.

1.5 Problem Statement

In some buildings, it is not feasible to use slender beams, so the solution is to use deep beams. However, little information is available in the literature that studies the existence of longitudinal hollows in reinforced concrete deep beams. Thus, studies and research are directed to discover this field more and how to develop it and increase knowledge in this field.

1.6 Aim, Objectives and Scope

The main objective of this study is to show the effect of the structural behavior of reinforcement concrete deep beams that have longitudinal hollows inside them. And verify the possibility of applying such beams in civil engineering projects. To achieve the aim of the study, the following are the objectives that were obtained:

1- The concrete mix was designed according to the compressive strength required in this study.
2- To create longitudinal hollows in the deep beams, recycled plastic pipes were used.
3- Sixteen RC deep beam samples that were divided into five groups were poured, each group containing three samples with a reference sample to study the structural behavior of the hollow deep beams,

including the number, diameter, location, shape, and inclination of longitudinal hollows.

1.7 Thesis Layout

The current study can be divided into five chapters:

- **Chapter One:** It contains a general introduction to the hollows in reinforced concrete beams, the longitudinal hollows in the deep beams, the specifications of the beams according to the ACI – Code, a review of the types of failures in the deep beams, the research problem, and a statement of the importance of the study, and the scope covered.
- **Chapter Two:** A review of the latest literature on concrete beams with hollows is relevant to the current study.
- **Chapter Three:** It explains the experimental program and all its details, in addition to the materials used in this study and their characteristics.
- **Chapter Four:** Presents the results of the tests in the experimental program, as well as discussed these results.
- **Chapter Five:** It includes the main conclusions of this study, as well as recommendations for future studies.