Ministry of Higher Education
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University of Diyala
College of Engineering

FLEXURAL BEHAVIOR OF HOLLOW REINFORCED SELF – COMPACTED CONCRETE T-BEAMS

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

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Dedication

To …

God, The greatest truth in my life.

My father, my heartbeat.

My mother, the sight of my eyes.

My wife, 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

Haider

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"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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Haider M. Abdulhusain

Abstract

Hollow-core reinforced concrete beams are the beams which have longitudinal cavities through their entire span. The hollow reinforced concrete beams have many advantages over the solid beams, the longitudinal cavities reduce the concrete amount resulting in reduction in dead loads which means cost-saving, fast construction and getting long-span. Moreover, such cavities are used to pass electrical and mechanical equipment. The abatement of concrete contributes in the sustainability process due to reducing the CO_2 emitted.

The present study comprises the implementation of an experimental program to investigate the flexural behavior of hollow reinforced concrete T- beams. The experimental program includes casting and testing thirteen reinforced concrete beams that were casted with dimensions of 250 mm flange width (b_f), 75 mm flange depth (h_f), web width of 150 mm (b_{web}) and total height of 300 mm (h) and total length (L) of 2000 mm, twelve of these specimens were hollow reinforced concrete T- beams (HRCTBs) and the other was solid T-beam as a reference specimen. These beams were proposed to study the effect of longitudinal cavities number (one, two and three), longitudinal cavities diameter (25 mm, 32 mm and 50 mm), longitudinal cavities depth (105 mm, 170 mm and 235 mm) and longitudinal cavities geometry (sharp parabolic, normal parabolic and circular) on the structural behavior of hollow reinforced concrete T-beams.

The experimental results showed that the presence of longitudinal circular cavities in HRCTBs has a significant effect on first crack load, while the effect on the yield load and ultimate

strength is slight. However, using cavities with number from one to three reduces the first crack load by 7.14 % to 14.27% and ultimate strength between 1.67 % to 3.60% and using cavities with diameter from 25 to 50 mm reduces first crack load by 10.71 % to 17.86 % and ultimate load strength between 1.03 % to 3.60 % .

In addition, it was reported that using cavities with depth changes from 105mm to 235 mm reduces first crack load by 3.57 % to 17.86 % and ultimate load strength between 0.39% to 2.31%. Moreover, the first crack load decreased by 3.57 %, 7.14 % and 7.14 ultimate load strength decreased by 0.26 %, 0.39 % and 1.03 % at using longitudinal cavity of circular shape, normal parabolic and sharp parabolic shape respectively. Furthermore, the presence of circular cavities has a negligible effect on the deflection before 55% from the ultimate load and has effect after that load causing an increase in the yield and ultimate deflection.

The reported ductility factor was reported to be 5.54, 5.68 and 5.66 when one, two and three cavities are existed respectively while 5.53, 5.69 and 5.66 were reported when the diameter of cavity was increased from 25 mm to 32 mm and 50mm respectively. The reported levels were reported as 5.57, 5.61 and 5.6 when the depth of cavity is 105mm, 170mm and 235mm respectively while 5.6, 5.59 and 5.53 were reported as the longitudinal cavity of HRCTBs changes from circular shape to normal parabolic and sharp parabolic shape respectively.

Finally, using the hollow reinforced concrete T - beams can reduce the raw materials weight to 12 % with cost saving up to 8%, additionally, using the hollow reinforced concrete T- beams can reduce the CO_2 emission and the embedded energy by about 12%.

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LIST OF ABBREVIATIONS

Abbreviation	Description
ANSYS	Analysis System
CFRP	Carbon Fiber Polymer
CVA	Concrete Volume Abatement
PVC	Poly Vinyl Chloride
HRCTB	Hollow Reinforced Concrete T Beam
HRCB	Hollow Reinforced Concrete Beam

LIST OF SYMBOLS

Symbol	Description
Δy	Deflection at yield load
Δu	Deflection at ultimate load
$\mathcal{E}y$	Strain at yield load
$\mathcal{E}u$	Strain at ultimate load
d	Effective depth
E	Modulus of elasticity
fc'	cylinder Compressive strength
fct	Splitting Tensile Strength
fcu	Cube Compressive strength
fr	Flexural Strength
h	Total thickness of slab
L	Span length
Pcr	Crack load
Pu	Ultimate load
Py	Yield load

CHAPTER ONE

INTRODUCTION

1.1 General

Beams can be defined as structural elements that resists loads applied laterally to the beam's axis. The total effect of all the forces acting on the beam produces shear forces and bending moments within the beams. In civil engineering, most of beams are made of reinforced concrete. Such members can be classified according to many criterions, it can be primarily classified according to the material type, supporting type and section shape.

In many concrete structures, the beam is casted monolithically with the reinforced concrete slab resting on the beam. This process leads to create a T-section beam as shown in Figure (1.1) (Chen and Lui, 2005).

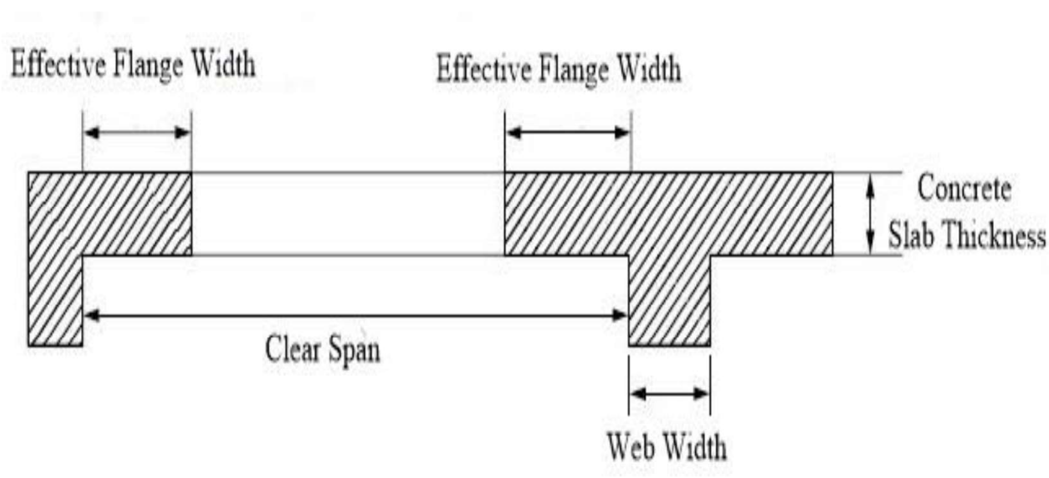

Figure (1-1) The T-beam section (Chen and Lui, 2005)

1.2 T Beams Requirements According to ACI - Code

In fact, when T beam is subjected to negative moment, it is designed as normal rectangular beam, while when it is subjected to positive moment, the width of the beam *b* is substituted by the effective width b_{eff} since the slab is participating in compression zone resistance. The effective width of T beam is calculated as follows:

b_{eff} = 2 effective flange width + Web width ……………..(1.1)

Where :

Effective flange width is the lesser of the clear span /2 or 8 times concrete slab thickness or clear beam length / 8 (ACI-18).

Additionally, if the T - beam is isolated, the flange thickness should not less than one half of the web width while the effective flange width should be not more than four times the width of the web. Finally, at some infrequent cases, the stress block depth exceeds the slab thickness which results that the T - beam design is submitted to the conventional compatibility analyses and the design of the cross-section should take the width of the web b_w as the effective width.

1.3 Reducing Reinforced Concrete Self Weight

In general, the self-weight of the structures represents a very large portion of the existing design weight, thus, implementing a practical technique to reduce such type of weight is required more and more since it is resulting in reducing the accumulated design loads and the size of foundations (Ray, 1998; Bernardo, 2019; Balaji and Vetturayasudharsanan, 2020).

Using light weight concrete is considered as a general method that can be applied to all types of structural members (Kvedaras, 1999; Felicetti et al., 2013; Anon, 2016; Hanus et al., 2018). In addition, there are many approaches that deal with reducing floor self - weight such as bubbled slabs, precast beam and block slabs, hollow core slabs and waffle slabs(Lam and Nip, 2002; Jimenez, 2010; McDermott, 2018; Ibrahim, 2019).

Innovation of any technique that can reduce the concrete volume within any structural member other than slabs represents a good step to increase the overall reduction in concrete amount, in this context, the subtraction of concrete within the reinforced concrete beam section can play a considerable role within this area since beams are considered as vital structural members. This role can be attained using a practical subtraction technique such as installing suitable tubes or pipes along its entire span where the flexural stresses is minimum or in the tension zone to create what is known as a Hollow-Reinforced Concrete Beam (HRCB). The Hollow-Reinforced Concrete Beam has many advantages over the conventional beam (Nimnim, 1993) can be summarized as follows:

1. A noticeable reduction in concrete quantities and the consequent costs.
2. longitudinal cavities of HRCB can be used to run mechanical and electrical equipment and protect the services that is passing through it from the expected environmental aspects.
3. As a result of concrete reduction, more fast construction can be attained.
4. Since the reduction in cement leads to decrease CO_2 emission, implementing HRCB is considered as a sustainable technique.

Conversely, any type of structural element may have disadvantages, however, HRCB have the following disadvantages (Hassan, 2015):

1. A good quality control in term of modern concrete technology is needed when such type of beams is casted.
2. Such type of beams is not suitable when loads are concentrated

at a particular point within the beam domain.

This study tries to add some experience about that technique in term of hollow reinforced concrete beams (HRCB) of T sections.

1.4 Composition of Hollow Reinforced Concrete Beams

In sections subjected to positive moment, the upper part above natural axis will undergo compression stresses, while in the lower part down the natural axis, tension stress will induced. In the tension zone, the concrete is working as a transferring medium for passing strain to the reinforcing steel and any share of this concrete is neglected in design procedures. As a result of that, the concrete quantity within tension zone can be reduced without serious loss in reinforced capacity. Figure (1.2) shows the location of longitudinal cavities within the reinforced concrete section. During the present study, the concrete quantity in the tension zone of T beam was reduced by insulating recycled plastic pipes.

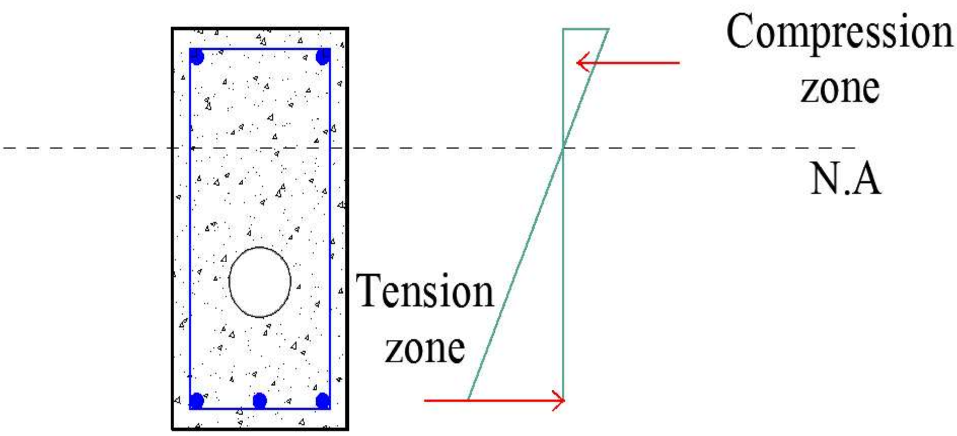

Figure (1.2) Location of longitudinal cavities within the reinforced concrete section.

1.5 Concrete Volume Abatement

The concrete volume abatement (CVA) is used to characterize the minimizing level of concrete within a section. When any new material is used to construct the structural element and / or new construction technique have to be innovated, the strength and serviceability requirements have to be ensured for the individual structural elements. For many times before, these requirements were studied in many recent contributions for beams with web openings, but on the other hand, CVA did not have enough interest within that scientific trends due to the low levels of concrete that can be made.

As a result of above, it is believed that studying CVA ratios is very justified and effective in HRCB, thus, scientific research programs should cover this issue next times. However, this study is trying to include this concern as well as the other common structural behavior criterions.

1.6 Importance of the Study

As a matter of fact, the proper execution of HRCB is very governing issue in the civil engineering projects for both strength and service ability requirements. More precisely, collecting reliable experimental results about HRCB is very useful to compare its performance with the traditional reinforced concrete beams.

Consequently, structural designers, research organizations and scientific authors are still having 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 hollow core concrete T-beam.

1.7 Problem Statement

Obviously, the presence of rectangular sections within the common building system is rather seldom because most of beams are considered as T beams since it is casted monolithically with slabs, however, a little information are now available in the literature about considering HRCB with T section. For this purpose, scientific research contributions should be directed to discover this field more and more.

1.8 Aim, Objectives and Scope

The basic aim of this study is to investigate the structural behavior of HRCB that casted in beams of T section to achieve a descriptive view about the presence of such beams in civil engineering projects.

The following are the objectives obtain to realize the study aim:

1. A mix design has been initially established to obtain a certain level of concrete compressive strength.
2. Recycled pipes with different sections and diameter have been brought in order to make a longitudinal cavities in the tension zone within the tested specimens.
3. Four groups of th irteen reinforced concrete beams have been casted with the same compressive strength to investigate the effect of four variables on the structural behavior of these beams including: the number of longitudinal cavities, the diameter of the longitudinal cavities, the position of the longitudinal cavities and the geometry of these cavities.

1.9 Thesis Layout

The present study is divided into five chapters:

Chapter One: Includes general introduction about reinforced concrete beams, T-beam specification, hollow-core concrete beams, importance of the study, problem statement and the covered scope.

Chapter Two: Comprises the related contributions through the literature about hollow core beams.

Chapter Three: Comprises the materials characteristics used in this study in addition to the details of the experimental program.

Chapter Four: Views the results of the tests conducted in the experimental program and a brief discussion.

Chapter Five: Includes the main conclusions that can be recognized in this study in addition to some recommendations about the future