Republic of Iraq
Ministry of Higher Education and Scientific Research
University of Misan/College of Engineering
Civil Engineering Department

BEHAVIOR OF HYBRID STRENGTH REINFORCED CONCRETE BEAMS OF TRAPEZOIDAL SECTION

A THESIS
SUBMITTED TO THE COLLEGE OF ENGINEERING OF MISAN UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER IN CIVIL ENGINEERING
(STRUCTURES)

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October, 2020

بِسْمِ اللَّهِ الرحْمنِ الرَحِيمِ

((فَمَنْ حَاجَّكَ فِيهِ مِن بَعْدِ مَا جَاءَكَ

مِنَ الْعِلْمِ فَقُلْ تَعَالَوْا نَدْعُ أَبْنَاءَنَا

وَأَبْنَاءَكُمْ وَنِسَاءَنَا وَنِسَاءَكُمْ وَأَنفُسَنَا

وَأَنفُسَكُمْ ثُمَّ نَبْتَهِلْ فَنَجْعَل لَّعْنَتَ اللَّهِ

عَلَى الْكَاذِبِينَ))

صَدَقَ اللَّهُ العَلِيُ العَظِيم

سورة آل عمران

الآية (٦١)

To my Parents …

To my brothers…

To my sisters…

To my wife …

To my sons…

And all my friends

With entire my honorary and my respect

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Certification

I certify that this thesis entitled **"Behavior of Hybrid Strength Reinforced Concrete Beams of Trapezoidal Section"** was prepared by **Majid Jafar Sada** under my supervision at University of Misan College of Engineering, in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering (Structures).

Signature

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Date: / / 2020

In view of the available recommendation, I forward the thesis for debate by the examining committee.

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Date: / / 2020

Examining Committee's Report

We certify that we the examining committee, have read the thesis titled ″ **Behavior of Hybrid Strength Reinforced Concrete Beams of Trapezoidal Section**″ which is being submitted by **Majid Jafar Sada,** and examined the student in its contents and in which concerned with it, and that in our opinion, it meets the standard of a thesis for the degree of master of Science in Civil Engineering (Structures).

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Abstract

The present study aimed to investigate the structural behavior of hybrid reinforced concrete beams of trapezoidal section. The experimental work of this investigation consists of thirteen beams simply supported by both sides under static two-point loading. The studied variables were the side angle of beam section (75°, 80°, 85°, and 90°), and concrete strength in the tension and compression zones of the beam section for the production of hybrid concrete Ψ= fcu(bottom)/fcu(top). Three strengths were used to produce hybrid concrete (70, 50, and 25 MPa). Effects of these variables on behavior of hybrid strength-trapezoidal section beam were studied and compared. The behavior including crack patterns, first crack load, ultimate loads, load-deflection response, and flexural strain distribution. The specimens were divided into three groups depending on the type of hybrid concrete (GR1, GR2, and GR3). Each group contains a type of hybrid concrete (Ψ1=0.714, Ψ2=0.5, and Ψ3=0.357), respectively. Experimental testing showed that the effectiveness of the hybrid trapezoidal formation maintained little decreasing in concrete strength despite the large difference between concrete strength in the region of tension and compression. The flexural strength capacity is increased with the expanding area of high-strength concrete in the compression zone by increments ranging from 2.16%–6.77% compared with reference specimens of uniform section (rectangular section). While, the first crack load is decreased. The hybrid concrete exhibited high ductile behavior, and the significant failure mode was flexure mode without slippage of hybrid concrete layers. The comparison of results with hybrid strength reduction index (Ψ) showed that the reduction of Ψ1= 0.714 to Ψ 3 = 0.357 resulted in the following: the average rating of ductility varies between 1–1.24 and 1.03–1.26 considering rectangular specimens and the trapezoidal section of uniform strength, respectively. An optimum side angle of trapezoidal configuration is found, this angle is the best result for all hybrid strength trapezoidal sections indicated in specimens of (Θ = 76° and Θ = 85°).

ACKNOWLEDGEMENTS

First and foremost, So much thanks to God for many graces and blessings.

The author would like to express grateful and deepest indebtedness to his supervisor **Prof. Dr. Sa'ad Fahad Resan**, for the considerable assistance, constructive suggestions, tireless guidance, and enduring patience throughout this work.

Grateful thanks are due to **Assist. Prof. Dr. Abbas Oda Dawood**, Dean of the college of Engineering, and **Assist. Prof. Dr. Samir M. Chasb**, Head of the Civil Engineering Department, for providing facilities for conducting the investigation, and all my teachers **Prof. Dr. Ahmed Khadim Al-Shara, Prof. Dr. Abdulkhaliq A. Jaafar, Dr. Nasir Hakeem, Dr. Hayder Al-Khazraji.**

An expression of gratitude is presented to the staff of Structural materials laboratory and the library staff for their assistance in preparing the work.

The author expresses greetings to for their help and real support in many moments of crisis.

Majid Jafar Sads

2020

CONTENTS

List of Abbreviations

Symbol	Description
ACI	American Concrete Institute
ASTM	American Society of Testing and Material
B.S	British Standard
R.C	Reinforcement Concrete
RPC	Reactive Powder Concrete
CC	Conventional concrete
CFRP	Carbon fiber reinforced polymer
UHPFRC	Ultra-high-performance fibre reinforced concrete
UHPC	Ultra-high-performance concrete
LWC	Light weight concrete
IQS	Iraqi Standard
EN	European Standard
R. O	Reverse Osmosis

List of notations

Symbol	Description
f_{cu}	Concrete compressive strength, MPa
f_r	Radial stress, MPa
f_t	Strength of tensile, MPa
f_y	Yield strength of steel reinforcement bar, MPa
E_c	Concrete modulus of elasticity, GPa
S	Stress, MPa
ϵ	strain in concrete
ψ	Concrete Class
Θ	Side Angle of Beam Cross-Section Degree
λ	ductility index, unitless
Δ	Deflection, mm
L	Specimens length, mm

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CHAPTER ONE

INTRODUCTION

CHAPTER ONE

Introduction

1.1 General

Smart distribution of section area and optimum selection of proper strength are powerful factors used in design philosophy for economic structural member. Durability, cost and construction time in addition to knowing the factors of complexity are the main elements for the success of any project. The adoption of these elements for each part of the project ultimately lead decrease the cost of the build construction, with least possible time. Also, the most important parts of the construction project are the concrete members, the improving of their properties, increasing their strength and using additives certain, and uncomplicated construction methods are contribute effectively in the project's success [1].

Among many methods of improving the properties of concrete are those that related to increasing its strength by using additives[2] as well as implementing them in certain forms that are appropriate to the facility on the other hand, which contributes to the increase durability in general, while the use of hybrid concrete contributes effectively to reduce the constructions cost[3] . It is more effective of using high strength concrete in compression regions of concrete beams. This fulfills the requirements of ACI 318 cod [4].

It is possible to obtain a high strength concrete beams with lower costs, by using hybrid concrete with special shape. The trapezoidal shape is proportionate with the compressive and tensile strengths so that it increases the compression area and thus increases the compression strength and vice versa for the tensile area, where the rebar strength will distribute tensile stresses.

1.2 Reinforced Concrete Beams of Trapezoidal Section

The trapezoidal beams are a special shape that is dealt with in analysis and design using special computational methods. The shape is generally trapezoidal, a transitional shape between the rectangle and the triangle. When one of the two bases are equal to zero, the shape becomes a triangle. If the measurement for both bases is equal, the shape becomes a rectangle. This gives us a visualization of the process of analyzing and designing reinforced trapezoidal beams. Reinforced concrete beam with non-rectangular section can be treated as a special shape in analysis and design. In trapezoidal section it should be noted the code permits the use of the stress block [5]. Figure (1.1) depicts typical reinforcement concrete sections of different shape, while Plate (1.1) shows trapezoidal concrete sections.

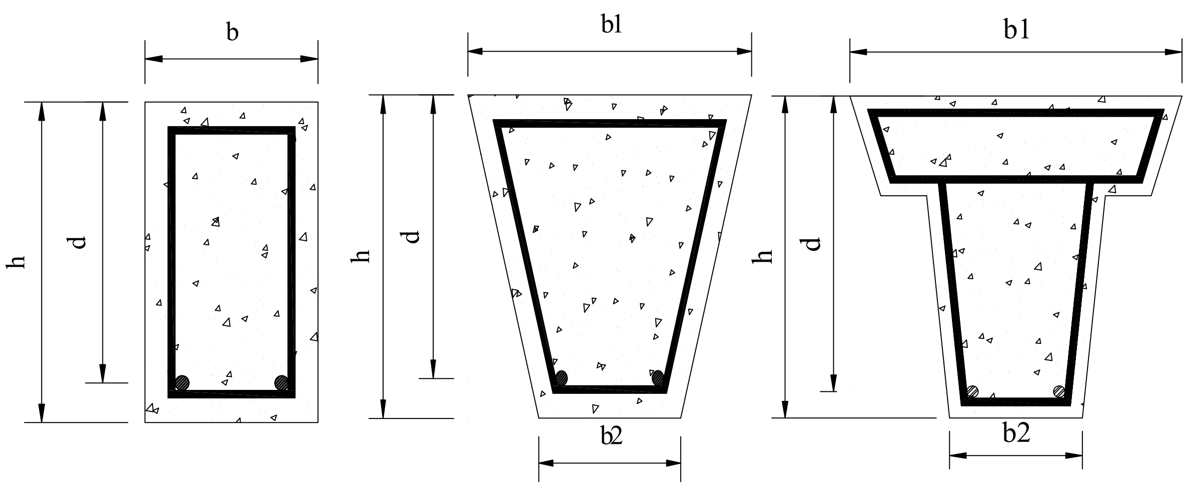
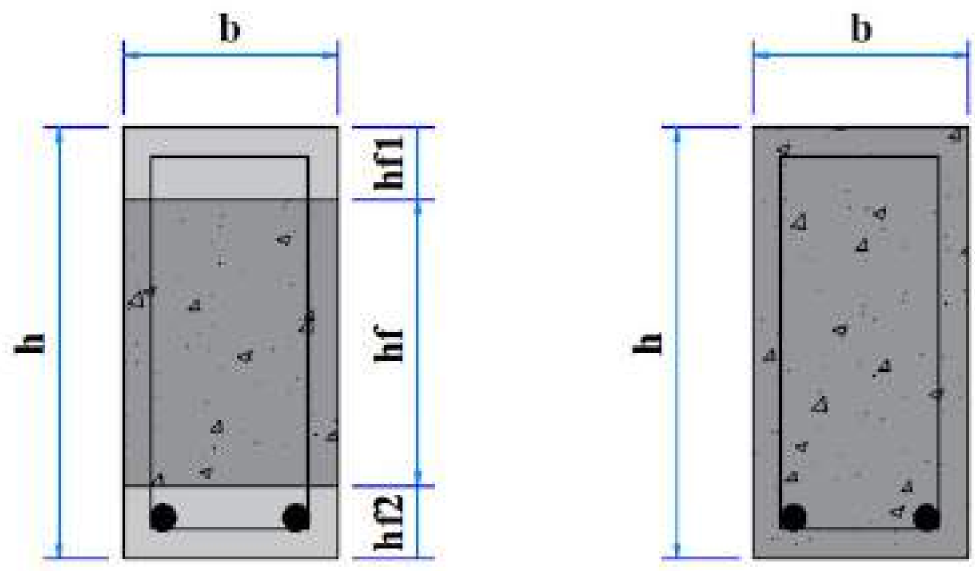


Figure (1.1) Typical reinforced concrete sections of different shape

Plate (1.1) Trapezoidal reinforced concrete section

1.3 Reinforced Concrete Beams of Hybrid Strength

The hybrid concrete strength is a concrete substance that consists of more than one type of concrete. Almost it consists of two types of concrete with two different strengths. The reason behind the use of hybrid concrete is reducing construction cost. For example, for reinforced concrete beams, the concrete's ability to withstand tensile strength is so low that it is neglected in design calculations. In the other hand the concrete's ability to withstand compressive strength is high. Therefore, the use of concrete with lower strength in the tensile zone and relatively high strength in the compression meets the design requirements with optimum section size. The casting of hybrid concrete at the site is difficult in the implementation and quality control, but it may be more suitable for precast section as the quality control is high compared to the work site. Figure (1.2) shows the typical configuration of hybrid sections of different strength [6]. Hybrid concrete can be use in multiple areas such as bridges, roads, buildings, etc. as shown in Plate (1.2). Old-new concrete can be considered as a type of hybrid strength concrete, due to influence on the Young's modulus of each concrete layer and, consequently, on the differential stiffness of the composite concrete member [7].



A. Hybrid section strength

B. Homogenous section strength

Figure (1.2) Typical configuration of hybrid sections of different strength [6]

Plate (1.2) Structures of hybrid strength

1.4 High Strength Versus Normal Strength Concrete

At the beginning of the used of high strength concrete and upgrading of required strength was carried out in limited applications and depends on controlling the proportions of its components.

The development of the production of high strength concrete was done gradually and continuously. In the 1950s, the strength of 34 MPa was considered high. In the 1960s, concrete with a strength of 41-52 MPa was used. In the 1970s concrete with a strength of 62 MPa was produced. At the present time concrete was produced with a strength greater than 150 MPa. High strength concrete allows engineers to construct taller buildings and produce thinner and taller structural members [8]. High strength concrete has been used in most constructions exposed to high loads such as bridges, roads, airports, tanks, skyscrapers, etc.

1.5 Flexural Strength Capacity

Flexural strength is an indicator to determine the tensile strength in concrete. Also, it is an indirect method for measuring the tensile strength in concrete that displayed cracks. The tensile strength of concrete in flexure is approximately 10 to 15 percent of the compressive strength [2]. Measurement of flexural strength also helps in assessing the deflections that occur in concrete at service loads. The relationship (1.1) gives a direct value for the flexural strength [9]. In practice, it is possible to obtain the value of flexural strength by testing a sample of plain concrete by simply supporting it from both sides and applying a concentrated load in the middle of the span, by applying the equation (1.2) [10] it can get the value of the flexural strength. This equation shows the effect of a shape section on the flexural strength value. Flexural strength is an important feature in the analysis and design of structural members. Design codes supply an assumption that the compressive strength behavior can be expressed as a rectangular stress block for simplify design [5], See Figure (1.3).

$$f_r = 7.5\sqrt{f\acute{c}} \quad \text{.......................................} \quad (1.1)$$

$$f_r = 3pl/2bd^2 \quad \text{.......................................} \quad (1.2)$$

where;

f_r: modulus of rupture (MPa)

$f_{\acute{c}}$: compressive strength of standard concrete cylinders (MPa)

p: Maximum applied load (N)

l: Average depth of specimen (mm)

b: Average width of specimen (mm)

d: Average depth of specimen (mm)

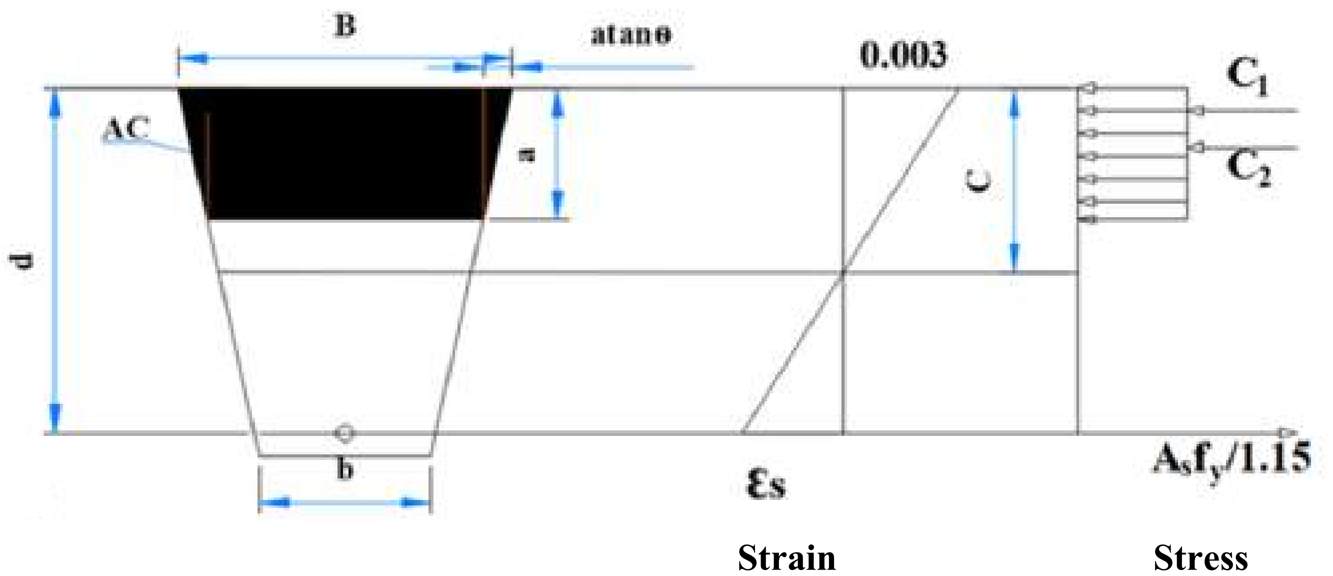


Figure (1.3) Equivalent rectangular stress block to trapezoidal section [5]

1.6 Aim of Study Target

The optimum distribution of concrete strength within section of best area distribution extremely affects overall section structural characteristics. This study intended to investigate introduced trapezoidal sections with hybrid concrete strength. The main variables considered in this study are hybrid concrete with two deferent types of strength, side angle for cross-section, main reinforcement, and web reinforcement.

1.7 Layout of The thesis

The thesis was organized into five chapters;

- Chapter one, which is the current chapter, has a general introduction to reinforced concrete beams of trapezoidal section, the hybrid concrete used in reinforced concrete beams, high strength concrete versus normal strength concrete, flexural strength capacity, in addition to the objectives and scope of use.

- Chapter two is dealing with previous studies carried out by researchers and scholars on topics of non-prismatic section, trapezoidal section, hybrid concrete, specie technique to upgrade deeps beam.
- Chapter three is contain the experimental work was explained, which includes the materials used in the production of concrete and reinforcing steel and its test. Also, the number and type of samples are indicated.
- In chapter four, the results are included and the experimental work is discussed.
- In chapter five, the conclusions and recommendations for studying and developing this work are presented.

CHAPTER TWO

LITERATURE REVIEW

CHAPTER TWO

LITERATURE REVIEW

2.1 General

The behavior of hybrid reinforced concrete beams of a trapezoidal cross-section is different from other beams of a rectangular cross-section and a homogenous concrete cross-section. This study concerned on the experimental investigation of RC beams of hybrid strength-trapezoidal section beams. The related previously studies regard hybrid strength and trapezoidal section, are presented in this chapter.

2.2 Hybrid Strength Reinforced Concrete Beams of Non-Rectangular Section

In 2015, Al-Hassani et al. [11] conducted an experimental study concerned with mixed reinforced concrete boundaries consisting of ordinary concrete and reactive powder concrete T- sections were tested. The first and second specimens fully ordinary concrete and reactive powder concrete RPC. They used as a control specimens. The third specimen it was used a reactive powder concrete in the flange and the ordinary in the web. The fifth sample was the opposite so that the ordinary concrete was used in the flange and the reactive concrete in the web while the fourth sample consisted of the reactive concrete in the flange and half of the web and normal concrete in the lower half of the web. The results showed that the use of reactive powder concrete gave better results compared to the model made entirely of ordinary concrete. The use of RPC in the flange with normal web concrete strength for hybrid T section beam, shows an increase in first crack load, ultimate flexural strength, and max. deflection 20%, 34.28%, and 14.96%, respectively. In the case of using RPC in the flange and upper half of the web, the results appeared an increase in first crack load, max. deflection, and ultimate flexural strength 20%, 14.96%, and 34.28%, respectively. The study also showed that a hybrid beam of ordinary flange concrete and RPC in the web leads to an increase in cracking load, ultimate load, and max. deflection 86.67%, 29.19%, and 60%.

In 2017 Jassim [12] tested 12 reinforced concrete box beams with dimensions 300×300×1200 mm. The compressive strength, stirrups, steel fibre ratio and thickness of the top and bottom layers are variables. The test results showed that ultimate torsional strength of hybrid specimen was higher than the conventional concrete CC specimen by approximately (58%), and below the modified RPC specimen by approximately 40.75%. The angle of twist is reduced by increasing the compressive strength, the amount of stirrups reinforcement, steel fibre ratio and top and bottom flanges thickness. The capacity of cracking of test box beams increased when increasing all variables by about 12.12%, 14.47% and 8.48% respectively. But the first crack load is decreased when increasing the spacing between stirrups reinforcement bars from (110-150 mm) by about 34.1%.

In 2018, Fang et al. [13] studied the shear capacity of reinforced concrete beams with a T cross-section. Two-components of concrete strength was used, lightweight concrete in the flange and high-strength concrete in the web. The test program included the casting and examination of twelve beams, variants included, light concrete strength, clamping stress, and interface preparation. The results showed that most of the beams failed with horizontal shearing, which indicates the separation of the flanges with lightweight concrete from the web with high-strength concrete. Most of the reinforcement for shear strength (stirrups) reached the yielding stage when slipping occur at a distance (0.5 and 1.0) mm before the final failure of the horizontal shearing occurred.

In 2018, Alawsh and Mehdi [14] investigated the behavior of concrete box girders consisting of a hybrid concrete strength and compared with similar ones that were poured with one type of concrete. The experimental program included casting five beams of box girders divided into two groups. The first group which was consisted of two girders with concrete strength of 35MPa while the other with 55 MPa. The second group was casted by three high-strength hybrid of 55 MPa in the upper part and the normal concrete of 35 MPa in the lower part. In the numerical program, the researcher modeled and analyzed of laboratory specimens using ANSYS program was done. The numerical results were consistent with a difference (3.12% to 9.588%) as a rate of load as well as deflection. The results showed that the maximum strength of the hybrid girders increased 23% more than their homogeneous beams of normal strength, but they showed a decreasing of 9% over their homogeneous beams with high strength.

2.3 Reinforcement Concrete Beams of Trapezoidal Section

In 2001, Al Ansari [15] presented an analytical study to estimate the cost of the RC beam based on the shape of the cross-section and to ensure structural safety and reliability. In that study, five RC beams with different sections rectangular, triangle, inverted triangle, trapezoid, and inverted trapezoid were designed based on ACI code. The study showed that the cost of materials in a triangular cross beam is lower than the rectangular and trapezoidal by average of 12%, and 37%, respectively. The cost of a triangular cross-section and an inverted triangular section is approximately equal, but an inverted trapezoidal beam was lower cost of a trapezoidal cross-section.

In 2011, Tito and Rivas [16] studied design, construction, and testing of a post-tensioned segmental concrete beam consisted of a set of concrete blocks in the form of a trapezoid. The segments were two solid end block and nine hollow blocks. Two strands were located along the bottom of beam and another were located along center and a fourth half strand raw along the top of the beam. The results showed that the deflection, strains, and the ultimate load capacity matched with theoretical predictions.

In 2017, Khalil et al. [17] studied the effect of trapezoidal cross-sectional area on the beam's ability to resist shear stresses. Experimental work was conducted on two groups of beams, each group consisting of four beams. First groups have a rectangular cross-section and the rest have a trapezoidal cross-section with three different side angles. The second group of beams were without stirrups. All beams had the same area as well as width and depth. The results showed that the behavior of all beams was similar in the first part of the load deformation curve, and the relationship in this part was linear. Also, the results showed that the trapezoidal beams gave less deflection compared to the rectangular beams, the beams with trapezoidal gave higher ultimate shear capacity than the rectangular beams. cracking load results varied and the specimens did not show a steady behavior. While shear cracking load of the trapezoidal specimens were higher than the reference beams. The specimens in which the stirrups were used, a higher failure load was recorded than the one without stirrups.

In 2018, Shafeeq et al. [18] study investigates the behaviour of trapezoidal cross-sections self-compacting reinforced concrete beams under flexural failure, with and without strengthening with carbon fiber reinforced polymer CFRP. The studied beams were divided into two groups according to their cross-sections; each group included five beams, and the first group (T20) were those with trapezoidal cross-sections with dimensions length 1,600 × height 260 × width of 160 mm at the bottom and 200 mm at the top, while second group (T24) consisted of those with trapezoidal cross-sections with dimensions length 1,600 × height 260 × width of 160 mm at the bottom and 240 mm at the top. The experimental program included studying the effects of top width on the flexural behaviour of beams with trapezoidal cross-sections, in addition to studying the effect of reinforcing those beams with varying numbers, locations, and methods of placement of CFRP strips. The experimental results showed that trapezoidal cross-sections with 240 mm top width gave higher ultimate load capacity by 4 to 11.54%, as well as offering lower deflection, compared to trapezoidal cross-sections with 200 mm top width.

2.4 Reinforced Concrete Beams of Hybrid Strength

In 2007, Habel et al [19] studied the flexural behaviour of composite beams. The beams were composed of RC substrates and UHPFRC layers in the tension face. They concluded that applying the UHPFRC layer to form a composite beam increases the stiffness, minimizes the deformations for given imposed loads, reduces crack widths and crack spacing and delays the formation of localized macro cracks as compared to the original conventionally reinforced concrete beams. They found that the composite beams behaved monolithically and the debonding only occurred near the ultimate load for the beams without reinforcing bars in the UHPFRC layer whereas the presence of such bars in UHPFRC prevents the debonding.

In 2010, Mohammed [20] studied torsional behaviour of hybrid rectangular sectional beams combining reactive powder concrete at the peripheral and conventional concrete at the core. The experimental work includes casting twelve reinforced concrete beams that were tested to failure using two opposite cantilevers steel arms that contribute to transferring the torque to the centre of the beam. The overall dimensions of the beams were (100×200×150) mm. The first beam was poured from reactive powder concrete mix. The second one was poured from conventional concrete, and the remaining ten beams were poured as hybrid ones. The compressive strength of conventional concrete was about 28.1 MPa, and for reactive powder concrete is about 90.5 MPa for compressive. The work also included studying the effects of the following main variables: longitudinal reinforcement area, transverse reinforcement area steel, thickness of reactive powder concrete RPC (20 and 40 mm), steel fibres ratio, spacing of stirrups. The experimental data for all beams focused on the ultimate capacity, the cracking torsional loads, the failure pattern, the twisting angle, and shear strain gained for each beam. Experimental results showed higher ultimate torsional strength for hybrid beams compared to the conventional concrete CC ones by about (68.75, 65.71, 71.96, 81.25, 50.00, 39.11, 63.93, 79.64, 70.36 and 35.89) % for ten hybrid beams, and slightly less than RPC specimen in about (11.52, 13.11, 9.83, 4.96, 21.35, 27.06, 14.04, 5.81, 10.67, and 28.75) % for ten hybrid beams with five variables used in this work.

In 2010, Kheder et al. [21] studied the flexural and cracking behavior of reinforced concrete beam and casted with hybrid concrete. Two concrete compressive strength were used (20 and 70 MPa) and compared with homogenous of 20 and 70 MPa. The experimental program was based on testing twelve beams divided into three groups. The variables that govern these groups were the strength of concrete, the homogeneity of concrete, and the amount of reinforcing steel. The first group was made of fully normal concrete and the difference between the beams in this group was only in the amount of reinforcing steel. The second group was made of concrete of high strength was steel, while the third group was a hybrid concrete strength with a difference in the reinforcing steel ratio. The results showed that the hybrid beams showed an improvement in the load carrying capacity at cracking, yielding and ultimate loading as compared to normal strength beams. The increase in load carrying capacity was (1.80–70.8%) higher than normal strength beams and only (3.3–9.8%) lower than corresponding high compressive strength beams. Also, from experimental results the crack spacing of hybrid beams were between those of normal strength and high strength beams, but the crack width in the hybrid beams were narrower than both types of beams at all loading stages. At service and ultimate loading stages, the crack width in the hybrid beams were 19.5–26.0% narrower than those of corresponding normal strength beams, and 9.2–15.1% narrower than high strength beams.

In 2011, Abbas and Abd [22] showed, through an experimental study, the shear behavior of a reinforced concrete beam with a cross-section of a hybrid strength concrete beam. The experimental program consists of test six beams divided into three groups, each of them contains a beam with homogenous concrete (using one strength) and the other was hybrid strength. The results showed that the using of high-strength concrete in the compression zone increased ultimate shear strength capacity and cracking load, in addition to an increasing in ductility response. In beams (HS3, HS5 and HS7) with high strength concrete in compression zone the strength capacity increased by (10.8, 13.7 and 11.1) %, the cracking load by (15.38, 20.46, and 12.3) %, and the ductility by (47.9, 97,3 and 46.85) %, respectively.

In 2014, Fahmy et al. [23] developed a reinforced concrete beam, consisting of reinforced concrete with a U cross-section in which conventional concrete was substituted for alternative materials. The experimental program included the casting and testing of six reinforced concrete beams divided into two groups. First group consisting of three beams of normal concrete. The second group consists of three beams of precast ferrocement form filled with concrete. The material used were conventional concrete, lightweight concrete, and recycled concrete. The testing was done with simple support for the beam from both sides then applied a three-point load. The results showed that cracking, ultimate load and serviceability were high and good energy absorption. Experimental results were compared with theoretical results and were well converged.

In 2015, Hassan [24] studied the behavior of the deep beam in terms of deflection, mode failure and the ultimate load of the beam when using high-performance concrete in full or as a hybrid concrete with traditional concrete in the same beam. The experimental work consisted of testing twelve beams divided into three groups, each group consisting of four beams. First group was cast with traditional concrete completely, the second group was completely cast with high-performance concrete, while the third and fourth groups were cast with hybrid concrete consisting of high-performance concrete, traditional concrete. The difference between the third and fourth groups was the depth of the high-performance concrete. Also, the volumetric ratio of steel fibers was another variable. Results displayed that the shear was the failure pattern for all beams except for two beams in which failure pattern was (shear - flexural) because it contained steel fiber. Crack strength, final strength, and the stiffness of ultra-high-performance concrete (UHPC) and hybrid beams were increased by increasing steel fiber. Also, the deflection decreased by increasing the thickness of the performance layer of concrete and by increasing the percentage of steel fibers relative to hybrid concrete.

In 2015, Nabeel et al. [25] prepared eight deep beams made of composite concrete and the purpose to study the structural behavior of these beams. The variables included the thickness of the plate steel used to reinforce the web, the ratio of shear space to depth (a/d) and the concrete's strength to compression (f_c'). The testing of the beams was done by simple support by both sides, and a concentrated load of two points was projected. The results showed that the ultimate load capacity decreased by (9.13%) when using the pallet steel instead of the reinforcing steel bars, but when increasing the strength of concrete from (24 MPa to 38 MPa) it was observed that the ultimate load capacity increased by (17.12%). Also, the increase of the pallet thickness from 1.0mm to 1.4mm led to a decrease in the ultimate load capacity by (3.82%) while increasing the thickness of the iron pallet from 2mm to 4mm increased the ultimate load capacity by (6.58 %).

In 2015 Shinde et al, [26] investigated hybrid beams with fibre (steel and polypropylene) reinforced concrete deep beams with consideration to their flexural behaviour and how the characteristics of the mechanical of the concrete mix were affected by that behaviour. Fibers of steel and polypropylene were be used in different ratios in the mix proportion (0%-0%), (0%-100%), (25%-75%), (50%-50%), (75%-25%) and (100%-0%) by volume. The splitting tensile strength and the compressive strength were also examined alongside the flexural behaviour. It was observed that, by the comparison to normal concrete, the increasing was from (6.61%) to (6.21%) in the compressive strength of (f_c) for respectively (100%-0%) hybridization ratio and polypropylene fibre reinforcement concrete (0%-100%) hybridization ratio. The higher the splitting tensile strength occurred when more steel fibre SF was added to the hybridization ratio. Compered to normal concrete, the splitting tensile strength of (f_c) (100%-0%) and polypropylene fibre reinforcement concrete (0%-100%) hybridization ratio, was respectively 41.61% and 6.35% higher. In addition, by comparison to normal cement concrete, the hybrid fibre reinforcement concrete of the flexural strength (75% -25%) hybridization ratio was 36.68% higher, the flexural strength of FC (100% - 0%) hybridization ratio was 23.58% higher, and the flexural strength of polypropylene fibre reinforcement concrete (0%-100%) hybridization ratio was 8.29% higher.

In 2016, Abass and Abd [27] studied the structural behavior of a reinforced beam consisting of hybrid strength of beam. Where they made a practical program from testing twelve beams with a rectangular section divided into four groups, each group consisting of three beams. As for the main variables, it was the type of concrete used in terms of strength, as well as the proportion of reinforcement in each beam. So that the first group and the third group were made entirely of homogeneous (not hybrid) concrete while the second and fourth groups were each of them is made of half-to-half hybrid concrete, two types of high-strength concrete. About the results, it was found that the use of hybrid and high-strength concrete improves its ultimate capacity by (10.41%–48.80%) compared to traditional concrete, and also the use of high-strength concrete only led to an increase in ultimate capacity by (14.28% –42.30%) compared to traditional concrete. The perimeter of failure increased considerably in samples with high strength and hybrid compared to samples with traditional concrete.

In 2016, Abtan and Jaber [28] studied the bending behavior of the beam consisting of a hybrid reinforced concrete of two types of concrete. The Reactive Powder Concrete (RPC) in the compression zone, and Light weight concrete (LWC) type in the tension zone was used. The testing program included twelve beams tested of simple support and these models were varied in the concrete layer thickness of RPC, (0, 50, and100) mm. The main variables were type of concrete LWC and RPC, thicknesses of RPC layer (h_R=0, 50 and 100) mm, volumetric steel ratios (Vf=1%) in LWC and type of LWC (porecilenite aggregate, polystyrene and sawdust). The results obtained from the study was showed that the cracking load and the ultimate load increased with increasing layer thickness of RPC. This increase was about (7% -100%) and (32%-133%) for crack load and final load, respectively. The opposite results were in terms of occurred deflection, it was decreased by (1-17) %. It was noted that concrete fibers with steel and polysilane were better than aggregated concrete (sawdust and polystyrene). Besides, ceramic concrete showed more cracks, compared to sawdust and polystyrene, also, it was noted that all the beams failed by flexural so that the shear cracks did not appear.

In 2018, Hassan and Mhebs [29] presented an experimental and analytical investigation to study the behavior of deep reinforced beams of hybrid strength concrete subjected to repeated and monotonic loads. The idea of hybrid in this research was based on using two types of concrete in the specific areas along the beam. High-strength concrete was placed in regions that were subject shear stresses in the deep beam to enhance these strength shear. Their experimental program consisted of ten models of the deep reinforced beam and the models were divided into five groups. Each group contains two beams. The first group was non-hybrid and was casting with fibrous concrete, while the second, third and fourth were served as hybrid strength concrete, the fifth group was not hybrid and casting with high strength concrete. The results showed increased in the ultimate load capacity of the deep reinforced concrete beams with hybrid concrete of 1% steel fiber compared to the beams with conventional high strength concrete.

In 2019, Kazem [30] studied a new method to strengthen the deep beams by confining the strut region of deep beams in which the forces are transmitting to the support from loading point by using RPC layer. One was cast totally from Conventional concrete (CC) of compressive strength about of 28.83 MPa and RPC of compressive strength about 93.78MPa. The steel fiber ratios (0.5, 1 and 1.5 %) are used with 100 mm thickness of Reactive Powder Concrete (RPC). 1% percentage of steel fiber is used with thickness of RPC 150 and 200 mm, respectively. The effect of RPC confinement represented by the increasing of ultimate load, decreasing the earlier deflection, increasing the ultimate deflection.

In 2019, Mohammed and Ali [31] dealt with the behavior of the concrete beam consisting of two types of concrete of different strengths and linked with each other by epoxy. The experimental program consisted of examining ten reinforced concrete beams. All models were used with concrete of 20 MPa and five of them were strengthened by adding a cover of high-strength concrete 40 and 60 MPa by attaching them using epoxy and with a thickness of 15 mm for four of them. The fifth specimens were prepared with 30 mm thickness. The results indicated that the technique of linking the two types of concrete using epoxy was effective. Also, the composite models gave results closed to the beams made entirely of high concrete strength.

2.5 Concluding Remarks

Based on what was mentioned in the above studies, we can make the following remarks conclusions: -

1- Some studies dealt with the effect of the shape of the beam section of hybrid concrete strength on the structural behavior of reinforced concrete beams, depending on several variables, including the shape of the cross-section and hybrid concrete materials.

2- Some studies dealt with the structural behavior of beams with a trapezoidal cross-section, the most prominent variables that were adopted it was the change in the side angle of the trapezoid.

3- Many studies dealt with the structural behavior of the reinforced beam with hybrid concrete and the approved variables were the strength of concrete and its location relative to the natural axis in addition to the materials used in the concrete. In this study, the structural behavior of reinforced concrete beams with a trapezoidal cross-section consisting of hybrid concrete were investigated, as interaction effect of hybrid strength within trapezoidal section did not consider directly, all related studies concerned with hybrid strength effectiveness or with trapezoidal section effectiveness.

CHAPTER THREE
EXPERIMENTAL INVESTIGATION

CHAPTER THREE

EXPERIMENTAL INVESTIGATION

3.1 General

The purpose of the current experimental program is to provide data and information about the structural behavior of hybrid reinforced concrete beams of a trapezoidal cross-section. The main objective of this chapter is to present the properties of materials (cement, fine and coarse aggregate, additive material). Also, the overall details of the test specimens, reinforced details, used instrumentations, and testing setup are described. Thirteen beam specimens were casting in this study. The specimens are divided into three groups Standard tests according to the American Society for Testing and Materials (ASTM) and Iraqi Specifications are conducted to determine the properties of materials. The experimental work was carried out in the Civil Engineering Laboratory of Engineering College at Misan University and Laboratory Engineering Materials of Technical Institute in Amarah / Maysan province.

3.2 Properties of Materials

The basic substances used in specimens manufacturing which are cement, gravel, sand, superplasticizer, silica fume, and reinforcing steel which is tested according to the (ASTM) specifications and Iraqi specifications.

3.2.1 Ordinary Portland cement

For all concrete mixtures in this test work, Iraqi Portland cement (Karasta cement) which is produced by Lafarge company, according to the European standard EN 197-1:2011 [32]. It was extracted from natural materials using sustainable production techniques. The results are listed in Tables (3.1) and (3.2).

Tests of the physical and chemical properties of the used cement have been performed according to the Iraqi Standard I.Q.S No. 5/1984 [33].

3.2.2 Fine aggregate (sand)

The sand that has been used in all concrete mixtures is a natural sand. The maximum grain size is 4.75 mm, Laboratory tests for sand have been carried out according to the Iraqi specifications I.Q.S No. 45/1984[34]. The results of these tests listed in Table (3.3).

Table (3.1) Physical properties of cement

Physical property	Test result	Limit of I.Q.S No.5/1984[33]
Specific surface area (Blaine method), (m^2/kg)	281	(Min) 230
Setting time (Vicat apparatus), (hr:min)		
Initial	1:15	(Min) 00:45
Final	4:37	(Max) 10:00
Soundness (%) (Autoclave expansion)	0.51	(Max) 0.8
Compressive strength (70.7mm cube) MPa		
3-day	19.37	(Min) 15
7-day	31.77	(Min) 23

Table (3.2**)** Cement chemical test

Chemical analysis	Percentage, by weight	Limit of I.Q.S No.5/1984[33]
Calcium oxide (CaO)	63.10	....
Silicon dioxide (SiO2)	23.43	....
Aluminum oxide (Al2O3)	2.15	....
Ferric oxide (Fe2O3)	4.5	....
Magnesium oxide (MgO)	2.35	5.00 (Max.)
Sulfur trioxide (SO3)	2.33	2.80 (Max.)
Potassium oxide (K2O)	0.61	....
Sodium oxide (Na2O)	0.22	....
Loss on ignition (L.O.I)	3.5	4.00 (Max.)
Insoluble residue (I.R)	0.96	1.50 (Max.)
Lime saturation factor (L.S.F)	0.82	0.66-1.02

3.2.3 Coarse aggregate (gravel)

In all tests, gravel with a maximum size of 12.5 mm was used as a coarse aggregate. It washed and stored in a water-saturated and dry surface before use. Its specific absorption and the specific gravity equal to 0.5% and 2.65, respectively. Physical test results were showed in Table (3.4). The laboratory test results indicate its conformity with the limits of Iraqi Standard I.Q.S No. 45/1984 [34].

Table (3.3) The sieve analysis of fine aggregate

Sieve size	% Passing	Passing limits of (%) according to I.Q.S 45/1984 [34] (Zone 2)
10 mm	100	100
4.75 mm	100	90-100
2.36 mm	93	75-100
1.18 mm	81	55-90
600 µm	52	35-59
300 µm	13	8-30
150 µm	7	0-10
< 150 µm	-	-

Table (3.4) The sieve analysis of coarse aggregate

No	Sieve Size (mm)	Percent of Passing (%)	Iraqi Specification I.Q.S 45/1984 [34]
1	12.5	100	100
2	10	38.58	30-60
3	4.75	1.22	0-10
4	pan	0	0-10

3.2.4 Water

Reverse osmosis (R.O) water was used in the manufacture and curing of concrete. It was used in all concrete mixtures, and curing after casting, it has been proven through laboratory testing to conform with the limits of Iraqi Standard No. (1703/1992) [35]. The results of the testing are listed in Table (3.5).

Table (3.5) Chemical test of used water

Component	Standard limits (mg/litter)	Tested Sample
SO3	1000	240
Carbonate and bicarbonate	1000	None
Chloride	500	91
Non-Organic	Summation of ions < 3000	325
Organic	Tested if their color or taste	None

3.2.5 Reinforcement steel bars

In this study Ukrainian steel bars were used in reinforcing concrete beams. Steel bars Ø12mm and Ø8mm were used as longitudinal and stirrups reinforcements, respectively. It is tested according to ASTM 370-05a [36]. The results of the tensile test are shown in Table (3.6). Plate (3.1) shows the tensile strength test setting of a reinforcing bar in the machine test. The steel bars have been tested in the Material Laboratory of Engineering College in Misan University.

Table (3.6) Properties of reinforcement steel bar

Steel bar diameter (mm)	Modulus of elasticity (GPa)	Yield stress (fy) (MPa)	Ultimate strength (fu) (MPa)
8	215	537	699
12	200	564	743

Plate (3.1) Tensile strength of reinforcement test bars

3.2.6 Superplasticizer (Sika ViscoCrete-225 S)

SuperPlasticizer (Sika ViscoCrete-225 S) was added to concrete admixtures to improve workability. In Table (3.7), the manufacturer's standard specifications of used superplasticizer are presented.

3.2.7 Silica fume

The silica fume used in this study is a grey powder ultra-fine commercially named (Mega Add MS(D)), compatibility with ASTM C 1240-03 [37], it is an additive in the form of a powder used with concrete mixtures to produce high strength concrete in proportions determined by the manufacturers, a percentage of 5 to 8% by weight of cement materials is used. Table (3.8) shows the manufacturer's standard specifications of used silica fume.

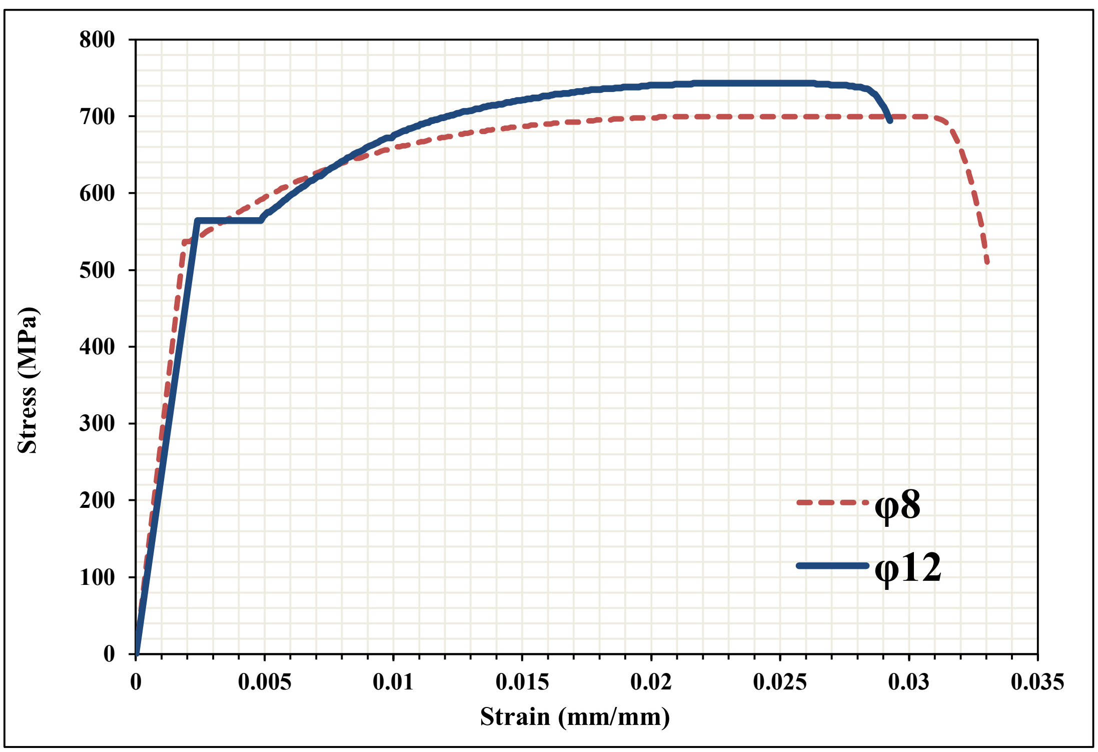


Figure (3.1) Stress-strain curve of steel bars

Table (3.7) Properties of used superplasticizer (Sika ViscoCrete-225 S)

Basis	Aqueous solution of modified poly carboxylates
Appearance	Light brownish liquid
Density	1.09-1.11 gm/cm^{3}at 20 ^{o}C
Solid Content	31-34 %
PH Value	4-6

Table (3.8) Properties of silica fume (Mega Add MS(D))

Property	Test method	Value
State	Amorphous	Sub-micron powder
Colour	-	Grey to medium grey powder
Specific gravity	-	2.10 to 2.40
Bulk density	-	500 to 700 kg/m3
Chemical requirements		
Silicon dioxide (SiO2)	-	Minimum 85%

3.3 Concrete Mixing Types

Three concrete mixes were used to investigate the influence of the concrete strength on the behavior of simply supported hybrid strength reinforced concrete beams of trapezoidal section. Two of them were normal strength concrete (25, 50) MPa, while the third one was high strength 70 MPa. Mixing was carried out according to BS 1881[38]

3.3.1 Normal strength concrete

The mix proportions of the ingredients of the first mix, Mix 1, by dry weights were [1 cement: 2 sand: 3.2 gravel], and the water cement ratio (w/c) was 40%, to give a cube compressive strength of about 25 N/mm2 at age of 28 days. For the second mix, Mix 2, the mix proportions of the ingredients by dry weights were [1 cement : 1.45 sand : 2.75 gravel], the water cement ratio (w/c) was 38%, and 0.05% superplasticizer by weight of cement to give a cube compressive strength of about 50 N/mm2 at age of 28 days.

For Mix 1, electric mixer was used after the mixer cylinder was cleaned, the ingredients were added in order and dryly, as follows, half the amount of gravel and the entire amount of sand, as well as for cement and then the rest of the gravel was added and finally, the water was added and the mixing time was approximately three minutes until the mixture was homogeneous.

For Mix 2, In addition to what was mentioned in preparing the first mixture Mix 1, the superplasticizer was dissolved in water and the solution of water and superplasticizer was added to the rotary mixer and whole mix ingredients were mixed for about 1 minute, then the mixer was stopped and mixing was continued manually especially for the portions not reached by the blades of the mixer and cleaning the mixer wall from the dry batch. The mixer then was operated for another 4 minutes to attain reasonable fluidity.

3.3.2 High strength concrete

For the third mix, Mix 3, the mix proportions of the ingredients by dry weights were [1 cement: 1.16 sand: 2.26 gravel], and water cement ratio (w/c) was 30%. Superplasticizer 0.077% and silica fume 0.075% were addition by weight of cement to give a cube compressive strength of about 70 MPa at age of 28 days. The steps of the process of producing high-strength concrete (70 MPa) are the same as those that were performed in production of concrete of (50 MPa) as explained previously. The desired quantity of silica fume was mixed in dry state with the required quantity of sand. This operation was continued to 2 minutes to ensure that silica fume powder was thoroughly dispersed between the sand particles.

The contents considered in the preparing of the three types of concrete are listed in Table (3.9).

Table (3.9) Weights of materials included in concrete mixtures

ID Matrix	Symbol of concrete	Cement kg/m^3	Sand kg/m^3	Gravel kg/m^3	W/C (%)	Super plasticizer kg/m^3	Silica Fume kg/m^3	f_{cu} MPa in 28 day
I	Normal strength concrete	350	680	1108	0.54	----	----	25
II	Normal strength concrete	433	628	1190	0.38	2.17	-------	50
II	High strength concrete	490	570	1110	0.3	3.76	3.68	70

3.4 Hard Concrete Testes

For each type of concrete, three cubes (150 × 150 × 150) mm, three cylinders (150×300 mm) and three prisms (100 × 100 × 500) mm were casted. All molds preparing, cleaning and lubricating before casting. Casting and curing were carried out under the same conditions as the beams production.

3.4.1 Concrete compressive strength

Concrete cubes were tested to obtain the compressive strength for the concrete according to BS 1881[39], see Table (3.10) and Plate (3.3).

Table (3.10) Result of compressive strength of concrete

Compressive strength f_{cu} (MPa)				
ID Matrix	Cube 1	Cube 2	Cube 3	Average
I	70.3	71.8	69.3	70.47
II	50.5	51.6	52.0	51.37
II	26.1	25.6	25.2	25.63

Plate (3.2) Compressive strength test

3.4.2 Splitting tensile strength (Brazilian test)

Brazilian test was conducted according to BS 1881 [40] to specify concrete splitting strength, see Table (3.11) and Plate (3.4)

$$f_t = 2F/\pi dl \qquad (3.1)$$

where:

f_t = tensile strength of concrete in (MPa).

F = maximum force in (N).

d = diameter of cylinder specimen (mm).

l = length of specimen (mm).

Table (3.11) Concrete splitting strength

ID Matrix	Concrete Type	f_t (MPa)
I	C70	3.8
II	C50	3.0
II	C25	2.0

Plate (3.3) Splitting tensile strength test of concrete cylinder

3.4.3 Flexural strength test

The flexural strength of the concrete used in this research was conducted according to the ASTM- C78[41] specification, where specimens examined in the form of specimens with dimensions (100×100×500) mm using the testing machine of flexure with a capacity of (5000 kN) in College of Engineering, Laboratory Misan University, Plate (3.5). The results of the testing are tested in the Table (3.12).

Plate (3.4) Flexural strength test

Table (3.12) Flexural strength results

ID Matrix	Concrete type	Average flexural strength f_r (MPa)
I	C25	3.381
II	C50	4.845
II	C70	5.612

3.4.4 Modulus of elasticity (E_c)

Modulus of elasticity of concrete test was carried out according to ASTM C469-02 [42], using (150 × 300 mm) concrete cylinders, the instrument is shown in Plate (3.6). Modulus of Elasticity was determined as follows:

$$E_c = \frac{s2 - s1}{\epsilon 2 - \epsilon 1} \quad \text{……..………..…………………………………….... (3.2)}$$

Where;

E_c **:** modulus of elasticity of concrete (MPa)

S_2 : stress corresponding to 40 % of ultimate load (MPa)

S_1 : stress corresponding to a longitudinal strain, ϵ_1 (MPa)

ϵ_1= 0.00005

ϵ_2 : longitudinal strain produced by stress S_2

The results of the testing are tested in the Table (3.13) below: -

Table (3.13) Modulus of elasticity results of concrete

ID Matrix	Concrete Type	Modulus of elasticity E_c (GPa)
I	C25	29.962
II	C50	35.273
II	C70	40.134

Plate (3.5) Modulus of elasticity test setting

3.5 Details of Tested Beams

This part of the experimental work deals with testing twenty-seven of RC beams. Thirteen beams were prepared to study the flexural behavior of the reinforced concrete hybrid beams with a trapezoidal cross-section. The overall length of flexural specimens was 2100 mm. Variables included in this study were concrete compression strength, hybrid section of strength, and the side angle of the cross-section.

All beams were of the trapezoidal cross-section with the constant area, and have a length of 2100 mm and depth of 300 mm with an average width of 170 mm, the side angle of the cross-section was variable. The total number of beams were thirteen, they were divided into three groups depending on considered hybrid strength class, class $\psi 1=0.714$, class $\psi 2=0.5$ and class $\psi 3=0.357$, where $\psi=f_{cu}$(bottom)/f_{cu}(top)the first and second groups consists of five beams while the third group consists of three beams.

BL1 and BL2 from GR1 were a uniform concrete strength, 70 MPa, with a rectangular and trapezoidal cross-section, respectively, as well as BL6, BL7 from GR2, but with 50 MPa concrete strength.

(BL3, BL4, and BL5) from GR1, (BL8, BL9, and BL10) from GR2, and (BL11, BL12, and BL13) from GR3 were a hybrid strength-trapezoidal concrete beam, with $\psi 1=0.714$, ($\psi 2=0.5$, and $\psi 3=0.357$, respectively.

The cross-section side angle of hybrid strength-trapezoidal concrete beam specimens variation (75°, 80°, and 85°).

The main reinforcement is the same for the first and third groups, 7Ø12 used as longitudinal reinforcement and Ø8@50mm as stirrups. The second group have deferent longitudinal reinforcement to be competitive with considered f_{cu} in compression section to satisfied the requirement design according to ACI 318, where (4Ø12) is used as main reinforcement. Table (3.14) and Figure (3.2) briefly descript prepared specimens for flexural behavior inspection. Table (3.15) shows specimens section area and moment of inertia

3.6 Casting Procedure

Plate (3.7) shows the longitudinal reinforcement bars and stirrups distribution. The main, horizontal and vertical web bars were assembled by steel wires manually and then using plastic spacers to maintain the concrete cover and secure the position of reinforcement in designated location. Timber forms with plywood face were used in casing beams, the interior face of forms were coated with oil prior to casting and before the reinforcement cage was placed in position. Tilting drum mixer was used, mixing was carried out according to BS 1881. The interior surface of the mixer drum was cleaned and moistened before use. The dry ingredients were added in the following order, about one half of the coarse aggregate, all the fine aggregate, all the cement, and finally the remaining part of the coarse aggregate. Then the water was added and mixing was started.


Plate (3.6) Fabrication and installation of reinforcing bars

The period of mixing ranged from two to three minutes so that a homogenous mix was obtained. After the mixing process was completed, concrete was poured in the forms and then compacted mechanically by using a standard pencil vibrator to ensure the proper placement and consolidation of the concrete in and around the reinforcement cage, The top surface of concrete was leveled and smoothly finished after casting was completed using hand trowel. Plate (3.8) shows, fabrication, casting and curing procedure of prepared specimens.

Plate (3.7) Casting and curing procedure of the specimens

3.7 Instrumentation and Test Procedure

3.7.1 Testing equipment

3.7.1.1 Testing machine

In the structural Laboratories of the Technical Institute in Maysan, an automatic compression machine with a capacity of 600 kN and with dimensions (3 meters length × 1 meter's height) was used to test big beams, see Plate (3.9)

Table (3.14) Flexural behavior specimens description

Group	Specimen symbol	Concrete compressive strength (f_{cu}) (MPa)		Main longitudinal steel bars reinforced fy=564 MPa		Stirrups fy=537 MPa	Cross-section width (mm)		Side angle (degree)
		top	bottom	top	bottom		top	bottom	
GR1	BL1	70	70	2Ø12	7Ø12	Ø8@50mm	175	175	90
	BL2	70	70	2Ø12	7Ø12	Ø8@50mm	250	100	75.96
	BL3	70	50	2Ø12	7Ø12	Ø8@50mm	250	100	75.96
	BL4	70	50	2Ø12	7Ø12	Ø8@50mm	225	125	80.54
	BL5	70	50	2Ø12	7Ø12	Ø8@50mm	200	150	85.24
GR2	BL6	50	50	2Ø12	4Ø12	Ø8@50mm	175	175	90
	BL7	50	50	2Ø12	4Ø12	Ø8@50mm	250	100	75.96
	BL8	50	25	2Ø12	4Ø12	Ø8@50mm	250	100	75.96
	BL9	50	25	2Ø12	4Ø12	Ø8@50mm	225	125	80.54
	BL10	50	25	2Ø12	4Ø12	Ø8@50mm	200	150	85.24
GR3	BL11	70	25	2Ø12	7Ø12	Ø8@50mm	250	100	75.96
	BL12	70	25	2Ø12	7Ø12	Ø8@50mm	225	125	80.54
	BL13	70	25	2Ø12	7Ø12	Ø8@50mm	200	150	85.24

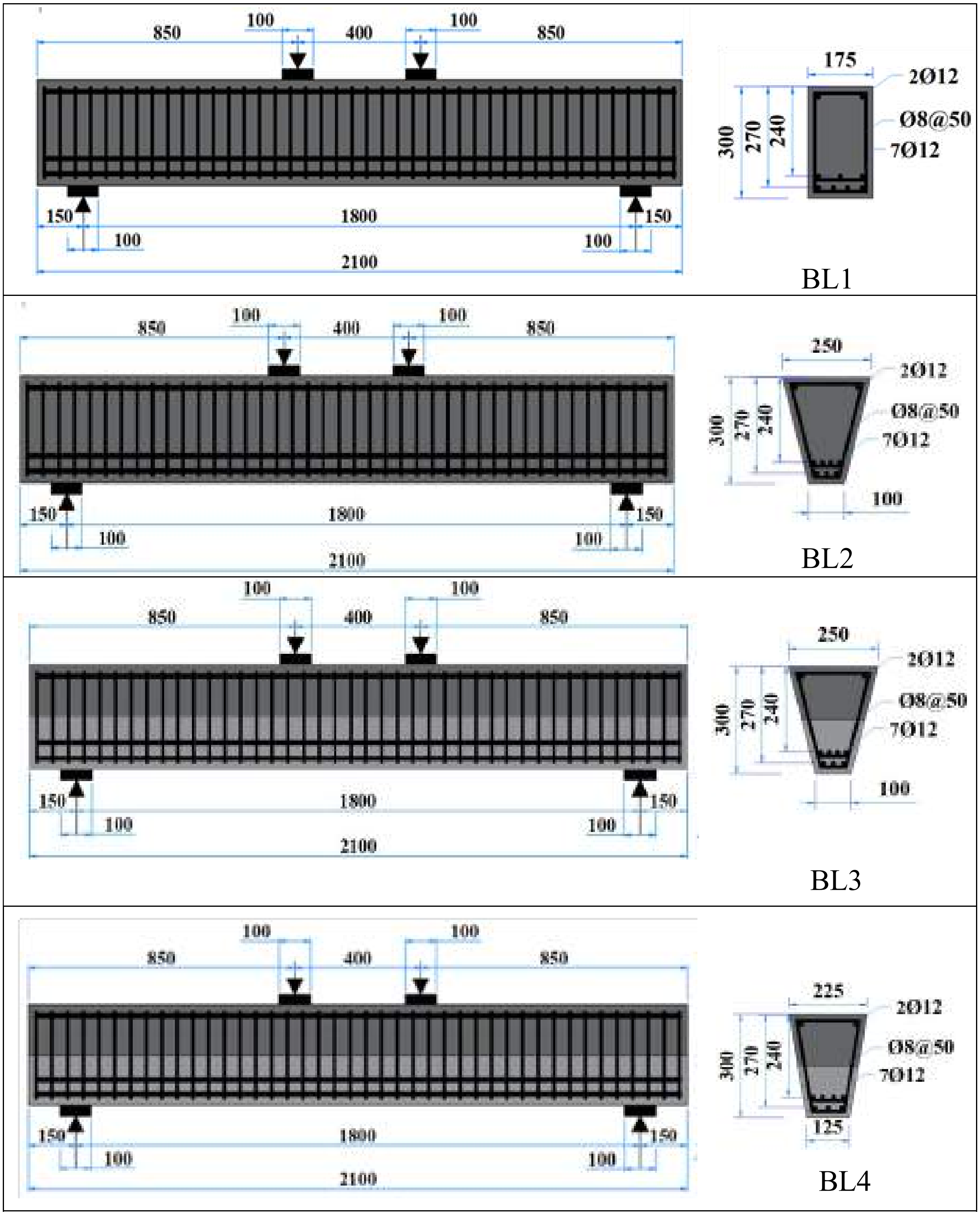


Figure (3.2) Specimen's details of flexural inspection strength

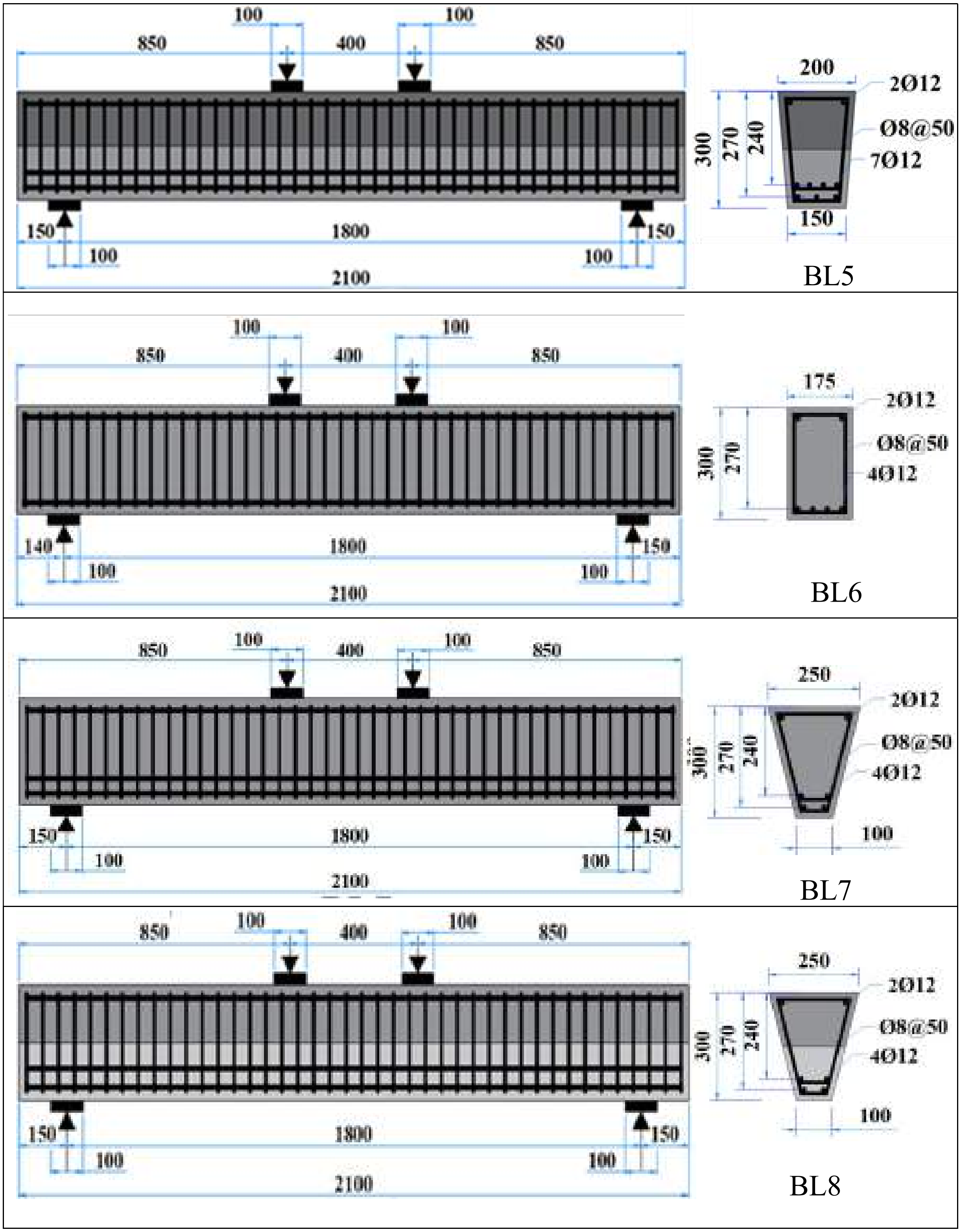
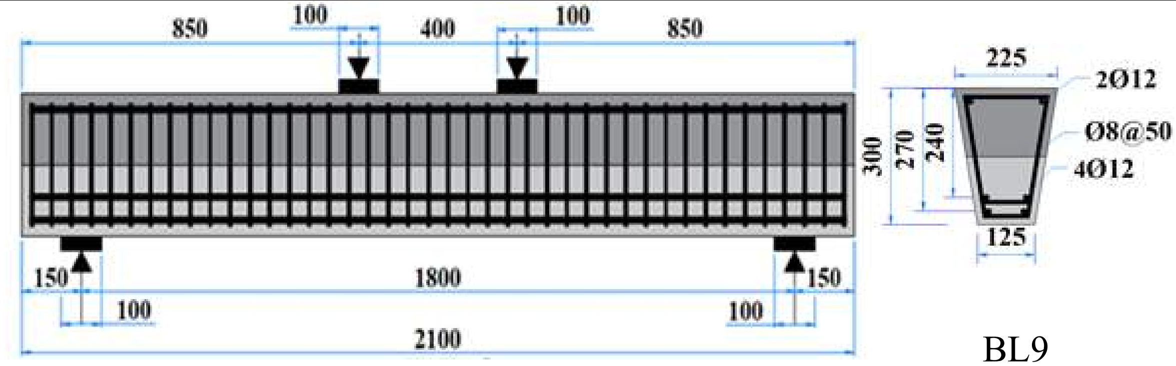
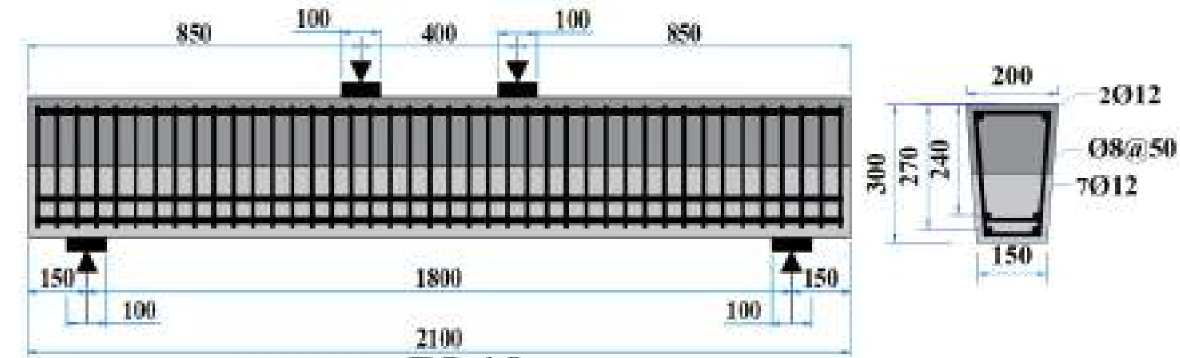


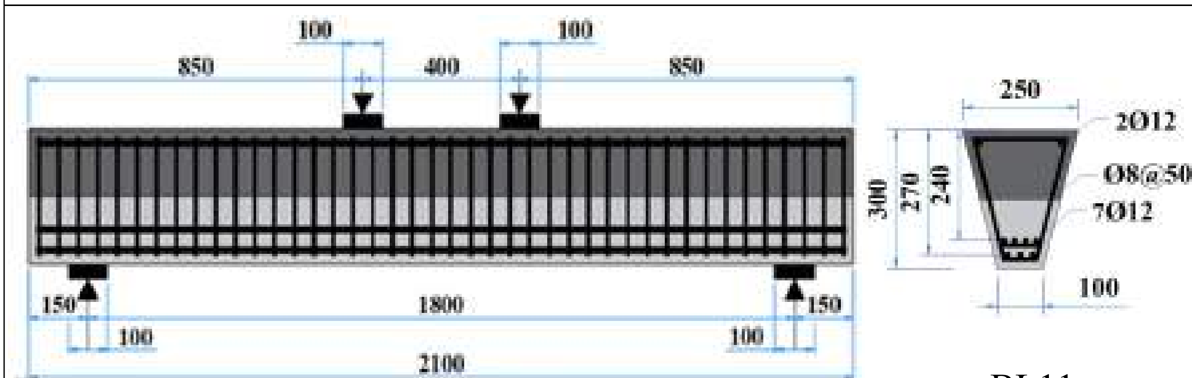
Figure (3.2) Continue



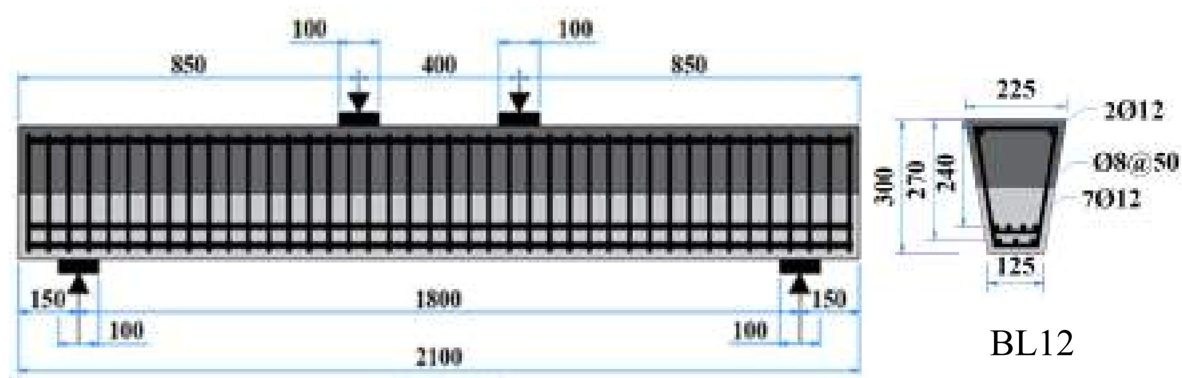
BL9



BL10



BL11



BL12

Figure (3.2) Continue

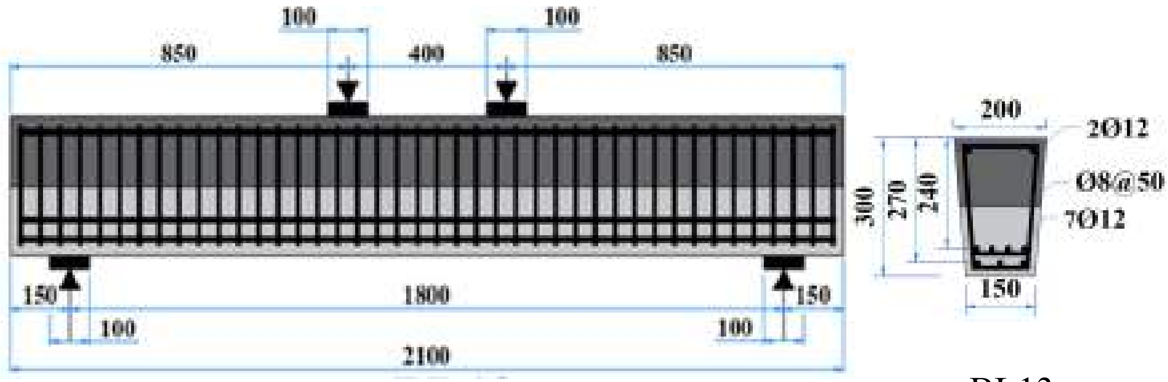


Figure (3.2) Continue

Table (3.15) Specimens section area and moment of inertia

Specimen	Section area (mm^2)	Moment of inertia(mm^4)
BL1, BL6	52500	393750000
BL2, BL3, BL7, BL8, BL11	52500	369642857.1
BL4, BL9, BL12	52500	383035714.3
BL5, BL10, BL13	52500	391071428.6

Plate (3.8) Testing machine

3.7.1.2 Electrical strain gauges

The electrical strain gauge is used to determine strain excitation on the material's surface. It was invented by Edward Simons and Arthur C. Rouge in 1938. The strain gauge consists of a flexible insulating backing that supports the foil pattern. The gauge is connected to the solid with a suitable adhesive, such as cyano acrylate. When the solid is deformed, the foil is deformed, causing its electrical resistance to change. This change in resistance, usually measured using the Wheatstone Bridge, is related to the strain by the amount known as the measurement factor, see Figure (3.4).

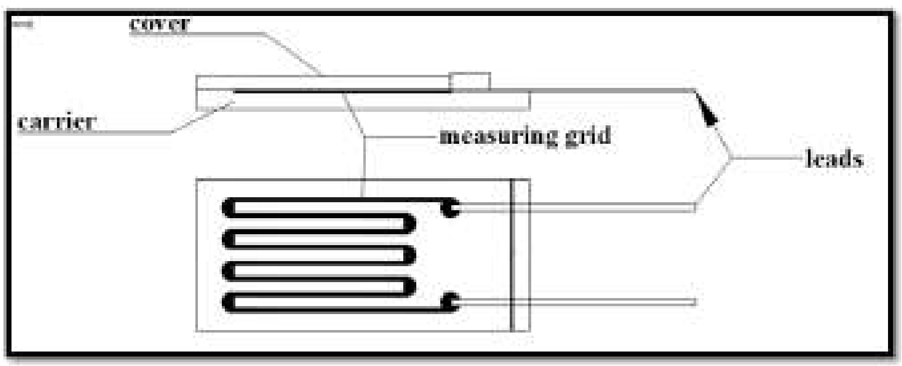


Figure (3.3) Strain gauges details

3.7.1.3 Data obtaining system

The data obtaining system includes a personal computer, a strain indicator called the data logger and Its function is receiving data from a set of strain gauges that adhesion on the beam, the data logger named is GEODATALOG 30-WF6016 and its properties are 16 channels data acquisition unit. 110-240 V, 50-60 Hz, 1ph supplied complete with DATACOMM software for PC data acquisition as shown in Plate (3.10).

Plate (3.9) Used data logger unit

3.7.1.4 Deflection measurement

The mid-span deflection of each beam was measured by using a dial gauge with a magnetic base. The accuracy of the dial gauge was 0.01 mm. See Plate (3.11)

Plate (3.10) Used dial gauge

3.7.2 Test procedure

After the curing of the specimens was completed, the beams were painted in three colors distributed according to the strength of the concrete for easy observation of the cracks that are appearing during the loading process. After that, the beams were transferred to the testing location, then locate the strain gauges and then start the process of adhering the strain gauges, after a stainless-steel disk was used to smooth the places of the strain gauges and then the strain gauges were adhered by the epoxy. Strain gauges were adhered to in the middle for the compression and tension areas. Figure (3.4) shows the locations of the strain gauges. Torsee's Universal Testing Machine with a capacity of 2000 kN was used to apply the load. The beam was loaded from top at the center of the top spreader. Load was applied in increments. Each beam was tested individually and placed inside the frame of the testing machine for testing on a supported merely configuration where the length of the beams was 2100 mm, while a clear span becomes 1800 mm between the center line of the supports. The position has been adjusted so that the middle line for each of the loading points and supports in the correct places. Installing the deflection gauge (Dial gauge) at mid span under the specimen and checking its status. Re arrange the initial reading of dial gauge to zero and taking the initial reading of the strain gauges. Strains were reading by data logger, and deflections were recorded at the end of each loading increment. Figure (3.7) and Plate (3.12) show the details of the test machine (test setup) and the position of beam during the testing process (test arrangement).

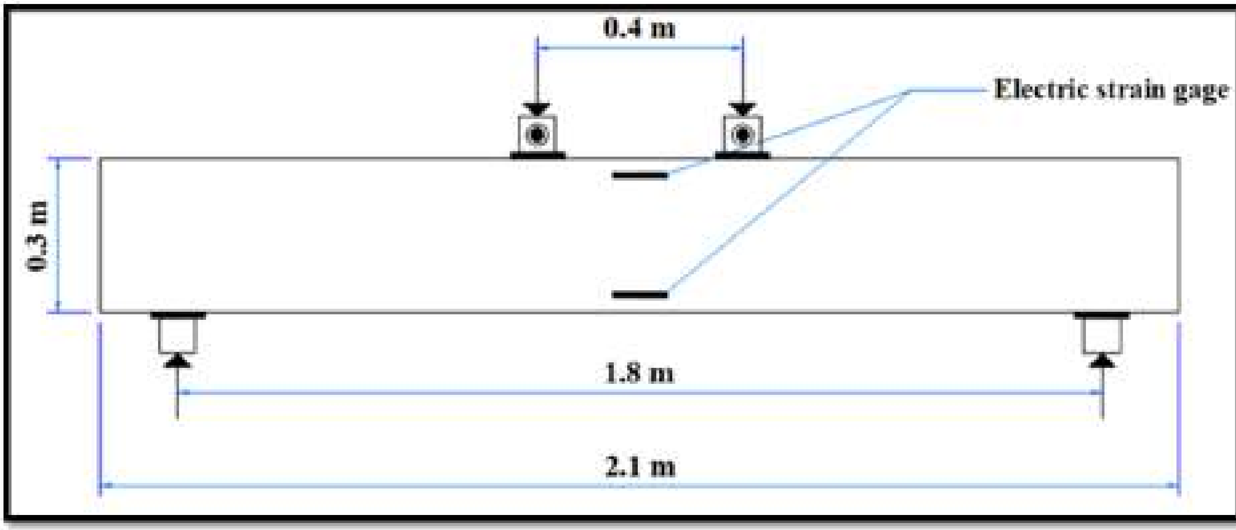


Figure (3.4) Strain gauge position

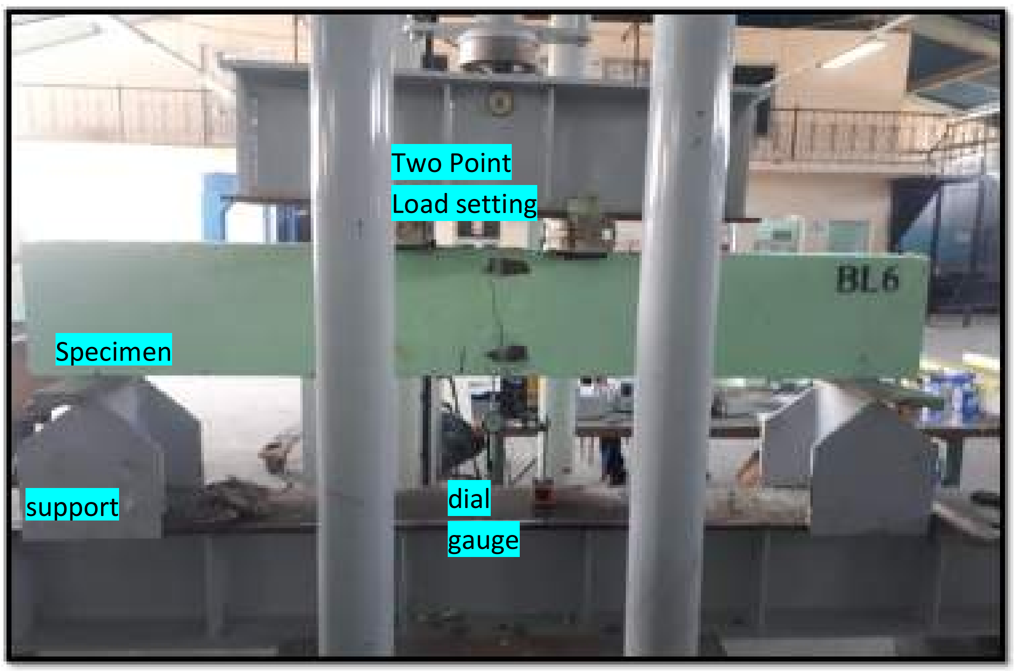


Plate (3.11) Test arrangement

CHAPTER FOUR
RESULTS
AND DISCUTION

CHAPTER FOUR

RESULTS AND DISCUTION

4.1 General

As a continuation of what was mentioned in the previous chapters, the main object of this research was to study the structural behavior of the reinforced concrete beams of hybrid strength-trapezoidal section. Depending on dimensional characteristic relates to specimen's length, specimens designed to investigate flexural. The beams are tested under static loading and subjected to two points load. The main variables for this study were, concrete compression strength, hybrid section of strength, and the side angle of the cross-section.

4.2 Flexural Behavior Results

Through experimental work, the results of thirteen beams with a length of 2100 mm and different variables (as illustrated in chapter three) were obtained, including four control beams, classified as rectangular beam. Two-point loads test setting is considered throughout this study. The ultimate load, load-deflection, load-strain, and first crack load of tested specimens were obtained experimentally. While the determination of flexural strength capacity, flexural stiffness, failure modes, flexural ductility, and path of cracks were discussed based on comparison analysis with control beams.

4.2.1 Strength capacity and ultimate load

The flexural strength capacity of tested beams is presented in Table (4.1) and compared to control specimen. The specimen BL1 of concrete compressive strength f_{cu}=70 MPa and BL6 compressive strength f_{cu}=50 MPa.

Two other specimens are considered as control specimens, BL2 that have concrete compressive strength f_c=70 MPa and BL7 that have concrete compressive strength f_{cu}=50 MPa. Where the remain specimens, were of hybrid section, ψ1=0.714 in (BL3, BL4, BL5), ψ2=0.5 in BL8, BL9, BL10 and ψ3=o.357 in (BL11, BL12, BL13), with a trapezoidal cross-section and a side angle (Θ_1=76°, Θ_2=80°, Θ_3=85°), respectively.

4.2.1.1 The effect of cross-section:

When the cross-section of the beam was changed from the rectangle BL1 to the trapezoid with a homogeneous concrete BL2 this resulted in an increase in the ultimate load by 2.16%, in group one. In group two the increasing became 6.77% when the beam was changed from BL6 to BL7. This means that the ultimate load increases with the increasing in the area of compression.

4.2.1.2 The effect of hybrid concrete:

When the cross-section of the beam was changed from the rectangle BL1 to the trapezoid with a hybrid concrete BL3, this resulted in decrease in the ultimate load by 2.82%, in group one. In group two the decreasing became 6.77% when the beam was changed from BL6 to BL8. When comparison BL1 with a hybrid concrete BL11 from group three, the decreasing became 19.47%. This means that the ultimate load decreases with the decreasing in the compression strength at tensile zone. It was observed that the increase in the area of concrete in the compression zone contributed to reducing the decrease in the ultimate strength value despite the decrease in concrete strength in the tension zone.

4.2.1.3 The effect of hybrid strength-trapezoidal section:

When the concrete strength of the beam was changed from the homogenous BL2 to hybrid BL3 concrete of trapezoidal cross-section, this resulted in a decrease in the ultimate load by 4.88%, in group one. In group two the decreasing became 12.69% when the beam was changed from BL7 to BL8. When comparison BL2 with a hybrid concrete BL11 from group three, the decreasing became 21.18%. This means that reducing the strength of the concrete in the tension zone reduces the ultimate strength.

Despite the relatively large decrease in concrete strength in the tension zone, the ultimate load decreased by relatively small. The results are clearly assigned that hybrid strength-trapezoidal configuration effectiveness maintained specimens strength dropping more than that of hybrid strength influencing.

4.2.1.4 The effect of side angle of hybrid strength-trapezoidal concrete beams:

When the trapezoidal side slope of the beam was changed from the 76° (BL11) to 80° and 85° hybrid concrete of trapezoidal cross-section BL12, BL13, this resulted in a decrease in the ultimate load by 2.72% and 9.18%, respectively. These results illustrate the effect of increasing the area of compression zone on the ultimate load.

The above ratios apply to moment capacity, as shown in Table (4.2). The assigned slightly reduction in strength in comparison to control specimens depicts positive effect of hybrid strength-trapezoidal section as compression strength dropped to half in tension region. From the above comparison, specially of indicated strength increments which are corresponding the section compression area increment enhanced are the developing proper compression stress blocks with in trapezoidal sections. Table (4.2) briefly exhibited moment strength capacity of tested specimens, besides; comparison analysis in scope of references specimens. The comparison of results with hybrid strength reduction index shows that as (Ψ) decreased from 0.714 (GR1) to 0.357 (GR3) the average rating varies between (0.95-0.77) in respect to rectangular specimens and from (0.93-0.75) in respect to trapezoidal section of uniform strength. The same finding is recorded in GR2, and best result for all hybrid strength-trapezoidal section are indicated in specimens of (ϴ=76°).

4.2.2 Failure modes and crack patterns

The recorded experimental results show that all the beams failed in flexure by crushing of concrete at the compression zone. The first visible flexural cracks were noticed at 16.83 to 21.61% of failure load. These cracks were vertical, started from the bottom side of the beam between the applied two- point loads. As the load increased the cracks propagated diagonally towards the concentrated loads. Those cracks formed out the region between the two loads as flexural-shear cracks. It can be observed that uniform-trapezoidal beams show, almost the same crack pattern as uniform-rectangular beams. Crack patterns for the beams are presented in Plate (4.1).

At early stages of loading, the deformations were initially within the elastic ranges (linear), then the applied load was increased until the first crack became visible which was observed in the maximum moment region under the two- point loads. As the load was increased further, several flexural cracks initiated in the tension face at intervals throughout the beam, gradually increased in number, became wider and moved upwards reaching the compression face of the beam. As the load was increased further, a loss of stiffness occurred and one mode of failure appeared which can be classified as flexural failure in tension by yielding of the steel reinforcement followed by crushing of concrete. The reason for this is that concrete with normal strength is less brittle than concrete with higher strength. When the cracks reach the high strength concrete with the continued increase in load, an increase of crack development down to failure is observed.

Table (4.1) Experimental results of tested beams

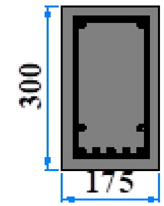
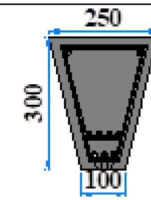
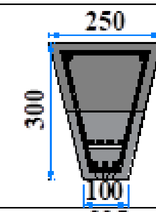
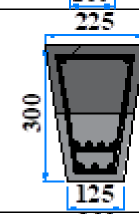
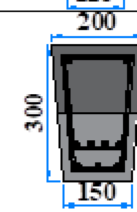
Group	Specimen	Description	Ultimate load (Pu) (kN)	Deflection (mm)		Crack. Load (Pcr) (kN)	Strain (mm/mm)		Cross- Section
				elastic	fail				
GR1	BL1	Rectangular (fc = 70) MPa reference (1)	365.1	9.25	13.4	77.3	0.000189	0.003	
	BL2	Trapezoidal, 76° angle, (fc = 70) MPa, reference (2)	373	11.78	16.7	80.6	0.000218	0.003598	
	BL3	Trapezoidal, 76° angle, (fct = 70 MPa, fcb = 50 MPa)	354.8	12.1	18	65.7	0.00036	0.00347	
	BL4	Trapezoidal, 80° angle, (fct = 70 MPa, fcb = 50 MPa)	340	12.5	17.4	65.1	0.000178	0.003389	
	BL5	Trapezoidal, 85° angle, (fct = 70 MPa, fcb = 50 MPa)	349	11.3	17	72	0.000374	0.003234	

Table (4.1) Continue

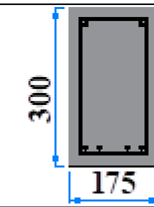
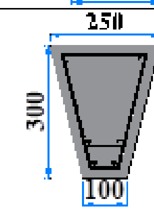
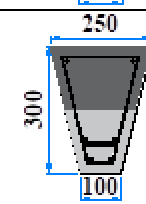
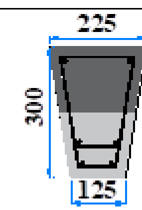
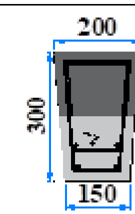
Group	Specimen	Description	Ultimate load (Pu) (kN)	Deflection (mm)		Crack. Load (Pcr) (kN)	Strain (mm/mm)		Cross- Section
				elastic.	fail				
GR2	BL6	Rectangular (fc = 50) MPa reference (3)	310	9.5	14.1	65.5	0.000175	0.003168	
	BL7	Trapezoidal, 76° angle, (fc = 50) MPa, reference (4)	331	11.6	19.35	55.7	0.000196	0.004401	
	BL8	Trapezoidal, 76° angle, (fct = 50 Mpa, fcb = 25 MPa)	289	14.6	22.11	54.2	0.00019	0.004577	
	BL9	Trapezoidal, 80° angle, (fct = 50 MPa, fcb = 25 MPa)	268	14	21	55	0.000105	0.005393	
	BL10	Trapezoidal, 85° angle, (fct = 50 MPa, fcb = 25 MPa)	257	14.1	17	52.4	0.000272	0.004839	

Table (4.1) Continue.

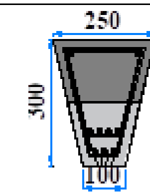
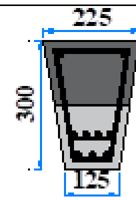
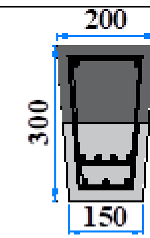
Group	Specimen	Description	Ultimate load (Pu) (kN)	Deflection (mm)		Crack. Load (Pcr) (kN)	Strain (mm/mm)		Cross- Section
				elastic.	fail				
GR3	BL11	Trapezoidal, 85° angle, (fct = 70 MPa, fcb = 25 MPa)	294	11.75	19.3	50.6	0.000285	0.003667	
	BL12	Trapezoidal, 80° angle, (fct = 70 Mpa, fcb = 25 MPa)	286	12.1	20.7	49.7	0.000278	0.003957	
	BL13	Trapezoidal, 85° angle, (fct = 70 MPa, fcb= 25 MPa)	267	9	18.3	45.8	0.000309	0.004454	

Table (4.2) Moment capacity analysis

Group	Specimen	Ψ	moment capacity (kN.m)	Rating with respect to reference -1-	Rating with respect to reference -2-	Rating with respect to reference -3-	Rating with respect to reference -4-
GR1	BL1 (refere.1)	1	255.57	1			
	BL2 (refere.2)	1	261.1		1		
	BL3	0.714	248.36	0.97	0.9512		
	BL4	0.714	238	0.93	0.9115		
	BL5	0.714	244.3	0.96	0.9357		
GR2	BL6 (refere.3)	1	217			1	
	BL7 (refere.4)	1	231.7				1
	BL8	0.5	202.3			0.9323	0.8731
	BL9	0.5	187.6			0.8645	0.8097
	BL10	0.5	179.9			0.829	0.7764
GR3	BL11	0.357	205.8	0.80	0.7882		
	BL12	0.357	200.2	0.78	0.7668		
	BL13	0.357	186.9	0.73	0.7158		

Table (4.3) briefly exhibited cracking loads of tested specimens, besides; comparison analysis in scope of references specimens. The comparison of results with hybrid strength reduction index shows that as (Ψ) decreased from 0.714 (GR1) to 0.357 (GR3) the average rating varies between (0.87-0.63) in respect to rectangular specimens and from (0.84-0.60) in respect to trapezoidal section of uniform strength. The same finding is recorded in GR2, and best result for all hybrid strength-trapezoidal section were indicated in specimens of Ψ3 = 0.357 (GR3). The results assigned that the influence of compressive strength within tension region upon first crack developing, specimens of Ψ3 = 0.357 which are of f_{cu}(bottom) =25 MPa (GR3) exhibited early cracking in comparison with those of Ψ2=0.5 with same f_{cu}(bottom) (GR2). This finding confirms the effectiveness of the hybrid strength reduction index and the quality of concrete within tension region upon cracking progressive.

Table (4.3) Cracking loads analysis

Group	Specimen	Ψ	Cracking load (Pcr) (kN)	Rating with respect to reference -1-	Rating with respect to reference -2-	Rating with respect to reference -3-	Rating with respect to reference -4-	Pcr/Pu %
GR1	BL1 (refere.1)	1	77.3	1				21.17
	BL2 (refere.2)	1	80.6		1			21.61
	BL3	0.714	65.7	0.8499	0.8151			18.52
	BL4	0.714	65.1	0.8422	0.8077			19.14
	BL5	0.714	72	0.9314	0.8933			20.63
GR2	BL6 (refere.3)	1	65.5			1		21.13
	BL7 (refere.4)	1	55.7				1	16.83
	BL8	0.5	54.2			0.8275	0.9731	18.75
	BL9	0.5	55			0.8397	0.9874	20.52
	BL10	0.5	52.4			0.8	0.9408	20.39
GR3	BL11	0.357	50.6	0.6546	0.6278			17.21
	BL12	0.357	49.7	0.6429	0.6166			17.38
	BL13	0.357	45.8	0.5925	0.5682			17.15

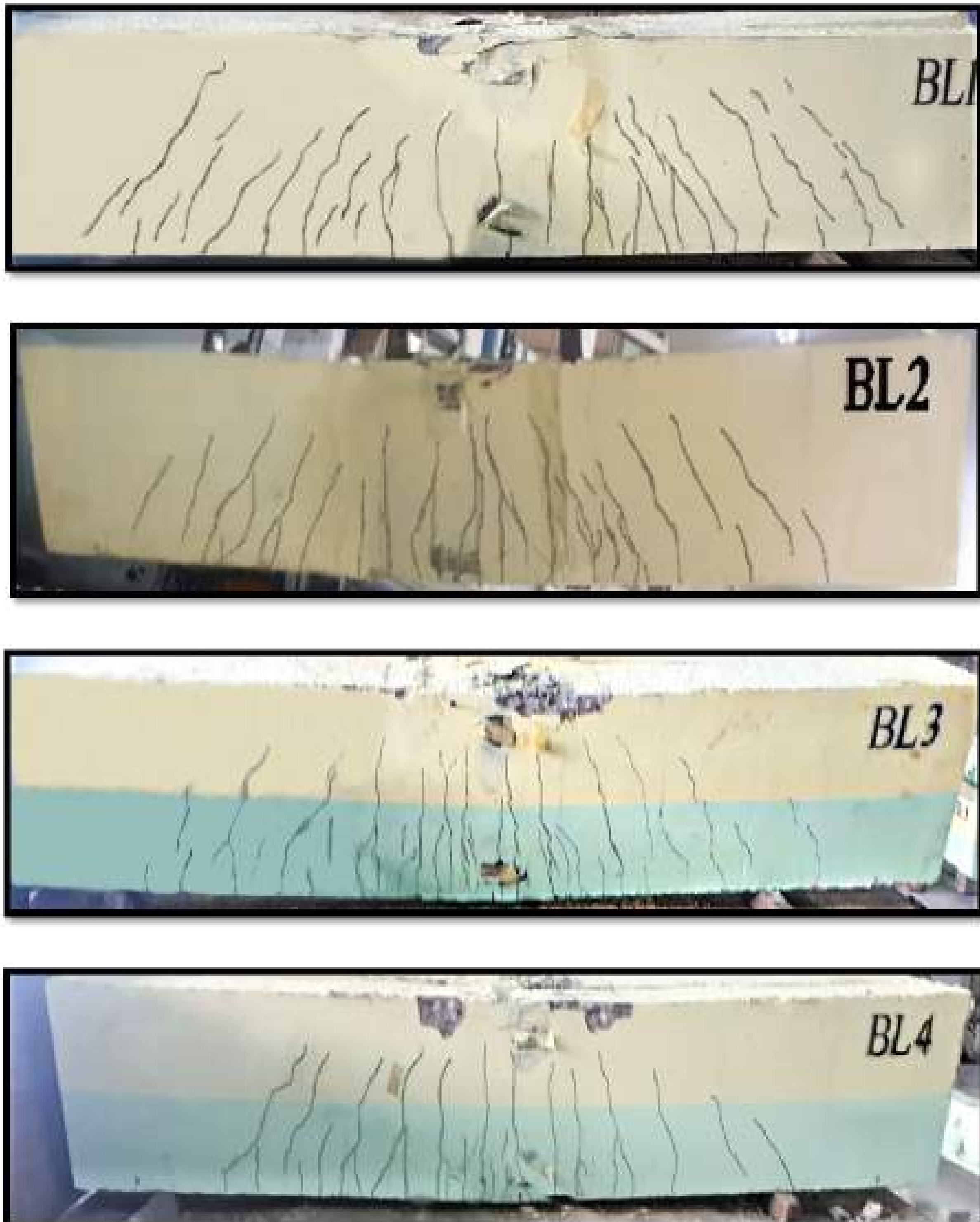


Plate (4.1) Failure mode and crack pattern

Plate (4.2) Continue

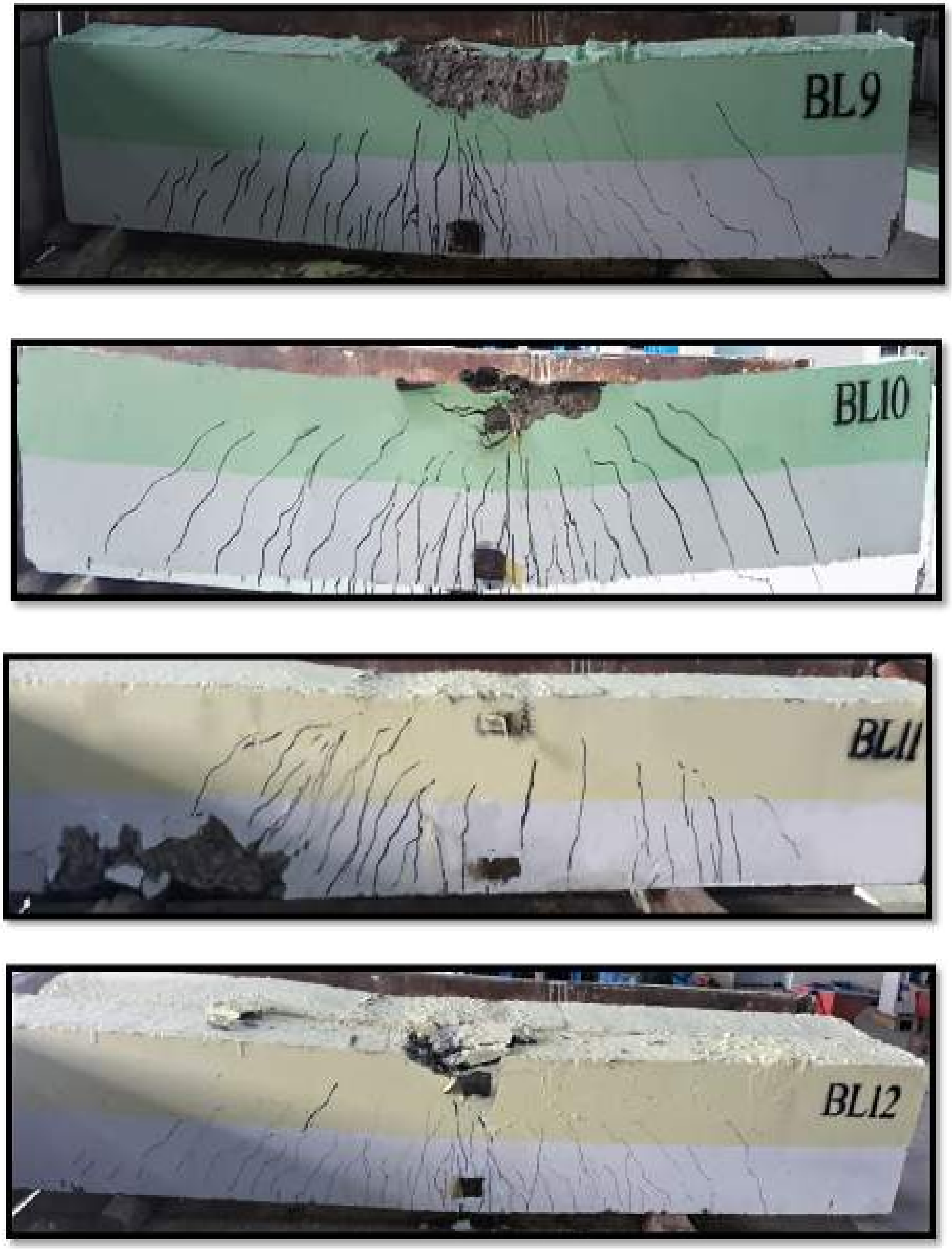


Plate (4.2) Continue

Plate (4.2) Continue

4.2.3 Load - deflection response

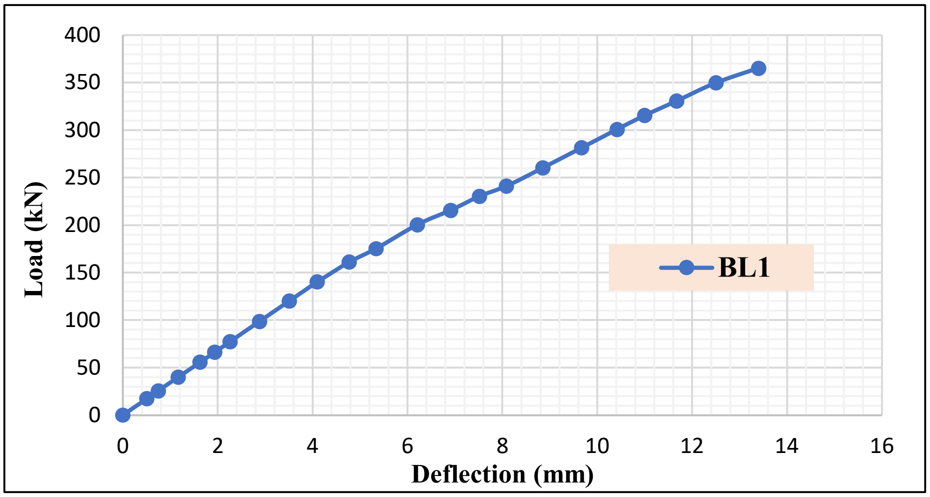
Figure (4.7) shows the load-deflection curves for control beam, while Figure (4.8) shows the curves for hybrid strength-trapezoidal concrete beams, deflection was measured at mid span of the beams at different loading stages. The maximum deflections at failure were not obtained to avoid dial gauge damage. By observing the shape of the curves, it is clear that the beams with rectangular sections, the curve shape is almost linear compared to the rest of the curves, as well as the curve shape of the trapezoidal beam is similar to the curve of the rectangular beam even after the first crack has occurred. The rest of the beams showed almost the same behavior where the curves were linear in the elastic stage, and then the shape of some curves changed after the first cracking occurred. While others continued almost in a linear and then the curve shape became more curved up to the failure stage. Figure (4.8) show the deflection-load curve of the three groups in relation to the effect of shape and hybrid.

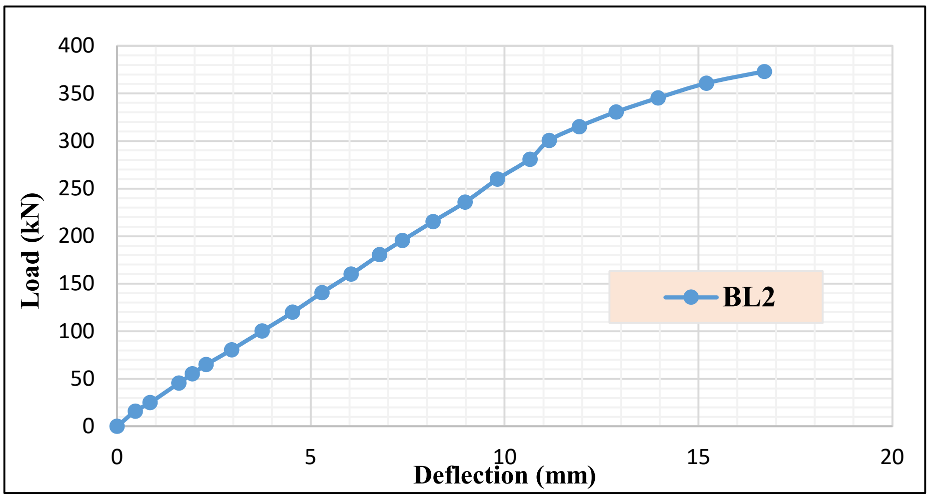
Table (4.4) briefly exhibited mid span deflection analysis of tested specimens, besides; comparison analysis in scope of references specimens. The comparison of results with hybrid strength reduction index shows that as

(Ψ) decreased from 0.714 (GR1) to 0.357 (GR3) the average rating varies between (1.3-1.45) in respect to rectangular specimens and from (1.05-1.16) in respect to trapezoidal section of uniform strength. The same finding is recorded in GR2, and best result for all hybrid strength-trapezoidal section are indicated in specimens of (ϴ=76°)

Table (4.4) Mid span deflection analysis

Group	Specimens	Ψ	Deflection (mm)	Rating with respect to reference -1-	Rating with respect to reference -2-	Rating with respect to reference -3-	Rating with respect to reference -4-
GR1	BL1(refere.1)	1	13.4	1			
	BL2(refere.2)	1	16.7		1		
	BL3	0.714	18	1.3433	1.0778		
	BL4	0.714	17.4	1.2985	1.0419		
	BL5	0.714	17	1.2687	1.018		
GR2	BL6(refere.3)	1	14.1			1	
	BL7(refere.4)	1	19.35				1
	BL8	0.5	22.11			1.5681	1.1426
	BL9	0.5	21			1.4894	1.0853
	BL10	0.5	17			1.2057	0.8786
GR3	BL11	0.357	19.3	1.4403	1.1557		
	BL12	0.357	20.7	1.5448	1.2395		
	BL13	0.357	18.3	1.3657	1.0958		





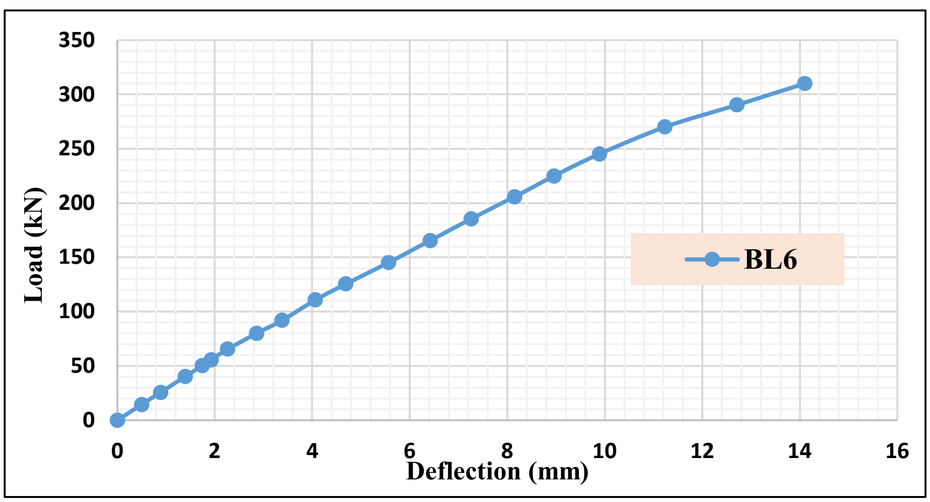


Figure (4.1) Mid span load-deflection of control beams

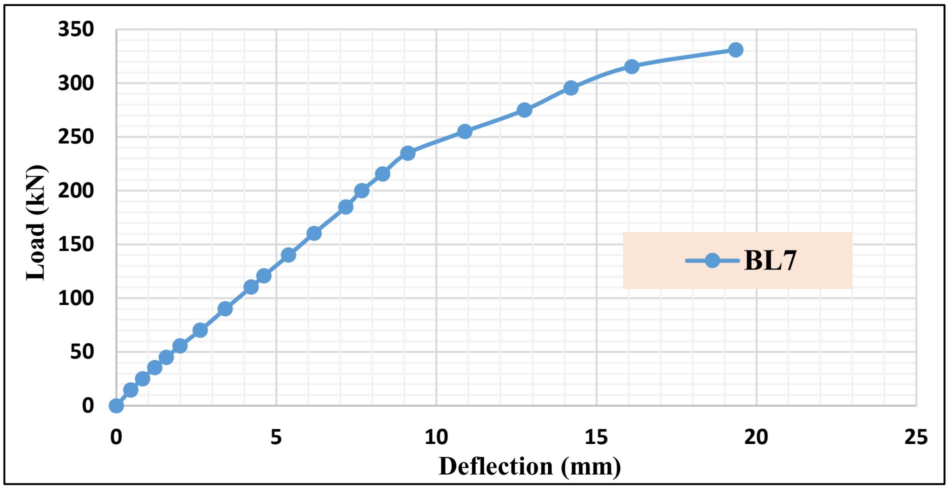
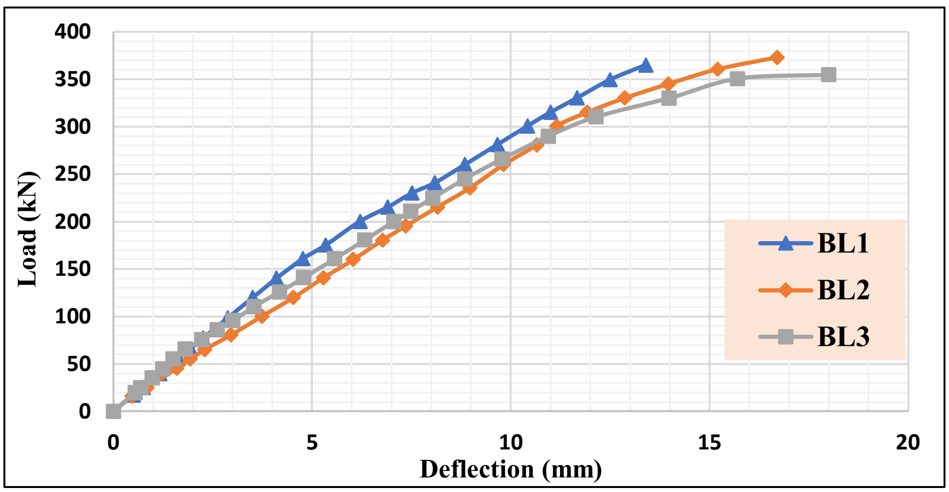


Figure (4.1) Continue



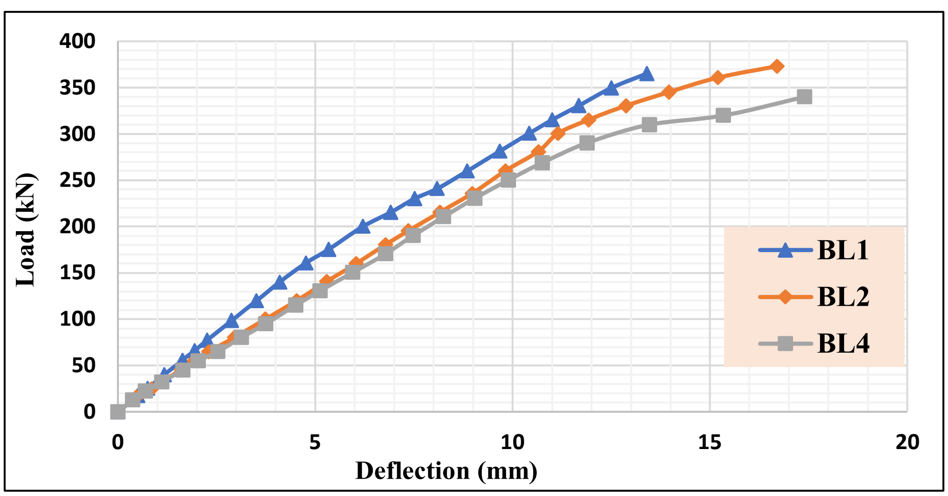
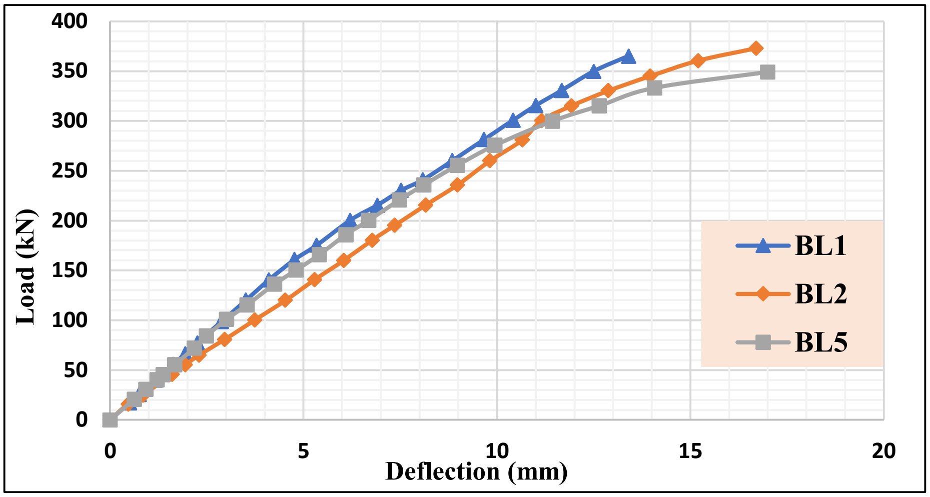
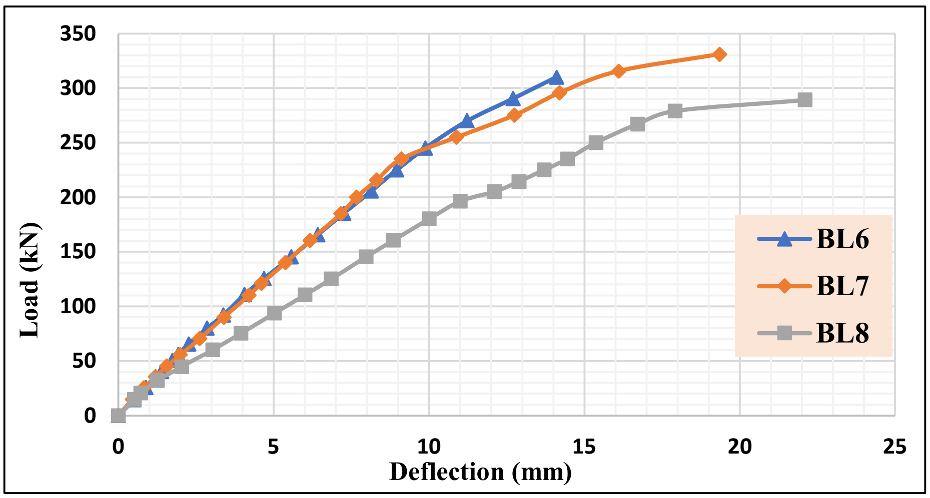
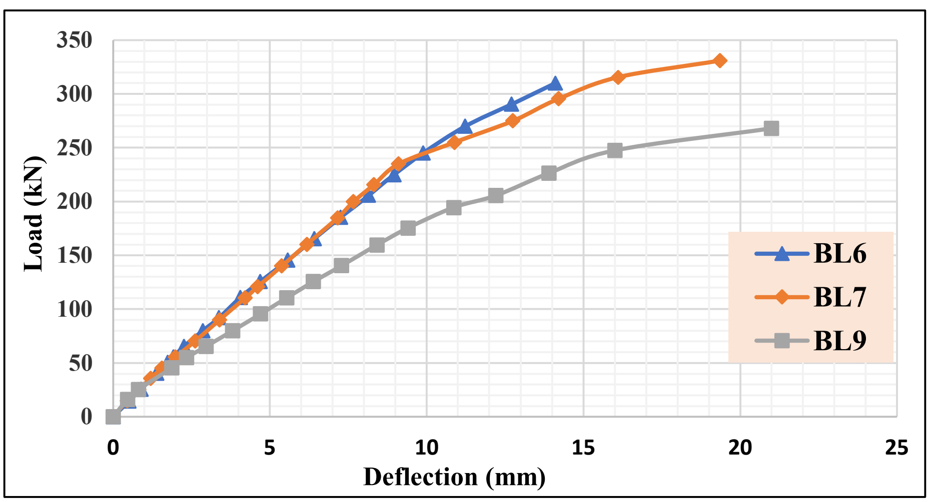


Figure (4.2) The effect of beam cross-section and hybrid concrete on load-deflection response







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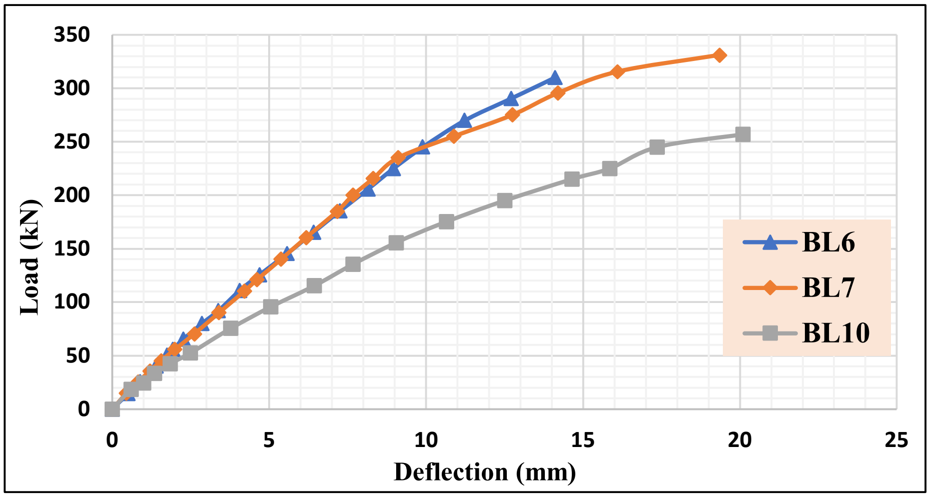

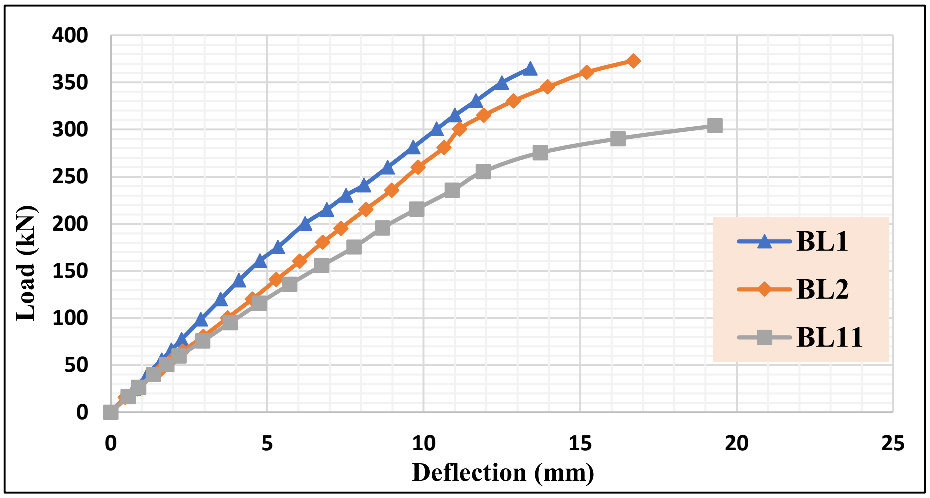

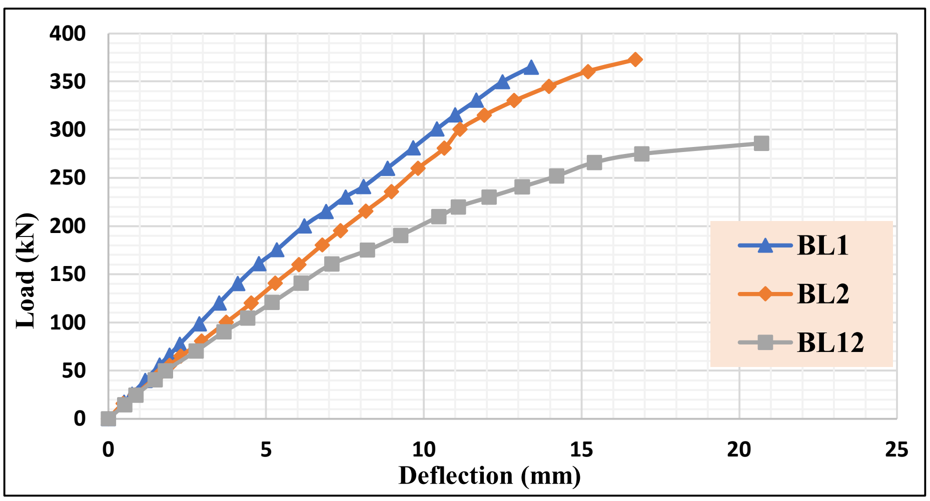

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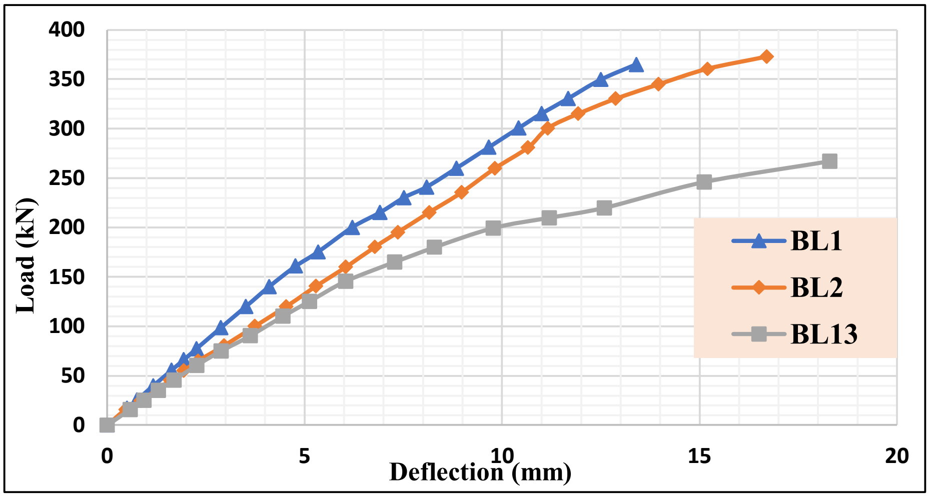
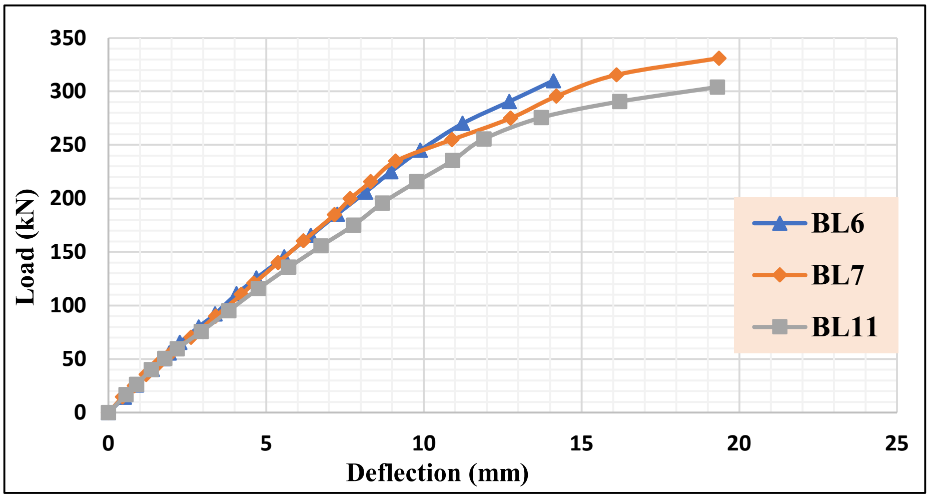




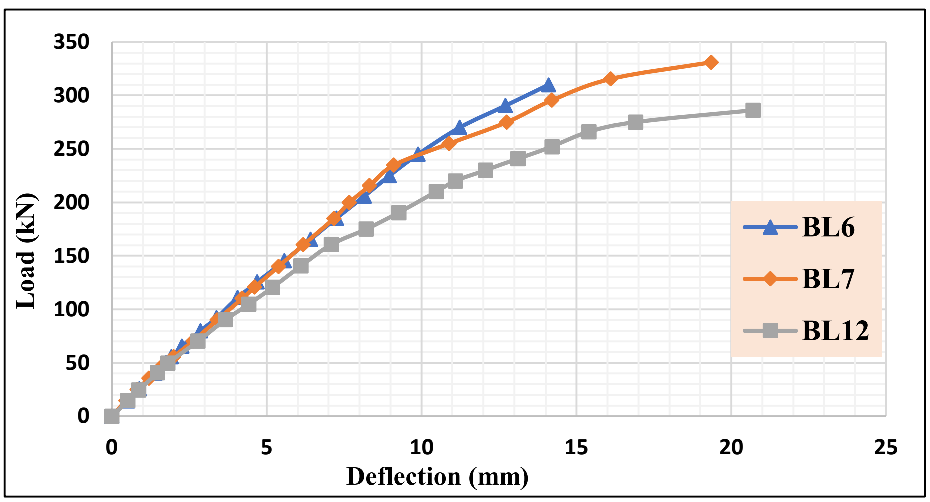


Figure (4.2) Continues

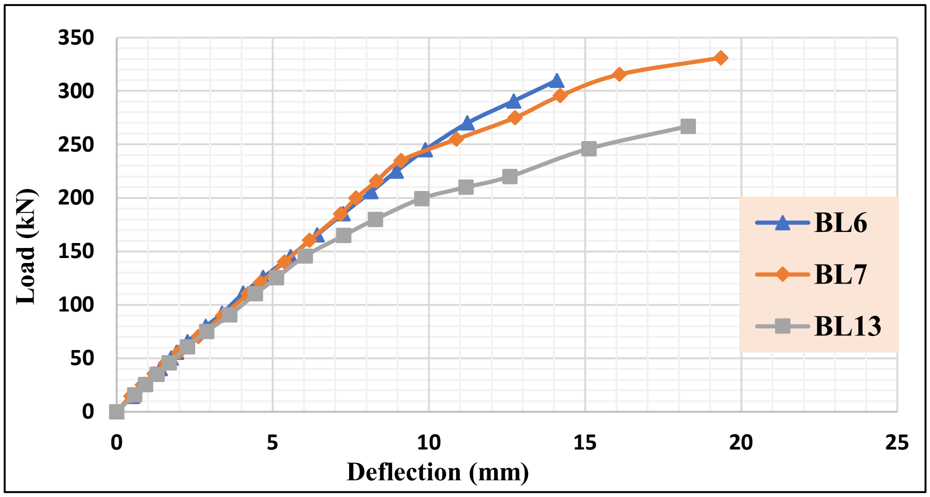


Figure (4.2) Continues

4.2.4 Flexural stiffness

Stiffness can be defined as the required load for causing one-unit of deflection. The value of the stiffness can be calculated by dividing the ultimate load on the maximum deflection in the tested beam [43].The flexural stiffness of a structure is a function based upon two essential properties: the elastic modulus (stress per unit strain) of the material that composes it, and the moment of inertia, as a function of the cross-sectional geometry. Flexural stiffness could be detected from load-deflection curve by slope of linear parts. Load-deflection curves as shown in Fig. (4.2) clearly indicated that the beams of each group have closed stiffness despite the change of cross section.

This could be related to the central region where the moment of inertia is convergent in value for all sections. The concrete subjected to tensile force is generally neglected in analysis when it is cracked. The effect of tension stiffening effect, is considered in ACI code by the effective moment of inertia determined between cracked and uncracked section. Table (4.5) briefly exhibited moment strength capacity of tested specimens, besides; comparison analysis in scope of references specimens. The comparison of results with hybrid strength reduction index shows that as (Ψ) decreased from 0.714 (GR1) to 0.357 (GR3) the average rating varies between (1.14-0.83) in respect to rectangular specimens and from (1.12-0.83) in respect to trapezoidal section of uniform strength. The same finding is recorded in GR2, and best result for all hybrid strength-trapezoidal section are indicated in specimens of (ϴ=76°). The results confirm that hybrid strength-trapezoidal section is severely affected by extremely hybrid strength reduction index Ψ3=0.375.

Table (4.5) Flexural stiffness analysis

Group	Specimen	Ψ	Stiffness kN/mm	Rating with respect to reference -1-	Rating with respect to reference -2-	Rating with respect to reference -3-	Rating with respect to reference -4-
GR1	BL1 (refere.1)	1	34.2	1			
	BL2 (refere.2)	1	34.26		1		
	BL3	0.714	36.2	1.0585	1.0566		
	BL4	0.714	34.68	1.014	1.0123		
	BL5	0.714	33.18	0.9702	0.9685		
GR2	BL6 (refere.3)	1	28.91			1	
	BL7 (refere.4)	1	32.9				1
	BL8	0.5	29.22			1.0107	0.8881
	BL9	0.5	35.22			1.2183	1.0705
	BL10	0.5	30.67			1.0609	0.9322
GR3	BL11	0.357	30	0.8772	0.8757		
	BL12	0.357	28.27	0.8266	0.8252		
	BL13	0.357	27.41	0.8015	0.8		

4.2.5 Ductility

Ductility is one of the most important features to be taken into account in the designs of structures exposed to a large number of inelastic deformations resulting from different loading conditions [43]. It can be defined as the structural member's ability to undergo inelastic deformations beyond yield deformation without significant loss in its load-carrying capacity.

The ductility in the flexural member can be obtained through its load-deflection curve. It is the ratio between the deflection value when the member fails, to the deflection value at the time of yield stage occur.

The flexural ductility is measured in terms of a ductility index, given by:

$$\lambda = \Delta u/\Delta y \quad \text{...(4.1)}$$

where:

λ: Ductility index, unitless

Δu: Maximum deflection corresponding to maximum strength, mm

Δy: Deflection corresponding to elastic or yield behavior limit, mm

Table (4.6) briefly exhibited moment strength capacity of tested specimens, besides; comparison analysis in scope of references specimens.

The comparison of results with hybrid strength reduction index shows that as (Ψ) decreased from (0.714 to 0.357) the ductility index varies between (1-1.24) in respect to rectangular specimens and from (1.03-1.26) in respect to trapezoidal section of uniform strength. The same finding is recorded in GR2, and best result for all hybrid strength-trapezoidal section are indicated in specimens of (Θ=76° and Θ=85°). The assigned flexural ductility of tested specimens has been varied according to section type and considered parametric.

Table (4.6) Ductility index analysis

Group	Specimen	Ψ	Ductility index	Rating with respect to reference -1-	Rating with respect to reference -2-	Rating with respect to reference -3-	Rating with respect to reference -4-
G1	BL1 (refere.1)	1	1.449	1			
	BL2 (refere.2)	1	1.418		1		
	BL3	0.714	1.488	1.0269	1.0493		
	BL4	0.714	1.392	0.9607	0.9817		
	BL5	0.714	1.504	1.038	1.0606		
G2	BL6 (refere.3)	1	1.484			1	
	BL7 (refere.4)	1	1.668				1
	BL8	0.5	1.51			1.0175	0.9052
	BL9	0.5	1.5			1.0108	0.8993
	BL10	0.5	1.206			0.8127	0.723
G3	BL11	0.357	1.643	1.1339	1.1587		
	BL12	0.357	1.711	1.1808	1.2066		
	BL13	0.357	2.03	1.401	1.4316		

The Higher ductility upgrading was assigned in specimens BL5 (λ = 1.504) which is regard hybrid strength the trapezoidal Ψ 1=0.714 section of ϴ=85°. The sane finding is assigned for class Ψ3 =0.357, where BL13 of λ = =2.03, while for class Ψ3 =0.5 the corresponding specimens does not exhibit higher ductility as specimen BL7 assigned as best one. This could be related to effect of hybrid strength as its global effect associated with dominated E_c which is affected by f_{cu} of upper region.

4.2.6 Normal strain distribution

For all thirteen beams, the change in strains was measured at mid span in the tensile and compression regions. The aim was to find out the effect of the trapezoidal shape and hybrid concrete on the distribution of the flexural strain. The readings have been taken by data acquisition system as described in chapter three and the positive sign refer to tension strain and negative sign refer to compression strain. It was used to measure surface concrete strain for every stage of loading at points located in mid span of beams in compression top fiber (point 1) and tension bottom fiber (point 2). They are measured by using electrical type strain gauges.

The concrete strains were measured at every stage of loading, the process of measuring the strain was continued up to the failure of the beams. Figure (4.3) clearly depicts compressive and tension strain distribution verse applied loading. According to determined compression strength of various hybrid class (Ψ1, Ψ2 and Ψ3) which are obtained by cylindrical specimens, and utilizing Hook's low ($E = \frac{\sigma}{\varepsilon}$) concrete strain could by summarized in Table (4.7).

Tension strains reached to limited value as shown in Table (4.1) during the test, the reinforcement steel nearly to yield and initiate plastic behavior while for concrete when compressive strains reached limit values, it is nearly to crack. The measured normal strain of tested specimens has been varied according to section type and considered parametric. For specimens with in GR1 of hybrid class Ψ1, which are of hybrid ratio Ψ1=0.714, all specimens exhibited strain higher than rectangular specimens BL1 and approximately identical to trapezoidal specimen of uniform strength BL2. While for specimens in GR2 of class Ψ2, which are of hybrid ratio Ψ2=0.5, hybrid-trapezoidal interaction clearly affect strain sustainability. The best one is BL9 (ε =0.005) in comparison with BL6 rectangular (ε =0.0031) and BL7 (trapezoidal of uniform strength) (ε =0.0045). Fig (4.14) clearly depicts section area distribution of hybrid strength upon strain distribution, specimens BL13 which is of (Θ=85°) exhibited higher strain as ε =0.0044 in compassion with those of Θ=76° or Θ=80° which are exhibited ε =0.00367 and ε =0.004, respectively.

Table (4.7) Concrete strain within elastic level

	Ψ1	Ψ2	Ψ3
$\psi=f_{cu}(bottom)/f_{cu}(top)$	0.714	0.5	0.357
E_t (MPa)	39323	33234	39323
E_b (MPa)	33234	23500	23500
σ_t (MPa)	21	15	21
σ_b (MPa)	3	2	2
ε_t	0.0005	0.00045	0.0005
ε_b	0.000128	0.000085	0.000085

Generally, measured compressive strains of all tested specimens are within indicated limit values while measured tensile strains are excessed assign limits.

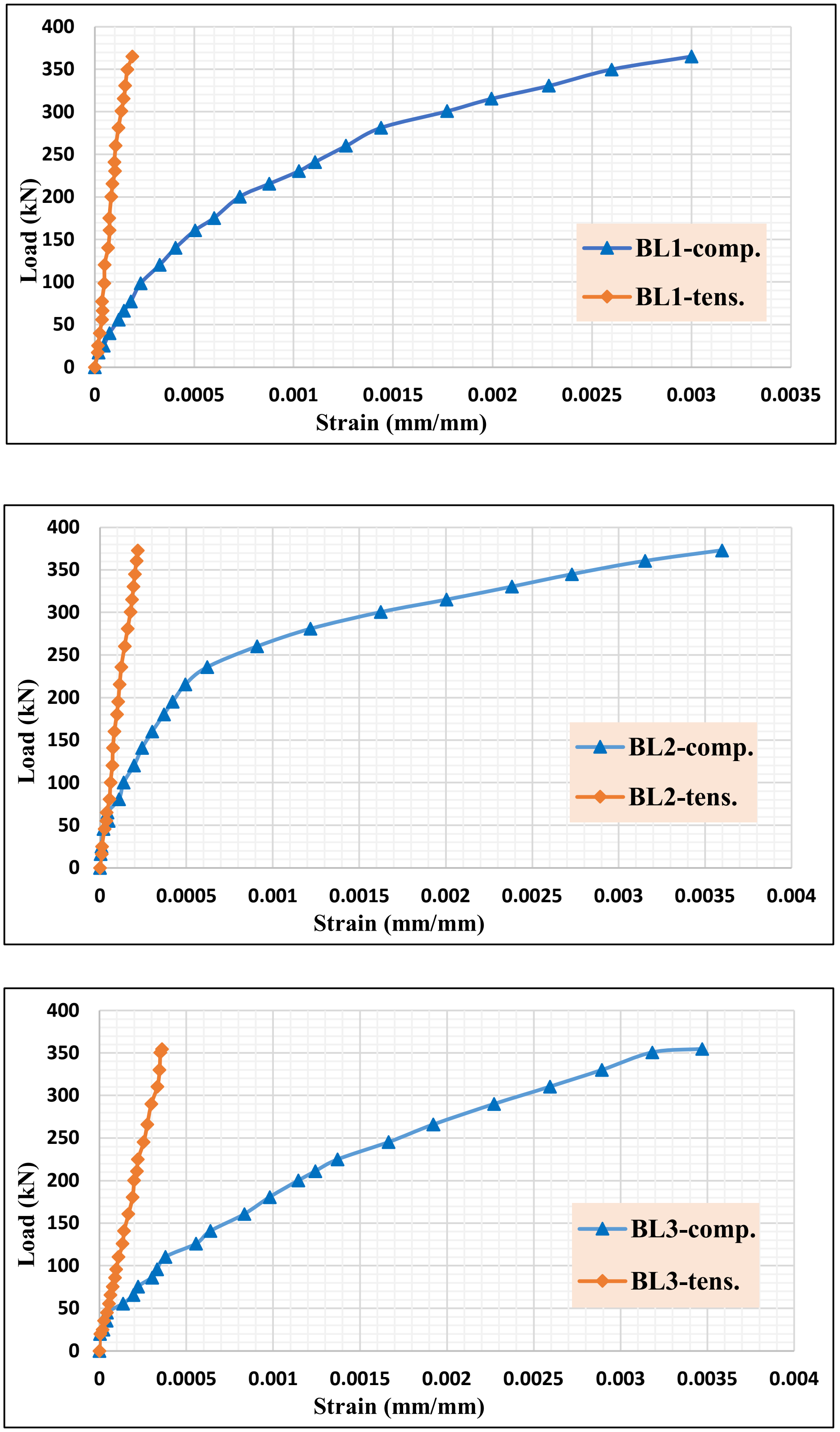
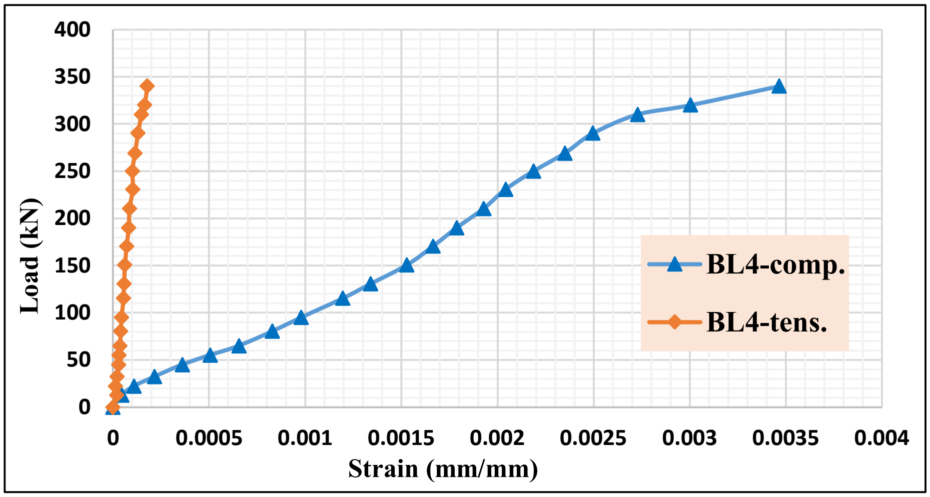
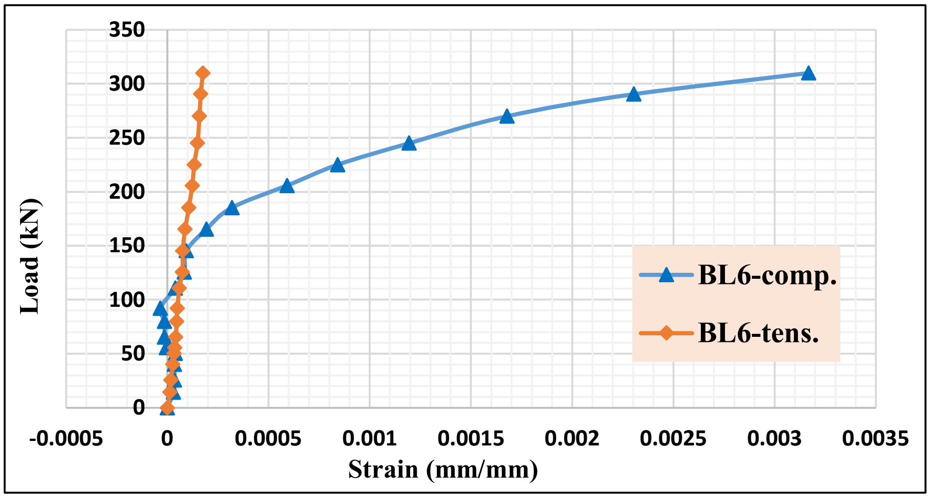


Figure (4.3) Strain distribution





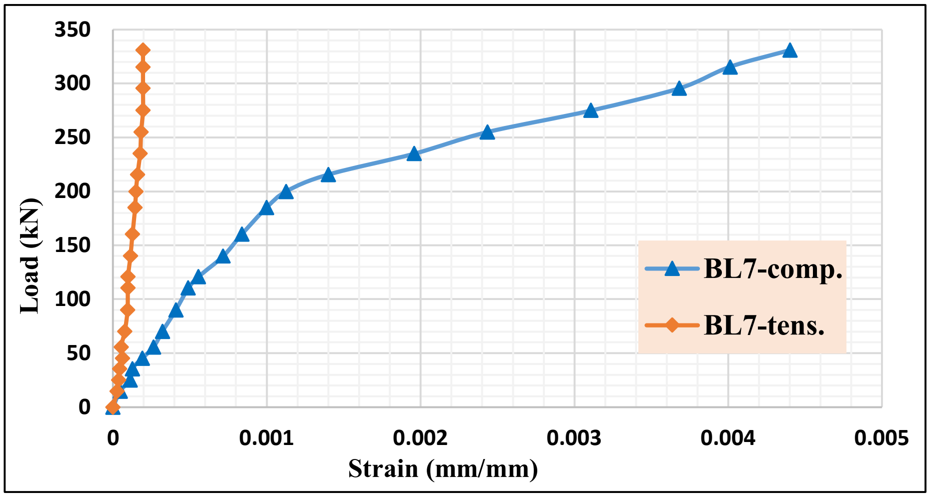
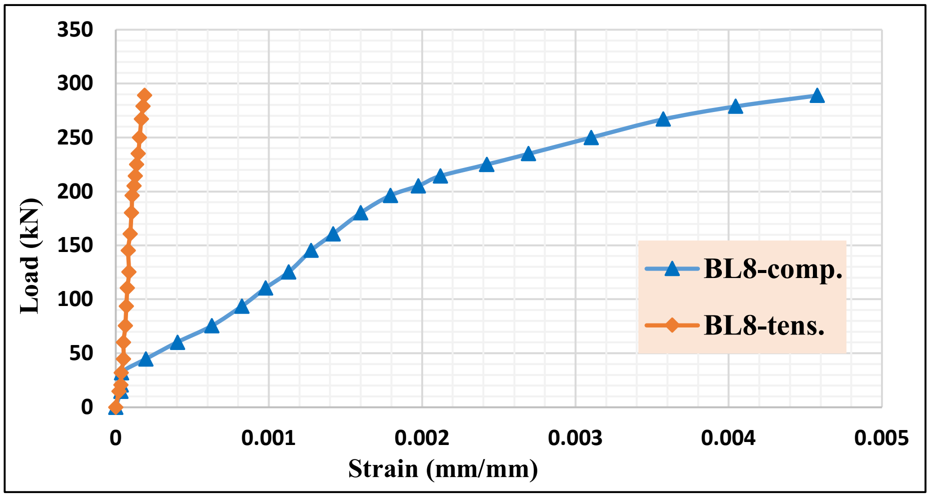
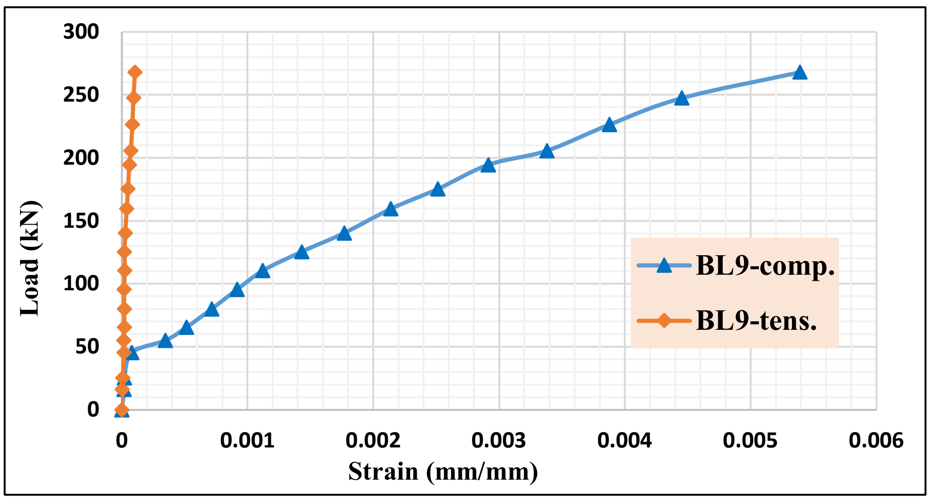


Figure (4.3) Continues





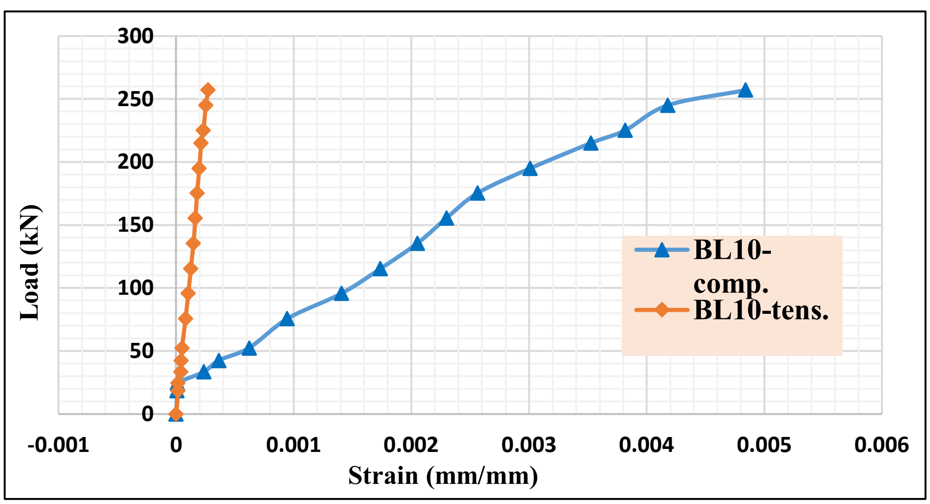
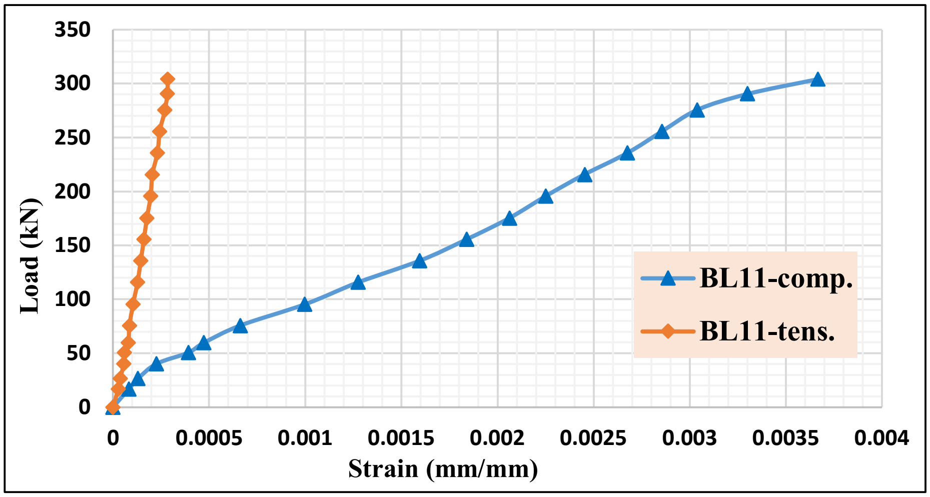
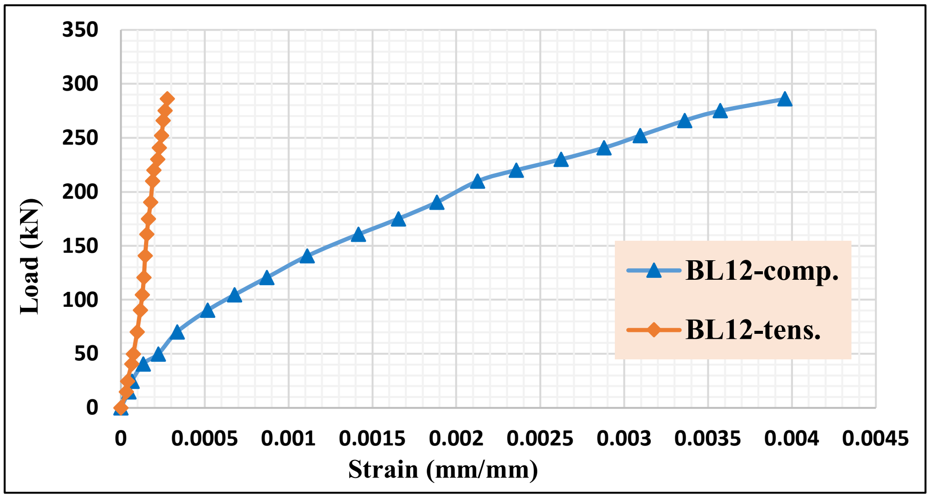


Figure (4.3) Continues





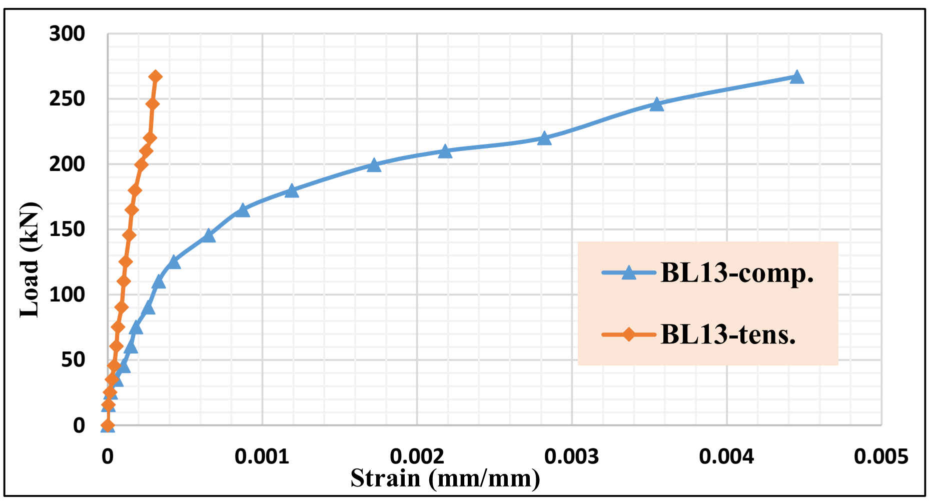


Figure (4.3) Continues

CHAPTER FIVE

CONCLUTIONS

AND RECOMMENDATIONS

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Tests were produced a collection of important data, which was adopted as a basis for the following conclusions: -

1- The general behavior of trapezoidal section of reinforced concrete beams is very similar to those of rectangular section, in terms of effect load, failure mode, deflection and cracks path.

2- The ultimate failure load of hybrid-trapezoidal section of reinforced concrete beams recorded a reduction ranging 2.82% - 6.77% compared to control specimens, this assigned slightly reduction in strength depicts positive effect of hybrid strength-trapezoidal section as compression strength dropped to half in tension region. However, the homogeneous specimen with a trapezoidal cross-section achieved a failure load increasing by range of 2.16% - 6.77% compared to the specimen with a rectangular cross-section.

3- The results are clearly assigned that hybrid strength-trapezoidal configuration effectiveness maintained specimens strength dropping more than that of hybrid strength influencing, the comparison of last ratios, shows significantly that.

4- The comparison of results with hybrid strength a reduction index shows that when (Ψ) decreased from 0.714 to 0.357, the average strength rating of rectangular section specimens and trapezoidal section of uniform strength varies between (0.95- 0.77) and (0.93-0.75), respectively.

5- The results assigned the influence of compressive strength within tension region upon first crack developing, where the specimens that possesses Ψ =

0.357 which are of (fc)t = 25 MPa (G3) exhibited early cracking in comparison with those possesses Ψ =0.5 with same (fc)t (G2), this finding confirm the effectiveness of the hybrid strength reduction index and the quality of concrete within tension region upon cracking progressive.

6- All tested beams fail by flexural trend which is contributed to tension failure mode due to yield of main reinforcement in tension zone and associated with excessive deflection, without splitting.

7- The results showed in general that the hybrid strength-trapezoidal gave higher results in deflection, and that the highest values were obtained in specimens of Ψ = 0.357 and Ψ = 0.5 , these increases ranging of (20% to 56.81%) and (8% to24%) which are corresponding to deflection rating of rectangular specimens and trapezoidal section of uniform strength, respectively, this results clearly confirm the powerful effect of hybrid strength-trapezoidal section to upgrade section ductility in comparison with those of rectangular section or of uniform strength, this means that, the area distribution with in hybrid section have main rule in ductility updating of hybrid section and Ө= 76 assigned as best one.

8- The results of flexural stiffness analysis confirm that hybrid strength-trapezoidal section were severely affected by hybrid strength reduction index Ψ =0.375

9- Specimen BL5 was achieved best ductility upgrading of (1.504), which is regard hybrid strength the trapezoidal (class A) (Ψ=0.714) section of (Ө)=85°. The sane finding is assigned for class (C) (Ψ=0.357), where the ductility index of specimen BL13 was 2.03, while for class B (Ψ=0.5) the corresponding specimens does not exhibit higher ductility and specimen BL7 assigned as best one. This could be related to effect of hybrid strength as its global effect associated with dominated E_c which is affected by fc of upper region.

5.2 Recommendations

1- Investigation of various hybrid strength ratio of lightweight concrete with in trapezoidal reinforced concrete beams.
2- Study of moment redistribution within continuous hybrid-trapezoidal section.
3- Study of hybrid strength reinforced concrete deep beams of trapezoidal section
4- Studying the structural behavior of hybrid strength reinforced concrete beam with other cross section area like flanged-trapezoidal section.

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الخلاصة

تهدف الدراسة الحالية إلى بحث السلوك الإنشائي للعتبات الخرسانية المسلحة الهجينة ذات مقطع عرضي عل شكل شبه منحرف. يتكون البرنامج التجريبي من اختبار ثلاثة عشر عينة بطول 2100 مم مسندة اسنادا بسيطا. تم اختبار جميع العينات تحت تحميل ثابت من نقطتين. كانت المتغيرات المدروسة هي الزاوية الجانبية (75°, 80°, 85°, and 90)) ومقاومة الخرسانة في منطقتي الشد والضغط واللتان تشكلان الخرسانة الهجينة (($\Psi = f_{cu}(bottom)/f_{cu}(top)$). تم استخدام ثلاث مقاومات لانتاج الخرسانة الهجينة (70, 50, and 25 MPa). تم الحصول على سلوك التشوه–الحمل، واستجابة انفعال الحمل، والحمل النهائي، والانحراف المرن، وحمل الشقوق الأول بالإضافة إلى تحديد سعة قوة الانثناء، والصلابة المرنة، وأنماط الفشل، الليونة المرنة ومسار الشقوق, والتي نوقشت على أساس تحليل المقارنة مع العتبات الخرسانيه المرجعيه. أظهرت الاختبارات التجريبية أن فعالية التكوين شبه المنحرف الهجين حافظت على انخفاض طفيف في قوة الخرسانة على الرغم من الاختلاف الكبير بين قوة الخرسانة في منطقة الشد والضغط. ظهرت النتائج بشكل عام أن قدرة مقاومة الانحناء تزداد مع زيادة مساحة الخرسانة عالية القوة في منطقة الانضغاط بزيادات تتراوح من 2.16٪ إلى 6.77٪ مقارنة مع العينات المرجعية للمقطع الموحد (المقطع المستطيل). بينما قلت قيم حمل الشق الأول. أظهرت الخرسانة الهجينة سلوك مطيل عالي. مقارنة النتائج مع موشر الهجين (Ψ) يبين ان تقليل هذا المؤشر من (Ψ 3 = 0.357) الى (Ψ 3 = 0.714) ادى الى معدل زيادة في المطيلية من (1.24–1) و(1.26–1.03) مقارنة مع النماذج غير الهجينة المستطيلة وذات شبه المنحرف على التوالي. افضل نتائج تم الحصول عليها بالنسبة كانت في النماذج ذات الزوايا (Θ = 76° and Θ = 85°).

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة ميسان / كلية الهندسة
قسم الهندسة المدنية

سلوك العتبات الخرسانية هجينة المقاومة وذات مقطع شبه منحرف

اطروحة
مقدمة إلى قسم الهندسة المدنية في جامعة ميسان كجزء من متطلبات نيل شهادة الماجستير في علوم الهندسة المدنية/انشاءات

من قبل

ماجد جعفر سادة

(بكالوريوس هندسة مدنية 2002)

باشراف
ا.د.سعد فهد رسن

تشرين اول 2020