

**Republic of Iraq
Ministry of Higher Education
and Scientific Research
University of Babylon
College of Engineering
Department of Civil Engineering**



Behavior of Cold-Formed Steel Built-Up Section with Hollow Box-Web

A Research

**Submitted to the College of Engineering / University of
Babylon in Partial Fulfillment of the Requirements for
Higher Diploma in Engineering/Civil Engineering/
Structures Engineering**

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2023 A.D

1444 A.H

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

(نَرْفَعُ دَرَجَاتٍ مَن نَّشَاءُ^{قَلْبًا} وَفَوْقَ كُلِّ ذِي عِلْمٍ عَلِيمٌ)

صَدَقَ اللَّهُ الْعَلِيُّ الْعَظِيمُ

سُورَةُ يُوسُفَ (آيَةٌ 76)

ACKNOWLEDGEMENT

*In the name of Allah, the most gracious, the most merciful
Praise is to Allah, who has granted me the syncretizing and
enabled me to achieve this research.*

*I would like to take this opportunity to express my sincere
thanks to my supervisor; Asst.Prof.Dr. Najla'a Hameed AL-
Shareef for reviewing my research and guidance throughout
the course of the project. I had the honor of being under her
guidance and supervision. Her precious advices and
constructive suggestions are highly distinct throughout this
work.*

*I would also like to thank my parents to whom I'm in debt of
gratitude and appreciation that could never be repaid.
"Thank you for all the sacrifices you have made, and for the
support, you have constantly given".*

*Finally, special thanks to my friends from the bottom of my
heart for assisting me in the experimental tests.*

Great Thanks for All

ABSTRACT

A type of steel made by the cold-forming process, cold-formed steel (CFS) is utilized in construction of buildings, bridges, vehicle bodies, transmission towers, and other structures and equipment. These kinds of sections are cold-formed using a roll-forming machine, a press brake, or bending operations from steel sheet, strip, plate, or plate bar.

This study provides and examines the flexural behavior of cold formed steel beams with varying gap distance between two back-to-back web lipped C sections used to produce built up hollow box CFS beams and the influence of lipped sections on ultimate load capacity. To achieve this objective, the research included both experimental and numerical components.

A four point bending test was produced and evaluated to establish the effect of varying gap distance between two back-to-back web lipped C sections used to produce built up hollow box CFS beams. By obtaining load–displacement curves, the influence of lipped sections on ultimate load capacity was analyzed. As test specimens, five cold-formed steel beams were constructed during the experimental phase.

The test specimens were classified in to two type of beams according to using lipped channels to construct the beams or absence of lipped channels. Four specimens have varying gap distance between two back-to-back web lipped C sections used to produce built up hollow box CFS beams and one specimen with 33% (21mm) of maximum possible gap distance between two back-to-back web C sections used to produce built up hollow box CFS beams without lipped channels.

The specimens were evaluated experimentally based on the ultimate load caring capacity, load deflection response and failure modes. The results

of maximum load capacity of sections from experimental results (144 kN) for CFS beam with (40) % of maximum possible space between back to back web channels of current beam design with lipped channels.

The specimens were evaluated by finite element modeling using the ABAQUS 2017 software based on the ultimate load carrying capacity ,load deflection response and failure modes. The results maximum load capacity of sections from finite element analysis results (156 kN) for CFS beam with (47) % of maximum possible space between back to back web channels of current beam design with lipped channels.

By comparing CF33L and CF33NL the provision of lipped channels had a significant effect in increasing the load carrying capacity of back to back build up hollow box sections by (27.7%),(34.6%) from Experimental and finite element analysis , respectively .

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Notation

Most commonly used symbols are listed below, these and others are defined where they appear in the research;

Symbol	Description	Units
b_f	Width of flange	mm
D	Depth of cross section	mm
E_s	Modulus of elasticity	MPa
F_y	Yield stress of steel profile	MPa
F_u	Ultimate tensile strength of Steel	MPa
L	Total length of cold formed steel beam	mm
P_u	Ultimate load	kN
t	Thickness of plate	mm
t_f	Flange thickness of steel profile	mm
t_p	Thickness of plate	mm
t_w	thickness of web	mm
X	Gap between web channels	mm

ABBREVIATIONS

Abbreviations	Descriptions
AISI	American Iron And Steel Intuition
ASTM	American Society for Testing and Materials
AS	Australia Standards
CFS	Cold Formed Steel
DSM	Direct Strength Method
EC3	EUROCODE 3: Design of Steel Structures
Exp	Experimental
FE	Finite Element
FEA	Finite Element Analysis
FEM	Finite Element Method
LB	local buckling
LCB	Lipped Channel Beam
LRFD	Load Resistance Factor Design
Max	Maximum
Min	Minimum
No	Number
Num	Numerical
NZS	New Zealand Standards

CHAPTER ONE

INTRODUCTION

CHAPTER ONE

INTRODUCTION

1.1 General

Cold formed and hot rolled steel are used in steel structural projects. It is important to mention that the main different between cold rolled and hot rolled steel is the process of formation. Cold rolling term mean that formation process was at temperature near the room temperature, while term of hot rolling mean that formation process was by heating at high temperature. In spite of these two approaches effect on performance but it should distinguish between its effect and effect of grades and specifications of steel that concerned with and rating and metal compositions of material. Carbon steel which have various grades and specifications can be formed by cold or hot rolling.

1.2 Cold rolled steel

Cold rolled steel are more durable and harder as compared with common hot rolled steels. ^[1]

Cold rolled steel is similar to hot rolled steel but go through more processing as shown in plate (1-1). After hot rolled steel cooled down, process of rerolling it at room temperature start to reach accurate dimensions and get better properties for the surfaces.

Cold rolled steel term actually mean exclusively to sheets which formed by press between rollers, but frequently this term used for define a diversity of finishing approaches. Other methods of cold finishing such as polishing, grinding and turning each of these techniques convert hot rolled to more advanced products. ^[1]

Cold rolled steel can be illustrious by the subsequent features:

- 1- Higher quality and more perfect surfaces.
- 2- Smooth and oily touch surfaces.
- 3- Channels are accurate with frequently distinctive angles and edges.
- 4- Tubes shown more straightness and concentric homogeneity.

The cold rolled steel advantage are as following:

- 1- Cold rolled steel has better surface condition as compared with hot rolled steel, so that Cold rolled steel used in conditions where artistic or technical accuracy are important .However ,due to additional techniques which used for finishing cold products, they are have higher cost .
- 2- Cold rolled steel are more durable and harder as compared with hot rolled steel from physical aspect. Work hardening improve resistance to deformation, hardness of steel and tension breaking for steel which form at low temperature. ^[1]

Even so, cold rolled steel may be develop internal stress in the metal due to these additional treatments, which may occur due to warping of steel if steel not relaxed before process of welding and cutting.



Plate (1-1) Cold rolled steel. ^[1]

1.3 Hot rolled steel

Hot rolled steel formed at high temperature (926 C⁰) by roll pressed, which is higher temperature compared with the temperate of recrystallization of nearly all steels, which increase the ability of shaping, result in easier manipulation of products as shown in plate (1-2). [1]

Hot rolled steel Can by produced by heating a big rectangular member of steel then compressed to rolled steel then exposed to preprocessing technique ,after that to achieve the desirable dimensions and proportions steel pass at high speed through series of rollers at high temperature ,then rolled by coils and left to cool down. Hot rolled steel can be manufacture as variety of forms such as plates and bars.

Hot rolled steel not fitted to use for high accurate projects because final products of hot rolled steel lake for high accurate dimensions, which caused by cooling of product while manufacture processing ,so that hot rolled steel used for conditions were accuracy not very impotent ,usually it used for trains railways construction works. [1]

Hot rolled steel can be illustrious by the subsequent features:

- 1- Due to cooling of steel at high temperature hot rolled steel have flaky surface
- 2- Due to inaccurate finishing and shrinkage hot rolled steel products have a curved edges.
- 3- Due to deformation which happen while cooling, product angle may take trapezoidal shapes

The hot rolled steel advantage are as following:

- 1- Hot rolled steel less costly from cold rolled steel because its manufacture required less procedures to produce. Hot rolled steel cool down,

its simply normalized which mean avoid development internal stress which accused by work hardening.

2- Hot rolled steel can be suitable for structural work where surface high quality and dimension accurate less important than required strength. Abrasive blasting by sand, plashing and pickling path by acid can be used to remove scaling on surfaces when surface high quality required for better coating and panting. [1]



Plate (1-2) Hot rolled steel [1]

1.4 Cold Formed Steel Structure

Cold formed steel sections can be manufactured by twisting steel sheets at room temperature with different forms of members to achieve constructional and serviceable standers [2].

Several of cold formed steel members which utilize in construction works have configurations similar to hot rolled members. All edges and corners of cold formed steel formed by one process to produce single portion [3].

Cold formed steel have light weight and high strength ,usually employed in bridges, railways, electricity towers, tanks, roof constructions, walls systems, highway features ,sanitation works, storage stands, vehicle manufactures and other .

Carbon steel tube, thin sheet and channels manufactured by processes of bending brake, press break or cold rolling process [4].

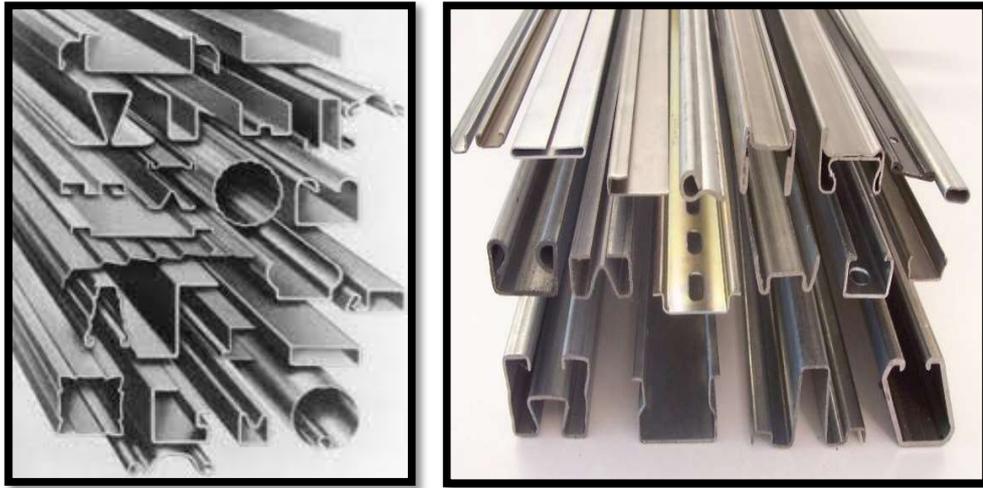


Plate (1-3): Various shapes of cold formed steel sections [4].

For cold formed steel members parts connected with each other's by bolts, nuts and welds where two types of welding resistance and arc welding. Resistance welding by Applying electric wave through the two parts which needed to connect. Arc welding by using weld metal to join required surfaces.

There are variety of shapes and sizes of bolts which can be classified according to mechanical transition of loading as following

- Attachment of tension sections where bolts weak to resist shear the shank loading.
- Simple connect at edge of beam where bolts weak to resist shear the shank loading.
- Existence of hanger attachment where bolts undergo tension force [5].

1.5 Research Objectives

The purpose of the research is to investigate, experimental tests and Finite element analysis, the flexural behavior of CFS built-up members with hollow box-web with different gap distance between back to back web steel channels on failure modes and load carrying capacity. This study's key targets can be outlined as following:

- 1- Execute Exp and FEA on five specimens with different gap distance between two back to back C channels construct the web of built up hollow box CFS beam to Investigating influence of gab distance and absence of lipped channels on flexural behavior under four point bending condition
- 2- Evaluating the validity and precision of finite element analysis to model the nonlinear behavior of the failure of cold-formed steel beams using the ABAQUS Standard/Explicit 2017 software.
- 3- Prediction of gap distance between two back to back C channels construct the web of built up hollow box CFS which resist higher load carrying capacity.

1.6 Research Layout

Chapter One: This chapter deal with the general introduction of cold-formed steel beams

Chapter Two: Includes literature review of this study including experimental and finite element analysis studies about cold-formed steel beams.

Chapter Three: Explains the preparation of experimental work and description of the specimens, materials properties, molds and instruments

Chapter Four: This chapter showing the experimental results and its comparison.

Chapter Five: In this chapter, finite element to analyze tested CFS beams using the ABAQUS computer program and the comparison between the finite element results and experimental results were included.

Chapter Six: Finally, this chapter includes the main conclusions and recommendations for the future studies.

CHAPTER TWO

LITERATURE

REVIEW

CHAPTER TWO

LITERATURE REVIEW

2.1 General

Over the last several years, there has been a growth in the construction industries for CFS beams that have better strength. This demand has come mostly from low height and intermediate height commercial and residential construction. It results to the manufacture of sections by joining many individual parts to produce "built-up" cross-sections. In most cases, the built-up portions were joined together with the use of components nuts, screws, and welding. Because of the formation of the built-up beam components as a composite, the moment capacity of the built up members were greater than the total of the strength of the individual beam members. Built-up sections with doubly symmetric patterns provide an extra benefit in the form of increased torsional stiffness. [6]

Because the design of built up closed-form CFS sections was not considered in the current design standards such as that provided by AISI for designing of CFS structural members, there was a need for further study in order to get a better understanding of the structural behavior of these sections. The following is a summary of some of the earlier publications that have been used as references in this chapter:

Xu, et al (2009) [7] performed FEA for built up closed CFS beams as shown in plate (2-1) with eccentric loading as simulation for Exp tests which investigated by Beshara B [8], investigation of influence of bolt spacing, height-thickness ratio and yield strength. It found that there is good agreement between FEA and Exp test result, flexural strength increase with increase of height- thickness ratio and decrease of bolt spacing and recommended to use factor 0.9 for calculation flexural strength for cold form steel built up

members as summation of nominal strength of each c section which build the beam.



Plate (2-1) Cross-sections of the tested beams by Xu, et al (2009).^[7]

Zhou and Shi (2011)^[9] investigated Exp and FEA test of three group of beams each group of three beams, all beam consist of two C sections specimens connected back to back to build up I shaped beams as showed in figure (2-1), to examine the effect of variation of length of beams, steel grade, width/thickness of flange and height/thickness of web .It's found that FEA provided valid result as compared with Exp result, width/thickness of flange and grade of steel have great influence on flexural strength of beam .

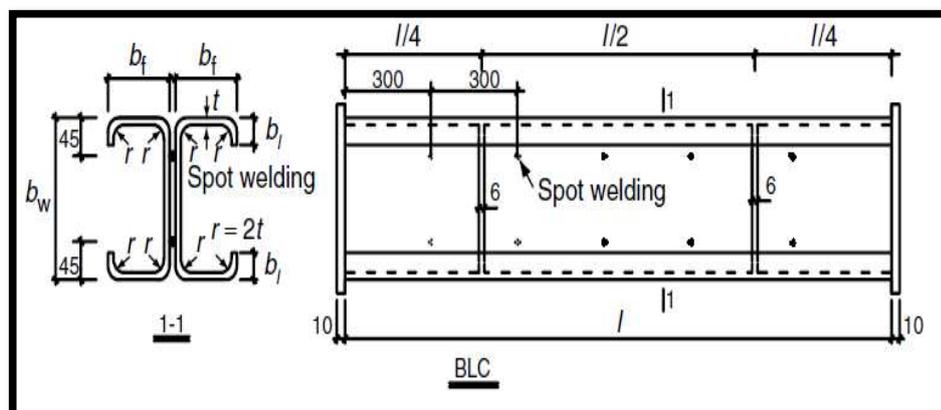


Figure (2-1) Cross-sections of the tested beams by Zhou and Shi (2011).^[9]

Laim I, et al (2013) [10] carried out four point bending test on cold formed steel with various configuration as shown in figure (2-2) and compare the results with FEA where good agreement found from aspect of ultimate strength and failure mode. Where mode of failure for beams with C, I was lateral torsional bulking, distortional bulking for (R, 2R) and found that strength/weight proportion decrease with increase of span over 3m .

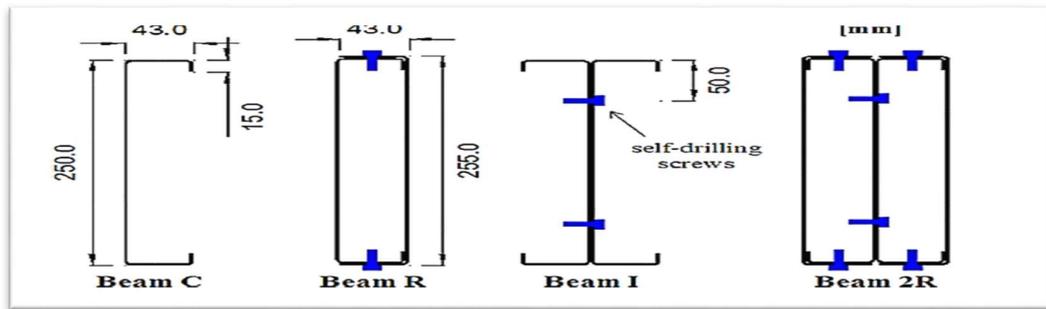


Figure (2-2) Cross-sections of the tested beams by Laim I, et al (2013). [10]

Manikandan P, et al (2014) [11] studied the impact of edge stiffener by carrying four point bending test Exp and Num using ANSYS on 5 different geometrical sections of built up cold formed as shown in figure (2-3) , where length of specimens 2300mm and thickness of 2mm. FEA predicted the Exp result. most of C, H type beam which have less cross sectional area failure with flexural bending and for beams with larger cross sectional area failure mode where LTB, All HU,HC beams fail by pure bending, HI failure mode where mixed between bending and LB .

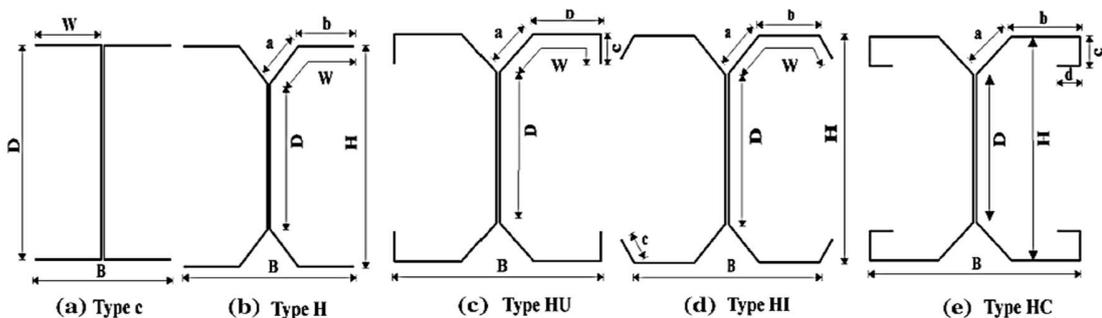


Figure (2-3) Cross-sections of the tested beams by Manikandan P (2014). [11]

Ying l, et al (2016) ^[12] conceded Exp and Num tests on 14 specimens of cold formed steel beam consist of C and U sections and built up beam of combined C, U section to show the flexural behavior of section separately and combined as shown in figure (2-4), from finding of bending about strong axis that moment capacity of built up beam were 90% of moment capacity summation of each part which beam consisted of. Additionally, numerical result differences then the Exp result by less than 10%.

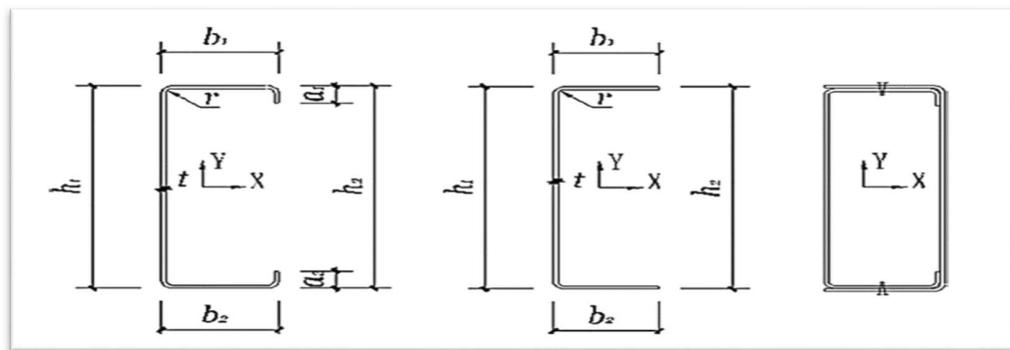


Figure (2-4) Cross-sections of the tested beams by Ying l, et al (2016). ^[12]

Jun Ye, et al (2018) ^[13] investigated Exp and FEA the flexural behavior of 6 specimens of built up I shaped cold form steel consist of two back to back channels as shown in figure (2-5), where strain Harding of rounded edges influence taken in account, results compared with finding which provided by using Direct Strength Method (DSM) and EUROCODE 3 (EC3), where results was convergent.

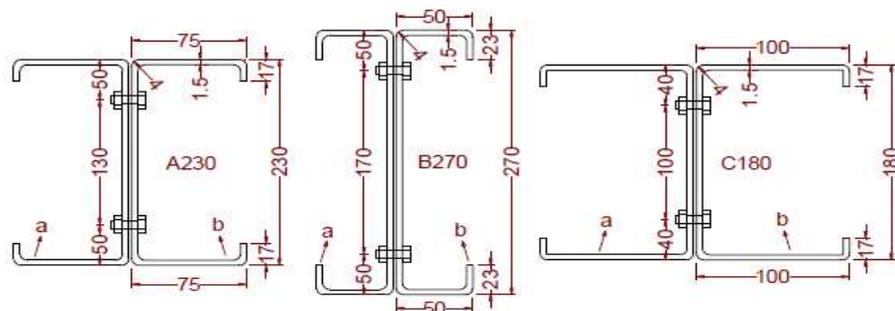


Figure (2-5) Cross-sections of the tested beams by Jun Ye, et al (2018). ^[13]

Dar et al (2018) ^[14] investigated Exp and Num test using ABAQUS on build up cold formed steel beam with different stiffness arrangement and thickness as shown in (2-6) four specimens been tested by four point bending test, failure mode for first specimen with 2 mm thickness without stiffness was flange LB, for second (2mm) spacemen by providing stiffness for location of failure ultimate strength increased by 50%. For third specimen with 1mm thickness fail by LB .stiffeners which provided in fourth specimens (1mm) increase ultimate bending capacity by nearly 10% and found the beams with 1mm thickness were very vulnerable to fail at low loading by buckling.

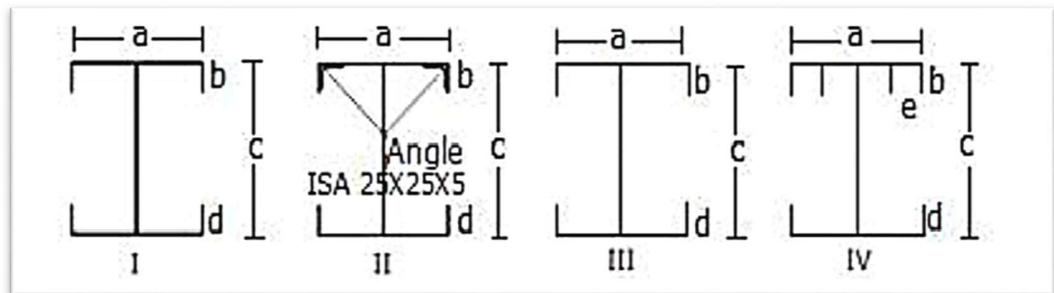


Figure (2-6) Cross-sections of the tested beams by Dar et al (2018). ^[14]

Wang L, Young B (2018) ^[6] provided Exp and Num investigation by testing 35 specimens showing the influence of screw arrangement on flexural capacity, where screw connect two channels in two different ways, first by connected to C shaped channels back to back to build up open beams, second way by connect to channels face to face to build up closed beams. Finite element analysis result was close to experimental result. It found that impact of screw spacing on bending strength capacity of open specimens is little due to screw spacing less then halve wave of distortional failure, but for close specimens the impact is more significant.

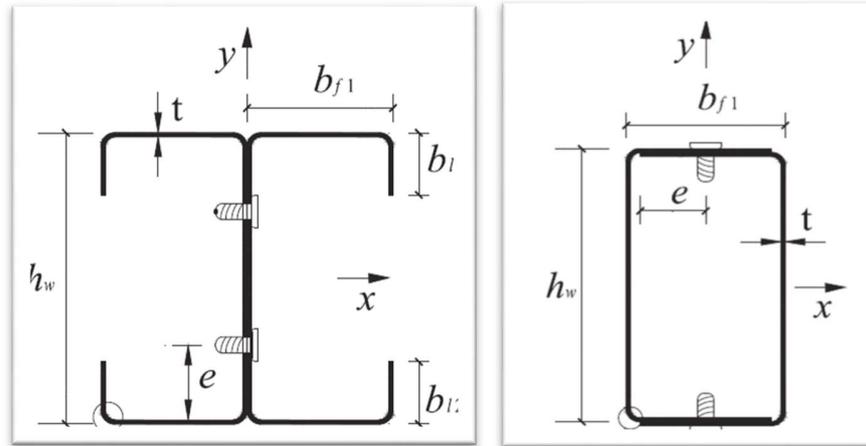


Figure (2-7) Cross-sections of the tested beams by Wang L (2018). [6]

Shi Y, Zhou XH, et al. (2020) [15] carried out Exp and Num a four point bending test on 30 specimen of built up open and closed beams as shown in figure (2-8) to study flexural behavior ,failure mode , influence of height to width ratio and flange width to thickness ratio ,failure mode for open sections was LB and distortional, failure mode for closed sections was LB and bending , FEA result valid the Exp results, influence of height ratio to width of open section beam was great ,where bending strength capacity increase with increase of height to width .

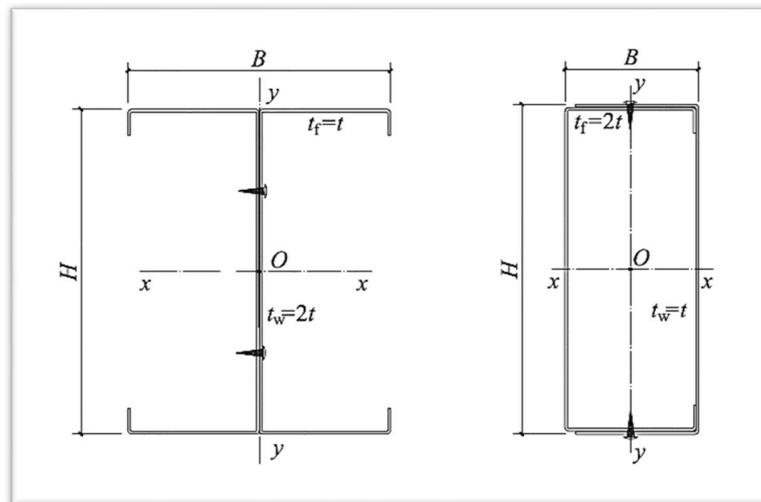
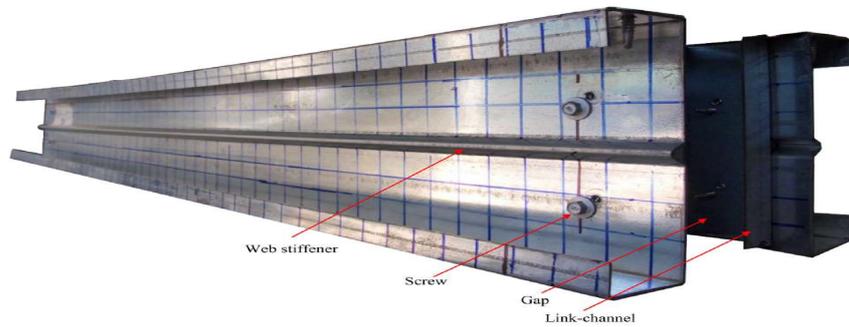
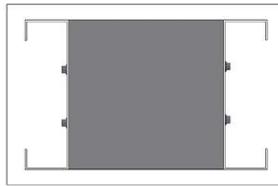


Figure (2-8) Cross-sections of the tested beams by Shi Y,et al (2020). [15]

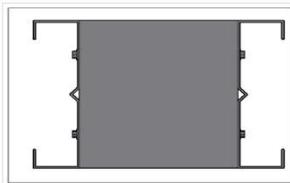
Krishanu Roy ,et al (2020) ^[16] carried out 18 Exp and 72 Num tests on built up CFS beams consist of two C channels connected back to back with gap by linked each other by intermediate sections as shown in figure (2-9), to study flexural behavior of beam with 1000mm and 2000mm length and influence of web stiffeners. As result from study, two web stiffeners increase flexural strength capacity by 10% and for specimens with one web stiffener no significant impact on strength.



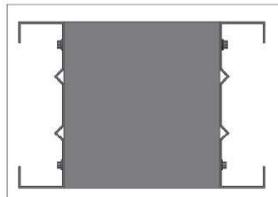
a) Photograph of the back-to-back gapped built-up CFS channel beams



b) Gapped built up without web stiffener



c) Gapped built up with one web stiffener



d) Gapped built up with two web stiffener

Figure (2-9) Cross-sections of the tested beams by Krishanu Roy (2020). ^[16]

Krishanu Roy ,et al (2021) ^[17] presented Exp and Num flexural behavior of twelve specimens classified into two type as shown in figure (2-10) to examination the influence of bolts configurations and specimens geometry , Num result agree with Exp results and compared with calculations resulted from Australia Standards (AS) and New Zealand Standards (NZS) ,where was increase in flexural strength by 15%, 8% for beams with height 75mm, 90mm respectively by reducing bolts gab distance from (1900-475)mm.

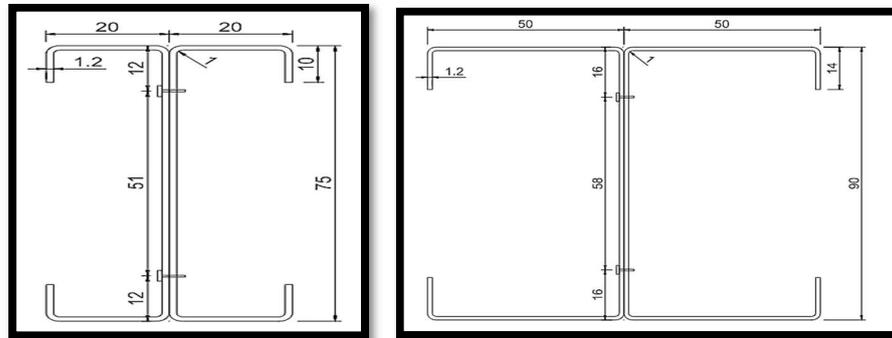


Figure (2-10) Cross-sections of the tested beams by Krishanu Roy (2021). ^[17]

Deng F, et al (2022) ^[18] investigated Exp and Num flexural behavior of open and closed built up cold form steel consist of four identical parts connected with each other by screws shown in figure (2-11) by preform four point bending tests and get ultimate load and failure mode, result showed that open specimen fail at higher loading as compared with closed specimen, flexural strength increased by increase thickness and beam height.

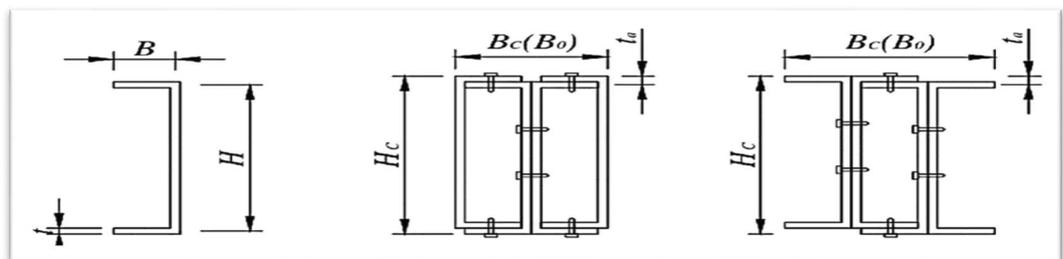


Figure (2-11) Cross-sections of the tested beams by Deng F (2022). ^[18]

Kanthisamy E, et al (2022)^[19] presented Exp and Num on built up CFS beams with different geometries and materials such as carbon steel, stainless steel and aluminum as shown in figure (2-12) to show the flexural behavior for each kind, results showed good agreement between FEA and Exp, as well as result show that flexural strength capacity of folded flange tested beams for all property were higher than other geometries.

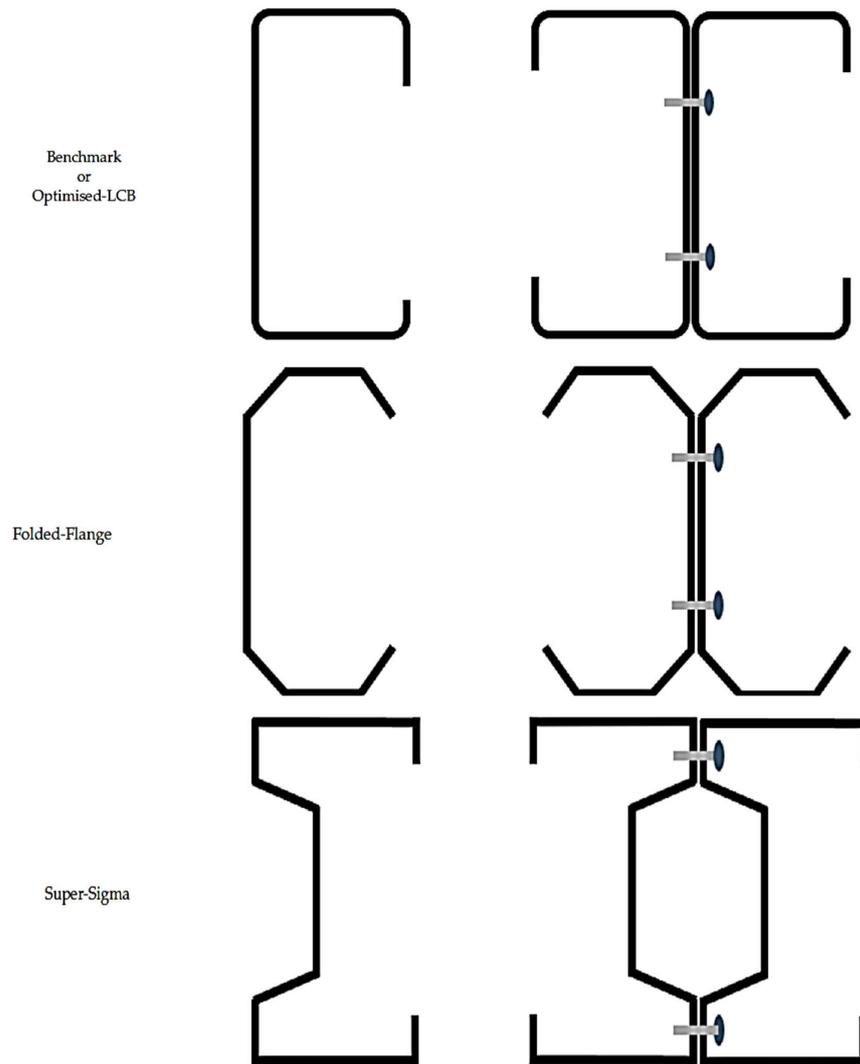


Figure (2-12) Cross-sections of the tested beams by Kanthisamy E (2022).^[19]

2.2 Summary

Many studies in literature concerned with Exp study and/or FEA of flexural behavior of built up CFS effected by screw gab distance ,steel yield strength, section depth, thickness, beam span, depth, flange width, width to thickness ratio, geometries, stiffening arrangements, screw configurations in span and comparison between single and built-up sections, closed and open section beams. This research focus on studying flexural behavior of built up CFS beam with hollow box-web effected by variation of gab distance between back to back web channels which construct the beam experimentally and numerically using ABAQUS 2017.

CHAPTER THREE

EXPERIMENTAL

WORK

CHAPTER THREE

EXPERIMENTAL WORK

3.1 Introduction

The object of this research is to study the effect of variation of gap distance between two back to back web C section construct the built up hollow box CFS beam on the flexural strength of specimens. For this objective, all specimens of steel beams were prepared and tested under four point bending condition at University of Babylon's Laboratory .Moreover, the tested preparations, geometry, dimensions, property of specimen, forming and cutting process are shown in this chapter and concludes with a discussion of testing instruments and specimens, the experimental work and the test procedure.

3.2 Properties of Steel Sections

In accordance with the ASTM Standard test method (A370-05)^[20],specimens taken from the steel sheets used to construct channels are subjected to tensile testing, the dimension of tensile testing specimen are shown in table (3-1) .Plate (3-1) depicts an image of a testing machine holding a tensile specimen and tested coupons. The yield and ultimate stress for flanges and webs determined from two tension coupons from the steel plate are shown in Table (3-2), where figure (3-1) represent a standard tensile specimen. Modulus of elasticity and Poisson ratio assumed as 200 GPa and 0.3 respectively.

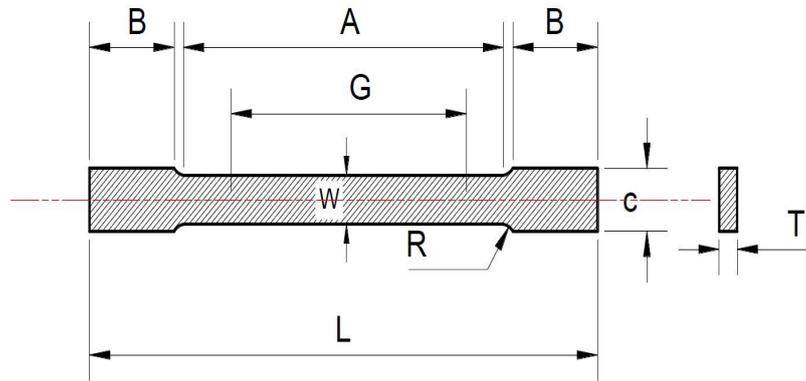


Figure (3- 1): Specimen for tensile testing [20]

Table (3- 1): Dimension of tensile testing specimen [20]

parameter	mm.
G-Gage length	200 ± 0.25
W-Width	40 + 3-6
T-Thickness	3
R-Radius of fillet	13
L- Over-all length	450
A- Length of reduced section	225
B-Length of grip section	75
C-Width of grip section	50



Plate (3-1) Machine for tensile testing and tested coupons.

Table (3-2) Yield stress and ultimate tensile strength

NO of specimen	Yield stress (MPa)	Ultimate tensile strength (MPa)
1	240	304
2	244	307
Average value	242	305

3.3 Description of Specimens

In this part, the geometry of the tested specimens, the hypothesis of the research, and the manufacturing process of steel sections will be detailed as flowing.

3.3.1 Geometry

In order to study the effect of deflection and flexural strength .The experimental work involved testing five specimens under four point loading condition to get the ultimate load capacities and failure modes of the built-up section beams which having similar span length (1500mm), all specimens produced from ST37 carbon steel sheet of thickness (3mm) .

3.3.2 Specimen's Dimensions

A CFS Built up hollow box beam with dimensions ($D=150$ mm, $b_f=120$ mm, $t_f=3$ mm and $t_w=3$ mm) was used for all sections of specimens. All tested beams consist of four channels, two channels for web and other two for flange, the four channels connected with each other by carbon steel bolts with diameter (10mm). Tested specimens are shown in figure (3-2) .The description of channels which construct the cold formed steel beam with back to back web channels and two flange channels are figure (3-3).

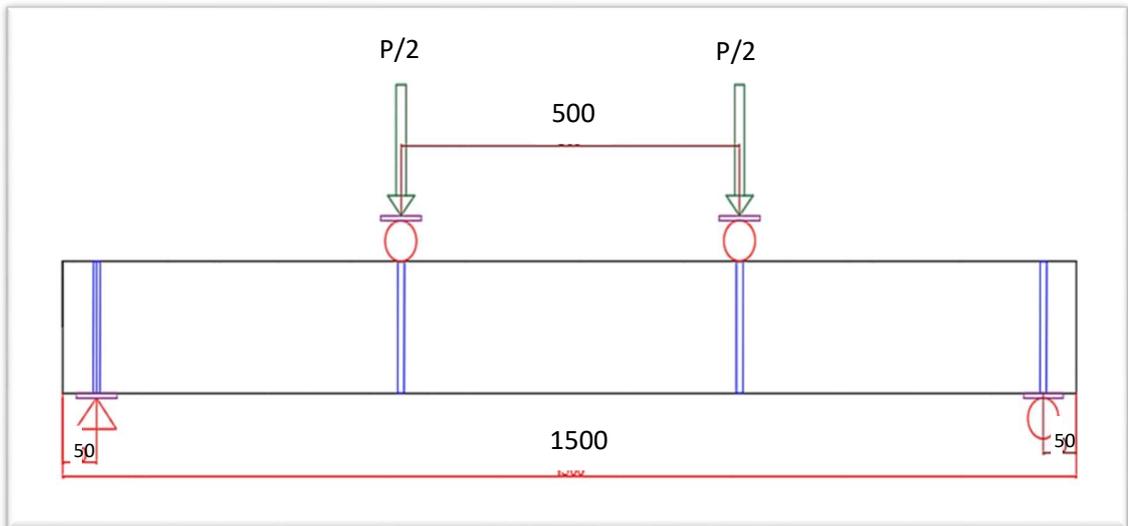
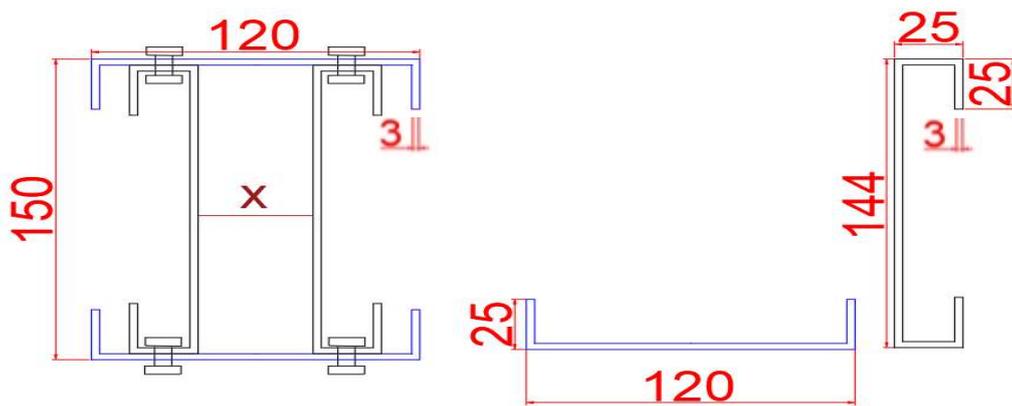
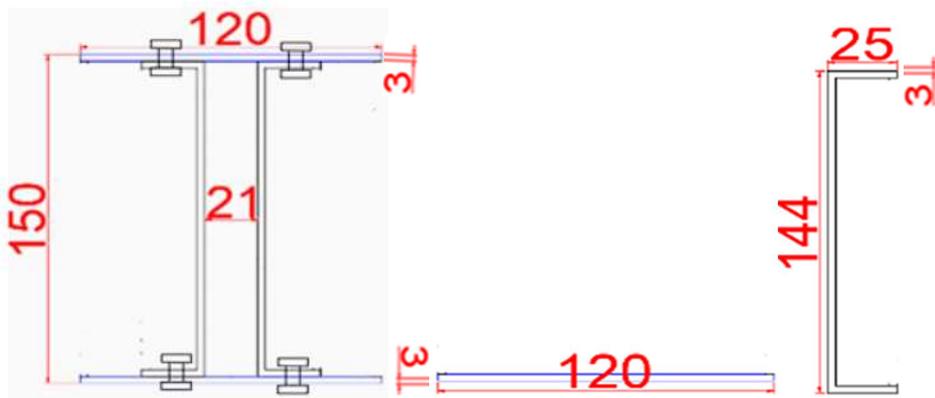


Figure (3-2) Applied concentrated load P1 all dimension in mm



(a) Channels construct beams with lipped section type



(b) Channels construct beam without lipped section type

Figure (3-3) Dimensions of channels construct beams all dimension in mm

3.3.3 Steel Section Forming and Cutting

Electric cutting machine used to cut the steel sheet to achieve desirable measurement of sections. Hydraulic press brake plate machine used for bending and shaping process of channels. The cutting machine and hydraulic press brake plate machine shown in Plate (3-2).



Plate (3-2): Cutting and shaping sections

After the parts are shaped into channel sections, which are then connected each four channels by bolts to form an built up hollow box cold form steel with varied gap distance between back to back web channels , the distance between the bolt was $L/6$ of the span length shown in plate (3-3).



Plate (3-3) Connecting parts of sections

3.3.4 Hypothesis of the Study

In this study, The tested beams can be distinguish into two type first type represented by four specimens have a different gap distance between the back to back web channels with lipped web and flange sections. The second type represented by one specimen have gab distance 21mm distance between the back to back web channels without lipped web and flange sections.

Table (3-3) show the characteristics of each specimen with lable CFX_1X_2

Where:

CF: referes to a cold formed steel.

X_1 : referes to ratio of the gab between webs.

X_2 : referes to with or with out lipped chanals L,NL respectively.

Table (3-3) Reading the identification of specimens

Specimen identification	Reading the Identification of Specimens
CF0L	Cold formed steel beam with no gap between webs of current beam design and with lipped channels (as control specimen).
CF33L	Cold formed steel beam with 33 % of maximum possible space between webs of current beam design with lipped channels
CF66L	Cold formed steel beam with 66 % of maximum possible space between webs of current beam design with lipped channels
CF100L	Cold formed steel beam with maximum possible space between webs of current beam design with lipped channels
CF33NL	Cold formed steel beam with 33 % of maximum possible space between webs of current beam design without lipped channels

All beams parts connected by carbon steel bolts (10 mm) diameter with top view arrangement as shown in figures (3-4) to (3-8) and beam stiffened with eight 3mm stiffeners welded at the supports and loading points to resist any distortional and lateral torsional failure, table (3-4) show dimensions of each beam.

Table (3-4): Dimensions and Details of Tested Specimens

Details Of beams	Sample identification	D mm	Bf mm	T mm	Span mm	Gap between web channels (X) mm
With lipped	CF0L	150	120	3	1500	0
	CF33L	150	120	3	1500	21
	CF66L	150	120	3	1500	42
	CF100L	150	120	3	1500	64
Without lipped	CF33NL	150	120	3	1500	21

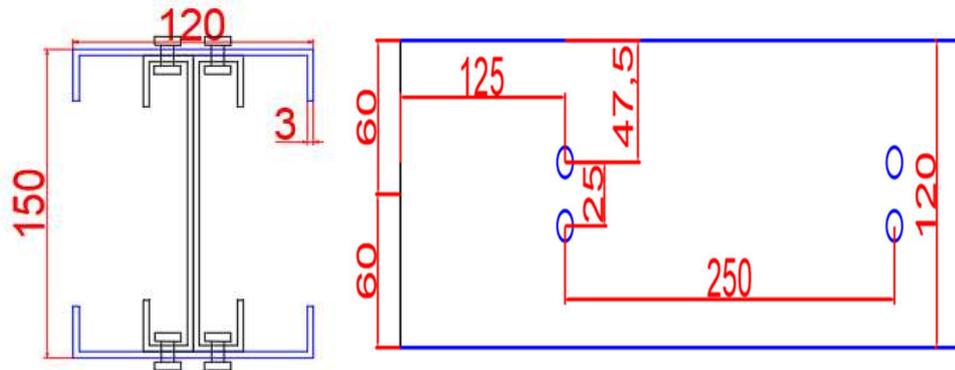
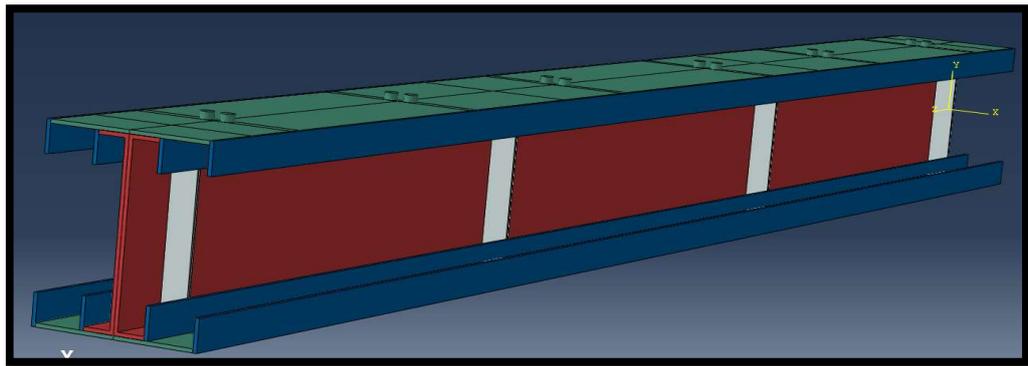


Figure (3-4) Beam with no gap between webs with lipped channels
CF0L (all dimension in mm)

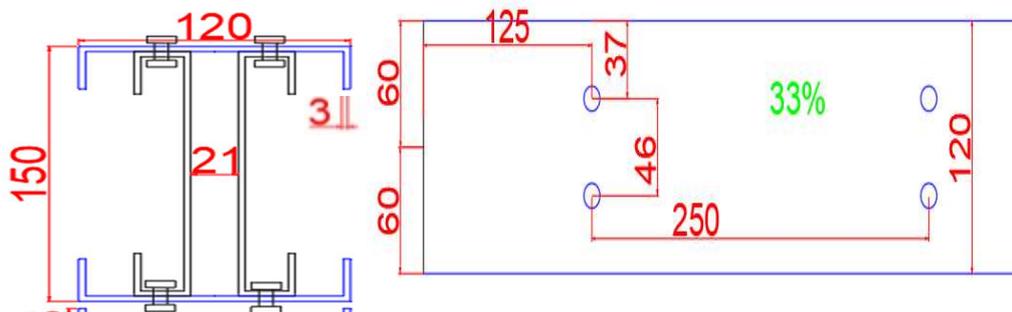
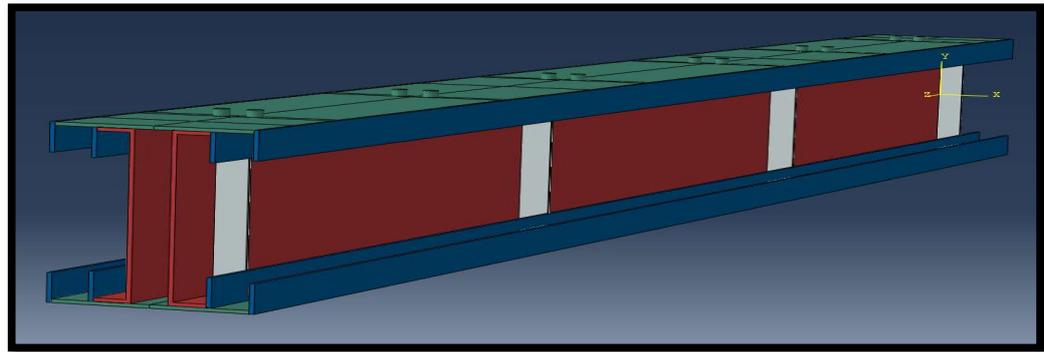


Figure (3-5) Beam with 33 % of maximum possible space between webs with lipped channels CF33L (all dimension in mm)

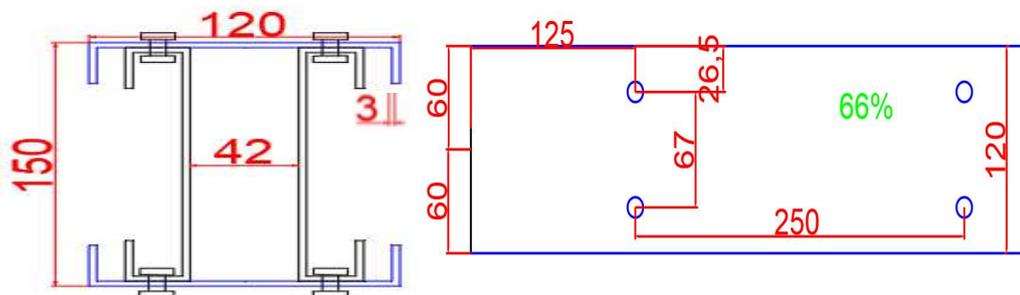
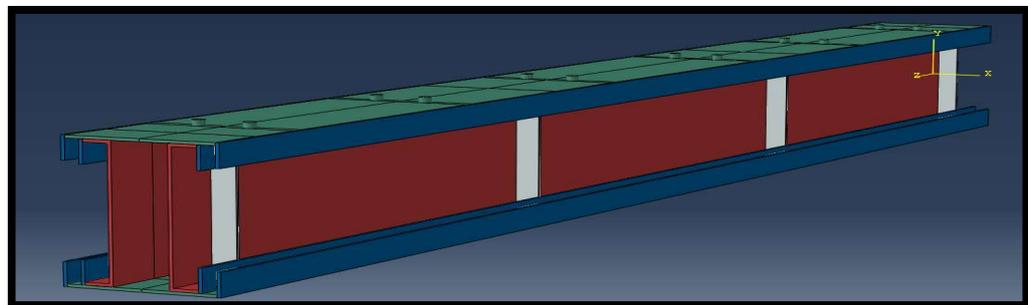


Figure (3-6) Beam with 66 % of maximum possible space between webs with lipped channels CF66L (all dimension in mm)

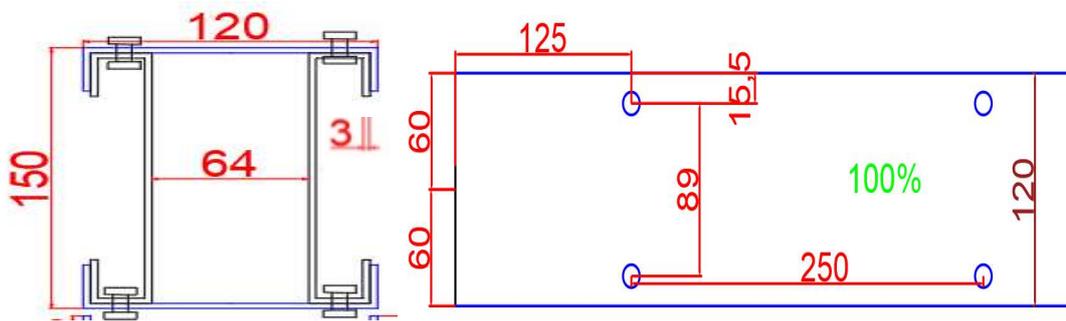
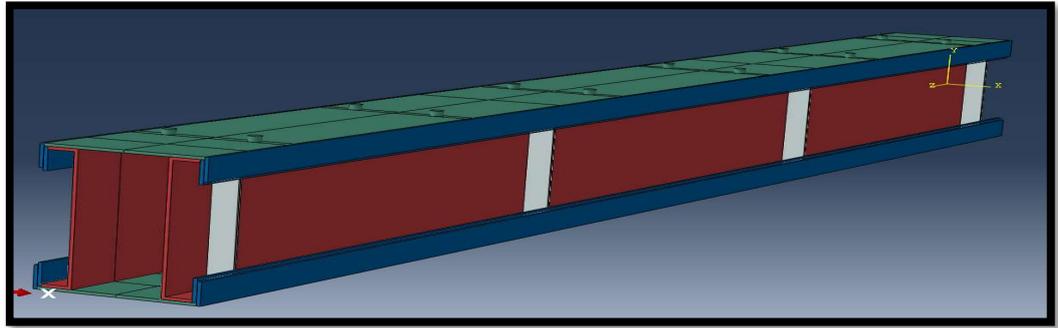


Figure (3-7) Beam with 100 % of maximum possible space between webs with lipped channels CF100L (all dimension in mm)

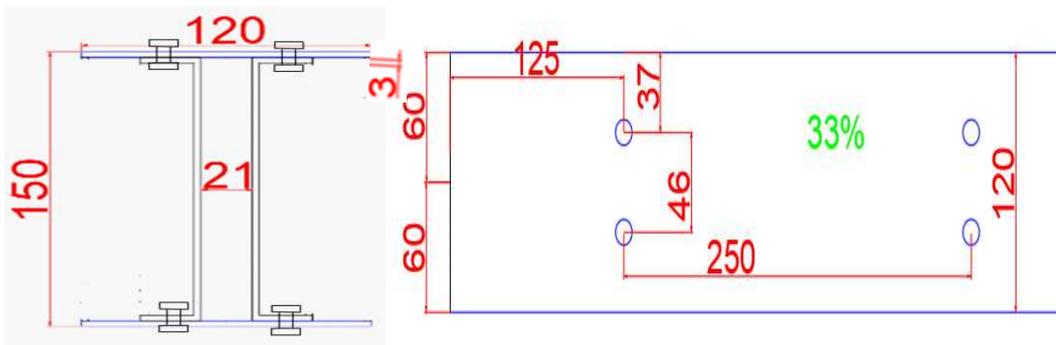
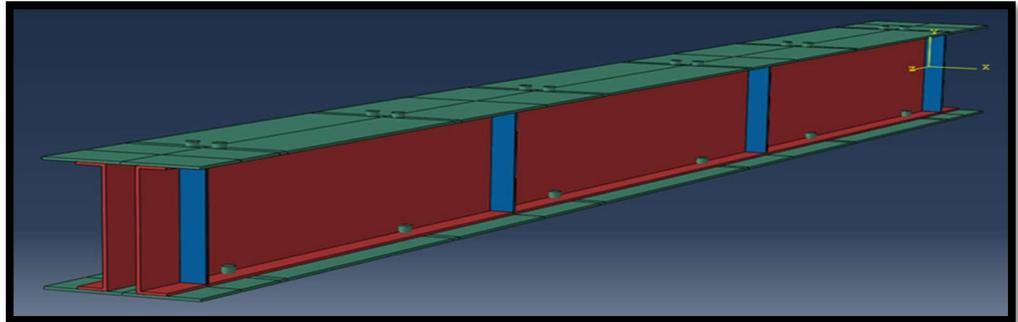


Figure (3-8) Beam with 33 % of maximum possible space between webs without lipped channels CF33NL (all dimension in mm)

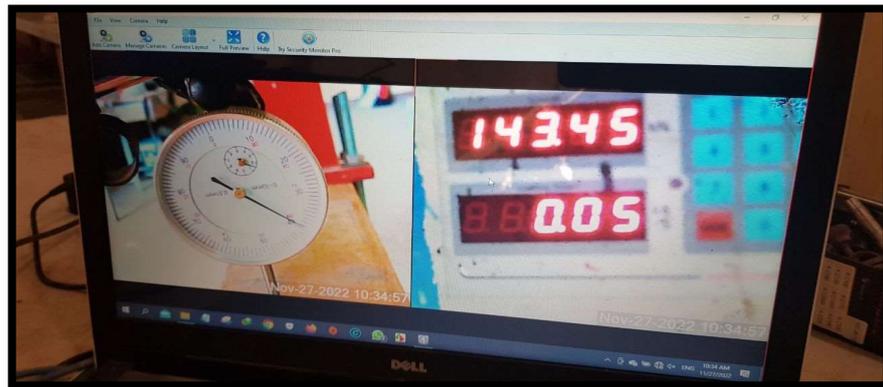
3.4 Instruments

For measuring the vertical deflection of the beam, a dial gauge is used. Digital caliper with a sensitivity of 0.01 mm for calculating deflection. The locations of the contact gauge used in the test are shown in plate (3-5) of the equipment used in the test, which is depicted on Plate (3-4). During the investigation, webcam cameras were utilized to record the load and demand meters for reading purposes, since these cameras are linked to the equipment through computer software. Cameras connected to the device by a computer software that assembles these cameras.



a) Camera

b) Dial gauge



c) Computer

Plate (3-4): Instruments Utilized During the tests

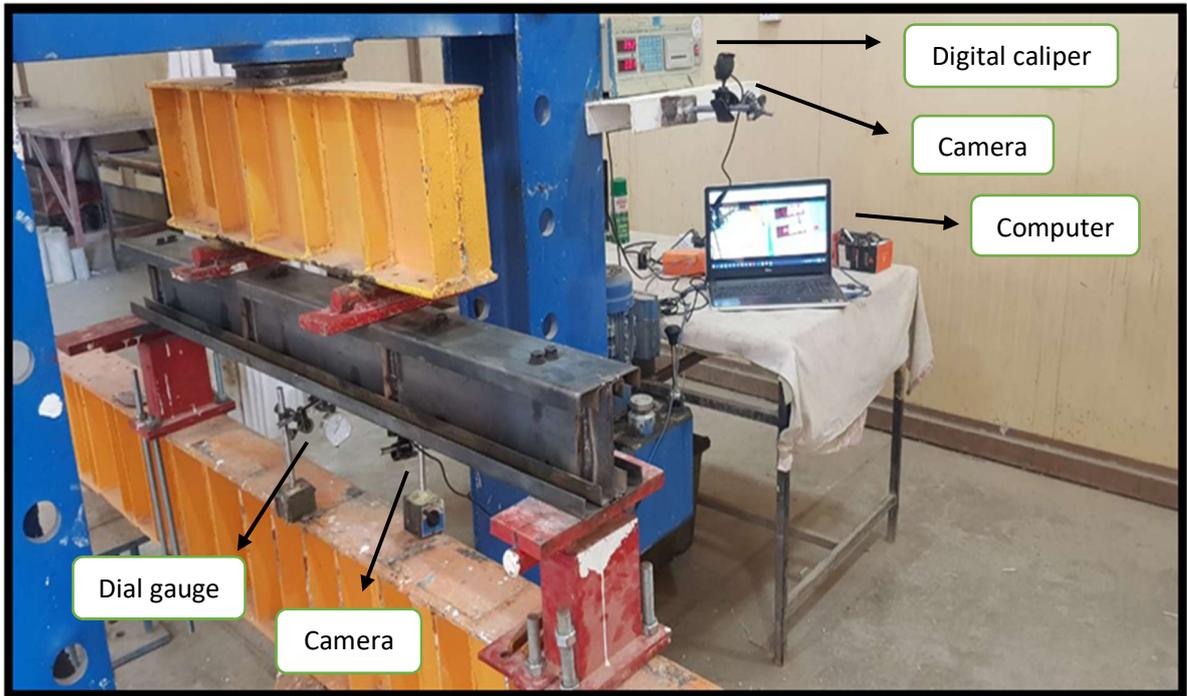


Plate (3-5): Positions of instrument

3.5 Test Procedure

In the structures testing Laboratory at the University of Babylon, five built up cold formed steel beams with simple support were subjected to two similar concentrated forces using a 600 kN hydraulic testing machine. All the beams were supported at one end by a roller and at the other by a hinge. Bearing plates were used as supports and at loading areas to counteract local yielding in steel. The load then applied, and the self-weight and first reading of the deflection are recorded. Each of force values corresponds to a 0.25mm increase in deflection were registered.

CHAPTER FOUR

EXPERIMENTAL

RESULTS AND

DISCUSSION

CHAPTER FOUR

EXPERIMENTAL RESULTS AND DISCUSSION

4.1 General

This chapter discussed result of five beams tested experimentally under four point bending condition, the result recorded from tested beams were mid span deflection at ultimate load and failure mode shape.

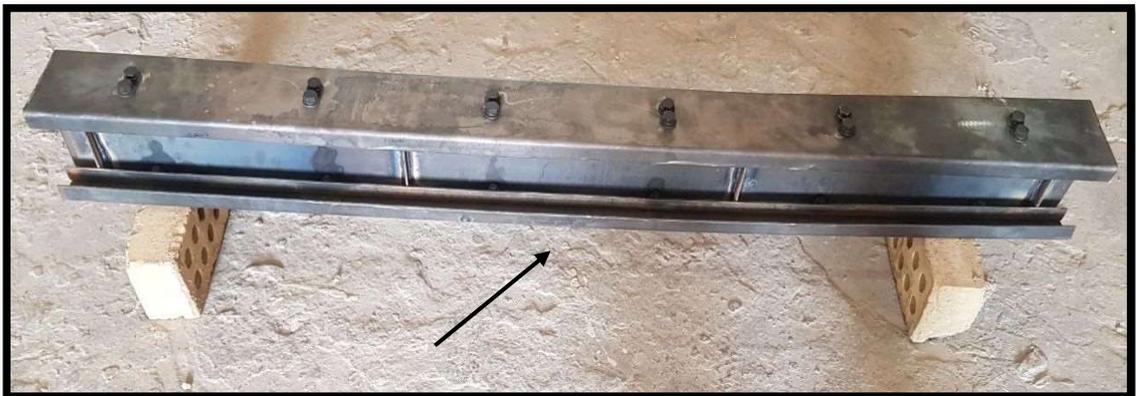
4.2 Test Results of Beams Specimens

All beams were examined under the same loading and as a result for variation of the distance between the web's back to back channels and lipped situation. Failure modes have been identified.

4.3 Behavior of Tested Beams

4.3.1 Behavior of Specimen CF0L

The beam CF0L as control beam was loaded progressively at a rate of (0.2 kN/sec), loading failure was reported at about 130.168 kN and 12.28 mm maximum deflection and failure mode was bending failure as shown in plate (4-1).



A) Mode of failure of tested specimen CF0L

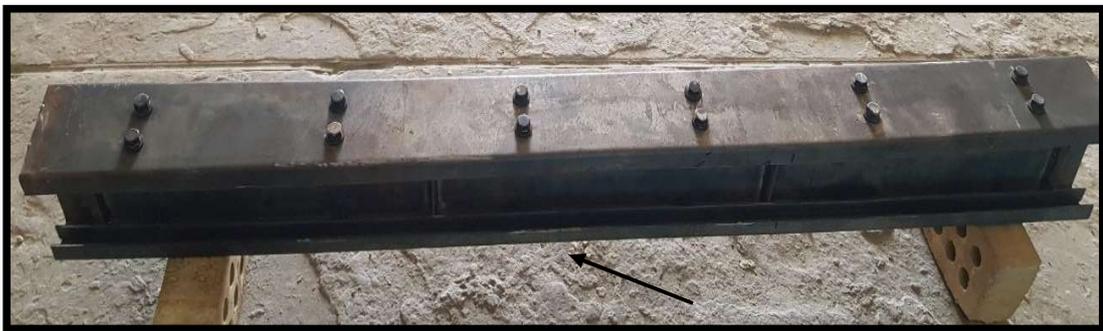


B) Side view of tested specimen CF0L.

Plate (4-1): Shows the failure that occurs at specimen CF0L.

4.3.2 Behavior of Specimen CF33L

The beam CF33L was loaded progressively at a rate of (0.2 kN/sec), loading failure was reported at about 143.2 kN and 15.14mm maximum deflection and failure mode was bending failure as shown in plate (4-2) .Where the amount of increase in strength in this specimen CF33L compared with specimen CF0L was (10) % and the increase in deflection in this specimen CF33L compared with specimen CF0L was (22.4) % may be due to reduction of unstiffened width of flange.



A) Mode of failure of tested Specimen CF33L



B) Side view of tested specimen CF33L.

Plate (4-2): Shows the failure that occurs at specimen CF33L.

4.3.3 Behavior of Specimen CF66L

The beam CF66L was loaded progressively at a rate of (0.2 kN/sec), loading failure was reported at about 141.42kN and 15.73mm maximum deflection and failure mode was bending failure as shown in plate (4-3). Where the amount of increase in strength in this specimen CF66L compared with specimen CF0L was (8.6) % and the increase in deflection in this specimen CF66L compared with specimen CF0L was (28.5) %.



A) Mode of failure of tested specimen CF66L



B) Side view of tested specimen CF66L.

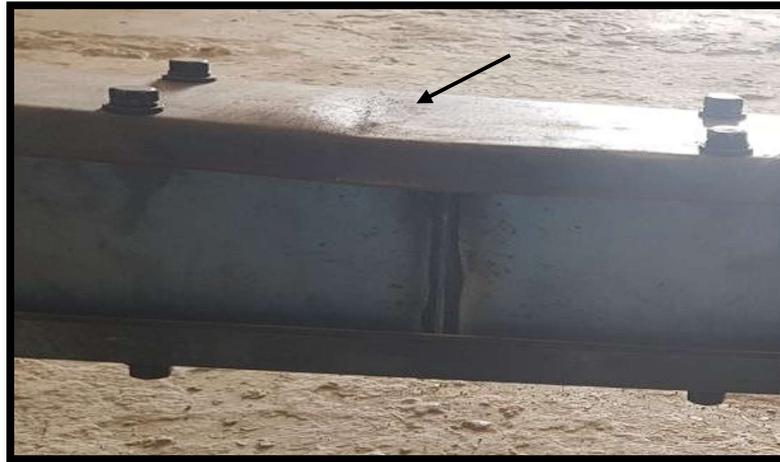
Plate (4-3): Shows the failure that occurs at Specimen CF66L.

4.3.4 Behavior of Specimen CF100L

The beam CF100L was loaded progressively at a rate of (0.2 kN/sec), loading failure was reported at about 138.1kN and 16.65 mm maximum deflection and failure mode was flange local buckling failure under one of the loading plate as shown in plate (4-4). Where the amount of increase in strength in this specimen CF100L compared with specimen CF0L was (6.1) % and the increase in deflection in this specimen CF100L compared with specimen CF0L was (36.7) %.



A) Mode of failure of tested specimen CF100L



B) Flange local buckling failure of specimen CF100L.

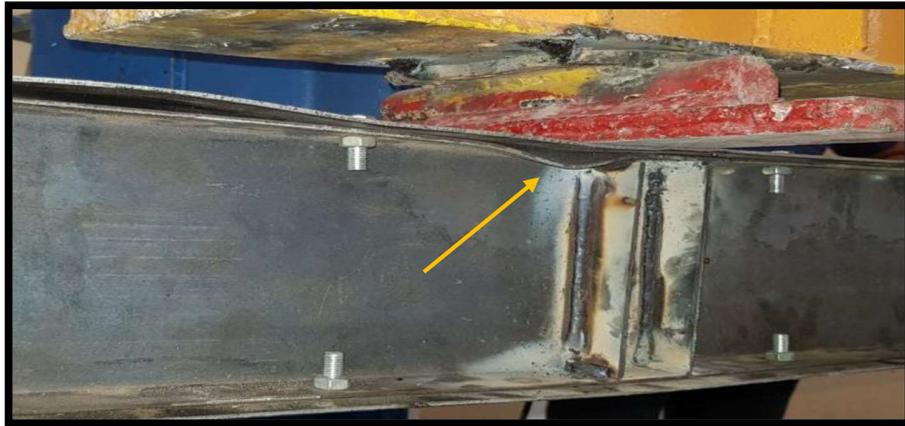
Plate (4-4): Shows the failure that occurs at specimen CF100L.

4.3.5 Behavior of Specimen CF33NL

The beam CF33NL was loaded progressively at a rate of (0.2 kN/sec), loading failure was reported at about 112.1kN and 19.1 mm maximum deflection and failure mode was flange local buckling failure as shown in plate (4-5). Where the amount of decrease in strength in this specimen CF33NL compared with specimen CF33L was (-21.7) % and the increase in deflection in this specimen CF33NL compared with specimen CF33L was (20.7) %.



A) Mode of failure of tested specimen CF33NL



b) Flange local bulking of specimen CF33NL.

Plate (4-5): Shows the failure that occurs at specimen CF33NL.

4.4 Results of load vs mid-Span deflection

During the testing of each beam, a dial-gauge was installed on the mid-span to record the beams' deflections in order to document the load-Deflection behavior. Exp load deflection curves for each tested beam are shown in Figures (4-1) to (4-5). Figure (4-6) shows the compression of the load deflection curves between control beam CF0L and all specimens with or without lipped channels and different gap distance between webs.

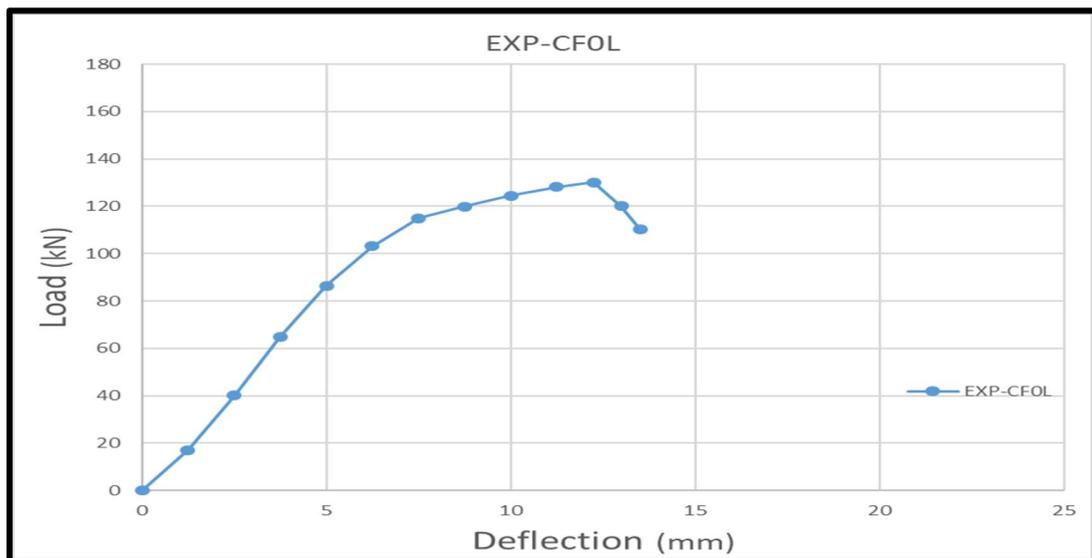


Figure (4-1): Load deflection curves for beam (CF0L).

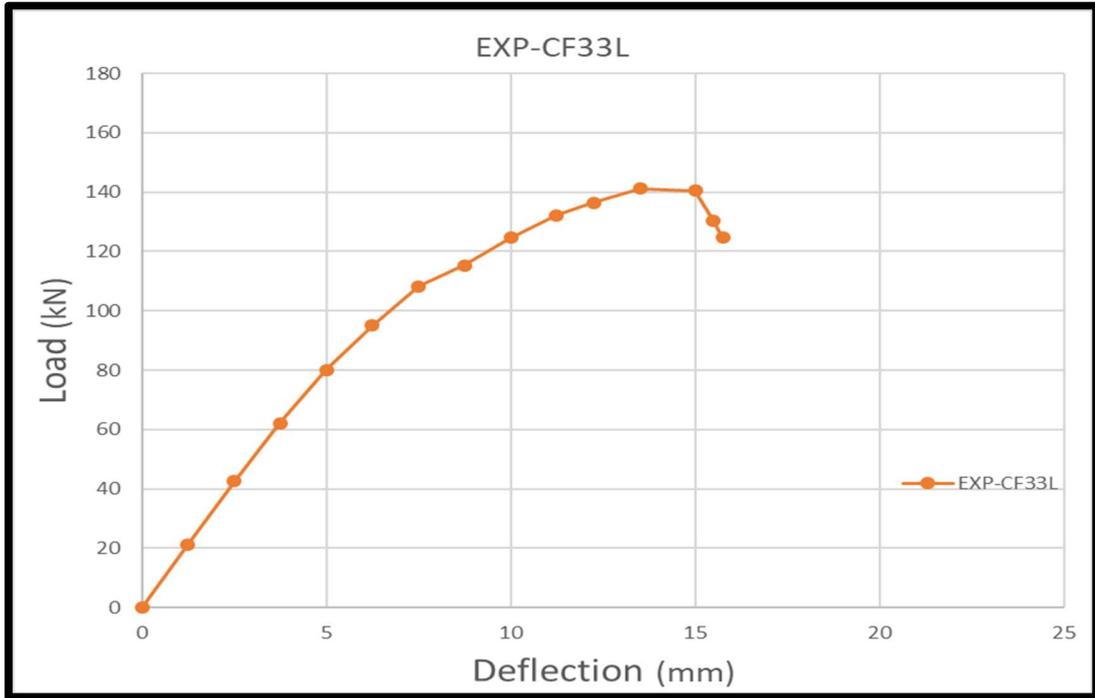


Figure (4-2): Load- deflection curves for beam (CF33L).

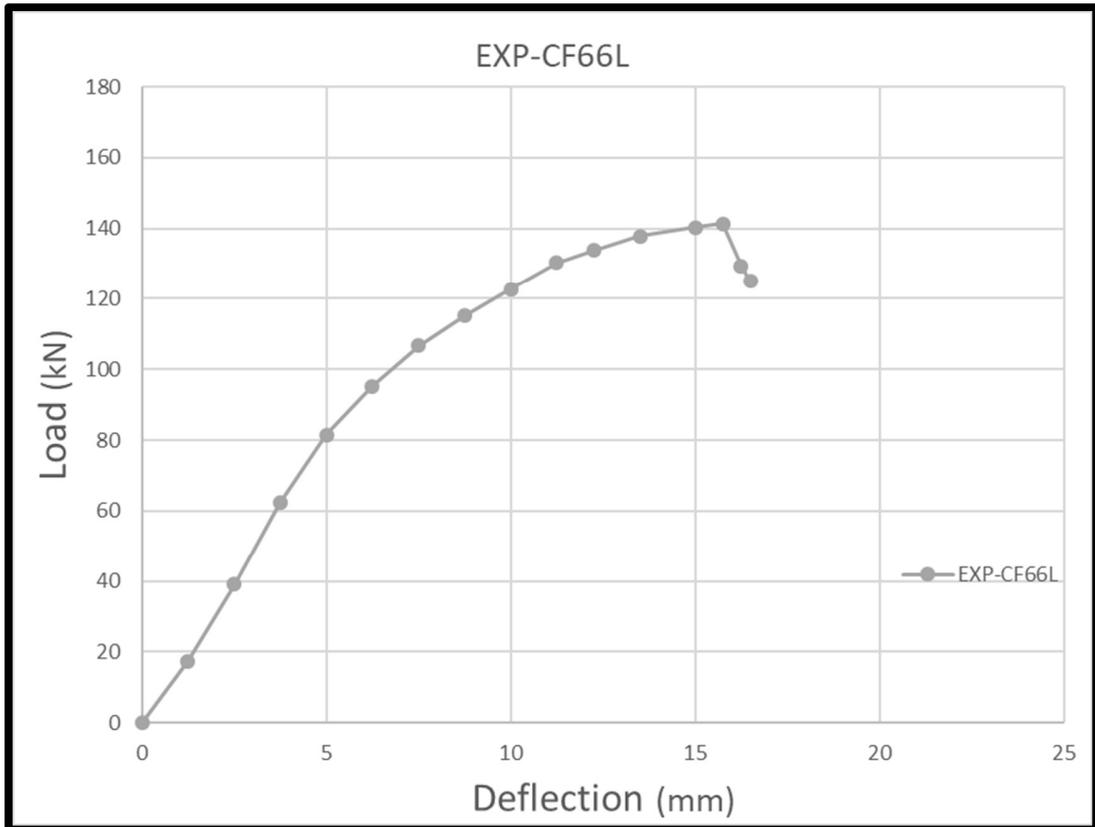


Figure (4-3): Load- deflection curves for beam (CF66L).

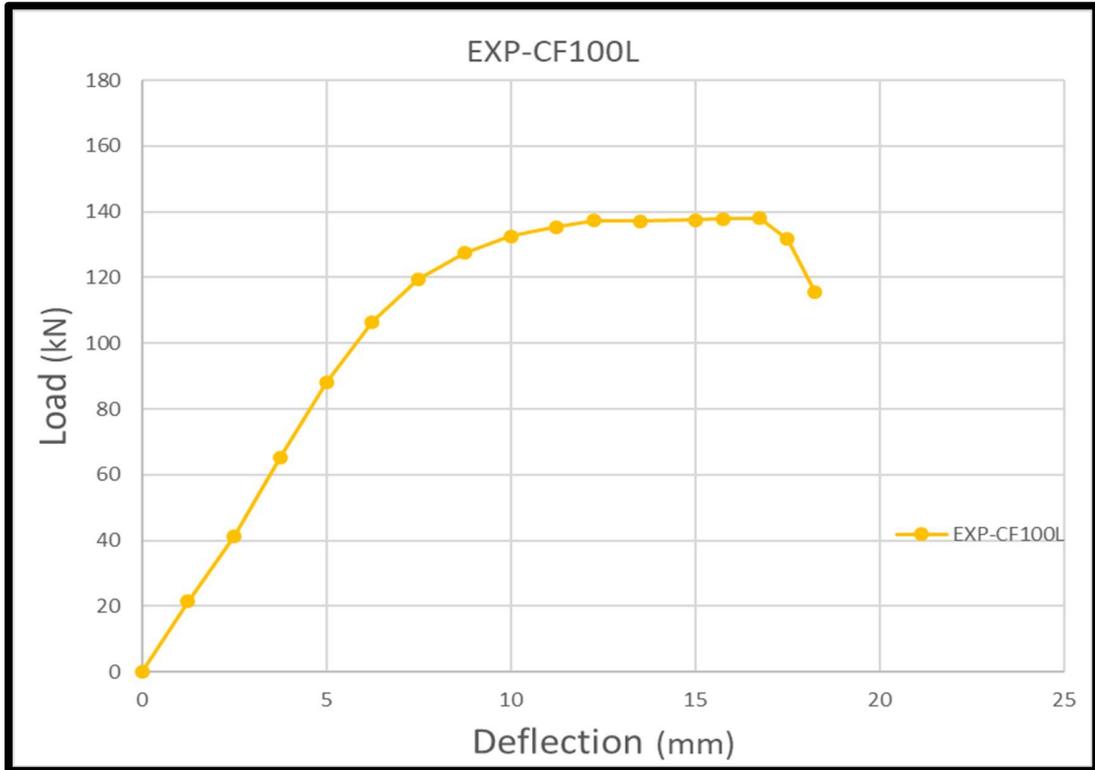


Figure (4-4): Load-deflection curves for beam (CF100L).

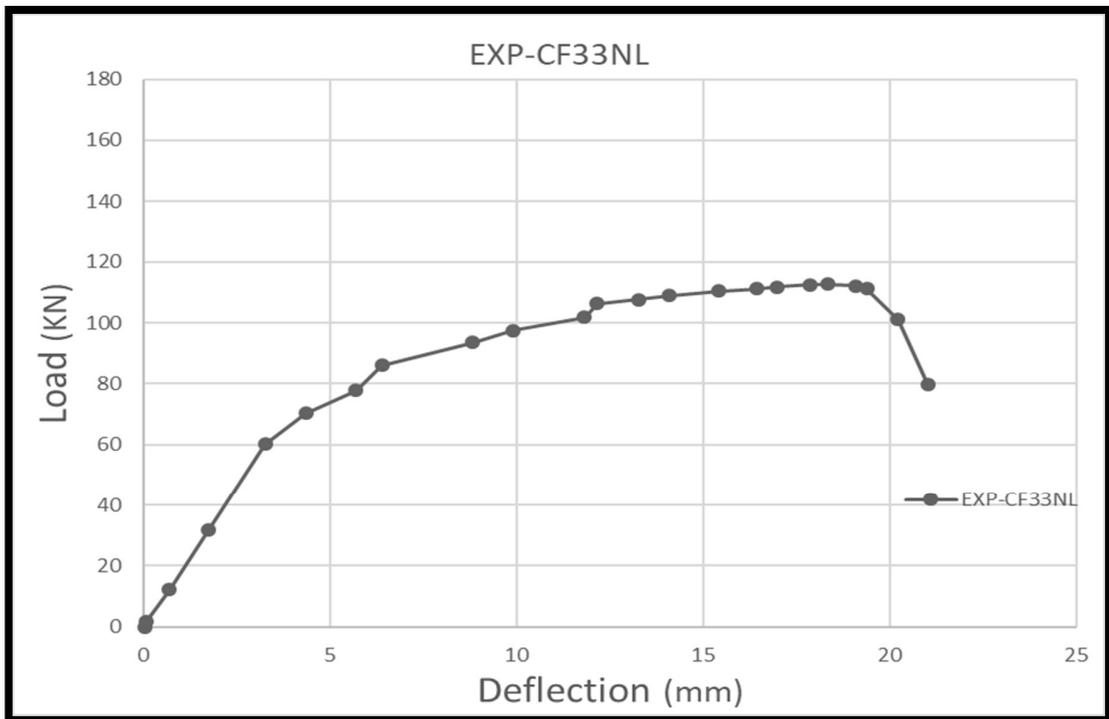


Figure (4-5): Load-deflection curves for beam (CF33NL).

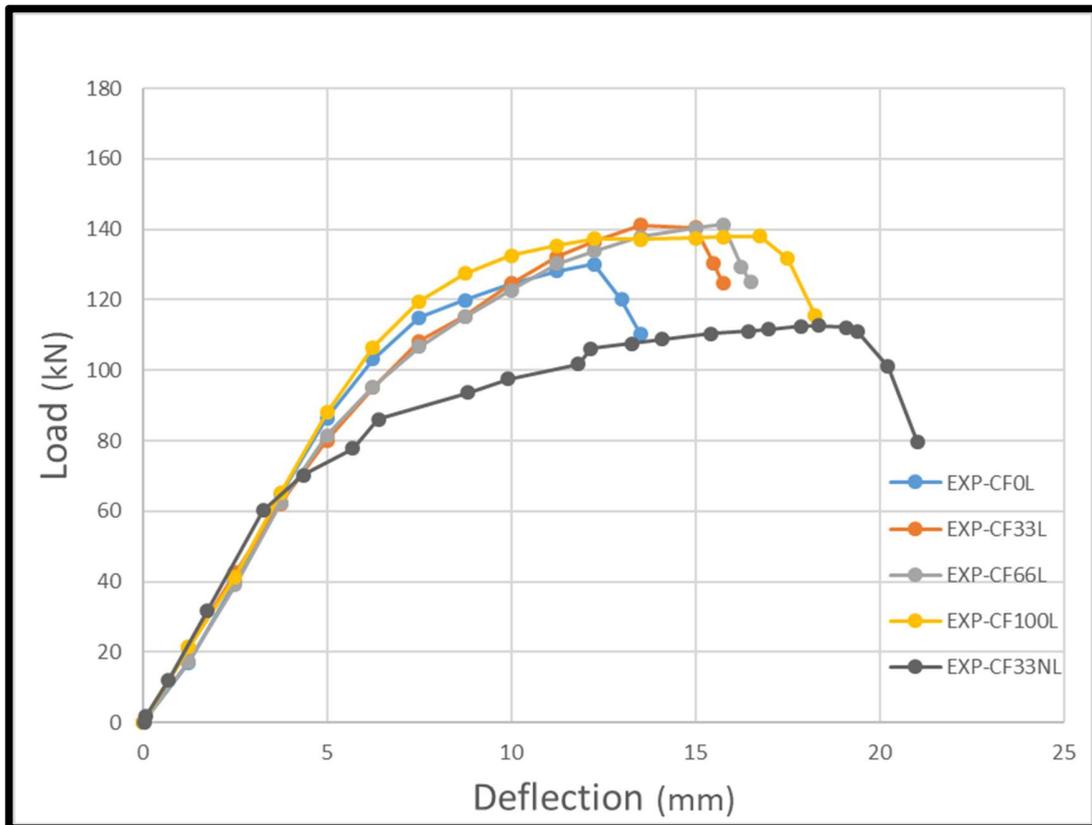


Figure (4-6) Ultimate load strength-max vertical mid span deflection curves for all experimental tested beams

4.5 Ultimate Load and Failure modes

Few observations were made as the beams were tested till failure, such as the ultimate loads, failure mechanisms and the mid-span deflection. The maximum load and mid span deflections are listed in table (4-1), table (4-2) show percentage of increase of the ultimate strength of the beams with lipped sections, and the mid-span deflection as compared with control beam CF0L. Table (4-3) show percentage of decrease of the ultimate strength of beam without lipped sections CF33NL and increase of the mid-span deflection as compared with CF33L.

Table (4-1): Experimental test of tested beams.

specimens	Ultimate load (kN)	Mid span deflection (mm)	Failure mode
CF0L	130.1	12.2	bending
CF33L	143.2	15.1	bending
CF66L	141.4	15.7	bending
CF100L	138.1	16.6	Flange LB
CF33NL	112.1	19.1	Flange LB

Table (4-2) Show percentage of increase of the ultimate load capacity and the mid-span deflection of lipped sections as compared with control beam

CF0L

Specimens	Total Ultimate Load		Max Mid-span deflection	
	(kN)	% increase	(mm)	% increase
CF0L	130.1	----	12.2	----
CF33L	143.2	10	15.1	23.6
CF66L	141.4	8.6	15.7	28.5
CF100L	138.1	6.1	16.6	36.7

Table (4-3) Show percentage of decrease of the ultimate load capacity increase of the mid-span deflection of CF33NL as compared with CF33L

Specimens	Total Ultimate Load		Max Mid-span deflection	
	(kN)	% decrease	(mm)	% increase
CF33L	143.2	----	15.1	----
CF33NL	112.1	-21.7	19.1	26.1

4.6 Effect of lipped channels

For improvement of cross section geometry, a comparison was made between specimens CF33NL and CF33L, the load – deflection curve as shown in figure (4-7). The specimens failure load improve by (27.7) % when changing the section without lipped channels to section with lipped channels .The reason for this increase due to increase of cross sectional area which caused an increase in the moment of inertia .Failure mode changed from flange local buckling to bending failure which accrue due to presence of a flange that is having a thin unsupported edge and has compression stress due to bending failure when changing the section without lipped channels to section with lipped channels.

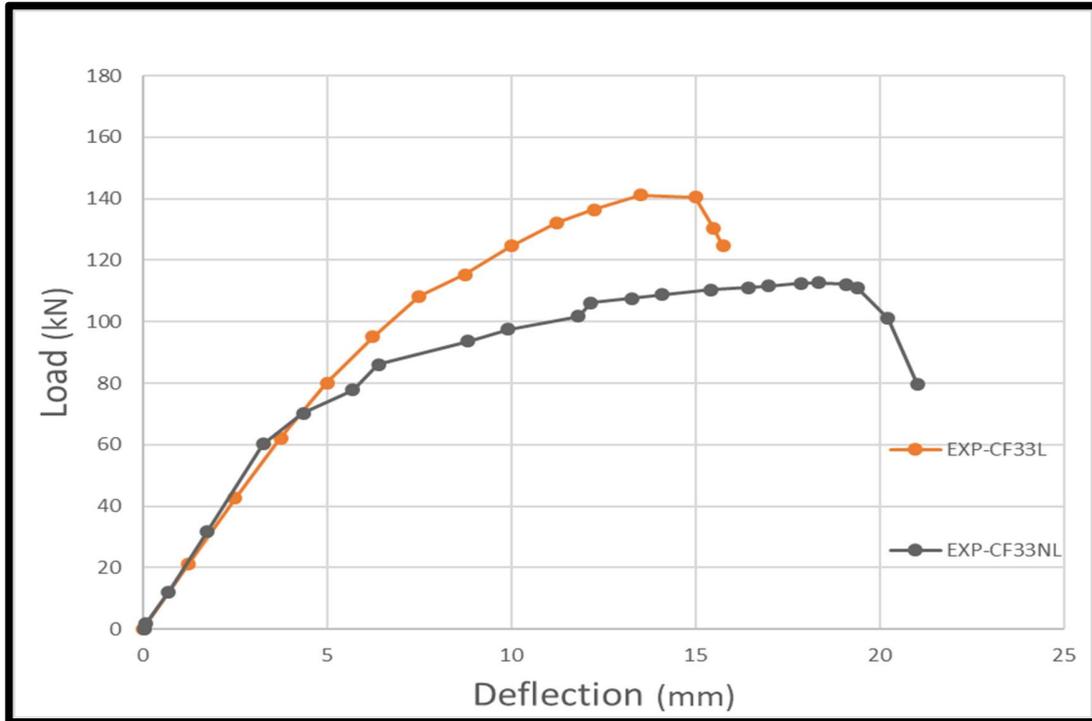


Figure (4-7) Ultimate load strength-max vertical mid span deflection curves for CF33NL and CF33L beams.

4.7 Prediction of maximum Load Capacity and deflection

The experimental findings indicate in beams with lipped sections that ultimate strength of the tested CFS built up hollow box beam increase gradually by (10%) by increasing gap distance between back to back webs channels from no gap to 33% (21mm) of max possible clear distance available for the tested beams design. Ultimate strength decrease slightly by (-1.24%) by increasing gap distance between back to back webs channels form 33% (21mm) of max possible clear distance available for the tested beams design to 66% (42mm) of max possible clear distance available for the tested beams design and .Finally ,the ultimate strength slightly decrease by (-2.5%) by increasing gap distance between back to back webs channels form 66% (42mm) of max possible clear distance available for the tested beams design to (64mm) max possible clear distance available for the tested beams design.

Maximum load capacity of sections can be predict from experimental results, where ultimate load (144 kN) for cold formed steel beam with (40) % of maximum possible space between back to back web channels of current beam design with lipped channels as shown in figure (4-8).

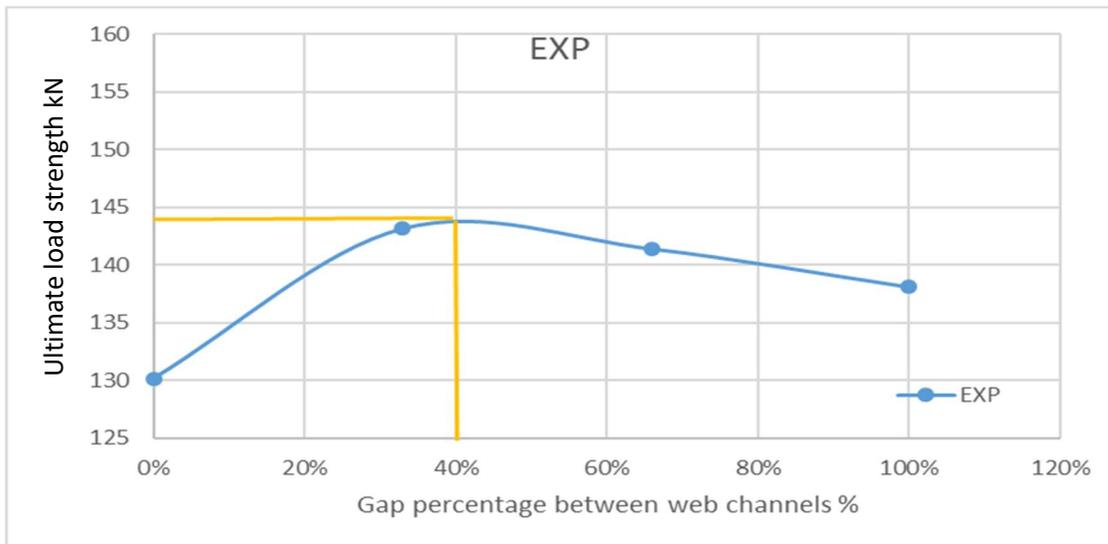


Figure (4-8) Ultimate load vs gap percentage between web channels

however for beams with lipped sections, the maximum vertical deflection at mid span before failure of the four tested CFS built up hollow box increase gradually by (22.4%) by increasing gap distance between back to back webs channels from no gap to 33% (21mm) of max possible clear distance available for the tested beams design. Maximum deflection continue increasing by (6.1%) by increasing gap distance between back to back webs channels form 33% (21mm) of max possible clear distance available for the tested beams design to 66% (42mm) of max possible clear distance available for the tested beams design .Finally the maximum deflection increase by (8.2%) by increasing gap distance between back to back webs channels form 66% (42mm) of max possible clear distance available for the tested beams design to (64mm) max possible clear distance available for the tested beams design.

The maximum vertical deflection at mid span before failure of tested beams increase with increase of gap distance between back to back web channels of current beam design for with lipped channels at average rate of increase (0.7mm) of Exp result for every 10 % increase of gap distance between back to back web channels from maximum available gap distance as shown in figure (4-9).

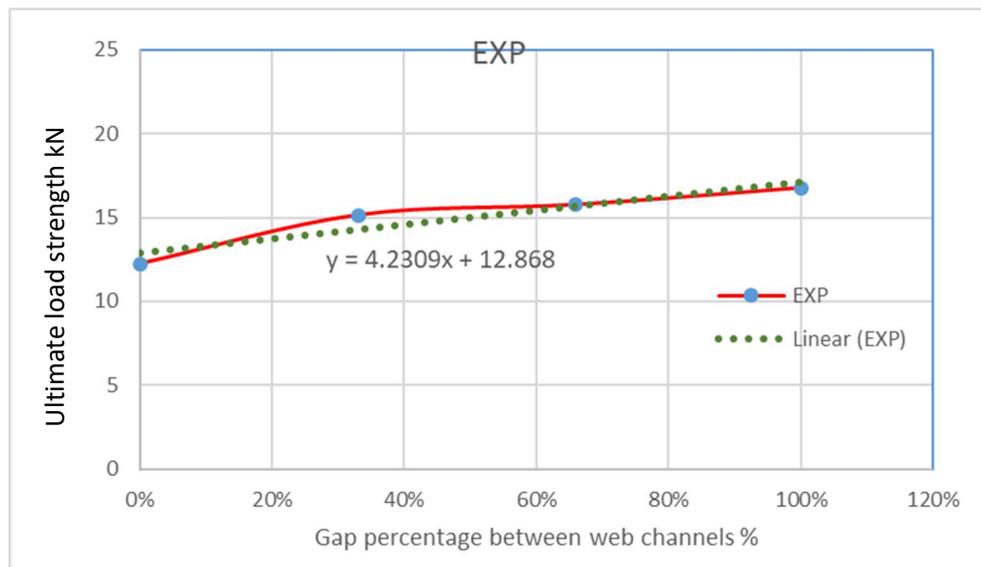


Figure (4-9) Mid span deflection vs gap percentage between web channels

4.8 Summary

The result of experimental test of cold formed steel beams with hollow web box under four point bending test failure mode for tested beam with lipped channels was bending failure except the beam with max possible clear gap distance available between back to back webs channels CF100L for the tested beams design failure mode was by flange local buckling.

For beam without lipped channels CF33NL as compare with corresponding beam with lipped channels CF33L, the absence of lipped channel can be observe by the result of tested beam CF33NL, where ultimate

strength decrease by (-21.7%) as compare with corresponding beam with lipped channels CF33L.

Maximum deflection increase by (26.7%) For beam without lipped channels as compare with corresponding beam with lipped channels and .finally, mode of failure for beam without lipped channels CF33NL convert to flange local bulking while for corresponding beam with lipped channels CF33L was bending failure

Maximum load capacity of sections can be predict from experimental results, where ultimate load (144 kN) for Cold formed steel beam with (40) % of maximum possible space between back to back web channels of current beam design with lipped channels can be predicted.

The maximum vertical deflection at mid span before failure of tested beams increase with increase of gap distance between back to back web channels of current beam design for with lipped channels at average rate of increase (0.7mm) of Exp result for every 10 % increase of gap distance between back to back web channels from maximum available gap distance.

CHAPTER FIVE

NUMERICAL

ANALYSIS BY

FINITE ELEMENT

CHAPTER FIVE

NUMERICAL ANALYSIS BY FINITE ELEMENT

5.1 Introduction

The purpose of this chapter is to validate the present nonlinear finite element model in order to investigate the behavior and ultimate strength of four simply supported cold formed steel beams consisting of different gap distances between two back-to-back web lipped C sections used to construct the built up hollow box CFS beam's specimens and another specimen without lipped channels. Using the ABAQUS Standard/Explicit 2017 finite element model, numerical calculations are performed to determine the validity and degree of accuracy of the selected analytical finite element model and to compare the findings to the experimental results presented in chapter four.

5.2 Finite Element Modeling

Finite Elements Analysis (FEA) is a method for solving complex mechanical problems using the power of modern computers. Choosing boundary conditions and loads, the engineer is able to simulate reality whatever the situation or complexity. The mechanical behavior of products and constructions can be analyzed and optimized without the necessity of prototyping. Direct results are profits with respect to time and cost in the design phase. It also adds to the reliability of product.

5.2.1 Part Module

All specimens are modeled to study the load capacity and behavior of the cold formed composite beam. All tested beams are modeled by using three-dimensional deformable solid extrusion elements in the modeling of stiffeners, flange and web parts of CFS beam as shown in plate (5-1), for loading and

support plates a three-dimensional discrete solid extrusion elements has been used and after modeling the plate converted using great shell from solid order.

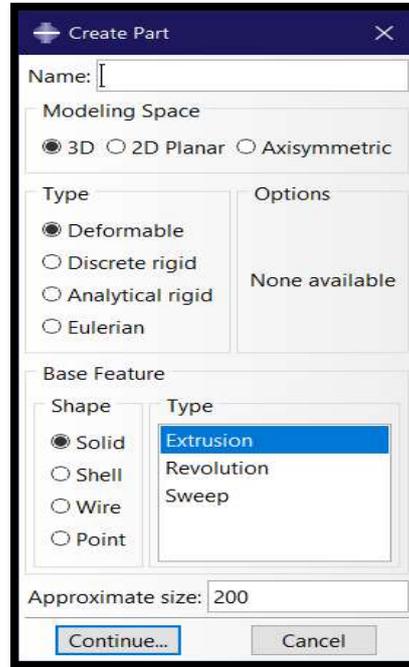


Plate (5-1) Finite Element Part Modeling

5.2.2 Property Module

The performance of any structure under load in three dimensional FEA was dependent on the property of material which was used to create the member (Poisson's ratio ,modulus of elasticity, and stress-strain relationship of material) .Stiffeners , flange and web parts of CFS beam have the same martial, So that material created and under the mechanical properties of material elastic property defined by identify young's modulus (200000 MPa) and Poisson ratio (0.3) and plastic property defined by identify the F_y (242.45 MPa) and F_u (305.9 MPa),then section decided and assigned to stiffeners , flange and web parts of CFS beam as shown in plate (5-2).

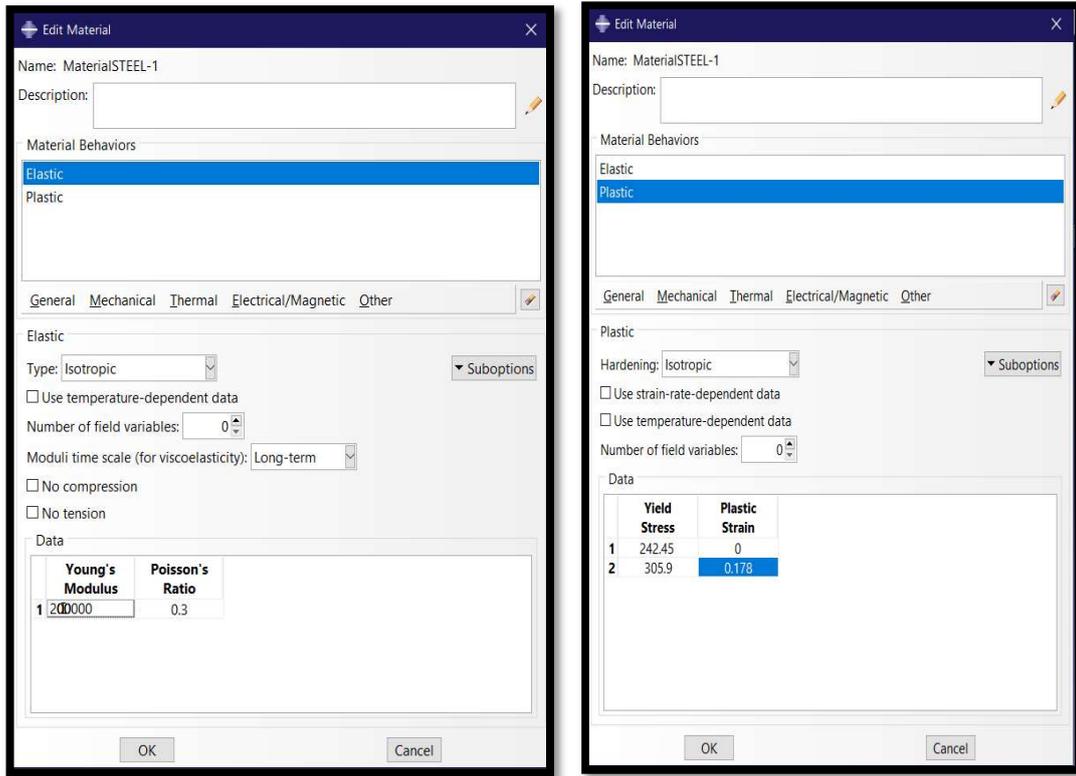


Plate (5-2) FEA Property of Materials

5.2.3 Assembly Module

Each specimen in this investigation was comprised of four components: two flanges, two webs, four bearing plates, and eight stiffeners, these parts assembled and merged to get cold formed steel beam as shown in plate (5-3).

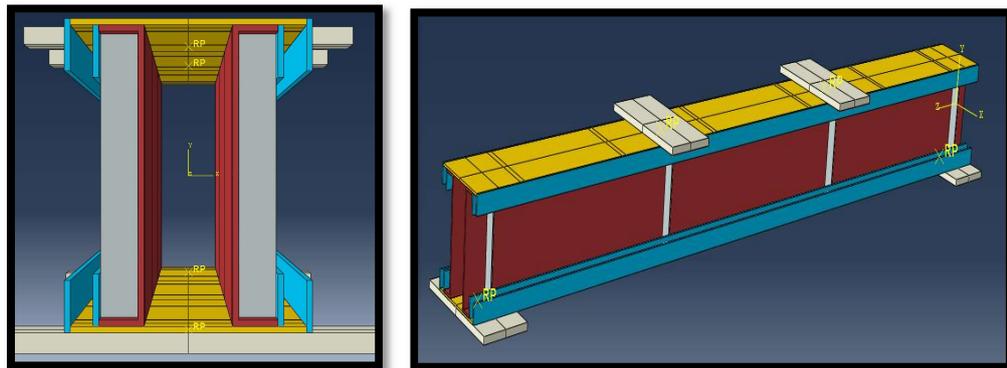


Plate (5-3) FEA Assembly

5.2.4 Step Module

Each specimen in this investigation has initial step and step one added with procedure type (static, general), under basic option period time selected (1) and Nlgeom off selected and udder incrementation option select increment size initial (0.1), minimum (1E-009) and maximum (0.1) as shown in plate (5-4).

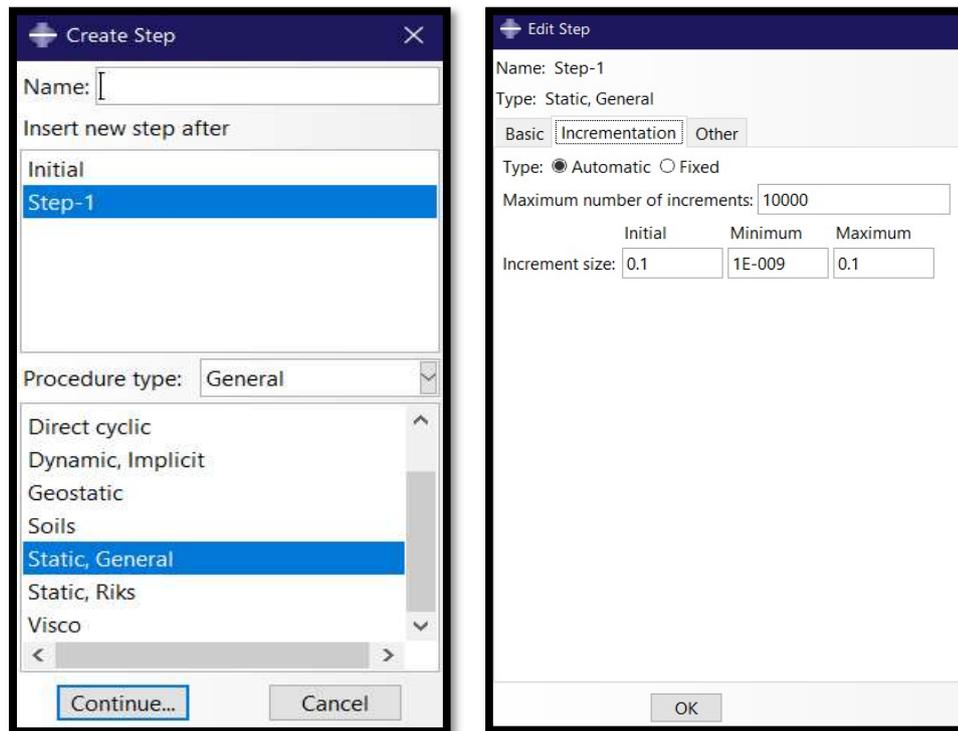


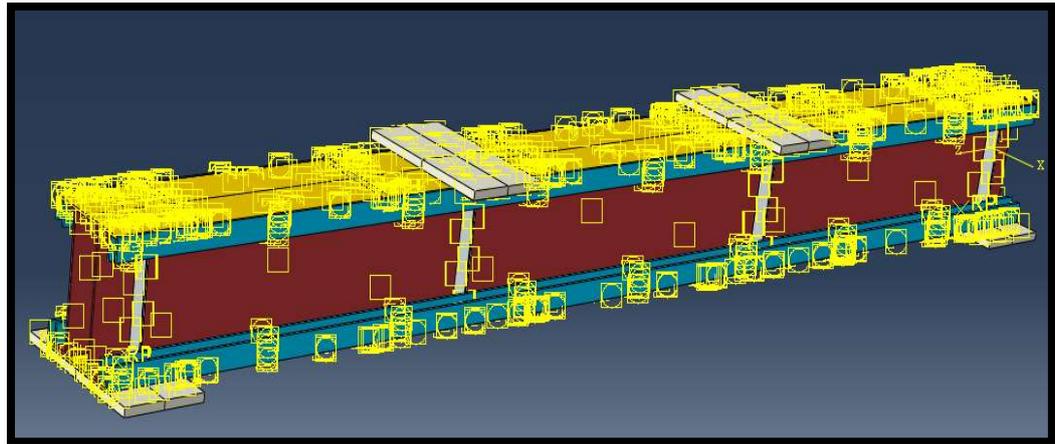
Plate (5-4) FEA Step Module

5.2.5 Interaction of Module

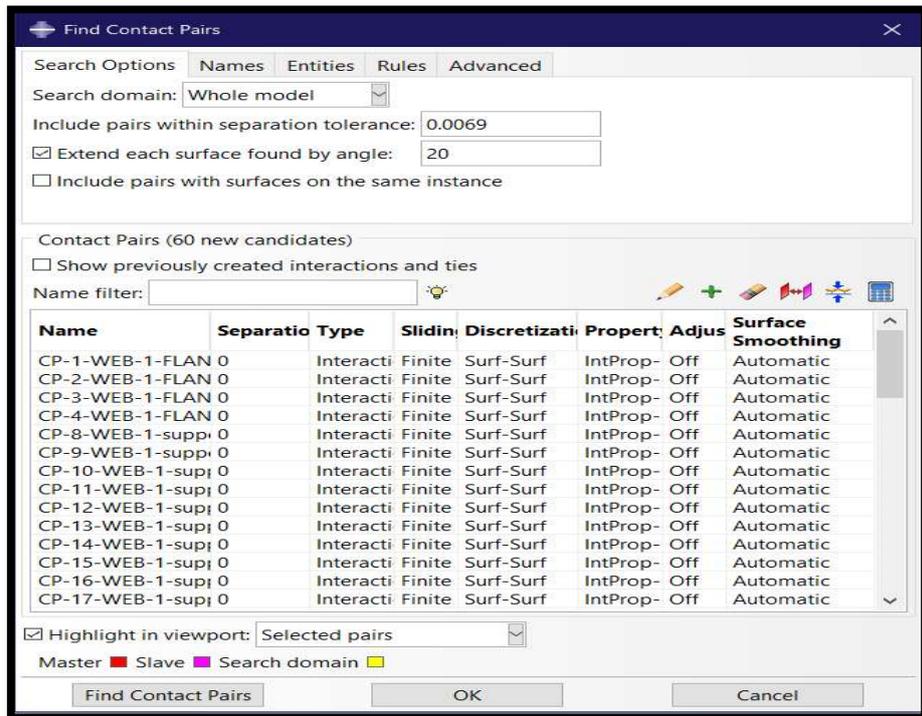
According to the Exp test findings, the screws had not been failed. Thus, the connections were modeled using the ABAQUS program's basic "fastener" model. At the position of the screws, all translational and rotational degrees of freedom of the nodes were constrained. The screw's 10 mm radius was utilized as the radius dimension in the ABAQUS application.

For the interaction between all other surfaces at beginning, interaction property deployed, In order to create the contact, the interaction characteristics

established using the property with finite sliding, frictionless, "hard" contact pressure. After that, master surface and slave surface defined for all contact surfaces of beam, either one side chosen as master surface and another side as slave surface using finding contact pair's option as shown in plate (5-5).



(a) Contact surfaces of beam



(b) Finding contact pair's

Plate (5-5) Interaction of Module

5.2.6 Boundary and loading Condition Module

The experimental work and finite element model for all beams loaded at identical positions, the load represented as a vertical displacement of bearing plate by using boundary condition (displacement/rotation) option and constrained the (X) displacement and (Y,Z) rotation and modified step one Y displacement to (-40mm)

The supports are modeled according to experimental findings, in which constrained the displacement in the direction (X,Y,Z) axis for hinge support case by using boundary condition (Symmetry/Antisymmetric/Encastre) and constrained the displacement in the direction (Y,Z) axis and free displacement is assumed in the direction z axis for case roller support using boundary condition (displacement/rotation) as shown in plate (5-6).

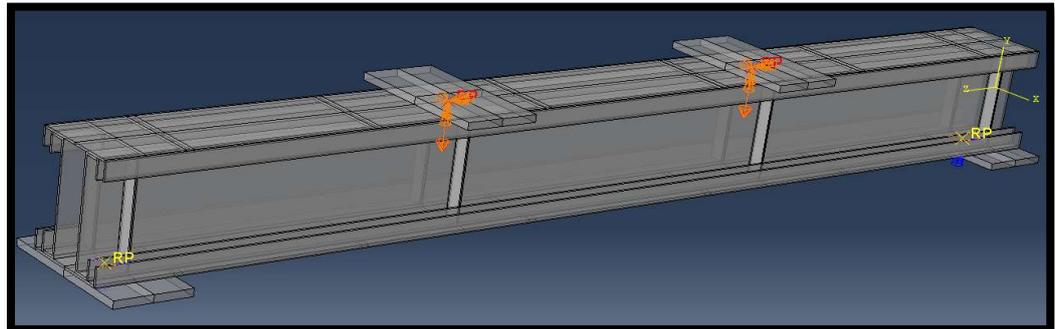


Plate (5-6) Boundary and loading Module

5.2.7 Mesh Module

To precisely investigate the behavior of a beam till its failure, a suitable choice of finite element mesh is required for modeling. To prevent element form distortion, a fine mesh and square shape were proposed. The stiffeners, flange, and web components of a CFS beam were modeled using a fine mesh of 10 x 10 x 3mm elements for accurate study to avoid the distortion of element shape.

The dimensions of bearing plate mesh are 20 x 20 x 10 mm as shown in plate (5-7).

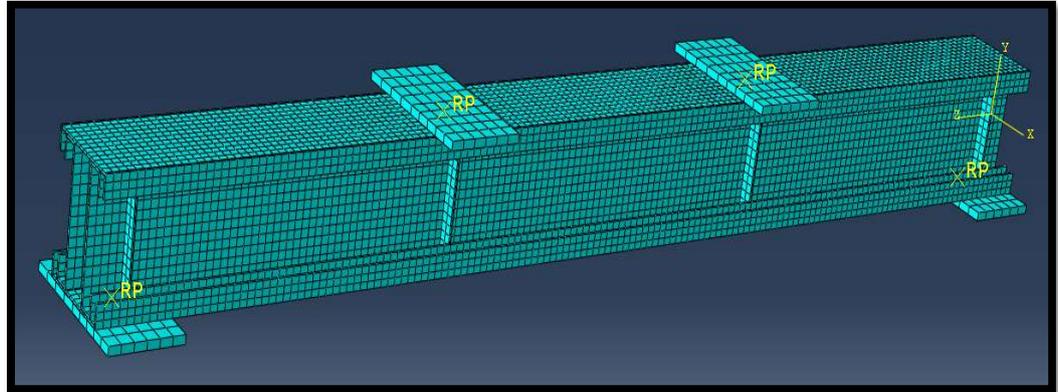


Plate (5-7) Mesh Module

5.2.8 Job Module

Job created for each tested beam with full analysis type, submitted, monitored and get result of analysis on the visualization module.

5.3 Results of Finite Element Analysis

For each tested beam, the findings of finite element analysis using the ABAQUS software are compared to the experimental results. ABAQUS findings comprising ultimate load, maximum deflection and load-deflection curves. The outcomes from the experimental testing are comparable.

Maximum variation in results was from 2.3% increase to 9% increase for ultimate force. However, the variation in the max displacement at mid span was from 5.5% increase to 24.2% increase.

5.3.1 Result of Beam CF0L

CF0L Cold formed steel beam with no gap between webs of current beam design and with lipped channels. Plate (5-8) shows the stress distribution at ultimate load..

The load-deflection curve derived for this beam by the FEA and experimental work is shown in Figure (5-1).

The ultimate strength increased 7.2 % and the maximum displacement increased about 5.5% for compared with the experimental ultimate load and maximum deflection of this beams.

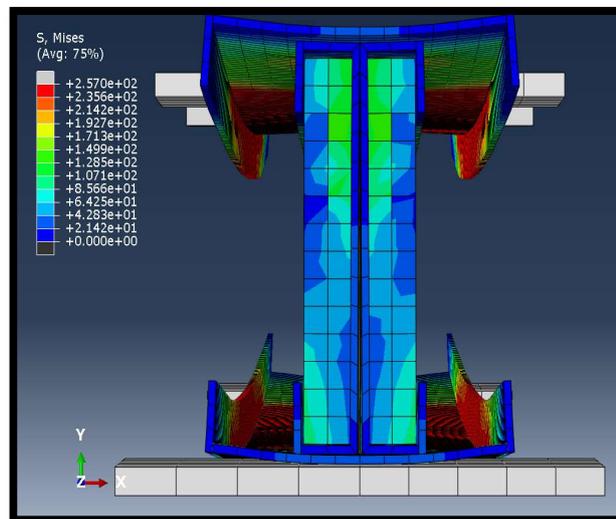
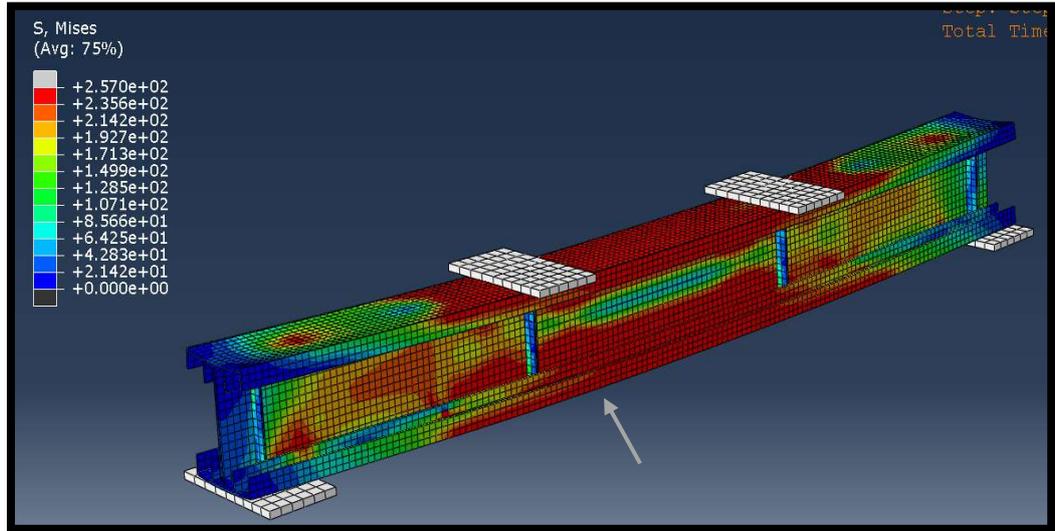


Plate (5-8): Stress distribution at ultimate load for beam CF0L.

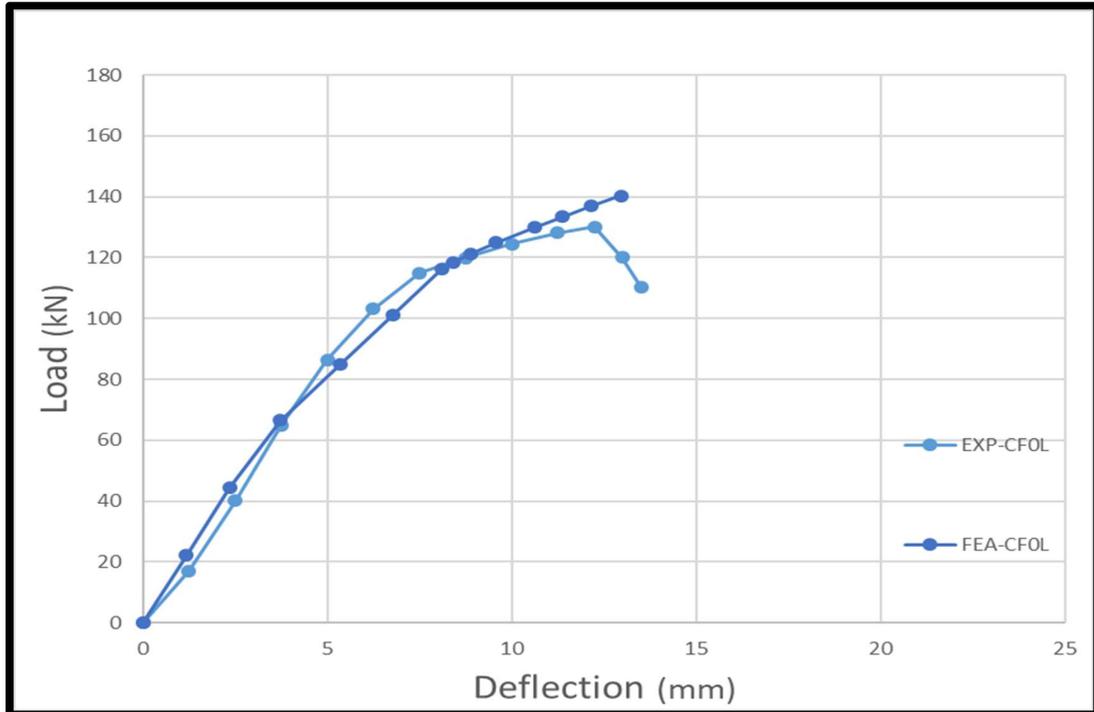


Figure (5-1): Load-deflection curve for beam CF0L.

5.3.2 Result of Beam CF33L

CF33L Cold formed steel beam with 33 % of maximum possible space between webs of current beam design with lipped channels. Plate (5-9) show the stress distribution at ultimate load.

The load-deflection curve derived for this beam by the FEA and experimental work is shown in Figure (5-2).

The ultimate strength increased 9 % and the maximum displacement increased about 24.2% for compared with the experimental ultimate force and maximum displacement of this beams. The failure mode of the beam in FEA was bending failure.

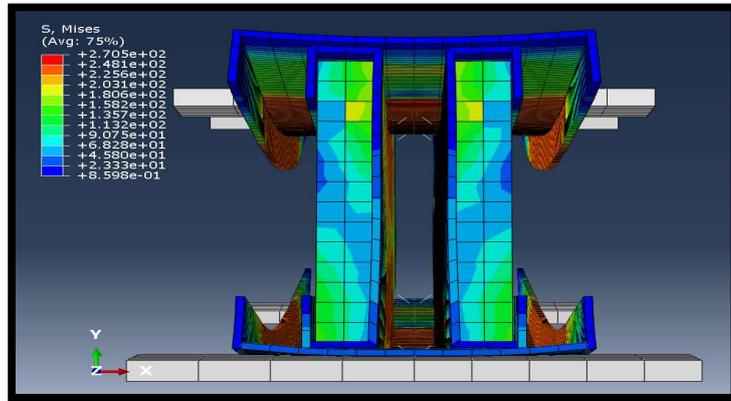
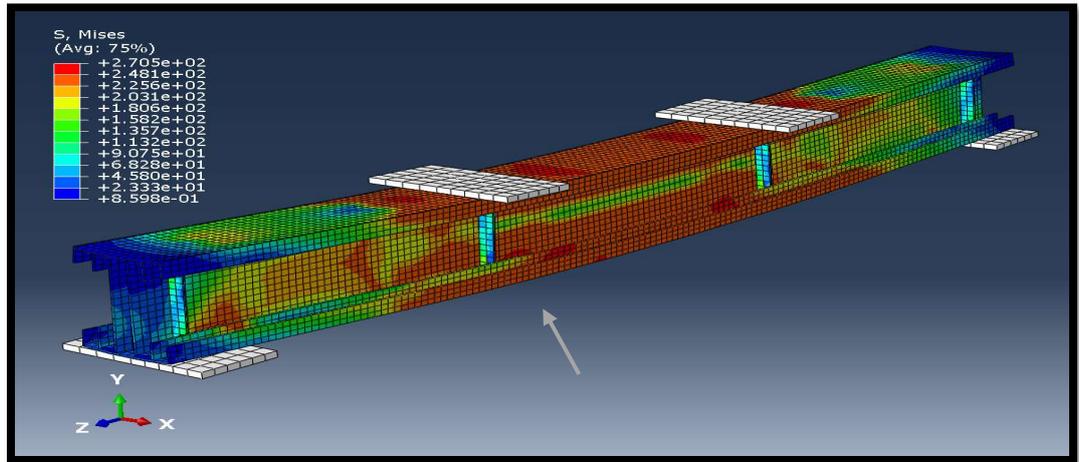


Plate (5-9): Stress distribution at ultimate load for beam CF33L.

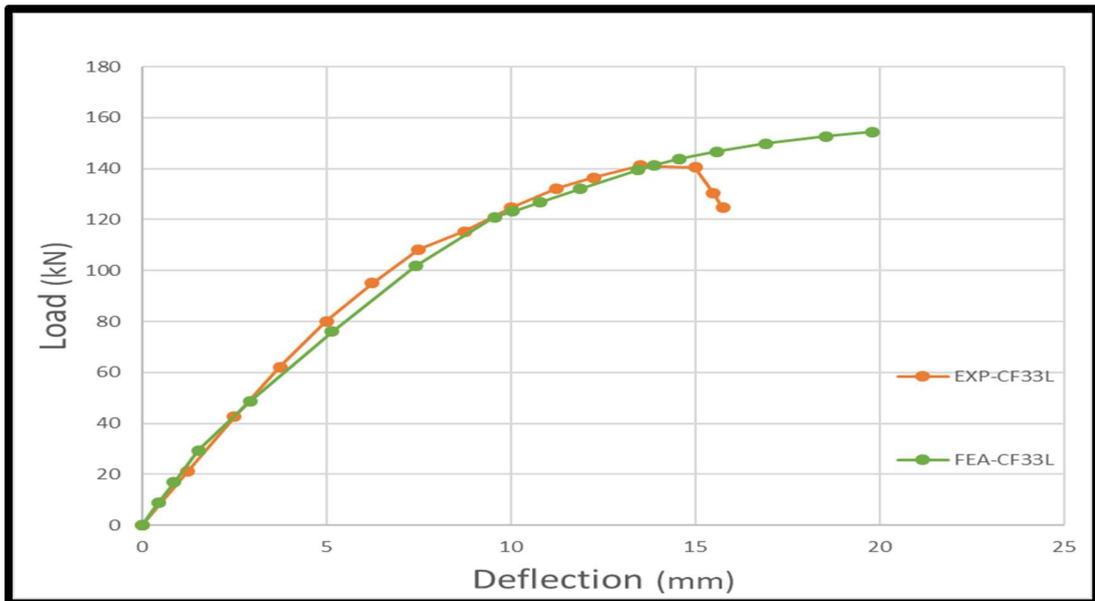


Figure (5-2): Load-deflection curve for beam CF33L.

5.3.3 Result of Beam CF66L

CF66L Cold formed steel beam with 66 % of maximum possible space between webs of current beam design with lipped channels. Plate (5-10) show the stress distribution at ultimate load.

The load-deflection curve derived for this beam by the FEA and experimental work is shown in Figure (5-3).

The ultimate strength increased 8.3% and the maximum displacement increased about 16.3% for compared with the experimental ultimate load and maximum displacement of this beams. The failure mode of the beam in FEA was bending failure.

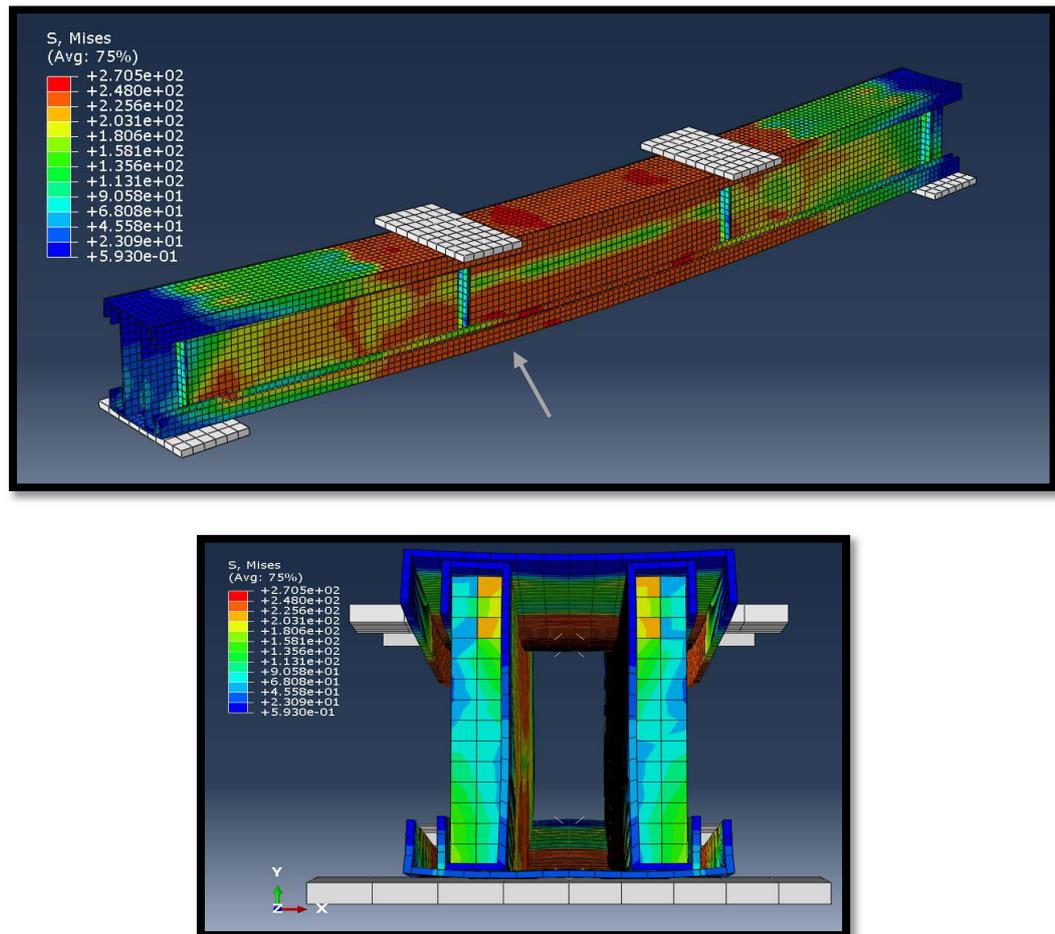


Plate (5-10): Stress distribution at ultimate load for beam CF66L.

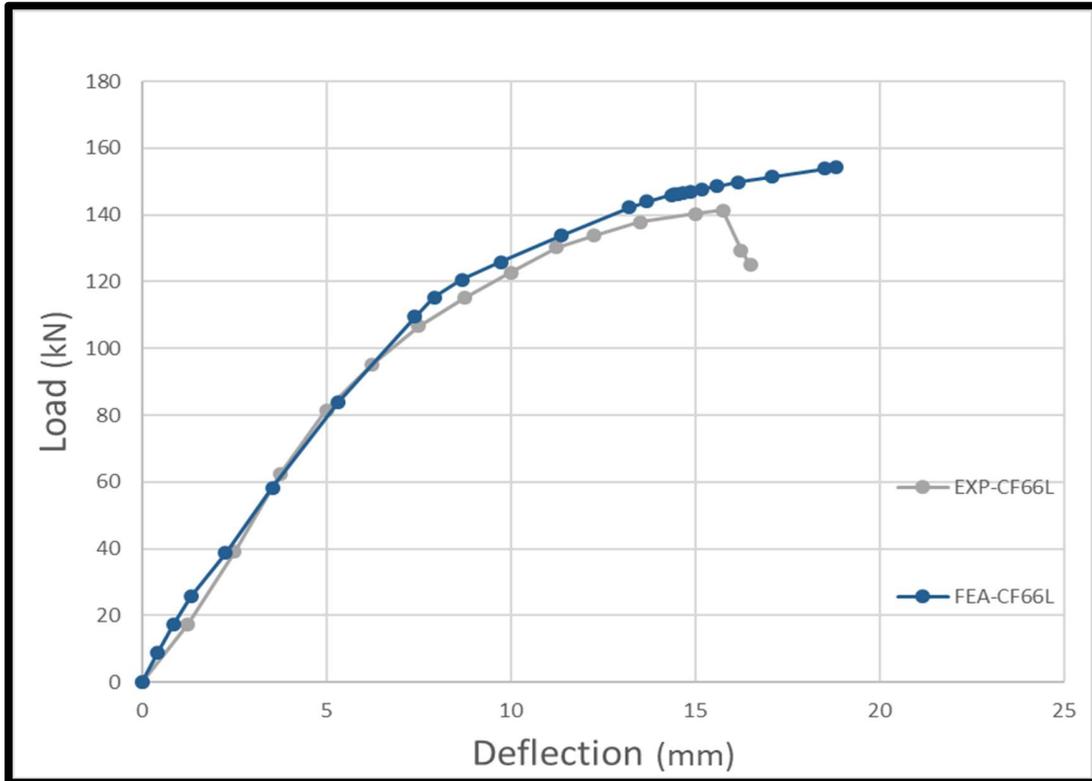


Figure (5-3): Load-deflection curve for beam CF66L.

5.3.4 Result of Beam CF100L

CF100L Cold formed steel beam with maximum possible space between webs of current beam design with lipped channels. Plate (5-11) show the stress distribution at ultimate load, respectively.

The load-deflection curve derived for this beam by the FEA and experimental work is shown in Figure (5-4).

The ultimate strength increased 5.8 % and the maximum displacement increased about 18.2% for compared with the experimental ultimate force and maximum displacement of this beams. The failure mode of the beam in FEA was bending failure.

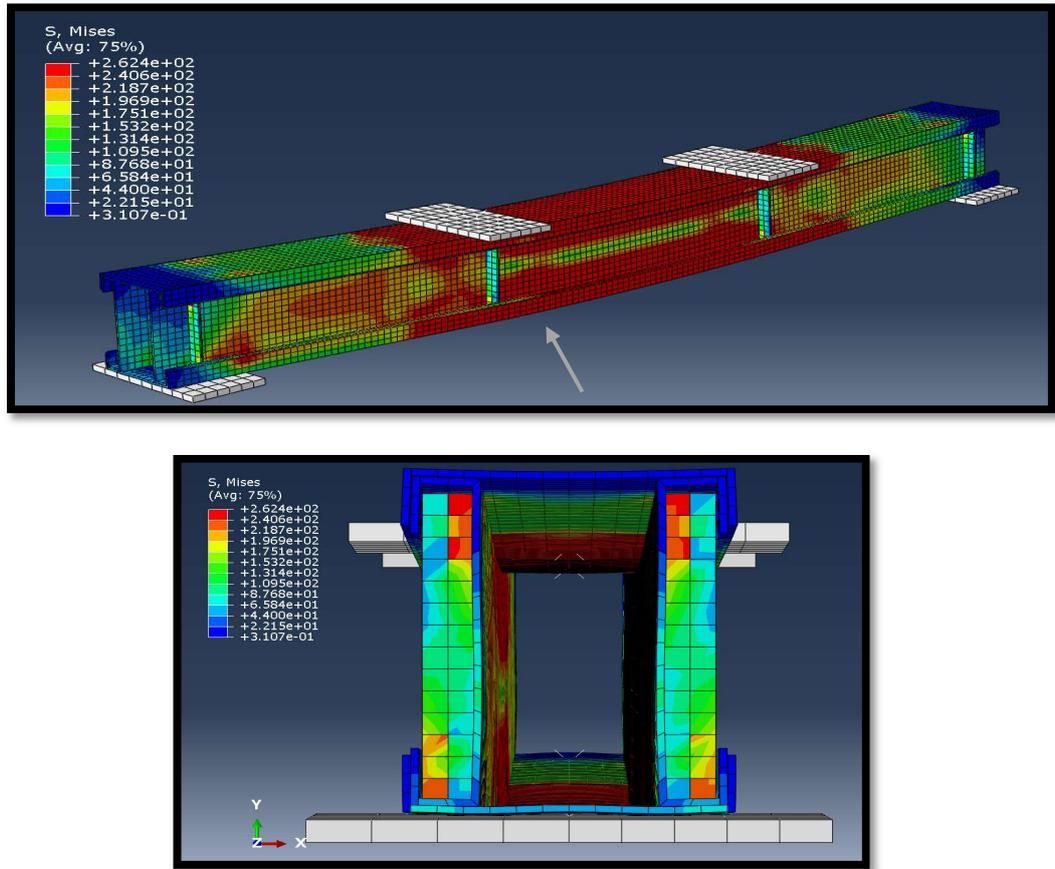


Plate (5-11): Stress distribution at ultimate load for beam CF100L.

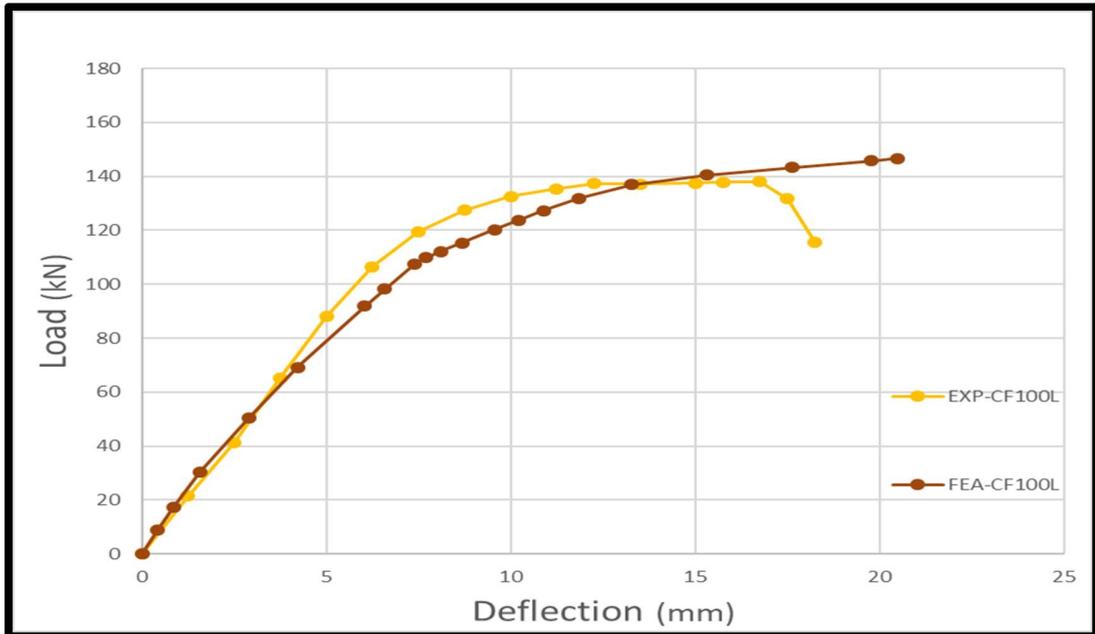


Figure (5-4): Load-deflection curve for beam CF100L.

5.3.5 Result of Beam CF33NL

CF33NL Cold formed steel beam with 33 % of maximum possible space between webs of current beam design with lipped channels. Plate (5-12) show the stress distribution at ultimate load, respectively.

The load-deflection curve derived for this beam by the FEA and experimental work is shown in Figure (5-5).

The ultimate strength increased 2.3 % and the maximum displacement increased about 11.82% for compared with the experimental ultimate force and maximum displacement of this beams. The failure mode of the beam in FEA was local buckling failure.

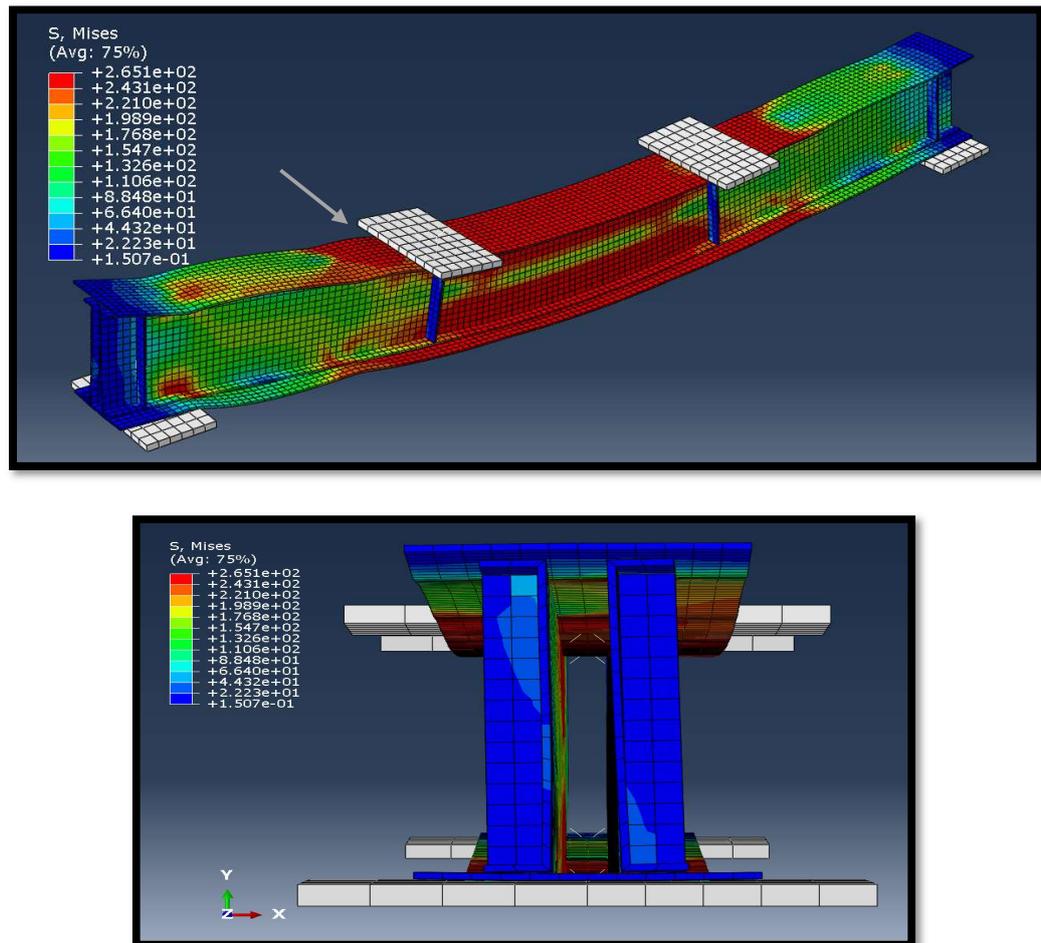


Plate (5-12): Stress distribution at ultimate load for beam CF33NL

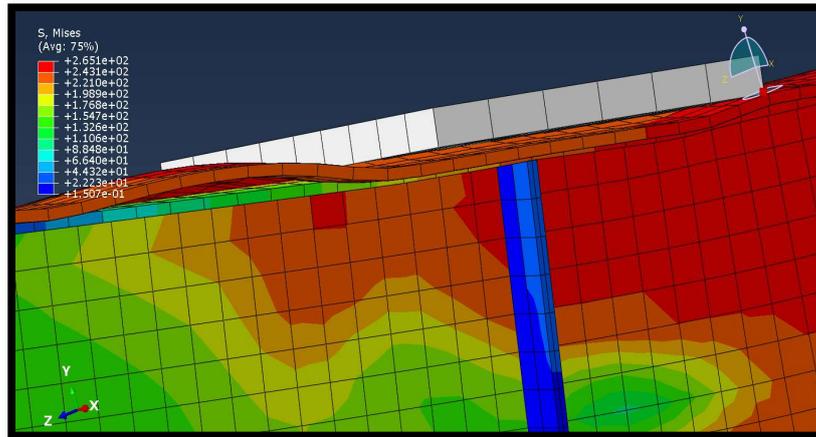


Plate (5-13) flange buckling failure mode of beam CF33NL

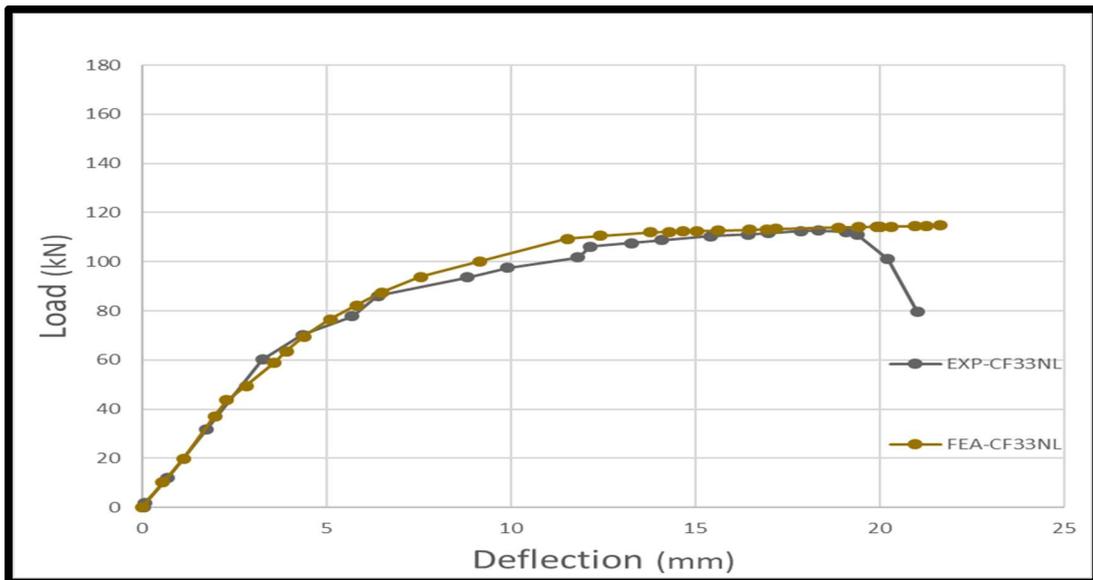


Figure (5-5): Load-deflection curve for beam CF33NL

5.4 FEA Ultimate Load and deflection

As the beams were FEA tested to failure, few observations were taken, such as the ultimate loads and the mid-span deflection. The comparison of the ultimate strength and Maximum vertical displacement from Exp testing and Num models derived from FEA of the examined beams is shown in Table (5-1). Figure (5-6) shows the comparison of the load deflection curves between control beam CF0L and all specimens with or without lipped channels and different gap distance between webs.

Acceptable agreement between experimental results and FEA results was obtained after several trials where specimens exhibited the same load deflection response as clarified in Figure (5-7).

Table (5-1): Experimental and numerical results for all tested beams.

Specimens	Ultimate loads (kN)		$\frac{P_u) FEA - P_u) EXP}{P_u) EXP}$ %	Max. deflection (mm)		$\frac{\Delta u) FEA - \Delta u) EXP}{\Delta u) EXP}$ %
	$P_u)_{EXP}$	$P_u)_{FEA}$		$\Delta_{max})_{EXP}$	$\Delta_{max})_{Num}$	
	CF0L	130.2	140.25	7.2	12.25	12.96
CF33L	140.5	154.41	9	15	19.80	24.2
CF66L	141.4	154.27	8.3	15.75	18.82	16.3
CF100L	138.1	146.71	5.8	16.75	20.48	18.2
CF33NL	112.1	114.70	2.3	19.1	21.65	11.82

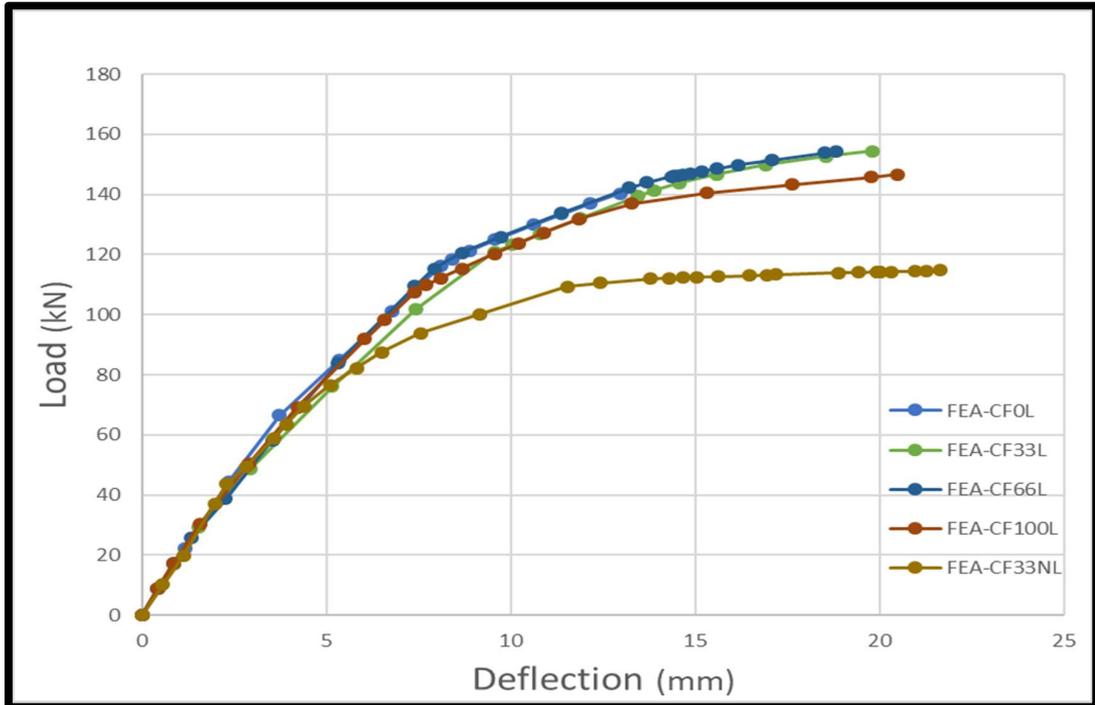


Figure (5-6) Load-deflection curve for all FEA tested beams.

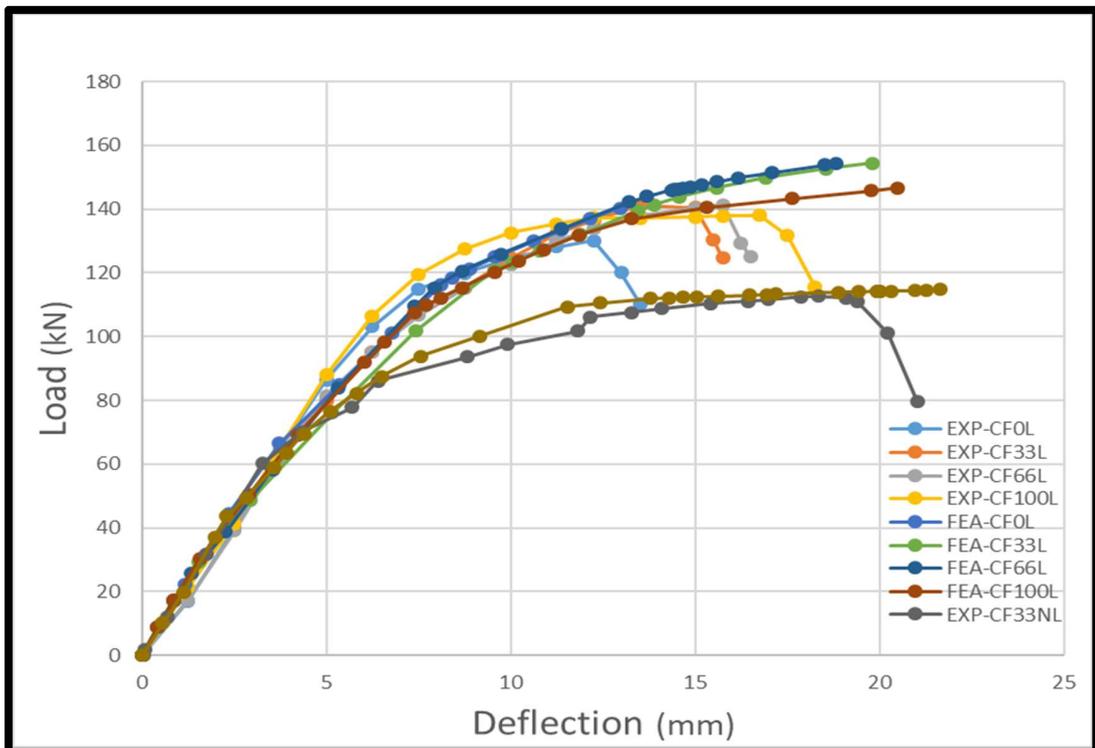


Figure (5-7) Load-deflection curve for all experimental specimen versus calibrated FEA

5.5 Effect of lipped channels

For improvement of cross section geometry, a comparison was made between specimens CF33NL and CF33L, the load – deflection curve as shown in figure (5-8). The specimens failure load improve by (34.6) % when changing the section without lipped channels to section with lipped channels ,the reason for this increase due to increase of cross sectional area which caused an increase in the moment of inertia and failure mode changed from flange local buckling to bending failure which accrue due to presence of a flange that is having a thin unsupported edge and has compression stress due to bending failure when changing the section without lipped channels to section with lipped channels.

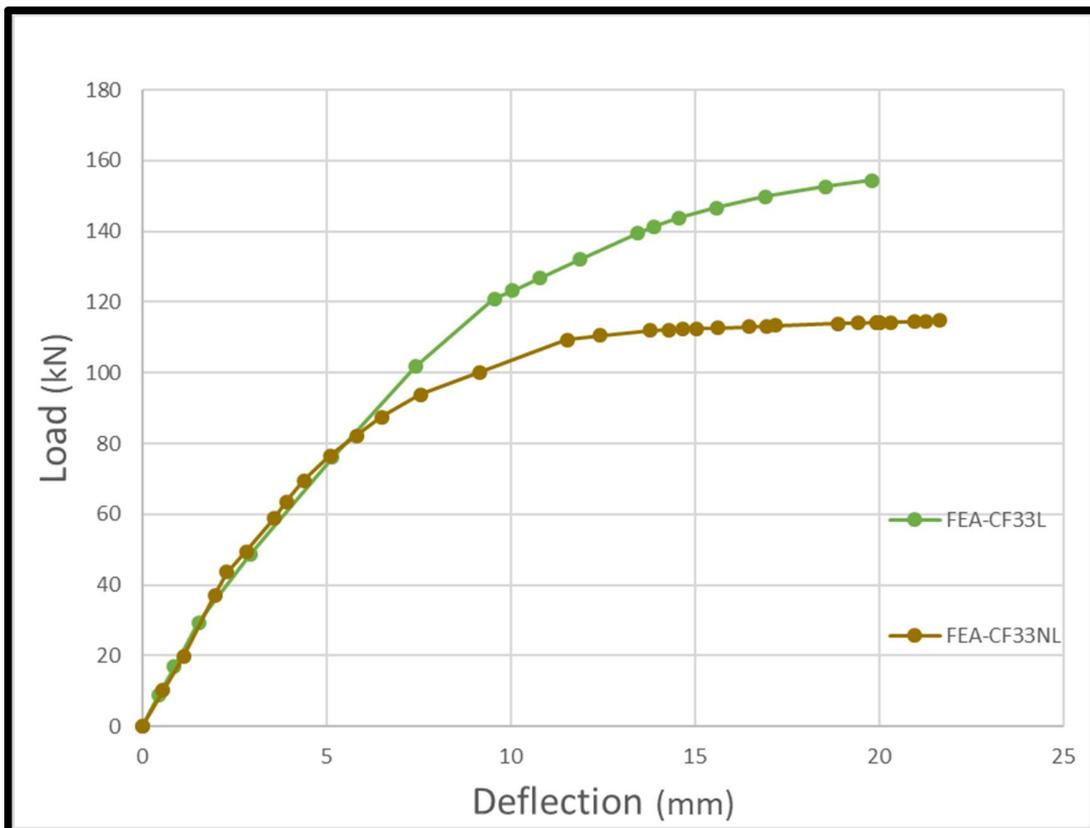


Figure (5-8) FEA ultimate load strength-max vertical mid span deflection curves for CF33NL and CF33L beams.

5.6 Prediction of maximum Load Capacity and deflection

The FEA findings indicate for beams with lipped sections, the ultimate strength of the tested CFS built up hollow box beam increase gradually by (10.1%) by increasing gap distance between back to back webs channels from no gap to 33% (21mm) of max possible clear distance available for the tested beams design may be due to reduction of flange unstiffened width. Ultimate strength does not change by increasing gap distance between back to back webs channels form 33% (21mm) of max possible clear distance available for the tested beams design to 66% (42mm) of max possible clear distance available for the tested beams design and. Finally, the ultimate strength decrease by (-4.9%) by increasing gap distance between back to back webs channels form 66% (42mm) of max possible clear distance available for the tested beams design to (64mm) max possible clear distance available for the tested beams design maybe due to increase of unstiffened distance of flange.

Maximum load capacity of sections can be predict from FEA results (156 kN) for Cold formed steel beam with (47) % of maximum possible space between back to back web channels of current beam design with lipped channels as shown in figure (5-9).

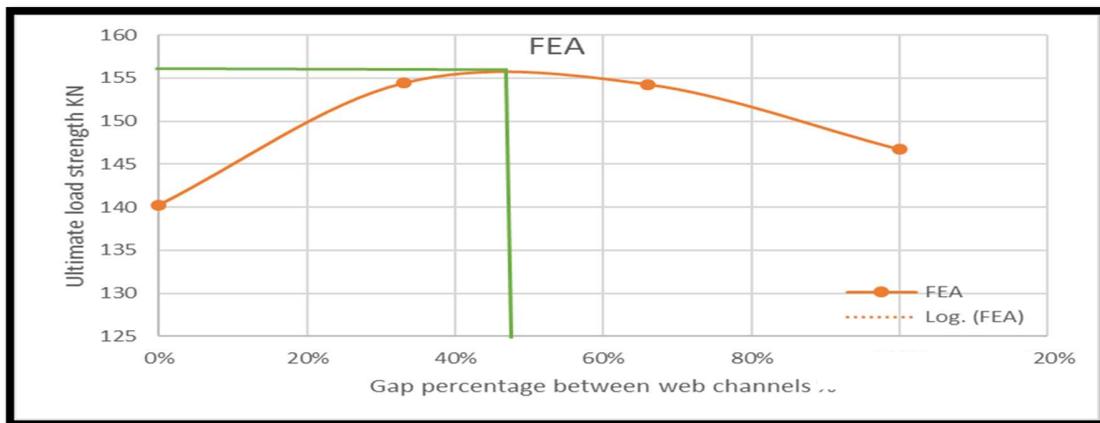


Figure (5-9) Ultimate load vs gap percentage between web channels for FEA tests

However for beams with lipped channels, the maximum vertical deflection at mid span before failure of the four tested CFS built up hollow box increase gradually by (52.33%) by increasing gap distance between back to back webs channels from no gap to 33% (21mm) of max possible clear distance available for the tested beams design. Then, decrease of maximum deflection by (-4.9%) by increasing gap distance between back to back webs channels form 33% (21mm) of max possible clear distance available for the tested beams design to 66% (42mm) of max possible clear distance available for the tested beams design and. Finally, the maximum deflection began increase by (8.8%) by increasing gap distance between back to back webs channels form 66% (42mm) of max possible clear distance available for the tested beams design to (64mm) max possible clear distance available for the tested beams design.

The maximum vertical deflection at mid span before failure of tested beams increase with increase of gap distance between back to back web channels of current beam design for with lipped channels at average rate of increase (0.5mm) from FEA result for every 10 % increase of gap distance between back to back web channels from maximum available gap distance as shown in figure (5-10).

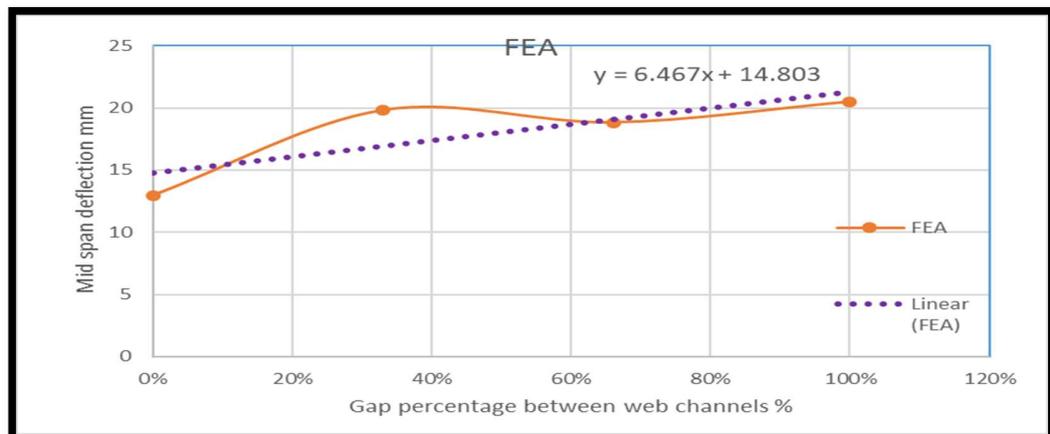


Figure (5-10) Mid span deflection vs gap percentage between web channels FEA.

5.7 Summary

The result of finite element analysis of cold formed steel beams with hollow web box under four point bending test, failure mode for tested beam with lipped channels was bending failure and for beam without lipped channels CF33NL was flange buckling failure.

The absence of lipped channel can be observed by the result of tested beam CF33NL, where ultimate strength decrease by (-25.7%) for beam without lipped channels CF33NL as compare with corresponding beam with lipped channels CF33L, maximum deflection increase by (9.35%) For beam without lipped channels CF33NL as compare with corresponding beam with lipped channels CF33L and finally mode of failure for beam without lipped channels CF33NL convert to flange local bulking which accrue due to presence of a flange that is having a thin unsupported edge and has compression stress while for corresponding beam with lipped channels CF33L was bending failure.

Maximum load capacity of sections from FEA results (156 kN) for Cold formed steel beam with (47) % of maximum possible space between back to back web channels of current beam design with lipped channels.

The maximum vertical deflection at mid span before failure of tested beams increase with increase of gap distance between back to back web channels of current beam design with lipped channels at average rate of increase (0.5mm) from FEA result for every 10 % increase of gap distance between back to back web channels from maximum available gap distance.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

Depending on obtained results from the experimental study and finite element simulation by the ABAQUS software for the cold-formed steel beam models subjected to a four point bending condition, the following conclusions and recommendation which can be mentioned.

6.2 Conclusions

1. From the experimental and finite element analysis results, the failure modes were bending failure for Cold formed steel beam for all beam with lipped channels due to presence of supported edge flange, except beam with maximum possible space between back to back web channels of current beam design with lipped channels CF100L the failure mode was local buckling failure from experimental results may be due to increasing of unstiffened flange width.

The failure modes were local buckling failure for Cold formed steel beam with (33) % of maximum possible space between back to back web channels of current beam design without lipped channels CF33NL due to presence of a flange that is having a thin unsupported edge and has compression stress.

2. Maximum load capacity of sections predicted from experimental results (144 kN) for Cold formed steel beam with (40) % of maximum possible space between back to back web channels of current beam design with lipped channels.

3. Maximum load capacity of sections predicted from FEA results (156 kN) for Cold formed steel beam with (47) % of maximum possible space between back to back web channels of current beam design with lipped channels.
4. The maximum vertical deflection at mid span before failure of tested beams increase with increase of gap distance between back to back web channels of current beam design for with lipped channels at average rate of increase (0.7mm), (0.5mm) of Exp and FEA result, respectively for every 10 % increase of gap distance between back to back web channels from maximum available gap distance.
5. The provision of lipped channels had a significant effect in increasing the load carrying capacity of back to back build up hollow box sections by (27.7%) , (34.6%) from Exp and FEA , respectively due to presence of supported edge flange.
6. In terms of section load capabilities and associated failure causes, experimental and numerical data are in acceptable agreement. This shows the dependability of the Finite element analysis program ABAQUS 2017 utilized in this experiment.

6.3 Recommendations

1. Study of effect of filling the gap between back to back web channels with concrete on flexural strength capacity of the built-up hollow box beam.
2. A realistic 3D depiction of screws in the FE model is recommend.
3. The study of larger sections is required. Different span length is recommended for future studies, and the height to span length ratio should be investigated more in order to establish a future-beneficial design strategy for built-up hollow box section beams.

4. Study of the effect of changing the thickness of CFS channels which used to construct the beams on flexural strength of the built-up hollow box beam.
5. Study of the effect of changing the bolts arrangement distance on flexural strength of the built-up hollow box beam.
6. Study the effect of hybrid section using flange channels with different yield strength then web channels on flexural strength of the built-up hollow box beam.
7. Study the effect of using flange and web stiffener on flexural strength capacity of the built-up hollow box beam.

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وبمقارنة النموذجين CF33L و CF33NL كان لاستخدام شفاه للمقاطع أثر كبير في زيادة
سعه التحميل القصوى للاعتاب ذات المقاطع الصندوقية المجوفة بنسبة زياده (27.7%) و (34.6%)
من جانب العملي و النظري على التتابع.

الخلاصة

CFS هو نوع من المقاطع الحديدية يتم تشكيله بدرجة حراره الغرفة يتم استخدامه في تشيد المباني وهياكل السيارات وابراج النقل وغيرها. يتم تشكيل هذه النوع من لمقاطع الحديدية من الاشرطة او اللواح الحديد باستخدام آلة التشكيل بالدلفنة او الثني بالضغط.

تقدم وتدرس هذه الدراسة سلوك الانحناء للعتاب الفولاذية المشكله بدرجة حراره الغرفة بتأثير اختلاف المسافه المجوفه بين مقطعين C ظهر الى ظهر ذات الشفه المشكلين للعتب الفولاذي المشكل على البارد بشكل صندوقي مجوف وتأثير اضافة الشفه للمقاطع على سعه التحميل القصوى. ولتحقيق هذا الهدف، شمل البحث كلا من الجانبين العملي والنظري.

تم اجراء فحص الانحناء لدراسة تأثير اختلاف المسافه المجوفه بين مقطعين C ظهر الى ظهر ذات الشفه المشكلين للعتب الفولاذي المشكل على البارد بشكل صندوقي مجوف وذلك بايجاد منحني الحمل المقابل الهطول ودراسة تأثير وجود الشفه للمقاطع على سعه التحميل القصوى حيث تم دراسة خمسة نماذج خلال الجانب العملي.

يمكن تصنيف النماذج الخاضعه لدراسة الى صنفين بالاعتماد على استخدام مقاطع ذات شفه لتشكيل الاعتاب او غياب استخدام الشفه للمقاطع . اربع نماذج تختلف من حيث المسافه المجوفه بين مقطعين C ظهر الى ظهر ذات الشفه المشكلين للعتب الفولاذي المشكل على البارد بشكل صندوقي مجوف و نموذج واحد المسافه المجوفه 21 ملم بين المقطعين C ظهر الى ظهر دون شفه المشكلين للعتب الفولاذي المشكل على البارد بشكل صندوقي التي هي تشكل 33% من اقصى مسافه تجويف يمكن توفيرها للمقطع المستخدم في الدراسة.

تم تقييم عينات المجموعه الأولى عمليا على اساس سعه التحميل القصوى و الهطول المقابل للتحميل وانماط الفشل . بلغت سعة التحميل القصوى للمقاطع من النتائج العملية (144 كيلو نيوتن) للالعتاب الفولاذية المشكله على البارد ذات (40) % من اقصى مسافه ممكنة بين بين مقطعين C ظهر الى ظهر ذات الشفه المشكلين للعتب الفولاذي.

تم تقييم عينات المجموعه الأولى نظريا باستخدام برنامج ABAQUS على اساس سعه التحميل القصوى و الهطول المقابل للتحميل وانماط الفشل . بلغت سعة التحميل القصوى للمقاطع من النتائج النظرية (156 كيلو نيوتن) للالعتاب الفولاذية المشكله على البارد ذات (47) % من اقصى مسافه ممكنة بين بين مقطعين C ظهر الى ظهر ذات الشفه المشكلين للعتب الفولاذي .



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

سلوك الاعتاب الفولاذية المشكله على البارد ذات الشكل الصندوقى المجوف

بحث

مقدم إلى كلية الهندسة / جامعة بابل
كجزء من متطلبات نيل شهادة الدبلوم العالي في الهندسة/الهندسة
المدنية/هندسة الانشاءات

من قبل

احمد مكي شعلان الاسدي

إشراف

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2023 A.D

1444 A.H