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Study on the Non-Linear Finite Element Analysis of Corrugated Webs in Steel Sections with Varying Thickness

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Abstract

Using corrugated plate to reinforce the shear zone of a plate girder on both sides of its web is the subject of this investigation. An experimental and theoretical investigation of the web of plate girder revealed that it is constructed from corrugated plates, which serve to strengthen the shear zone. To investigate the interaction of the corrugated plate with the plate girder, seven plate girder specimens were examined under two point loads. It is necessary to compare the results of the six specimens with corrugated web having a zigzag pattern to the results of the last specimen who was employed as a control beam. Corrugated plates have a significant impact on the stability of the plate girder, according to these findings. Researchers discovered that reinforcing the plate girder with corrugated web will result in an increase in the ultimate load capacity. In addition, the buckling load is increased greatly due to the contribution of the corrugated to the delay of the buckling of the plate girder web, which results in the buckling load being increased significantly. Using nonlinear finite element analysis in three dimensions, a numerical investigation was carried out. Ansys, version 17.0, was used to investigate the structural behavior of reinforced plate girders. Between the experimental and numerical results, there was a high level of agreement**.**

Keywords: plate girder, corrugate plates.

Notations

B: wide of web panel

D: deep of web

b_f: Width of flange

t_f : thickness of flange

t_w : thickness of

CWB: corrugated web beam

FE: finite element

1. Introduction

It is possible to increase the strength of a plate girder by using plate components in its construction. When using rolled pieces of material, it is possible to arrange the materials more efficiently. Especially in circumstances when an efficient design girder with a high weight to strength ratio is required, plate girders are frequently used to support heavy loads over long periods of time. When carrying pressureb plates, flanges are utilized to keep the relative space between the flanges constant while also resisting shear. When considering a particular bending moment, the web depth must be as large as possible in order to deliver the least amount of axial flange force. In order to reduce the self-weight, the web thickness must be kept to a bare minimum. As a result, it is a web plate that is frequently of thin dimensions, rendering it susceptible to buckling at low shear strength levels. [1][2][3],

Web plate shear buckling, lateral-torsional buckling of girders, compression buckling of webs, and local buckling and crippling of webs are all types of instability that are taken into consideration in design approaches. Webbing plates buckle early in the loading process because of their slenderness. The shear buckling and failure of web parts following the buckling of plate girders, as a result, are important design considerations; the stress distribution in the web is quantified as a result. As a result of the adjustments, additional post-buckling strength is made available. [4] [5]

However, even when the diagonal tension is constant, the web may buckle as a result of diagonal compression on the web. There are two possible approaches to dealing with this problem: It may be possible to produce panels with improved shear strength by incorporating web stiffeners into the design process, as well as panels that resist diagonal compression due to tension-field action. When a web is on the edge of buckling, it loses its ability to sustain itself and becomes unstable. It is supported on the diagonal, and the stress is transferred to the flanges and stiffeners on the transverse by the support. The stiffeners act as a barrier against vertical forces. The flanges resist the diagonal compression component, and the component that is only horizontal will need to be resisted by the site, as will the component that is only vertical. It is not known what mechanism the tension field action uses to describe how a buckled web resists loads when it is applied. Similar to the behavior of a Pratt truss, in which compression is handled by the vertical members and tension is carried by the diagonals, this behavior can be described as follows: Until the web buckles, no contribution to the shear strength of the web will be made by the buckling. A composite of the strength before buckling and the strength after buckling obtained from tension field action will be used to calculate the overall strength. [6]

It is common to utilize stiffeners in these instances because they are meant to divide the web into panels that are supported along their length. Stiffness lines are drawn along the surface of the water. The disadvantages of stiffener welding, on the other hand, are as follows: The first is that it is pretty expensive to create, and the second point to highlight is that it only lasts for a limited period of time until it becomes exhausted. Designers must choose which stiffener is most appropriate for a given plate thickness in order to achieve the desired stiffness. A way of providing appropriate stiffness while moving out of plane and buckling, as shown in Figures 1, can be used to achieve resistance without the need of stiffeners or thicker material webs, as shown in Figure 1. [7]

Figure 1: The robotic welding method used by CWG

Dr. Mazin A. Al-Mazini,(2015)[8], It was decided to investigate plate girders with circular and square apertures in the web. Testing of seven plate girder specimens under two point loads was performed as part of the experiment. Three specimens were tested to determine the effect of the circular web opening on the strength of the circular web. The influence of the inclusion of square web apertures on the performance of the other three specimens was investigated. As a reference (control) specimen, the final one was tested without opening, the experimental results revealed that the ultimate load capacity of the girders diminishes as the size of the opening increases, and that the position of the plastic hinge is dependent on the size of the hole. **M A Al-Mazini, A Alhamaidah and M S Zewair, (2021)[9],**studied Investigation the effect of central openings in the web on the behaviour of the plate girders , As results of experimental studies demonstrated that the critical buckling of girders dropped as the size of the openings increased, with the size of the openings also varying based on the geometry of the opening. Additionally, theoretical equations were initiated as a result of elastic local buckling and were then compared to experimental results. The numerical analyses of the structural reaction of the girders with varying form of holes were carried out with the help of the ANSYS software, which combined both experimental and analytical work (version 12.0).**Xudong ET al, (2017) [10],** studied the buckling behavior of corrugated steel web composite box girders under shear. This study shows a direct correlation between increased thickness and increased local and global buckling occurs initially because the rate of growth of local buckling strength is faster than the rate of development of global buckling strength. As web thickness rises, buckling strength and performance increase. While buckling strength increases, amplitude reduces as the angle increases to a certain degree.**Jongwon Yia et al (2008) [11],** studied the types of shear buckling failures in trapezoidal corrugated webs it have three: local, global, and interactive shear buckling. In local buckling, there is just one panel that buckles; in global buckling, there are several panels that buckle across the web. There are multiple panels involved in the interactive buckling, which is an intermediate form of shear buckle between local and global buckles. The geometric factors impacting interaction shear buckling modes and strength were examined using a series of finite element computations in this work. The interactive shear buckling strength formula is presented in light of the findings of the investigation. The experimental data was in agreement with the proposed formula.**B. Kövesdi et al (2014)** [12], studied behavior of girders with corrugated webs was tested, the results of the tests on the effects of fatigue life on the corrugation profile, normal stress ratio, in combination with normal and shear forces, and weld size . The test findings showed that the weld size have a positive effect on a fatigue design. The fatigue life of the tested girders was increased by using a lower weld size. This design therefore calls for the use of the smallest possible weld size**. Raged nassry naji and Assist. Prof. Dr. Aqeel H. Chkheiwer,(2022)[13],** Effect of the Geometrical Properties and Corrugation Thickness of the Web on Shear Strength of Steel Plate Girders, investigates the use of corrugated plate to strengthen plate girder shear zone on both side of its web. The web of plate girder are made from a corrugated plates that strengthening the shear zone, which examined experimentally and theoretically, It was found that the strengthening of the plate girder using corrugated web will increase the its ultimate load. In addition it increases significantly the buckling load through the contribution of the corrugated to delay the buckling of the plate girder web. A numerical study was performed using nonlinear finite element analysis in three dimensions. It was studied the Structural behavior of strengthen plate girders by using Ansys

2 .Plate Girder Proportions Requirements from AISC [14]

Structural steel design is primarily concerned with ensuring that the structure is stable, either locally or on a larger scale. It's important to remember that when using a plate girder, the designer has to take into consideration elements that aren't an issue when using hot-rolled shapes. Plate girders have a number of unique issues, including local instability, due to their deep, thin webs.

According to the web's h/$t_w$ratio, which measures the width-to-thickness proportion, a girder's width to thickness ratio is termed noncompact or slender based on the depth-to-depth ratio of the web.

For a doubly symmetric I-shaped section, according to AISC B4, Table B4.1, the web is noncompact if

$$3.76\sqrt{\frac{E}{F_y}} < \frac{h}{t_w} \le 5.70\sqrt{\frac{E}{F_y}} \qquad (1.1)$$

If the web is slender

$$\frac{h}{t_w} \ge 5.70\frac{h}{t_w} \qquad (1.2)$$

This restriction is set to avoid Flange buckles vertically into the web as it is compressed. The limiting value of h/$t_w$is determined by the girder panels' aspect ratio, a/h, In other words, this is the ratio between web depth and intermediate stiffener spacing

For a/h ≥ 1.5

$$\frac{h}{t_w} \le 11.7\sqrt{\frac{E}{t_w}} \qquad \text{(The AISC Equation. F13.3)}$$

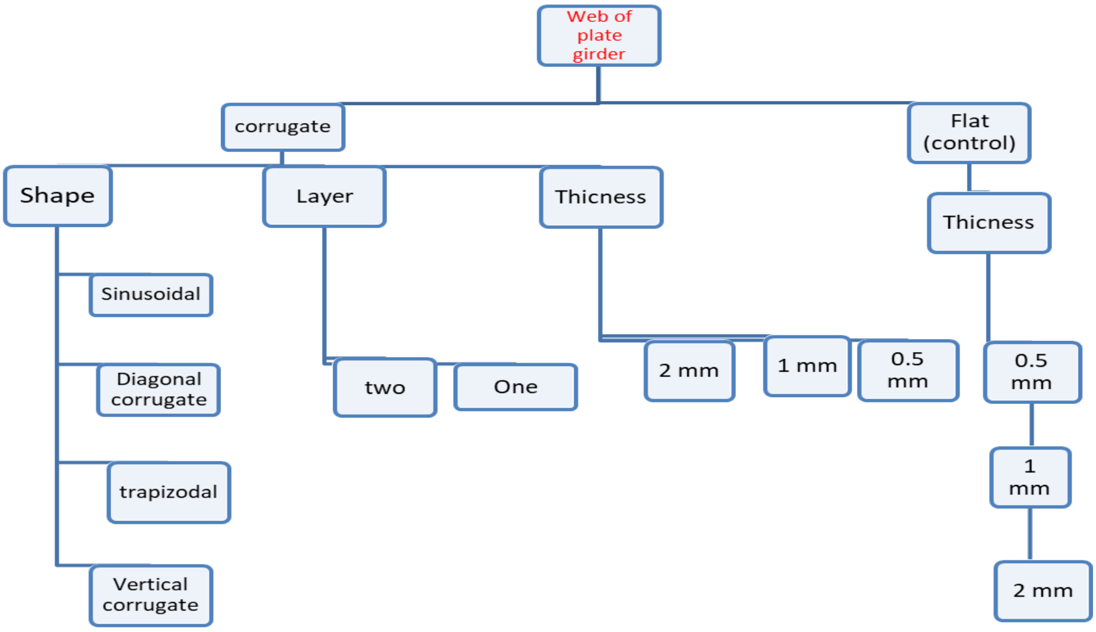
For $\frac{a}{h} > 1.5$

$$\frac{\boldsymbol{h}}{\boldsymbol{t_w}} \le \frac{\mathbf{0.42}\,\boldsymbol{E}}{\boldsymbol{F_y}} \qquad \textbf{(The AISC Equation F13.4)}$$

The clear distance between stiffeners is a.

AISC F13.2 mandates that h/$t_w$be no larger than 260 and that the web area to the compression flange area ratio be no greater than 10 in all girders without web stiffeners.

3. Model details



4. The non-linear finite element analysis

The non-linear finite element analysis of unstiffened and corrugated plates of steel structures was carried out using a proprietary finite element analysis tool ANSYS (ANSYS17.0). The analysis' primary goal is to determine the precision of the finite element model used to anticipate the overall performance of the tested beam the findings of finite element analysis are presented in this section. For all beams tested in our study, element analyses are presented. The results are compared to the experimental results once more. There's also an extra Examples are investigated in order to create a parametric study that covers a large variety of possibilities. a wide range of design parameters of unstiffened and corrugated plates of steel structures was carried out using a proprietary finite element analysis tool ANSYS (ANSYS17.0). The analysis' primary goal is to determine the precision of the finite element model used to anticipate the overall performance of the tested beam the findings of finite element analysis are presented in this section. For all beams tested in our study, element analyses are presented. The results are compared to the experimental results once more. There's also an extra Example is investigated in order to create a parametric study that covers a large variety of possibilities and wide range of design parameters.

5. Specimens Identification and Stiffening Schemes

In this investigation, seven beam specimens were evaluated, six of which were corrugated strengthened plate girders and one of which was a reference beam without any corrugations. Both shear zones of the girder have corrugated web beams of plates (CWB), which are attached to both sides of the web of the girder and are given on both sides of the web. An example procedure for identifying a specimen, as illustrated in Figure 2 and Table 1, is clearly demonstrated.

Table 1: detail of beam

Beam No.	a/h ratio	plate	Orientation α°	Length of Beam (m)	Effective span(m)
B1	1.6	Control	90	1.6	1.3
B2	1.6	CWB one layer thick (1mm)	90	1.6	1.3
B3	1.6	CWB two layer thick (1mm)	90	1.6	1.3
B4	1.6	CWB one layer thick (0.5mm)	90	1.6	1.3
B5	1.6	CWB two layer thick (0.5mm)	90	1.6	1.3
B6	1.6	trapezoidal		1.6	1.3
B7	1.6	Diagonals	90	1.6	1.3


B1


B2


B3


B4

B5 B6

B7

Figure 2.Specimens of plate girder

7. Meshing of plate girders

The structure should be mesh after the model has been defined. This mesh is a graphical split of the entire structure into little components or finite elements as they are known. Nodes must link these items appropriately within their limits. The mesh density selection is a crucial stage in finite element modeling.When a suitable elements number are utilized in the model, the results will converge; this is realistically when increasing mesh density has no effect on the results. Eight alternative numbers of components were employed to test the convergence of the findings for the control beam no. B1: 200,400, 277, 1414, 1390, 660,200, 280. To explore the convergence of data, the deflection at the mid-span of the beam was chosen for the same applied load. The connection between the number of elements and the mid-span deflection of a beam. Was created as shown in Figure 13, When the number of pieces exceeds 1414, the deflection at mid-span becomes essentially constant, according to the graph. As a result, the 1414 elements model was chosen, which was comparable to a mesh size of 25x25 mm. This mesh size served as the foundation for the rest of the beams.

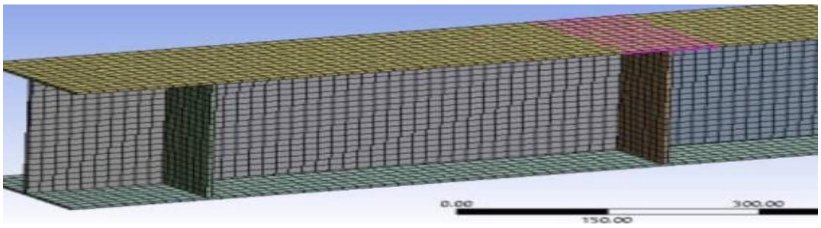


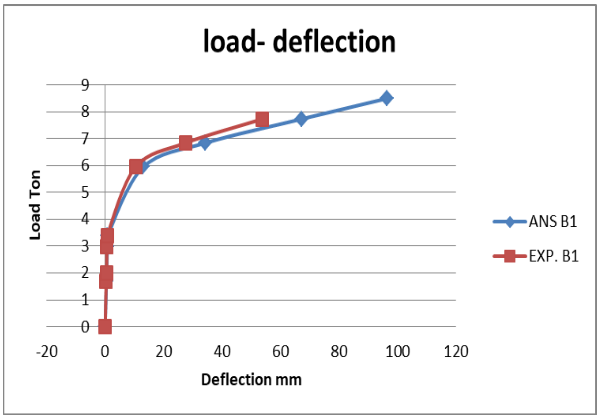
Figure 3. Finite element

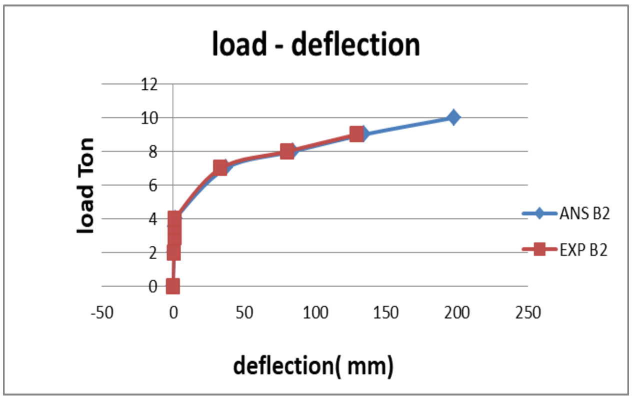
8. Numerical rustle

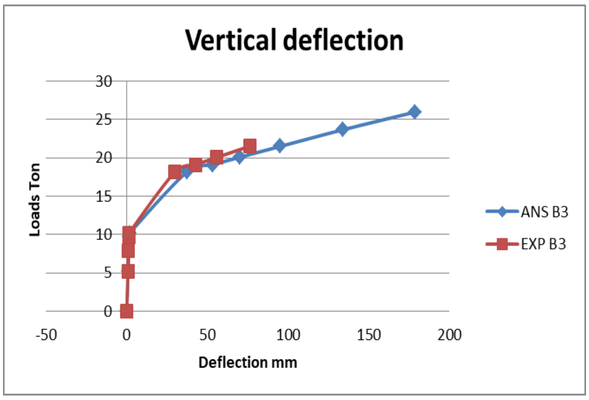
Plate girders were subjected to buckling and ultimate loads in the finite element analysis, which were then compared to experimental data in Table 2. Putting the finite components through their paces against buckling and ultimate loads reveals that they are rather close in performance. For both control and reinforced beams, the ultimate loads recorded experimentally nearly match those predicted by the finite element method. According to the results of the comparison, finite element modeling is capable of effectively forecasting buckling and ultimate loads in a given situation.

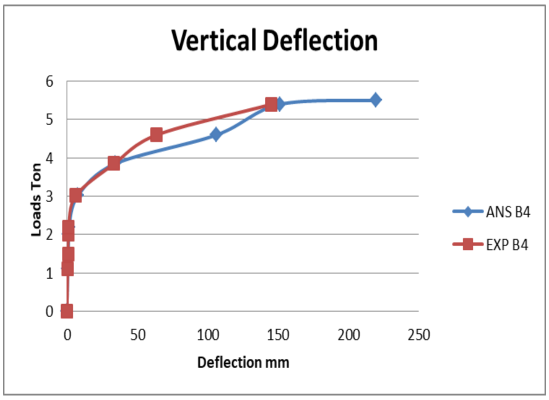
Table 2. Buckling and Ultimate Load of Beams

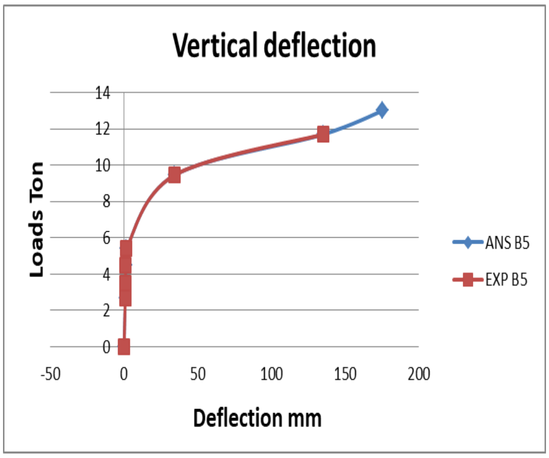
Beam No	a / h ratio	Buckling Load Exp. (p_{cr})	Ultimate Load Exp. (p_u)	Buckling Load Ans.(p_{cr})	Ultimate Load Ans.(p_u)	$\frac{Ans_{pu}}{Exp_{pu}}$	$\frac{Ans_{\ pcr}}{EXP_{PCR}}$
B1	1.6	20	77.35	29.75	85	1.09	1.4875
B2	1.6	29	90	35.2	100	1.11	1.21
B3	1.6	79	215.28	97	260	1.2	1.22
B4	1.6	15	54	20	55	1.01	1.33
B5	1.6	35	117	45	130	1.11	1.28
B6	1.6	36	108	41.5	110	1.01	1.15
B7	1.6	38	127	46	135	1.06	1.21

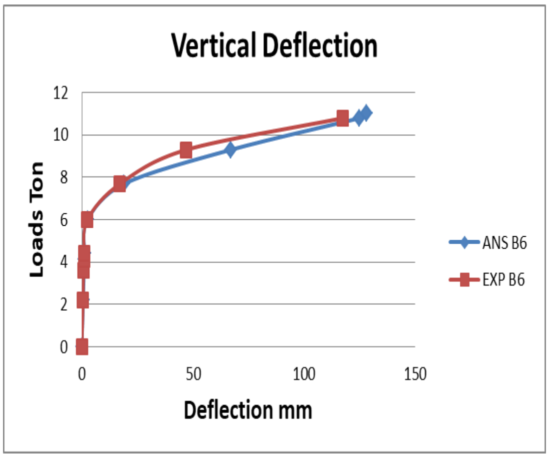












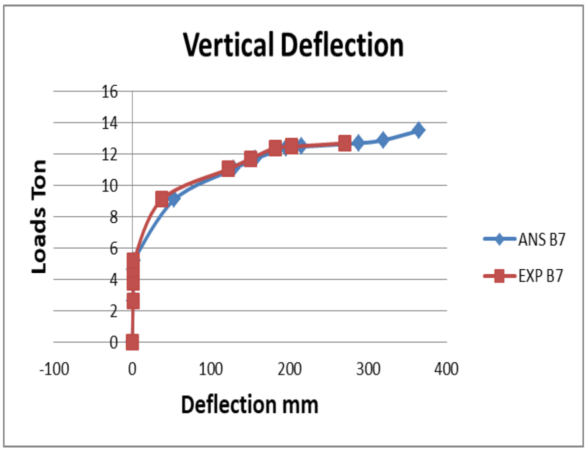
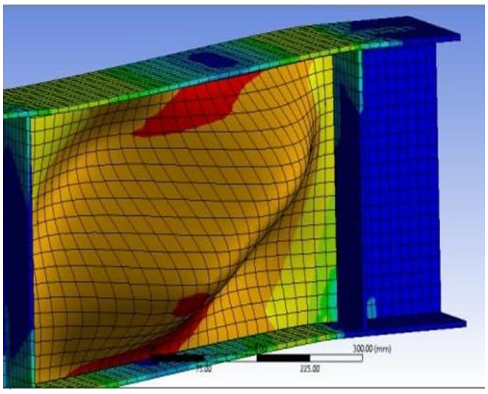
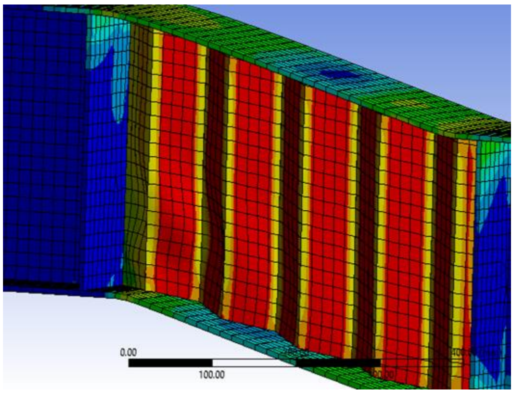


Figure 4: Variation of Deflection with Load for

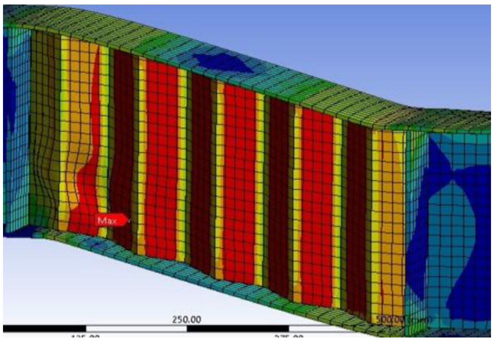
Figure 14 depicts the failure modes of the tested beams as well as the failure modes predicted by the finite element method. The FE-generated data had a high degree of agreement with the test failure modes.
The correctness of future FE models may be relied upon in light of these findings.



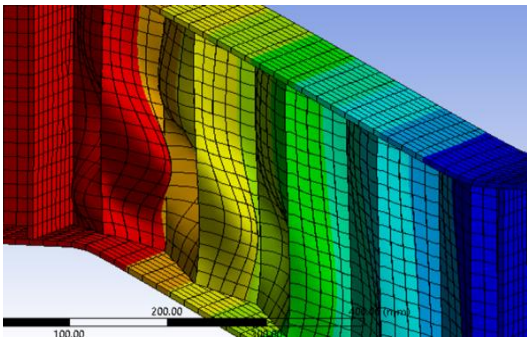
B1



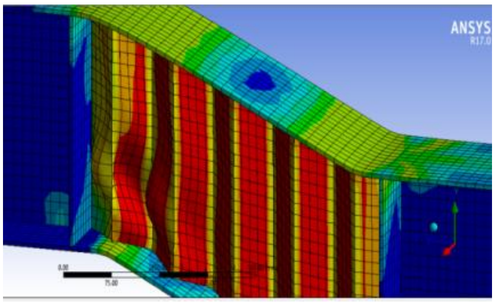
B2



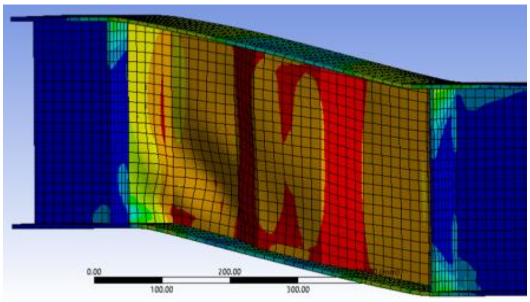
B3



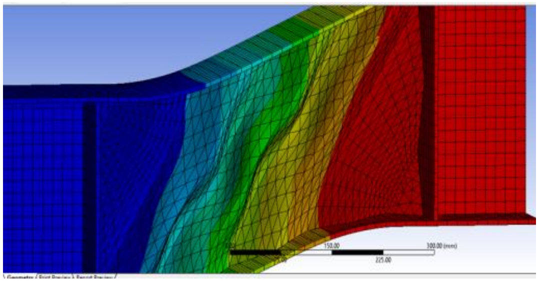
B4



B5



B6

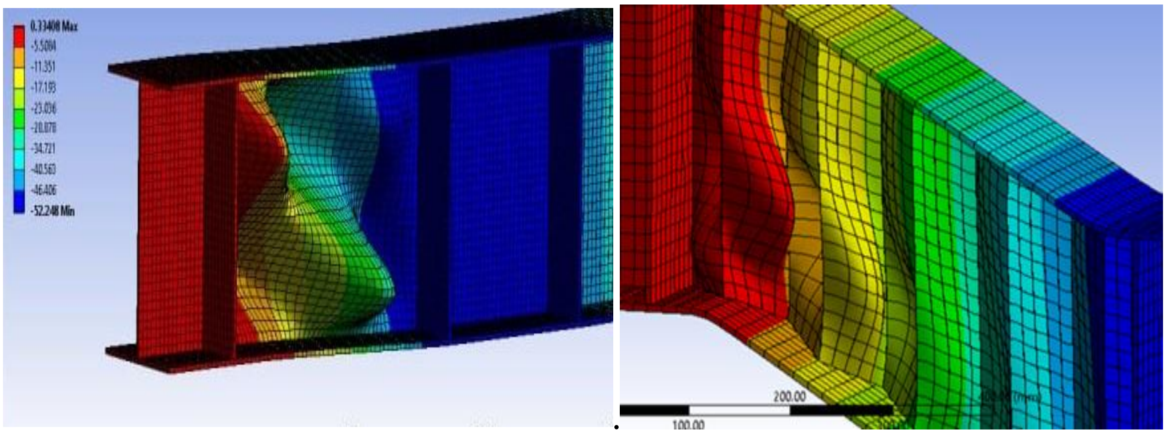


B7

Figure 5. Numerical Failure Modes.

9 .Case of study

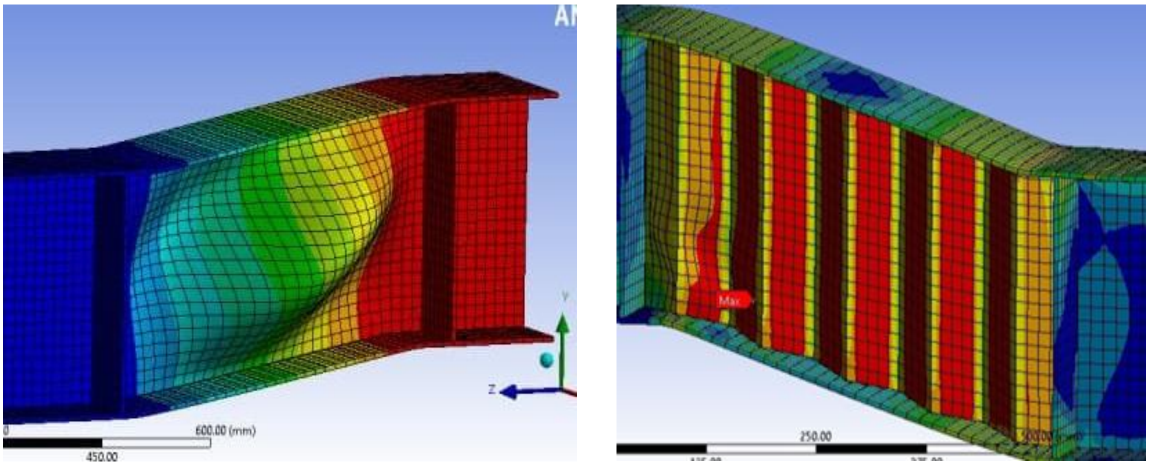
Due to the high cost and lack of time, and in order to complete the study of the effect of corrugation in the web area, four models were created with the same dimensions and characteristics as the previous models, and the results were analyzed using the ansys program. The ansys program is used to assess the four models, which are then compared to their equivalents from the preceding models that were tested in the laboratory: The first model without corrugate in the web (control) call it B8 and had a thickness of 0.5 mm, which was compared to the fourth corrugated beam B4 that was evaluated in the laboratory and conceptually, and it was found, the ultimate load for B4 was 55 KN but the ultimate load for B8 was 30 KN.



B8 B4

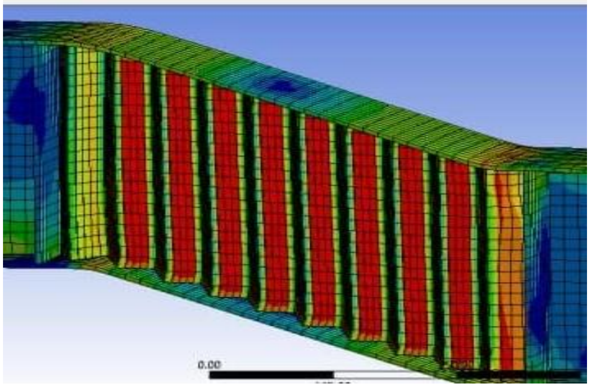
The second model in study case B9 without corrugate and it had thickness 2 mm, which was compared with B3 evaluated in the laboratory and conceptually, it was found B9 is smaller than B3

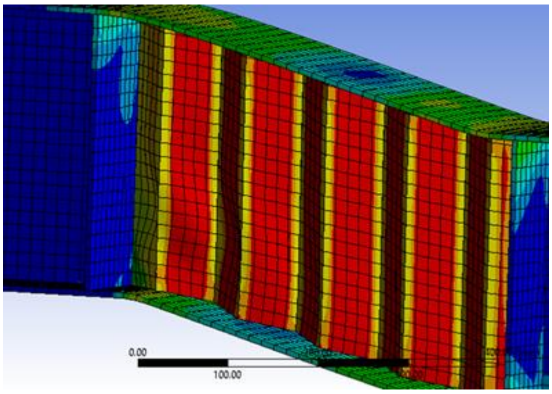
This is due to that the buckling of the web occurs in the upper zone of the web and smaller deformation is recorded in center of the web. While, beamB3 has maximum value of out-of-plane deformation. Finally, beam B3 has the highest buckling and ultimate load, and best ductility is achieved**.**



B9 B3

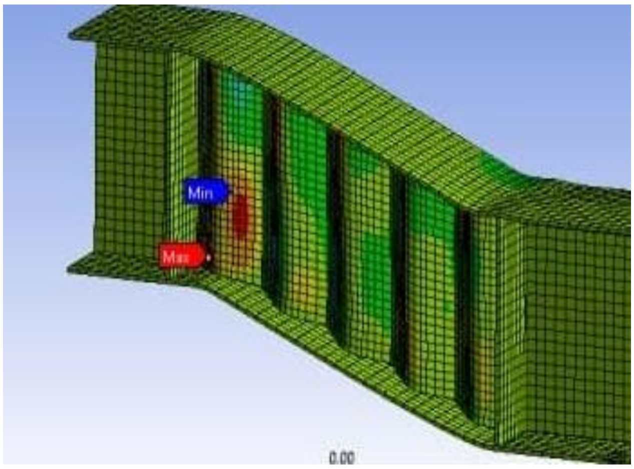
Because of the importance of the angle and the big effect it has on the strength of the model, designers reduced the angle to see if there was a difference in the effect on the structural stability of the beam.B10 have angle 30° where proven it is more efficient than models with larger angles for example B2 it was angle 45.





B10 B2

The last model had corrugation form of curves, and the ultimate load was 270 KN, It has shown affectivity of web stability and shear resistance as a result of the applied loads on the web**.**



B11

6. Conclusions

1. According the experimental data, flange plate buckling and distortional buckling are the most common causes of section failure. In addition, the load-bearing capability of corrugated web increases with the increase in thickness of the material.
3. Because of the corrugation in the web, the failure rate of compression in the web is lowered.
4. An efficient joint is provided as a result of the connection between the corrugated web and stiffeners. Providing point welds at regular intervals is essential.
Five, based on the experimental data, a finite element analysis is carried out in order to confirm the experimental results. The findings of the experimental tests are more consistent as a result of this.
6. When compared to flat beams, corrugated web beams have a lower weight per unit area of the beam.
7. Plate girder corrugated web will improve shear strength while increasing the ultimate load. This gain in load carrying capacity is attributed to an increase in buckling load on the plate girder corrugated web The primary benefit of the corrugated web is that it increases the stability of the web of the plate girder structure.

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