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Effect of the Geometrical Properties and Corrugation Thickness of the Web on Shear Strength of Steel Plate Girders

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Abstract

This study 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. Seven specimens of plate girder were tested under two point loads for investigating the association of the corrugated plate. Six specimens with corrugate web have a zigzag pattern, which their results are compared with the results of the last one whom used as a control beam. According to the results, the corrugated plates have a considerable effect on the plate girder's stability. 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, version 17.0. a good agreement was found between the experimental and numerical results.

Keywords: plate girder, corrugate plates.

1. Introduction

A plate girder is a beam made up of plate components that allows for greater strength. Material may be arranged more efficiently than with rolled pieces. Plate girders are often designed to carry large loads over extended periods of time, especially in cases where an efficient design girder with a weight to strength ratio is quite high. Flanges are used to carry pressureb plates maintain the relative distance between flanges at the same time and resist shear. The web depth must be as large as possible for a given bending moment to provide the lowest axial flange force. The web thickness must be decreased to a minimum in order to lower the self-weight. As a result, it is a web plate that is often of thin dimensions, making it susceptible to buckling at relatively low shear strengths. [1]

Various types of instability are considered in design methods, including web plate shear buckling, lateral-torsional buckling of girders, compression buckling of webs, and local buckling and crippling of webs. Due to their slenderness, web plates buckle early in the process of loading. As a result, one of the design aspects of plate girders is the shear buckling and failure of web elements after the web has buckled; the stress distribution in the web is measured. Additional post-buckling strength is mobilized as a result of the modifications [2].

Although the diagonal tension is constant, the web may buckle because of the diagonal compression. There are two options for dealing with this issue: Using web stiffeners may aid in producing panels with increased shear strength and design panels that resist diagonal compression through tension-field action. When the web is on the verge of buckling, it loses its capacity to support itself. The compression on the diagonal is supported and the stress is transferred to the flanges and stiffeners on the transverse. Vertical forces are resisted by the stiffeners. The flanges resist the diagonal compression component, and the component that is horizontal only the diagonal will need to be resisted by the site. The mechanism by which the tension field action describes how a buckled web resists loads is unknown. This behavior is similar to that of a Pratt truss, in which compression is carried by the vertical members and tension is carried by the diagonals. Until the web buckles, there will be no contribution to the shear strength of the web. The overall strength will be made up of the strength before buckling and the strength after buckling obtained from tension field action. [3]

In most situations, stiffeners are used and are intended to split the web into panels that are supported along their length. Lines of stiffness Stiffener welding, on the other hand, have two drawbacks: The first is that it is quite expensive to manufacture, and the second point to mention is the short time of exhaustion. The job of a designer is to identify the best stiffener in conjunction with the thickness of the plate. A method of producing sufficient stiffness while moving out of plane and buckling as shown below (1and 2), resistance can be achieved without making use of stiffeners or a thicker material webs [4]

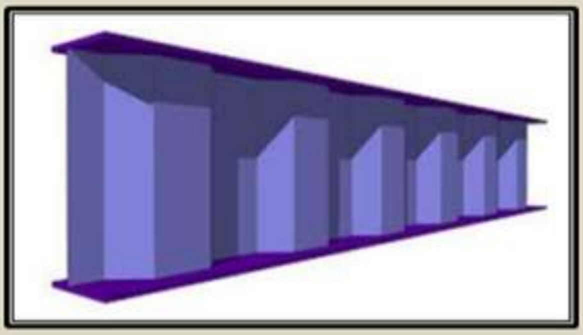
 

fig1. Corrugate web with stiffeners fig2. Corrugate of different web without stiffeners

R. Luo and B. Edlund (1996) [5], studied shear capacity of plate girders with trapezoidal corrugated webs there were tested by using a non-linear finite element approach to determine their shear capacity. In order to account for the effects of massive deflections, an elastic plastic material model adhering to the Yon Mises yield criteria is taken into consideration. In order to determine the shear capacity of such girders, the following geometric characteristics are examined: overall panel dimensions, girder width, web thickness, web corrugation depth, corrugation angle, and web panel width. To be specific, these characteristics have a direct impact on both ultimate shear capacity and the post-buckling shear capacity in addition to buckling modes.

Limaye A. and Alandkar P. M (2013)[6], this study focuses on rectangular corrugated web plates for the purpose of buckling strength calculation for a plate girder. The Analysis of plate girders is done using the ANSYS finite element software package. The analysis's outcomes are then in comparison to a plate girder with a uniformly deep planar web. Several variables, including as buckling strength and ductility. Weight is taken into account while making comparisons. High buckling strength and enough thickness are found in the corrugated web plate. In comparison to plate girder with plane web, light gauge parts save weight.

Witold Basiński1 (2018) [7], investigated the effects of end stiffener flexural stiffness on girder sinusoidal waveform web design buckling resistance. There are two types of web failure mechanisms in web girders with sine wave corrugations: local and interactive. The radius of a web wave, its wavelength, as well as the web height, all affects the web failure. It is suggested that ends stiffened using, the approach given in this study be compared to buckling resistance estimate formulae currently used. Using girder rigid end stiffeners has been shown to boost shear buckling strength by as much as 11%. With regard to including semi-rigid web girders with rigid end stiffeners based on sine-wave corrugation.**Jongwon Yia et al (2008) [8]** 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.

2. Experimental Work

The experiments are being carried out in the Engineering Materials Laboratory of the University of Basra's College of Engineering. The program's main goal is to generate data and give information. Data on the structural behavior of plate girders reinforced with a corrugated web of different shapes, thicknesses, and angles in an experimental study program, the performance of plate girders strengthened with corrugated plates subjected to two point loads is investigated.

A total of seven plate girders with corrugated web in different shapes and thicknesses and their simple supports are put to the test. . The main variables considered in the investigation are the followings the different thickness of corrugated plate is investigated by using 1mm, 2mm, and 0.5 mm. The orientation of corrugated plate: three different orientations are used in this study.

2.1 Material Properties

The required properties of the materials used in this study are evaluated experimentally or defined by certain references or by the manufacture data sheet. Mild steel plates of 1.6 and 6 mm thickness were used to build the required plate girders. The material roperties of the steel were determined according to ASTM A370 [9] Coupons were cut from a plate of 1.6 mm and 6 mm thickness. The average yield stress and modulus of elasticity are 220 and 200000 MPa respectively.

Figure 3: Test Setup and the Coupon

Table 1: Yield and Ultimate Stress of Steel Plates

Steel plate thickness mm	Yield stress N/mm²	Modulus of elasticity N/mm²	Ultimate stress N/mm²	Average of elongation %
1.6	220.1	200000	380	20
	220.0	200000	380.4	20.1
	220.1	200000	380.1	20
6	220.0	200000	381	20
	220.3	200000	380	20.7
	220.6	200000	380.1	20.3
Average	220.2	200000	380.2	20.1

2.2 Preparation of Test Specimens

The flange and web dimensions of all girders were the same for all double symmetric sections. The girder Steel plates with a thickness of 6 mm were used for the flanges and stiffeners, and (1, 2, 0.5) mm steel plates were used for the specimens. the web's thickness is 6mm. The flanges, stiffeners, and web were cut from steel sheet in accordance with the specifications. Using measurements and welding, the necessary plate girders had been constructed. The proportions of the object following the theoretical analysis in the appendix, designers utilized plates for our experimental work. In support of the propositions made here. A total of seven beams have been constructed in this investigation (one of them is control specimens). For a while now before to the tests, coated with a white oil paint figure as may be seen.

Figure 4: Preparation of Plate Girder.

Corrugated plate was used to strengthen the steel test beams. In this study, the plate in the web making corrugations in different shapes and thicknesses. The specimens formed two flanges (160*20*0.6) cm and welded with web (160*30*0.6) cm. All of the seventh specimens carried the same dimensions but different in the web plate. The first was without corrugation, called Control B1, to compare it with the other corrugated specimen to know the differences and the most tolerable. The corrugated plate girder was formed vertically for four specimens; two of them thought 1 mm once one layer and the other two layers, and the other two thought 0.5 mm once one layer and the other two-layer as shown.

Figure 5. Corrugates plate

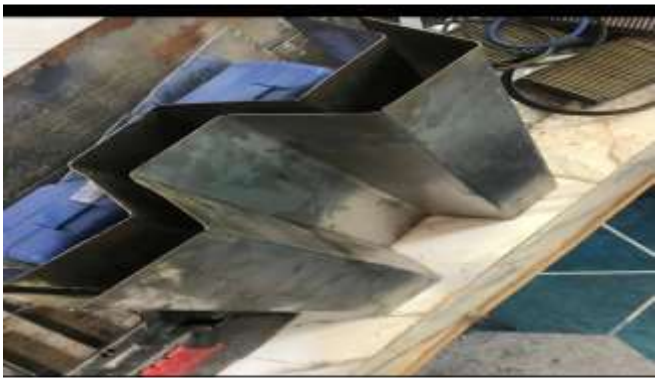


Figure 6: plate with trapezoidal corrugate

The sixth model plate girder trapezoidal shape thickness 1mm, as shown .

Figure 7. Diagonal corrugate plate

The last model we placed the corrugate diagonally vertical to tension field thick 1mm, the specimen in the shown figure:.

B1

B2

B3 B4

B5 B6

B7

Figure 8.Specimens of plate girder

2.1 Specimens Identification and Stiffening Schemes

In this study, seven beam specimens were tested, six corrugate strengthened plate girders and one specimen without corrugate as a reference beams. The corrugate web beam of plates (CWB) are attached at both shear zones of the girder and provided on both sides of the web of the Girder. Figure 9 in conjunction with Table 2 clearly shows a typical method for identifying a specimen.

Table 2: 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

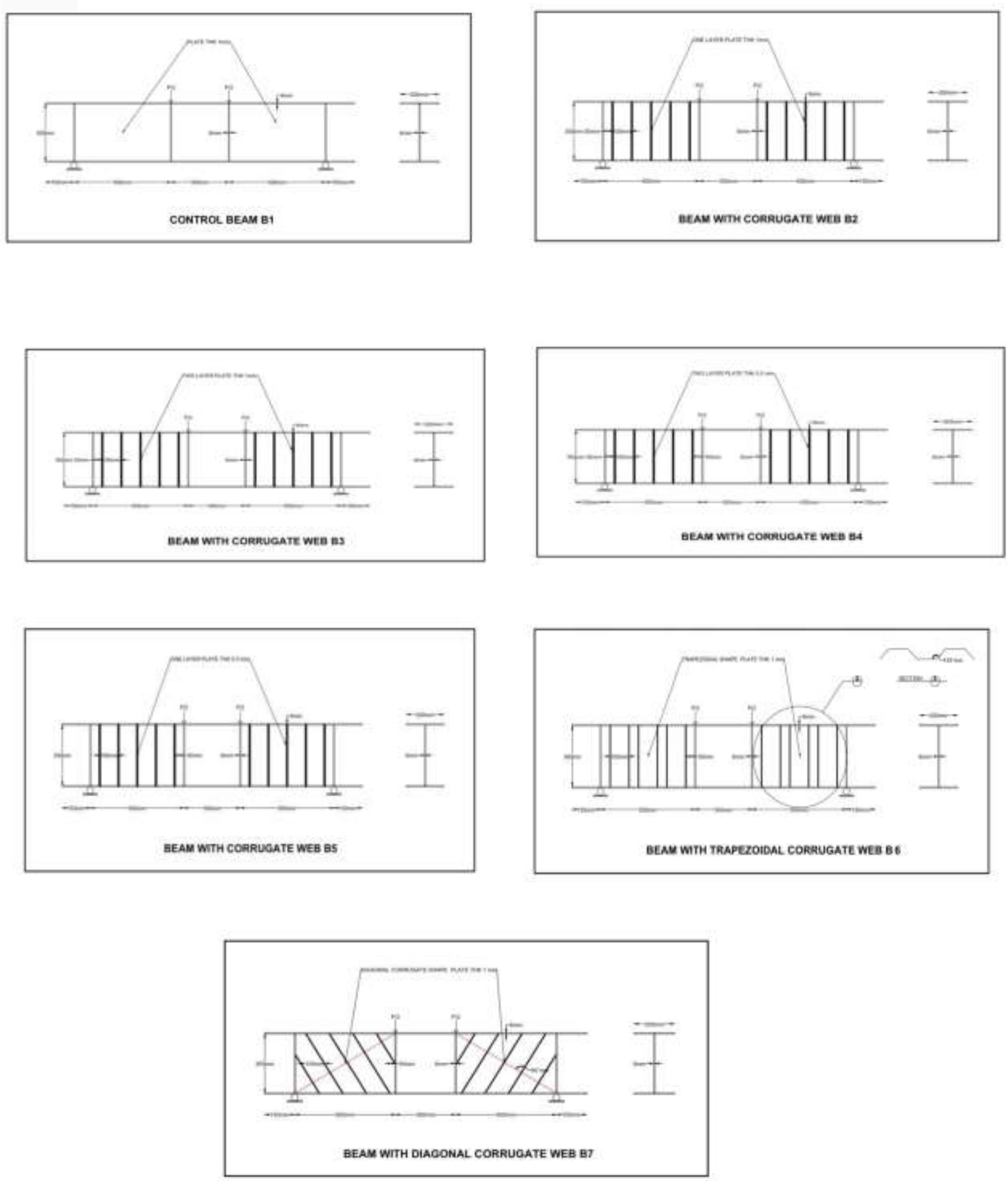


Figure 9. Stiffening Schemes of Beams

2.2 test procedure

Under a two-point load, the girders were evaluated as simply supported. The load was constant and steadily grew until it reached its limit. When the overall force on the specimen starts to drop, the test is over. A Teasers Universal Testing achine with a 200-ton capacity is used to apply the load. The test setup for these beams is shown in Figure 10. According to the aspect ratio of the shear panel for beams, the distance

Figure 10. Preparation of Plate Girder.

A strong steel spreader beam was used to apply the weight. Two transverse steel plates(100*300) mm covering the whole width of the specimen were used to apply the inner two point loads from the above flange .also we were used two steel plates (100*300) under the supports Between the spreader beam and each of the steel plates that would bear the support reaction loads, steel rollers were installed. Rotation and movement along the longitudinal axis were permitted in both bearings.

3. Experimental Results and Discussion

Constantly increasing loads are placed on the beams. Testing machines record the highest amount of stress they can handle. Due to web buckling, all of the beams were unable to support the load. Because stiffness is lowered when a beam buckles, a buckling load may be measured using the load deflection curve; the load at which the curve changes slope is the buckling load for test specimens. Out-of-plane deformation can only occur when the shear stress exceeds the critical buckling load; hence buckling loads may be calculated as the load at which an abrupt change occurs in out-of-plane deformation.

3.1 Buckling and Ultimate Load

A summary of experimental results of beams is presented in Table 3 The strengthened specimens, (i.e. beam B2, B3, B4, B5, B6 and B7) give higher critical load of about (45%, 295%, 20%, 75%, 80% and 90 %) percent, respectively as compared with (control) beamB1. It can be seen that the use of the corrugate plate increases the buckling load significantly. The increases in the buckling load provided by the used corrugate web may be considered as a result of the restriction to buckling deformations provided by the corrugate. The ultimate load for B1 was (77.3 KN). The strength specimens (beams B2, B3, B4, B5, B6, and B7) had a greater ultimate load of around (16.4%, 178.4%, 30.1 %, 51.3%, 39.6 %, 64.2%) comparison with B1, due to the corrugated web.

Table 3: Experimental Results of Tested Beams.

Beam No.	a/h ratio	Orientation α	Buckling Load (KN)	Ultimate Load (p_u) (KN)
B1	1.6	Control	20	77.35
B2	1.6	90	29	90
B3	1.6	90	79	215.28
B4	1.6	90	16	54
B5	1.6	90	35	117
B6	1.6	45	36	108
B7	1.6	diagonal 90	38	127

3.2 Load deflection curve

From the Figure 11 the elastic behavior of the seven specimens are coincides, this means that the initial stiffness of the plate girder does not affect when strengthened it with corrugate. While their behavior in the post buckling range is variable, the behavior of the strengthened plate girders is studied. For this purpose, six specimens (i.e. B2, B3, B4, B5, B6 and B7) were tested. For the beams studied, four specimens were made by using corrugate plates attached to shear zone on both Sides of the web in vertical direction, but the B6 was trapezoidal corrugate and the B7 was diagonal corrugated web, the last one was tested without corrugate as a control beam B1, The girder deflection vs. lo monitored in the Figure 10: below for specimens:

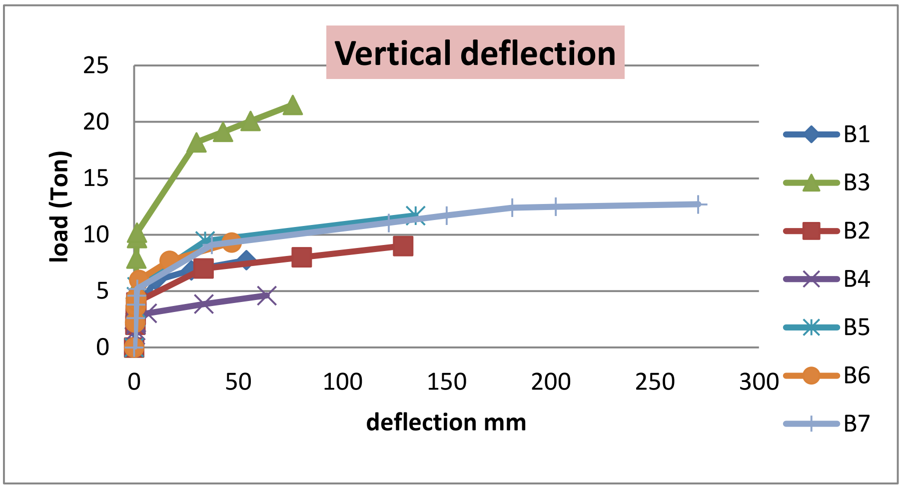


Figure 11. The Load Deflection for Various

From the figure 11 it was found in the first stage of loading it is noticed that within the elastic area with a percentage of 25.8 % from ultimate load, then the buckling began from the bottom on the side near the supports at a load, the buckling was along of the plate girder, the vertically stiffened webs may withstand greater loads after buckling. Web buckling strength can be improved by vertical and horizontal stiffeners and the beam fails with bending moment much less than the moment capacity. At the load (20 KN) the vertical and lateral deflection at this moments they were (0.47835, 2.2465) mm respectively, the buckling continued increasing until it arrived the ultimate load at 77.35 KN) and the maximum vertical and lateral deflection at (53.84, 361.02) mm. When the bearing stress exceeds the yield strength of the web closest to the applied reaction or load, web crippling failure occurs.

the specimen B2 was within in elastic area with percentage of 32.2 % from ultimate load, then the buckling began from bottom on the side near supported also at (29 KN) and the vertical with the lateral deflection were (0.746, 0.17512) mm, the buckling continued it was in the form of parts its clear in three corrugated until it arrive ultimate load at (90 KN), and the maximum vertical and lateral deflection were (129.216, 9.496) mm respectively.

For the specimen B3 it was within in elastic area with percentage of 37 % from the ultimate load then the buckling started from the bottom also but it was clear in two corrugate only in the form of parts from the near side supported, at (79 KN), the vertical and Lateral deflection were (1.007, 0.186) mm and the ultimate load for this girder was (215.28 KN) and the maximum deflection (vertical and lateral) were (76.208, 4.44) mm respectively.

The specimen B4 was within in elastic area with percentage of 27% from the ultimate load, then the buckling began at 15 KN at this moments we record the (vertical and lateral deflection) they were (0.738, 0.8344) the buckling continues on the long plate from bottom then it reach ultimate load at 54 KN and the maximum deflection (vertical and lateral) it were (145.344, 26.192) mm respectively.

The specimen B5 within in elastic area with percentage of 30% from the ultimate load , were the buckling began from the bottom on the side near supported at (35 KN) and the deflection (vertical and lateral) were (0.856, 0.256) mm respectively, the ultimate load was (117 KN) and the maximum deflection (vertical and lateral) were (135.13, 19.8) mm respectively .

The B6 (trapezoidal girder) it was within in elastic area with percentage of 33%from the ultimate load, the buckling began in the middle inside the middle stiffener at (36 KN) and the ultimate load was (93 KN), the maximum deflection (vertical and lateral) were (46.83, 12.384) mm .

for B7 the result showed the buckling in the middle lightly because we put corrugate in the form of slanted and vertical on tension field, It was within in elastic area with percentage of 30 % from the ultimate load , the ultimate load was(127 KN) and the maximum deflection (vertical and lateral) were (270.908,9.65) mm respectively .

4.3 Failure modes

The beams in this study were intended to collapse due to shear buckling of the web. Other sorts of failure scenarios that may have occurred were avoided. Local buckling of the flanges, for example, was previously prohibited by the manufacturer. Compact flanges are a good choice. The buckling and crippling of the web on a local level avoided as well by properly distributing the weight on the upper wall flange, as well as providing strong stiffeners for the girders, Figure 12 depicts a typical shear failure scenario in a control plate girder. The web's buckling axis, which runs along the compression diagonal, is visible. Figure following depicts the failure of strengthened beams. All beams fail in the same way that the control beam fails. Figures shows dawn how the corrugate plate bends and deforms at the same time as the web. The general bucking mode describes this situation.

B1

B2

B3

B4

B5

B6

B7

Figure 12. Mode of failure

4. Numerical Results

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.

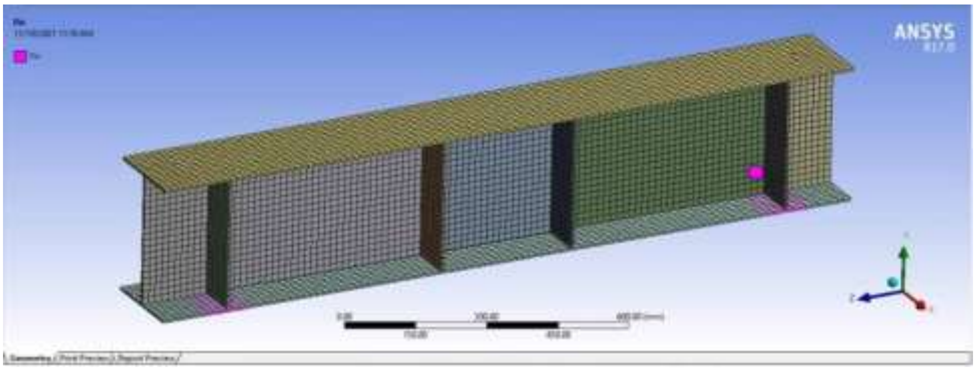


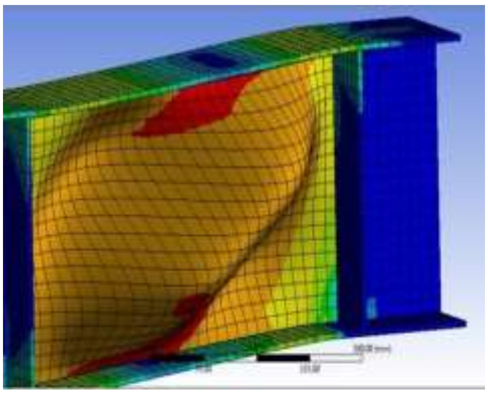
Figure 13. Finite element

Table 4 summarizes the finite element analysis results for buckling and ultimate loads on plate girders, as well as the related experimental values. Testing the finite components against the buckling and ultimate loads indicates a reasonable agreement. Experimentally measured ultimate loads closely match those predicted by the finite element approach for both control and reinforced beams. The comparison indicates that finite element modeling is capable of accurately predicting buckling and ultimate loads.

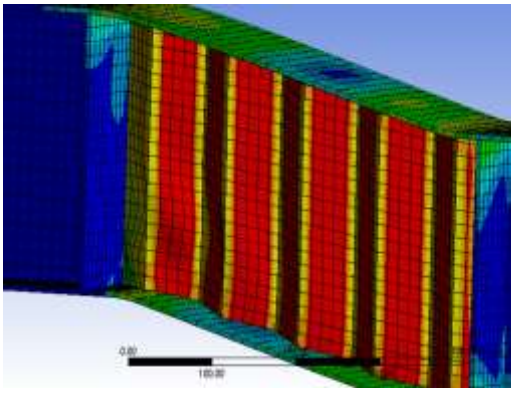
Table 4. Buckling and Ultimate Load of Beams

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

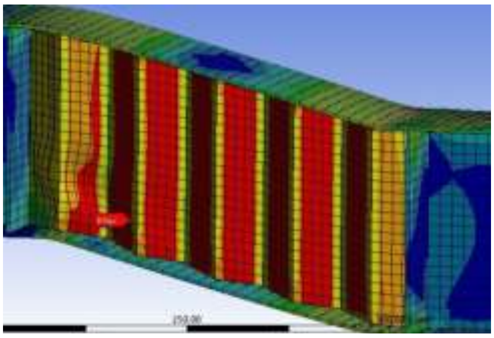
Pictured failure modes of tested beams are shown in Figure 14, along with the FE projected failure modes. Test failure modes were closely matched by the FE-generated data.
The correctness of future FE models may be relied upon in light of these findings.



B1



B2



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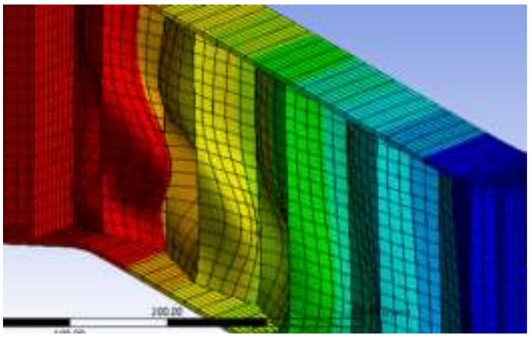

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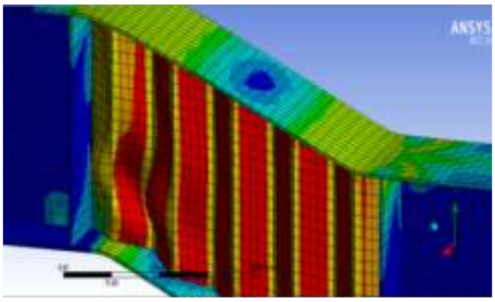
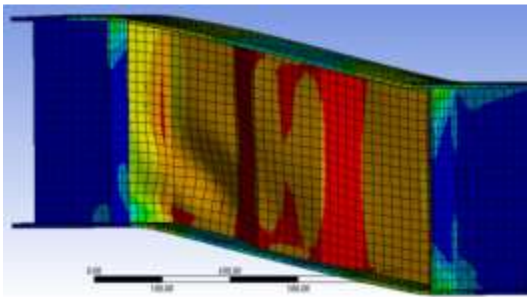
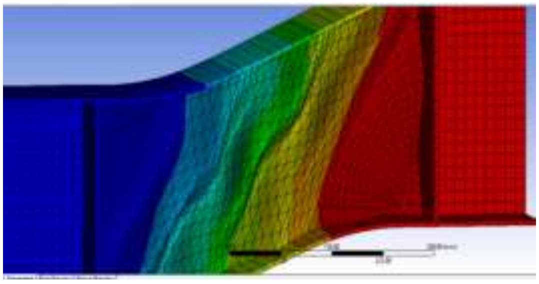


B5



B6



B7

Figure 14. Numerical Failure Modes.

5. Conclusions

1. According to experimental results, the failure of the section is mostly caused by flange plate buckling and distortional buckling.
2. As the thickness of the corrugated web increases, the load-carrying capacity improves as well.
3. Compression failure in the web is reduced due to corrugation in the web.
4. Because of the connection between corrugated web and stiffeners, an efficient joint is given. Providing point welds at regular intervals.
5. From these results, finite element analysis is carried out to verify the experimental results. This gives better agreement with the experimental test results.
6. Compared with flat beams, corrugated web beams have reduced the weight of the beam.
7. Plate girder corrugated web will improve the shear strength; increase of the ultimate load this improvement in load carrying capacity is due to increases in buckling load. The major effect of the corrugated web is to enhance the stability of the web of the plate girder

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