

Numerical Study of Dual Web Steel Plate Girders Under Buckling, Monotonic Load Response And Hysteresis Behaviour

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Abstract. Steel Plate Girders are generally I shaped steel beams made of two or more individual steel plates which are bolted, welded or riveted to form the girder's flanges and web. Plate girders are usually used in railway bridges. Predominantly, these girders contain only a single central web plate. In this paper, we propose and study the behavior of dual parallel web girders under buckling, monotonic loading, and hysteresis response. The control beam is first modeled and validated based on experimental results and a comprehensive numerical investigation has been discussed in this paper. From the analysis results, model with 20 mm web spacing shows better performance. The finite element code of ANSYS APDL 16.2 is used for modeling the test cases.

Keywords: Plate girder, Buckling, Hysteresis

1. Introduction

The plate girders are generally I-beams made from separate steel plates which may be bolted or welded or riveted to form the horizontal flanges and vertical web of the beam. Stresses on the flanges are larger near the centre of the span than near the end of the span, hence the top and bottom flange plates are reinforced in the mid portion of the span. Vertical stiffeners prevent the buckling of web due to shear stresses. Vertical stiffeners are uniformly spaced along the girder with additional stiffeners over the supports and wherever concentrated loads occurs. Plate girders are mainly used as beams under railway bridges.

Behaviour of plate girders under load is important. Previous studies have been made to improve the method for predicting the buckling resistance and cyclic behavior of steel plate girders. The design and buckling behaviour of stainless steel plate girders subjected to shear failure have attracted attentions in recent year[2-4]. Olsson[1] conducted eight tests on austenitic and duplex stainless steel plate girders and developed a new design expressions for calculating the shear resistance. Real et al.[5] conducted a test setup of nine plate girders which are made using austenitic stainless steels. The test results showed the effect of material non-linearity on the shear strength. Shanmugam et.al[14] conducted experimental and numerical study on ultimate load bearing capacity of curved plate girders. It was seen that the load carrying capacity of girders decreased with increase in curvature. Saliba and Gardner[12-13] conducted nine tests on duplex stainless steel plate girders with rigid end condition and a design approach was presented to determine ultimate shear resistance of plate girders. Hassanein[10-11] carried out numerical studies on stainless steel plate girders to determine the influence of imperfections on the buckling behavior. New design methods for predicting the ultimate buckling resistance of stainless steel plate girders have been proposed[6-9]. In monotonic loading, an increasing load is applied to the structure, to determine its yield and ultimate strength. The effect of cyclic loading is also studied. The main objective of this paper is to investigate buckling behaviour, monotonic load response and hysteresis behaviour of dual web steel plate girders.



2. Methodology

2.1 Experimental Tests

The test set up is given in figure 1, in which the plate girders were subjected to a concentrated load at mid span. Two bearings, supported over a rigid steel pedestal is used to provide the simply supported condition. 60 mm diameter cylinder was used to form the end bearing. The pin support on one side was provided by a bearing that was welded on a flat plate, while the other was a roller support, allowing longitudinal displacements and rotations. The small clamping frames were provided at each end, allowing restraints on plate girders with varying flange widths. A thin layer of lubricating oil was applied between the two plates and specimen, to avoid friction. Two lateral supports were provided by using a pair of triangular frames, with aspect ratio of 1.5 at each side of the plate girder, to prevent lateral-torsional buckling failure. The test set up is given in figure 1. A 5000 kN capacity hydraulic testing machine is used for performing the shear buckling tests. The experiment was done by X.W.Chen *et.al* (2017) Wuhan University, China.

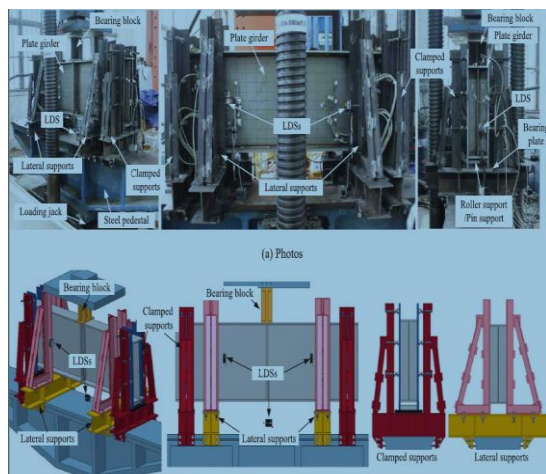


Figure 1 Test setup[15]

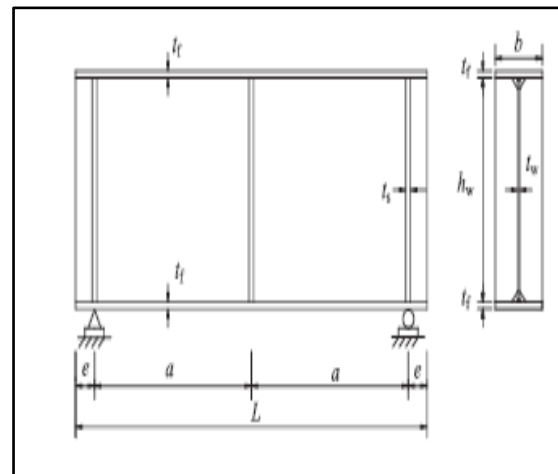


Figure 2 Geometry of test specimen[15]

2.2 Finite Element Modeling and Calibration of Test Specimens

The test specimen consists of a stainless steel plate girder with three transverse stiffeners as given in figure 2. The geometry of test specimen was modeled as shell element due to the less complexity involved, and is shown in Figure 3 and the geometric dimensions are given in Table 1. The material properties of the test specimen are shown in Table 2.

Table 1. Geometric dimensions for test plate girder

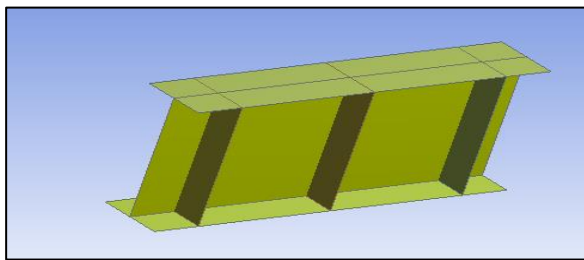
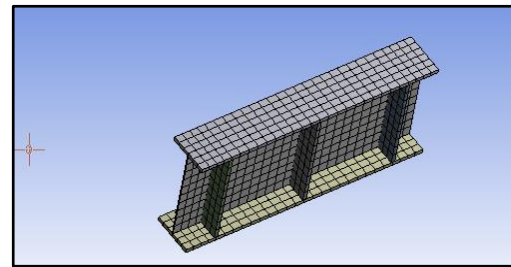
Plate girder	L (mm)	a (mm)	e (mm)	h_w (mm)	b (mm)	t_w (mm)	t_f (mm)	t_s (mm)
Specimen	798.8	299.2	100.2	299.5	134	3.82	11.85	11.85

Table 2. Material Properties

Grade	E(GPa)	ν
1.4301	200	0.3

2.2.1. Geometric Modeling

The modeling is done using ANSYS Static Structural. The geometric model is shown in figure 3.

**Figure 3** Model of test steel plate girder**Figure 4** Meshed test model

2.2.2. Meshing and Discretization

Mesh convergence study was conducted. The meshed model is shown in figure 4. It was found that the results tend to remain constant beyond 25000 elements under a mesh size of 17mm Quadratic elements and hence the choice for the study.

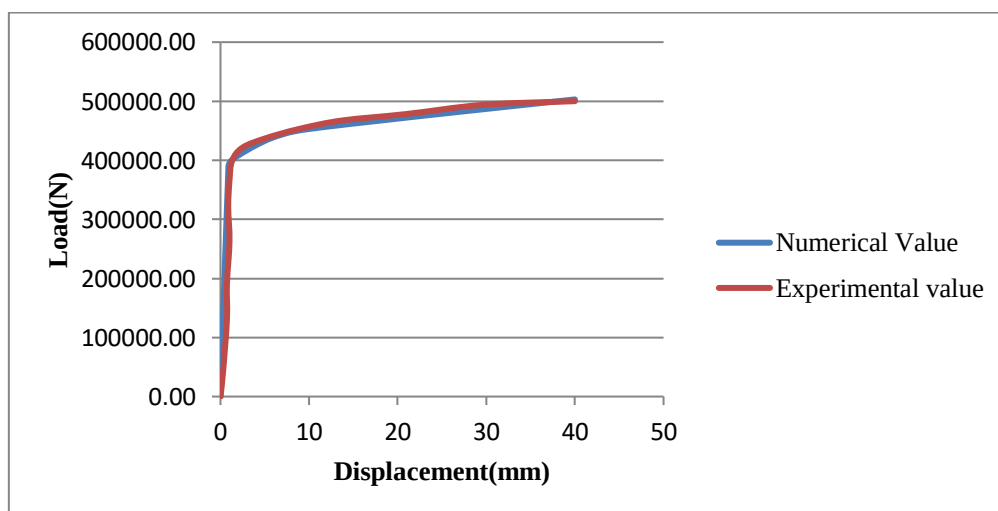
**Figure 5** Calibration Curve

Table 3. Calibration result

	Load(N)	Error %
Experimental result	500100.00	0.583
Numerical result	503020.00	

3. Calibration of Finite Element Model

The result obtained from the base journal is similar to that obtained from software analysis. The result is obtained by plotting displacement versus load graph and it is seen that experimental value obtained from the base journal is approximately equal to the value that we obtained during our validation procedure. The obtained result is given in Table 3 and the graph is shown in figure 5. The deformed shapes of tested plate girder obtained experimentally from journal and that from the FE model is shown in figure 6. The obtained error percentage is 0.583% which is less than 5% hence numerical validation is considered to be acceptable.

**Figure 6** Deformation pattern

4. Project Models

Here, all the support and load conditions used here are same as that of the validation geometry. The single web of the plate girder is split into dual web. The web thickness is halved from original geometry thickness to study the iso-volumetric strength. Six models were modeled with web spacing of 10 mm, 20 mm, 30 mm, 40 mm, 50 mm and 60 mm. The web thickness is halved to 1.91 mm. The models are shown in figure 7. Designation and dimensions of project models are given in Table 4.

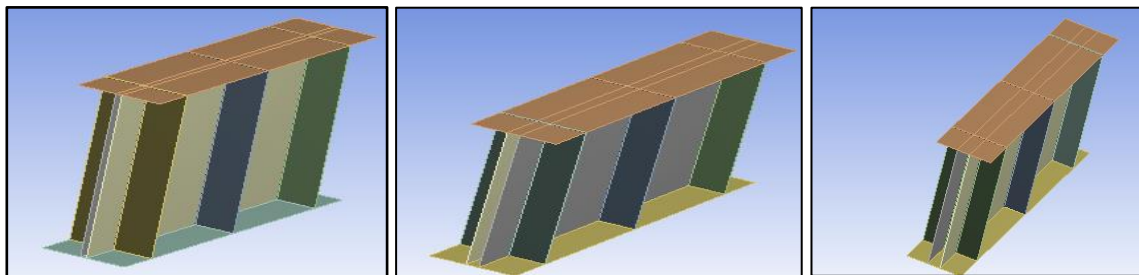
**Figure 7** FE Models of G-1, G-2, G-3 web spaced models

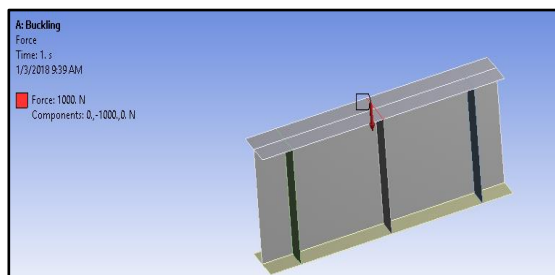
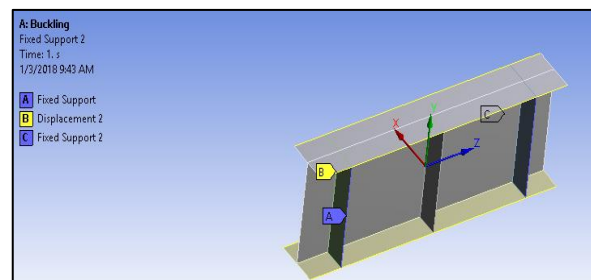
Table 4. Dimensions of project models

No.	Designation	L (mm)	A (mm)	e (mm)	h_w (mm)	b (mm)	t_w (mm)	t_f (mm)	t_s (mm)	Spacing of web (mm)
1	G-1	798.8	299.2	100.2	299.5	134	1.91	11.85	11.85	10
2	G-2	798.8	299.2	100.2	299.5	134	1.91	11.85	11.85	20
3	G-3	798.8	299.2	100.2	299.5	134	1.91	11.85	11.85	30
4	G-4	798.8	299.2	100.2	299.5	134	1.91	11.85	11.85	40
5	G-5	798.8	299.2	100.2	299.5	134	1.91	11.85	11.85	50
6	G-6	798.8	299.2	100.2	299.5	134	1.91	11.85	11.85	60

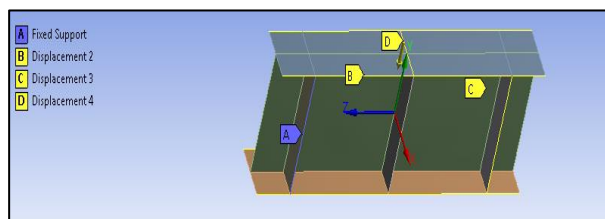
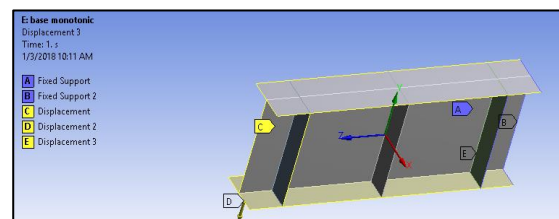
4.1. Boundary conditions of project models

4.1.1 Post Buckling

Linear buckling: An initial perturbation load of 1 kN was applied to generate the linear stresses for the Eigen value buckling and is shown in figure 8. A fixed support is provided on two edges on either side of the plate girder. A displacement is provided on the top and bottom edges with x axis restrained. The boundary conditions are shown in figure 9.

**Figure 8** Initial loading**Figure 9** Initial Boundary condition

Nonlinear Buckling: Eigen value buckling mode shape is selected as the initial geometry for the Nonlinear Post Buckling Analysis. Finite Element Modeler was used for transferring the imperfect mode shape geometry. The boundary conditions are shown in figure 10. A fixed support is provided on one end and a displacement constraint on other end to attain simply supported condition. A lateral displacement constraint is also provided on top and bottom edges. A displacement controlled load of 40 mm is provided from top to make the structure buckle. The load deflection curves were plotted after solving.

**Figure 10** Boundary conditions of axial buckling**Figure 11** Boundary conditions of monotonic load

4.1.2 Monotonic Load Performance and Testing

The boundary conditions used in monotonic loading are shown in figure 11. A fixed support is provided on two edges on one end and a displacement constraint was given on other end to suit simply supported condition. A displacement constrained load of 100 mm is provided on five edges on one end and a fixed support is provided on five edges on other end. A displacement constraint in the lateral X is provided on sixteen edges on top and bottom. The load deflection curves were plotted after solving.

4.1.3 Hysteresis Behaviour

The boundary conditions are similar to monotonic loading. The programme is based on ATC 24 Cyclic Testing Guidelines. The strain controlled load was increment in the order of $0.25d_y$, $0.5d_y$, $0.75d_y$, d_y , $2d_y$, $3d_y$, and $4d_y$, to understand the hysteresis behaviour. Though it is recommended to continue the test until complete failure, we have chosen to reduce the cycles and test the comparative behaviour. The d_y value was calculated from the load obtained in monotonic test.

5. Results And Discussions

5.1 Buckling Analysis

The load- displacement graph obtained from the buckling analysis is shown in figure 12 and critical buckling load values in figure 13.

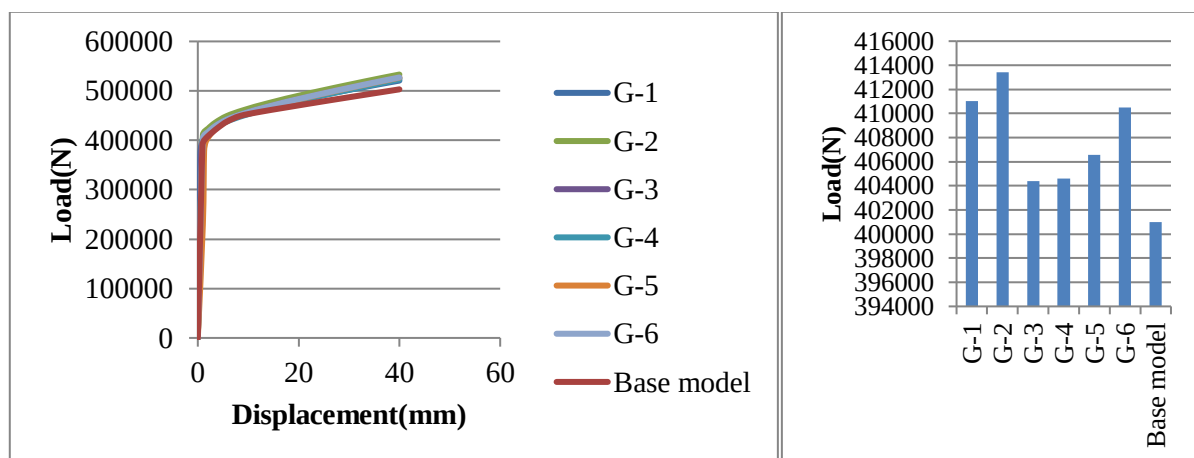


Figure 12 Load- displacement graph in buckling analysis values

Figure 13 Critical buckling load values

From the graph, it is seen that model G-2 shows higher critical buckling load.

5.2 Monotonic Loading

The load – displacement graph obtained from monotonic loading analysis is shown in figure 14. The model G-2 with 20 mm spaced web plate girder shows maximum yielding load value and is given in figure 15.

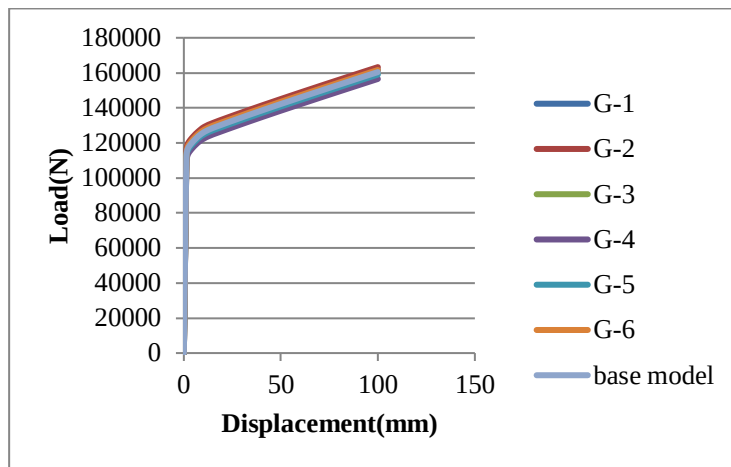


Figure 14 Load- displacement graph

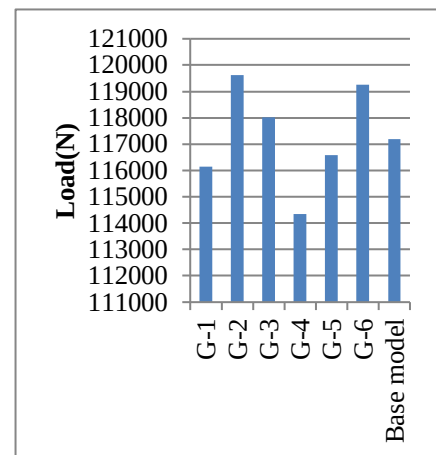


Figure 15 Yield load values

5.3 Hysteresis behaviour

The hysteresis curve corresponding to the load displacement for each model is shown in figure 16.

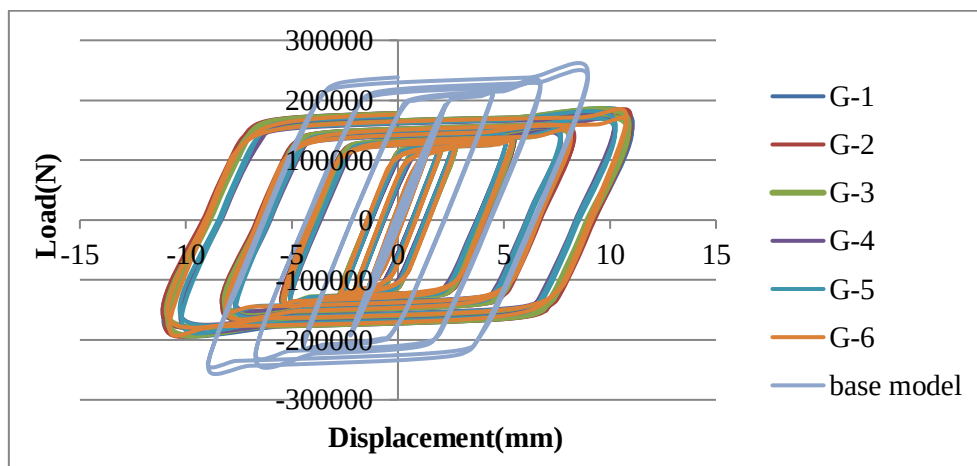


Figure 16 Hysteresis behaviour of models

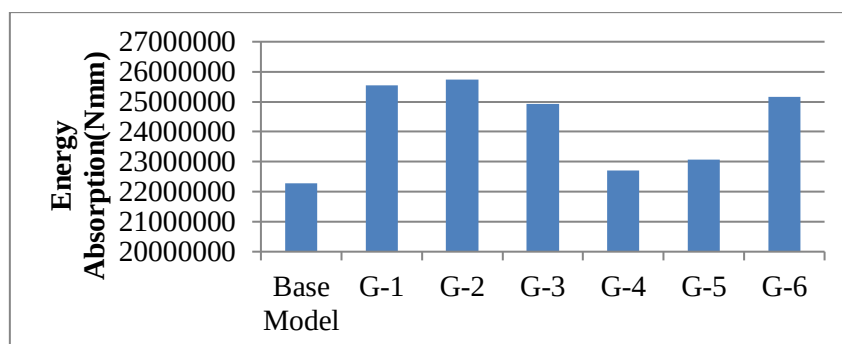


Figure 17 Energy absorption

The energy absorption capability is calculated as the area of the cyclic curve obtained for each model as given in figure 17. Model G-2 with 20 mm web spacing has more area which indicates more energy absorption.

6. Conclusion

From the buckling analysis, it is found that model G-2 with 20 mm web spacing has greatest critical buckling load and hence more load carrying capacity. In the monotonic load response we find that model G-2 with 20 mm web spacing has better load carrying capacity. Lastly, for the hysteresis response, model G-2 tends to show better energy absorption capabilities which gradually decreases and then increases when it approaches the box girder configuration. Conclusively, we find that model G-2 with 20 mm web spacing shows better load carrying capacity and energy absorption and hence can be adopted as the optimum model which may be experimentally verified and set for industrial applications.

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