Experimental Study on Buckling Behaviour and Load Capacity of Steel Plate Girders

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Abstract— This paper presents experimental procedure on the unstiffened steel plate girder, girder with bearing stiffeners, girder with bearing and alternate intermediate stiffeners. The aim of this experimental test was to observe the behavior of the steel plate girder, to study modes of failure and in particularly determine the load capacities of steel plate girder. Accordingly three set of plate girder was prepared and subjected transverse midpoint and two point loading and with the help of dial gauges deflection in plate girder is observed.

Key words: Buckling Behaviour, Steel Plate Girders

I. INTRODUCTION

In general plate girder is I-beam shape constructed from plates by using riveting or welding. It consist of vertical plates called web which resist the resulting shearing forces and two flange plates each consisting of horizontal plate which resist the normal stresses associated with bending moment. Sufficient weld must be used to insure bottom, top flange and web plate act as a one unit. Plate girder also consisting of horizontal stiffeners which increase the buckling resisting of the web and transverse stiffeners are provided near the support to increase bearing resistance and to improve shear capacity. Generally plate girder is used when large load cannot carry by rolled beams and also plate girder provides maximum flexibility and economy as compared to rolled beam. Plate girder is used in railway bridges of span 15 to 40 m and in highway bridges of span 24 to 46 m. Also used in building when it is required to support heavy concentrated load Ex-Large hall.

For more efficient and economical design of plate girder more attention must be focused on post buckling strength of plate girder and accurate prediction of ultimate load capacity of the girder. Hence many experimental and theoretical investigations carried out to understand the actual post buckling behavior and ultimate capacity of plate girder. Where Wilson [1986] was the first to introduce the post buckling behavior of plate girder web panels by studying the slender aluminium shear panels with rigid boundary elements utilized in aircraft structures. Wagner [1931] developed the theory of uniform diagonal tension field in . In contrast, Basler [1950s] proposed the theory of limited diagonal tension field. Porter et al introduced Cardiff model in which collapse of girders was associated with the emergence of plastic hinges in flanges. Cardiff model was later adopted into the British Standards. Hoglund proposed a simplified rotating stress field theory to simulate stiffened and unstiffened web plates. His theory was later introduced into the Eurocode 3.

II. SELECTION OF PROBLEM STATEMENT FOR DESIGN OF PLATE GIRDER

A simply supported welded plate girder having span of 30 m and udl of 30 kN/m and two concentrated load of 150 kN. Each acting at 10 m from both end and having load factor of 1.5, yield stress \( f_y = 250 \text{ MPa} \) is selected and design can be solved according to clauses of IS 800-2007.

The values can be obtained from selected problem is-
- Maximum bending moment =7987.5 kN/m and Maximum shear force= 990 kN
- Required flange area = 21965 mm² and Assume flange width = 550 mm.
- Thickness of flange = 40 mm. and Section of the flange = 550×40 mm.
- Total depth of girder =1680 mm. and Assume thickness of web = 20 mm.

III. MODEL ANALYSIS

As the selected span of the girder was 30 m. such a large span cannot economical to be tested in the laboratory so the model analysis technique was used. The actual structure is prototype and exact small scale image of the actual structure or machine is model. The study of models of actual structure or machine is model analysis and can be used in the research work for design and conducting model test. The objective of the model analysis is to determination of stress value (bending moment, shear force, deflection) and to determine the critical or buckling load and determination of stress distribution, stress pattern in structure.

A. Types of Model Analysis

There are two types of model analysis 1) Direct model analysis 2) Indirect model analysis.

In this study direct model analysis technique was used. In which the model is loaded exactly same manner as in prototype. Some derivatives can be used to scale down the actual structure of the girder.

Where \( K = \) Linear scale, \( j = \) Force scale, \( z_i = \) Slicing factor.

1) Area, \( A_m = (A_i / k^2) \)
2) Moment, Bending moment, Torsion, \( (M_i / M_m) = k^2 z \)
3) Force, \( (W_i / W_m) = (F_i / F_m) = j \)
4) Moment of Inertia, \( (I_5 / I_m) = k^4 z (E_m / E_i) \)
5) Material density, \( (\gamma_i / \gamma_m) = (1/ k) (E_i / E_m) \)
6) Deflection, \( \Delta_{z_m} = k \Delta_{z_i} \)

B. Reduced Dimensions and Loads of Actual Structure by Direct Method

By using above derivation dimensions and load of actual structure can be reduced and given below.

By assuming span of the model is 1.5 m.
Scale for length \( k = (L_s / L_m) = (30 / 1.5) = 20 \)
Approximate depth of girder = 80 mm
Required flange area = 54.91 mm²
Required flange width = 27.5 mm
Required thickness of flange = 2 mm
Therefore the section of the flange model is 27.5 x 2 mm
Thickness of web = 1 mm
Factored load –
Udl / m = 0.107 kN/m
1\textsuperscript{st} concentrated load = 0.472 kN
2\textsuperscript{nd} concentrated load = 0.472 kN
Maximum moment = 0.839 kN/m
Maximum shear force = 2.07 kN

Fig. 1: Cross section of the plate girder

IV. MATERIAL AND EQUIPMENT

This study involves total experimental work i.e. testing of plate girder with proper arrangement of end condition, dial gauges and loading also some views and ideas are referred from research papers. The whole matter in the research paper depends upon experiment done by researchers. So for project the required material and equipment for making whole arrangement are

- Cutting machine - The cutting machine was used for doing cut the various size of steel plate in different length and size. The Machine was capable of cutting maximum length of about 8 feet’s. The machine is operated hydraulically.
- Bar cutter - Bar cutter was used for cutting the various diameter of steel bar in proper length. It was also used for cutting the steel plates.
- Dial gauges - Dial gauges is an indicator has a dial display and in which a needle points to graduations in a circular array around the dial. In this study two 10 mm and one 25 mm dial gauge was used.
- Mild steel plate - Mild steel plate can be used as flange of thickness 2 mm, 27.5 mm and length 1500mm and web plate of thickness 1 mm, width 80 mm and length 1500 mm.
- Other material - Other necessary material for making the model and testing were loads, pliers, vertical stand, binding wire etc.

V. WELDING OF MODEL

An intermittent fillet weld of thickness of 2 to 3 mm and length of weld 40 mm was provided to connect the symmetrical flange plate and web plate throughout the length of girder. Steel plate of thickness 2 mm and depth 80 mm was used as bearing stiffener provided at mid point and at two support and alternate intermediate stiffeners provided at 250 mm from two ends.

Fig. 2: Welding of girder model

Fig. 3: Welding of alternate transverse stiffeners

Fig. 4: Welding of bearing stiffeners at middle and support

VI. EXPERIMENTAL PROCEDURE

The same experimental procedure was applied for unstiffened plate girder, girder with bearing stiffeners, girder with bearing stiffeners and intermediate stiffeners. In all set load was increase gradually and deflection value was noted at the desired position of dial gauges.

A. One Point Loading

In this assume that the compression flange is not moving laterally. In this load is applied centrally and 25 mm dial
gauge is attached below at centre of weight hanger. At a distance of L/3 one 10 mm dial gauge is attached at bottom width of flange and at a distance of 2L/3 second 10 mm dial gauge is attached at bottom width of flange.

**B. Two Point Loading**

In this assume that compression flange is not moving laterally. In this load is applied at a distance of L/3 and 2L/3. At a distance of L/3 and 2L/3 10 mm dial gauge is attached below at centre of weight hanger. At a distance of L/2 a 25 mm dial gauge is attached at bottom width of flange.

**C. Flange Displacement**

In this assuming compression flange is moving laterally. In this load is applied centrally and 25 mm dial gauge is attached at a distance of L/2 to the centre of upper flange plate thickness. At a distance of 650 mm, one 10 mm dial gauge is attached to the centre of flange plate thickness and second 10 mm dial gauge is attached exactly opposite of first 10 mm dial gauge.

**D. Web Crippling**

In this assume compression flange is moving laterally. In this load is applied centrally and a 25 mm dial gauge is attached at a distance of 30 mm from the upper end of web plate and placed at a distance L/2. One 10 mm dial gauge is attached at a distance of 15 mm from upper end of web plate just left to centre and second 10 mm dial gauge is attached at a distance of 40 mm from bottom end of web plate just right to the centre.

**E. Web Buckling**

In this assume that compression flange is moving laterally. In this load is applied centrally and 25 mm dial gauge is attached at a distance of L/2 to the centre of web plate. At one end 10 mm dial gauge is attached at a distance of 46 mm from the upper end of web plate and at another end second 10 mm dial gauge is attached at a distance of 46 mm from lower end of web plate.
VII. CONCLUSION ON EXPERIMENT

As the 47.2 kg (0.47 kN) was the calculated permissible load and during the application of transverse loading in case of unstiffened plate girder it was observed that at the load of 46 kg (0.46 kN) longitudinal deformation i.e. local buckling throughout the length of girder with distortion in cross-section was observed as shown in fig-8. Also under the transverse load it can observed that the beam undergoes bending and deflection can be takes place in the plane of load as shown in fig-9.

When plate girder subjected to under the transverse load the compressive stresses are formed. This stresses spread widely throughout the length of the girder and as the load was increases continuously undulation along the web plate is observed and as load was increases continuously. Due to this buckling of web, the shear capacity of the web gets reduced. When plate girder with bearing stiffeners is subjected to application of loading at the load of 53 kg (0.53 kN) local buckling was observed with minimum distortion in cross section. During transverse loading most of the bending stresses carried by flange. This bending stresses spread along the length of flange, due to this flange local buckling can be observed as shown in fig-12.

When girder with bearing stiffeners and alternate intermediate stiffeners subjected to transverse loading at the load of 59 kg (59 kN) the buckling of whole section of girder in S-shape was observe as shown in fig-16. This S-type shape was observed due to that some residual stresses were remaining in the girder. Due to the provision of intermediate stiffeners with bearing stiffeners the lateral torsional buckling was fully restricted i.e. the cross section act as rigid. In this case the deflection, web buckling, lateral movement of flange, web crippling, was minimum as compared to unstiffened girder and girder with bearing stiffeners. This was observed from the graph which draws from dial gauge reading.

![Fig. 11: Local buckling of girder](image1)

![Fig. 12: Showing deflection in beam](image2)

Under the transverse load when apply dial gauges at the flange. It can observed that the flange trying to move laterally i.e. lateral movement of flange takes place as shown in fig-10 and due to this instability of compression flange girder trying to tilt sideways and try to rotate about longitudinal axis. This behavior is exactly same as lateral torsional buckling as shown in fig-11. Due to this lateral torsional buckling girder losses its bending capacity.

![Fig. 13: Lateral movement of flange](image3)

![Fig. 14: Showing torsional buckling](image4)

![Fig. 15: Flange Local Buckling](image5)

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![Fig. 16: Buckling of girder in s-shape](image6)

![Fig. 17: Showing deflection value in one point loading](image7)
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Fig. 18: Showing deflection value in two point load

Fig. 19: Showing Flange displacement value

Fig. 20: Showing web crippling value

Fig. 21: Showing web buckling value

REFERENCES


