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Plate Girder – Parametric Study with Variations in Loading and Span

Aamod Garg
Undergraduate Student
Department of Civil Engineering,
MNNIT, Allahabad, India
Corresponding Author: *aamodgarg1994@gmail.com*

Abstract

The paper is based upon the derived results of variation of loading for dissimilar spans of plate girders. Plate girders have been assigned I-shaped cross section with symmetrical flanges. The depth of the girder is has been kept between one-tenth to one-twelfth of the span and is assigned according to loading and architectural requirements. The girders have been designed using simple post-critical method. The end-load bearing stiffeners have been designed. Shear capacity of web, lateral-torsional buckling, buckling and bearing capacity and torsional resistance of end-bearing stiffener has been checked through Indian Standard codal provisions. The end-stiffener connection has also been designed for ready-made usage by designers.

Keywords: *End-Bearing Stiffener, Flange Design, Lateral-Torsional Buckling, Plate Girder, Web Design*

1. INTRODUCTION

Plate girders are built-up flexural members. A flexural member is designed usually for bending and occasionally for shear. When spans are large and the loads are heavy, plate girders are usually chosen. Plate girders (as shown in Figure 1) have a moment resistant capacity between rolled I-sections and truss girders. Plate girder scan be built to any desired proportion to suit the particular requirements, and of a cross section with exactly the properties needed. The disadvantages of the truss girder are higher cost of fabrication and erection, problem of vibration and impact, requirements of higher vertical clearance and costly maintenance.

The design of a plate girder is essentially an exercise in ordinary beam design: the proportioning of a member with a section modulus adequate to resist bending, a web capable of resisting shear in the normal fashion, and sufficient stiffness, except for the greater control over the dimensions.

Since the flange provides most of the flexural strength, most of the steel must be concentrated in the flanges and as far possible away from the neutral axis of the girder which consequently results in deep, thin web. The three principal types of buckling to be considered are: shear or diagonal buckling, bending or longitudinal buckling and bearing or vertical buckling.
At locations of high shear in a girder web, the principal planes will be inclined with respect to the longitudinal axis of the member, and the principal stresses will be diagonal tension and diagonal compression, the latter of which causes the web to buckle. This problem is addressed in three ways: (1) the depth-to-thickness ratio of the web can be made small enough to eliminate the problem, (2) web stiffeners can be used to form panels with increased shear strength, or (3) web stiffeners can be used to form panels that resist the diagonal compression through tension-field action.

Utilizing all points of consideration, we utilize a designing procedure in order to obtain the most economic as well as stable section of the plate girder.

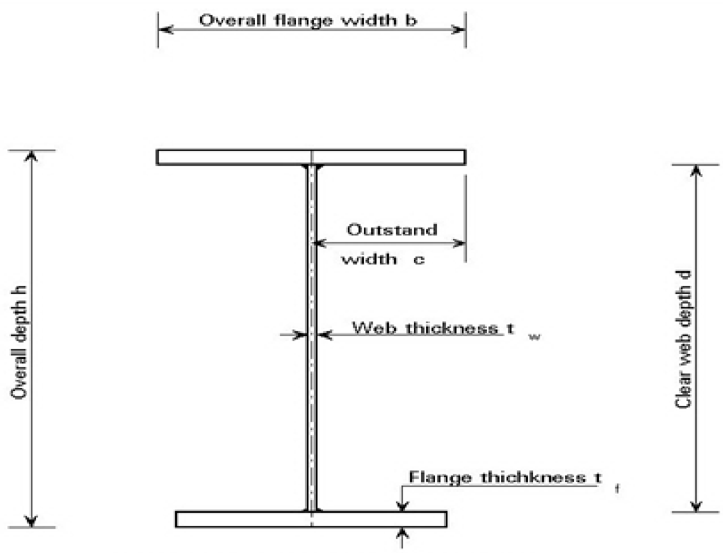

Fig.1: Built-Up Plate Girder

2. HISTORY & MERITS

The plate girders [1]were widespread in the 1880s, when they were used for construction railroad bridges. By the 1950s, welded plate girders became more popular than the bolted and riveted ones. Their size allowed builder to construct structures which were larger in dimensions and were more heavy-duty. They were usually prefabricated and their length was frequently decided by the approach of transportation utilized as shown in Figure 2.

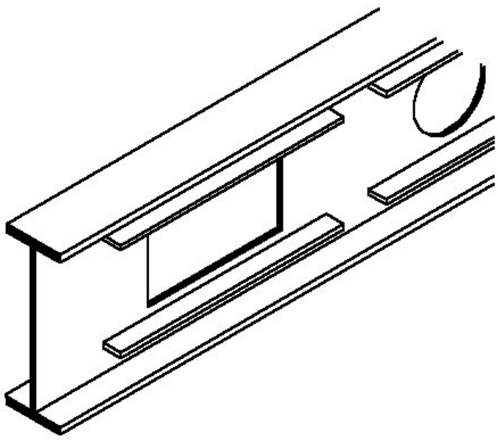

Fig.1: Plate Girder with hole for services

The advantages of using plate girders are many, but the major ones are:

i. Expedient transportation

ii. Prompt assembly

iii. Higher carrying capacity

iv. Higher stability and longer fatigue life

v. Variable spans and loading capacities

Fig.2: Usage of plate girder in bridges

3. SECTION PROPORTIONS

3.1. Web Proportioning

For webs with no longitudinal stiffeners, the maximum d/t_w ratio of the web is kept below 270 for steel with yield stress, f_y = 250 MPa. Also, *c/d* ratio, the aspect ratio, is limited to 3, where *c* is the spacing of the transverse stiffeners and *d* is the depth of the web as shown in Figure 3.

Primarily, the depth of the web[2] depends on the loads but the head room clearances for high water level and transportation of the fabricated girders to the site may limit it. The depth varies from about 1/6 to 1/15 of their spans, with average values of 1/8 to 1/12 of their spans, the former being for short spans.

The optimum value of web thickness is calculated by the following formula:

$t_w = (\frac{M_z}{f_y \times k^2})^{0.33}$

The optimum value of depth of plate girder is calculated by the following formula:

$d = (\frac{M_z \times k}{f_y})^{0.33}$

3.2. Flange Proportioning

The plate thickness is kept about 1/12 to 1/8 of the span of the girder and is limited to the maximum value of 100mm. The flange width should not exceed 1 meter in all cases as shown in Figure 4.[3]

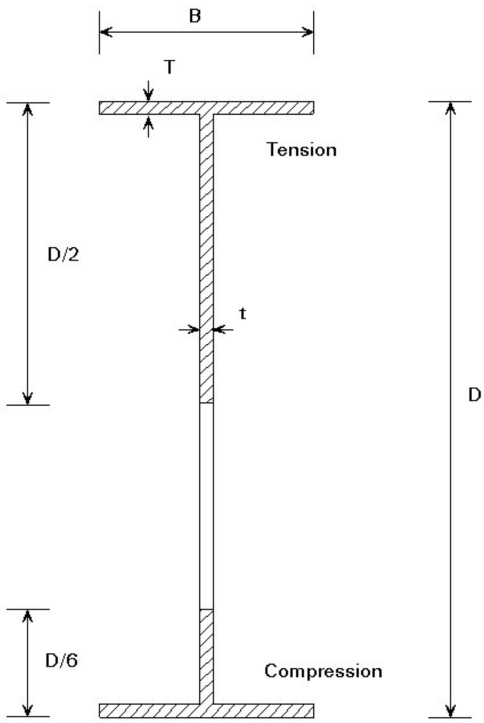

Fig.3: Reduced effective cross-section

In a welded plate girder, the flange generally consists of one plate only and the variation in the flange area id achieved either by varying the width of the flange plate or its thickness. If more than one flange plate is provided they are connected together by longitudinal welds.

Flanges are designed from the consideration of strength and rigidity[4]. Flange size may be so selected that it will not be overloaded in bending. Assuming that the flanges carry the bending moment,

$A_f = \frac{M_z \times \gamma_{mo}}{f_y \times d}$

3.3. End Panel Design

The end panel is designed by the simple post-critical method[5]. When designed by the post-critical method, the end panel along the stiffeners was also checked as a beam spanning between the flanges of plate girder (as shown in Figure 5) to resist the given shear force and moment due to the tension field anchor force.

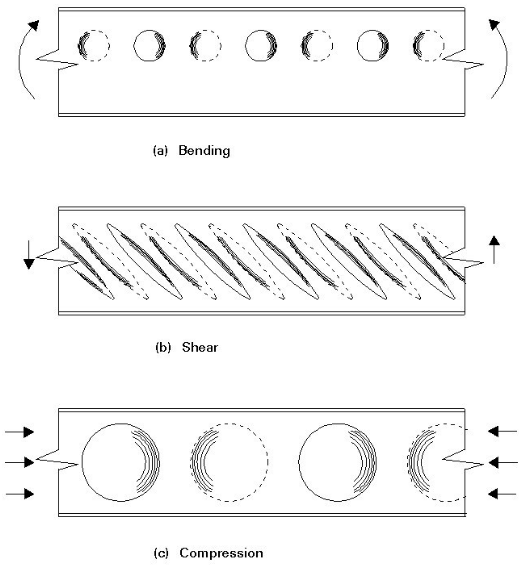

Fig.4: Slender webs buckle easily due to shear or bending

If a single stiffener is provided, it acts both as a bearing stiffener as well as the end post. When a double stiffener is provided, the bearing stiffener is designed for compressive stresses due to external reaction and the inner stiffener carries the vertical reaction from the girder.

3.4. Stiffeners

In steel building construction[6], when the web of a plate girder acting alone, without stiffeners, proves inadequate, stiffeners are provided for specific purposes as shown in Table 1.

Table 1: Types of Stiffeners

1.	Intermediate Transverse and Longitudinal Web Stiffeners	Enhancement of buckling strength of slender web due to shear.
2.	Load-Carrying Stiffeners	Prevention of local buckling of web due to concentrated loading.
3.	Bearing Stiffener	Prevention of local crushing of web due to concentrated loading.
4.	Torsional Stiffener	Provision of torsional restraint at supports
5.	Diagonal Stiffener	Provision of local re-inforcement to web under shear and bearing.

6.	Tension Stiffener	Transmission of tensile forces to web through flange.

4. DESIGN PROCEDURE

Design of a plate girder [7] basically consists in determining the most efficient and economical size of the web and flanges. A girder of high strength-to-weight ratio can be designed by incorporating the post-buckling strength of the web in design method employed. The step-by-step design procedure for an efficient plate girder is as follows:

i. The girder is usually kept laterally restrained as this will yield economical section. Lateral-torsional buckling is checked where compression flange is not restrained.

ii. Factored Self-weight of the plate girder is assumed as 9 kN/m.

iii. The optimum thickness and depth of plate girder is determined using the appropriate formulas for t_w and d where k is assumed as 180.

iv. The flange area is computed by the formula for A_f.

v. The flange is classified. Plastic flanges are preferred and therefore are designed so. For plastic flanges, the ratio of the outstand and the flange thickness,

$$b/t_f \leq 8.4\, \varepsilon_f$$

vi. The trial section is checked for bending. The moment capacity of the beam is determined as per the codal provisions (*Moment capacity* should be greater than the *sectional modulus of the section*).

vii. The flanges are curtailed [8] in length to achieve the most cost-effective design. Two weld lengths are placed along the span for each flange to web connection using the formula:

$$q_w = \frac{V \times A_f \times y'}{2 \times I_z}$$

viii. The girder is checked for maximum shear. The shear strength is a function of web slenderness ratio and aspect ratio. Intermediate stiffeners are ascertained and the web panel is checked by the post-critical method. The shear capacity of the web comprises of its strength before buckling and the post-buckling strength. The end panel is checked for tension field anchorage forces.

ix. Stiffeners are designed as required. The effective outstand is kept as $(14 \times t_q \times \varepsilon)$ where $t_q$is the thickness of the web.

x. Stiffeners are checked for buckling, bearing capacity and torsional resistance.

xi. All the web and flange splices are made using full strength fillet weld.

5. RESULTS

The plate girders are designed with a span ranging from 36 meters to 12 meters. This range is chosen as it is the usual range in which bridges and dams utilize plate girders. The uniform loading chosen is40 kN/m, 60 kN/m, 80kN/m and 100 kN/m. This loading range indicates the most widely used loading conditions taken into usage in the steel industry. Table 2 to Table 7 mentions the specifications for spans in the range of 12 to 36 meters.

Table 2: Specifications for 36m span

Span (m)	Load (kN/m)	Depth (mm)	tw(mm)	bf (mm)	tf (mm)	Stiffener Weld
36	40	2000	14	600	40	3
	60	2300	18	700	44	4
	80	2500	20	750	50	4
	100	2700	22	820	52	5

Table 3: Specifications for 30m span

Span (m)	Load (kN/m)	Depth (mm)	tw(mm)	bf (mm)	tf (mm)	Stiffener Weld
30	40	1750	14	530	35	3
	60	2000	16	600	40	4
	80	2200	18	680	45	4
	100	2400	20	750	44	5

Table 4: Specifications for 24m span

Span (m)	Load (kN/m)	Depth (mm)	tw(mm)	bf (mm)	tf (mm)	Stiffener Weld
24	40	1450	12	420	34	3
	60	1650	14	500	36	3
	80	1950	16	570	38	4
	100	2000	18	600	42	4

Table 5: Specifications for 20m span

Span (m)	Load (kN/m)	Depth (mm)	tw(mm)	bf (mm)	tf (mm)	Stiffener Weld
20	40	1300	10	380	28	3
	60	1530	12	450	32	3
	80	1700	14	500	34	3
	100	1780	16	540	36	4

Table 6: Specifications for 16m span

Span (m)	Load (kN/m)	Depth (mm)	tw(mm)	bf (mm)	tf (mm)	Stiffener Weld
16	40	1100	10	300	28	3
	60	1200	12	360	30	4
	80	1400	12	420	32	4
	100	1500	16	440	35	4

Table 7: Specifications for 12m span

Span (m)	Load (kN/m)	Depth (mm)	tw(mm)	bf (mm)	tf (mm)	Stiffener Weld
12	40	940	10	300	18	3
	60	1050	10	340	22	3
	80	1170	12	350	24	4
	100	1260	12	370	26	4

Furthermore, the above results have been plotted accordingly to show the variation across the aforesaid spans and loading conditions. Fig. 6 shows the variations of depth of plate girder with span and loading.

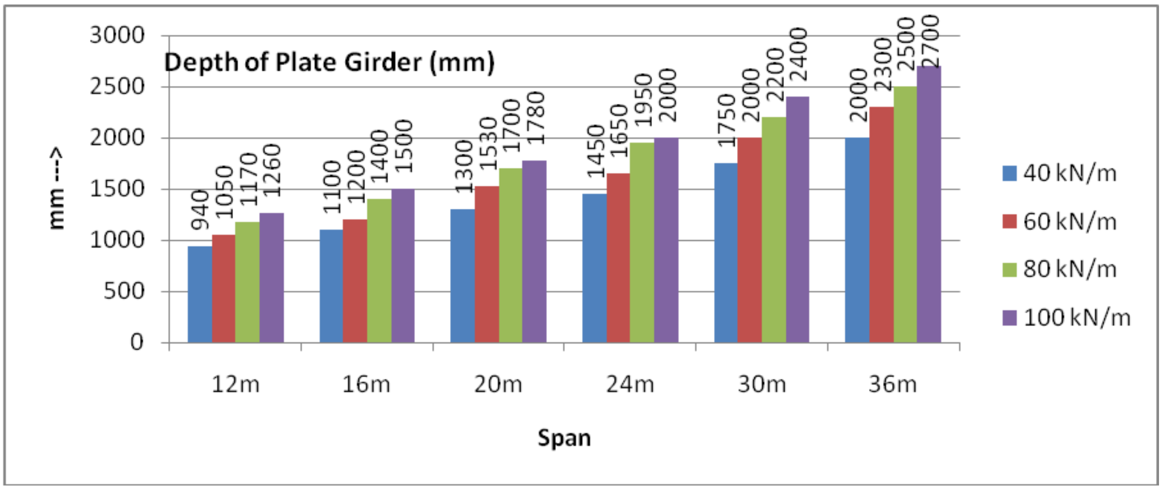

Fig.5: Depth of Plate Girder vs. Span

The Fig. 7 below shows the variations in web thickness of the plate girder with span and loading.

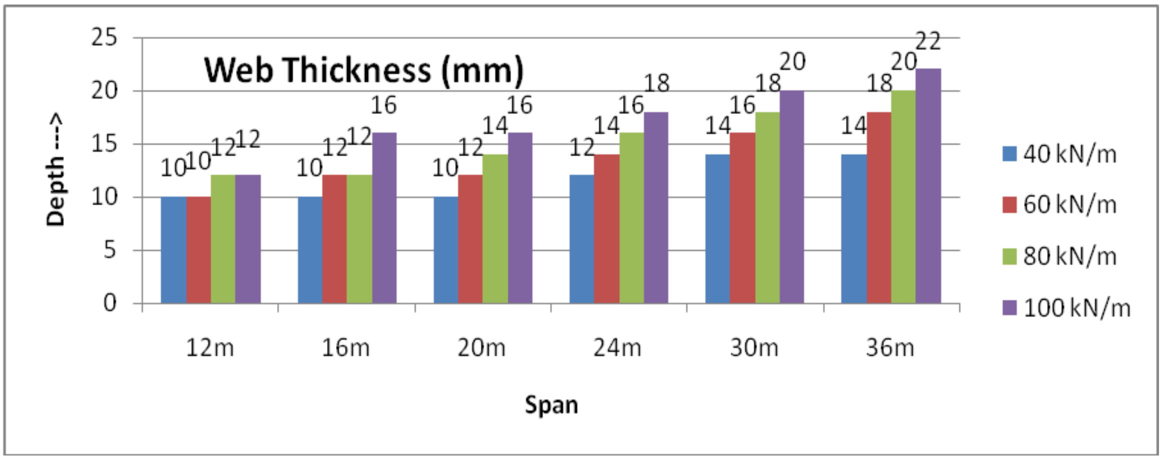

Fig.6: Web Thickness vs. Span

The Fig. 8 below displays the variation of flange breadth with respect to changes in span and loading.

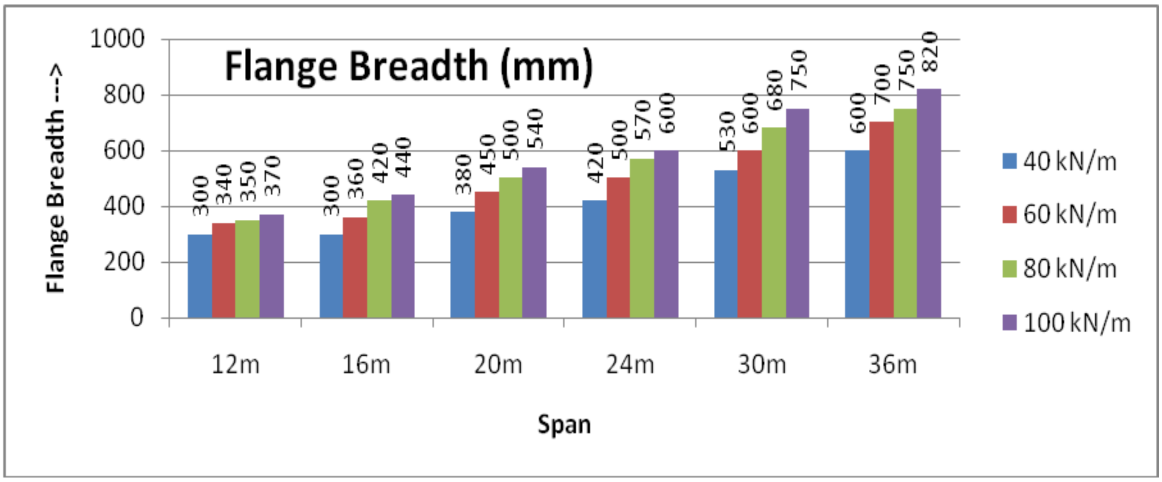

Fig.7: Flange Breadth vs. Span

The Fig. 9 below shows the flange thickness variation with span and loading.

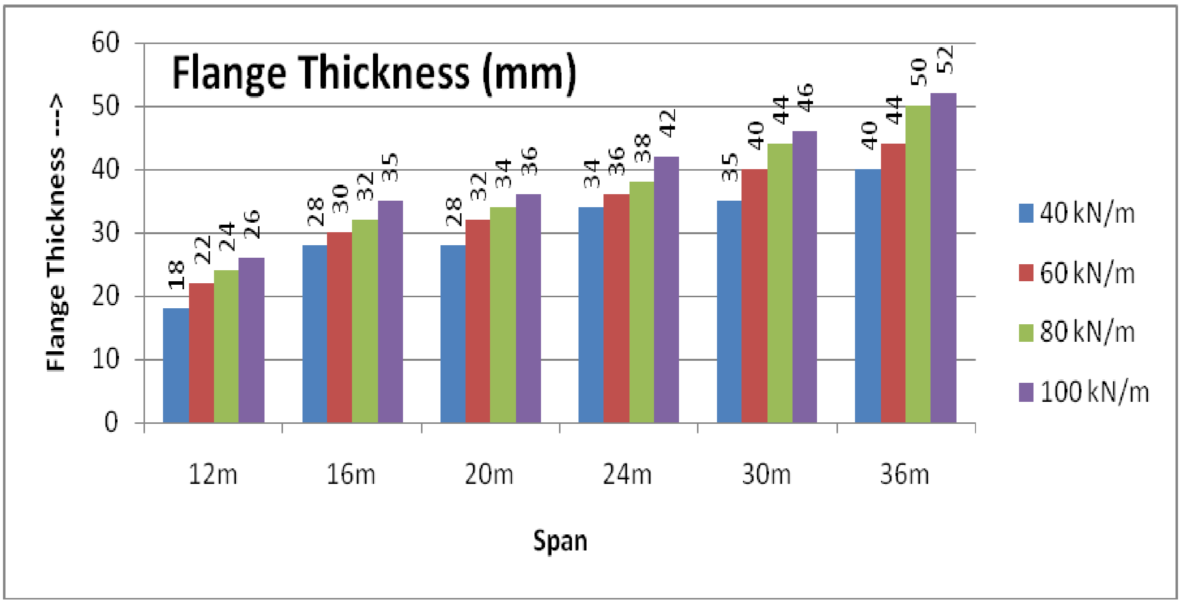

Fig.8: Flange Thickness vs. Span

CONCLUSION

Forevery 20 kN/m increase in uniform loading, following are the average increments in each field as shown in Table 8.

Table 8: Average Increment with 20 kN/m increase in loading

Depth	**171.1 mm**
Web Thickness	**1.77 mm**
Flange Breadth	**55.00 mm**
Flange Thickness	**3.00 mm**

Therefore, the paper has laid out the general specification of the design of plate girder which can be used at several junctures.

Significant technological advances have led to the development [9] of plate girders with excellent mechanical properties; important progress has also been made in the improvement of surface finishes for architectural applications. Structural research programmes across the world have laid the ground for the development of national and international specifications, codes and standards spanning both the design, fabrication and erection processes.

Recommendations are made on research activities aimed at overcoming obstacles to the wider use of stainless steel in construction. New opportunities for plate girder design arising from the shift towards sustainable development are reviewed, including its use in nuclear containment structures, thin-walled cladding, gantry cranes, bridges and composite floor systems.

The tensile residual stress on the flange and flame cutting edges increases as the width-thickness ratio increases. But the effect is not obvious if the value of width-thickness ratio is beyond the extent. The compressive residual stress on the central portion of web and projecting flange is constant. Stress in all sections meets the requirement of self-equilibrium.

There is a huge potential for research in the field of plate girders, which would certainly thrust the construction industry in India many years ahead of its current position. The plate girders are universal components which have umpteen usages. It is upon the civil engineers in India to utilize these components to their full potential in order to be able to draw India closer to its zenith in the construction industry.

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