Optimisation of Trapezoidal Corrugated Plate Girder

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Abstract. Trapezoidal Corrugated web girders is a newly developed structural design. The major advantage of such design of web is that the corrugated webs enhance the stability of beam against buckling, which results in a very economical design by the reduction in the use of web stiffeners. The flanges are made up of flat plates and welded to the trapezoidal web sheet with the modern manufacturing process and modern advance welding technology. The flanges are mainly used to provide flexural strength to the beam and web are used to increase the shear capacity of the beam. Main reason for the failure of the web is the steel yielding or web buckling. Other possible failure reasons are lateral torsional buckling of the girder and local flange buckling, separately or in combination. This paper presents a new technological solution of such a system, composed by web made of trapezoidal shape. The buckling strength of the girder is studied under different geometrical modifications performing a nonlinear finite element analysis in ANSYS.

1. Introduction
The main advantage of using corrugated web girder is to enhance the stability of beam against web buckling which may result in reduction in the use of stiffeners and which will directly make the corrugated web girder an economical system of construction. With the help of new welding technology like automatic fabrication it is possible to use corrugated web thickness up to 6mm. With the reduction in the thickness of the web the cost of the material is saved up to 30% in comparison with conventional girder and more than 30 - 35% when compared with standard hot-rolled Girder. This paper is all about the design and modelling of I section and trapezoidal corrugated plate girder and to study the effect of corrugation on strength of beam. The conventional I-section plate girder are widely used in construction of bridges, trusses, industrial structures, high-rise buildings, transmission towers, etc. It is commonly used for general construction purpose particularly suitable for structure subjected to dynamic loads and impacts such as bridge decking, girders and crane girders. With the help of modern manufacturing and highly precise welding process flanges are welded to the trapezoidal corrugated web. The flanges mainly provide flexural strength to the girder and corrugated web contribute to the shear capacity. The possible failures are web buckling or steel yielding and local flange buckling and lateral torsional buckling of girder and or in intersection [1–3].

1.1. Scope of work
An attempt has been made to study the following points.

- Study the behaviour of trapezoid corrugated web girder with the variation in web thickness and geometry.
- Numerical investigation to study the buckling behaviour,
- Compare the buckling strength and weight with the conventional plane web I-section girder.
1.2. Purpose of corrugations

The resistance of the girder against plane bending increases if we keep the web at some distance from the neutral axis. If we decrease the thickness of the web and increase the depth of the section, then there are chances that the girder may fail due to web buckling and to avoid the web buckling failure, we use the stiffeners to provide stability against elastic buckling. But the stiffeners can now be replaced with the corrugations provided on the web.

2. Numerical modelling of plate girder

2.1. Geometry

Figures 1(a) and 1(b) show the dimensions of the sections considered for the study with a span of 10 m subjected to a mid-span concentrated load of 100 kN, and Table 1 presents the variation in the geometry of corrugation.

![Figure 1. (a) Dimension of Conventional I Section Plain Web Plate Girder, (b) Trapezoidal Beam Interior Design Parameters.](image)

Section classification as per IS 800 – 2007:

\[
\frac{b}{t_f} = 8 < 8.4\varepsilon \quad \text{(Flange is plastic)}
\]

\[
\frac{d}{t_{w1}} = 133.33 > 126\varepsilon \quad \text{(Web is slender)}
\]

\[
\frac{d}{t_{w2}} = 100 > 84\varepsilon \quad \text{(Web is plastic)}
\]

**Table 1. Variation in the Geometry of Corrugation.**

| Corrugation length, \(L\) (mm) | Corrugation width, \(C\) (mm) | Thickness of web, \(t\) (mm) | Angle of corrugation |
|--------------------------------|-----------------|-----------------|-------------------|
| \(200\) | 20 | 6 | \(30^\circ\) | \(45^\circ\) | \(60^\circ\) |
| | 8 | | | | |
| \(400\) | 20 | 6 | \(30^\circ\) | \(45^\circ\) | \(60^\circ\) |
| | 8 | | | | |
| | 40 | | | | |
2.2. Finite element analysis using ANSYS
A flow chart showing analysis in ANSYS is shown in figure 2.

2.2.1. Material specification.
- Mass density: 7850 kg/m³, Poisson’s Ratio: 0.3
- Modulus of elasticity: 2×10⁵ MPa, Shear modulus: 75×10³ MPa
- Yield strength: 250 MPa, Ultimate tensile strength: 450 MPa

2.2.2. Boundary conditions. After giving material properties proper meshing is to be done for both flange and web with the proper mesh size. After meshing it is required to give proper boundary conditions. For all the models prepared in ANSYS, both the ends are fixed and the web is restrained in $U_x$ direction along the length. After proper meshing and boundary conditions loading is assigned as shown in Figures 3 and 4.

3. Analysis and weight comparison

3.1. Analysis using ANSYS

3.1.1. Structural analysis. The strength of components is the important requirement in gaining knowledge about product’s performance, lifecycle and possible modes of failure. Mechanical loading, thermal stress, bolt tension, pressure conditions and rotational acceleration are number of individuals that will show strength requirements for determine which beam is strong for same loading condition. It helps us to determine the internal forces, stresses and deformation of structures under various loading conditions.
3.2. Dead weight comparison
a) For Conventional I-girder as shown in Figure 4.
   Web plane thickness = 6 mm, Total span = 10m, Depth of web = 800mm, Buckling resistance = 308.76 kN, Self-weight = 1507.20 kg.
b) For corrugated web plate girder as shown in Figure 3.
   Web plane thickness = 6mm, Total span = 10m, Depth of web = 800mm, Angle of corrugation = 30°, Corrugation width = 20mm, Corrugation length = 400mm, Buckling resistance = 1029.5 kN, Self-weight of web = 1511.4 kg.

4. Results and discussions

4.1. Comparison of buckling load
The variation of buckling load with the geometry is presented in Table 2.

| Corrugation length, (mm) | Corrugation width, (mm) | Thickness of web, (mm) | Buckling load (kN) |
|--------------------------|-------------------------|------------------------|-------------------|
| Conventional I Girder    | 6                       | 632.73                 |
| Conventional I Girder    | 8                       | 308.76                 |
| 200                      | 20°                     | 6                      | 1039.4            |
|                          |                         |                        | 1046.7            |
|                          |                         |                        | 1049.5            |
|                          |                         | 8                      | 1062.9            |
|                          |                         |                        | 1092.7            |
|                          |                         |                        | 1067.5            |
|                          | 40                      | 6                      | 1094.9            |
|                          |                         |                        | 1159.5            |
|                          |                         |                        | 1106.9            |
|                          |                         | 8                      | 1110.4            |
|                          |                         |                        | 1177.8            |
|                          |                         |                        | 1121.0            |
|                          | 400                     | 6                      | 1029.5            |
|                          |                         |                        | 1036.7            |
|                          |                         |                        | 1029.6            |
|                          |                         | 8                      | 1045.3            |
|                          |                         |                        | 1080.0            |
|                          |                         |                        | 1050.5            |
|                          | 40                      | 6                      | 1080.0            |
|                          |                         |                        | 1108.6            |
|                          |                         |                        | 1082.7            |
|                          |                         | 8                      | 1096.4            |
|                          |                         |                        | 1128.7            |
|                          |                         |                        | 1101.3            |

Figure 5. Variation of buckling load due to corrugation angle.

Figure 5 shows the graph of the buckling load vs variation in the angle of corrugation. The Comparison is made by varying the angle of corrugation with the constant length of corrugation plate of 200mm and constant web width of 200mm and thickness of 8mm. From Figure 5, it is seen that maximum buckling load is found at 45°. From Table 2, it is found that the other girders also show maximum buckling strength at the corrugation angle of 45°.

Figure 6. Variation of buckling load due to corrugation length.
Figure 6 shows the graph of buckling load vs variation of corrugation plate length. The comparison is made with the beam having constant web width of 40 mm, constant web thickness of 6 mm and varying corrugation length of 200 mm and 400 mm. It can be seen that the maximum buckling load is for the corrugation plate length of 200 mm having a corrugation angle 45°. From Table 2, it is found that other girders also show maximum buckling strength with corrugation length of 200 mm with the other parameters being same.

![Graph showing buckling load vs variation of corrugation plate length](image)

**Figure 7.** Variation of buckling load due to web thickness

Figure 7 shows the graph of buckling load vs variation of corrugation web thickness. The comparison is made for the beam having constant corrugation length of 200 mm and constant web width of 40 mm and by varying the web thickness of 6 mm and 8 mm. From Figure 8, it can be seen that with the increase in the web thickness the buckling load also increases with the maximum buckling load at the corrugation angle of 45°. From Table 2 it is found that the other beams also show maximum buckling strength.

4.2. *Comparison of weight*

Table 3 shows the dead weight of the modelled beam for the span of 10 m and the comparison is made between the conventional I-girder and trapezoidal corrugated web beam.

| Corrugation length, (mm) | Corrugation width, (mm) | Thickness of web, (mm) | 30°  | 45°  | 60°  |
|-------------------------|------------------------|----------------------|------|------|------|
| Conventional I Girder, C_w | 6                      | 1507.2               |
| Conventional I Girder, C_w | 8                      | 1632.8               |
| 200                     | 6                      | 1515.5               |
|                         | 8                      | 1643.8               |
|                         | 20                     | 1521.3               |
|                         | 40                     | 1651.6               |
| 400                     | 6                      | 1511.4               |
|                         | 8                      | 1638.5               |
|                         | 20                     | 1515.4               |
|                         | 40                     | 1643                |

5. **Conclusions**

Buckling strength is more for the trapezoidal corrugated web girder compared to conventional I-girder. The buckling strength is maximum for the corrugation angle of 45°. Buckling strength increases significantly for the corrugation width of 200 mm as compared to 400 mm. Buckling strength is more for the web of thickness 8 mm as compared to 6 mm thickness. Weight of corrugated in higher as compared to plane web. If we compared the buckling strength and weight for 8 mm thick plane web and 8 mm thick corrugated web with 30° angle and 400 mm corrugation length and 20 mm corrugation width the buckling strength increases by 65% with the 8% increase in weight.
6. References

[1] Karthikeyan K and Senthil P 2018 A study on flexure capacity of steel beams with corrugated web *International Journal of Civil Engineering and Technology* 9(4) 679–89

[2] Limaye A A and Alandkar P M 2013 Strength of welded plate girder with corrugated web plate *International Journal of Engineering Research and Application* 3 1925–30

[3] Sachin K G, Sowjanya G V and Muralidhar N 2014 Behaviour of plate girder with flat web and corrugated web *International Journal of Civil and Structural Engineering Research* 2(1) 130–6

[4] Duggal S K 2010 *Limit State Design of Steel Structures* (Tata McGraw Hill Education Private Limited: New Delhi)

[5] IS 800 2007 *Code of Practice for General Construction in Steel* (Bureau of Indian Standards: New Delhi)