Study of steel I-beams with plate corrugated web at restrained torsion

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Abstract: The behavior of the steel I-beam with plate corrugated webs in conditions of restrained torsion is considered. The problem is solved numerically in the «ANSYS 14.5» software package based on spatial model where finite elements of shell type are used. Results obtained allowed us to calculate geometric characteristics of web beams associated with torsional deformation in order to continue to perform the calculation of these beams on the rod model. Analysis was made using two models of corrugated web I-beams with different corrugation configurations with geometric parameters and giving similar values of metal. A comparative analysis of the stress-strain state of corrugated beams and I-beams with flat web at torsion with bend.

1. Introduction

Constructions consisting of thin-walled rods are actively used in modern design of buildings, structures and other technical objects. The most common rods of this type include rolling profiles, welded I-beams with different wall outlines, for example, corrugated and perforated.

The use of thin-walled elements provides a significant reduction in the own weight of the structure and, as a result, material savings.
In paper [1] devoted to the study of the overall stability of beams with corrugated web, the same characteristics are used as in the calculation for restrained torsion.

In general, a lot of research has been done on the subject of transverse torsional bending of corrugated beams, but the general methodology of their design has not been developed.

Currently, designers have to either use relatively complex and labor-intensive finite element models for each unique design in order to catch the positive effects of corrugated web, or use the same approach as for beams with flat webs, thereby ignoring any additional resistance to corrugated webs from the point view of torsional stability [1].

The purpose of this work is to determine the strength and stiffness characteristics of I-beams with corrugated (trapezoidal and triangular) webs at restrained torsion.

To achieve this goal, the calculation was performed in «ANSYS» software package using a spatial FE model with elements of the shell type. On the basis of obtained deformed scheme, the geometric characteristics associated with torsional deformations are determined, which can be used to further calculate the BPCW in the spatial framework of the rod model.

2 Numerical study of I-beams with corrugated web at restrained torsion

Variants of discretization of beams of complex section with different types of deformed state are given in [2-5].

2.1 Justification of the calculated models

Consider three models of I-beams with geometrical parameters, giving close values of metal consumption.

*Model 1* – I-beam with flat web (M1).

*Model 2* – I-beam with corrugated trapezoidal web (M2).

*Model 3* – I-beam with corrugated triangular web (M3).

Beams work in conditions of restrained torsion. This type of deformed state is provided by action of concentrated force having an eccentricity relative to the beam axis. In Fig. 1.b. shows an example of such loading for I-beam with trapezoidal web.
Figure 1. Restrained torsion with bend of I-beam with corrugated web:
  a) spatial 3D model, b) the cross section of calculation model M2.
Designations of geometric parameters adopted for beams with corrugated webs (M2, M3) are shown in Fig. 1 and in Fig. 2.

Figure 2. Parameters defining the web geometry of calculation models: a) M2, b) M3.
Numerical values of the geometric and physical parameters of these models are given in Table 1 and 2.

Table 1. Initial data of accepted models.

| Models | Parameters of the cross section | Calculated data |
|--------|---------------------------------|-----------------|
|        |                  |                |
|        | \( H, \) \( h, \) \( b_f, \) \( t_f, \) \( t_w, \) \( E, \) \( G, \) \( P, \) \( L \) |                |
|        | mm \text{ mm} \text{ mm} \text{ mm} \text{ mm} GPa GPa kN mm |
| M1     | 400 374 200 133 200 76.9 10 6000 |
| M2     | 400 374 200 133 200 76.9 10 6000 |
| M3     | 400 374 200 133 200 76.9 10 6000 |
Table 2. Parameters of the corrugated webs.

| Models | $a$, mm | $f$, mm | $d$, mm | $\varphi$ |
|--------|---------|---------|---------|-----------|
| M2     | 200     | 100     | 100     | 45°       |
| M3     | 200     | 100     | 100     | 26,6°     |

2.2 Numerical study of stiffness and strength characteristics of the calculation models

Within the confines of this work, we will present only some comments concerning the features of modeling and matching of individual finite elements. The calculation was made using software package «ANSYS 14.5», where shell finite elements SHELL181 were used.

Generation of a grid of a quadrangular type was made automatically. The size of the finite elements was within 43 mm on the long side. Near the junction of the web and the flang, the mesh size was reduced to 9 mm. The calculation was carried out in elastic stage.

The deformed diagram of the calculation models of beams after loading with a torsional - bending force is shown in Figure 3. The calculation results are shown in Figures 4-6.

Figure 3. Deformed design beams at restrained torsion: a) I-beam with flat web (M1), b) I-beam with trapezoidal webs (M2), c) I-beam with triangular webs (M3).
2.3 Comparative analysis of the results

Let’s compare the maximum values of normal and shear stresses, as well as maximum deflections \( f_{\text{max}} \) and angles of twist \( \theta \) for models of beams M1, M2, M3, obtained in software package «ANSYS 14.5» (Table 3).

| Models | \( \sigma_{\text{max}} \) \( \text{MPa} \) | \( \tau_{\text{max}} \) \( \text{MPa} \) | \( f_{\text{max}} \) \( \text{mm} \) | \( \theta \) \( \text{(°)} \) |
|--------|-------------|-------------|-------------|-------------|
| M1     | 124,87      | 23,67       | 33,7        | 3,4         |
| M2     | 108,73 (12,9%) | 21,7 (8,3%) | 27,4 (18,7%) | 2,8 (17,64%) |
| M3     | 114,75 (8,1%) | 24 (1,4%)   | 27,8 (17,5%) | 2,9 (14,7%)  |
From the table shows that for the models M2 and M3 all stiffness and strength properties are better than in M1. In brackets is indicated the relative difference in parameters of the corrugated beams compared to the model M1.

### 3 Determination of geometric characteristics of the cross-section of corrugated web I-beams with different corrugation configurations at restrained torsion

Studies to determine the geometrical characteristics of restrained torsion of single-span double-support beams with corrugated webs of arbitrary type were performed in [6-10]. We present results of the study of restrained torsion of the beams with corrugated webs for the cantilever calculation scheme. Studied 5 models of corrugated trapezoidal web beams (BCTW1-BCTW5). In Table 4 shows characteristics of these beams. The designations of the parameters of the cross-section of corrugated beams, shown in Table 4 are shown in Fig. 1 and 2.

**Table 4. Parameters of the cross section of the models corrugated beams.**

| Accepted models | $H,$ mm | $h_w,$ mm | $b_f,$ mm | $t_f,$ mm | $t_v,$ mm | $f_v,$ mm | $a_v,$ mm | $d_v,$ mm | $\varphi$ |
|-----------------|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|---------|
| BCTW1           | 200      | 184       | 100       | 8         | 2         | 50        | 180       | 50        | 45$^\circ$ |
| BCTW2           | 300      | 282       | 150       | 9         | 3         | 76        | 150       | 76        | 45$^\circ$ |
| BCTW3           | 400      | 374       | 200       | 13        | 3         | 100       | 200       | 100       | 45$^\circ$ |
| BCTW4           | 500      | 468       | 200       | 16        | 4         | 80        | 200       | 80        | 45$^\circ$ |
| BCTW5           | 600      | 564       | 200       | 18        | 4         | 100       | 300       | 100       | 45$^\circ$ |

Based on theoretical expressions, we obtain the following formulas for determining the geometric characteristics of the selected models of beams at restrained torsion.

Pure torsion $I_K$ for the cross-section of corrugated beams is calculated by the formula 3 [11].

To determine flexural-torsional characteristic $K$, the equation is used:
Sectorial moment of inertia $I_w$ for the cross-section of corrugated beams is determined by the formula 23 [12]:

$$I_w = \frac{b_f^2 H^2 t_f}{24}.$$  

### Table 5. Results calculation of the geometric characteristics of models corrugated beams.

| Models  | $I_K$, cm$^4$ | $T$, kN cm$^2$ | $I_w$, cm$^8$ | $K$, m$^3$ |
|---------|---------------|----------------|---------------|------------|
| BCTW1   | 4.15          | 26626          | 11285.3       | 1.08       |
| BCTW2   | 9.1           | 58013          | 100648        | 0.54       |
| BCTW3   | 35.56         | 227854         | 606129.4      | 0.43       |
| BCTW4   | 43.6          | 427654         | 1168128       | 0.427      |
| BCTW5   | 97.76         | 607227         | 1908576       | 0.4        |

The obtained values of the geometrical parameters of the corrugated beams are supposed to be used when solving problems of static calculation of spatial rod frames with corrugated elements [13].

### 4 Conclusion

Comparative analysis of the results of the automated calculation of steel I-beams of the same metal intensity revealed that during torsion with a bend:
- beams with plate corrugated webs are more rigid than regular flat-webs I-beams;
- extreme stress values in the corrugated beams also have smaller values (by 4-12%) compared to flat-web beams.

The results of the studies performed allow us to improve the methods of analysis and the search for optimal parameters of I-beams with corrugated webs of arbitrary type, which are part of flat and spatial frameworks.
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