The Researches on I-beam of different web’s shapes

Chao SHUANG, Dong Hua ZHOU

School of Civil Engineering, Kunming University of Science and Technology, Kunming, Yunnan650500, China

Email: ff564lk@vip.qq.com

Abstract: When the ratio of height to thickness of girder web is relatively high, generally the local stability of web is enhanced by setting up stiffeners. But setting up stiffeners not only increase the use of material, but also increases the welding work. Therefore, the web can be processed into trapezoid, curve, triangles and rectangle to improve its stability. In order to study the mechanical behavior of the web with different shapes and its local stable bearing capacity, the finite element analysis software ANSYS was used to analyze the six I-beam, and the stress characteristics under different web forms were obtained. The results show that the local stability bearing capacity of the I-beam is improved, especially the shape of the trapezoidal web and the shape of the curved web have a significant effect on the local stability of the I-beam. Finally, based on the study of the local stability of the trapezoidal web and the curved web, the influence of their geometrical dimensions on the local stable bearing capacity is also studied.

1. Introduction

Mechanical properties of different web’s shapes of I-beams have greatly improved. Compared with straight web beam, corrugated web beam has many advantages, the structure of corrugated steel webs has been applied to aviation, marine, industrial and civil buildings and bridges. The use of corrugated webs instead of straight webs in I-beams was originally proposed by structural experts. In the analysis of deep web instability, they recognized the defects of straight webs and advocated the use of corrugated webs [1]. The unique characteristics of corrugated steel webs are an effective way to improve the economic indicators of beams. At present, our country's research on corrugated webs is mainly focused on trapezoidal webs and research it’s shear, bending and other’s properties [2 3]. On the basis of the trapezoidal web, we have added triangular web, rectangular web and curved web, and studied its local stability, and further analyzed the influence of the geometrical size on the local stable bearing capacity.

2. The Shape of The Web

Combined with the engineering practice and consideration of the construction convenience, the design of the web’s shape includes: rectangle, trapezoid, curve, and triangular shapes. (see Figure 1). All shapes have the same height, h = 50, w = 250. Six kinds of steel beams, including straight web and straight web with stiffener, are designed to comparative analysis.
3. Finite Element Modeling

3.1 Element Types and Material Properties

SHELL181 [4] is used for webs, flanges, and stiffeners of the I-beam. Each node of the SHELL181 unit has 6 degrees of freedom (three linear displacements and three rotations), through the unit we can consider bending, torsion and warping deformation.

The thickness of the upper and lower flange of the steel beam is 40mm, the length is 200mm, the web adopts thin-wall steel, the thickness is 5mm, and the height is 800mm. The elastic modulus (E) of the above material is 200GPa, and the Poisson's ratio is 0.3.

3.2 Boundary Conditions and Loads

Due to the structural symmetry, it is more effective to model specimen by 1/2 model structure. In order to calculate accurately, the stiffener is set at both ends of the beam and concentrated load. The calculation diagram shown in Figure 2.

3.3 Verification of the Finite Element Model

In order to check the correctness of the analysis of finite element model and accuracy of calculation, We select a straight web I-beam with a simple constraint on both ends, and apply uniformly distributed constraints to it, we use ANSYS to establish the finite element model to calculate the critical moment, and then we use the theoretical formula to calculate the critical moment, the two results were
compared to verify the rationality of finite element model. The theoretical calculation of the critical moment of steel beams is based on the method one and method two, method one and method two adopt the formula of Eurocode 3 [5]. The formula for method one is

$$M_{cr1} = \zeta N_{cr} \left( \sqrt{c^2 + 0.25 z_p^2} + 0.25 z_p \right),$$

in the uniformly distributed load, $\zeta$ takes 1.12, $N_{cr} = \frac{\pi^2 E I_z}{l^2 Y_M}$.

c² = (I_w + 0.039 · l² · I_t)/I_z, $z_p = -h/2$. The formula for method two is

$$M_{cr2} = \frac{1.32 b t E I_y l h^2}{I_k^2}.$$  

The dimensions of the I-beam and the calculation results are shown in Table 1.

| Web's Shapes | Critical Concentrate Force Fcr (10³ KN) | Critical Moment Mcr (10³ KN/m) | Web Area (m²) | Relative Web Area | Increased Percentage of Stable Bearing Capacity | Bearing Capacity Per Unit Web Area (10³ KN /m²) | Relative Bearing Capacity Per Unit Area of Web |
|--------------|----------------------------------------|-------------------------------|--------------|------------------|-----------------------------------------------|-----------------------------------------------|---------------------------------------------|
| Straight web | 0.5                                    | 0.75                          | 4.8          | 0                | 0.1                                           | 1                                            |                                             |
| Straight web with stiffener | 2.87                                   | 4.31                          | 8.48         | 0.77             | 4.74                                          | 0.34                                         | 3.25                                        |
| Trapezoidal web | 8.35                                   | 12.53                         | 5.38         | 0.12             | 15.7                                          | 1.55                                         | 14.9                                        |
| Curved web   | 9.56                                   | 14.34                         | 5.38         | 0.12             | 18.12                                         | 1.78                                         | 17.06                                       |

From the results of Table 1, it can be seen that the result of the finite element model of the straight web I-beam has a small deviation with the result of the theoretical calculation, which shows that the boundary of the finite element, the equivalent load and the mesh satisfy the accuracy requirements, so the constraints, loads and the mesh of the straight web I-beam can apply to the finite element analysis of other web's shapes.

4. Result Analysis

4.1 Local Stability

The local stability of the web with different shapes is obtained by establishing a finite element model verified previously. (see table 2). As the steel beams have the same flange dimensions, their material consumption can be seen only by comparing the area of the web. The relative web area, the increased percentage of stable bearing capacity and the relative bearing Capacity Per Unit Area of Web are calculated relative to the value of the straight web. (values of other web shapes-values of the straight web)/values of the straight web.
Through the above table we can see that the local instability of different webs is very different. Compared with the straight web, we can obviously find the local stability of straight web with stiffeners is minimum, and the local stability of trapezoidal web and curved web of have the maximum capacity.

For the bearing capacity of the unit area, according to the size of the local bearing capacity, the shape of the web shall be: straight web, straight web with stiffeners, rectangular web, triangular web, trapezoidal web, and curved web. The results are consistent with the results of the direct comparison of the bearing capacity. It can be seen that the material utilization of the curved web is the highest, it’s 17.06 times to that of the straight web. Followed by the trapezoidal web, it’s 14.9 times to that of the straight web, and the straight web with stiffeners is the measures that we often used to improve the local stability is turned out to be the lowest utilization of materials, only 3.25 times.

4.2 Comparison of Local Instability Diagrams
Now, the local instability diagram of the different web’s shapes is compared, as shown in Figure 3.

(a) Straight web  (b) Straight web with stiffener

(c) Trapezoidal web  (d) Curved web
Obviously, the deformation of local instability of the straight web is the largest, and the deformation of local instability of the curved web is the smallest.

4.3 The Influence of The Geometric Dimensions of The Trapezoidal Web and The Curved Web on The Local Stability

According to the previous study, the local stability bearing capacity of the trapezoidal web and the curved web has been found to be the largest, so we study influence of the geometric dimensions of the trapezoidal web and the curved web on the local stability to make paper more integral. The dimensions of the trapezoidal web and the curved web are shown in Figure 4. The abscissa is amplitude h, and the ordinate is the bearing capacity. The variation of the wavelength w of the trapezoidal web is caused by the change of a.
It can be seen from the graph that the shorter the length of the trapezoidal web’s wavelength is, the larger the local stable bearing capacity is, but the trapezoidal web has a largest local stable bearing capacity. The maximum local stable bearing capacity is related to the wavelength and the amplitude, the wavelength is shorter, the maximum local stable bearing capacity is larger. Before the local stability reaches the maximum bearing capacity, the greater the amplitude is, the local stability bearing capacity is. For the curved web, the larger the amplitude and the shorter the wavelength is, the greater the local stability bearing capacity is.

5. Conclusion
1. The shape of web has a significant influence on its local bearing capacity. Trapezoidal webs and curved webs are more reasonable, both of which not only play an important role in improving local stability, but have good economic benefits and good practical value.
2. For the trapezoidal web, before the local stability reaches the maximum bearing capacity, the larger the amplitude and the shorter the wavelength is, the greater the local stability bearing capacity is.
For the curved web, there is no maximum local stable bearing capacity, the larger the amplitude and the shorter the wavelength is, the greater the local stability bearing capacity is.

Acknowledgments
This work was financially supported by the National Natural Science Foundation (51668027) and (51468026).

References
[1] Chang F Q, Zhang W Z, Wu B. Numerical Analysis of Strength of I-Beam With Corrugated Web[J]. Steel Construction, 2005, 20(2): 4-7.
[2] Song Y J, Ren H W, Nie J G. Nonlinear Shear Buckling Analysis of Corrugated Steel Webs[J]. Journal of Highway and Transportation Research and Development, 2005, 22(11): 89-92.
[3] Zhang Z, Li G Q, Sun F F. State-of-the-Art of Research on H-beam with Trapezoidally Corrugated Webs[J]. Progress in Steel Building Structures, 2008, 10(6): 41-46.
[4] Wang X M. ANSY Structural Analysis Unit and Application[M]. Beijing: China Communications Press, 2011.
[5] Eurocode 3: Design of Steel Structures: Part 1-1: General Rules and Rules for Buildings[S]. European Committee for Standardization, 2005.