Research on ultimate Bearing Capacity of large Steel Box Girders under bending Moment

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Abstract. In order to study the ultimate bearing capacity of large welded box girder with initial imperfections, this paper considers the influence of material nonlinearity, geometric nonlinearity and initial imperfections, and uses the arc length increment method to modify Newton-Raphson formula to solve the problem. Through a large number of numerical simulation calculation, the calculation formula of stability ultimate bearing capacity of box girder under bending moment is summarized. The formula takes web height thickness ratio and flange width thickness ratio as parameters, which has a certain reference value for calculation and design of stability ultimate bearing capacity of welded box girder.

Keywords: box-section beam, ultimate bearing capacity, bending moment, nonlinearity.

1. Introdution

As an excellent bearing member, steel box girder has been widely used in various projects [1-7]. Steel box girder as thin-wall closed structure, its torsional rigidity is large, and the overall performance is good. But in the large steel box girder structure, the shear deformation effect is large and the shear lag effect is obvious, because the wall plate is relatively thin. At the same time, under the action of bending moment, the ultimate bearing capacity of steel box girder should consider the mutual influence of side length ratio, width to thickness ratio, length to fineness ratio, and initial defect of section. However, GB 50017-2017 *Code for Design of Steel Structures* [8] didn't provide the expression of ultimate bearing capacity of box-section beam under bending moment on width-to-thickness ratio of flange plate, height-to-thickness ratio of web plate and other parameters. At the same time, Lin Tao and Yang Hailin etc. [9-10] studied the ultimate bearing capacity of steel-concrete structures, but the webs of their structures were all concrete structures. Cao Ke [11] studied the influence of initial defects on the ultimate bearing capacity of steel box girder under fixed section, without considering the influence of the height-to-thickness ratio of web plate and the width-to-thickness ratio of flange plate on the ultimate bearing capacity. Considering the material nonlinearity, geometric nonlinearity and initial defects, the calculation method of ultimate bearing capacity of large welded box girder under bending moment is studied in this paper to provide reference for the design of box girder.

2. Computational Models and Initial Defect Assumptions

The simply supported box girder is analyzed as the object in this paper. The calculation diagram is shown in Figure 1. A total of 162 calculation models were established to simulate the influence of the height-to-thickness ratio of the web plate and width-to-thickness ratio of the flange plate on the ultimate bearing capacity of steel box girder under bending moment. The steel girder employs the welded box girder section. Steel box girder span L=50 m, beam height H (from 1.8m to 2.5m), beam width B=1.5m, flange plate thickness D (10mm-40mm), flange plate width/thickness ratio B/d (32.5-130); web plate thickness t (6mm-32mm), web plate height/thickness ratio H/ T (62.5-333.3). The steel box girder in each state is equipped with supporting stiffeners at the end to ensure the stiffness of the supporting parts, and the transverse stiffeners are arranged at a distance of 2.0 meters. The steel used in the simulation calculation is low alloy high strength structural steel Q235, yield strength 235MPa, elastic modulus E= 2.06×1011N /m2, Poisson's ratio 0.3, as shown in Fig. 2.

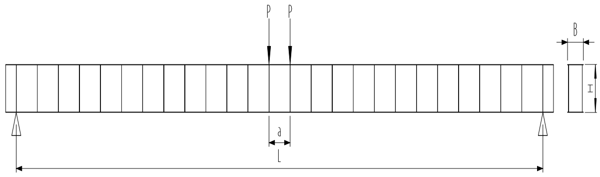

Fig. 1 Calculation diagram of steel box girder under bending Moment

Fig. 2 Stress-strain curve of the material

2.1 Influence of Flange Plate Width-to-thickness Ratio on Ultimate Bearing Capacity of Steel Box Girder

According to the calculation model shown in Figure 1, the ultimate bearing capacity of the steel box girders with three kinds of box section are calculated under the same span L, the same web plate height-to-thickness ratio (H/ t) and the different flange plate width-to-thickness ratio (B/ d)(B/d=32.5~130.As most of the values are greater than the standard limit value of 33, there is a longitudinal reinforcement in the middle of the flange plate). Fig.3-5 show the relation curves between the width/thickness ratio (B/ d) and the ultimate bearing capacity of the flange plates of three sections. Fig. 6 shows the load displacement curve of the steel box girder with various of thickness of flange plates with a section of 1.5m×1.8m and a web plate thickness of 8mm.

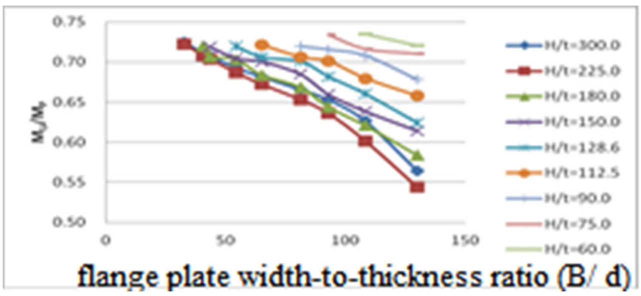

Fig. 3 Ultimate bearing capacity curve of 1.5m×1.8m section

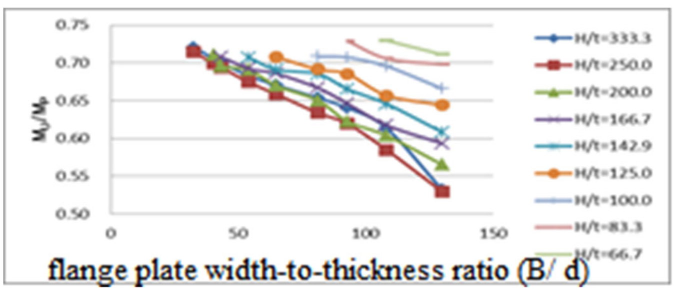

Fig. 4 Ultimate bearing capacity curve of 1.5m×2.0m section

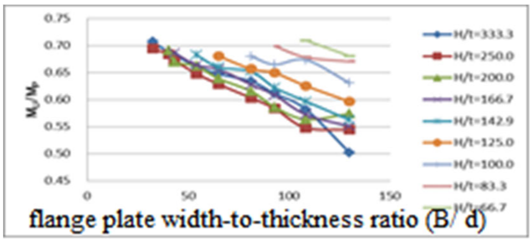

Fig. 5 Ultimate bearing capacity curve of 1.5m×2.5m section

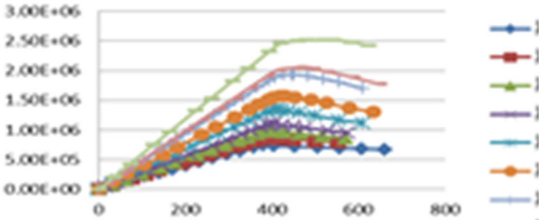

Fig. 6 Load displacement curve of steel box girder with 8mm web plate

It can be seen from Fig. 3 to Fig. 5 that the ultimate bearing capacity of steel box girder decreases approximately linearly with the increase of the width/thickness ratio of flange plate. This is because with the increase of the width to thickness ratio and the constant width of the steel box girder, the thickness of the flange plate decreases. Thus the flexural rigidity and effective cross-sectional area of the section is reduced. Therefore, the ultimate bearing capacity is bound to decrease. It can be seen that the ratio of width-to-thickness of the box girder has a greater impact on the ultimate bearing capacity. As can be seen from Fig. 6, there is a linear relationship between the structural bearing capacity and the deformation of the box girder, and a nonlinear growth relationship between the ultimate bearing capacity of the steel box girder and the thickness of the flange plate before the load under all kinds of thickness of flange plates reaches the extreme point .

2.2 Influence of Web Plate Height-to-thickness ratio on Ultimate Bearing Capacity of Box Girder

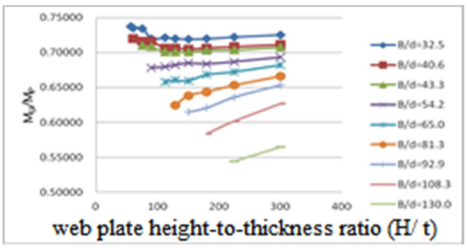

Fig. 7 Ultimate bearing capacity curve of 1.5m×1.8m section

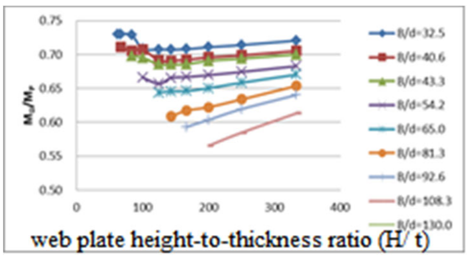

Fig. 8 Ultimate bearing capacity curve of 1.5m×2.0m section

Same as the method in 2.1, the ultimate bearing capacity of the steel box girders with three kinds of box section are calculated under the same span L, the same flange plate width-to-thickness ratio (B/ d) and the different web plate height-to-thickness ratio (H/ t) (H/t=56.3~416.7). Fig. 7- Fig. 8

show the relationship between the height/thickness ratio (H/ t) and ultimate bearing capacity of the three sections.

It can be seen from Fig. 7-8 that when the width/thickness ratio of flange plate (B/ d) is less than 54.2, the ultimate bearing capacity of steel box girder decreases first and then increases with the increase of the height/thickness ratio of web plate. When the width/thickness ratio (B/ d) of flange plate is greater than 54.2, the ultimate bearing capacity of steel box girder increases with the increase of the height/thickness ratio of web plate. This is because the ultimate bearing capacity of the steel box girder decreases with the increase of the web plate height-to-thickness ratio within 56.3~139. When the height-thickness ratio of the web plate is greater than 139, the steel box girder belongs to the beam with thin abdominal section, and the elastic buckling of the web plate occurs at the bending moment. After the web plate buckling, the web bending resistance is improved due to the film effect.

3. Suggested design formula and comparison

By analyzing and summarizing the calculation results of the above 162 finite element models and using Matlab for data processing, the regression equation of ultimate bearing capacity of steel box girder under the action of bending moment is obtained, as shown in Equation (11). The calculation formulas proposed in this paper unify the formulas which are used to calculate ultimate bearing capacity of steel box girder under bending moment with the web plate height/ thickness ratio (H/ t) and flange plate width/ thickness ratio (B/d) as the parameters, which provides a reference for the design work. Fig. 9-11 show the comparison results of fitting calculation formula and finite element analysis of ultimate bearing capacity under bending moments.

$$\frac{M_u}{M_p} = \begin{cases} 0.771681 + 4.03 \times 10^{-5} \frac{H}{t}\sqrt{\frac{f_y}{235}} - 1.4 \times 10^{-3} \frac{B}{d}\sqrt{\frac{f_y}{235}} & 64 \le \lambda \le 70 \\ 0.763566 + 6.09 \times 10^{-5} \frac{H}{t}\sqrt{\frac{f_y}{235}} - 1.85 \times 10^{-3} \frac{B}{d}\sqrt{\frac{f_y}{235}} & 54 \le \lambda < 64 \\ 0.728499 + 9.12 \times 10^{-5} \frac{H}{t}\sqrt{\frac{f_y}{235}} - 1.91 \times 10^{-3} \frac{B}{d}\sqrt{\frac{f_y}{235}} & 44 \le \lambda < 54 \end{cases}$$

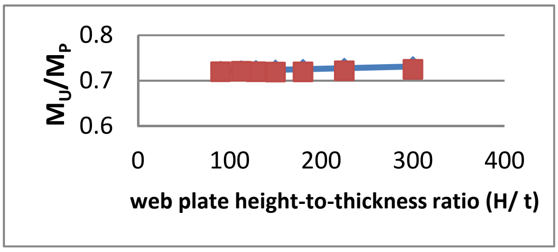

Fig. 9 Comparison between fitting value and simulated value withwidth/ thickness ratio 43.3

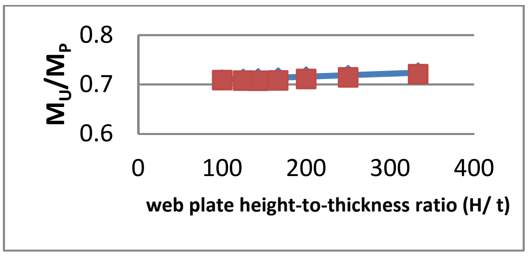

Fig. 10 Comparison between fitting value and simulated value with width/ thickness ratio 40.6

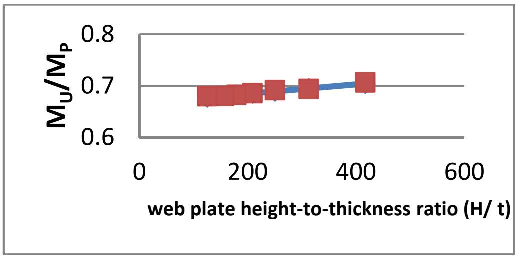

Fig. 11 Comparison between fitting value and simulated value with width/ thickness ratio 32.5

4. Experimental Verification

Through the above analysis and calculation, the ultimate bearing capacity of welded steel box girder under bending moment is affected by many factors. To verify the correctness of the analysis, two groups of model tests were carried out in this paper. The steel plate used in the specimen is Q235b plate, whose yield strength is 235N/mm2, elastic modulus E= 2.06×1011N /m^2, and Poisson's ratio =0.3.

In order to ensure the smooth progress of the test, the support reinforcement ribs were set at the support positions of each specimen to prevent the premature instability of the fulcrum web plates, which would affect the test results. The model test under the action of bending moment in the test is shown in Figure 12.

Fig. 12 Test model of ultimate bearing capacity under shear force of steel beam

Fig. 13 Picture of web plate buckling under shear action of steel box girder

The web plate buckling deformation of the test steel box girder under bending moment is shown in Fig. 13. Its buckling deformation is located at the mid-span of the web plate of the test steel box girder (pure bending beam section).

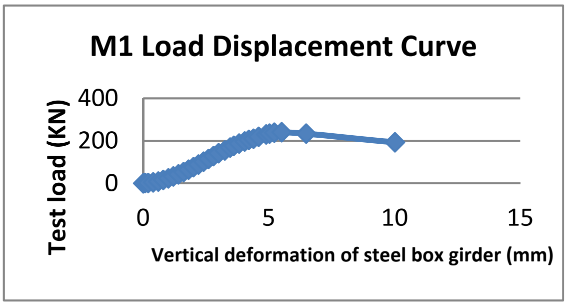

Fig. 14 Load displacement curve of test beam

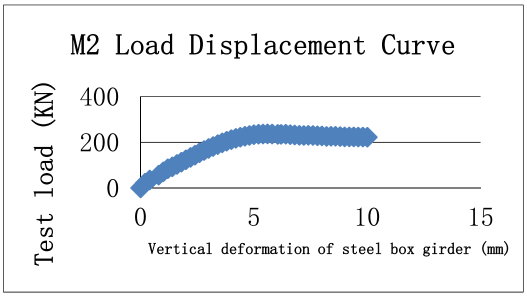

Fig. 15 Load displacement curve of test beam M2

5. Comparative Analysis of Theoretical Analysis and Experimental Results

In order to verify the correctness of the theoretical analysis, the finite element calculation model of the experimental model was established in this paper, as shown in Figure 16. The load displacement curve of the theoretical analysis component was shown in Figure 17. The comparison between theoretical analysis results and experimental results is shown in Table 2, and the error between the two is 4.35%~6.52%. The failure of the specimen M1 and M2 was the buckling failure of the web plate at the loading point of the steel box girder. The buckling deformation of the web plate presented sinusoidal half wave, which was very close to the simulation calculation. Moreover, the ultimate bearing capacity of the steel box girder was less than the buckling load solved by the eigenvalue method. The theoretical analysis of the steel box girder instability deformation and the test steel box girder instability deformation contrast figure is shown in Figure 18 - Figure 19.

Tab. 1 comparison between test results and simulation results

Specimen Number	Analog Computation Value(KN)	Test Measured Value(KN)	Relative Error ε%	Buckling Characteristic Load (KN)
M1	251.4	240.9	4.35	1194.6
M2	251.4	236.0	6.52	1194.6

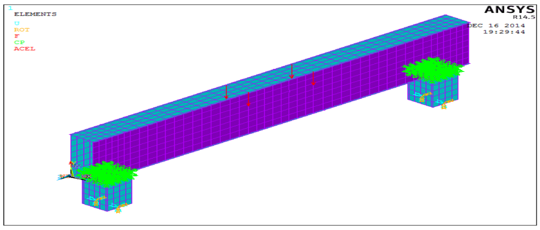

Fig. 16 Finite element model of steel box girder under shear force

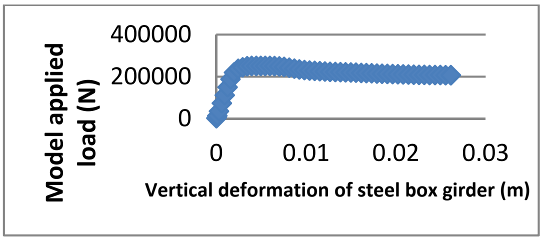

Fig. 17 Theoretical calculation of load displacement curve under shear force

Fig. 18 Partial enlarged drawing of instability position of test beam

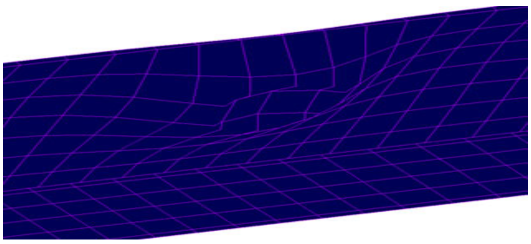

Fig. 19 Partial enlarged drawing of instability position of shaped beam under shear force

6. Conclusion

1) In this paper, the ultimate bearing capacity of large steel box girder considering material nonlinearity and geometric nonlinearity under bending moment are simulated and analyzed accurately. The influence of flange plate width thickness ratio and web height thickness ratio on the ultimate bearing capacity of box girder is analyzed Emphatically.

2) In this paper, the simplified formula of ultimate bearing capacity of large steel box girder under bending moment is established based on a large number of simulation calculations. According to the code, the initial defect of 5 ‰ [12] is considered in the formula, and the width thickness ratio of flange plate and the height thickness ratio of web plate are directly used as parameters. The formula has great convenience in use, and provides a certain reference for the design and calculation of large steel box girder.

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