Numerical Study of the Effect of the Wall Thickness of a Steel I-Beam on the Form of Loss of Local Stability

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Abstract. A large number of elements of steel building structures made of I-beam section profiles. It is economically advantageous to use I-beams with thin web thickness (vertical member of I-beam section). The safe use of thin web thickness of I-beams prevents possible deformation of the section profile member of the steel I-beam under load, before the loss strength (resistance) of the element. Research on the loss of stability, i.e. buckling of web plate (vertical member of I-beam) shows that thin web plate thickness does not reduce safety of the building and structures during its operation and maintenance. The results of calculation on stability of test models of I-section steel beams with a span of 12 m with various web thicknesses: 4, 5, 6, 7, 8, 9 and 10 mm. The load is collected for beams with steps of 6 m. The calculations are performed in a program “the SCAD Office computer complex”, which is based on the finite element method. The design testing model which is a simple supported beam is prepared in a finite element form; left support is a pin joint while the right support is a roller joint. The load was applied evenly distributed with constant intensity. The web wall of the I-beams is divided into seven compartments by transverse stiffening ribs. Thicknesses of the web plate of each beam were taken to be the same for all compartments. The forms of loss of local stability for various web thicknesses are shown. The change in the influence of force factors on local stability, with changing thickness of the web of the I-beam (section profile). So, for web thicknesses of 8, 9 and 10 mm in the studied steel beams, the loss of local stability occurs in the middle section, where the maximum value reaches bending moment $M_y$. While for I-beam with web thicknesses of 4, 5, 6, 7 mm in the beams under study loss of local stability occurs in the extreme compartment where the maximum values reach the transverse (shear) force $Q_z$. The revealed change in the shape of the loss of I-beam’s web plate (vertical member of the I-section) stability may indicate a more significant effect of the shear force $Q_z$ for webs of smaller thickness. The analysis of the results is given numerical calculations.

1. Introduction

When assigning a type of cross section for elements of building structures, a large number of factors are taken into account [5, 6, 8, 12]. One of the determining factors is the low value of the dead load (own weight) of the building structure [7, 15, 17]. I- section beams meet the requirements of economic efficiency for many elements of building structures [2, 3]. To achieve the greatest efficiency, it is necessary to use I-beams with a thin (flexible) web plate [8, 13, 16]. Good indicators of metal should
not reduce the reliability of building structures during operation. Good indicators of metal should not reduce the reliability of building structures during operation. For cost-effectiveness without sacrificing reliability, it is necessary to study the features of the operation of thin-web plates. One of the important features of thin-web plate open profile elements is the problem of loss of local stability i.e. buckling [6, 16, 22, 23]. A number of papers describe issues related to the loss of local stability i.e. buckling of thin-web plate [18, 20]. Known design solutions to improve the efficiency of the thin web thickness of the I-beam [9, 19]. One of such solutions is the partition of the web plates into separate compartments with the help of stiffening ribs. But in the areas between the stiffeners, inside the compartments, the problem of loss of local stability (buckling) remains relevant. There is a method for testing local sustainability described by the rules (SP 16.13330.2017). However, analytical methods are very laborious and do not allow to take into account the spatial work of elements of building structures. Manufacturers of programs using numerical methods are constantly improving and expanding the functionality of their software products. In this paper, we will use the SCAD Office design complex [11] to study the effect of the web thickness of a steel I-beam on local stability. The calculating apparatus of this program is the finite element method [1, 10].

2. Statement of the problem and assessment methodology

To study the local stability of the web, a test model of I-beam steel with a span of 12 m was adopted. Beam pitch (in steps of) in 6 m. Structural material is C255 steel. Seven design models with different wall thickness were prepared: 4, 5, 6, 7, 8, 9, 10 mm (Figure 1). The calculation was made in the SCAD Office software package (Version 21.1.1.1) based on the finite element method [1, 10]. Elements of computational models (Figure 2): web plate, belts, stiffening ribs, supporting ribs, are presented in the form of quadrangular finite elements of the shell [21]. In this case, the following dimensions of quadrangular QEs were used: web-65x85 (t4, t5, t6, t7, t8, t9, t10) mm, flanges-53x85 (t16) mm, support ribs-65x53 (t16) and 30x53 (t16) mm, stiffeners-65x53 (t8) mm. In general, the design model consists of 3572 specified plate CE. Relationships in the form of restrictions on linear deformation are established in such a way that it corresponds to a constructive solution to the junction of elements [14]: a left hinged fixed bearing (pin joint), a right hinged mobile support (roller joint) and limited linear deformation in the level of the upper belt from the plane along the Y axis (Figure 1).

2.1. Load on the design scheme

![Figure 1. Design scheme for beams with web thickness: 4, 5, 6, 7, 8, 9, 10 mm.](image)

Given load: dead load (constant loads) 4.55 kN/m²; Live loads 2.4 kN/m². Full load: q = 6.95 kN/m² x 6 m = 41.7 kN/m.
2.2. Assessment method

The criterion for assessing local web (of I-beam) stability is the value of the coefficient of reliability for stability - “k". The reliability coefficient for stability numerically describes how many times it is necessary to increase the calculated load in relation to the critical one in order for a loss of stability to occur. The minimum value of the reliability coefficient for the stability of the system according to the norms (SP 16.13330.2017) is 1.3 for calculations in computing complexes. To analyze the results of the calculations, the forms of loss of local stability web plate (of I-beam) are compared for different thicknesses. Loss of geometric forms of local stability web plates are estimated by the amplitude of displacements from the plane and by the location in the beam [6, 16, 20].

3. Analysis of the results of numerical calculation

By varying the I-section web thickness in the range from 4 to 10 mm with a span of 1 mm in the SCAD Office program, we obtained the values of the safety coefficient for stability - “k". Figure 3 shows a plot of the coefficient “k" for the first form of I-section web buckling from thickness. With a wall thickness of 4 mm, the stresses in the right compartment No 1 reach critical values and a loss of local stability of I-section web (buckling) occurs, according to the shape shown in “Figure 4”. Up to 7 mm inclusive, as shown in “Figure 4", the first form of loss of local stability (buckling) is in the form of a sinusoid, the two half-waves of which are located in the right support compartment. The half-waves of the geometric shape of the deformed web of I-beam are directed from the plane in opposite directions. In the right compartment No 1, the maximum value of the transverse (shear) force Qz is noted, and therefore it is the shear stresses that cause the loss of local stability (i.e. buckling) of the webs of small thickness (up to 7 mm). The smallest web thickness value satisfying the requirements of the standards (SP 16.13330.2017) is 5 mm. Further, with an increase in web thickness, the value of “k" almost linearly increases [4], the largest increase is observed with an increase in the web thickness from 7 to 8 mm (Figure 3). The graph on “Figure 3" shows that for web with a thickness of 9 and 10 mm there is a minimal increase in the values of the reliability coefficient for stability - “k". It can be concluded that an increase in web thickness of more than 8 mm for this I-beam almost does not improve the resistance of the web to the loss of local stability (buckling). Starting from 8 mm, according to “Figure 5", the first form of buckling of the web has the form of half-wave sinusoids located in the upper zone along the section height in three middle compartments: No 3 - left, No 4, No 3 - right. The maximum amplitude of the sinusoid is observed in the middle compartment No 4 and gradually fades away in the compartments No 3. It is in the middle compartment that the bending moment M, reaches its maximum value, therefore normal stresses in the upper compressed zone of the wall cause local stability loss (buckling) for thicknesses of 8, 9 and 10 mm.
Figure 3. Reliability Ratio Graph on stability – K (1st form), from the wall thickness $t_w$.

Figure 4. The first form of buckling for a beam with a web thickness $t_w = 7$ mm.

Figure 5. The first form of buckling for a beam with a web thickness $t_w = 8$ mm.
4. Conclusions

Based on the results of research conducted in this work, we can draw the following conclusions:

3.1. For flexible web of steel I-beams, shear stresses are more dangerous, namely the values of shear stresses arising in the extreme compartments from the shear force can reach critical values.

3.2. After reaching a certain value, it is not advisable to increase the wall thickness of steel I-beams for economic reasons and for reasons of reliability in terms of stability.

3.3. At extreme the sections, from the action of tangential stresses and at medium sections, from the action of normal stresses, loss of local stability of the web (buckling of the web) for the first form occurs along two half-waves of a sinusoid in the longitudinal direction of the section. The geometry of the form of loss of local stability of the web depends on the web thickness, the dimensions of the compartment, the load, the conditions of fixing and span of the beam.

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