Optimal rib configuration in steel welded beams and its robustness

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Abstract

A linear stability analysis using FEM with shell elements was carried out for a large set of steel welded beams with variable configuration and dimensions of ribs. A subset of designs providing minimum mass of ribs for prescribed critical load was found and used in next step of detailed cost optimization. This made possible to compare the economic effectiveness of two classes of ribs' configurations, orthogonal and diagonal. In the following the optimal solutions representing these two classes of ribs were subjected to examination of their robustness. Stability response was analysed in case when holes were introduced into webs. Also, various combinations of global and local geometric imperfections were generated and nonlinear stability response of beams was analysed. Finally the numerical model and obtained computational results were verified experimentally in real scale tests. Two thin walled girders with 7.5 m length of span, 0.76 m height, and slender web with thickness 3 mm were manufactured. Geometric imperfections of these girders were precisely measured. The girders were subjected to concentrated load at the mid-span. Good agreement of numerical simulations with the experiments was obtained. Both, the computer simulations and the experiments proved that diagonal rib configuration provides better performance of girders than orthogonal one.

Keywords: optimization, robustness in optimization, optimal ribs in beams, stability of beams, thin-walled beams, FEM, Abaqus

1. Introduction

Designing lightweight structures is a permanent global strategy. It follows from economic reasons and is in agreement with the environment protection policy. Designers of steel structures follow this trend. However, thin-walled slender structural members are apt to loss of stability that eventually can lead to structural failure. It also applies to thin-walled beams. Here, increasing role is played by local forms of instability due to high slenderness ratio of the web and to initial geometric imperfections unavoidable in welding thin metal sheets. Cost minimization of steel girders was studied in [6]. Stability of steel welded girders focussed much attention in the literature. In [3, 4, 5] the influence of various rib configurations was studied. The authors proved there that diagonal ribs better protect the web of beam against loss of stability and provide higher load bearing capacity, than traditional orthogonal ribs. Sensitivity analysis for a large class of beam parameters and stiffeners was developed in [9]. Stability problems for doubly symmetric steel girders with thin webs was studied in [2, 7, 8]. The present paper further develops the studies reported in [3, 4, 5] by updating the specific manufacturing costs, by examination of the response of optimal girders in case of existing unfavourable initial imperfections, introduction of holes in the web and by the study of torsional stiffness.

2. Numerical analysis

The paper aims at the multi aspect optimization of the configuration of ribs in steel thin-walled girders accounting for safe response in case of existing geometric imperfections and introduction of holes into webs. In the first step linear stability analysis was carried out for a large set of approx. 250 beams with orthogonal and diagonal rib configurations and variable length of span and web slenderness. Some results are shown in Fig. 1. Rectangular and triangular shell finite elements within ABAQUS system [1] were used throughout. Global and local forms of instability were identified. In the following eight girders representative for orthogonal and diagonal rib configurations were chosen and subjected to detailed manufacturing cost evaluation. Four step-wise increasing manufacturing costs were considered. The girders with diagonal rib configuration provided definitely higher stability eigenvalues than orthogonal ones: 23 %, 62 %, 56 % and 48 %, respectively. Finally two girders with 3 mm thick webs, representative for orthogonal and diagonal configurations were analysed numerically for various combinations of geometric imperfections. The imperfections corresponded in form and magnitude with the codes [10, 11], manufacturing tolerances and imperfections measured on real scale beams before testing. These analyses covered also the girders with holes of various shapes. Forms of failure are shown in Fig. 2. Impact of rib configuration on torsional resistance of beams was also studied developing the considerations presented in [5].

3. Experimental verification of numerical models

Two girders (orthogonal and diagonal ribs) with length of span L=7.5 m and cross-section 740×(t_w=3)×180×10 mm were subjected to three point bending with simple fork supports against torsion and the load as is shown in Figs. 1a, b. In experiments horizontal lateral support of the upper flange was introduced for safety of the loading system. The horizontal lateral displacements were measured in 6 points. The strains were measured by electro-resistance gauges: longitudinal in

flanges and rosette type in webs. The comparison of simulated numerically displacements and strains with measured experimentally quantities demonstrated good agreement.

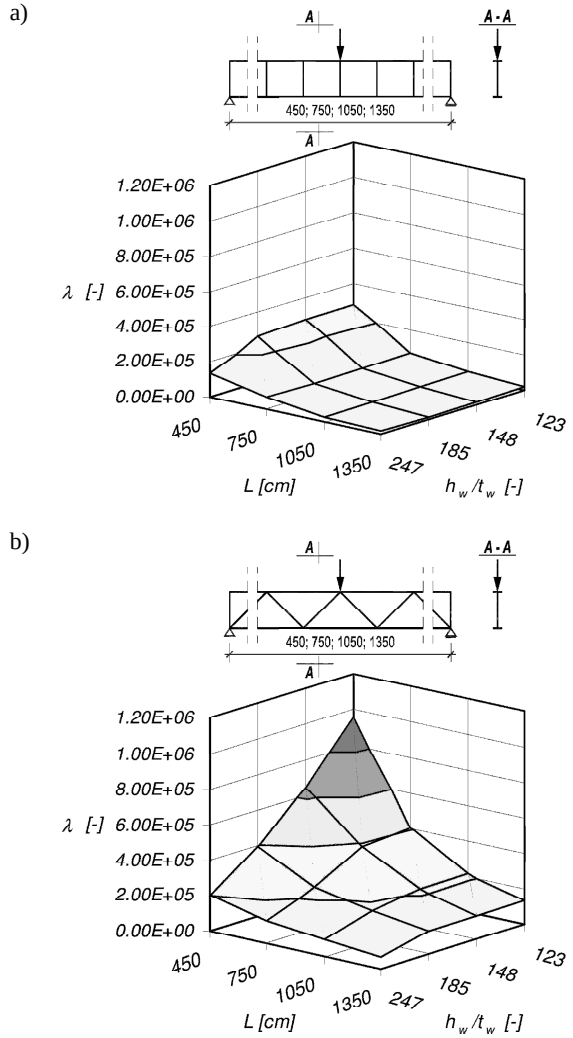

Figure 1: Critical load parameter λ as a function of length of span L and web slenderness ratio h_w/t_w for one-span girders with cross-sections $740\times(t_w=3\div6)\times180\times10$ loaded by a concentrated force at the mid-span point for: (a) orthogonal ribs, (b) diagonal ribs

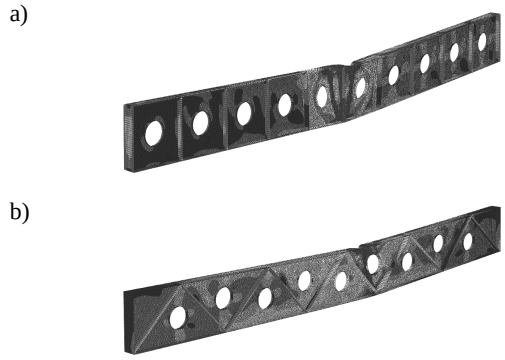

Figure 2: Typical failure modes of girders with holes for: (a) orthogonal ribs and initial local imperfection 1.0 mm, (b) diagonal ribs and initial local imperfection 2.0 mm

4. Concluding remarks

Two types of rib configurations in steel girders were considered, namely orthogonal ones including longitudinal ribs and diagonal one. Optimization was carried out considering various aspects of the optimal solutions. Structural robustness in case of introduction of holes into web and introduction of various combinations of imperfections was studied. The diagonal configuration proved to be definitely more advantageous than the former one, because it resulted in better resistance to local and global instability at the similar weight and/or cost of girders. Interestingly, diagonal ribs provide much higher torsional stiffness and shear resistance of beams. Diagonal rib configuration improves the structural response in case of very slender webs. Numerical models were verified and validated by real scale experiments.

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