Imperfections in steel plated structures – should we straighten their plate elements?

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ABSTRACT: As a result of their fabrication, in particular of the welding involved, steel plated structures exhibit initial imperfections, the most important of them being probably the initial curvature of the plate elements of the system. With this being so, it is understandable, that they be kept under control by means of prescribed tolerances, and there is a tendency to reduce the initial curvatures by means of (usually heat) straightening. But this procedure is costly and necessarily enlarges the price of the fabrication of the structure. Is it therefore indispensable to proceed in this way? And is this so for all kinds of steel plated structures? Parallelly with experiments, the ultimate load tests were computer modeled. In so doing, the girder was modeled, using the geometrically and materially non-linear variant of the shell finite element method, by the ANSYS program. Considering a random influence of all initial imperfections, a case study analysis of the effect of all imperfections on the load-carrying capacity of the girder was carried out. In this way, it was found out which initial imperfections exhibited the greatest influence on the load-carrying capacity.

1 INTRODUCTION

Nowadays, the thin-wall steel structures are to be found more and more frequently, their usage leading to considerable economical and material savings. Their application is widely spread in a number of engineering branches. The low cost and weight represent one of the main advantages. On the other hand, the thin-wall system is more susceptible to displacements. Compared to the usual hot-rolled beams, the thin-wall system design is always more complicated. The resistance of thin-wall girders being highly sensitive to the influence of initial imperfections, these have to be taken into account (Kala et al 2002).

The buckling of thin-walled members is the main kind of stability loss with thin-wall systems composed of these elements. The insufficient knowledge of stability problems as well as the low trust in the designers' work has their consequences in the projects of non-economical constructions. The case analysis of initial imperfection enables to discriminate the influence of individual imperfections on the resistance. The effect of the initial curvature of the web is twofold, via.(i) the effect of the shape of the initial curvature and (ii) that of its magnitude, Maquoi & Škaloud (2003). Therefore, both of the two aspects will be subjected to analysis. Of course, the main objective of the striving of the authors of this paper is to carry out a s analyses, of the shape and magnitude of the initial out-of-flatness of the girder web, in terms of the magnitude of the load to which the girder is subjected and taking account of the size of the girder flanges and thereby of the boundary conditions of the web. Realizations of the load-carrying capacity were calculated by a non-linear analysis using the ANSYS program.

2 NUMERICAL MODEL OF THE STRUCTURE DESCRIPTION

Model based on finite element method has the same geometry as experimentally tested structure. The girder was modeled, in very detailed way, using the program system ANSYS, ANSYS (2008), at the Department of Structural Mechanics in Brno University of Technology; with the aim to understand the stability phenomena as in detail as possible, the girder was modeled by shell finite elements The ultimate static load-carrying capacity and the stress state were analyzed by the finite elements method. The geometrically and materially nonlinear solution was applied. It has followed from numerous studies, e.g., Škaloud & Zörnerová (2003), Soares (1988), that it is necessary to take into account the influence of initial imperfections.

Special attention was paid to the size and shape influence of the initial curvature of the girder's slender web. The initial curvature shape of the slender web was modeled by the sine function. As it is in their nature that the initial imperfections are random variables, case study analysis seems to be an accurate tool for an analysis of their effect. By applying the analysis, the participation of initial imperfections in ultimate static load-carrying capacity is studied.

The Euler method based on proportional loading in combination with the Newton-Raphson method was used. The girder was modeled, in a very minute manner, by means of a mesh of shell four-node elements SHELL 181. The girder symmetry and that of loading were made use of. The loading test is simulated by the incrementation of a loading step in the Euler method. The load-carrying capacity was determined as the loading rate at which the matrix of tangential toughness determinant K_t of the structure approaches zero with accurateness of 0.1 %. The incrementation run was decremented automatically. For steel grade S235, bilinear kinematic material hardening was supposed. Further on, it was assumed that the onset of plastification occurred when the Mises stress exceeded the yield stress.

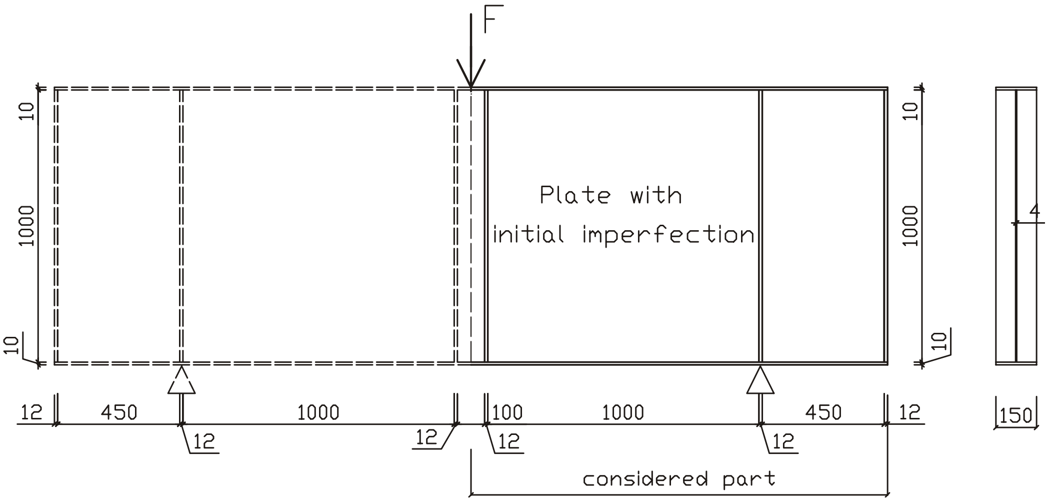

Figure 1. Geometry of a thin-walled modeled girder

With the view to solve the problem by means of FEA, the program system ANSYS was used. With respect to the symmetry of the girder studied, and to the exacting character of the numerical calculation involved, only half of the plate girder length was considered. The symmetry plane was prescribed under the point of load application by preventing any displacement in the axis *x* and by the rotation around the axes *y* and *z* (*Ux*, *ROTy*, *ROTz*).

The arrangement of the structure geometry can be seen in Figure 1. The hinge support was modelled so as to prevent the displacements *Uy*, *Uz*.

3 SOLUTION OF THE PROBLEM

The density of the elements mesh was chosen as high as to enable the authors to describe the local buckling of the plate elements of the girder. The layout was then formed by 5344 finite elements with 5434 nodes. The solution of the problem leads to a system of 32 370 equations. The initial imperfection shape was selected as sine function with (1) one wave in *x* and *z* direction, (2) two waves in *x* and *z* direction, (3) one wave in *x* and three in *z* direction and (4) one wave in *x* and two in *z* direction. All initial shape are plotted in figure 2 for magnitude equal to 10 mm. These shapes were selected for its simple description and good correspondence with real measured imperfection shape.

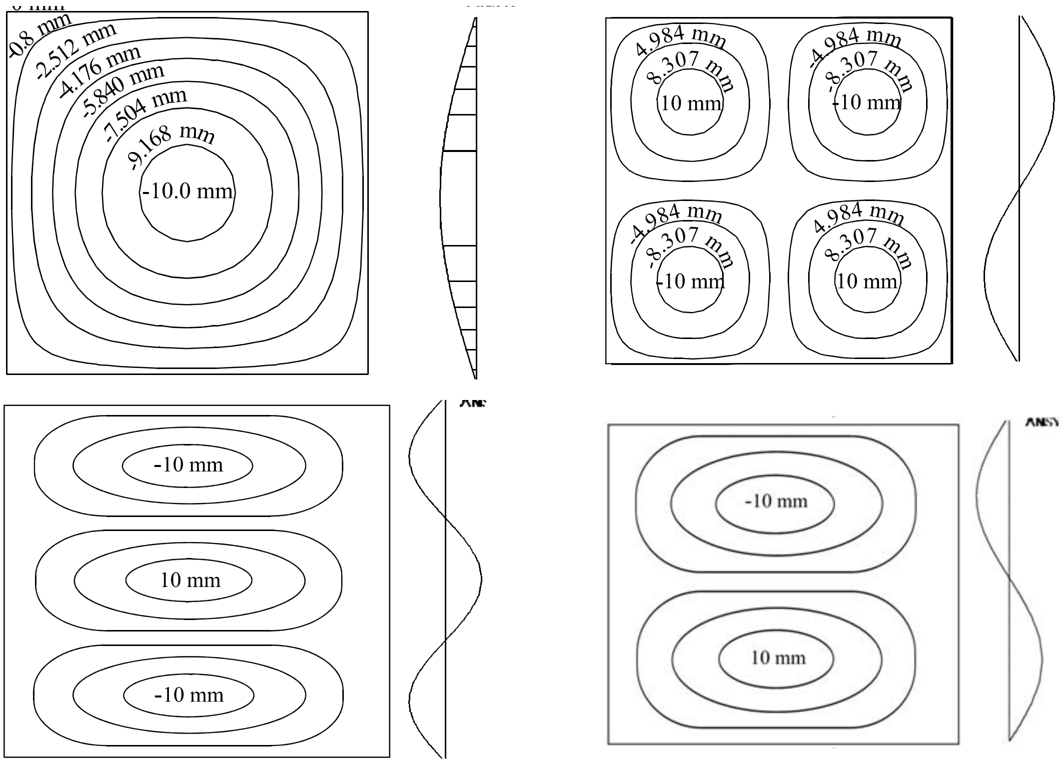

Figure 2. Geometry of a thin-walled modeled girder

The magnitude of initial imperfection was from 1 mm to 25 mm with step of 1 mm. The geometrically non-linear solution should always have non-ideally straight web. The value of 0.0001 mm to 0.1 mm was tested. It was considered that value of 0.1 mm represents straight plate from manufacturing point of view and for numerical analysis is this initial imperfection big enough for stable convergence.

4 RESULTS OF ANALYSIS

For each initial imperfection shape number of tasks was solved to obtain the limit load as a function of initial imperfection magnitude. The magnitude varies for almost straight web plate to 25 mm i.e. 1/40 of dimension. Whole interval was calculated for four initial shapes given by sine waves.

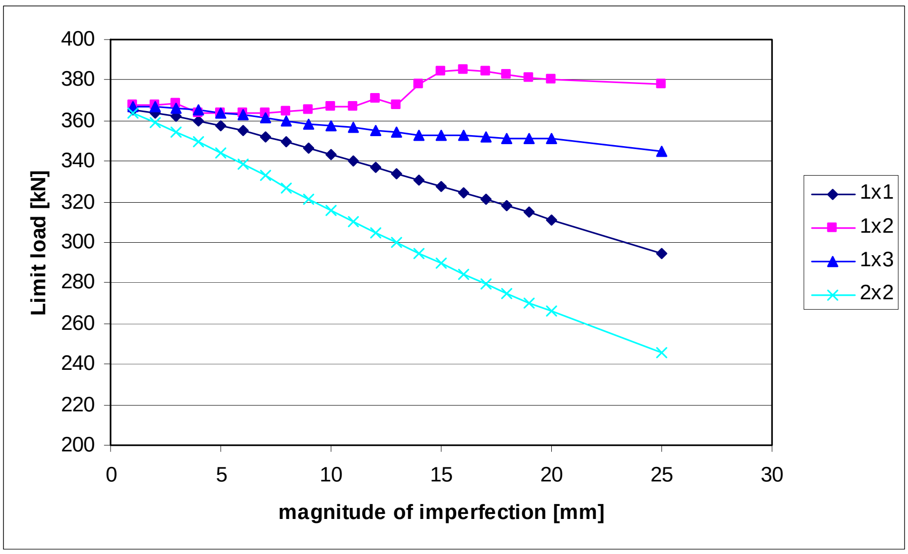

Figure 3. Relation of load carrying capacity on initial value and shape of imperfection

An analysis of the results obtained shows that even though the shapes of the initial curvature very significantly vary from one another, the shape of the buckled pattern of the web follows the initial curvature just for lower values of load. For higher loading, it tends to converge, frequently by way of snap-throughs, to the characteristic diagonal buckling mode, and the membrane stresses in the buckled web to the diagonal stress field, characteristic of the truss action in the post-buckled behavior of slender webs in predominantly shear.
On the graph in figure 3 can be seen the relation of limit load on magnitude of initial imperfection. Each curve represents one initial imperfection shape. Every shape has different influence on limit load. Comparing the limit load of girder with "straight" web and with magnitude of 25 mm (by manufacturing code inadmissible) (Melcher et al 2003) the difference varies from +5.7% to -34.4%. When we consider the tolerable magnitude 10 mm the interval of difference narrowed to +0.5% to -6.3%. To produce a more detailed analysis of the load level as a function of displacement it would be convenient to define the initial curvature according to the higher initial imperfection modes Kala (2004). The most general approach suggests choosing the initial curvature as a random field. Since the complex problem of a thin wall snap-through mechanism has not been solved sufficiently yet, it has become the topic of interest of many research centers.

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