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THE INFLUENCE OF THE WEB INITIAL SHAPE CURVATURE UPON THE MEMBER STRESS STATE IN THE CRACK-PRONE AREAS

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Summary. *The subject of the present paper is the stress state analysis of a girder in which limit state has been reached by the effect of repeated loading. The stress state is studied by means of a calculation model elaborated within the frame of the ANSYS programme. The girder was modelled by the finite element method SHEL181. The geometrically and materially nonlinear solution was applied. The extent to which the stress state has been influenced by initial imperfections is analysed. As the initial imperfections are random quantities, the so-called stochastic sensitivity analysis was applied. The realisations of random quantities were simulated by the Latin Hypercube Sampling method. By the so-called stochastic sensitivity analysis, it has been analysed how the variability of initial imperfections influences the stress state variability in the points where - according to the results of experimental research – crack initiation and propagation take place most frequently.*

1 INTRODUCTION

Reaching the structure load-carrying capacity limit state can occur due to single sudden overload or, more frequently, due to many times repeated loading which generates fatigue cracks. With increasing failure by cracks, the static ultimate load-carrying capacity of structure decreases, i.e., the probability of reaching the load-carrying capacity limit state increases. The experimental study of structure behaviour under many times repeated loading is led by one of the authors and his colleagues in Prague. Theoretical analyses are carried out at the working place in Brno. The results of experiments include much useful information which can be taken use of for theoretical analyses. The stress state which cannot be measured immediately is analysed by applying the calculation models based on the nonlinear finite element variant. The stress state is studied in the points in which crack initiation and propagation occur most frequently. The so-called stochastic sensitivity analysis is applied for quantification of initial imperfections effect on stress state [8, 2, 3].

2 GENERAL SPECIFICATIONS

The geometry of the girder solved is presented in Fig.1. For thin-walled girder, buckling of slender web represents the major type of stability loss. When stressing the web by many times repeated loading, repeated buckling takes place; this is the phenomenon the modern name of which is „web-breathing". Due to the web-breathing, fatigue crack initiation and propagation take place in peripheral web area. The limit state of fatigue resistance is limited by the size of repeated stress state due to buckling above all. Bending stress arising due to breathing is concerned in particular.

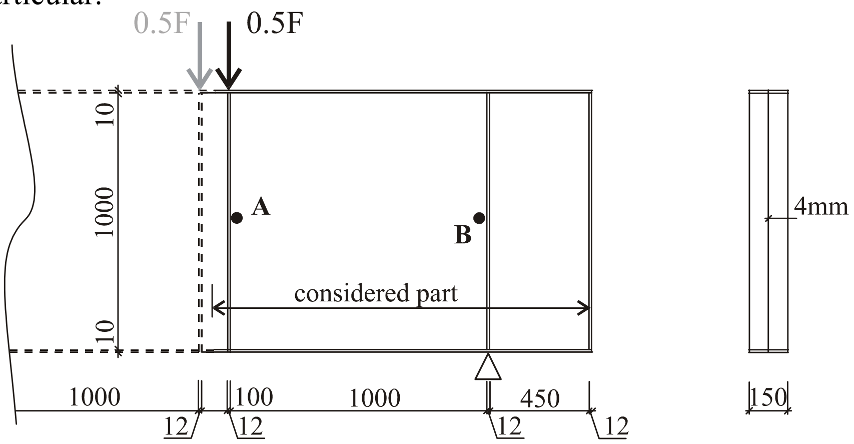

Figure 1: The girder geometry

The girder was modelled by the finite element method, by applying the ANSYS programme. In a very minute manner, it was done by means of a mesh of shell elements SHELL181. The girder symmetry and that of loading were made use of. For steel grade S235, bilinear cinematic material hardening was supposed. Further on, it was assumed that the onset of plastification would occur after the Mises stress would have exceeded the yield stress. The numerical simulation method LHS was applied. The sensitivity analysis was evaluated in the form of ratio of squares of variation coefficients according to (1):

$$S_i = 100 \frac{v_{yi}^2}{v_y^2} \; [\%] \tag{1}$$

v_{yi}^2 variation coefficient of the output quantity has been calculated for input quantities introduced by their mean values (they have been applied as deterministic ones) except the i_{th} one used as random one.

v_y^2 is the variation coefficient of the output quantity for all input quantities used as random ones.

Within the framework of each run of the LHS method, the stress state was found out by the geometrically and materially nonlinear FEM solution. The Euler method based on proportional loading in combination with the Newton-Raphson method was used.

3 INPUT RANDOM VARIABLES

Statistical characteristics of the sheet thickness given in Tab. 1 were evaluated, based on experimentally found data [7].The statistical characteristics of Young's modulus were taken from [1, 9]. Another important quantity is the amplitude of initial curvature of a slender web [10]. The characteristics based on measurements at the working place in Prague have been applied in the present paper [4]. It has been found by a detailed statistical analysis that the initial curvature shape can be approximated by two half-waves of the sine function [4].

No.	Name of random quantity	Type of distribution	Dimension	Mean	Standard deviation
1.	Web thickness	Gauss	mm	4	0.2
2.	Web Young's modulus	Gauss	GPa	210	12.6
3.	Thickness of upper flange	Gauss	mm	10	0.7
4.	Young's modulus of upper flange	Gauss	GPa	210	12.6
5.	Thickness of lower flange	Gauss	mm	10	0.7
6.	Young's modulus of lower flange	Gauss	GPa	210	12.6
7.	Thickness of left-hand stiffener	Gauss	mm	12	0.84
8.	Young's modulus of left-hand stiffener	Gauss	GPa	210	12.6
9.	Thickness of central stiffener	Gauss	Mm	12	0.84
10.	Young's modulus of central stiffener	Gauss	GPa	210	12.6
11.	Thickness of right-hand stiffener	Gauss	Mm	12	0.84
12.	Young's modulus of right-hand stiffener	Gauss	GPa	210	12.6
13.	Amplitude of sine initial web curvature	Lognormal	mm	3.575	3.336

Table 1 : Input random quantities

4 CONCLUSIONS

The influence of the variability of initial imperfections on the variability of bending stress in points A and B was studied by applying the sensitivity analysis. The bending stress was defined as the difference of normal stress perpendicular to the web margin. For an evaluation of variation coefficients in relation (1), 40 LHS method runs were used. The load action was considered deterministically - to be the value 60 % of average static ultimate load-carrying capacity of the structure, see [4, 5]. It is evident from Figs. 2 and 3 that bending stress in the points studied shows the maximum sensitivity to web thickness, and to a lesser extent, to the flange initial curvature. It follows from the results of numerous studies still elaborated (see, e.g., [4, 5, 6]) that the sensitivity to imperfections gets changed in dependence on working load. For lower values of loading (approximately between 10 to 20 percent of average load-carrying capacity), bending stress shows the maximum sensitivity to the web initial curvature [6]. Real values of working load, e.g., of steel bridges, are somewhere between 10 to 60 percent of average static load-carrying capacity. From the point of view of fatigue phenomena the web imperfection is relevant in particular. In the manufacturing process, the observation of tolerance limits of plate thickness and of the slender web initial curvature should be controlled above all.

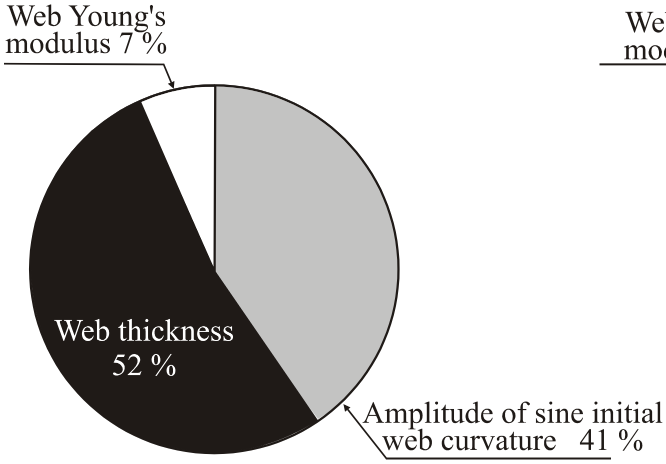

Figure 2: Sensitivity analysis results – point A

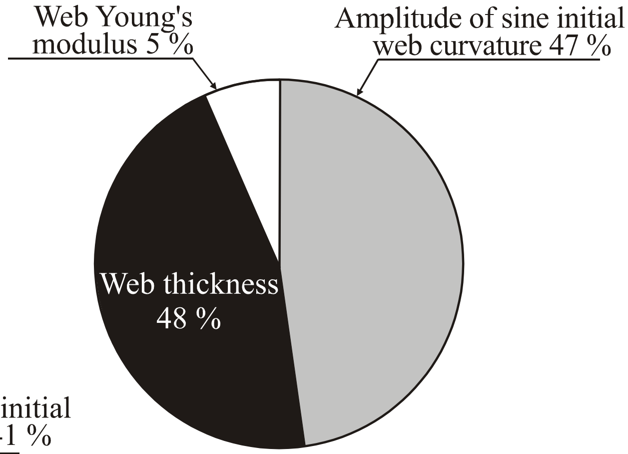

Figure 3: Sensitivity analysis results – point B

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