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The "Miracle" of Post-Buckled Behaviour in Thin-Walled Steel Construction and its Breathing-Induced Limitation

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Abstract: Thin-walled construction represents a powerful tool for saving steel and thereby for increasing the competitiveness of steel structures. However, on the other hand, as the limit state of thin-walled structures is substantially affected by stability phenomena, the above concept can be implemented just on the condition of post-buckled behaviour being taken into account in the solution to these stability phenomena. The paper first studies the factors on which the intensity of the very favourable post-buckling reserve of strength depends and then in detail turns attention to the most important among them, viz. the effect of the cumulative-damage process that becomes manifest in the case of bridges and other systems subjected to many times repeated loading.

Introduction

One of the most promising trends in our striving to save steel is to use thin-walled structures, i.e. systems made of slender plate elements. Of course, it can be argued at this juncture that by decreasing the plate thickness we do reduce the consumption of steel, but on the other hand make the system more sensitive to stability phenomena. The situation is however remedied by the stabilizing effect of membrane stresses which come into play when plate deflections are of the order of plate thickness, so that a very significant post-buckled reserve of strength is generated. That is why a great attention has been internationally paid to research on post-buckled behaviour, the authors always striving to play a useful role in these activities.

It goes without saying that the favourable reserve of strength cannot be exploited blindly, and therefore in the full version of the paper the first part is devoted to "mapping" the factors on which the intensity of the beneficial post-buckled behaviour depends. In so doing, the effects of the slenderness of the plate element, its initial imperfections, the kind of loading and its material are analysed.

The main attention is paid to the impact of the cumulative-damage process that comes into being when the structure is subjected to many times repeated loading - as is the case, for example, in steel bridgework.

Experimental investigation into the cumulative-damage process generated by the breathing of the slender web of a thin-walled steel plate girder

As the extent of this paper is limited, we will herebelow concentrate only on the results of the authors´ experiments on the "breathing" of webs subjected to combined shear and bending. It is this kind of loading that governs the design of the webs of bridge girders and similar structures.

One of the test girders in the testing position is shown in Fig.1. It can be seen there that the test girders are fairly large, so that their character is not far from ordinary girders.

The main impact of the cumulative-damage process generated by the "breathing" of the web is the initiation and propagation of fatigue cracks. They initiate in the crack-prone areas at the toes of the fillet welds connecting the breathing web sheet with the girder flanges and stiffeners.

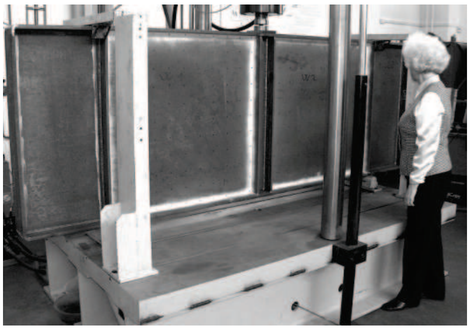

Fig. 1: One of the Prague girders in the testing position

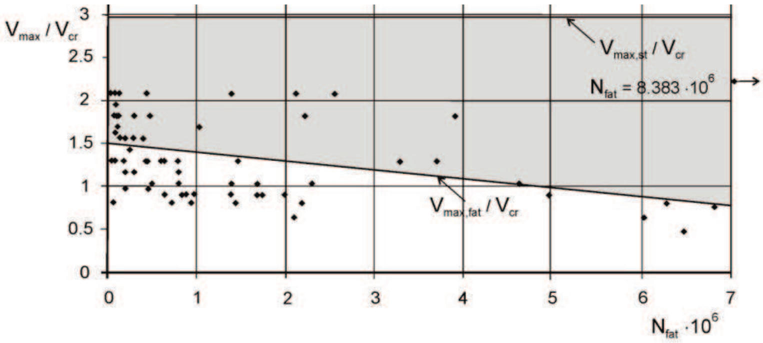

Fig. 2: The cumulative-damage-induced “erosion” of the maximum sustainable load – repeated predominant shear

Partial “erosion” of the post-buckled behaviour in webs subjected to repeated predominantly shear

The results of the writers´ experiments are shown in Fig. 2. The corresponding ratios V_{max}/V_{cr} are plotted on the vertical axis (V_{cr} being the critical shear force), the related numbers N of loading cycles on the horizontal axis.

A very significant impact of the cumulative damage process on the fatigue tests can easily be seen in the figure.

Impact of the breathing phenomenon on design

It follows from the above analysis that the problem of web “breathing” can play a very important role and therefore cannot be disregarded; on the contrary, it can significantly affect the design of steel bridges, crane-supporting girders and other structural systems under the action of many times repeated loads.

In establishing a suitable method for design, the authors follow the general features of the design philosophy according to which two limit states are introduced in the analysis, viz. (i) the fatigue limit state, (ii) that of serviceability.

While the fatigue limit state can be related to the failure of the girder (i.e. to unrepairable damage – which is acceptable in view of the fact that the fatigue limit state can never be attained during the planned life of the girder), the limit state of serviceability should be related to a much more limited, easily repairable degree of damage. In the case of steel girders with “breathing” webs, this means that, in the course of the useful fatigue life of the girder, either no or very small fatigue cracks can develop, such as to be easily kept under control, or easily retrofitted in case of need. That is why this limit state can successfully be used for governing inspections of the structure concerned for the occurrence of breathing-induced fatigue cracks.

The corresponding S-N curves and formulae are given in the full version of the paper.

Summary

It follows from the results of the authors´ research that the cumulative damage process generated in slender webs breathing under many times repeated loads can substantially influence the limit state behaviour and useful life of steel thin-walled structures. Therefore. this phenomenon ought to be taken into account in design.

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