Lateral-torsional buckling of cellular beams

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I. INTRODUCTION

Cellular beams are steel I-section beams with large circular web openings that appear in a regular pattern (Figure 1). Due to these openings, cellular beams have a number of advantages over classical I-section beams, the main one being optimization of material use. Other advantages are the possibility of reducing the total construction height by making utility and service ducts pass through the openings in the beams instead of under the beams and the ability to let light through. Consequently, the use of cellular beams has increased steadily during the last decade.

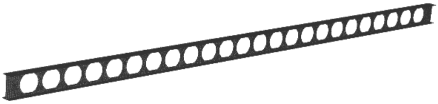

Figure 1. Cellular beam.

Figure 2. Cellular beam after failure by LTB

However, the presence of the web openings affects the structural behaviour of these beams considerably. New failure modes can manifest themselves and common failure modes for regular I-beams, such as lateral-torsional buckling (LTB), are altered (Figure 2). We will demonstrate in this paper, using finite element analysis, that the existing design rules for LTB of cellular beams are not adequate, and that there is a need for a new, accurate LTB design rule.

II. LATERAL-TORSIONAL BUCKLING

When beams are loaded in bending about their strong axis (Figure 3), instability can occur due to buckling of the top part of the beam that is under compression. Because the bottom part is in tension, it will offer some resistance to the lateral movements of the compressed upper part. This results in a combined lateral and torsional movement of the beam (Figure 4). This phenomenon is known as lateral-torsional buckling.

Figure 3. Beam loaded in bending

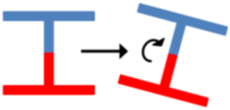

Figure 4. LTB: displacement and torsion

In the past, it has been shown that web distortion (Figure 5) of plain-webbed I-section beams and the accompanying decrease in LTB critical moment can play an important role [1]. We believe that this influence could also exist for beams with web openings, and so we will examine the influence of web distortion on LTB of cellular beams as well.

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Up until now, very limited research has been done regarding LTB for cellular beams and only two very approximate design rules for calculating the LTB resistance of these beams exist, to which we will further refer to as design rule 1 [2] and design rule 2 [3].

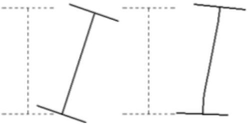

Figure 5. Cross-section during LTB: straight web (left) - distorted web (right)

III. NUMERICAL ANALYSIS

A. Model

We modelled the cellular beam using shell elements in Abaqus (Figure 1 and Figure 2). For the loading and boundary conditions, the classical LTB setup with a uniform moment was used. The model was (partially) validated by calculating the critical moment for plain-webbed I-beams and comparing the obtained results with known values.

The critical moment was calculated for a number of geometries using a linear buckling analysis. These geometries can be divided into two groups, according to the cross-section geometry: beams for which the web is thin compared to the flanges, and beams with a relatively thick web. For each buckled beam, a measure of the web distortion was calculated using the coordinates of the web nodes in the original and deformed states.

B. Results

For the examined beams with a relatively thin web, the web distortion is important, and even more so as the beams get shorter or the web openings larger. Design rule 1 can overestimate the critical moment by 22%, whereas design rule 2 underestimates the critical moment by as much as 80%.

If the web is thicker, the influence of web distortion is much smaller, and design rule 1 approximates the obtained critical buckling moment well. The underestimation of the critical buckling moment by design rule 2 is even larger than for thin webs.

IV. CONCLUSIONS AND FUTURE WORK

Nowadays, 2 design rules exist for calculating the LTB critical moment. Through numerical simulations, we have shown that design rule 1 is overly conservative and that design rule 2 can sometimes be on the unsafe side, when web distortion is large.

These results show that there is a need for a design rule that takes into account the web distortion on the one hand, and is not uneconomic on the other hand.

In order to obtain such a design rule, more factors that may have an effect on the LTB strength must be taken into consideration. The geometry must be varied to a greater extent, as well as the loading and boundary conditions of the beam. Non-linear simulations, in which plasticity, imperfections, and residual stresses are introduced, must be taken into account.

Furthermore, the numerical model needs to be validated by means of experimental results. For this purpose, tests on scale models and prototypes will be performed.

REFERENCES

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