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Safety formats for nonlinear analysis tested on concrete beams subjected to shear forces and bending moments

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ABSTRACT

Safety formats for nonlinear analysis have mainly been tested on beams and columns subjected to normal forces and bending moments. Therefore, it is unclear, whether available safety formats lead to the intended reliability when they are applied to structures that fail due to shear loading. To test available safety formats for nonlinear analysis, a tool was developed which allows a full probabilistic nonlinear analysis of beam sections subjected to arbitrary combinations of normal and shear forces as well as bending moments. Applying this tool to test the safety format according to EN 1992-2 on beams subjected to a combination of shear forces and bending moments showed that EN 1992-2 led to a reliability level that was lower than the target reliability. The safety format according to Schlune et al. (submitted for publication) [1] led to better agreement with the target reliability.

1. Introduction

In the past, nonlinear analysis of concrete structures has mainly been used to analyse beams, columns or frames subjected to normal forces and bending moments. Available safety formats for nonlinear analysis, [1–5], have therefore been tested mainly on these types of structures, which have quite well understood failure modes due to yielding of the reinforcement steel or concrete compressive failure. However, nowadays nonlinear analysis is increasingly used to analyse structures which fail due to shear or torsional loading. In these cases, the concrete is subjected to a multi-axial stress-state and the structures can fail in multiple failure modes. Factors like friction in cracks and bond properties can become important, which makes it more difficult to describe the structural behaviour numerically. This implies a higher model uncertainty.

Furthermore, the capacity of the structure can be limited by the tensile strength of the concrete which has a large variability. This can lead to a large variability of the structural resistance. Therefore, it is not clear whether available safety formats for nonlinear analysis are appropriate for these types of analyses.

This article describes how the safety formats according to EN 1992-2 [2], and according to Schlune et al. [1] were tested on beam sections subjected to a combination of bending moments and shear forces. Firstly the two safety formats tested are described in Section 2. In Section 3 the development of a tool for full probabilistic nonlinear analysis of concrete sections is explained; this is followed by the application of the tool to test the safety formats. The results and conclusions are given in Sections 5 and 6.

2. Safety formats

The safety formats for nonlinear analysis of concrete structures, according to EN 1992-2 [2], and Schlune et al. [1], use the principles of the semi-probabilistic approach, i.e. fixed weight factors for the action effects and resistance are assumed. According to EN 1990 [6] the weight factor for the resistance can usually be set to $\alpha_R = 0.8$, which provides a target reliability index for the design resistance of $\beta_R = \alpha_R \beta = 3.04$ (Class RC2, ultimate limit state, reference period of 50 years). The load effects for both safety formats must be treated according to EN 1990 [6] and EN 1991 [7].

2.1. Safety format according to EN 1992-2

To apply the safety format for nonlinear analysis according to EN 1992-2, the material strengths that are to be used in the analysis, can be calculated according to

$$\tilde{f}_y = 1.1 f_{yk} \tag{1}$$

$$\tilde{f}_c = 1.1 \frac{\gamma_s}{\gamma_c} f_{ck} \tag{2}$$

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