In-plane shear and out-of-plane beding – examining hidden margins

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Introduction

The design of concrete walls or slabs loaded in a combination of out-of-plane and in-plane forces is not that straightforward. The structural behaviour is not very transparent, especially because the reinforcement and the cracks are not perpendicular anymore. The Dutch codes cover the combination of in-plane normal and shear forces, but the combination of in-plane and out-of-plane actions is left to the craftsmanship of the structural engineer.

Roughly speaking two common-practice design approaches can be distinguished:

- combining the in-plane normal and shear forces to design forces and subsequently designing the reinforcement for the combination of design forces and bending.
- separating the bending and shear forces: for the shear forces the practical reinforcement in the compression zone can be used.

A third method (cracked membrane method, CMM) accounts for the real principal directions at the inner and outer plane. This method is not yet widespread, but it is transparent and theoretically correct.

The first method is rather conservative, while the second only applies for design in ultimate limit state. CMM is comparable with the first method, but results in a more balanced reinforcement design.

Case study

To illustrate these methods, a practical case study is presented. To investigate the ‘real’ strength, a nonlinear finite element analysis is carried out. The results show that the structure performs much better than expected with respect to durability and strength.

Examining the margins

The case study shows a considerable margin. But how does this margin vary with the combination of normal force, bending moment and shear force? For different combinations of these actions the ratio between designed and calculated strength is determined.