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Simulation of shear-type cracking and failure in reinforced and prestressed concrete members

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Abstract

Today, the non-linear finite element method is commonly used by practicing engineers, especially for assessment of concrete bridges. Simulating the shear behaviour and shear failure of reinforced concrete structures, using three dimensional non-linear finite element methods, has shown higher load carrying capacity, thus favourable load distribution, compared to conventional analyses. However, the modelling method for reinforced and prestressed concrete members subjected to shear and torsion has not been generally verified. Therefore, the method needs to be further investigated and verified to be practically reliable. The aim of this project is to work out, improve and verify an analysis method to simulate the shear response of reinforced and prestressed concrete members. The method should be possible to use for large structures, for example box-girder bridges, subjected to various load actions. Further aims are to examine and determine the most important parameters that need to be accounted for in the material model or in the material properties used. Experiments of panels loaded in shear and beams loaded in bending, shear and torsion are simulated using non-linear FE analysis. The results showed that four node curved shell elements with embedded reinforcement could simulate the shear response. It is well-known that the shear capacity determined by sliding along inclined cracks is larger than what can be explained by the reinforcement contribution determined from a truss model. This increase in shear stiffness and shear capacity is due to tension stiffening, dowel action, and friction due to aggregate interlock, and is also known as the *concrete contribution*. If the shear response is simulated with non-linear FEM, the *concrete contribution* has in the past been accounted for by modifying the concrete tension response in models, e.g. according to the modified compression field theory.

Results from the analyses showed that without any modification, i.e. if only the fracture energy of plain concrete was taken into account, the capacity was underestimated and the average strains, i.e. the crack widths, were overestimated. On the other hand, if the *concrete contribution* to the shear capacity was considered with the expression from MCFT, the capacity was in many cases overestimated and the average strains underestimated.

The analysis results from the shear panels showed that it was important to include the reduction of the compression strength due to transverse tensile strain for the behaviour and also for the capacity if the failure mode was crushing of the concrete between the shear cracks. In the analyses of the box-beam and the bending beam concrete compressive failure localised into one element, which size did not correspond to the size of the specimens used to calibrate the compression relationship used, i.e. the non-liner tension softening curve by Thorenfeldt. Hence, if the relationship by Thorenfeldt was used the model could not predict the response. This disadvantage was overcome by modelling the concrete in compression with an elastic-ideal plastic relationship instead. Altogether, the study implies that an analysis of a concrete member subjected to shear, torsion, and bending will be on the safe side when evaluating the load-carrying capacity or crack widths, if only the fracture energy is used to define the unloading branch of the concrete in tension.