Pertaining Master's Thesis TVBK-16/5249
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Experimental analysis of the limitations in the strut-and-tie method

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Structural engineers often face design situations which are too advanced to analyze in a simple way. In this case a simplification method such as the strut-and-tie method may be of use. After assuming the internal stress flow, a fictive truss may be assumed and then designed according to the code. If caution not is taken however, dangerous failures may occur and lives might be at stake.

Concrete structures with non-linear stress variations are rather common, and conventional design techniques cannot be applied. Therefore simplifications such as the strut-and-tie method are introduced. Region containing non-linear stress distribution, e.g. Figure 1, are known as discontinuity regions, and may appear close to concentrated loads or geometrical discontinuities.

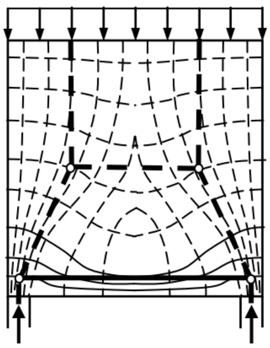

Figure 1: Stress field and internal truss [Engström, Björn, Design and analysis of deep beams, plates and other discontinuity regions, 2011)

This project consisted of three main parts: initiating calculations using the strut-and-tie method, a laboratory testing and computer simulation. The goal was to evaluate the internal behavior and hopefully rationalize the usage of the strut-and-tie method. This developed throughout the project, shining more light upon the limitations of the method as well as the risks.

Four specimens were designed, casted, tested and simulated in a finite element software called Brigade/Plus, Figure 2.

Unfortunately the results did not coincide in terms of stiffness and only one out of four beams could be tested all the way to failure. The failure that did occur was brittle and aggressive, and if being a member of a real structure, this could cause a major hazard.

Evaluating the load-deflection response from each of the specimens, surprisingly enough the beam equipped with minimum reinforcement according to the code cracked at a lower load. However its ductile behavior is far more desirable in a structure than the brittle behavior of the insufficiently reinforced beam.

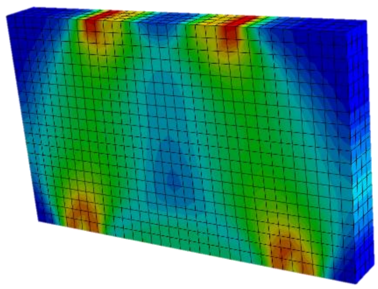

Figure 2: Beam, computer model

Conclusions drawn from the project are:

- Minimum reinforcement serves a well motivated purpose
- When using high design angles the tension strength of the concrete should be considered
- The strut-and-tie method is made for cracked cases
- It is difficult to model the behavior of concrete accurately