Abstract

Designing new concrete members and assessing the strength of existing elements subjected to in-plane stress state conditions is often conducted by means of Stress Fields (SF) and Strut-and-Tie Models (STM). These methods are usually accounting for identical load-carrying mechanisms for design and assessment, even if the goals for these two tasks are not the same. When designing new elements, the aim is to obtain solutions that are in equilibrium with external actions, with simple reinforcement layouts while ensuring satisfactory behaviour at serviceability limit state. When assessing the ultimate strength of existing elements, the goal is to avoid an unnecessary strengthening and limit the amount of retrofitting. The required complexity of assessment models depends on the strength requirements, and need to be gradually refined if the results from current models prove to be insufficient. This refinement process ultimately leads to increasingly more exact solutions that eventually correspond to the largest possible strength according to the limit analysis.

This thesis presents various strategies which can be employed to develop SF and STM suitable for the design and assessment of structural concrete members. The idea of a gradual model refinement (both for design and assessment) is introduced through practical examples, while potential challenges related to each solution are indicated and discussed.

Moreover, the accuracy and the generality of exact solutions obtained using Elastic-Plastic Stress Fields (EPSF) are investigated. To do this, ultimate loads estimated with EPSF are compared to test results found in the literature. To facilitate further studies by other researchers, they are available online. The analysis of structural members with insufficient anchorage and indirectly supported concrete elements with EPSF are presented and discussed.

Furthermore, this thesis focuses on a sensitivity analysis of the EPSF, to investigate the stability of the results as a function the size, shape and orientation of the finite elements. The influence of the number of iteration steps on the accuracy of EPSF models is evaluated, and clear recommendations are provided.

Stress fields based on exact solutions of the theory of plasticity simulate the physical behaviour of structural concrete members more accurately than current code provisions. On this basis, a procedure for tailoring partial safety factors for steel and concrete is presented and discussed. Reduced PSF could potentially be used when assessing the strength of existing reinforced and prestressed concrete elements, which would (could?) lead to significant cost reductions in the field of structural maintenance.

To better understand the mechanical origins of concrete compression softening (important for an accurate application of stress fields), a mechanical model for estimating the effective concrete compressive strength is developed and discussed. Concrete cover spalling, concrete crushing and crack sliding are taken into account. Special attention is given to the dowel action of the reinforcement and its effects on the surrounding concrete matrix. The model is validated using experimental results found in literature. Finally, the pertinence of existing semi-empirical approaches for determining the effective concrete compressive strength is evaluated and discussed.

Key-words: strut-and-tie models, stress fields, design, assessment, insufficient anchorage length, partial safety factors, concrete compressive strength constitutive law, mechanical model, efficiency factor