Numerical Limit Analysis of Precast Concrete Structures: A framework for efficient design and analysis

Precast concrete elements are widely used in the construction industry as they provide a number of advantages over the conventional in-situ cast concrete structures. Joints cast on the construction site are needed to connect the precast elements, which poses several challenges. Moreover, the current practice is to design the joints as the weakest part of the structure, which makes analysis of the ultimate limit state behaviour by general purpose software difficult and inaccurate. Manual methods of analysis based on limit analysis have been used for several decades. The methods provide excellent tools for engineers, however, the results are very dependent on the skill and intuition of the design engineer. Increasingly complex structures and the extensive use of computer-aided design on other aspects of civil engineering push for more accurate and efficient tools for the analysis of the ultimate limit state behaviour. This thesis introduces a framework based on finite element limit analysis, a numerical method based on the same extremum principles as the manual limit analysis. The framework allows for efficient analysis and design in a rigorous manner by use of mathematical optimisation. The scope is to be able to model entire precast concrete structures while accounting for the local behaviour of the joints. The in-situ cast joints are crucial to the capacity of precast concrete structures, however, the behaviour of joints is in practice assessed by simple, empirical design formulas. A detailed study of in-situ cast joints in two-dimensions is conducted using finite element limit analysis, and the findings are used in the development of a two-dimensional multiscale joint finite element, which can represent the complex behaviour of the joints to a satisfactory degree. Analysis of three-dimensional structures is rather difficult, especially by manual methods, however, considering three-dimensional nature of structures will generally increase the capacity. The two-dimensional joint element is therefore generalised to three-dimensions in order to be able to account for the influence of the joints. The strength and efficiency of the presented framework are demonstrated by two real size examples, a two-dimensional precast shear wall and a three-dimensional precast concrete stairwell. The analysis shows that the framework is capable of modelling complex precast concrete structures efficiently. Moreover, the influence and local behaviour of the joints are accounted for in the global model. The results of the two examples demonstrate the potential of a framework based on finite element limit analysis for practical design. The use of mathematical optimisation ensures an optimised design, and the optimisation problems are solved efficiently using state-of-the-art solvers. It is concluded that the framework and developed joint models have the potential to enable efficient design of precast concrete structures in the near future.

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