CERIS Civil Engineering Research and Innovation for Sustainability

A framework for the nonlinear finite element analysis of punching shear in flat slabs

Summary

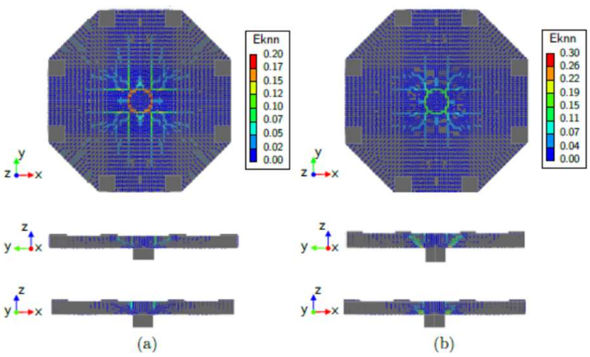
The ultimate limit state of reinforced concrete (RC) flat slab systems is generally governed by punching shear. This type of failure occurs due to high-stress concentrations at the slab column connection regions. Punching failure mode is brittle and can lead to the progressive collapse of a whole building. Over the last decades, several theoretical models have been proposed to estimate punching shear capacity. Most of these models include complex calculations and generally cannot consider all the parameters that affect the punching shear resistance. As a result, most codes of practice rely on empirical or semi-empirical equations limited to the experimental data available. Numerical simulations have also been applied to study the complexity of the punching failure mechanism. The application of nonlinear analysis has shown promising results in reproducing experimental tests. However, the reliability of the simulations is limited by the inherent uncertainty related to the input material parameters, mesh discretization, and solution-iterative procedures. Thus, the potential use of this tool for design practice has not been exploited.

In this context, this thesis aims to develop a framework for the local assessment and design verification of slab-column connections based on nonlinear finite element analysis (NLFEA). Among the different formulations found in the literature, the total strain fixed crack model implemented in the software DIANA was chosen to carry out the numerical analyses. Preliminary simulations, including one-single-element analyses and critical shear beam tests, were conducted to assess the material constitutive model. Also, special attention was given to the incremental iterative methods and the convergence criteria parameters. Furthermore, a stochastic approach was proposed to identify the most important parameters in the simulations and to calibrate the numerical results to the experimental ones. The approach was validated with the simulations of slab-column connections reported in the literature, and good agreement was found regarding load-carrying capacities and crack patterns in most cases. Also, some limitations of the chosen material constitutive model were identified.

The solution strategy for nonlinear analysis was further validated through the numerical simulations of 92 slab-column connection tests. The experimental database was also used to compare the punching shear capacities predicted by different design codes, including the new generation of Eurocodes. Based on this comparison, the resistance modeling uncertainty factor was computed for each approach, and the application of safety formats was assessed to guarantee a safety margin in the results obtained in the nonlinear analyses. Finally, the solution strategy and the recommendations obtained through the development of this work were applied in the design verification of a case study. The results indicate that NLFEA can be effectively applied for the design verification of punching shear in the design of RC flat slabs, provided that an adequate safety format is used.

Keywords

Punching shear, flat slabs, reinforced concrete, nonlinear analysis, finite element method, modeling uncertainty, safety formats.



Crack strain obtained in HP0_R0.6 analysis: a) at peak load, b) at last computed step.

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