Abstract

Sustained load actions are permanently present in concrete structures, as for example self-weight and dead loads on bridges or soil pressure on cut-and-cover tunnels. These actions may increase throughout a structure's lifetime, for instance after refurbishing or in the case of addition of new elements. It has been experimentally observed that under sustained load actions, the response of concrete may be significantly different than the response under rapid loads. Traditionally, sustained actions are treated differently at serviceability limit states (for instance delayed deflections) than at the ultimate limit state (as the potential failure under sustained load). The distinction is given by separating the time-dependent deformation due to linear creep from the strength reduction due to nonlinear creep. Although quite practical, this approach is not sufficient to understand the phenomenon of strength reduction under sustained loads and the potentially beneficial effects of the delayed response of concrete.

The present thesis introduces a comprehensive approach for the long-term analysis of concrete structures, allowing to consistently investigate the response both at serviceability and ultimate limit states. The first part of the thesis aims at establishing a theoretical framework for the evaluation of the time-dependent uniaxial compressive strength of concrete under sustained loads. This approach is accurate for any load level and loading pattern and is validated with specifically designed tests. Based on two test series on concrete cylinders under uniaxial compression with various loading rates as well as other sustained load tests from scientific literature, a failure criterion is established based on the inelastic strain capacity of concrete. For the prediction of nonlinear creep strain, the mechanical approach of Fernández Ruiz et al. (2007) is improved and extended to general loading patterns. Based on this work, it is demonstrated that the strength reduction is more severe under a constant sustained load than in the case of loads increased with a low loading rate. In addition, both the mechanical approach and the conducted tests show that the detrimental effect of sustained loading is associated with a potentially beneficial increase of deformation capacity at failure. For a detailed verification of structures with a complex loading history, the cumulative damage approach of Palmgren-Miner is adapted to account for time-dependent effects, leading to consistent results. Finally, typical engineering design situations are addressed, such as the case of application of a variable action after a period of sustained loading. The time needed for the continued cement hydration to overcome the detrimental effect of sustained loads is also investigated.

The second part of the thesis aims at verifying whether the shear strength of members without transverse reinforcement is influenced by the action of sustained loads. This topic has been little investigated in the past and current codes of practice show conflicting approaches. To contribute to this topic, two test series are conducted on slender and squat members failing in shear. Both series, as well as a comparison with other tests from the scientific literature, show that there is no marked decrease of the shear strength for longer durations of application of the load or very low loading rates compared to typical shear tests. This behaviour is supported by detailed observations performed by means of digital image correlation, allowing to quantify the contribution of the various potential shear transfer actions.

This work focuses on the long-term structural response of concrete under potentially sustained high load levels. Following the various mechanical approaches and findings, several proposals for improvement of design codes are presented and discussed.

Keywords: Sustained loading, loading rate, long-term strength, nonlinear creep, inelastic strain, deformation capacity, internal redistribution, shear strength, critical shear crack theory (CSCT), Digital Image Correlation (DIC)