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Finite element parametric study on the effect of loading rate on the bond of reinforcement in concrete

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Abstract

The bond behavior between concrete and reinforcing steel is examined under the influence of dynamic loading. The explicit finite element code LS-Dyna is used to conduct the three-dimensional analysis, and the results are compared with data obtained during experiments carried out in parallel. The numerical model is simulated at the rib-scale, which constitutes the most basic of all approaches. It involves explicit modelling of the geometry of the rebar ribs and the concrete keys in between with the final reaction being predominately controlled by the mechanical interaction between them. After a short description of the incorporated experimental set-ups, the numerical model and its calibration, the capabilities of the simulation are presented. They include detailed insights into the local structural phenomena with the model being able to capture stress and strain distributions as well as transversal and radial crack patterns inside the specimen with sufficient accuracy. The same code is thereupon used to execute a parametric study aiming at the investigation of the influence of varying loading rates on the results. Both dynamic impact scenarios and displacement controlled quasi-static executions are concerned. Loading rate dependent characteristics are identified, and the results are discussed with reference to strain rate independent constitutive materials, which were consistently used throughout the study in order to separate dynamic effects appearing at the material and the structural response level. The simulations indicate a tendency for increasing bond resistance with increasing loading rate that is qualitatively confirmed by the respective experimental data.

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Keywords: Finite element method; LS-Dyna; Bond of reinforcement in concrete; Dynamic loading

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1. Introduction

Reinforced concrete is the most frequently used material in the building industry. It is a composite material whose characteristics arise out of the concretes reinforcement with steel bars that are intended to transfer the bulk of acting tensile forces. In order to secure its safe operation mode, a deeper understanding of the bond mechanisms is required. While they are considered widely investigated under regular static loading, many uncertainties still exist with regard to their action under dynamic conditions. Especially a controversially discussed loading rate dependent resistance increase has long been a question of great interest in the field.

The work described herein presents a finite element model used for the simulation of bond behavior on the rib-scale. The specification refers to the degree of numerical resolution, whereby three different scales are generally identified: the member-scale, the bar-scale and the rib-scale, see [1]. To pursue the objective of the study, the latter scale was used, as it is the most basic one and the one that requires the smallest amount of assumptions. After a short description of the numerical model characteristics and the series of experimental tests serving as a reference, the simulations capability to predict key characteristics of bond behavior is presented, before in the last and most decisive step, a parametric study is conducted that shall help to address the referenced research gap.

2. Experimental test series

The finite element model is compared to a series of push-in tests conducted in parallel at the laboratory. Irrespective of whether quasi-static or dynamic tests were performed, cylindrical concrete specimens were always used. Both their height and diameter amount to 100 mm. For quasi-static tests servo-hydraulic displacement controlled machines were utilized, whereas for the intermediate and high dynamic executions a drop tower and a modified split Hopkinson bar set-up were employed respectively. In either of the latter cases, the load is introduced in the form of a compressive wave resulting from an impact event. Reaction force, steel strain and displacement signals were consistently recorded and used for the experimental evaluation of the tests [2].

3. Finite element analysis

3.1. Methodology

The numerical analysis was performed with use of the explicit finite element code LS-Dyna. In Fig. 1 the dynamic drop tower set-up is exemplarily shown to illustrate the geometry of the specimen and its meshing. In all cases, the average element size was chosen as 3 mm, whereas a finer mesh was used near the bond zone. Solid hexahedron elements were used for all parts but the concrete specimen, where solid tetrahedron elements were preferred. As indicated by the chosen rib-scale, explicit modelling of the geometry of the rebar ribs and the concrete keys in between was undertaken. The final reaction was thus predominately controlled by the mechanical interaction of the two parts. Regular contact definitions were applied between all surfaces and tiebreak contact was additionally used in order to physically account for the chemical adhesion between concrete and steel.

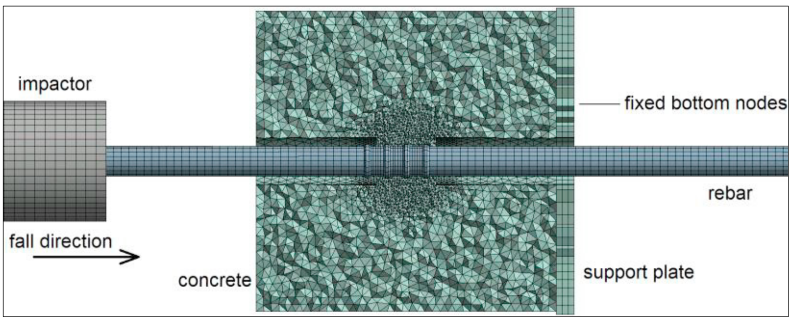

Fig. 1. Detail of the meshed model.