Zukunft Bau

Short Report

Title

Reinforced concrete slabs with integrated cavities

Initial Situation

In structural engineering reinforced concrete slabs are frequently used as installation spaces for building services piping. The resulting weakening of the slabs' cross section can lead to significant reductions of their shear strengths. The shear capacity of slabs with integrated pipes has already been studied in earlier research projects. However the influence of longitudinal tensile stresses on the shear strength of reinforced concrete slabs with integrated cavities has not been investigated to date.

Objective of the R&D Project

Within the research project the influence of longitudinal tensile loads on the shear strength of reinforced concrete slabs with and without cavities has been studied by means of experimental tests and numerical simulations.
The scheme of the experimental tests comprised ten test series with a total of 60 large scale tests. Sections of reinforced concrete slabs without stirrups measuring l/w/h = 270/40/30 cm have been used as test specimens and loaded to failure in three-point bending tests. Each test series comprised three test specimens with integrated cavities and three solid test specimens without cavities. The tests of the specimens without cavities were mainly used to gain reference values for the tests of the specimens with cavities. In the test stand, the longitudinal tensile force has been applied evenly over all of the longitudinal reinforcing bars at the ends of the test specimens and thus introduced centrically into the test specimens by means of hydraulic jacks. In each test series, the shear force resistance of components with and without integrated cavities has been determined for longitudinal tensile forces of N = 0 kN/m, N = 200 kN/m and N = 400 kN/m.

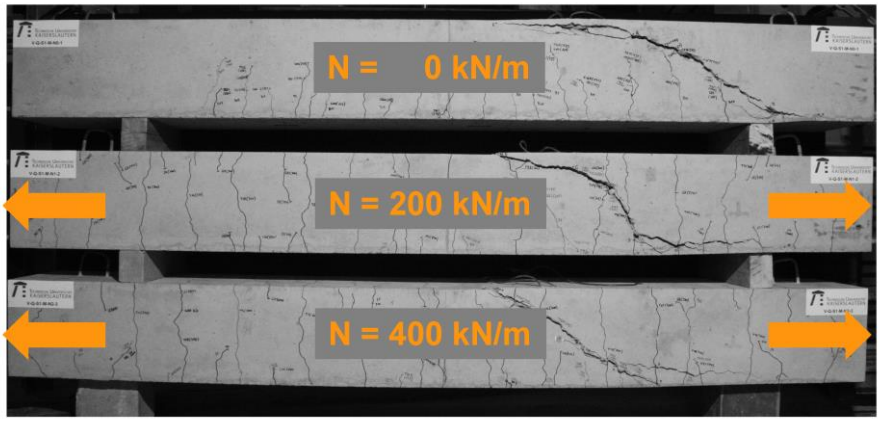

Fig 1: Schematic representation of the longitudinal tensile forces in the test stand for a test series of reinforced concrete specimens without cavities.

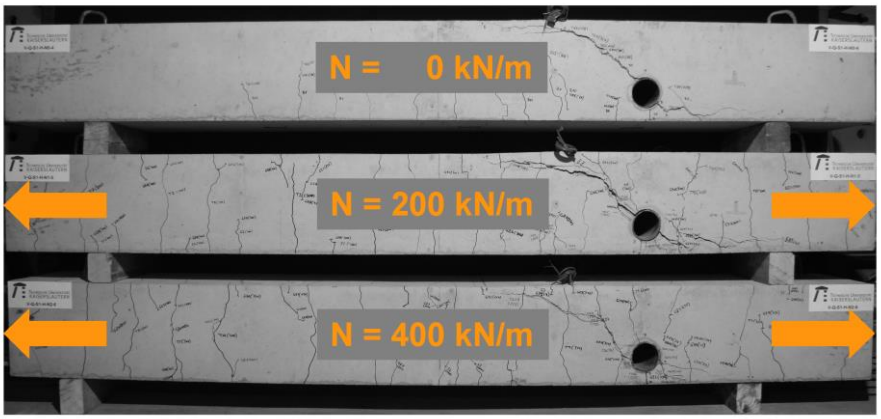

Fig 2: Schematic representation of the longitudinal tensile forces in the test stand for a test series of reinforced concrete specimens with cavities.

The testing sequence basically consists of three major steps:
- incremental increase of the tensile force until achieving the final crack pattern (quasi-indirect action)
- reduction of the tensile force to the intended level (quasi-direct action)
- incremental increase of the shear load to component failure

For massive reinforced concrete slabs the reduction of the shear capacity due to longitudinal tensile forces is well-known and part of the design concept in DIN EN 1992-1-1. The test results showed the expected negative and standard-compliant influence of longitudinal tensile stresses on the shear strength. In addition, the results showed a linear relationship between the reduction of the shear capacity and the acting tensile stresses. This behavior is in good accordance with the reduction of the shear strength given in DIN EN 1992-1-1, eq. 6.2a. ($\Delta V_{Rd,c} = k_1 \cdot \sigma_{cp}$). According to the tests the reduction of the shear capacity can be calculated accurately by adopting $k_1 = 0{,}15$ according to DIN EN 1992-1-1. On the other hand experiments conducted on sections of reinforced concrete slabs with integrated cavities found that the negative influence of longitudinal tensile stresses on the shear strength decreases with an increase of the cavities. This result applies to both reinforced concrete slabs with integrated pipings and reinforced concrete voided slabs. The linear relationship between the reduction of the shear strength and the longitudinal tensile forces is not suitable for these kinds of slabs.

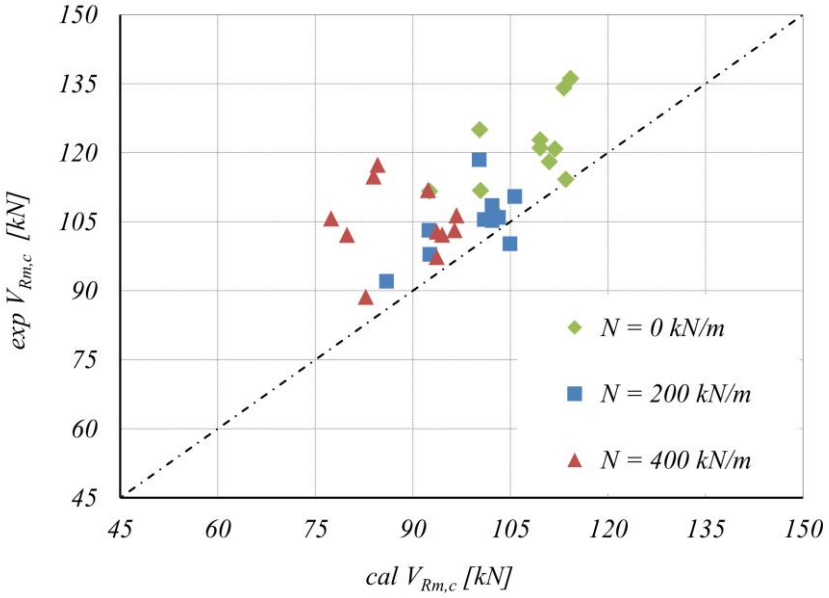

Fig 3: Relationship between the shear strength obtained from experimental tests and the shear strength obtained from numerical simulations for reinforced concrete slabs without cavities subjected to longitudinal tension.

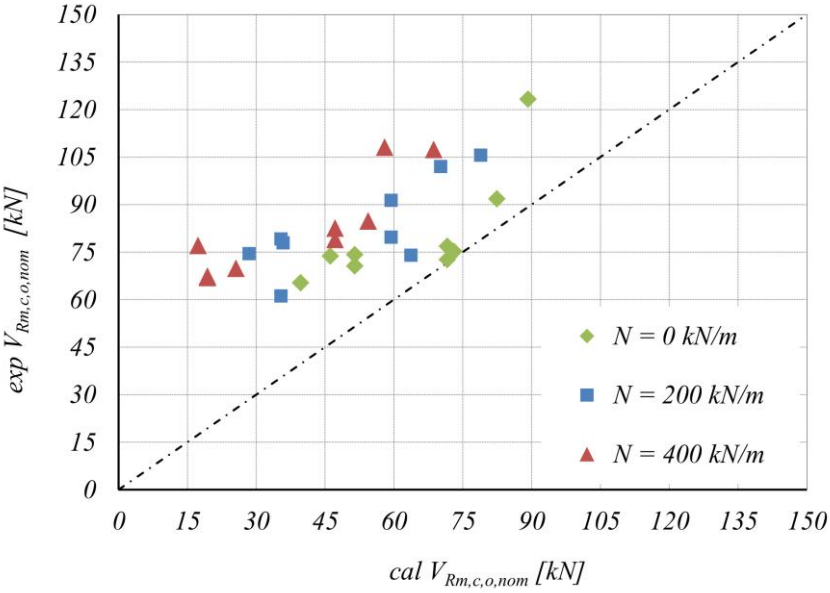

Fig 4: Relationship between the shear strength obtained from experimental tests and the shear strength obtained from numerical simulations for reinforced concrete slabs with cavities subjected to longitudinal tension.

The results of the experimental tests can be verified, with high accuracy by means of physically non-linear finite element calculations. Both the numerical simulation of the experimental tests as well as the additional parametric studies showed that for reinforced concrete slabs with integrated cavities the negative influence of longitudinal

tensile stresses on the shear strength decreases with an increase of the weakening. Based on the test results, the authors suggested to modify the existing design concept according to DIN EN 1992-1-1, 6.2 along with the national annex and the explanatory comment in DAfStb Heft 600. The existing safety level is not reduced if the linear reduction of the shear strength resulting from longitudinal tensile stresses ($\Delta V_{Rd,c} = k_1 \cdot \sigma_{cp}$) is reduced proportionally to the reduction of the shear strength resulting from the cavities (factor k_o).

$$V_{Rd,c,mod} = k_o * (C_{Rd,c} * k * (100 * \rho_l * f_{ck})^{(1/3)} + k_1 * \sigma_{cp}) * b_w * d$$

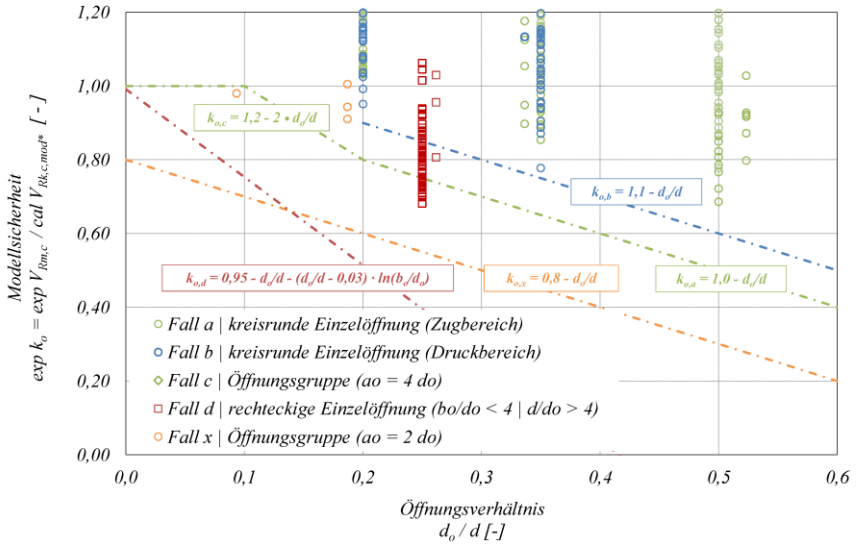

Fig 5: Visualization of the model safety V_{exp} / V_{cal} of the modified design concept depending on the opening ratio d_o / d for reinforced concrete slabs with integrated cavities subjected to longitudinal tension.

Conclusion

The objective of this research project has been to identify the influence of longitudinal tensile forces on the shear strength of reinforced concrete slabs with and without integrated cavities. The experimental and numerical results can be used to describe and evaluate the problem. Based on the results, modified concepts for the calculation of the shear strength of reinforced concrete slabs subjected to longitudinal forces have been suggested. The overall results are of significance for the construction practice regarding both safety and cost efficiency.

Basic data

Short title: Reinforced concrete slabs with integrated cavities

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