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Increasing the load-bearing capacity of installation floor slabs by shear reinforcing elements

Outline report

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This outline report comprises 9 pages.

1 Objective of the research challenge

In building construction reinforced concrete floors with integrated ducts are increasingly executed. In addition to tubes for electrical installations, both liquid and air-leading ducts are embedded into structures. Circular ducts but also rectangular (flat) channels are installed.

In general, reinforced concrete cross sections outside the bending pressure zone are not fully exploited. Therefore, the cross section can be utilized in this area for duct lining, provided that the shear force resistance is not reduced inadmissibly.

Related to the load bearing capacity of one-way floor slab systems without shear reinforcement Schnell and Thiele could be suggested design rules, which were also included in the reprint of DAfStb volume 525 [1] (see [4], [5] and [6]).

In case of installation of larger duct cross sections as well as in case of accumulation of small tubes the shear force resistance of reinforced concrete floors drops down so strongly, that in such cases shear reinforcement is getting required.

So far however, design rules according to which a local reinforcement in the area of ducting could be dimensioned are missing.

In practice, this often leads to refusal and prevention of such systems by structural engineers and checking engineers.

Therefore, looking on the load bearing behaviour of one-way reinforced concrete floor slabs with different types of ducting, the present research project should examine the increase of shear force bearing capacity provided by local shear reinforcing elements.

2 Project execution

2.1 Testing program

In due course of the research project a testing program was developed, which should provide insight views on the loading leading to failure, the modes of failure and the influence of shear reinforcement on the load-bearing capacity of the building elements. After previous trial testing a total of 14 tests at slab elements were carried out. There were circular and rectangular shaped single ducts and groups of circular shaped tubes tested, joined with a reference study for each geometry without shear reinforcing elements inside (see Figure 1). For better comparability an equal opening height of d_o / d = 0.5 was given in all testing arrangements.

In addition to the opening geometry, the type and the amount of shear reinforcement were varied. In this respect, a shear concentration factor was introduced. It describes the ratio between the load-bearing capacity of shear reinforcement as resulting with characteristic material properties to the average shear force resistance. For the testings, the shear concentration factor was chosen to 1.0, 0.75 and 0.5.

shear concentration factor: $$S_{V,Rm,ct} = \frac{f_{yk} \cdot A_{sw}}{V_{Rm,ct}} = 1.0 \; oder \; 0.75 \; oder \; 0.5$$

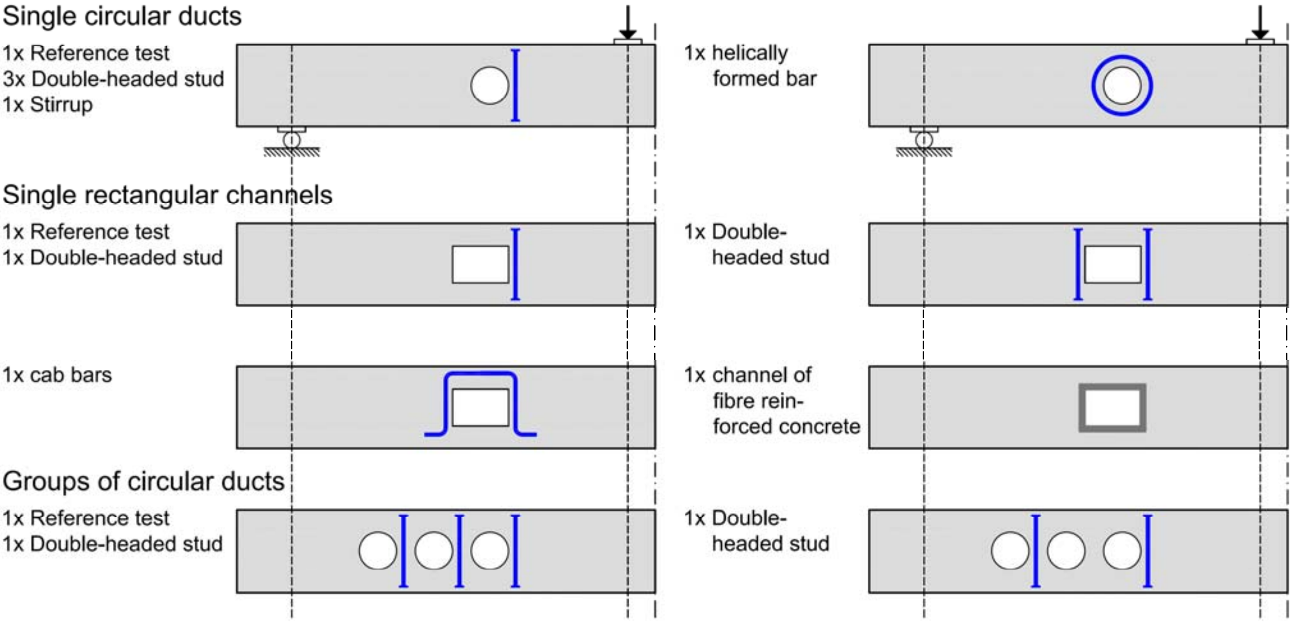

Figure 1: Tested building elements – summary

The test bodies were designed by the centre-line distances between bearings and loading in such way that the area of ducts failed in all testings. For each test body two experiments were conducted under modified positions of bearings (see Figure 2).

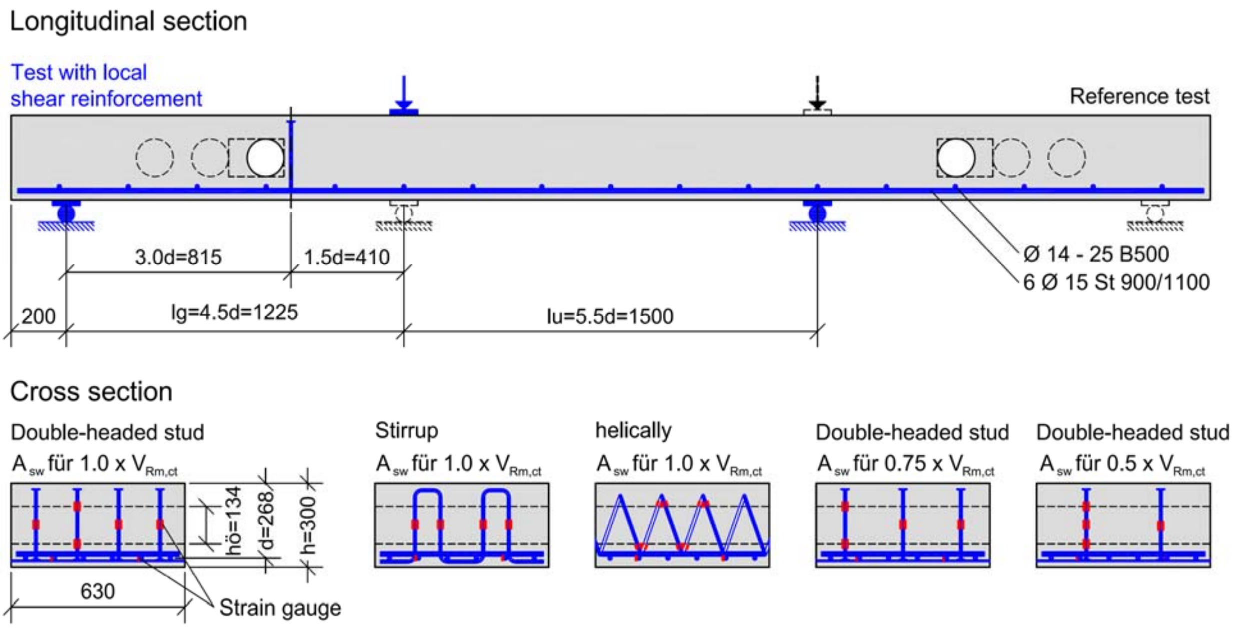

Figure 2: Longitudinal section and cross sections of tested elements

The tests were carried out in form of three-point bending tests. In addition to the steel strain vertical deformations and crack widths were measured (see Figure 3). To begin with the loading was increased in steps up to the expected service load level. This level of load was hit automatically a total ten times. Then, the element was successively loaded up to the failure. A typical cylinder force-time diagram is shown in Figure 4.

Figure 3: Testing arrangement

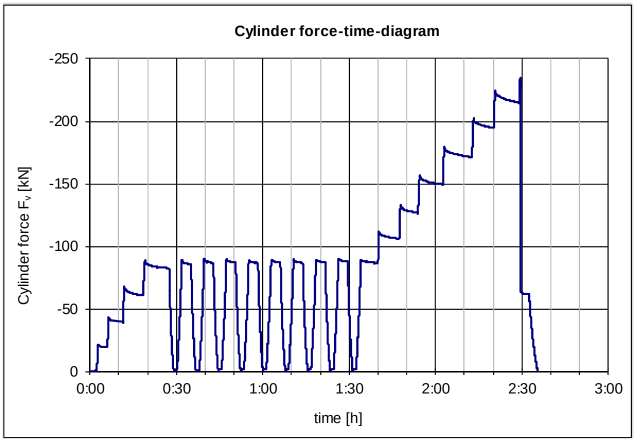

Figure 4: cylinder force–time-diagram

2.2 Testing results

The used test bodies after the stress tests are shown in Figure 5. Table 1 lists all achieved shear forces in the ultimate limit state in comparison with the results of reference tests and the theoretical load bearing capacity of a slab under the same boundary conditions.

The indicated shear forces had been converted into a cylinder strength of f_{cm} = 25 N/mm² ($V_{u,25}$). The calculation of the theoretical capacity of an identical slab element, not impaired by embedded ducts, has been done as per equation 70, DIN 1045 [2] using a prefactor of 0.2 and with $f_{cm} = f_{cm,test}$ = 25 N / mm² ($V_{Rm,ct}$).

The overview can clarify what effective influence do local shear reinforcing elements exert on the shear resistance of installation floors.

The comparison with the expected load bearing capacity according to [1] ($V_{o,Rm,ct}$) clearly indicates that the design approach based on [1] is kept on the safe side. The increase in load-bearing capacity turns out percentagewise accordingly.

Figure 5: testing specimen after loading

Table 1: Shear forces under ultimate loading

test no.	ducting	type of shear reinforcing element	$S_{V,Rm,ct}$ [-]	$V_{u,25}$ [kN]	$V_{u,25}$ / $V_{u,25,Referenz}$	$V_{u,25}$ / $V_{Rm,ct}$ *	$V_{u,25}$ / $V_{Rm,ct,o}$ [1] mit c=0,2
V-R-1	circular dØ = 0.5d	reference test – none	---	94.25	---	59.9%	78.74 kN nach [1]
V-R-2		shear rail – on one side	1.00	155.66	165.2%	98.8%	197.7%
V-R-3		shear rail – on one side	0.75	140.59	149.2%	89.3%	178.5%
V-R-4		shear rail – on one side	0.50	128.10	135.9%	81.4%	162.7%
V-R-5		stirrup – on one side	1.00	149.10	158.2%	94.7%	189.4%
V-R-6		helical	1.00	146.14	155.1%	92.8%	185.6%
V-E-1	rectangular hxl = 0.5d x 0.75d	reference test -none	---	57.10	---	36.3%	40.85 kN nach [1]
V-E-2		shear rail – on one side	1.00	121.74	213.2%	77.3%	298.0%
V-E-3		shear rail – on both sides	1.00	129.36	226.6%	82.2%	316.7%
V-E-4		cab bars – on one side	1.00	82.34	144.2%	52.3%	201.6%
V-E-5		flat rectangular channel made of fibre reinforced concrete	---	57.67	101.0%	36.6%	141.2%
V-G-1	group of ducts 3 x circular	reference test – none	---	57.30	---	36.4%	< 0 nach [1]
V-G-2		rows of shear rails- 3x	0.75	128.84	224.9%	81.8%	---
V-G-3		rows of shear rails - 2x	0.75	85.84	149.8%	54.5%	---

* $V_{Rm,ct} = V_{cal,25,\text{not impaired by ducts}} = 157.5$ kN

The shear forces topped in the state of failure and the failure modes of all testings become available within the final report. The following compares only the tested elements with circular ducts. The loading at failure and the modes of failure are shown in Figure 6 and a comparison of the strength deformation-diagrams is depicted in Figure 7.

The test no. V-R-4 with $S_{V,Rm,ct}$ = 0.5 achieved a shear force at 136%, compared with the reference test. The shear crack at failure ran through the opening as like to the reference test. The test no. V-R-3 with $S_{V,Rm,ct}$ = 0.75 achieved a shear force at 149%, compared with the reference test. The shear crack at failure did not run, otherwise as to the reference test, across the opening, but first above the opening and then below the opening down to the tension area. During test no. V-R-2 with $S_{V,Rm,ct}$ 1.0 = the shear force could be increased to 165%, compared with the reference test. The shear crack at failure did no longer run through the opening like in the reference test. A shear crack occurred above the opening.

A comparison of testings with shear concentration factor $S_{V,Rm,ct}$ = 1.0 (V-R-2, V-R-5 and V-R-6) yield that the load-bearing capacity evidently can be increased not only by shear rails, but also by helically formed bars or regular stirrups.

Test no.	tested elements after failure	cross section
V-R-1 94.2kN 100%		
V-R-2 155.7kN 165%		
V-R-3 140.6kN 149%		
V-R-4 128.1kN 136%		
V-R-5 149.1kN 158%		
V-R-6 146.1kN 155%		

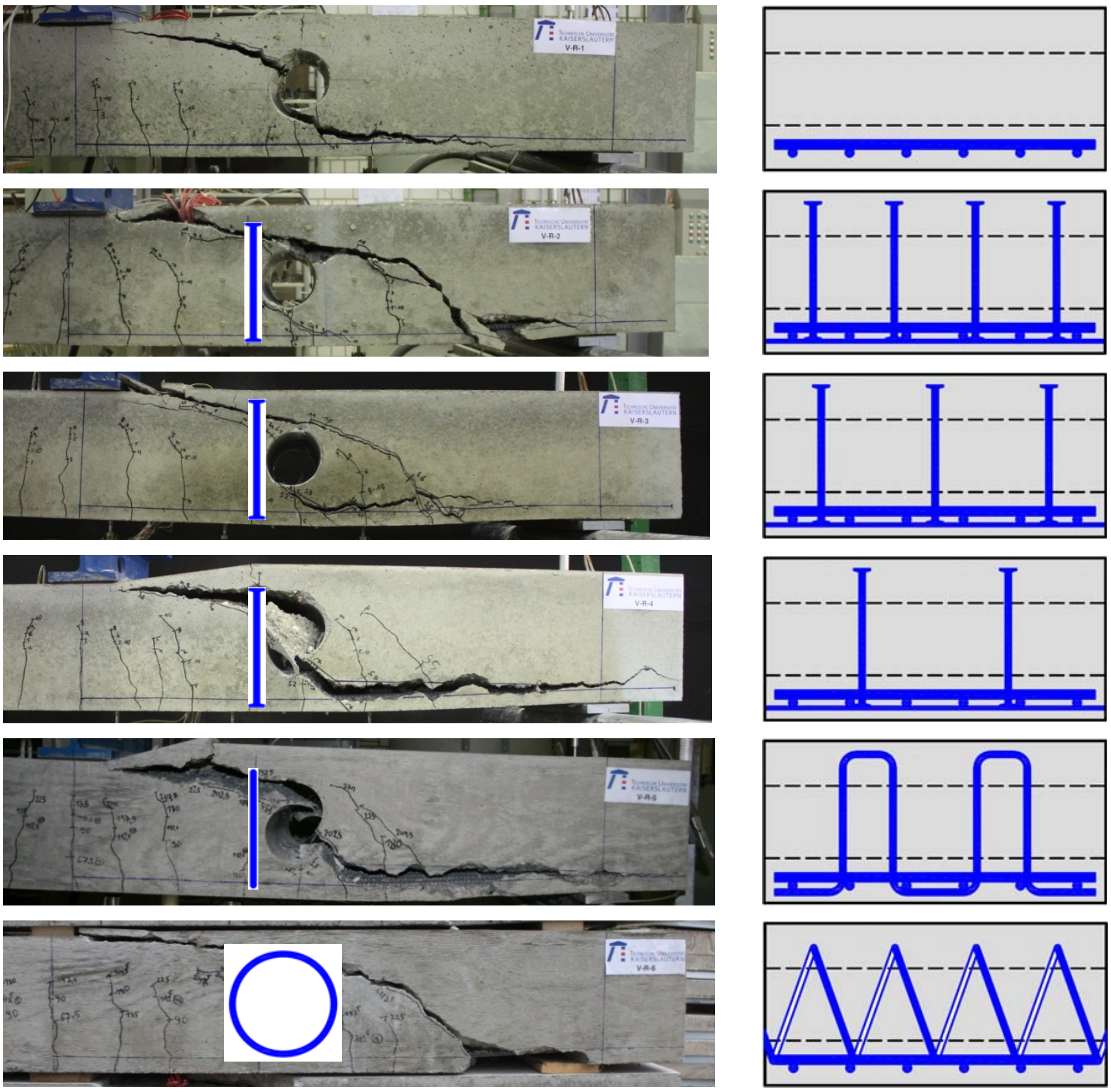

Figure 5: ultimate shear force and modes of failure at building elements with single circular ducts

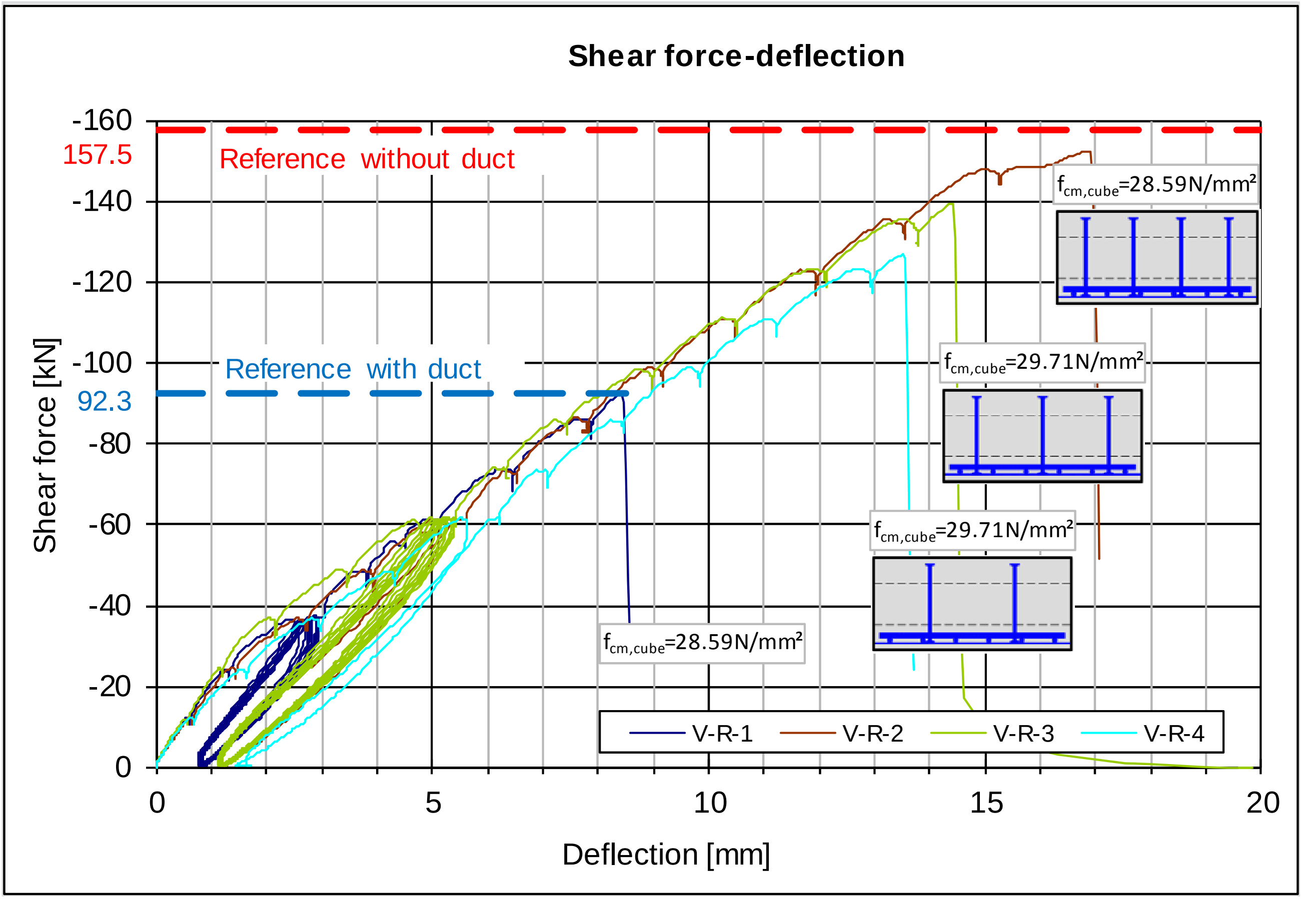

Figure 6: shear force-deflection-diagram – circular ducts: reference test and tests with shear rails located at the side of the loading input

2.3 Analysis of experimental studies using a finite-element-computation-method

The tests were checked with the FEM program ATENA 2D. In case of an adequate agreement between theoretical with the experimental ultimate loads, quite good correlations could be found looking on deformations and strain values of the reinforcing steel. In spite of similar modeling the FEM results of several testing's deviated rather heavily from test results, so no parameter study could be accomplished.

2.4 Preliminary design concept

A preliminary design concept was proposed for circular ducts with shear rails, which however still must be verified before application in practice.

The design concept shall cover the following conditions:

- limitation of shear force resistance by $V_{Rd,ct}$ resulting from a cross section not impaired by ducts
- impact of the opening on the shear force resistance
- effectiveness of studs

It is recommended, that the design assessment for floor slabs with embedded circular ducts is based on the equation proposed in [1] and to adjust the shear force such like calculated by an additive value depending on the effectiveness of the studs.

$$v_{Rd,ct,o+Dü} = v_{Rd,ct,o} + \Delta v_{Rd,Dübelleiste} \le v_{Rd,ct}$$

Shear resistance of floor slab comprising circular ducts and shear rails

taking:

$$v_{Rd,ct,o} = \left(k_0 \cdot \frac{0.15}{\gamma_c} \cdot \kappa \cdot \eta_1 \cdot \left(100 \cdot \rho_l \cdot f_{ck}\right)^{\frac{1}{3}} - 0.12 \cdot \sigma_{cd} \right) \cdot b_w \cdot d$$

Shear resistance of floor slab comprising ducts [1]

$$\Delta v_{Rd,shear\,rail}$$

Additive part to consider the increase of shear force resistance depending on the effectiveness of studs

$$v_{Rd,ct} = \left[\frac{0.15}{\gamma_c} \cdot \kappa \cdot \eta_1 \cdot \left(100 \cdot \rho_l \cdot f_{ck}\right)^{\frac{1}{3}} - 0.12 \cdot \sigma_{cd} \right] \cdot b_w \cdot d$$

Shear resistance of floor slabs not comprising ducts according to [2], equation 70

With regard to the testings performed, the effectiveness of studs was limited by the anchoring (see Figure 8). In case of smaller ducts embedded and in case the studs can sufficiently be anchored, the effectiveness of the studs must be limited by the capacity of the steel. The design of the anchor is based on the design of headed studs [3] and is listed in the final report of the research project.

V-R-2 V-R-3 V-R-4

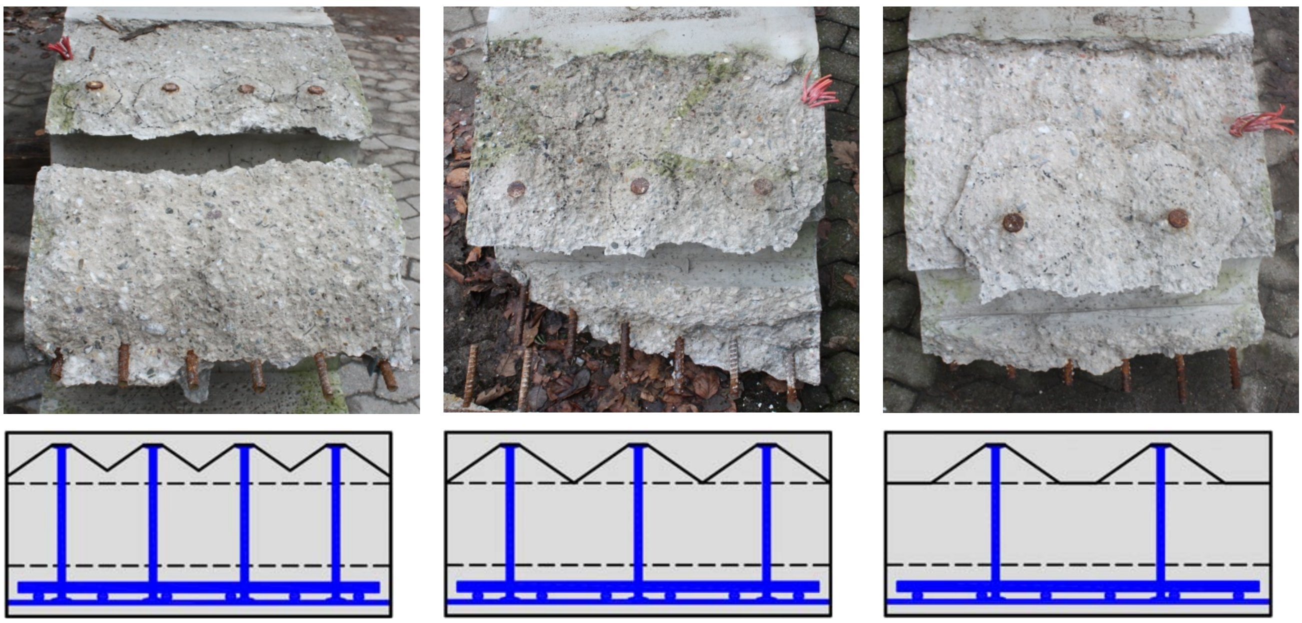

Figure 7: cones of failure at shear rails in case of circular ducts

3 Summary of results

The research project carried out could show that the load-bearing capacity of installation floors can effectively be increased by local shear reinforcing elements. Depending on the size and geometry of ducts, as well as on the built-in reinforcement quantity, even the level of load-bearing capacity of floor slabs the cross section of which are not impaired by ducts can be faced or exceeded without shear reinforcement.

The anchoring of the utilized shear reinforcing elements exhibits a decisive influence on the load-bearing capacity. Looking on this subject it is not only essential, whether shear rails or regular reinforcing bars are built in. It is also essential in which vertical and horizontal distance to the ducts the reinforcement is installed and whether the longitudinal reinforcement is enclosed.

A preliminary design concept for installation floors comprising circular ducts and local shear rails has been developed, which must however be verified through further testings and parametric studies. For a detailed study of the parameters it will be necessary, to apply a 3D FE-program, which requires a relatively large modeling and calculation effort. Then however, the anchorage can be better mapped and it can be assumed that a good correlation between the experimental and theoretical investigations can be achieved.

In addition, there are following aspects for further investigation:

- location of ducts within the cross section in transversal direction,
- location of ducts within the cross section in longitudinal direction,
- arrangement of ducts in cantilevering cross sections,
- arrangement of ducts within the area of zero bending moments,
- additional effects by centric constraint,
- downgrading the bonding joint in floor slabs made of precast filigree decks.

Such studies can be deducted from the knowledge obtained in [6].

The research based on the performed testing program will continue at Kaiserslautern University of Technology outside the financing by BBR.

4 References

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