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Safe use of hollow floors with screed and stiff coatings (flooring systems)

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Research objective

Hollow floors belong to system floors. They are tested according to DIN EN 13213 without coating and are approved for a corresponding load category. Elastic/textile coating can absorb higher deformation damage-free, whereas the deformation may damage the inelastic/stiff coating by fractures or delamination. Actually there are no general agreed regulations/rules for the coating of multi-layered hollow floors consisting of screed covered with inelastic/stiff coatings like tiles and natural stone slabs.

The screed is tested according to DIN 18560. However, the load bearing system of screeds used in hollow floors differs from DIN 18560, due to the fact that there is no holohedral stripping of load. The load bearing system of a hollow floor corresponds to a multilayer panel-borne on a prop arrangement.

The research project is triggered by the observation that floors although being constructed according to the official rules, were damaged in many cases. Experimental investigation and finite element modeling were conducted to aim at being safe in planning and using these floor systems. The results of this project should provide a sufficient planning and technical security for planners and executors.

Research execution

First the mechanical and physical material properties of the system components were determined. In full-scale tests afterwards several hollow floors (inelastic/stiff coating as well as no coating accordingly DIN EN 13213) with different system structures were examined concerning their loading capacity. In this process the load capacity and the deformation was tested at different positions. The deformation testing serves as basis for the finite element modeling.

Material properties

Flowing screed

The range of products was limited to customary calcium sulfate flowing screeds. The material properties of fresh mortar (temperature, slump, air void content and gross density) and of dry mortar (tensile bending - and compression strength, elasticity modulus) were tested in each case after seven, 28, 56 and 91 days. Moreover shrinkage was measured up to 91 days and confirmation tests were executed after 28 days. Finally two out of five screeds were chosen for the full-scale tests.

Sub construction: gypsum boards, pedestals

The gypsum boards were tested regarding to DIN EN 15283-2

The pedestals were tested according to DIN EN 12825. Thereby the pedestals had to withstand a compressive strain and a quadruplicated nominal load. The pedestals must not show any indication of failure.

Full-scale tests

System structure: Hollow floor without coating

Four different testing-fields were prepared and their system structure varied in screed thickness, sort of screed and pedestal space. Testing-field 1 corresponded to the system structure named by the manufacturer. Table 1 shows a summary of the examination program.

Table 1: Test set-up summary field one to four

Field	Pedestal span	Screed thickness	Used screed
Field 1	600 / 300*	38 mm	screed III (C30 F6)
Field 2	600 / 300*	38 mm	screed V (C30 F5)
Field 3	600 / 300*	76 mm	screed III (C30 F6)
Field 4	300 / 300*	38 mm	screed III (C30 F6)
*Pedestal span of two together reclined brinks			

System structure: Hollow floor with coating

Based on the results of previous experiments, two other fields were tested analogue to field 1. The only difference consisted in the kind of application of the coating (without bond as well as stretching bond). These tests were made to examine a possible influence of the gap formation on the load abrasion.

Experimental procedure

The system test of the hollow floor was conducted regarding to DIN EN 13213. While loading, the applied load and deformation were measured by inductive gauges.

For the final interpretation it is needed to consider that the measured deformations are composed of settlement of supports, deformation of gypsum boards and of screed as well as rubber plate deformation (which is needed for the test according DIN EN 13213)

Experimental procedure: Hollow floor without coating

Each testing-field was loaded at three normative specified positions as well as two respectively three additional positions. The formation of the measuring points per testing-field is shown in figure 1.

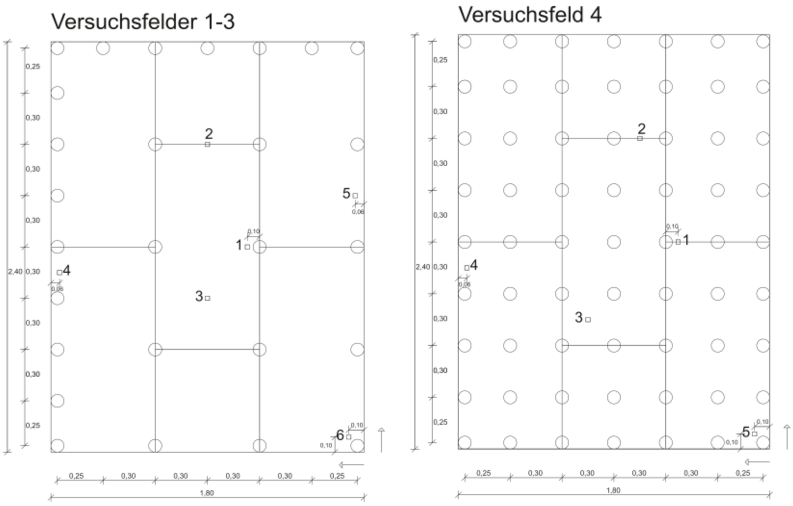

Figure 1: Measuring point formation of testing-fields

The test set-up is shown in the following drawing (figure 2):

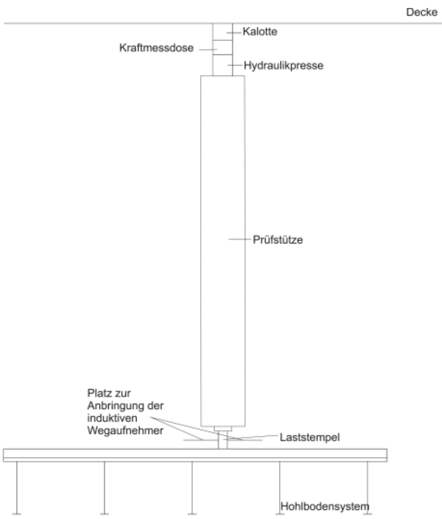

Figure 2: Test set-up

Experimental procedure: Hollow floor with coating

The hollow floors with coating were measured at six measuring points, corresponding to testing fields 1 - 3.

Finite Element Model

In a parameter study the influences on deformation of a hollow floor that arise out of material parameter (consistency, stiffness and thickness of the bearing layer, compo and coating) and parameter due to the system (consistency and stiffness of the sub construction, grid spacing and system height), were examined more closely. Previously it should be assessable at which load the hollow floor would collapse and how major the deformations would be for each time of testing. The FE Model was created with SOFISTIK.

Summary of results

Determination material properties of flowing screeds

Material properties of fresh – and hardened mortar

Every tested screed fulfilled the manufacturers' instruction requirements.

Shrinkage tests

Of each screed a group of prism was produced for a shrinkage test. All specimen swelled in the beginning (0.015 mm/m up to 0.09 mm/m) until subsequently shrinkage began within a range from 0.01 mm/m up to 0.038 mm/m.

Further shrinkage tests were carried out in the project partners' laboratory.

Full-scale tests

Hollow floor without coating

Mortar properties

For a better workability the maximum of feasible tempering water (pursuant to the manufacturer) was needed. Compared to aforementioned tests, determining the material properties, the dry mortar parameters of selected screeds were lower.

After finishing the full scale tests, surface tensile strength tests were additionally carried out. The required strengths for application of a coating were confirmed. The surface tensile strengths ranged between 1.22 N/mm² and 1.66 N/mm².

Shrinkage tests

The result of shrinkage tests was an average value of -0.08 mm/m for field one, and about -0.06 mm/m for field two. Field three and four, both created with screed three, swelled, compared to the other specimen. Different behavior may be explained by different storage conditions, especially to the air humidity within the laboratory.

System test

The examination program consisted of loading each measuring point with maximum load according to manufacturers given load category. Subsequently the collapse load of measuring point three was ascertained.

Table 2: Maximum loads in field one to four

Measuring Point	Field 1	Field 2	Field 3	Field 4
Near bearing (Measuring Point 1)	10,000 N	10,000 N	10,000 N	10,000 N
Between two pedestals (Measuring Point 2)	8,000 N	8,000 N	8,000 N	8,000 N
Midspan (Measuring Point 3)	8,000 N	8,000 N	19,500 N	8,000 N
Border area 300 mm (Metering Point 4)	7,800 N	8,000 N	8,000 N	7,500 N
Border area 600 mm (Measuring Point 5, not for field 4)	6,000 N	6,000 N	17,500 N	-
Near corner (Measuring Point 6 resp. 5 for field 4)	7,400 N	Not testable	6,000 N	8,000 N

Initially every testing field at measuring point one was loaded with ten kN. Afterwards metering points two, three, four and six were loaded with eight kN and metering point five was loaded with six kN according to their load category. The following remarkable observations were made:

- Field one: While testing measuring point two, a force drop could be observed after loading with 8,000 N. Settlement noises appeared at measuring points three, four and six. The required eight kN pursuant load category could not be applied all round. At measuring point six a fracture occurred in the screed.
- Field two: At measuring point five a fracture occurred after reaching maximum load, so that measuring point six could not be tested anymore.
- Field three: There were neither settlement noises nor fractures in the screed while testing.
- Field four: While testing a fracture occurred at measuring point four. Measuring point five could not yet be tested.

As expected the test results prove the considerable influence of a higher modulus of elasticity on system deformations. If the flowing screed thickness is increased or a screed with higher strength is used, the deflections will decrease, the system will be stiffer. If the grid space is halved, the deflections will also halve.

The four different test set-ups can be classified into element category three according to DIN EN 13213, due to the fact that for all systems the minimum requirements for element category 3 were proved (maximum deflection 2 mm at metering point three, for element category three reaching collapse loads higher than eight kN and three tests without collapsing).

Collapsing load

The system collapse occurred due to a new midspan positioned load at metering point three. The load application was increased until fractures indicated collapse appearance. Table three shows the ascertained collapse loads. For hollow floors two and four no further collapse load was determined, as they failed in advance. Field one was loaded up to 8,500 N until settlement noises and a further fracture in the screed were noticed. Field three was loaded up top 19.500 N at measuring point three without construction modifications. The load application was stopped then, due to the fact that the load cell could be loaded maximum 20.000 N. Additionally a load application at measuring point five was examined. The system showed fractures after loading 17.500 N.

Table 3: Collapse load determination

	Maximum load [N]	Deflection [mm]	Bemerkungen
Field 1	8,500	1.58	Settlement noises in screed, fracture visible
Field 3	19,500	1.29	No modifications, stopping load application

Hollow floor with coating

Material properties

The tests of the hollow floors were carried out after 36 days. The screed of Field 5 had an average tensile bending strength of 7.4 N/mm² and an average compression strength of 36.1 N/mm². The screed of field 6 had an average tensile bending strength of 6.2 N/mm² and an average compression strength of 31.2 N/mm².

All prisms of tile cement and jointing materials were tested after 36 days as well. The tile cement had an average tensile compression strength of 12.8 N/mm² and an average compression strength of 38.4 N/mm². The jointing materials were measured with an average tensile bending strength of 9.2 N/mm² and an average compression strength of 40.1 N/mm².

System test

Initially all fields were loaded at measuring point one with ten kN. Afterwards measuring points two, three and four were loaded with eight kN and measuring points five and six with six kN according to the load category. The following remarkable observations were made:

- Field five: Field five neither showed noises nor fractures in the screed while testing.
- Field six: Testing noises occurred at measuring points four and five just before reaching eight or six kN but no fractures.

Collapsing load

The maximum collapsing load was determined with a new load at measuring point three in the middle of a field. The load introduction was raised until there were fractures at the top or on the underside.

Field five reached a collapsing load of 13,800 N and a deformation of 2.06 mm. The system broke down at this load and there were visible damages like fractures in the jointing and in the screed.

Field six only reached a maximum load of 3,600 N at measuring point three. The system could not bear a further load. This does not correspond to the load of 8,000 N which was reached before. Despite this low load there were no visual damages.

Finite element model

Hollow floor without coating

All four fields were shown in a finite element model. A comparison of the real deformations with the calculated results of the model shows good accordance.

Hollow floor with coating

Four different models were designed in which the screed and the tile parameters were varied. Model 0 corresponds to a system without coating. The system construction is modeled by three layers with layer one corresponding to the screed. Thickness and modulus of elasticity vary there. Layer two presents the tile cement with a thickness of 3 mm and a modulus of elasticity of 5,000 N/mm². The third layer corresponds to the coating. All joints were neglected. Equal to layer one the thickness and the modulus of elasticity were varied. The aim of the modeling was to find out maximum deformation depending of the chosen screed and coating.

Conclusion

The tests showed that the properties of hardened mortar may differ from the specifications given by the manufacturer. In part this can be reduced to the required water to adjust a sufficient workability.

A higher stiffness of the screeds (modulus of elasticity and thickness) has a big influence on the deformation of the system. The deformation can be reduced if the stiffness of the screeds rises up.

The parameter study has shown that a thin and a soft screed combined with a thin and stiff coating leads to – for the coating critical – flexural stress at the top of the coating in the area of the pedestals.

A reducing of the flexural stress and the deformation is possible by increasing the stiffness of the screed and coating but also by reducing space between the pedestals.

A calculation of the deformation is possible with the developed finite element model for the system tests without coatings. The calculated and measured deformations concur mostly.

The materials law needs to be implemented for a correct calculation of the two axial flexural stresses. Afterwards they need to be verified in a system test.