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Projekt: Verbunddübel im Brandfall

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Datum: 02/05/2017

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1. Summary

On the research project „Verbunddübel im Brandfall" supported and financed by the Deutsches Institut für Bautechnik (DIBt) was conducted by the Technical University of Kaiserslautern from january 2015 to December 2016. Besides the DIBt the companies Chemofast Anchoring GmbH, Fischerwerke GmbH & Co. KG and Hilti AG have supported the research work advisory and financially.

The research project deals with the evaluation of fire resistance of bonded anchors and studies the understanding of the load bearing behaviour of bonded anchors under fire exposure. A short summary of the research work and its results are given below.

1.1. Thermal analysis

Thermal simulations give the opportunity to determine the temperatures along the embedment depth in case of a fire scenario. The simulation results obtained in the scope of this research project and by other institutes are in a good accordance with temperature measurements in fire tests. In the results the temperature profile of an anchor in fire can be simulated with adequate accuracy. The parameter study showed the following results:

- The comparison of temperature results at the steel-concrete-interface showed, that bigger anchor diameters result in higher temperatures and that greater embedment depths result in lower temperatures.
- The existence of mortar raises the temperature at the steel surface if the insulating properties of the mortar are higher than the insulating properties of the concrete.
- The influence of humidity up to 3 % on the temperature distribution is insignificant. At that time, the vaporization and the consequential transport of water can't be simulated.
- The type of fixture has a significant influence on the temperature distribution and has to be modelled in any case.
- For verification, the results from temperature simulations were compared to results obtained from two other different programs, as well as compared to the temperature results directly measured in fire tests.

1.2. Fire resistance tests acc. to EAD 330087-00-0601

The fire resistance tests according to EAD 330087-00-0601 give a good opportunity to represent the mortar properties at high temperatures. In this tests; resulting bond stress - temperature relation can be used as a basis for the calculation of fire resistance loads of bonded anchors in case of fire.

The parameter study showed the following results:

- The anchor diameter can have an influence on the bond stress – temperature relation depending on the mortar type.
- The residual moisture of the concrete has no influence on the result (comparison of tests between aged concrete and steel members).
- The type of anchor rod (threaded rod or rebar) has an influence on the bond strength – temperature relation especially for high bond strength respectively failure temperatures near by ambient temperature.

1.3. Calculation of the fire resistance of bonded anchors

On the basis of the results of the thermal simulation and fire resistance tests according to EAD 330087-00-0601 fire resistance loads for all combinations of anchor diameter and anchorage depth can be calculated. The comparison with results of fire tests showed that the calculation delivers slightly conservative results. This could be due to the following reasons:

- The bond strength - temperature relation, which was determined via “fire tests” according to EAD 330087-00-0601, delivers no result for high temperatures, which means parts of the anchorage depth can’t be assigned a bond strength.
- The real distribution of bond strength along the anchorage depth is not known.

1.4. Proposal for test execution and evaluation

The following design proposal complies only with bonded anchors composed of threaded rods or rebars and mortar.

On the basis of the results of the research project; the following procedure for the determination of the fire resistance of bonded anchors, based on a combination of tests and calculations is suggested.

1.4.1. Simplified design model

The fire resistance for bonded anchors under axial loads can still be determined with the simplified design model according to TR020 chapter 2.2. This is only valid for the failure modes steel failure and concrete cone failure. The characteristic fire resistance load for c-steel can be chosen as showed in Table 1-1. The fire resistance concerning bond failure has to be determined experimentally.

Table 1-1: New fire resistances concerning steel failure for carbon steel

thread diameter [mm]	anchorage depth h_{ef} [mm]	characteristic tension strength of an unprotected anchor made of C-steel in case of fire exposure in the time up to: $\sigma_{Rk,s,fi}$ [N/mm²]			
		30 min (R15 to R30)	60 min (45 and R60)	90 min (R90)	120 min (R120)
M6	≥ 30	14	12	9	7
M8	≥ 30	20	15	11	9
M10	≥ 40	25	19	14	11
M12 and greater	≥ 50	30	23	16	13

The determination of the fire resistance concerning shear loads can still be carried out according to TR020 chapter 2.2.2.

1.4.2. Experimental/calculative evaluation of the fire resistance

a. Fire resistance against steel failure

The resistance against steel failure can be determined according to TR020 chapter 2.3.1.1.

b. Fire resistance against concrete cone failure

The fire resistance against concrete cone failure can be determined with the simplified design model according to TR020 chapter 2.2.1.3.

c. Fire resistance against bond failure for constant anchorage depth

The experimental determination of the fire resistance according to TR020 chapter 2.3 should still be possible. However the experimental setup described in chapter 2.3.1.1 should be used, because the use of the setup shown in figure 2.5 chapter 2.3.1.2 of TR020 leads to smaller temperatures along the embedment depth. The tests have to be executed in cracked concrete.

d. Fire resistance concerning bond failure for flexible anchorage depth

For the evaluation of the fire resistance against bond failure of axial loaded bonded anchors, a combination of thermal simulation and fire tests should be executed.

The test program below has to be executed for a bonded anchor system with flexible anchorage depth.

Table 1-2: Test programme

	Purpose of the tests	crack width	Minimal number of tests per anchor size					test description
	[-]	[mm]	s	i	m	i	l	[-]
1	Tests for confirmation of the temperature results from the simulation	-	-	-	3	-	-	Unloaded anchors with Thermocouples
2	Tests for confirmation of the bond strength-temperature relation with threaded rods	-	-	-	5	-	-	"fire test" acc. to EAD 330087-00-0601 with threaded rod
3	Optional: tests for expansion of the temperature range, $\tau < 0,5$ N/mm²	-	-	-	1	-	-	"fire test" acc. to EAD 330087-00-0601 with threaded rod
4	Optional: Tests for the improvement of the upper bond strenght limit, $\tau > 10$ N/mm²	-	-	-	1	-	-	"fire test" acc. to EAD 330087-00-0601 with threaded rod
5	Fire tests for confirmation of the calculation results	-	3	2	5	2	3	Fire test acc. to TR020 Abschnitt 2.3.1.1
6	Fire tests in cracked concrete	0,3	3	-	5	-	-	Fire tests acc. To TR020 Abschnitt 2.3.1.1 + crack

Notes to Table 1-2 line 1:

For the verification of the test results, temperature profiles defined by thermal simulations can be used. The fixture used for the tests has to be considered in the thermal simulation. Generally the simulation of mortar can be omitted, if the tests according to line 1 confirm the simulation results. (i.e. it can be excluded that the insulating properties of the mortar have an influence on the temperature profile along the anchor).

The confirmation tests according to line 1 should confirm the simulation results. Three anchors with a medium anchor size and minimal embedment depth should be used, and thermocouples TC1 (10 mm), TC2 (0.5 * h_{ef}) and TC3 (h_{ef} – 10 mm) should be added. Afterwards the anchor should be installed according to the manufacturer's instructions of use. The requirements below should be fulfilled for the comparison of measured temperatures and simulation results:

- The temperatures along the embedment depth and the temperature distribution over the time should have a similar profile.
- The equation below, which describes the relation between simulation results and test results, should be fulfilled for each temperature value.

$$\frac{1}{1,5} < \frac{T_{sim}}{T_{test}} < 1,5$$

- The average value of the measured temperatures $T_{test,m}$ should be smaller than the simulation results $T_{sim,m}$ with 10% additionally at the same place and time.

$$T_{test,m} < T_{sim,m} \cdot 1,1$$

- The execution of additional tests is optional.

Notes to Table 1-2 line 2:

Tests according to line 2 are carried out for confirmation of the transferability of the bond strength – temperature relation, determined by "fire tests" according to EAD 330087-00-0601, to threaded rods. Five tests with medium anchor size according to chapter 2.2.3 "resistance to fire" of EAD 330087-00-0601 should be executed. Threaded rods should be used divergent to the details in EAD. The boreholes should be drilled with the decisive drilling method and cleaned with the decisive cleaning method. The sustained loads for test execution should be chosen in a way that results distributed over the whole temperature range can be expected. The bond strength – temperature relation of the "fire tests" according to EAD 330087-00-0601 can be used for calculation if the requirements below are fulfilled:

- Each deviation between test result and bond strength–temperature curve should not exceed 50 °C.
- The trend line determined by the five new tests should not deviate from the existing trend line more than 20°C. The bond strength–temperature relation has to be determined again for threaded rods. Therefore 15 additional tests according to the specifications in EAD 330087-00-0601 concerning minimal temperature and bond strength differences, have to be executed.

For an expansion of the range of the bond strength–temperature relation across the limits according to EAD 330087-00-0601 (maximum bond strength = 10 N/mm²; minimum bond strength = 0.5 N/mm²), the execution of additional tests is allowed.

- 10 N/mm² < $\tau_{sust} \leq \tau_{Rk,0}$ (line 4) and/or
- 0.2 N/mm² < $\tau_{sust} \leq$ 0.5 N/mm² (line 3)

Notes to Table 1-2 line 5:

With the bond strength–temperature relation (line 2 to 5) and the temperature simulation along the embedment depth a calculation of fire resistances for all combinations of anchor diameter and anchorage depth is possible. For confirmation of the results, fire tests according to TR020 chapter 2.3.1.1 should be executed. The aspects below should be considered for choosing the installation data and the load for confirmation tests.

- The execution of at least two tests for each anchor size is required (for the choice of the sustained load the calculation results for 60 min and 90 min can be used).
- The smallest anchorage depth has to be tested.
- With a medium anchor size, minimum five tests should be executed. The failure time for four of them should be more than 60 min, one of them should have a failure time less than 60 min.

For the use of different types of anchor rods (e.g. different materials) and drilling methods, the aspects below should be considered:

- For the use of anchor rods made out of stainless steel the same fire resistance as for carbon-steel can be used without execution of additional tests.
- The calculation results can’t be applied directly to other anchor elements or drilling methods.

Notes to Table 1-2 line 6:

Fire tests with anchors in cracked concrete should be executed for the evaluation of the influence of cracks on bonded anchors. At test beginning the crack width should be 0.3 mm. The sustained loads should be chosen similar to the tests in line 5 with the smallest and medium anchor diameter. The sustained loads of the tests with the medium anchor size in cracked and non-cracked concrete should be plotted over the failure time and a fitting function following the equation given below should be found.

$$\sigma_{b1} = c_1 + \frac{c_2}{t}$$

The minimum quotient of the two functions in the range between t = 30 min to t = 120 min gives the reduction factor γ_{cr} for cracked concrete, vgl. Figure 1-1. The reduction factor γ_{cr} is limited to a value between 0 and 0.75. The test results of tests executed with the smallest anchor size have to confirm the reduction factor in minimum. That means the quotient of test results and calculation results is equal or bigger than a value of one.

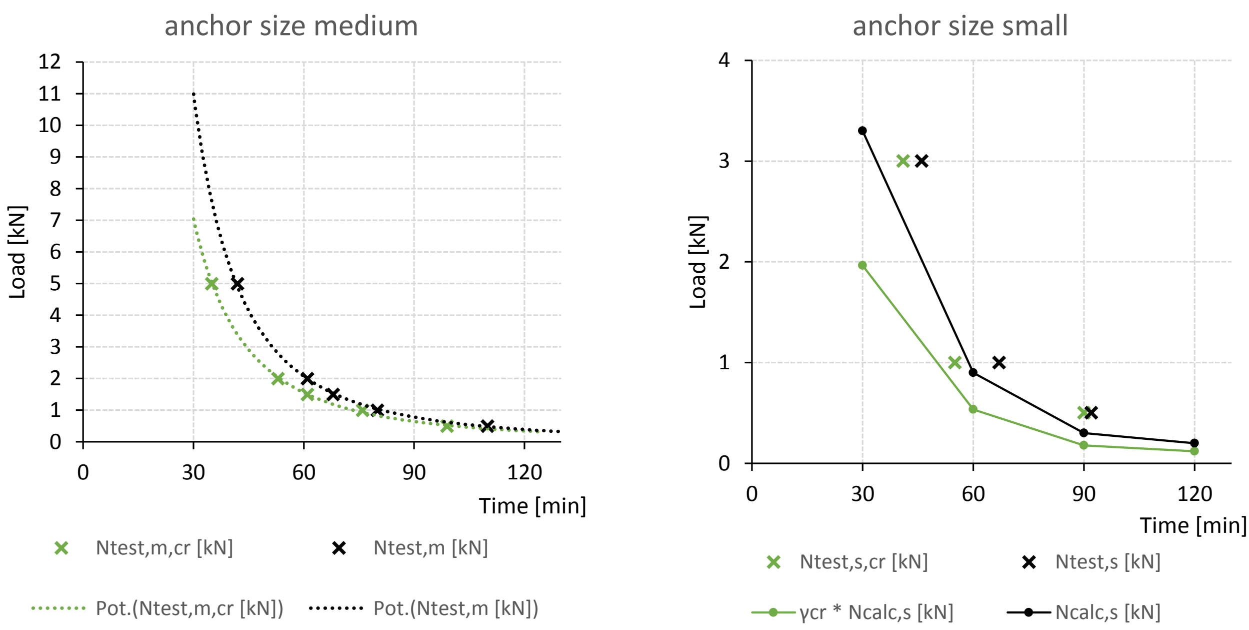

Figure 1-1: Example fort he determination and confirmation of the reduction factor γ_{cr}

Table 1-3 and Table 1-4 are showing the procedure exemplary. The test results by use of the medium anchor size in cracked concrete $N_{test,m,cr}$ and non-cracked concrete $N_{test,m}$ are given in Table 1-3. The corresponding resistances at the times 30 min, 60 min, 90 min and 120 min are determined with a power function fitting curve and marked with $N_{trend,m,cr}$ and $N_{trend,m}$. The reduction factor γ_{cr} was determined according to the function below.

$$\gamma_{cr} = MIN\left\{\frac{N_{trend,m,cr,30}}{N_{trend,m,30}};\frac{N_{trend,m,cr,60}}{N_{trend,m,60}};\frac{N_{trend,m,cr,90}}{N_{trend,m,90}};\frac{N_{trend,m,cr,120}}{N_{trend,m,120}}\right\}$$

The test results by use of the smallest anchor size in cracked concrete $N_{test,s,cr}$ and non-cracked concrete $N_{test,s}$ are given in Table 1-4. The fire resistances calculated according to the procedure described in this research report for the smallest anchor size $N_{calc,s}$ are given for 30 min, 60 min, 90 min and 120 min. The multiplication of this values with the reduction factor γ_{cr} results in the fire resistances for cracked concrete $N_{calc,s,cr}$. Finally the confirmation of the reduction factor γ_{cr} is finished by compliance of the equation below.

$$\frac{N_{test,s,cr}}{N_{calc,s,cr}} \geq 1$$

Table 1-3: Example for calculation of reduction factor γ_{cr}

	test results, **non-cracked**, medium									
t [min]	**30**	42	-	**60**	61	68	80	**90**	110	**120**
$N_{trend,m}$ [kN]	10,97	-	-	2,07	-	-	-	0,78	-	0,39
$N_{test,m}$ [kN]	-	5	-	-	2	1,5	1	-	0,5	-

	test results, **cracked**, medium									
t [min]	**30**	35	53	**60**	61	76	-	**90**	99	**120**
$N_{trend,m,cr}$ [kN]	6,52	-	-	1,42	-	-	-	0,58	-	0,31
$N_{test,m,cr}$ [kN]	-	5	2	-	1,5	1	-	-	0,5	-

$N_{trend,m,cr}$ / $N_{trend,m}$	**0,59**	-	-	**0,69**	-	-	-	**0,74**	-	**0,79**
γ_{cr}	**0,59**									

Table 1-4: Example for confirmation of reduction factor γ_{cr}

	test results and calculation results, **non-cracked**, small							
t [min]	**30**	46	-	**60**	67	**90**	92	**120**
$N_{calc,s}$ [kN]	3,3	-	-	0,9	-	0,3		0,2
$N_{test,s}$ [kN]	-	3	-	-	1	-	0,5	-

	test results and calculation results , **cracked**, small							
t [min]	**30**	41	55	**60**	-	**90**	90	**120**
γ_{cr} * $N_{calc,s}$ [kN]	1,96	**1,44**	**0,78**	0,54	-	0,18	**0,18**	0,12
$N_{test,s,cr}$ [kN]	-	**3**	**1**	-	-	-	**0,5**	-

$N_{test,s,cr}$ / $N_{calc,s,cr}$	-	2,08	1,29	-	-	-	2,78	-
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The fire resistances resulting for bond failure have to be compared with the fire resistances of steel failure and concrete cone failure and the decisive failure mode has to be determined.

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