IEA GmbH & Co. KG
Eligehausen - Asmus - Hofmann
Hauptstraße 4
70563 Stuttgart

Telefon: 0711 677 19 08
Telefax: 0711 677 19 27
Internet: www.i-ea.de
E-Mail: info@i-ea.de

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Evaluation Report

for the resistance under fire exposure

of the Mungo MHDA

for anchoring in normal hollow prestressed concrete slabs

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1 INTRODUCTION

The company Mungo Fastening Technology, Bornfeldstrasse 2, 4603 Olten, Switzerland wants to assess the fire resistance of the anchor MHDA for hollow prestressed concrete slabs under fire. The Mungo MHDA anchor provides no ETA approval. No tests for suitability or admissible conditions are available. Therefore, tests at the Institute of Construction Materials (IWB) were performed to evaluate the pullout failure of the MHDA under non-fire conditions for hollow prestressed concrete slabs. Based on these results the resistance under fire is assed for hollow prestressed concrete slabs in accordance to the EOTA TR 020 [G2], “anchorage under fire exposure.” The given evaluation is only valid for the tested application and tested anchors (with respect to the production method and materials) and does not replace an ETA.

2 ANCHORAGE SYSTEM FOR NORMAL CONCRETE SLABS

2.1 Anchors and materials

The anchor MHDA is available for the sizes M6, M8, M10 and M12 as a zinc plated version (M6 to M12) and a stainless steel version (M8 to M12). The zinc plated version has a zinc layer of at least 5μm and can only be used under dry indoor conditions.

The anchor exists of a metal sleeve and a metal expansion cone. By screwing in a normal metric screw with necessary length, (see MPII) the expansion cone is pulled into the sleeve. Therefore, the sleeve expands outside the concrete in the hollow area of the hollow prestressed concrete slab. To ensure that the anchor is expanded properly and the expansion cone is pulled into the sleeve sufficient a torque moment of T_{inst} must be applied on the anchor.

2.2 Installation

The anchors shall be installed according to the manufactures installation instruction (MPII). A borehole must be drilled with the requested drill bit for each size. The nominal drill bit diameter d_0 is given in Table 1. No hole cleaning is required according to the installation instruction. The anchor is installed by pushing it into the drilled hole. The anchor is installed properly if the sleeve is plain with the concrete surface of the hollow prestressed concrete slab.

Dimensions	Unit	Anchor sizes			
		6x37	8x43	10x52	12x52
Internal thread size	[-]	M6	M8	M10	M12
Nominal diameter d_0 of the anchor element	[mm]	10	12	16	18
Drill hole depth h_0	[mm]	50	60	65	65
Thread length L	[mm]	11	14	19	19
Used diameter of clearing hole in the fixture d_f	[mm]	7	9	12	14
Installation torque T_{inst}	[Nm]	10	10	20	20
Materials	[-]	zinc plated > 5 µm			
		-	A4 / 316		

Table 1: Size and dimensions of the Mungo anchor MHDA for hollow prestressed concrete slabs.

The attachment is positioned and a metric screw is used and screwed into the sleeve by using a torque wrench. The required installation torque moment according to Table 1 (and used in the tests) shall be applied. The MPII is given in the Table 2.

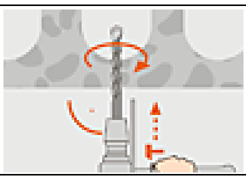
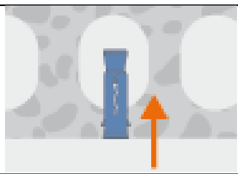
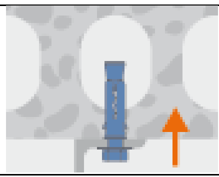
Step1:	**Step 2:**	**Step 3:**	**Step 4:**
			
Drill a bore hole with d_0	Push in the anchor	Fix the attachment	Tighten by a torque wrench to T_{inst}

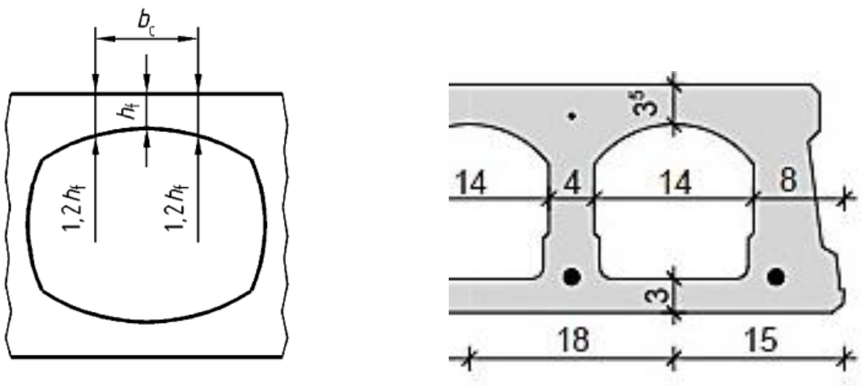
Table 2: Installation instruction (MPII) by the manufacturer for the MHDA anchors for prestressed hollow concrete slabs.

Furthermore, the provisions of ETAG 001, Part 6 and TR 020 shall be taken into account with respect to the minimum edge distances and anchors spacing. Furthermore, the distances to the prestressed reinforcement shall not be smaller than 50 mm.

3 ANCHORAGE SYSTEM FOR HOLLOW PRESTRESSED CONCRETE SLABS

3.1 General

This assessment covers prestressed concrete slabs according to DIN EN 1168. A prestressed concrete slab consists of a hollow prestressed concrete slab with a constant thickness existing of a lower and an upper flange connected with footbridge. Due to this fact, longitudinal holes with a constant cross section are existing in such a slab. (see Figure 1). The strength class of hollow prestressed concrete slabs are usually in between C30/37 and C50/60.



a) b)

Figure 1: a) Schematic picture of a hollow prestressed concrete slab [DIN EN 1168] and b) dimensions of the cross-section used in the tests.

The dimensions of the hollow slabs are given in [G3]. Normally the thickness of the concrete slabs is between 12 cm and 55 cm. The minimum thickness of the footbridge between the upper and lower flange is the maximum of $0.05 \cdot h_{slab}$ or 20mm or d_g + 5mm or h. The minimum thickens of the flange is the maximum of $(2 \cdot h)^{0.5}$ or 17 mm or d_g + 5mm or h. In both cases, the used unit for d_g and h is [mm].

The minimum thickness of the concrete in the anchorage zone was measured for every test. The evaluation shows, that the actual thickness was between 18 mm and 25 mm as the residual thickness after drilling the hole. The nominal thickens of the slab is 30 mm.

Therefore, the evaluation covers only hollow prestressed concrete slabs with a flange thickness of at least 30 mm.

3.2 Anchors and materials

3.3 Installation

The anchor MHDA will be installed in a hollow prestressed concrete slab in the area of the caves. The distance to the prestressed reinforcement shall be at least 50 mm ([G1]). The installation is given in the manufacturer´s installation instruction.

The anchors are allowed to be installed in hollow slabs, if the distance of the hollow areas and the prestressed reinforcement is more than 100mm (from axis to axis). Additionally the distance of the anchor to the prestressed reinforcement shall be larger than 50 mm.

In hollow concrete slabs the minimum edge distance c_{min} is 200 mm or larger. The minimum spacing shall be s_{min} = 400 mm parallel to the prestressed reinforcement and s_{min} = 200 mm orthogonal to the prestressed reinforcement.

4 ASSESSMENT OF THE TESTS PERFORMED WITH MHDA

4.1 General

To show the behaviour of the MHDA anchor under non-fire conditions (cold state) tension tests for pull-out failure mode were performed in hollow prestressed concrete slabs. Based on the tested pull-out resistance under cold state, the pull-out resistance under fire is calculated according to the provisions of TR 020 [G2] “anchorage under fire exposure.”

4.2 Tests with MHDA under non-fire conditions

In the following, the test results of the pull-out tests in prestressed hollow concrete slabs are evaluated to derive the characteristic pull-out failure load under non-fire conditions. The thickness of the concrete web for the tested anchors was between 14 mm and 23 mm. However due to installation and drilling efforts the minimum concrete web thickness shall not be smaller than 30 mm (as nominal value).

Size	f_{cc}	d_{cut}	t	cleaning	T_{inst}	N_u	s (N_u)	s (0,5N_u)	Failure mode
-	N/mm²	mm	mm	-	Nm	kN	mm	mm	-
M6x37	79,52	10,26	22,7	no	10	10,96	2,58	0,07	C
M6x37	79,52	10,26	21,1	no	10	10,8	1,38	0,03	C
M6x37	79,52	10,26	21,3	no	10	11,83	1,86	0,06	C
M6x37	79,52	10,26	16,9	no	10	7,36	2,15	0,88	C
M6x37	79,52	10,26	18,8	no	10	8,1	1,43	0,58	C
M8x43	79,52	12,27	17,9	no	10	10,28	1,55	0,1	C
M8x43	79,52	12,27	21,8	no	10	13,08	1,39	0,07	C
M8x43	79,52	12,27	13,4	no	10	5,39	0,66	0,42	C
M8x43	79,52	12,27	16,2	no	10	8,8	0,77	0,11	C
M8x43	79,52	12,27	15,0	no	10	6,58	0,53	0,14	C
M10x52	79,52	16,29	16,4	no	20	8,5	0,7	0,08	C
M10x52	79,52	16,29	14,8	no	20	6	1,13	0,06	C
M10x52	79,52	16,29	14,6	no	20	7,63	1,21	0,23	C
M10x52	79,52	16,29	14,5	no	20	8,17	1,55	0,4	C
M10x52	79,52	16,29	14,1	no	20	4,42	1,26	0,95	P
M12x52	79,52	18,28	25,4	no	20	15,05	4,55	0,33	P
M12x52	79,52	18,28	17,2	no	20	9,15	2,28	0,59	C
M12x52	79,52	18,28	14,4	no	20	6,72	1,49	0,43	C
M12x52	79,52	18,28	17,0	no	20	8,79	2,42	0,75	C
M12x52	79,52	18,28	17,2	no	20	6,51	2,52	1,36	C

Table 3: Tests performed in prestressed hollow concrete slabs

The test results are normalised to a concrete strength of 30 N/mm² with Eq. (4.2).

The statistical assessment of the tests results show that the mean failure loads of the different size belong to one statistical population. This can be verified by a statistical two-sided t-test using a confidence level of 5%.

Therefore, the tests results can be evaluated together to assess the characteristic pull-out failure load $N_{Rk,p,ucr}$ in non-cracked concrete. The statistical assessment comes up with the following values:

$N_{um,p,ucr}$ = 8.71 kN for $f_{c,test}$ = 79.8N/mm^2 with COV = 12.63% (s = 1.1kN)

For 20 tests results a statistical k factor of 2.25 can be used (unknown standard deviation). The characteristic values can be determined with Eq. (4.1):

$\mathbf{N_{Rk,p,ucr}}$ = 8.71kN – 2.25 · 1.1kN **= 6.26** (for $f_{c,test}$ = 79,8N/mm^2) (4.1)

For a concrete strength of 30 N/mm² the characteristic pull-out failure load $N_{Rk,p,ucr}$ can be determined with Eq. (4.2):

$\mathbf{N_{Rk,p,ucr}}$ = 8.71kN·(30/ 79,8)$^{0.5}$ **= 3.9kN** (for $f_{c,test}$ = 30N/mm^2) (4.2)

In cracked concrete, the characteristic resistance must be reduced with a factor 0.7. The characteristic pull-out failure load $N_{Rk,p,cr}$ therefore is 2.7kN.

5 CHARACTERISTIC FIRE RESISTANCE FOR HOLLOW PRESTRESSED CONCRETE SLABS

5.1 General

The resistance in case of fire (fi) is evaluated using the given maximum tensile stresses $\sigma_{Rk,s,fi}$ according to TR 020, [G2], for steel failure $N_{Rk,s,fi}$ of the anchor. The fire resistance for concrete cone failure $N_{Rk,c,fi}$ is evaluated according to TR 020 and therefore no tests are necessary. The pull-out failure $N_{Rk,p,fi}$ in cases of fire is calculated by reducing the pull-out failure at ambient temperature evaluated in section 4. The evaluation covers anchors with a fire attack from one side only. If the fire attack is from more than one side, the design method may only be used if the distance of the anchor to all edges is $c \geq 300$ mm.

5.2 Tension loading

5.2.1 Steel failure

The steel failure in case of fire can be calculated using the steel stresses from [G2] given in Table 4. The failure load can be calculated using Eq. (5.1)

$$N_{Rk,s,fi} = \sigma_{Rk,s,fi} \cdot A_s = \sigma_{Rk,s,fi} \cdot Min(A_{s,thread}; A_{s,sleeve}) \qquad (5.1)$$

$\sigma_{Rk,s,fi}$: Characteristic tensile steel stress under different fire duration [N/mm²]
A_s : Minimum tensile cross section area [mm]

The decisive steel cross section area was determined using the minimum steel cross section area of the screw/bolt, the sleeve and the cone-nut with an internal thread. The calculations of the different cross section areas clearly show that the remaining steel section of the cone-nut with the internal thread is the minimum one and therefore decisive if the loads are assed by calculation without tests.

This is conservative because the cone-nut is placed not directly on the surface of the concrete. However, the screw will conduct eth heat to the cone nut with the internal thread.

Size MHDA		6x37	8x43	10x52	12x52
$A_{S,thread}$ (internal thread of cone)	[mm²]	3,81	11,43	31,63	56,59
$A_{S,Sleeve}$	[mm²]	22,3	28,6	58,4	67,8
$\sigma_{Rk,s,fi(30)}$	[N/mm²]	10	10	15	20
$\sigma_{Rk,s,fi(60)}$	[N/mm²]	9	9	13	15
$\sigma_{Rk,s,fi(90)}$	[N/mm²]	7	7	10	13
$\sigma_{Rk,s,fi(120)}$	[N/mm²]	5	5	8	10
Steel failure $N_{Rk,s,fi}$					
$N_{Rk,s,fi\ (30)}$	[kN]	0,04	0,11	0,47	1,13
$N_{Rk,s,fi\ (60)}$	[kN]	0,03	0,10	0,41	0,85
$N_{Rk,s,fi\ (90)}$	[kN]	0,03	0,08	0,32	0,74
$N_{Rk,s,fi\ (120)}$	[kN]	0,02	0,06	0,25	0,57

Table 4: Evaluated characteristic resistances for tensile steel failure in case of fire.

5.2.2 Pull-out failure

According to [G2] the characteristic resistance of an anchor in case of pull-out failure when exposed to fire from 90 (R90) up to 120 minutes (R120) may be obtained by Equation (5.2a) or Equation (5.2b).

$$N_{Rk,p,fi(90)} = 0.25 \cdot N_{Rk,p} \qquad (5.2a)$$

$$N_{Rk,p,fi(120)} = 0.20 \cdot N_{Rk,p} \qquad (5.2b)$$

$N_{Rk,p}$: *Characteristic resistance in cracked concrete C30/37. If at normal ambient temperature pull-out failure is not decisive, $N^0_{Rk,c}$ must be inserted [kN].*

Size		6x37	8x43	10x52	12x52
$N_{Rk,p\ ucr}$ 1)	[kN]	6,26	6,26	6,26	6,26
$N_{Rk,p\ ucr}$ 2)	[kN]	3,9	3,9	3,9	3,9
$N_{Rk,p\ cr}$ 3)	[kN]	2,7	2,7	2,7	2,7
Concrete pullout failure $N_{Rk,p,fi}$					
$N_{Rk,p,fi\ (30)}$	[kN]	0,68	0,68	0,68	0,68
$N_{Rk,p,fi\ (60)}$	[kN]	0,68	0,68	0,68	0,68
$N_{Rk,p,fi\ (90)}$	[kN]	0,68	0,68	0,68	0,68
$N_{Rk,p,fi\ (120)}$	[kN]	0,54	0,54	0,54	0,54

1) $f_{c,test}$ = 79,8N/mm²
2) Normalised to a concrete strength $f_{c,test}$ = 30N/mm²
3) Cracked concrete is considered by a factor of 0.7.

Table 5: Evaluated characteristic resistances in case of fire and pullout failure in hollow prestressed concrete slabs.

5.2.3 Concrete cone failure

According to [G2] the characteristic resistance of an anchor with a large edge distance and spacing in case of concrete cone failure in concrete *C20/25* to *C50/60* when exposed to fire for 90 minutes (R90) up to 120 minutes (R120) may be obtained by using Equation (5.3a) or Equation (5.3b).

$$N^0_{Rk,c,fi(90)} = \frac{h_{ef}}{200} \cdot N^0_{Rk,c} \leq N^0_{Rk,c} \quad (5.3a)$$

$$N^0_{Rk,c,fi(120)} = 0.8 \cdot \frac{h_{ef}}{200} \cdot N^0_{Rk,c} \leq N^0_{Rk,c} \quad (5.3b)$$

$N_{Rk,c}$: *Characteristic resistance in cracked concrete C30/37 to C50/60 in case of concrete cone failure at ambient temperature [kN].*

Size		6x37	8x43	10x52	12x52
$N_{Rk,c\ cr}$ 1)	[kN]	7,0	7,0	7,0	7,0
Concrete cone failure $N_{Rk,cs,fi}$					
$N_{Rk,c,fi\ (30)}$	[kN]	1,05	1,05	1,05	1,05
$N_{Rk,c,fi\ (60)}$	[kN]	1,05	1,05	1,05	1,05
$N_{Rk,c,fi\ (90)}$	[kN]	1,05	1,05	1,05	1,05
$N_{Rk,c,fi\ (120)}$	[kN]	0,84	0,84	0,84	0,84

1) *Calculated concrete cone failure according to ETAG 001, Annex C with h_{ef} = 30 mm (minimum concrete web) and f_{cc} = 30 N/mm²*

Table 6: Evaluated characteristic resistances in case of fire and concrete cone failure.

The characteristic spacing and edge distance for anchorages near the edge under fire exposure are taken as follows $s_{cr,N} = 2\ c_{cr,N} = 4h_{ef}$.

5.2.4 Concrete splitting failure

This failure mode is not decisive. It is assumed that the reinforcement can take up the splitting forces of the anchorages.

5.3 Shear loading

5.3.1 Steel failure without lever arm

When attacked by fire, the behaviour under shear loading is similar to the behaviour under tension loading (see [G2]). The characteristic fire resistance is influenced by the type of steel, the time of fire exposure, the diameter, and the embedment depth of the anchor. The fire resistance of bolt type anchor may be calculated according to Equation (5.4).

$$V_{Rk,s,fi} = \tau_{Rk,s,fi} \cdot A_s \tag{5.4}$$

$\tau_{Rk,s,fi}$: *Characteristic shear steel stress under different fire duration [N/mm²]*
A_s: *Minimum tensile cross section area [mm]*

According to [G2] the characteristic steel shear strength ($\tau_{Rk,s,fi}$) is equal to the characteristic tensile strength ($\sigma_{Rk,s,fi}$) the same values for tensile and shear loading can be applied. Therefore, the same values given in Table 4 can be applied.

5.3.2 Concrete edge failure

According to [G2] the characteristic resistance of an anchor in case of concrete edge failure (concrete C20/25 to C50/60) when exposed to fire from 90 minutes (R90) up to 120 minutes (R120) may be obtained using Equation (5.6a) or Equation (5.6b).

$$V^0_{Rk,c,fi(90)} = 0.25 \cdot V^0_{Rk,c} \tag{5.5a}$$

$$V^0_{Rk,c,fi(120)} = 0.20 \cdot V^0_{Rk,c} \tag{5.5b}$$

$V_{Rk,c}$: *Characteristic resistance in cracked concrete C20/25 to C50/60 [kN] in case of concrete edge failure at ambient temperature.*

For anchorages in concrete with a strength class > C20/25 (or for anchor groups, anchorages in a corner or in a thin concrete member) the characteristic fire resistances can be calculated according to [G2], Annex C by replacing the value $V_{Rk,c}$ by the values $V_{Rk,c,fi}$ according to Equation (5.6a) or Equation (5.6b) and using a characteristic edge distances of $c_{cr} = 1.5c_1$ according to [G1].
In the following evaluation it is assumed that the given edge distance is larger than $10{\cdot}d_s$ and the concrete edge failure is not decisive compared to other failure modes under shear loading.

5.3.3 Steel failure with lever arm

The characteristic resistance of one anchor in case of shear loading with lever arm is calculated according to Equation (5.6).

$$M_{Rk,s,fi} = 1.2 \cdot \sigma_{Rk,s,fi} \cdot W_{el} \qquad (5.6)$$

$\sigma_{Rk,s,fi}$: Characteristic tensile steel stress under different fire duration [N/mm²].
W_{el}: Elastic section modules of the sleeve resp. of the bolt or screw [mm³].

Size		6x37	8x43	10x52	12x52
$A_{s,screw}$	[mm²]	20,1	36,6	58,0	84,3
W_{el}	[mm³]	12,7	31,2	62,3	109,2
$\sigma_{Rk,s,fi(30)}$	[N/mm²]	10	10	15	20
$\sigma_{Rk,s,fi(60)}$	[N/mm²]	9	9	13	15
$\sigma_{Rk,s,fi(90)}$	[N/mm²]	7	7	10	13
$\sigma_{Rk,s,fi(120)}$	[N/mm²]	5	5	8	10
Steel failure with lever arm $M_{Rk,s,fi}$					
$M^0_{Rk,s,fi\,(30)}$	[Nm]	153	375	1121	2620
$M^0_{Rk,s,fi\,(60)}$	[Nm]	137	337	972	1965
$M^0_{Rk,s,fi\,(90)}$	[Nm]	107	262	748	1703
$M^0_{Rk,s,fi\,(120)}$	[Nm]	76	187	598	1310

Table 7: Evaluated characteristic resistances in case of fire and shear steel failure with lever arm (characteristic bending moment - failure of the screw / bolt).

The given characteristic moments are assuming a failure of the screw or bolt used as M6 to M12 with the MHDA. If this cannot be ensured the characteristic moments must be reduced the following values:

Size		6x37	8x43	10x52	12x52
$A_{s,screw}$	[mm²]	3,81	11,43	31,63	56,59
W_{el}	[mm³]	1,0	5,5	25,1	60,0
$\sigma_{Rk,s,fi(30)}$	[N/mm²]	10	10	15	20
$\sigma_{Rk,s,fi(60)}$	[N/mm²]	9	9	13	15
$\sigma_{Rk,s,fi(90)}$	[N/mm²]	7	7	10	13
$\sigma_{Rk,s,fi(120)}$	[N/mm²]	5	5	8	10
Steel failure with lever arm $M_{Rk,s,fi}$					
$M^0_{Rk,s,fi\,(30)}$	[Nm]	13	65	452	1441
$M^0_{Rk,s,fi\,(60)}$	[Nm]	11	59	391	1081
$M^0_{Rk,s,fi\,(90)}$	[Nm]	9	46	301	937
$M^0_{Rk,s,fi\,(120)}$	[Nm]	6	33	241	721

Table 8: Evaluated characteristic resistances in case of fire and shear steel failure with lever arm (characteristic bending moment - failure at cone nut)

5.3.4 Concrete pryout failure

According to [G2] the characteristic resistance of an anchorage in case of concrete pryout failure in concrete C20/25 to C50/60 when exposed to fire from 90 minutes (R90) up to 120 minutes (R120) may be obtained using the values for the characteristic pullout / concrete cone failure under fire. Therefore, the characteristic pryout failure can be calculated using the values form Table 5. This is conservative due to the both assumptions of a k value of 1.0 and $N_{Rk,p,fi} < N_{Rk,c,fi}$.

5.4 Combined tension and shear loading

The behaviour of anchors under combined tension and shear load under fire exposure may be determined according to the interaction condition at normal temperature of ETAG 001, Annex C [G1], in consideration of the determined resistances for each direction under fire exposure.

6 SUMMARY

For hollow prestressed concrete slabs with a concrete strength class between C30/37 and C50/60, the values of Table 9 can be taken as the relevant characteristic resistance under fire conditions for all loading directions and failure modes (beside bending).

Characteristic resistance $F_{Rk,fi}$ for hollow prestressed concrete slabs with C30/37 to C50/60 Thickness of the concrete web ≥ 30 mm, one side fire attack					
		6x37	**8x43**	**10x52**	**12x52**
$F_{Rk.fi\,(30)}$	[kN]	0,05	0,10	0,50	0,70
$F_{Rk.fi\,(60)}$	[kN]	0,05	0,10	0,40	0,70
$F_{Rk.fi\,(90)}$	[kN]	0,05	0,08	0,30	0,70
$F_{Rk.fi\,(120)}$	[kN]	0,025	0,05	0,25	0,55
$c_{cr,fi}$	[mm]	≥ 50 but not less than $c_{cr} = 2 \cdot h_{ef}$			
$s_{cr,fi}$	[mm]	≥ 100 but not less than $s_{cr} = 4 \cdot h_{ef}$			

Table 9: Characteristic resistances for all failure modes and loading directions for the Mungo MHDA anchors in hollow prestressed concrete slabs (C30/37 to C50/60).

The values are derived in accordance with EOTA TR020 [G2]. Therefore all provisions and preconditions given in EOTA TR020 [G2] shall be considered. The anchor MHDA provides no ETA (European technical approval). Tests in hollow prestressed, non-cracked concrete slabs under non-fire conditions are performed to assess the characteristic resistances for pull-out failure. All other failure modes are calculated according to EOTA TR020 [G2].

Prof. Dr.-Ing. Jan Hofmann

7 LITERATURE

7.1 Test reports

[R1] Test Report, Report no.: 387/01-14/10: Tests with Mungo MHDA hollow ceiling anchors in hollow concrete slabs (Sizes M6 – M12), May 19, 2014, Institute of Construction Materials Department of Fastening and Strengthening Methods

7.2 General

[G1] ETAG 001 used as an EAD Guideline for European Technical Approval of Metal Anchors for use in Concrete. Part 1 to Part 6 with Annex A to C. Brüssel 2013.

[G2] EOTA Technical Report (TR 20) "Evaluation of Anchorages in Concrete Concerning Resistance to Fire". May 2004.

[G3] DIN EN 1168, Precast concrete products - Hollow core slabs; German version EN 1168:2005+A3:2011.