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Advisory Opinion No. GS 6.1/21-060-3-r1

22.02.2022

Translation of the original German document GS 6.1/21-060-3-r1
Replaces: Advisory Opinion No. GS 6.1/21-060-3 vom 22.11.2021

Object:	Assessment of the load bearing behaviour of wedge anchors BZ3 A4 and BZ3 HCR under tension load and one-sided thermal loading of 450°C in combination with concrete members - abbreviated version
Client:	**MKT Metall-Kunststoff-Technik GmbH & Co.KG** Auf dem Immel 2 D-67685 Weilerbach
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This document covers 11 pages, including 0 appendices.

Contents

1 Objective and request

MFPA Leipzig GmbH was ordered by MKT Metall-Kunststoff-Technik GmbH & Co.KG to assess the load bearing behaviour of wedge anchors BZ3 A4 and BZ3 HCR under tension load and one-sided thermal loading of 450°C. The constant temperature relevant for applications in tunnel construction is to be verified for a duration of thermal loading of up to 300min. The assessment bases on results of fire tests and finite-element simulations and includes the failure modes "steel failure", "pull-out failure" and "concrete cone failure".
The document at hand summarizes the design concept and the corresponding characteristic load bearing capacities. For the detailed derivation of the values, please see [G1].

2 Description of the construction

The advisory opinion at hand covers wedge anchors BZ3 A4 and BZ3 HCR for anchorage in concrete structures, consisting of an anchor, expansion sleeve, hexagonal nut and washer.
Anchorage is produced by means of force-controlled expansion of the expansion sleeve within the drilled hole. With [P1] a current European Technical Assessment is available for the wedge anchors BZ3 A4 and BZ3 HCR, which allows use under static and quasi-static loading in reinforced and unreinforced normal weight concrete of strength class not less than C20/25 and not more than C50/60 according to [N1].
The geometry of the wedge anchors is specified in Figure 1. In the course of installation of the wedge anchors, the manufacturer's instructions have to be obeyed.

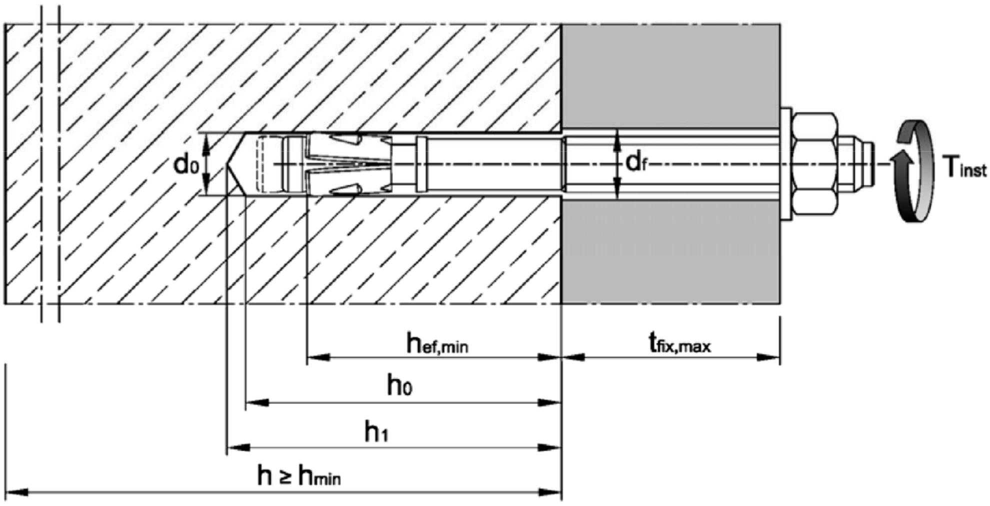

Figure 1: Wedge anchors BZ3 A4 and BZ3 HCR: On-site geometry, from [P1]

Figure 2 specifies the installation parameters of the wedge anchors.

Anchor size				**BZ3 / BZ3 A4 / BZ3 HCR**			
				M8	**M10**	**M12**	**M16**
Nominal drill hole diameter		d_0	[mm]	8	10	12	16
Cutting diameter of drill bit		$d_{cut} \leq$	[mm]	8,45	10,45	12,5	16,5
Minimum effective anchorage depth		$h_{ef,min}$	[mm]	35	40	50	65
Maximum effective anchorage depth		$h_{ef,max}$	[mm]	90	100	125	160
Depth of drill hole		$h_0 \geq$	[mm]	h_{ef} + 8	h_{ef} + 9	h_{ef} + 10	h_{ef} + 14
		$h_1 \geq$	[mm]	h_{ef} + 10	h_{ef} + 11	h_{ef} + 13	h_{ef} + 17
Diameter of clearance hole in the fixture [1)]		$d_f \leq$	[mm]	9	12	14	18
Projection after anchor has been inserted for installing with cap nut HM (according to Annex B5)		C	[mm]	10,5	12,5	16,0	19,5
Installation torque	BZ3	T_{inst}	[Nm]	15	40	60	110
	BZ3 A4 / HCR	T_{inst}	[Nm]	15	40	55	100

Figure 2: Wedge anchors BZ3 A4 and BZ3 HCR: Installation parameters, from [P1]

The wedge anchors BZ3, BZ3 A4 and BZ3 HCR are manufactured using the materials

- BZ3 A4: stainless steel A4,
- BZ3 HCR: high corrosion resistant steel.

Each type is available in sizes M8, M10, M12 and M16.
For a detailled product description and further information with respect to the scope of application, please see [P1].

3 References

3.1 Utilized guidelines, rules and standards

The analyses are based on the following guidelines, rules and standards:

[N1] DIN EN 206:2017-01: Concrete - Specification, performance, production and conformity; German version EN 206:2013+A1:2016

[N2] EAD 330232-01-0601: Mechanical fasteners for use in concrete; 05/2021

[N3] DIN EN 1992-4:2019-04: Eurocode 2 - Design of concrete structures - Part 4: Design of fastenings for use in concrete; German version EN 1992-4:2018

[N4] DIN EN 1992-1-2:2010-12: Eurocode 2: Design of concrete structures - Part 1-2: General rules - Structural fire design; German version EN 1992-1-2:2004 + AC:2008

[N5] DIN EN 1993-1-2:2010-12: Eurocode 3: Design of steel structures - Part 1-2: General rules - Structural fire design; German version EN 1993-1-2:2005 + AC:2009

[N6] TR 020: Evaluation of Anchorages in Concrete concerning Resistance to Fire; 05/2004

3.2 Reference documents

The analyses are based on the following additional documents:

3.2.1 ETAs and verifications of applicability

[P1] ETA-19/0619: Wedge Anchor BZ3 / BZ3 A4 / BZ3 HCR, Mechanical fasteners for use in concrete – Deutsches Institut für Bautechnik, 10.12.2021

3.2.2 Assessment and test reports

[G1] Gutachterliche Stellungnahme Nr. GS 6.1/21-060-2: Bewertung des Tragverhaltens von Bolzenankern BZ3 A4 und BZ3 HCR unter zentrischer Zugbeanspruchung sowie einseitiger thermischer Beanspruchung von 450°C in Kombination mit Betonkonstruktionen. – MFPA Leipzig GmbH; 01.11.2021

4 Assessment of the performance

4.1 Design concept

The load bearing capacity of mechanical anchors in concrete structures shall be determined experimentally according to [N2] or, if covered by the scope of the standard and if desired, mathematically according to [N3], Appendix D, when subjected to a fire load according to the standard temperature-time curve. In this context, a distinction is made in connection with centric tensile loading between the failure mechanisms "steel failure", "pull-out failure" and "concrete cone failure". In the following, it is assumed that the basic failure mechanisms as well as physical relationships do not depend on the function of time-dependent thermal loading. This assumption is supported by the fact that the design codes for steel and reinforced concrete structures explicitly permit the consideration of temperature actions other than the standard temperature-time curve in connection with simplified and general design methods (cf. [N4], Chapter 2.4.1(4) as well as [N5], Note to Chapter 2.4.1(1)).
The characteristic load bearing capacity of a wedge anchor under centric tensile loading in case of fire shall be determined from the minimum value of the load bearing capacity for steel failure, pull-out failure and concrete cone failure

$$N_{Rk,fi}(t) = min\left[N_{Rk,s,fi}(t), \quad N_{Rk,p,fi}(t), \quad N_{Rk,c,fi}(t)\right]. \tag{1}$$

4.2 Steel failure

The temperature-dependent load bearing capacity of the wedge anchors themselves is limited by the load bearing capacity of the anchor cross-section and the load bearing capacity of the connection between the anchor and the nut. Steel failure under fire exposure and centric tensile loading consequently occurs either in the form of a breakage of the wedge anchor or in the form of shearing off of the nut. Both the mode of failure and the magnitude of the load bearing capacity under fire exposure depend significantly on the cross-section of the anchor and on the temperature-dependent reduction of the mechanical properties of the material used (cf. [N5]).
Table 1 shows the characteristic load bearing capacities $N_{Rk,s,fi}$ of the wedge anchors BZ3 A4 and BZ3 HCR for a constant thermal loading of $T = 450°C$ and a duration of thermal loading of $\leq 300min$.

size	$N_{Rk,s,fi}$ $[kN]$
M8	13,2
M10	20,9
M12	30,4
M16	49,9

Table 1: Wedge anchors BZ3 A4 and BZ3 HCR: Characteristic load bearing capacities $N_{Rk,s,fi}$ $[kN]$ for steel failure under centric tensile loading and constant temperature of $T = 450°C$

4.3 Pull-out failure

If the applied tensile stresses on a wedge anchor are greater than the resistance to pull-out, failure by pull-out will occur. For the characteristic load bearing capacity $N_{Rk,p,fi}(t)$ for pull-out failure at a constant thermal loading of $T = 450°C$, the following applies

$$N_{Rk,p,fi}(t) = k_c(t) \cdot N_{Rk,p} \tag{2}$$

with: $N_{Rk,p}$: characteristic resistance to pull-out in cracked concrete C20/25 under room temperature according to [P1], Table C2. Using the reduction factors $k_c(t)$ from Table 3, which depend on the duration of thermal loading and the embedment depth, the values $N_{Rk,p,fi}(t)$ specified in Table 2 are obtained. Intermediate values of embedment depths may be linearly interpolated.

size	h_{ef} $[mm]$	duration of thermal loading $[min]$ 30	60	90	120	180	240	300
M8	35	9,17	8,67	8,31	8,07	7,62	7,58	7,56
	60	9,50	9,32	9,12	8,93	8,26	8,19	8,15
	90	9,50	9,50	9,50	9,39	9,06	8,98	8,88
M10	40	16,50	15,70	15,03	14,58	13,74	13,68	13,64
	70	17,00	16,85	16,53	16,28	15,18	15,00	14,86
	100	17,00	17,00	17,00	16,91	16,35	16,25	16,16
M12	50	21,69	21,00	20,22	19,61	18,33	18,15	18,02
	90	22,00	22,00	21,86	21,58	20,73	20,48	20,25
	125	22,00	22,00	22,00	22,00	21,62	21,50	21,38
M16	65,0	35,00	34,05	33,37	32,49	30,27	29,94	29,65
	110	35,00	35,00	35,00	34,80	33,69	33,48	33,30
	160	35,00	35,00	35,00	35,00	35,00	34,88	34,73

Table 2: Wedge anchors BZ3 A4 and BZ3 HCR: Characteristic load bearing capacities $N_{Rk,p,fi}$ $[kN]$ to pull-out failure in cracked concrete under centric tensile loading and constant temperature of $T = 450°C$

4.4 Concrete cone failure

Failure due to conical concrete breakout in centrally tensile loaded wedge anchors occurs when the tensile strength of concrete is locally exceeded. For the characteristic load bearing capacity $N^0_{Rk,c,fi}(t)$ for concrete cone failure at a constant thermal loading of $T = 450°C$, the following applies

$$N^0_{Rk,c,fi}(t) = k_c(t) \cdot N^0_{Rk,c} \tag{3}$$

with: $N^0_{Rk,c}$: characteristic resistance of a single wedge anchor at room temperature in cracked concrete C20/25. Regarding the characteristic resistance $N^0_{Rk,c}$ at room temperature, reference is made in [P1], Table C2 to [N3]. According to [N3], Chapter 7.2.1.4, the following applies to cracked concrete

$$N^0_{Rk,c} = k_{cr,N} \cdot \sqrt{f_{ck}} \cdot h_{ef}^{1,5}. \tag{4}$$

Considering [P1], Table C2 and [N3], Appendix D.4.2.2, we obtain

$$N^0_{Rk,c} = 7{,}7 \cdot \sqrt{20 \frac{N}{mm^2}} \cdot h_{ef}^{1,5}. \tag{5}$$

The reduction factors $k_c(t)$, which depend on the duration of thermal loading and the embedment depth, are shown in Table 3. Intermediate values of embedment depths may be linearly interpolated.

size	h_{ef} $[mm]$	duration of thermal loading $[min]$ 30	60	90	120	180	240	300
M8	35	0,97	0,91	0,87	0,85	0,80	0,80	0,80
	60	1,00	0,98	0,96	0,94	0,87	0,86	0,86
	90	1,00	1,00	1,00	0,99	0,95	0,95	0,93
M10	40	0,97	0,92	0,88	0,86	0,81	0,80	0,80
	70	1,00	0,99	0,97	0,96	0,89	0,88	0,87
	100	1,00	1,00	1,00	0,99	0,96	0,96	0,95
M12	50	0,99	0,95	0,92	0,89	0,83	0,82	0,82
	90	1,00	1,00	0,99	0,98	0,94	0,93	0,92
	125	1,00	1,00	1,00	1,00	0,98	0,98	0,97
M16	65,0	1,00	0,97	0,95	0,93	0,87	0,86	0,85
	110	1,00	1,00	1,00	0,99	0,96	0,96	0,95
	160	1,00	1,00	1,00	1,00	1,00	1,00	0,99

Table 3: Wedge anchors BZ3 A4 and BZ3 HCR: Reduction factors $k_c(t)$ for determining the characteristic load bearing capacities $N^0_{Rk,c,fi}$ of a single anchor for concrete cone failure under centric tensile loading and constant temperature of $T = 450°C$

The characteristic load bearing capacity $N_{Rk,c,fi}$ to be considered in the framework of the design has to be determined for each specific construction capturing the influences of neighbouring anchors and the edge distance. In this context, reference is given to [N3], Chapter 7.2.1.4 and Appendix D.4.2.2. For the characteristic spacing $s_{cr,fi}$ and edge distance $c_{cr,fi}$ in case of fire, the following applies according to [N3], Appendix D.4.2.2(3)

$$s_{cr,fi} = 4 \cdot h_{ef} \tag{6}$$

$$c_{cr,fi} = 2 \cdot h_{ef}\,. \tag{7}$$

5 Special notes

The assessment at hand is valid for wedge anchors BZ3 A4 and BZ3 HCR according to the specifications in [P1] for anchorage in concrete structures, which are installed according to the manufacturer's instructions. The mechanical loading must not exceed the load bearing capacity in ambient climate. The size of the fixed member must not exceed $t_{fix,max}$.

The load bearing capacities specified in the framework of the document at hand are determined for one-sided thermal loading of $T = 450°C$. Following [N6] the values may also be used for multilateral fire loading when the edge distance of the wedge anchor is $c \geq 300mm$ and $c \geq 2 \cdot h_{ef}$.

The load bearing capacities specified in the framework of the document at hand are determined for centrical tensile loading in the wedge anchor's longitudinal direction. Following [N2], on the safe side, a transfer to steel failure is possible for tensile loads perpendicular and oblique to the anchor axis. Failure modes affecting the substrate in transverse and oblique tension, such as concrete edge failure, shall be verified separately (cf. [N3]).

The assessment at hand is valid for constructions of reinforced or unreinforced normal weight concrete of the strength class $\geq$ C20/25 and $\leq$ C50/60 according to [N1], which exhibit at least the same fire resistance class as the utilized wedge anchors. The design of the concrete construction has to be carried out according to [N4].

The load bearing capacities specified in the framework of the document at hand are determined assuming that no explosive concrete spalling occurs and are only valid under this condition. Evidence on the prevention of explosive concrete spalling is given in [N4], Chapter 4.5.

6 Signatures

This document does not replace a certificate of constancy of performance or suitability according to national and European building codes.

Leipzig, 22.02.2022

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