Expansion and bonded anchors in (shallow) fixings in concrete substrate reinforced with steel and polypropylene fibres

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Abstract. Along with the development of engineering construction techniques, the interest in the issue of fastenings increases. In the construction of new facilities as well as in renovation works, a wide range of fasteners is currently used, enabling quick connections and safe fastening of various types of structural and installation elements. This progress is particularly visible in fixings made in concrete substrates. During assembly and during operation, the fasteners are subject to the influence of many external factors that may significantly affect their load capacity. Such factors include the type and nature of the load to be transferred, the strength and condition of the substrate, the temperature at which the fasteners will be installed and used. The technical parameters of fasteners determined by means of theoretical calculations still do not provide adequate accuracy, so that this method can be used to determine their impact on the behaviour of fasteners during their long-term operation. Therefore, their experimental verification is still required. In the countries of the European Union, the development of the rules for the use and assessment of expansion and bonded fasteners has been entrusted to the European Organization for Technical Assessment - EOTA. This organization groups bodies authorized by EU Member States to provide European technical assessments on the terms set out in Regulation No. 305/2011 (CPR) 2013. The current list of EOTA guidelines for expansion and bonded anchors used in the construction industry, specifying the basis for their use as well as standards for the design of fasteners. The scope and methods of fastener testing are presented in the EOTA guidelines. The purpose of these tests is to determine whether the behavior of the fasteners during their use will be safe and effective, taking into account the unfavourable conditions that can be encountered both during its installation and use. The publication will present the basic structural properties of fasteners made in drilled holes in concrete substrates reinforced with steel and polypropylene fibres.

1 Introduction

The development of engineering construction techniques, the interest in the issue of fastenings increases. A wide range of anchors is currently used in the construction of new facilities as well as in renovation works, enabling quick and safe fastening of various types

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of structural and installation elements [1]. This progress is particularly visible in fixings made in concrete substrates. During assembly and operation, the anchors are subject to the influence of many external factors that may significantly affect their load capacity. Such factors include: type and nature of the transferred load, strength and condition of the substrate, temperature at which the anchors will be installed and used. The technical parameters of fasteners determined by means of theoretical calculations still do not provide adequate accuracy, so that this method can be used to determine their impact on the behaviour of fasteners during their long- term operation. Therefore, their experimental verification is still required [2].

In the countries of the European Union, the development of the rules for the use and assessment of expansion and bonded fasteners has been entrusted to the European Organization for Technical Assessment - EOTA. This organization groups bodies authorized by EU Member States to provide European technical assessments on the terms set out in Regulation No. 305/2011 (CPR) 2013 [3].

The current list of EOTA's EAD guidelines for expansion and bonded anchors used in construction, defining the basis for their use, as well as standards for the design of fastenings is included in Table 1 [4].

The scope and methods of anchors testing are presented in the EOTA guidelines. The purpose of these tests is to determine whether the behaviour of the anchors during their use will be safe and effective, taking into account the unfavourable conditions that can be encountered both during their installation and use [5].

Table 1. Technical Guidelines and Reports and standards for construction fasteners

Guidelines / Technical Reports / Standards		**Name**	**Year**
EAD's	330232-01-0601	Mechanical fasteners for use in concrete	2021
	330232-01-0601-v01	Torque-controlled expansion fasteners for use in concrete with variable working life up to 50 years	2021
	330232-01-0601-v05	Mechanical fasteners for use in concrete C12/15 to C90/105 and in steel fiber reinforced concrete	project
	330250-00-0601	Post-installed fasteners in concrete under fatigue cyclic loading	2021
	330499-01-0601	Bonded fasteners for use in concrete	2020
	330747-00-0601	Fasteners for use in concrete in redundant for non-structural systems	2018
TR	018	Assessment of torque-controlled bonded anchors	2003
	020	Evaluation of anchorages in concrete concerning resistance to fire	2004
	029	Design of bonded anchors	2010
EN	1992-4	Eurocode 2. Design of concrete structures. Part 4: Design of fastenings for use in concrete	2018

The publication presents the basic structural properties of anchors made in drilled holes in concrete substrates reinforced with steel and polypropylene fibres.

It should be emphasized that the scope of tests is adapted to the scope of their application specified by the manufacturer of the anchors. It has the following mounting options to choose from [6,7,8,9,10,11]:

- structural fastenings in concrete substrates without cracks - option 7,

- structural fastenings in cracked concrete substrates (cracks up to 0.5 mm) - option 1,
- structural fastenings in concrete substrates, taking into account the impacts seismic (cracks up to 0.8 mm) - option C2,
- non-structural fixings (so-called multi-point) - cracks up to 0.35 mm.

The technical parameters of the fasteners determined in the tests are included in the national or European Technical Assessments (KOT or ETA). These assessments are issued at the request of the manufacturer by authorized bodies based on the assessment of the functional properties of construction anchors and their expected durability, confirmed, depending on the needs, by appropriate tests and/or calculations. After the manufacturer has issued a declaration of performance and marked the connectors with the CE mark, they are placed on the market and used.

It is important that all requirements for anchors included in the Technical Assessments are met both at the design stage of the anchors, their assembly and operation. In the event of failure to comply with them, one should take into account a decrease in the quality of the connections made, and sometimes even the inability to use them [12,13,14].

In connections, anchors can be loaded with tensile, shear or angled forces. Fig. 1 illustrates the conceptual model of the test stand for assessing the load capacity of joints subjected to tensile loads.

1 - load sensor
2 - actuator
3 - support
4 - displacement sensor
5 - socket
6 - concrete
7 - expansion or bonded anchor

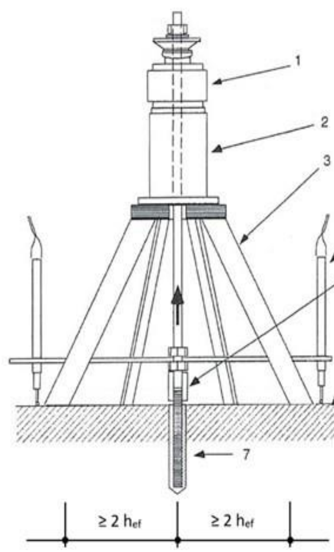

Fig. 1. Stand for testing the anchors fastening

As a result of the impact of tensile forces on the anchors, they may be destroyed due to damage to their structure or the substrate in which they are embedded. The most common model of failure mode of anchors made with expansion bolts under the action of tensile forces is tearing the bolts out of unreinforced concrete substrates together with the adjacent cone-shaped concrete with an angle of inclination within the range of α=35°÷40° (Fig. 2 and 3) [15].

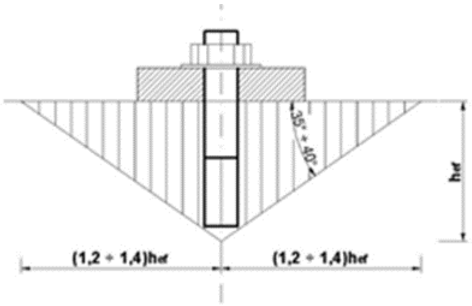

Fig. 2. Theoretical model of failure mode of the joint subjected to action tensile loads.

Fig. 3. Destruction of the connection made observed in the tests expansion anchors.

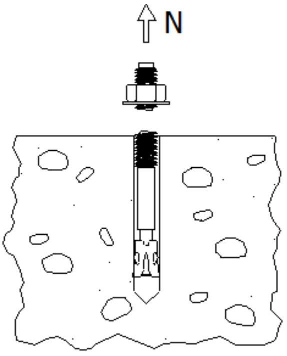

Fig. 4. Failure mode the connection as a result of breaking the steel of the anchors.

A characteristic picture of the destruction of joints made with bonded fasteners, subjected to tensile forces, is the cutting of the joint along the joint: adhesive mortar / concrete, with the simultaneous tearing out of the top layer of concrete in the shape of a cone, the height of which corresponds to about ¼ of the depth of fastening the fastener in the substrate (Fig. 5).

Fig. 5. Characteristic failure mode for bonded anchors.

In the case of bonded anchors, the form of destruction of the connection may also consist in pulling the connector threaded rod out of the hole in which it was installed. This will happen when the hole made in the substrate is not fully filled with the adhesive mortar or the adhesive mortar is not fully cured.

The requirements contained in the EOTA Guidelines recommend that when assessing the pull-out resistance of expansion anchors and bonded anchors installed in concrete substrates, the following factors should be taken into account: type of fasteners, condition and type of concrete substrate, anchor assembly parameters (torque value, diameter of drilled holes) [15,16,17]. Recently, it has also been planned to extend the tests of anchors to include fixings in fibre reinforced concrete. To what extent does the new type of substrate affect the technical parameters of the fasteners anchored in it?

A new type of concrete, which is fibre reinforced concrete, is characterized by specific technical properties.

Adding fibres to concrete causes, among other things:

- increasing its resistance to the formation of scratches and cracks,
- increase in fatigue resistance and impact strength,
- increasing the tensile strength of concrete.

It can therefore be expected that fixings in the substrate made of fibre reinforced concrete will have better technical parameters compared to fixings in unreinforced concrete.

2 Scope and aim of the research, analysis

In recent studies conducted at the Building Research Institute, the impact of the type and amount of fibres in concrete substrates on the load capacity of expansion and bonded anchors was assessed. Steel and polypropylene fibres were used for concrete reinforcement (Fig. 6).

(a) (b)

Fig. 6. General view: (a) of the steel and (b) polypropylene fibres used in research concrete substrates.

Steel fibres were dosed into concrete mixes in a concrete truck and mixed for about 15 minutes before being unloaded into moulds (Fig. 7) in which substrates were formed. The polypropylene fibers were added at the concrete plant to the stationary mixer together with the aggregate, prior to the addition of cement and water. The process of mixing the concrete mix also took place in a concrete truck on the way (approx. 15-20 minutes) from the plant to the place where the mix was unloaded into the moulds.

Fig. 7. Concrete mix with steel fibres during unloading into moulds.

Segment expansion anchors, bonded anchors and screw anchors were used in the tests, shown in Figs. 8-10.

Fig. 8. Segment expansion anchors.

Fig. 9. Steel threaded rods of M8, M10 and M12 bonded anchors.

Fig. 10. Screw anchors.

Anchors fixed in concrete substrates without cracks and with cracks were tested under tensile loads on the test stand shown in Fig. 1. Results of segment expansion anchors installed in non-cracked concrete substrates of class C20/25, reinforced with various amounts of steel fibres, are presented in Table 2.

Table 2. Results of pull-out resistance of M10 and M12 segment expansion anchors, installed in non-cracked concrete substrates of class C20/25 reinforced with steel fibres

Steel fibres content C_{fz} [kg/m^3]	**Pull-out resistance $N_{Ru,m}$ [kN]**	
	M10 expansion anchors h_{ef} = 42 [mm]	**M12 expansion anchors h_{ef} = 70 [mm]**
0	13.68	36.14
10	14.78	37.42
15	15.72	-
20	15.55	-
30	-	43.51
60	-	44.55

Analysing the results of pull-out resistance of M12 segment expansion anchors, installed in non-cracked concrete reinforced with steel fibres and subjected to tensile forces, it is clearly visible that their load capacity increases with the increase of the amount of steel fibres in the substrate. Attention is also drawn to the fact that while the effect of the amount of dispersed reinforcement up to 10 kg/m^3 of concrete slightly increases the pull-out resistance of segment expansion anchors (by about 3-6%), the increase in the amount of this reinforcement to the level of 30 kg/m^3 results in an increase in the pull-out resistance of anchors by about 20%. It was also observed in the tests that with a further increase in the amount of dispersed reinforcement to 50-60 kg/m^3 of concrete, the pull-out resistance of anchors increases much slower, by about 1-3%.

Fig. 11 presents a graphical representation of the tendency of changes in the pull-out resistance of M12 segment expansion anchors installed in a non-cracked C20/25 class concrete base with additional steel reinforcement dispersed in various amounts, as determined in the tests.

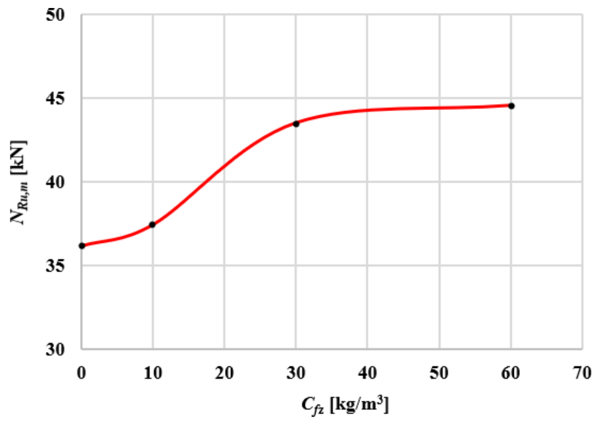

Fig. 11. Influence of the amount of steel fibres in concrete substrates of class C20/25 on the pull-out resistance of M12 segment expansion anchors at h_{ef} = 70 mm.

The tests of screw anchors, a clear influence of the reinforcement dispersed in the concrete and the condition of the concrete substrate on the pull-out resistance of the anchors was observed. Tables 3 and 4 show the impact of cracking of the concrete substrate on the pull-out resistance of the screw anchors installed in non-cracked and cracked concrete substrates, unreinforced and reinforced with steel fibres.

Table 3. Pull-out resistance of 14 mm screw anchors in non-cracked and cracked concrete substrates of class C25/30 without dispersed reinforcement

Anchor depth h_{ef} [mm]	**Pull-out resistance $N_{Ru,m}$ [kN]**		
	Non-cracked concrete	**Cracked concrete w = 0.30 [mm]**	**Load resistance decrease [%]**
45	25.59	14.61	42.9
54	35.87	23.13	35.5
62	44.37	30.02	32.3
71	53.14	37.31	29.8
79	62.25	44.68	28.2

Table 4. Pull-out resistance of 14 mm screw anchors in non-cracked and cracked concrete substrates of class C25/30 with the addition of steel fibres in the amount of 20 [kg/m^3]

Anchor depth h_{ef} [mm]	**Pull-out resistance $N_{Ru,m}$ [kN]**		
	Non-cracked concrete	**Cracked concrete w = 0.30 [mm]**	**Load resistance decrease [%]**
45	28.62	23.24	18.8
54	37.16	30.21	18.7
62	45.91	37.55	18.2
71	56.24	46.98	16.5
79	66.79	56.82	14.9

Failure mode of the screw anchors as a result of tensile loads was the shearing off of the mechanical thread lock of the bolt in the sidewall of the hole made in concrete with the simultaneous tearing out of the near-surface concrete cone. The dimensions of the cone to be pulled out were smaller than in the case of failure of joints with torque controlled expansion fasteners. The height of the cone torn out did not exceed 20-30 mm, while the diameter of the base of this cone for fixings in the fibre reinforced concrete was about 30-40% larger than for fixings in unreinforced concrete (Fig. 12).

Fig. 12. Characteristic failure mode of the connection made observed in the tests screw anchors in the fibre reinforced concrete.

In fastenings made with bonded anchors, installed in concrete substrates of class C20/25 with the addition of polypropylene fibres, changes in load resistance were observed depending on the size of the tested anchors, the amount of dispersed reinforcement built into the concrete substrate and the condition of the substrate (non-cracked and cracked concrete). The holes made, before anchoring the anchors, were cleaned by blowing, brushing and blowing again with compressed air. Two-component epoxy resin was used for anchoring. The test results are presented in Table 5 to 7.

Table 5. Pull-out resistance of M8 bonded anchors installed in non-cracked and cracked concrete substrates of class C20/25, h_{ef} = 50 [mm]

Polypropylene fibres content C_{fz} [kg/m^3]	Pull-out capacity $N_{Ru,m}$ [kN]		
	Non-cracked concrete	**Cracked concrete w = 0.30 [mm]**	**Load resistance decrease [%]**
0	22.31	15.78	29.3
1.0	23.35	16.01	31.4
1.5	24.28	16.49	32.1
2.0	24.90	17.54	29.6

Table 6. Pull-out resistance of M10 bonded anchors installed in non-cracked and cracked concrete substrates of class C20/25, h_{ef} = 60 [mm]

Polypropylene fibres content C_{fz} [kg/m^3]	Pull-out capacity $N_{Ru,m}$ [kN]		
	Non-cracked concrete	**Cracked concrete w = 0.30 [mm]**	**Load resistance decrease [%]**
0	31.16	17.95	42.4
1.0	32.48	18.56	42.9
1.5	33.71	19.39	42.5
2.0	34.68	20.62	40.5

Table 7. Pull-out resistance of M12 bonded anchors installed in non-cracked and cracked concrete substrates of class C20/25, h_{ef} = 70 [mm]

Polypropylene fibres content C_{fz} [kg/m^3]	Pull-out capacity $N_{Ru,m}$ [kN]		
	Non-cracked concrete	Cracked concrete w = 0.30 [mm]	Load resistance decrease [%]
0	46.58	33.29	28.5
1.0	48.74	35.83	26.5
1.5	50.34	37.40	25.7
2.0	50.80	38.43	24.4

3 Conclusions

With the use of modern anchors, more and more responsible fastenings are made in various building substrates (concrete, ceramics, lightweight concrete). These are also anchors in concrete substrates reinforced with steel and polypropylene fibres.

The article describes the influence of dispersed reinforcement in concrete on the pull-out resistance of expansion anchors, screws and bonded anchors. This type of reinforcement has a positive effect on the pull-out resistance of anchors installed in concrete, both with non-cracked and cracked concrete. It should be noted that the observed changes in the pull-out resistance of anchors are clearly dependent on the amount of dispersed reinforcement built into the concrete substrate, which should be taken into account when describing the characteristics of this type of fastening.

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