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BEHAVIOR OF METAL EXPANSION ANCHORS AND BONDED ANCHORS IN REINFORCED NON-CRACKED AND CRACKED CONCRETE

BY

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Abstract. An experimental study on the metal expansion and bond anchors behavior post-installed on cracked and non-cracked concrete specimens tested in tension is presented. Mechanical anchors used are the type of anchor bolt or sleeve expansive and the bond anchors are the type with resin glass capsule system of two components. The mechanical and bonded anchors are depicted by the anchors strength, displacement of the loaded end at the control and failure load and also by the failure mode of anchors and the specimens. The pull-out tests were performed according with the European standards. The results obtained on mechanical and bonded anchors show the influence of crack width in reinforced cracked concrete member on displacement before load end failure, load capacity, in comparison with the tests on anchors in non-cracked concrete member and the modes of failure of the anchors and specimens.

Keywords: bolt anchor; sleeve expansive; bond anchor; cracked concrete; non-cracked concrete.

1. Introduction

Cracks formation in concrete elements should be anticipated at loading services levels where is very likely that the location of anchor to be intersected

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by cracks. Experience shows that the concrete is cracking, there is a high probability that the crack to propagate across the anchorage area (Cannon 1981 and Eligehausen, Fuchs, Lotze and Reuter, 1989). It is therefore necessary to evaluate the effect of cracking on the performance anchors.

Crack width can vary with profundity of the element (cracking bending) or be constant (parallel cracks, i.e. cracks caused by tensile loads). In this case the results of mechanical and chemical anchors tested were compared with the results obtained on cracked element with cracks in one and parallel direction (member stretched in one direction).

To evaluate the effect of crack width on the bearing anchors capacity, in tests, the cracks are opened at a prescribed load applied on test member (usually cracks are formed through the reinforcement in concrete), after that the anchors are placed in cracks and tested to pull off.

2. Objectives

The objective of this study is to evaluate the behavior of mechanical and chemical anchors post installed in reinforced members by evaluating the strength of failure, displacements recorded from the beginning of the experiment to fail and the failure modes for anchors and specimens. The study will compare the behavior of anchors on reinforced non-cracked and reinforced cracked member.

3. Behavior of Mechanical and Bonded Anchors in Non-Cracked and Cracked Concrete

Anchorages displacements placed in cracks behave similar with those placed in non-cracked concrete until a critical load. This critical loading depends on the type of fracture and crack width. When loads are higher, anchorages movements in cracks are much higher than expected values in non-cracked concrete and anchorage capacity is significantly reduced.

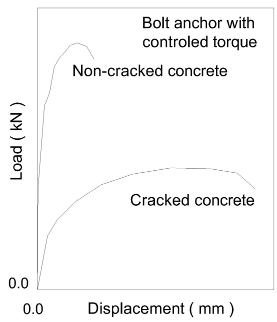


Fig.1 – Schematic representation of the influence of cracks on the load-displacement relation of expansive anchors (Rehm and Lehmann, 1982).

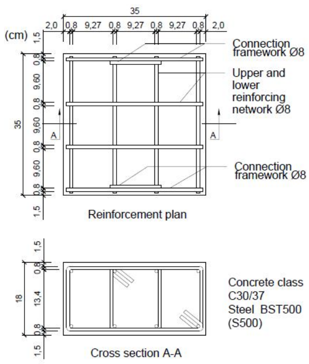
Fig. 1 shows the force-displacement typical curve for torque controlled expansion anchors installed in non-cracked and cracked concrete, static loaded until failure.

4. Materials, Installations and Methods

4.1. Reinforced Concrete Support. Reinforcement Used. Concrete Specimens

Considering the particularities of various experimental device, the behavior requirements of specimen, requested to stretching and cracking (compression is not the subject of this article) was considered that the patterns used to manufacture specimens ensure flatness and shape. Considering also the needs of a larger number of anchors tested and the difficulty of making patterns, and the weight specimens to test them, it realized to a size printing using recommendations ETAG 001-A: Guideline for European technical approval of " Metal Anchors for use in Concrete. Annex A: Details of Tests'' and ETAG 001-5: Guideline for European technical approval of "Metal anchors for use in concrete - Part 5: Bonded anchors". Following these recommendations, because of the mounting anchors and handling specimens, were realized concrete members with dimensions 35 × 35 cm and a thickness of 18 cm. Reinforced concrete support was only one class quality: C30/37. The composition of concrete was calculated so that the only requirement is to achieve resistance to compression standard range test, using the same recipe of dosage of cement, water-cement ratio and size of aggregates.

a



b

Fig. 2 – Realisation of specimens: *a* – formwork; *b* – reinforcement detail.

4.2. Mechanical and Bonded Anchors

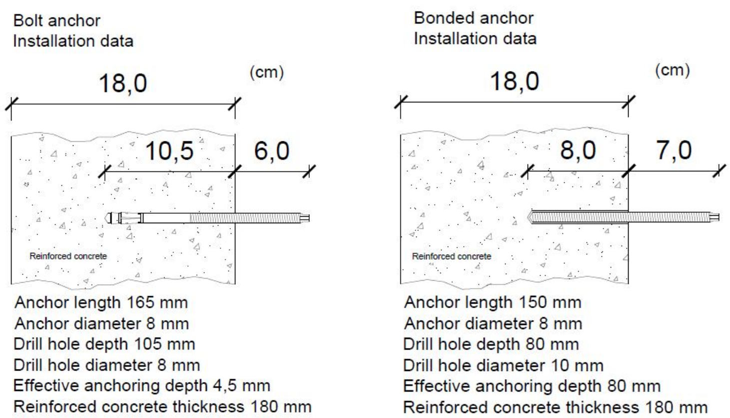
4.2.1. Mechanical Anchors (bolt anchors)

Tests have been made with mechanical anchorages the type of bolt or expansive sleeve anchor with the diameter of 8 mm and a maximum thickness of fixed element 10 cm. The rod is galvanized steel with 5.8 class. These anchors are approved for concrete C20/25 to C50/60 cracked and non-cracked according quality certificate ETA-05/0069 and according ETAG 001. Technical and installation data are detailed in Table1.

Table 1
Installation Data of Bolt Anchors used in Tensile Tests

Installation data 							
Type	Material	Drill hole diameter	Drill hole depth	Effective anchoring depth	Anchor length	Anchor diameter	Reinforced concrete thickness
		mm	mm	mm	mm	mm	mm
Bolt anchor	Zinc-plated steel grade 5.8	8	105	4,5	165	8	180

Installations data are illustrated in Fig. 3.



a *b*

Fig. 3 – Installation of a: a – bolt anchor and *b* – bond anchor in reinforced concrete specimen.

4.2.2. Bonded Anchors

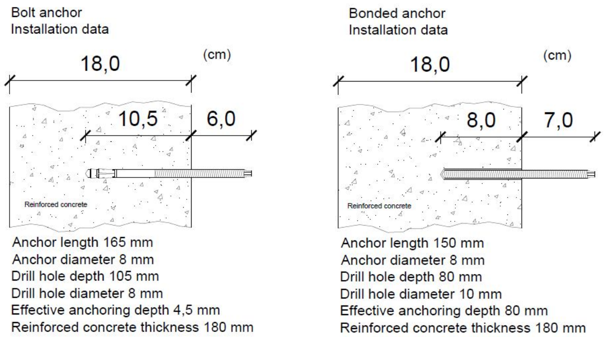
Simultaneously with mechanical anchors have been installed chemical anchors (bonded anchors). They are composed of two components chemical glass capsule with hardening accelerator RM8 (glass capsule resin with 8 mm in diameter) and galvanized steel rods of 8 mm in diameter and 150 mm long. These anchors are approved for use in concrete class from C20/25 to C50/60 only in non-cracked concrete according to quality certificate ETA-08/0010 and according to ETAG 001-5.

Table 2

Installation Data of Bonded Anchors used in Tensile Tests

Installation data R M8+RG M8X150						
Type	Material	Drill hole diameter	Drill hole depth	Effective anchoring depth	Reinforced concrete thickness	Threated rod (Diameter x length)
Bond anchor		mm	mm	mm	mm	mm
Glass capsule RM8	Bi-component resin	10	80	80	-	RGM8
Threated rod RG M8	Zinc Plated steel grade 5.8	10	80	80	180	M8x150

Installations data are illustrated in Fig. 3.



a *b*

Fig. 3 – Installation of a: *a* – bolt anchor and *b* – bond anchor in reinforced concrete specimen.

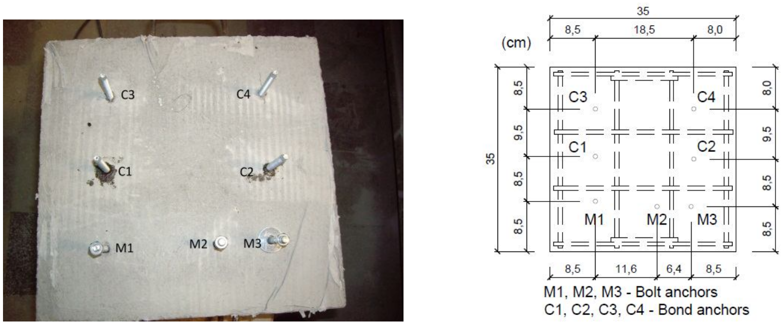
4.3. Installing Anchors and Disposition of Bolt and Bonded Anchors on Specimen

Installation anchors where made by drilling with drilling machine into concrete specimen with 8 mm in diameter for bolt anchors with the rod of 8 mm and 10 mm hole diameter for bonded anchors with rod of 8mm in diameter. After drilling, all holes were cleaned. Bolt anchors were inserted by knocking with a hammer, up to the bottom of the hole and when the tensile test in applied, the cone bolt is pulled into the expansion clip and expands it against the drill hole wall. In the case of bonded anchors the threated rod is set using a hammer drill with the accompanying setting tool in rotating and hitting motions. During setting, the oblique edge of the threated rod destroys the capsule, mixes and activate the mortar. Installing anchors was made respecting the manufacturer's recommendations. Anchorages were installed respecting the minimum distances from the specimen’s margins and minimum distances between anchors recommended by the manufacturer to have a more real behavior to pull off (Figs. 4 and 5).

Distances recommended by the manufacturer and highest permissible load for a single anchor are detailed in Table 3.

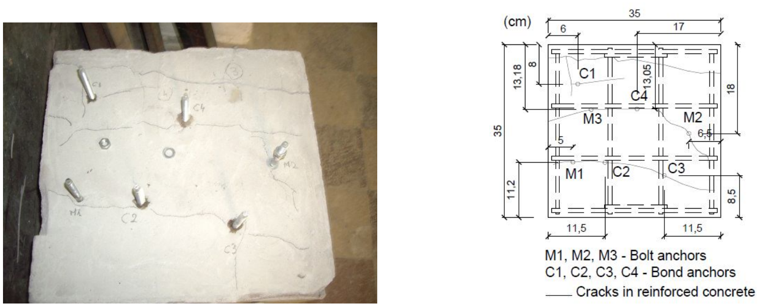
Table 3
Minimum Spacing and Edge Distance and the Highest Permissible Load for a Single Anchor Recommended

	Cracked concrete			Uncracked concrete		
Type	Tensile allowed	Minimum distance between anchors	Minimum distance to the edges	Tensile allowed	Minimum distance between anchors	Minimum distance to the edges
	N_{perm}	s_{min}	c_{min}	N_{perm}	s_{min}	c_{min}
	(kN)	(mm)	(mm)	(kN)	(mm)	(mm)
Bolt anchor	2,4	35	40	4,3	40	40
Bond anchor				8,8	40	40



a *b*

Fig. 4 –Anchors positions: *a* – on non-cracked specimen, *b* – toward reinforcement M1, M2, M3-bolt anchors; C1, C2, C3, C4 bonded anchors.



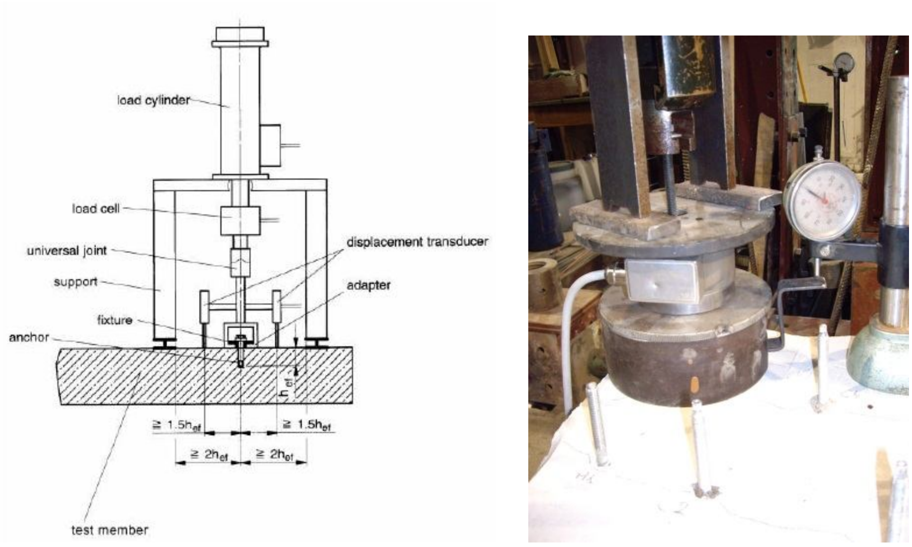
a *b*

Fig. 5 – Anchors positions: *a* – on cracked specimen, *b* – toward reinforcement M1, M2, M3-bolt anchors; C1, C2, C3, C4 bonded anchors.

4.4. Test method of the anchor resistance

To develop an experimental device for testing to pull off the mechanical and bonded anchors where considered the requirements of international technical agreements on measuring equipment.

So, according to ETAG 001-A tests are carried out using measuring equipment with calibration traceable to international standards. An example of the pull off test device is illustrated in the Fig. 6.



a *b*

Fig. 6 – *a* – Schematic example of test device of anchors, *b* – experimental device to attempt to pull off.

5. Results

During tests were recorded for each anchor in part for both type of anchors, the tensile forces (or tearing) and displacements until their disposal, the lost bearing capacity and failure mode Table 4.

Regarding the failure mode of mechanical anchors in non-cracked and cracked concrete is almost identical and can be seen in Figs. 7 and 8.

For bonded anchors, failure mode is different and it is illustrated in Figs. 9 and 10.

Table 4

Summary Table with Maximum Forces Supported by Anchors for the Two Cases: in Non-Cracked and Cracked Concrete, Crack Width, and Failure Mode of Anchors

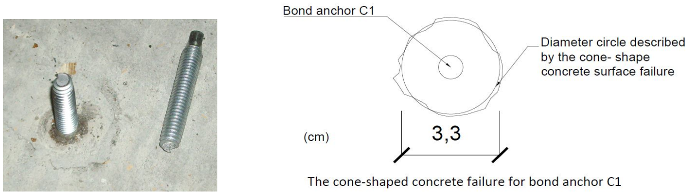
Uncracked concrete			**Cracked concrete**			
Type	Failure load (kN)	Failure Mode	Type	Crack width (mm)	Failure load (kN)	Failure Mode
M1 (Test 1)	16,59	rod sliding through sleeve, sleeve remaining inside specimen	M1	0,1	15,06	rod sliding through sleeve, sleeve remaining inside specimen
M2 (Test3)	13,83	rod sliding through sleeve, sleeve remaining inside specimen	M2	0,1	15,42	rod sliding through sleeve, sleeve remaining inside specimen
M3 (Test2)	14,82	rod sliding through sleeve, sleeve remaining inside specimen	M3	0,25	11,61	rod sliding through sleeve, sleeve remaining inside specimen
C1 (Test 5)	20,79	rod failure	C1	0,4	12,42	bonding failure between mortar and concrete
C2 (Test 4)	17,64	bonding failure between mortar and concrete	C2	0,1	18,96	bonding failure between mortar and concrete
C3 (Test 6)	21,12	rod failure	C3	0,1	17,91	bonding failure between mortar and concrete
C4 (Test 7)	19,92	rod failure	C4	0,1	20,91	rod failure

a *b*

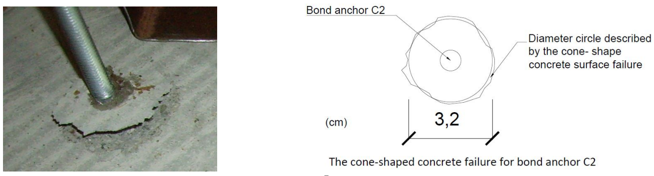
Fig. 7 – Bolt anchor failure mode M1, M2 and M3 in non-cracked concrete: *a* – rod anchor after pulling-out, *b* – the areas surrounding the holes after pull-out.

a *b* *c*

Fig. 8 – Failure mode of bolt anchors M1, M2 and M3 in cracked reinforced concrete: *a*, *b* – rod anchors and specimen after extracting M1 and M2 in cracks with 0.1mm width, *c* – bolt anchor M3 installed in crack with 0.25 mm width.



a



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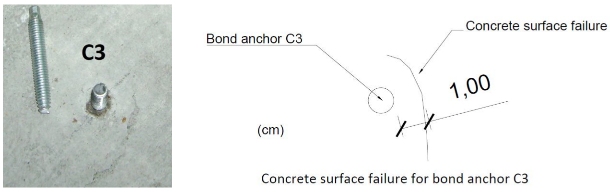
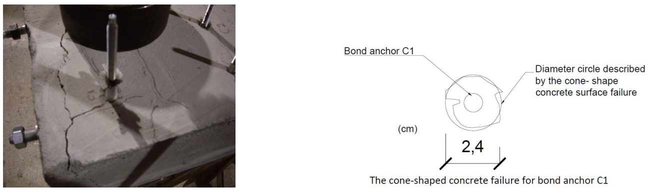


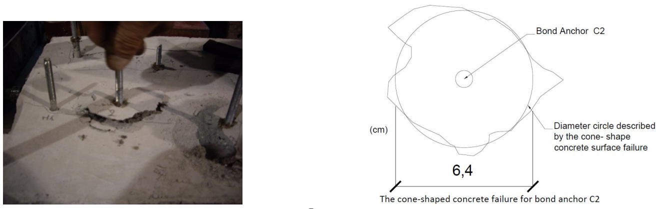
c

d

Fig. 9 – Failure mode of bonded anchors C1, C2, C3 ,C4 and the appearance of non-cracked reinforced concrete specimen.



a



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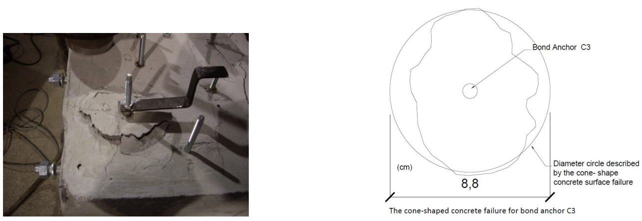

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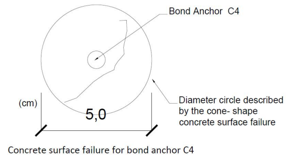
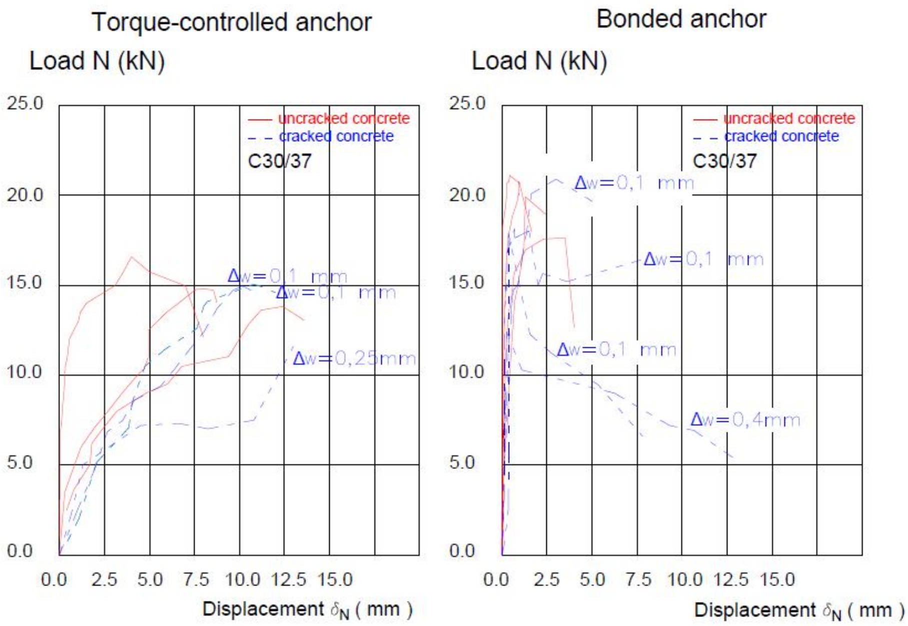


d)

Fig.10 – Failure mode of bonded anchors and appearance of cracked reinforced concrete specimen: *a* – anchor C1 installed in crack with 0.4mm width; *b*, *c*, *d* – anchors C2, C3 and C4 installed in crack with 0.1mm width.

According to recorded data it has been drawn the load-displacement curves (Fig. 11).



a *b*

Fig. 11 – Load-displacement curves for: *a* – bolt anchors (M8, h_{ef} = 4.5 cm) and *b* – bond anchors (M8, h_{ef} = 8 cm), in cracked and non-cracked reinforced concrete.

3. Conclusion

Bolt anchors

The behavior of the type anchors tested both in cracked concrete and non-cracked concrete is identical in the first phase of pullout. Since their introduction in the hole on the specimen and drive to pull off there is a trip (torque controlled installation) until to exercise force cone from the top of the rod by deforming the sleeve, creating a strain on the sleeve that acts on the walls of the hole. This initial movement can be appreciated (Fig. 11) to be higher than for bonded anchors that begin to have noticeable displacements starting at least at 10 kN. In case of these mechanical anchors, sizeable initial displacements start from the beginning of the tests.

The cracks in the test specimen made in concrete tend to be carried out following the arrangement transverse reinforcement, were anchors have been installed in cracks obtained with 0.1 and 0.25 mm width. For anchors in cracks of 0.1 mm width it observes that the values do not differ greatly, concluding that anchors in cracks with 0.1mm width behave almost identically with anchors tested in non-cracked concrete.

$$N_{u\ \text{(cracked concrete)}} / N_{u\ \text{(uncracked concrete)}} = 15.24\ \text{kN}/15.08\ \text{kN} = 1.01,$$

where: $N_{u\ \text{(cracked concrete)}}$ = (15.06 kN + 15.42 kN)/2 = 15.24 kN – pull-out failure load average of bolt anchors installed in cracked concrete with 0.1 mm cracks width; $N_{u\text{(uncracked concrete)}}$ = (16.59 kN + 13.83 kN + 14.82 kN)/3 = 15.08 kN – pull-out failure load average of bolt anchors installed in non-cracked concrete.

Instead for cracks of 0.25 mm width, it reaches large displacements at reduced pulling forces due to the fact that anchor sleeve had where to deform inside the hole favoring sliding. Besides large displacements, force failure was around 11.61 kN. If we consider failure forces obtained in non-cracked concrete, in order to calculate the average of failure forces, it results that in case of mechanical anchors of the kind tried in crack with 0.25mm aperture, the bearing capacity of the anchor can be reduced up to 25%.

$$\text{N}_{\text{u (craked concrete)}} / \text{N}_{\text{u (uncracked concrete)}} = 11.61\ \text{kN}/15.08\ \text{kN} = 0.76,$$

where: $N_{u\ \text{(craked concrete)}}$ = 11.61 kN – pull-out failure load average of bolt anchors installed in cracked concrete with 0.25 mm cracks width; $N_{u\text{(uncracked concrete)}}$ = (16.59 kN + 13.83 kN + 14.82 kN)/3 = 15.08 kN – pull-out failure load average of bolt anchors installed in non-cracked concrete.

According Eligehausen, pull-out failure load is decreasing rapidly until crack thickness of about 0.4mm and for major cracks ultimate tensile stress is practically constant (Fig. 12). The dispersion data is relatively large. On average, the failure load of anchorages installed in or near a crack with a thickness of > 0.4 mm is about 60% of the failure load installed in non-cracked concrete. It can be seen that under service loading, in reinforced concrete structures cracks whose thickness is less or equal to 0.4 mm are admissible. As well, it was observed a reduction of similar resistance when anchorages were installed in greater depth in the tensile zone of the beams for different relationships anchorage depth/height beam (Rehm, Eligehausen and Malle, 1988).

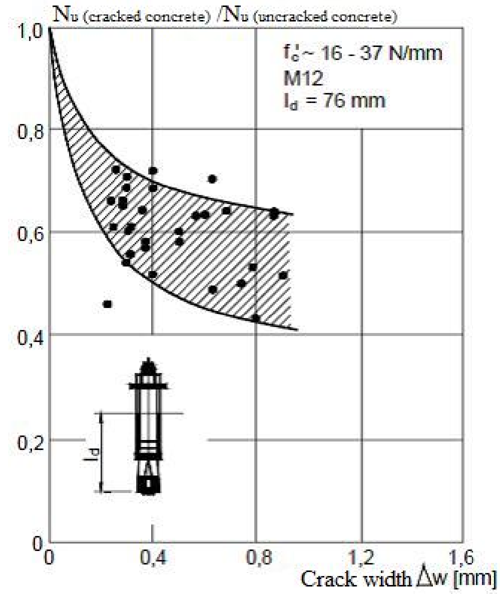
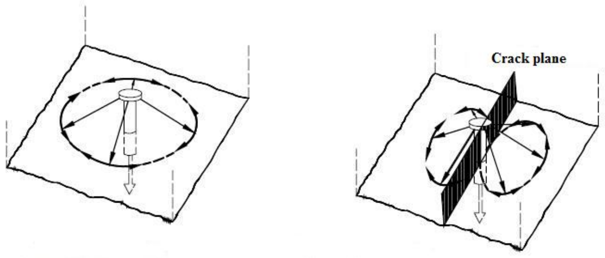


Fig. 12 – Influence of cracks on pull-out failure load for torque controlled anchors (Eligehausen, 1984).

For wider cracks the cone bolt is pulled into the expansion sleeve and break more frequently, because the expansion movement reaches a maximum upper limit and grip capacity is less than the strength of concrete cone failure. This gives an additional reduction of force failure compared with preinstalled anchorages or undercut anchors.

If an expansion anchorage such as a torque controlled anchor cannot expand more adequately or if the movement of expansion is too small, the influence of cracks on the breaking strength will be more pronounced than the one shown in Fig. 12.

The reduction of anchor resistance is due of exchanging the distribution of tensions that form the cracks in concrete (Eligehausen 1984 and Eligehausen, Fuchs and Mayer, 1987 and 1988). In the case of non-cracked concrete, tensions in the concrete have a radial symmetry around the anchor and is generating tensile stress form of a ring-shaped load caused by the transfer to the concrete (Fig. 13 *a*). If anchorage is installed in a crack, tensile stress may not be transferred through the crack. Therefore surface that can be used to transmit load to concrete is lower than in non-cracked concrete (Fig. 13 *b*).



a *b*

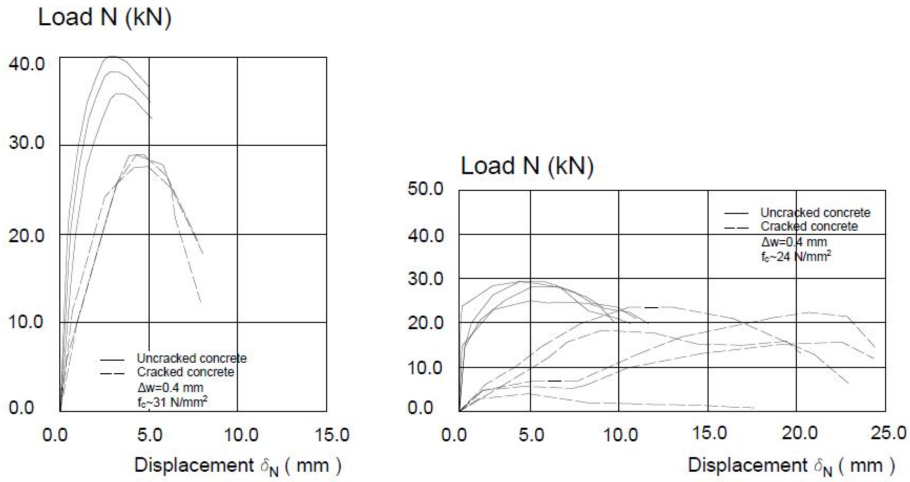
Fig. 13 – Schematic representation of the force transfer to the concrete: *a* – for non-cracked concrete and *b* – for cracked concrete (Eligehausen, Fuchs and Mayer 1987, 1988).

There are also situations when part of concrete cone can be cut by cracks neighbors. The combination of these effects cause a reduction in resistance of about 40% with respect to non-cracked concrete. Links between aggregates can transmit some tensile tension through the cracks, but these are very small (Eligehausen and Sawada, 1985). This explains why anchorages resistance increases when cracks are less than 0.4mm width.

Anchor failure mode in both cases is identical of sliding rod, the sleeve remains in concrete with no visible damages on the concrete specimen. This failure is attributed to the deformation of the sleeve realizing the load transfer mechanism from tensile force to friction. It was also found that the mechanical load capacity of anchors tested were higher than recommended by the manufacturer request forces, both in non-cracked and cracked concrete. Also these anchors are certified and approved to be used in concrete class C20 / 25 to C50 / 60. In literature, there are tests that model the behavior of torque-controlled anchors in cracked and non-cracked concrete making it a delimitation between those that are approved for use in cracked concrete or not.

Torque controled expansion anchors that are not suitable for applications in cracked concrete can exibit so-called uncontrolled slip when loaded in tensions in cracks, since such anchors may not develop follow-up expansion necessary to reestablish anchorage in the crack or do so only after significant displacement.

Figs. 14 a) and b) illustrate measured load-displacement curves for torque- controlled expansion anchors in crack and non-cracked concrete. The anchors in Fig. 14 a) are suitable for cracked concrete, whereby those shown in Fig. 14 b) are not. The load-displacement curves in Fig. 14 a) are characterized by uniform load development and stiffness in both the craked and non-craked concrete condition. Those curves showed in Fig. 14 b) are uniform only in the non-cracked concrete case. In cracks, these anchors exhibit large scatter in both peak load and slip, making their behavior unpredictable.



a *b*

Fig. 14 – Load-displacement curves of torque-controlled expansion anchors: *a* – (M12, h_{ef} = 80 mm) suitable for cracked concrete tested in tension in cracked and non-cracked concrete; *b* – (M12, h_{ef} = 60mm) developed for applications in non-cracked concrete tested in tension in cracked and non-cracked concrete (after Dieterle, Bonzenhardt, Hirth, Opitz (1990))

Bonded anchors

In case of bonded anchors there were no initial displacements, in comparison with the bolt anchors. What can be seen from the summary table is that the failure of anchors tested in uncracked concrete was mainly by breaking the rod and for the anchors tested on cracked concrete was bonding failure between mortar and concrete with a cone-shaped concrete breakout originating at the base of the anchor and ultimate load for the two cases on non-cracked and cracked element with cracks of 0.1 mm width is about identical:

$$N_{u\,(\text{craked concrete})}/N_{u\,(\text{uncracked concrete})} = 19.26\text{ kN}/19.86\text{ kN} = 0.96,$$

where: $N_{u(\text{craked concrete})}$ = (18.96 kN + 17.91 kN + 20.91 kN)/3 = 19.26 kN – pull-out failure load average of bonded anchors installed in cracked concrete with 0.10 mm cracks width; $N_{u(\text{uncracked concrete})}$ = (20.79 kN + 17.64 kN + 21.12 kN + + 19.92 kN)/4 = 19.86 kN – pull-out failure load average of bonded anchors installed in non-cracked concrete.

To reach a conclusion in terms of reducing the bearing capacity of the bonded anchors for various cracks front of their capacity in non-cracked concrete in the literature concluded variability of results obtained for anchors with different diameters tested in different openings cracks (Fig. 15).

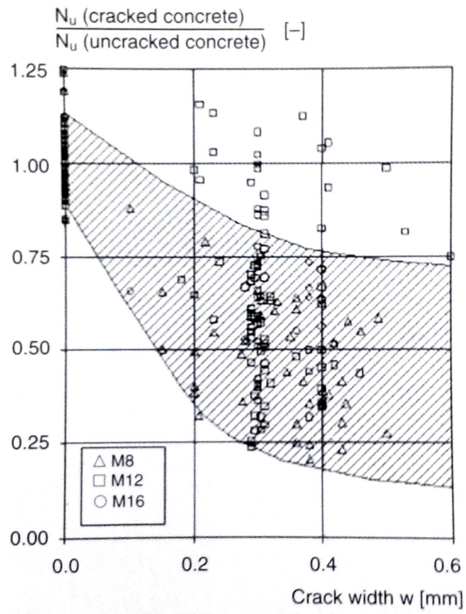


Fig. 15 – Influence of crack width on the failure load of bonded anchors Meszaros (1999)).

The main reason is that the irregular position of the crack with respect to the anchor, *i.e.* the crack may deviate from the plane of the anchor axis. If the results of tests with a ratio $N_{u(\text{cracked concrete})}/N_{u(\text{uncracked concrete})} > 0.8$ are neglected (because in these tests it may be assumed that only the upper part of the anchor was located in the crack) then the anchor capacities in cracked concrete with a crack width Δw = 0.3 mm to 0.4 mm is about 25% to 80% of the value valid for non-cracked concrete. On average the ratio is about 50%.

The anchor tested in crack with 0.4mm width where the ultimate load was 12.42 kN it was reached a 38% reduction in the average capacity of non-cracked concrete anchors tested. In this data variability an important factor can be the distance from specimen reinforcing, its position on the specimen, concrete class:

$$N_{u\,(\text{craked concrete})}/N_{u(\text{uncracked concrete})} = 12.42\text{ kN}/19.86\text{ kN} = 0.62,$$

where: $N_{u(\text{craked concrete})}$ = 12.42 kN – pull-out failure load average of bond anchor installed in cracked concrete with 0.4 mm crack width; $N_{u(\text{uncracked concrete})}$ = = (20.79 kN + 17.64 kN + 21.12 kN + 19.92 kN)/4 = 19.86 kN – pull-out failure load average of bonded anchors installed in uncracked concrete.

Anchors capacities in cracked concrete with a crack width Δw = 0.1 mm to 0.2 mm is about 25% of the value valid for non-cracked concrete, in the case tested the reduction of average capacity in cracks with 0,1 mm width and a specimen concrete class C30 / 37 has only 4% of the value for non-cracked concrete which leads to the conclusion that the bearing capacity of anchors tested in cracked concrete with cracks of 0.1 mm is roughly identical to the one tested in non-cracked concrete.

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COMPORTAREA ANCORELOR MECANICE SI CHIMICE IN BETON ARMAT NEFISURAT ŞI FISURAT

(Rezumat)

Se prezintă un studiu comparativ a ancorelor mecanice şi chimice privind comportarea la smulgere pe epruvete de beton armat nefisurat şi fisurat cu diferite deschideri de fisuri în ceea ce priveşte influența deschiderilor fisurilor asupra capacității portante ultime, a deplasărilor inițiale şi în timpul sarcinii, a modului de cedare atât al ancorelor cât şi ale epruvetelor. Din rezultatele obținute se poate concluziona că capacitatea portantă ancorelor mecanice şi chimice testate în beton armat fisurat cu deschidere de fisuri de 0,1mm este aproximativ identică cu cele testate pe beton armat nefisurat, capacitatea ultimă diminuindu-se odată cu deschiderea fisurilor şi influențând negativ deplasările. Modul de cedare al ancorelor mecanice a fost identic în ambele cazuri de beton armat fisurat cât şi nefisurat în schimb pentru ancorele chimice modul de cedare a fost diferit în sensul că în betonul fisurat cedarea s-a produs prin cedarea aderenței între raşină şi pereții orificiului epruvetei.

Acest studiu face parte din evaluarea comportării ancorelor pe diferite situații de stare ale epruvetelor de beton armat: nefisurat, fisurat, comprimat şi întins.