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

BY

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Abstract. An experimental study on the metal expansion and bond anchors behavior post-installed in non-cracked and compressed concrete specimen tested to pull-off is presented. The tests were realized initially on a concrete specimen in inert state of tension and then on another specimen in continuous state of compression in one direction. Mechanical anchors used are the type of bolt anchor 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 reinforced specimen state on anchors load capacity and displacements before load end failure, and failure mode of anchors and specimens.

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

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1. Introduction

Nowadays anchorages were established as a constructive solution allowing efficient transfer of loads from new elements attached to the structure. In various occasions in construction is determined the category and size of anchors depending on the material properties and data provided by manufacturers of anchors but not considering as part of a system, leading to over or under sizing generating in the first case a major economic expense and in the second case a reduction of service safety. In specialty literature there have been studies on the bearing capacity of anchors in different modes of work in cracked or non-cracked concrete, under continuous load applied to anchor, anchors in different classes of concrete, etc., but there are no remarks regarding the behavior of anchors in tension on specimens compressed at a constant or different levels of force. This study wants to bring clarification regarding the behavior of anchors in reinforced concrete specimen in constant compression in one direction.

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 specimen with the behavior on reinforced member compressed at a constant level force in one direction.

3. Behavior of Metal Expansion Anchors and Bonded Anchors in Reinforced Non-Cracked and Compressed Concrete in One Direction

To understand the results achieved in tests we need to take a look at the force-displacement relationship existing in literature, failure modes and ultimate load. Fig. 1 contains idealized relationships load-displacement for most common types of failure. Curve $a_{1,1}$ depicts representative load-displacement for a drop-in anchor, after the static friction is exceeded, the resistance drops and sliding friction occurs. In case of torque controlled anchors that the follow-up expansion does not develop properly, curves $a_{1,2}$ and $a_{1,3}$ correspond. For undercut anchors and headed studs that the interlock is inadequate load-displacement behavior is associated to curve $a_{1,4}$. This form of failure could happen to torque-controlled expansion anchors that exhibit a follow-up expansion. It is a failure that depends on the correct function of the anchor, the geometry and construction of the anchor.

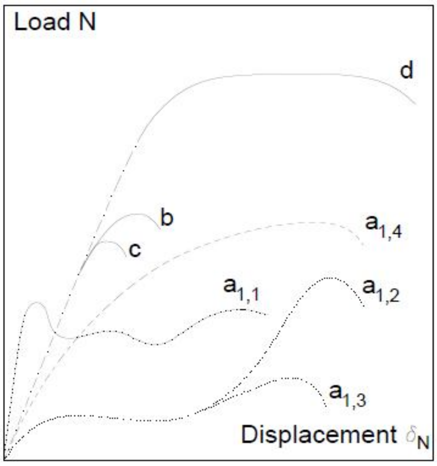
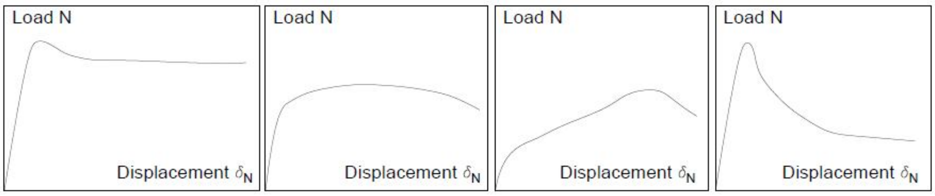


Fig. 1 – Idealised load-displacement curves for tension-loaded anchors exhibiting various failure modes (Fuchs, Eligehausen, Breen (1995)).

Curve b in Fig. 1 is a load-displacement curve characteristic of cone breakout failure and curve c correspond a splitting failure when the dimensions of the concrete component are limited or the anchor is installed close to an edge, or anchors are installed in close proximity to each other. Steel failure as bolt, steel stud or sleeve is represented in curve *d*.

As for bonded anchors there are four known cases of schematic relation load-displacement (Fig. 2).



a) b) c) d)

Fig. 2 – Schematic load-displacement curves of single bonded anchors (Meszaros, 1999).

The figures represent failure between mortar and wall of drilled hole when a) bond force between mortar and concrete is higher than friction force, b) bond force between mortar and concrete is lower than friction force, c) bond force between mortar and concrete is significantly lower than friction force. Fig. 2 d case represents failure between mortar and rod.

4. Materials, Installations and Methods

4.1.1. Reinforced Concrete Support. Reinforcement Used. Concrete Specimens

Considering the particularities of various experimental device, the behavior requirements of specimen, requested to compression was considered that the patterns used to manufacture specimens ensure flatness and shape. Considering also the needs of a larger number of anchors tested, 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.

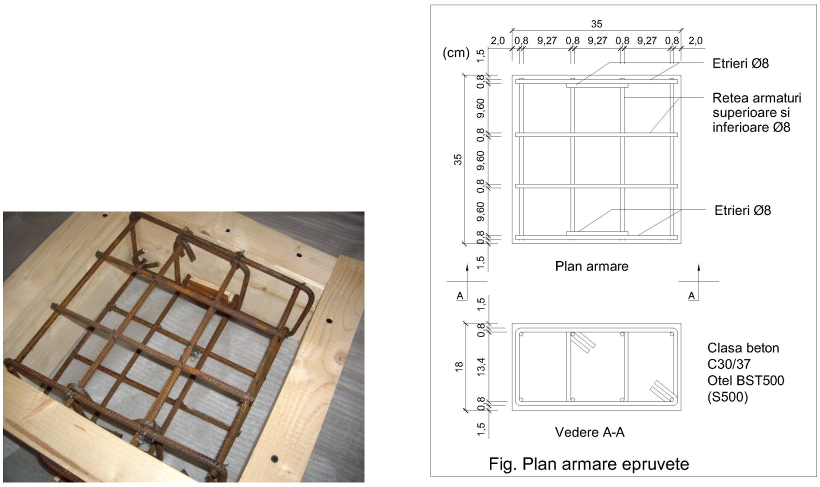


Fig. 3 – Realization of specimens: a) formwork; b) reinforcement detail.

4.1.2. Mechanical and Bonded Anchors

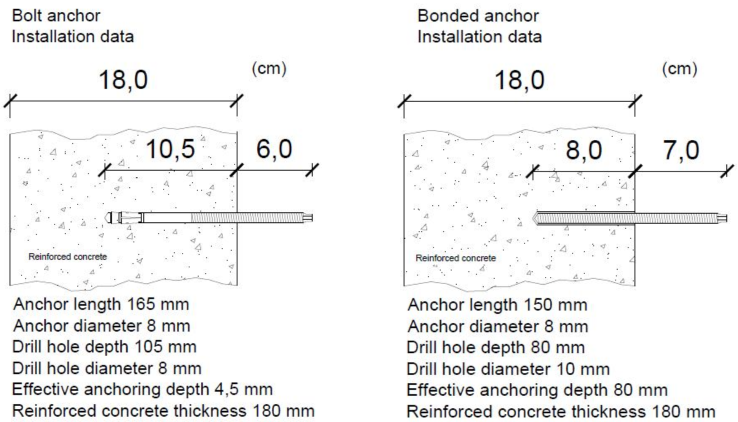
a) *Mechanical anchors (bolt anchors)*

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 the Table 1.

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. 4.



a) b)

Fig. 4 – Installation of a: a) bolt anchor and b) bond anchor in reinforced concrete specimen.

b) *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	Threaded 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

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

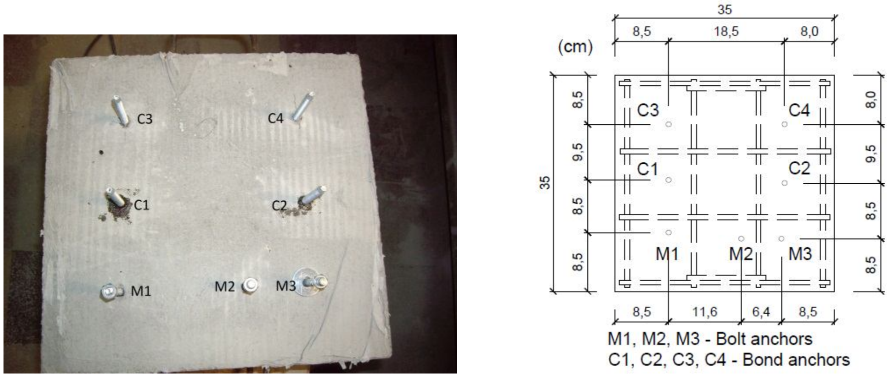
Installation anchors where made by drilling with drilling machine into concrete specimen with 8 mm in diameter for bolt anchors with the rod of 8 mm and 10 mm hole diameter for bonded anchors with rod of 8 mm in diameter. After drilling, all holes were cleaned. Bolt anchors were inserted by knocking 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 activates 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.

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

Table 3

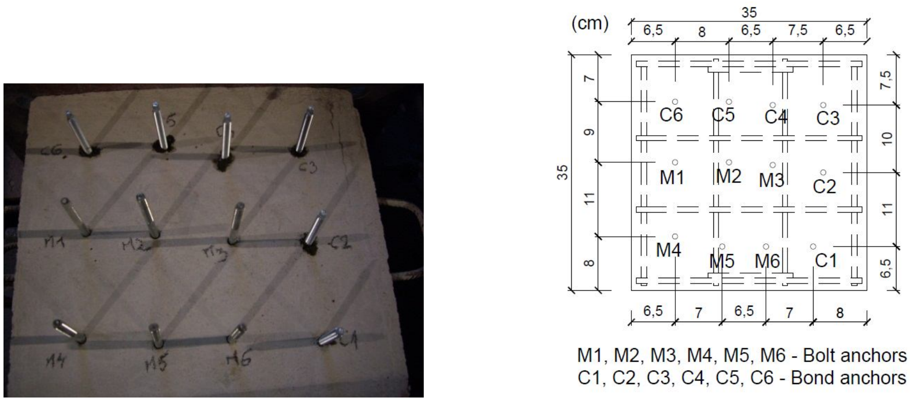
Minimum Spacing, Edge Distance and the Highest Permissible Load for a Single Anchor Recommended

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



a) b)

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



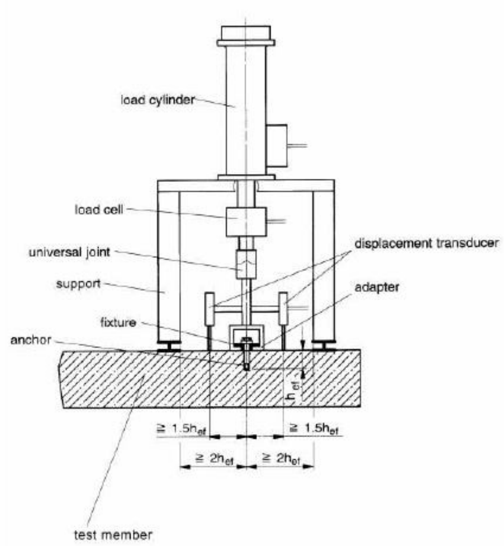
a) b)

Fig. 6 – Anchors positions: a) on cracked specimen; b) toward reinforcement M1...6 bolt anchors; C1...6 bonded anchors.

4.1.4. 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.

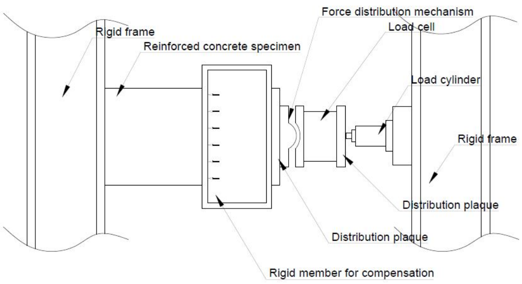
So, according to ETAG 001-A tests are carried out using measuring equipment with calibration traceable to international standards. An example of the pull off test device is illustrated in the Fig. 7.

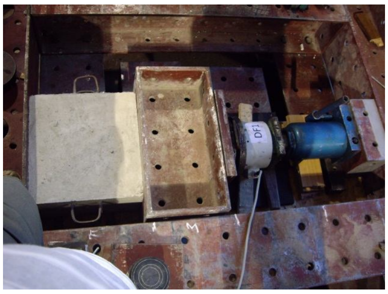


a) b)

Fig. 7 – a) Schematic example of test device of anchors; b) experimental device to attempt to pull off.

To obtain a continuous state of compression in the concrete specimen was taken into account that the distribution of load to be uniformly distributed on the entire section of the specimen, as is depicted in the Fig. 8.





a) b)

Fig. 8 – a) Schematic example of experimental device; b) experimental device for compression in one direction.

The anchors were installed after the specimen was induced a continuous state of compression, compression force applied was 150,00 kN.

5. Results

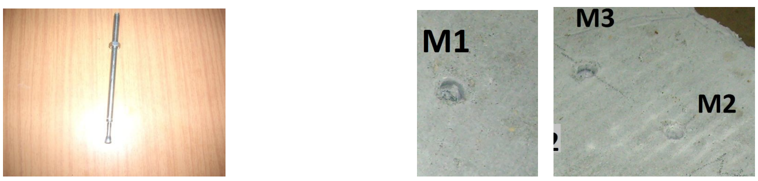
During tests were recorded for each anchor in part for both type of anchors, the tensile forces (or tearing) and displacements until their disposal, the lost bearing capacity and failure mode.

Table 4

Summary Table with Failure Load of Anchors, Compression Specimen Load and Failure Modes Tested in Non-Cracked and Compressed Concrete

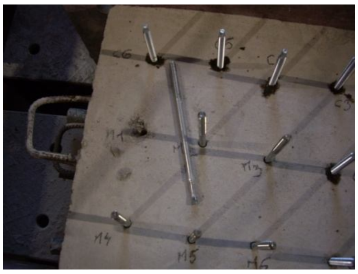
Uncracked concrete			**Compressed concrete**				
Type	Failure load (kN)	Failure mode	Test order	Type	Compression force applied to specimen (kN)	Failure load (kN)	Failure mode
M1	16,59	rod sliding through sleeve, sleeve remaining inside specimen	1	M1	156,66	26,07	rod sliding through sleeve, sleeve remaining inside specimen
M2	13,86	rod sliding through sleeve, sleeve remaining inside specimen	2	M2	156,36	20,82	rod sliding through sleeve, sleeve remaining inside specimen
M3	14,82	rod sliding through sleeve, sleeve remaining inside specimen	3	M3	156,12	11,04	rod sliding through sleeve, sleeve remaining inside specimen
			12	M4	150,42	13,89	rod sliding through sleeve, sleeve remaining inside specimen
			11	M5	150,54	17,43	rod sliding through sleeve, sleeve remaining inside specimen
			10	M6	150,72	14,61	rod sliding through sleeve, sleeve remaining inside specimen
C1	20,79	rod failure	9	C1	151,44	12,57	bonding failure between mortar and concrete, specimen had little crush in that area
C2	17,64	bonding failure between mortar and concrete	4	C2	153,90	19,65	bonding failure between mortar and concrete
C3	21,12	rod failure	5	C3	153,06	10,11	bonding failure between mortar and concrete, specimen had little crush in that area
C4	19,92	rod failure	8	C4	151,92	18,75	bonding failure between mortar and concrete
			7	C5	152,22	20,46	little bonding failure between mortar and concrete followed by rod failure
			6	C6	153,06	17,94	bonding failure between mortar and concrete with a concrete cone failure

Regarding the failure mode of mechanical anchors in non-cracked and compressed concrete is almost identical and can be seen in Figs. 9 and 10.



a) b)

Fig. 9 – 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.



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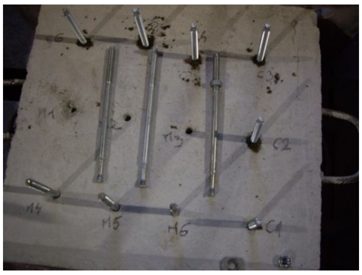

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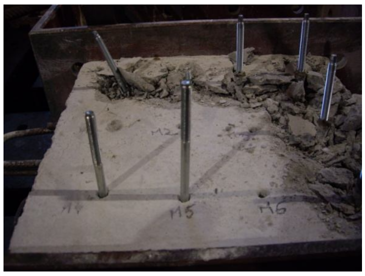
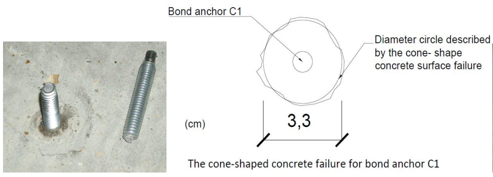


d)

Fig. 10 – Failure mode of bolt anchors: a) M1; b) M2, M3; c) M4; d) M5, M6 in compressed reinforced concrete.

For bonded anchors, failure mode is different and it is illustrated in Figs. 11 and 12.



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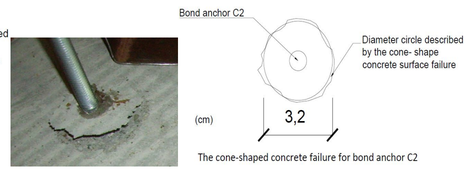

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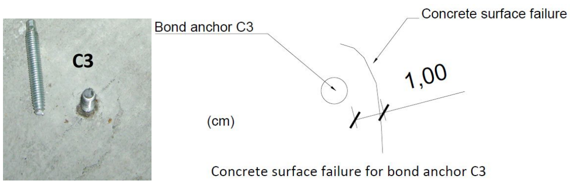

c)

d)

Fig. 11 –Failure mode of bonded anchors: a) C1; b) C2; c) C3; d) C4 in non-cracked reinforced concrete specimen.

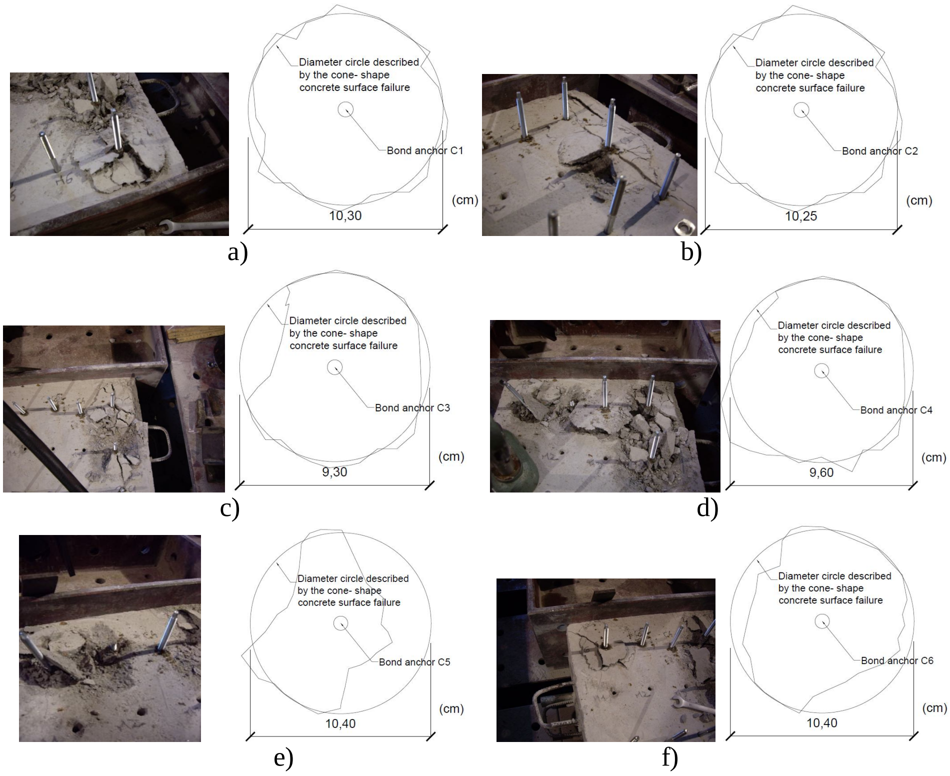

Fig. 12 – Failure modes of bonded anchors: a) C1 to f) C6 and specimen failure, with a schematic representation of the concrete cone failure inscribed in a circle.

According to recorded data it has been drawn the load-displacement curves that Fig. 13.

3. Conclusion

Bolt anchors

1. For anchor tested in compressed concrete specimen the failure mode is identical in comparison with anchors tested in specimen with no stress state mode, that is rod sliding through sleeve, sleeve remaining inside specimen.

2. Maximum load capacity of anchors tested to pull-off in compressed concrete are mostly higher, about 15% higher on average.

$$N_{u\,(\text{uncracked compressed concrete})} / N_{u\,(\text{uncraked concrete})} = 17.31 \text{ kN} / 15.09 \text{ kN} = 1.15,$$

where: $N_{u\,(\text{uncracked compressed concrete})} = (26.07 \text{ kN} + 20.82 \text{ kN} + 11.04 \text{ kN} + 13.89 \text{ kN} + 17.43 \text{ kN} + 14.61 \text{ kN})/4 = 17.31$ kN – pull-out failure load average of bolt anchors installed in non-cracked concrete compressed with 150 kN load and a normal tensions of 23.81 daN/cm^2; $N_{u(uncraked\ concrete)}$ = (16.59 kN + + 13.86 kN + + 14.82)/3 = 15.09 kN – pull-out failure load average of bolt anchors installed in non-cracked concrete.

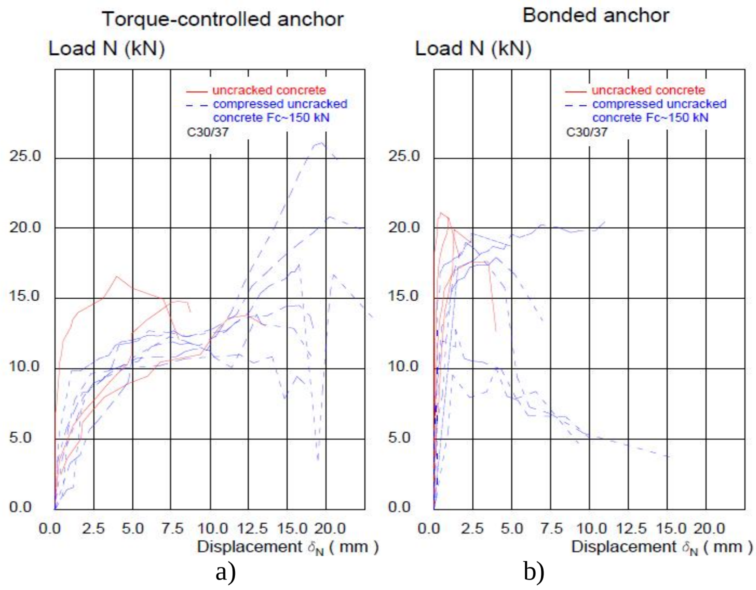

Fig. 13 – Load-displacement curves for a) bolt anchors (M8, h_{ef} = 4,5 cm) and b) bond anchors (M8, h_{ef} = 8 cm), in non-cracked and compressed reinforced concrete with a load of compression of 150 kN.

For a concrete class C30/37 with a compressive strength of R ~ 370 daN/cm^2 in tested cases, the bearing capacity of anchors in compressed concrete can reach an increase of 15% more than anchors tested in uncompressed concrete for a ratio of s/Rc = 0,06

where: s=N/A=15000daN/ 18cm*35cm = 23,81 daN/cm^2

3. Bolt anchors displacements are higher in case of compressed specimen, about 15,…,17 mm, than uncompressed specimen with values of 8,…,12 mm, after the static friction is exceeded, the resistance drops and sliding friction occurs, then in most cases there is an additional strength reserve before finale failure for anchors tested in compressed concrete.

Bond anchors

1. Failure modes of bonded anchors in compressed specimen with a force in one direction of 150 kN occurs mostly by failure between mortar and wall of drilled hole with a surface destruction most often by concrete cone failure.

2. Excluding anchors C1 and C3, ultimate load failure for anchors tested in compressed concrete are identical to those tested in concrete without any state stress mode, average load for the two cases is nearly similar.

$$N_{u\,(\text{uncracked compressed concrete})} / N_{u\,(\text{uncraked concrete})} = 19.20\text{ kN} / 19.86\text{ kN} = 0.97$$

where: $N_{u\,(\text{uncracked compressed concrete})}$ = (19.65 kN + 18.75 kN + 20.46 kN + 17.94 kN)/4 = 19.20 kN; $N_{u\,(\text{uncracked concrete})}$ = (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.

3. Regarding the displacements in general, in the moment of the highest load registered, it reach around same values 2,5mm, curves looking like idealized curves of the case a) (C2, C3, C5 and C6) and d) (C1, and C4) of Fig. 2, recording a reserve of strength until failure with displacements slightly higher before collapsing than anchors tested on uncompressed concrete.

Compared to metal anchor, the behavior of bonded anchors is more predictable in terms of strength and displacements, but the failure mode occurs with the destruction of the concrete element.

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COMPORTAREA ANCORELOR MECANICE ŞI CHIMICE ÎN BETON ARMAT NEFISURAT ŞI COMPRIMAT PE O DIRECȚIE

(Rezumat)

Se prezintă un studiu comparativ a ancorelor mecanice şi chimice privind comportarea la smulgere pe epruvete de beton armat nefisurat fără nici o stare de solicitare şi pe epruvetă de beton armat solicitat la compresiune pe o direcție, 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 în cazul ancorelor testate capacitatea portantă a ancorelor mecanice precum şi deplasările înainte de cedare sunt mai mari pe element comprimat iar pentru ancorele chimice este aproximativ identică cu deplasări uşor mai mari decât cele testate pe beton armat nefisurat dar cu un mod de cedare distructiv. Acest studiu face parte din evaluarea comportării ancorelor pe diferite situații de stare a epruvetelor de beton armat: nefisurat, fisurat, comprimat şi întins fără fisuri.