

Performance of expansion and bonded anchors installed into concrete in comparison to limestone and granite

M. Tóth, V. Hlavička, É. Lublóy, Á. Török & G. L. Balázs
University of Technology and Economics, Budapest, Hungary

ABSTRACT: There are uncertainties related to the usage of post-installed anchors in natural rocks. This study was performed in order to describe the properties of steel-natural rock connections. 93 pull-out tests were implemented, focusing on tension capacity of anchors. Three post-installed anchors were selected: fischer FBN II 8/50 (expansion anchor), fischer FIS EM epoxy and FIS V vinylester hybrid (bonded anchors). Five different strength classes of concrete from C20/25 up to C55/67; two types of freshwater limestone blocks – Süttő, Hungary (H) -, and a Spanish granite - RosaBeta - were tested. This study emphasizes the influence of apparent/primary porosity and the effect of freeze-thaw test on the performance.

1 INTRODUCTION

1.1 The aim of this study

An increasing number of connections between natural rocks and anchors are used, therefore the behaviour of these special solutions should be described. Mostly, a local *in situ* pull-out test is required before attaching temporal or even final structures to rocks. This procedure serves to predict the resistance of selected anchorages, the load-transfer method and the embedment depth. In practice, engineers prefer the application of bonded anchors in rocks, due to the possible inhomogeneities and variable pore-sizes in the rock matrix system. The connections currently used are typically over-engineered for structural safety, thus they lack efficiency and cost competitiveness. The aim of this study is to characterise the steel-rock and steel-concrete fastenings through numerous pull-out tests, to determine force-displacement curves. Destructive and non-destructive methods were used to find the relationship between the critical pull-out force and the measured parameters.

1.2 Overview of fastenings

Two main groups could be distinguished between anchors, cast-in-place and post installed. Cast-in-place anchors are as follows: pigtail and all-thread anchors, steel rebars, L-bolts and J-bolts. These connections are formed at the same time as the base material. Most designs consist of a special head, and cast in the concrete before it sets.

Several post-installed anchors are available for load-transfer. Figure 1 shows the load-transfer methods. In case of expansion anchors the load is transferred by friction, in undercut anchors by mechanical interlock, chemical fixings are anchored by bonding. In addition, bonded anchors can be divided into two subgroups: installation by glass capsule or injection cartridge. The acting loads are transferred from the metal part (normally a threaded rod) into the bonding material and are anchored by bonding between the bonding material and the sides of the drilled hole into the concrete (Fiestel et. al 2002).

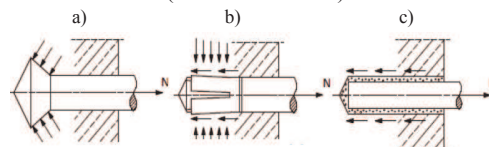


Figure 1. Load transfer methods: mechanical interlock (a), friction (b), bonding (c)

1.3 Failure methods

The following types of failures were noticed with the anchorages under tension: cone, pull-out, steel failure and concrete splitting (Figure 2.). The type of failure mostly depends on the strength properties of the materials and their condition (un-cracked or cracked etc.). It is recommended, that the tension load-bearing capacity of the anchorages, the strength of the material and the shrink resistance of mortar between anchor and material would be nearly equal, and so all the materials in the connections would be fully exploited (Nemes & Lublóy, 2011). According

to the CC (Concrete Capacity)-Method, the cone failure is an ideal status, where the concrete strength is completely utilised.

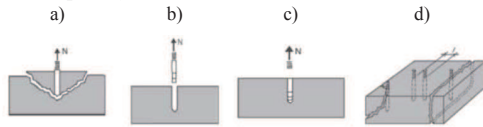


Figure 2. Failure methods: Cone (a), Pull-out (b), steel failure (c), splitting (d)

Concrete cone failures can be either full cone or partial cone. When the formation of a full cone is restricted by the high flexural strength of host material, the shearing of the bonding material may lead to a partial cone failure.

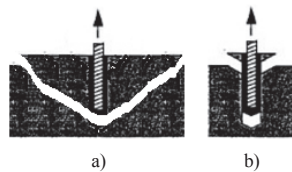


Figure 3. Cone failures – full (a) and partial cone (b)

2 TESTED MATERIALS

2.1 Tested post-installed anchors

A torque controlled expansion anchor (Fischer FBN II 8/50 gvz) and two bonded anchors were tested (Fischer FIS EM epoxy and FIS V vinilesterhibrid)(Figure 4). Both anchors were installed according to the instructions given by “The Guideline for European Technical Approval of Metal Anchors for Use in Concrete” (EOTA, 2007, Technical Report 29). The embedment depth was 50mm uniformly, and the diameter of anchors and threaded rods were 8 mm.

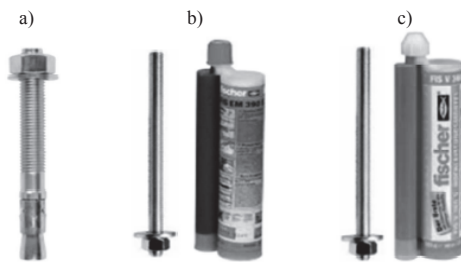


Figure 4. Tested anchors: Expansion anchor (a), bonded anchors (b-c)

2.2 Concrete mixtures

The composition of the tested concrete mixtures are shown in Table 1. All mixtures were made with NPC (CEM I 42.5 N).

The aggregates were natural quartz sand and quartz gravel, and the superplasticiser was BASF Glenium C323 Mix. From the mixtures 45 specimens of 300x300x100mm were formed, held under water for two days, then kept at the ambient temperature level of 20°C for 28 days (Figure 5). Further 4 cubic specimens of 150 mm and 3 specimens of 70x70x250 mm from each mixture were tested to determine the flexural and compressive strength properties. Concrete samples of increasing strength C20/25 C25/30 C40/50 C45/55 C55/67 were prepared for the pull-out tests. The geometry of concrete specimens were chosen with minimum uniformed dimensions, so all potential failure modes could occur during the tests.

Table 1. Composition of concrete mixtures

No.	Aggregates			cement kg/m ³	waterchemical	
	0/4	4/8	8/16		kg/m ³	kg/m ³
C20/25	833	463	556	290	196	0.58
C25/30	833	463	556	310	189	0.62
C40/50	833	463	555	365	170	2.60
C45/55	833	463	555	390	160	3.90
C55/67	833	463	555	410	152	6.20

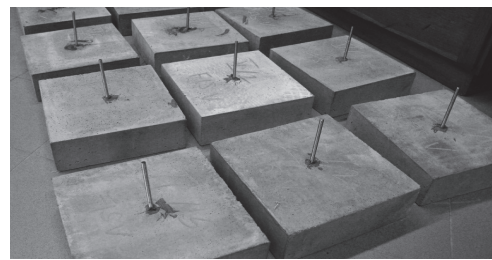


Figure 5. Concrete specimens for pull-out tests

2.3 Natural stone specimens

Three different types of natural stones were studied. Two types of freshwater limestone (Gazda-quarry and Haraszti-quarry, Süttő, Hungary) and granite (RosaBeta, Spain) (Figure 6). Lime stones are frequently used as external cladding. The sampled limestone blocks were relatively uniform. The bulk density of limestone was in the range of 2.65-2.70 g/cm³. The granite is a less porous material with nearly the same bulk density, a frequently used stone in practice. The dimensions of tested rock specimens were 250x200x100 mm and 400x200x100 mm, thus the required edge distance and thickness was assured.

3 TEST METHODS

3.1 Pull-out tests

The setup of the measurement arrangement is shown on Figure 7. The loading device is a displacement controlled machine, thus the residual stress can be measured after failure. The self-designed framework



Figure 6. Granite and limestone blocks for pull-out tests.

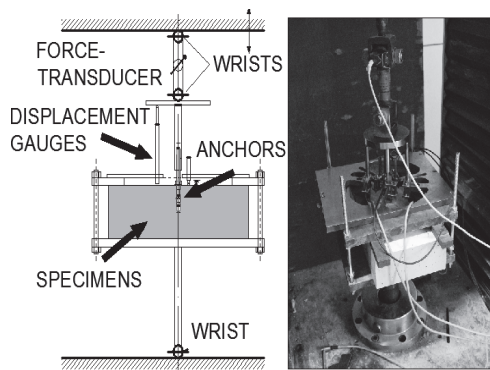


Figure 7. Arrangement of pull-out tests.

was produced by Dept. on Manufacturing Sciences and Technology, Budapest University of Technology and Economics.

This setup was assembled to provide all possible failure methods without any geometrical reductions. The measuring kit can be applied to determine the force-displacement curves of the connections focusing on central tension capacity. The perpendicular pin-joints allow the central position of the acting force. The overall displacement was measured by two gauges, the deformation of the surface was measured with three other independent displacement gauges. The acting force was metered by a calibrated force transducer. All channels were recorded by CATMAN® software through a Spider8 data acquisition device.

3.2 Apparent porosity

The test is based on the water-absorption capacity of specimens. The volume of absorbed water is indicative of the volume of air contained in the specimens. First, the stone blocks and concrete samples were oven dried until constant weight was achieved. Having established their dry weight, they were stored in

water. The weight measurements were repeated after the intervals of 1,24,48,72 hours. Finally, the apparent porosity could be calculated by the following equation (1). The measurements were carried out according to EN 13755:2008.

$$p_{por.ty} = \frac{v_w}{v} = \frac{M_w / \rho_w}{M / \rho_T} = \frac{n^{m/m\%}}{100} \rho_T = \left[\frac{V}{V'} \% \right] \quad (1)$$

3.3 Compressive strength

Compressive strength is the most indicative parameter on the performance of anchorages. The strength calculation uses the compressive strength as a primary parameter for the determination of anchor's capacity. The tests were carried out on concrete cubes at 28 days, and Ø50mm 100mm high cylinders on rocks. The results were evaluated in accordance with EN12390 -3:2009 for concrete and EN1926:2007 for stones respectively.

3.4 Flexural strength

The purpose of these measurements is to establish the boundary between the partial and full cone failure as a function of flexural strength. The determination of flexural strength under constant bending moment was carried out on 3 samples of 70x70x250mm from each concrete mixture. The tension resistance was calculated. This process was also implemented on rocks by applying 25x40x200mm specimens. The results were processed according to EN 12390-5:2009 for concrete and EN13161:2008 for rocks.

3.5 Durability tests

In this study, the effect of freeze-thaw tests were measured by ensuring accelerated weathering conditions. The specimens – with the previously installed anchors – were put in the freezer and were subjected to temperature load. 50 cycles of freeze-thaw cycles were performed. One cycle consisted of freezing down to -20°C for 6 hours and melting at +20°C for 6 hours. The pull-out tests were carried out before and after the durability tests.

The summary of pull-out tests and the number of tested specimens are given in Table 2-4.

Table 2. Pull-out tests on concrete

No.	Exp. anchors	epoxy	vinylester hybrid
	pc.	pc.	pc.
C20/25	3	3	3
C25/30	3	3	3
C40/50	3	3	3
C45/55	3	3	3
C55/67	3	3	3
Σ	15	15	15

Table 3. Pull-out tests on rocks – normal conditions

No.	Exp.anchors	epoxy	vinylester hybrid
	pc.	pc.	pc.
Limestone (Gazdabánya)	3	3	3
Limestone (Harasztibánya)	3	3	3
Granite (RosaBeta)	3	3	3
Σ	9	9	9

Table 4. Pull-out tests on rocks – after freeze-thaw test

No.	Exp.anchors	epoxy	vinylester hybrid
	pc.	pc.	pc.
Limestone (Gazdabánya)	1	3	3
Limestone (Harasztibánya)	1	3	3
Granite (RosaBeta)	1	3	3
Σ	3	9	9

4 TEST RESULTS

4.1 Typical failure curves

At steel failure, the force-displacement curve can be matched to the typical σ - ϵ curve of cold-rolled steel's failure process under tension (Figure 8.). It was observed that this failure occurs in case of expansion anchors when the compressive strength of material is at least 50 MPa. The mean value of resistance is 16.8-17.0 kN. The critical cross-section of failure is the reduced cross-section. The following curve belongs to the FBN II expansion anchor (Figure 8.), hence this failure can also be noticed in case of bonded anchors.

Both partial and full cone failures are shown on Figure 9. The left line symbolises the "undisturbed" cone (C20/25), it originates from the deepest point of the embedment depth. This failure means that the concrete/rock tension resistance is reached on the surface of the cone, and the concrete/rock's strength is fully utilised. The right line represents the partial cone failure, combined with pull-out. The residual stress after the failure is significant, the maximal load is 3 times higher than then the force related to the cone failure. The residual part is the result of the bonding agent.

As for expansion anchors, the pull-out failure is caused by the improper installation, inadequate embedment, incorrect installation-moment, wrong preparation of drilled hole etc. The force-displacement curves of bonded anchors are steep. The best performance belongs to epoxy mortars of the investigated steel-rock connections (29.5kN-granite, Figure 10.). The failure happens suddenly without residual part. When the critical bonding re-

sistance between the bonding material and the surface of the drilled hole is reached, the pull-out failure is imminent. The failure may also be caused by reaching the shearing resistance of bonding material. Moreover, the combination of these reasons can also be noticed (Figure 11.).

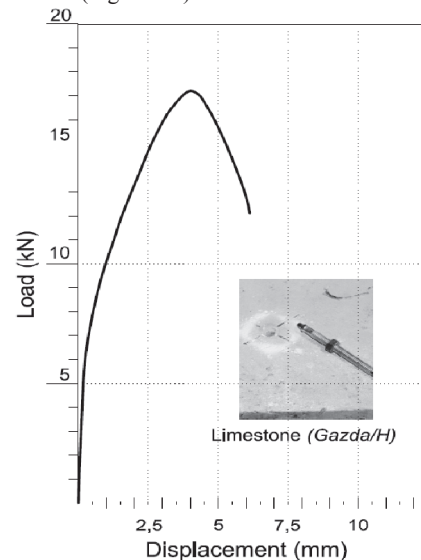


Figure 8. Typical steel failure curve

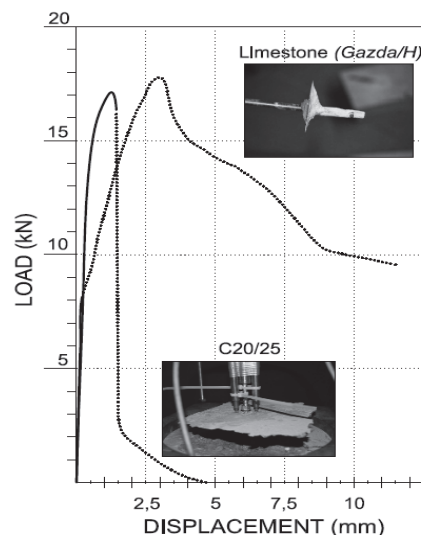


Figure 9. Typical cone failure curves (partial and full cone)

4.2 Relationship between the pulling force and compressive strength

In case of torque controlled expansion anchors(FBN II 8/50), when the material's strength exceeds 50

MPa, steel failure will be inevitable. The same trend can be observed in case of stones. When the strength of host material is less than 50 MPa, cone failure may appear. Cone failures in rocks were not experienced during the tests in case of expansion anchors, as all rocks had compressive strength greater than 50 MPa. For greater than 50 MPa strength the characteristic curves for rocks and concrete are very similar. On Figure 12-15 each indicated point is the mean value of 3 pull-out tests. The host material's strength values are the mean values of previous tests.

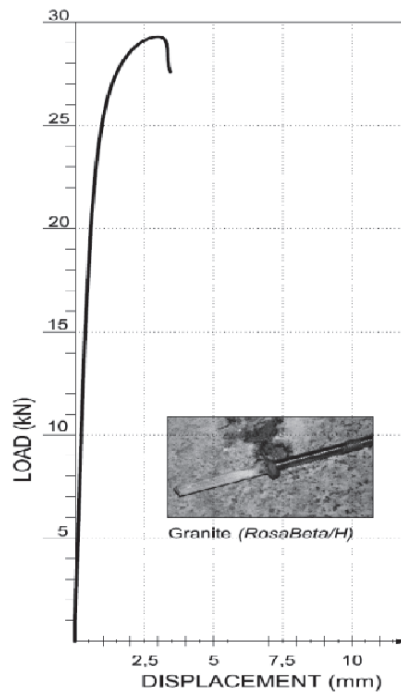


Figure 10. Pull-out failure curve

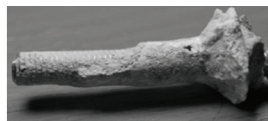


Figure 11. Combined failure

The behaviour of epoxy mortar is remarkably different. According to the EOTA Technical Report 029 design method, only the compressive strength and the previously mentioned geometric parameters affect the performance of bonded anchors. As for the concrete, there is a roughly linear relationship between the compressive strength and the pull-out force. The better the strength of the material, the greater the load-bearing capacity. Figure 13 shows that the forces related to the rocks do not show the same trend as the ones from concrete. Thus, it is obvious that not only the compressive strength influences the

capacity of the connection. Consequently, other physical parameters are required for complete analysis.

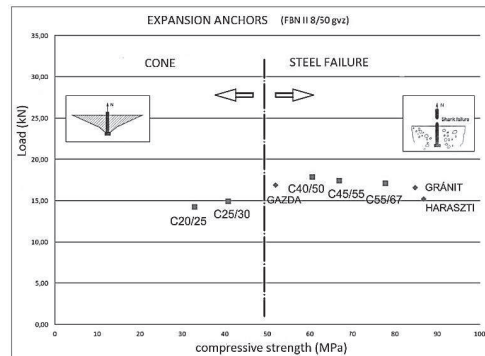


Figure 12. Critical force - Compressive strength of concrete and stone

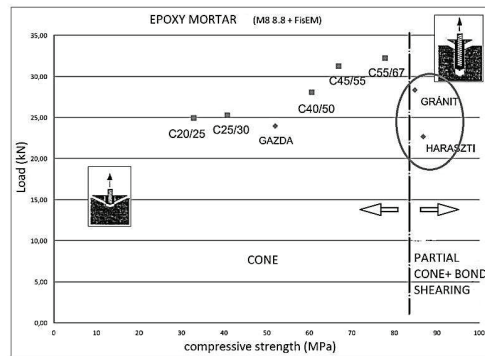


Figure 13. Critical force - Compressive strength of concrete and stone

4.3 Relationship between the pulling force and flexural strength

Our tests have shown that the failure type can be a function of the flexural strength. As it is mentioned, the cone failure is a result of over-loading the tension resistance of materials. When 13 MPa flexural strength is reached the partial cone failure dominates (Figure 14.).

4.4 Importance of primary porosity on performance

In case of expansion anchors the porosity does not seem to affect the performance. As for the bonded anchors the apparent porosity has significant impact on the connection's capacity. The more porous the material, the higher tension resistance it has related to epoxy mortar. The less porous rocks (<2%) have the highest compressive strength of all investigated specimens. Hence, those connections show higher resistance which were installed into the lower

strength – but more porous (>6%) – concrete blocks. Therefore, Figure 15 clarifies the influence of porosity on the performance of bonded anchors.

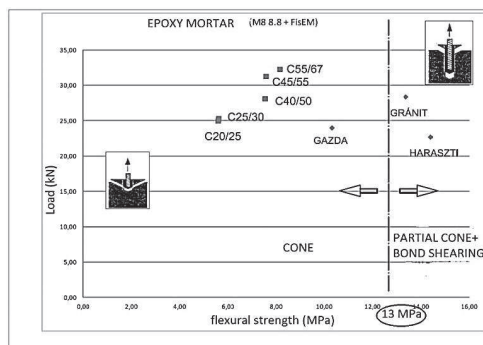


Figure 14. Critical force – flexural strength of concrete and stone specimens

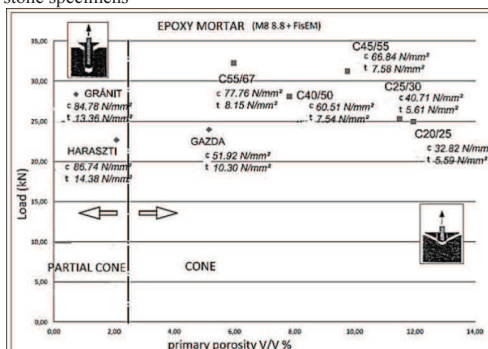


Figure 15. Critical force – apparent porosity of concrete and stone specimens

5 CONCLUSIONS

In this experimental study, 93 pull-out tests were carried out focusing on central tension capacity of post-installed anchorages. Force-displacement curves were determined to get a valuable, preliminary concept of the investigated anchors, to clarify the uncertainties related to the usage of anchors in rocks. The correlations between other physical parameters that can affect the performance of concrete-steel and rock-steel connections have been outlined. It is obvious that not only the compressive strength have influence on the connection's resistance as it is shown in TR 029 – Technical Report- EOTA. The flexural strength can also modify the failure type, the residual part of these connections is notable if the material's flexural strength is high (>13MPa). The failure load in granite (low porosity but high strength) was lower than the failure load in materials with lower strength but higher porosity. The freeze-thaw cycles did not influence significantly the per-

formance of the tested anchorages. The apparent porosity has a different influence on the critical force of concrete and natural stone. The roughness of the surface of drilled hole also affects the resistance of bonded anchors, which is a function of the drilling method. In the future, more pull-out tests will be implemented focusing on same strength concrete with different porosity, and the roughness of surface will be measured.

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