THE REAL BEHAVIOUR OF STEEL BONDED ANCHOR – EXPERIMENT AND NUMERICAL MODEL

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Abstract: *This article is focused on problems of steel bonded anchors real behaviour. Paper describes the procedure and actual results of experiments. The experiments were carried out using the specimens with different anchor diameter and different concrete cubic strength. This article also illustrates verification possibilities, in this case using numerical model created in ATENA software. Further, the present results of another experiment in which the same type of specimen was exposed to the long-term action of axial tension force are shown as well.*

Key words: *steel bonded anchor, bearing capacity, failure type, experimental analysis, anchorage length, numerical modelling.*

1. INTRODUCTION

The systems with the steel structure anchored into the concrete foundation by steel bonded anchorage elements are more often used in recent years. This system of anchorage can be used both in realization of new steel structures and in its reconstructions. It is possible, in dependence on used type of anchors, to apply this anchorage in all concrete strength classes in common use. In comparison with pre-installed anchors, the serious reduction of time in which the installed anchor is able to transfer a load from steel structure into the concrete foundation is the main advantage of this system. Additionally shouldered bonded anchors are as a rule installed as a steel threaded rod inserted in a previously drilled slot which has a diameter of 10-20% larger than the anchor. The interaction between the steel anchor and the concrete base is usually interlocked by the polymer glue. The safety of the anchorage is given not only by the properties of the steel anchor but also by the properties of the basic material. The properties of the basic material (usually concrete or masonry) as well as the properties of the contact material have normally a considerable scatter and their characteristics are not as a rule uniquely determined. A relative position of anchors, therefore their spacing, has a great effect on the real bearing capacity of the couple of bonded anchors.

2. BEHAVIOUR OF STEEL BONDED ANCHORS UNDER LOAD

Function of steel bonded anchor is very similar to the function of steel rod embed in concrete. However, verification of this predication is very difficult. Photoelasticimetry can be one of the simple way how to approximately monitor the load transfer process. Photoelasticimetry takes advantage of some materials (e.q. acrylic-glass) witch under load

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changes isotropic properties to crystallic. On this change are the optic axes identical to the axes of principal stress.
This effect called temporally double refraction can be watched in polarized light. Figure 1 shows the test with one anchor bonded in acrylic-glass. Anchor with diameter 10 mm was loaded by tension force about 25 kN. The bonded anchor transfers load with major part of its surface. The mechanical anchor [5] transfers load only around the spacing rod.

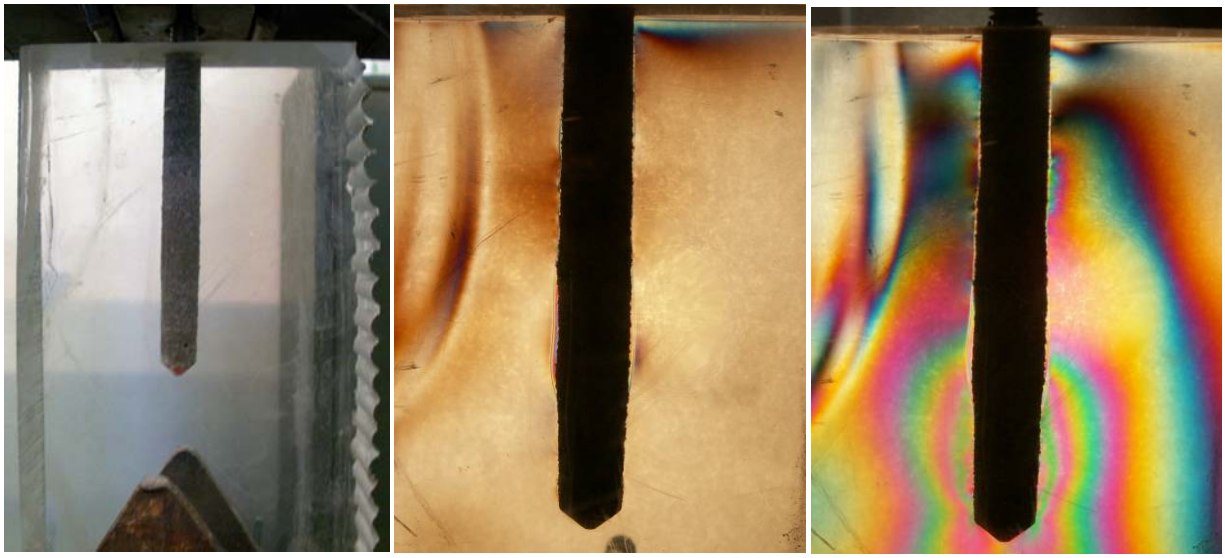

Fig.1. *Photoelasticimetry – anchor bonded in acrylic-glass loaded by tension force*

3. BEARING CAPACITY OF BONDED ANCHORS

The ultimate bearing capacity at failure by the rupture of the steel bolt in the area weakened by the thread can be set up by the expression

$$N_u = k_s \cdot A_s \cdot f_{ub} \qquad (1)$$

A_S is area of the bolt and f_{ub} is the ultimate strength. Coefficient k_S = 1 for mean value of bearing capacity [2].
The ultimate bearing capacity at failure by the extraction of the steel bolt from the concrete can be set up according to [3], [4] by the expression

$$N_u = \tau_d \cdot \pi \cdot d \cdot h_{ef} \qquad (2)$$

τ_d is an ultimate stress on the interface between the steel and glue or between the glue and concrete, d is the diameter of the steel anchor, h_{ef} is an efficient anchorage depth.
So far, the ultimate bearing capacity at failure by the extraction of the concrete cone has not been uniquely defined (from the point of view of mathematics) for the bonded anchor type.

$$N_u = f\left(k, f_{cc}, h_{ef}, d\right) \qquad (3)$$

the coefficient k depend on the shape of the extracted cone surface and include scatters of the basic mechanical and geometric magnitudes biasing the bearing capacity, f_{cc} cube strength of concrete, h_{ef} is effective anchorage length. The failure process in this case can be educed from realised experiments. By opening of the main crack the load moves to the bottom of the anchor. This leads to the failure of bond cohesion between the contact material and concrete.

4. EXPERIMENTAL ANLYSIS

In the first set of experiments, the anchors HILTI type HVA+HAS with diameter 10 and 12 mm shouldered to the concrete body with dimensions 500x400x250 mm were tested. The cube

strength in compression of used concrete is summarized in ***tab. 1.*** The tensile yield strength and ultimate tensile strength of HAS steel screw is in ***tab. 2.*** (Producer's rating is *fy* = 400 MPa; *fu* = 500 MPa)

set	Average f_{cc} [MPa]	deviation
1	18,9	1,3
2	26,9	0,4
3	46,2	1,3

Tab.1. *Concrete strength in compression*

Steel bolt	s1	s2	s3	average value [MPa]
fy	634,0	581,0	586,0	**601,0**
fu	810,0	754,0	768,0	**777,0**

Tab.2. *Steel bolt strength parameters*

For the loading as such, the hydraulic press KGF H50 - 75 with the general rating of 500 kN at 75 mm cylinder stroke is used. For the tension force measuring, the strain gauge ventricular dynamometer PD 500 (rating 500 kN, sensitivity 1 kN) is used. The displacements (anchors pulled out from concrete block) are measured by the help of inductivity track sensors HBM WA/2 T with the range of 2,0 mm and sensitivity of 0,001 mm. Electrically measured magnitudes are continuously scanned by the central measuring station HBM SPIDER 8 with 10 Hz saving frequency [1]. The measuring system is shown in ***fig.3.***

Fig. 3. *Measuring system*

For formulation of function describing bearing capacity of steel bonded anchor in failure by concrete cone extraction, is necessary to determine the influence of basic parameters. The anchorage length is one of them. There have been specimens with single anchor HILTI type HAS+HVU, diameter 12mm shouldered into the concrete (f_{cc} =26,9 MPa) in lengths from 40 to 110 millimetres tested. Range of these lengths depends on anchor type as well as on concrete strength. By lengths larger then 110mm, the failure of steel bolt occurred in this configuration. Reached failure types in experiments are in **fig. 4.** Results are shown in **fig. 7.** None of these experiments was ended by the failure due steel bolt extraction. This failure type can occur by using anchors with great diameter and high-strength concrete. Properties of contact material are presented in [1].

Fig. 4. *Failure types reached in experiments*

Also the experiment with the same type of anchor exposed to the long-term loading by tension force has been performed. The tension force has been applied and kept by special spring preloaded by hydraulic press **fig.5**. Deformation was measured on the top of the steel screw. The history of anchors loading and actual results of this experiment are shown in **fig. 8, 9.**

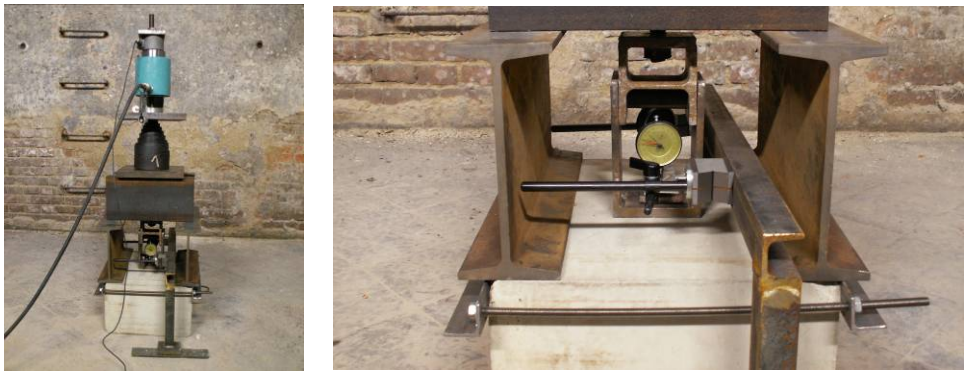

Fig. 5. *Experiment with long-term loading of steel bonded anchors*

5. NUMERICAL MODELLING

For assembling of numerical model of steel bonded anchor shouldered in concrete, the rotary symmetry mode of Atena software has been used. As material model, the preset 3d non-linear cementitious model generated by custom cubic compressive strength was chosen. The solution could be improved by entering other properties of concrete. Calculation is done by standard Newton-Rhapson method.

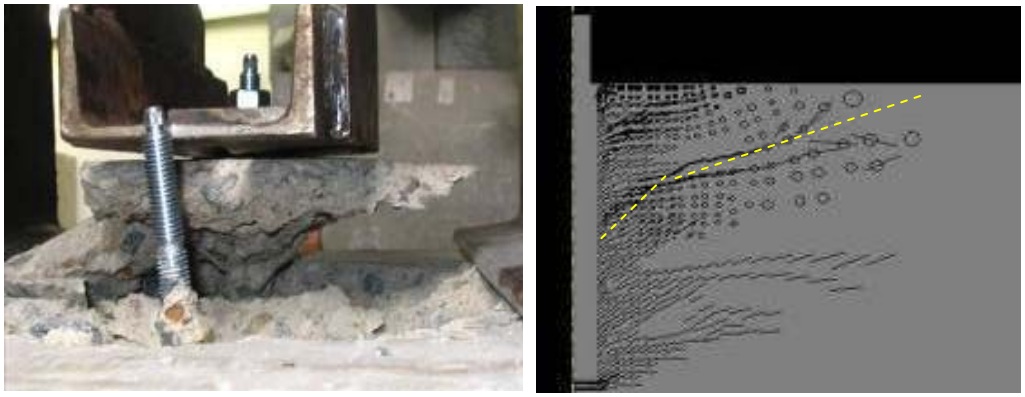

Fig. 6. *Concrete cone extraction*

Anchor is loaded in each step by vertical deformation of 0,025 mm. Maximum number of iterations is set to 40. Bond between contact material and concrete is defined by contact element with defined cohesion. Mesh size is approximately equal to the dimension of coarse aggregate of concrete. Failure due concrete cone extraction is shown in **fig. 6**

6. RESULTS

Model is assembled for average characteristic properties of materials. Results from experiments have due inhomogeneity of concrete and variance of material properties greater variability. Comparison between one of experiment configuration and adequate model as well as results of experiments with different anchorage length is shown in ***fig. 7.***

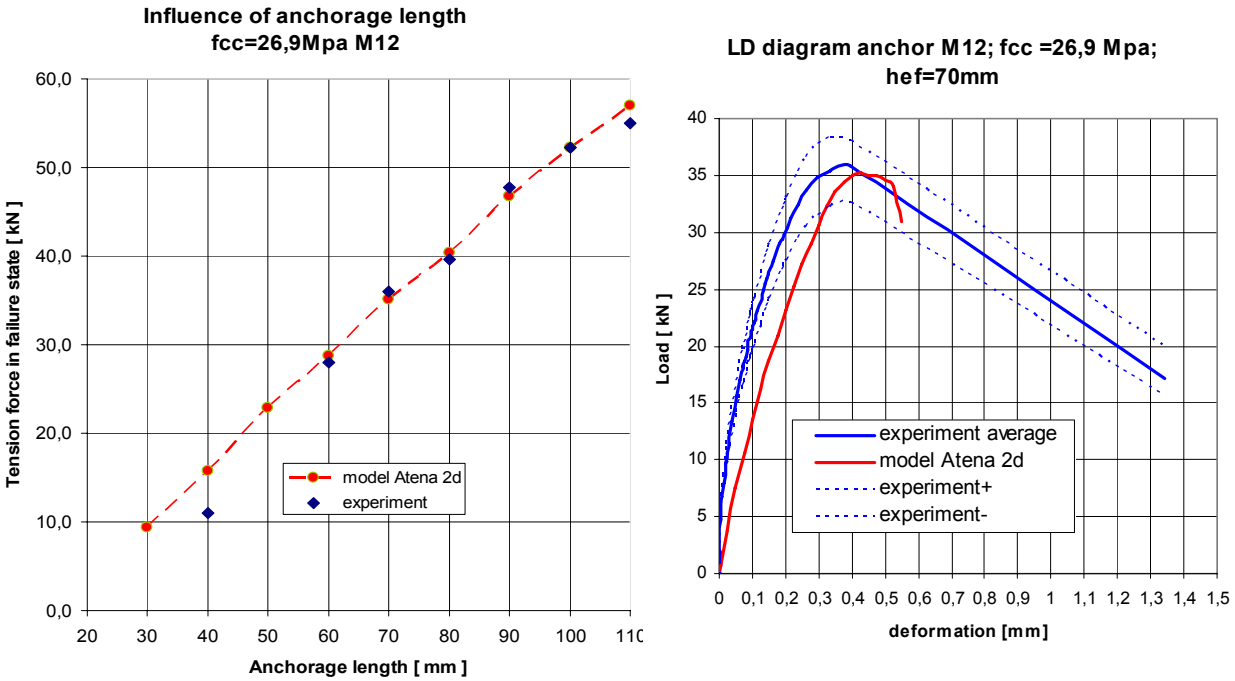

Fig. 7. *Comparison of results, model-experiment*

Actual results from experiment with long-therm loaded anchor are shown below.

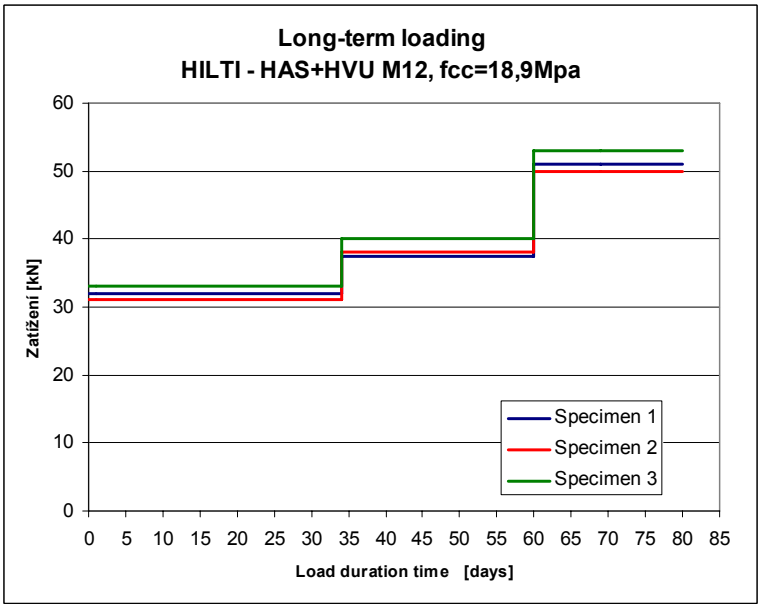

Fig. 7. *Long-term loading of anchors*

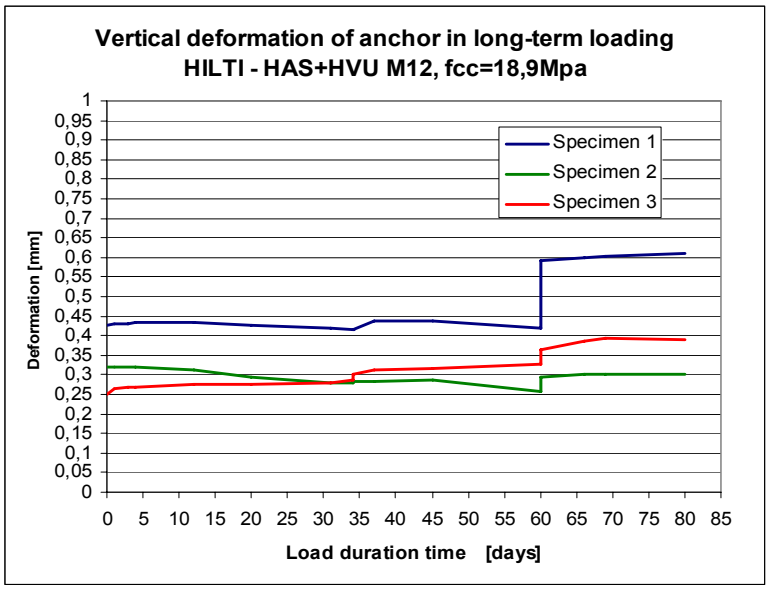

Fig. 8. *Deformation of anchor in Long-term loading*

These experiments validated the stable behaviour of steel bonded anchor under load closing the ultimate bearing capacity. The downtrend of deformation measured on the top of the anchor can be explained by deformation of bottom surface under the concrete specimen.

7. CONCLUSIONS

From few presented results can be gathered that the influence of anchorage length on bearing capacity by failure due concrete cone extraction is linear. The research of influence of particular parameters on steel bonded anchor bearing capacity still continues, as well as the experiment with long-term load. Another research focused to influence of distance between anchors is in progress. There are also numerical models in Atena 3D assembled.

ANNOUNCEMENT

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REFERENCE BOOKS:

1. Bajer, M., Kala, J., Barnat, J. Steel chemical members anchored in concrete, *Proceedigs of the Eighth International Conference on Computational Plasticity held in Barcelona, Spain,* Barcelona 5.-7.9.2005
2. Karmazínová M., Bajer M.: Utilization of experiments for comparison of actual behaviour of some types of post-installed steel fastening members to concrete, *Proceedigs of the Conference EXPERIMENT 04*, Faculty of Civil Engineering of Brno University of Technology, 10.2004
3. Fastening to Reinforced Concrete and Masonry Structures, State-of-art-report, CEB, *Bulletin d'Information*, Thomas Telford Services Ltd., 1994
4. Eligenhausen, R. (editor) *Proceedings of the International Symposium „Connections between Steel and Concrete"*, University of Stuttgart, RILEM 2001,ISBN 2-912143-25-X.
5. Schmid P.: Problémy navrhování zesílení ŽB nosníků lepenou ocelovou výztuží, Disertační práce , VUT v Brně ,1999