VI International Conference on Adaptive Modeling and Simulation
ADMOS 2013
J. P. Moitinho de Almeida, P. Díez, C. Tiago and N. Parés (Eds)

GLUE-CONCRETE INTERFACE OF BONDED ANCHOR – EXPERIMENT AND MODEL

JAN BARNAT*, MIROSLAV BAJER†

* Faculty of Civil Engineering, Brno University of Technology, Institute of Metal and Timber Structures, Veveří 95, 602 00 Brno, Czech Republic, barnat.j@fce.vutbr.cz, http://www.fce.vutbr.cz

† Faculty of Civil Engineering, Brno University of Technology, Institute of Metal and Timber Structures, Veveří 95, 602 00 Brno, Czech Republic, bajer.m@fce.vutbr.cz, http://www.fce.vutbr.cz

Key words: Bonded anchor, Tensile load, Bond stress, Experiments, Numerical Modeling, Contact,

Abstract. This paper considers the practical application of nonlinear models in the analysis of an anchor bolt additionally placed in a concrete specimen. The model also considers epoxy surface. The results of analyses performed using the concrete model of specialized Atena 3D finite element code are presented and discussed. The mesh density and convergence stability are compared in single anchor case study. All model results are compared with experimentally obtained data. There are also experiments focused on bond stress presented which are very important for verification of model assessment. The article is focused on problems of post-installed steel bonded anchors real behaviour. Experiments and numerical models described in this paper are focused on problems of bond stress quality, on anchor joint loaded by tension force.

1 INTRODUCTION

The development of a model for the behaviour of concrete is a challenging task. Concrete is a quasi-brittle material and has different behaviour in compression and tension. The tensile strength of concrete is typically 8-15% of the compressive strength.

In compression, the stress-strain curve for concrete is linearly elastic up to about 30 percent of its maximum compressive strength. Above this point, the stress increases gradually up to its maximum compressive strength. After it reaches its maximum compressive strength σ_{cu}, the curve descends into a softening area, and eventually, crushing failure occurs at an ultimate strain ε_{cu}. In tension, the stress-strain curve for concrete is approximately linearly elastic up to its maximum tensile strength. Beyond this point, the concrete cracks and the strength decreases gradually to zero. Modelling anchor behaviour we need to take into account also a high stress gradient near anchor rod, epoxy material behaviour, possibility of failure on (concrete-epoxy, epoxy-steel) contact surfaces.

In Atena system, the constitutive model of concrete includes 20 material parameters. These parameters are specified for the problem under consideration by the user. If the parameters are not known, automatic generation can be done using the default formulas given [1]. In this case, only the cube strength of concrete f_{cu} (nominal strength) is specified and the remaining parameters are calculated as functions of the cube strength. The formulas for these functions are taken from the CEB-FIP Model Code 90 and other research sources. Also the transfer coefficient, βt, can be calculated.

2. CONTACT - ATENA

There are two ways for failure criteria for concrete in Atena. In the rotated crack model in Atena system the direction of the principal stress coincides with the direction of the principal strain. Thus, no shear strain occurs on the crack plane and only two normal stress components must be defined. In the fixed crack model also included in Atena system the crack direction is given by the principal stress direction at the moment of the crack initiation. During further loading, this direction is fixed and represents the material axis of the orthotropy.

The problem remains in definition of glue working diagram and also the contact elements behaviour.

For contact behaviour description there are two set of stiffness in each direction defined. (Normal and tangent stiffness). The first is stiffness valid before reaching the ultimate stress value on contact and the second valid after exceeding this boundary value. For normal stiffness the boundary value of stress is defined by the value of contact tensile strength (in this case it is the mean value of concrete tensile strength). For tangential stiffness the boundary value is defined by the ultimate value of bond stress and by friction coefficient. For our model we used the mean value of ultimate bond stress from experiments and friction coefficient 0.3. For secure the solution stability the stiffness after the contact failure should not be zero. Contact model is in detail described in [2]. For concrete modelling the 3D nonlinear cementitious model was used. This concrete model is able to represent the non-linear behaviour of concrete inclusive tensile and compressive softening.

The setting of these two set of stiffness values is essential for optimisation of the model. The whole behaviour of anchor is depending on anchor bolt deflection. As it is shown further in model samples, there is a great dependence of results on mesh size. This is mainly caused by GAP elements behaviour which is defined by initial stiffness. Initial value of stiffness should be adjusted in dependence on contact elements size, as it is indicated in [3] as (1).

$$K\ [MN/m] = E{,}concrete\ [N/mm] \ /\ elem{,}size\ [m] * 10 \tag{1}$$

The relation (1) is defined and useful for standard Atena concrete models of structures or it parts whit element sizes in range of 0,1m. Relation (1) cannot be used In case of modelling of small detail such as bonded anchor where is need to use smaller elements in range of 0,01mm. Modell with such contact model is usually unstable and mismatch the results of experiments.

2 BONDED STRESS EXPERIMENTS

Tension resistance of bonded anchor can be increased together with larger anchoring length. However due to geometric conditions this solution in not always possible. This can be problem of modern structures using high performance materials. The experiments described in this paper are focused on verification of bonded anchor tension resistance limits determined by bond strength provided by the glue. Bond strength is an overall parameter used for description of connection quality between the steel anchor and concrete. The main principle of the bond quality test used (as depicted in fig.1) is to restrict bond failure to the anchor only. Load is applied to the anchor bolt by the loading mechanism which is itself supported by the concrete in the immediate vicinity of the installed anchor. Experiments are closely described in [2]

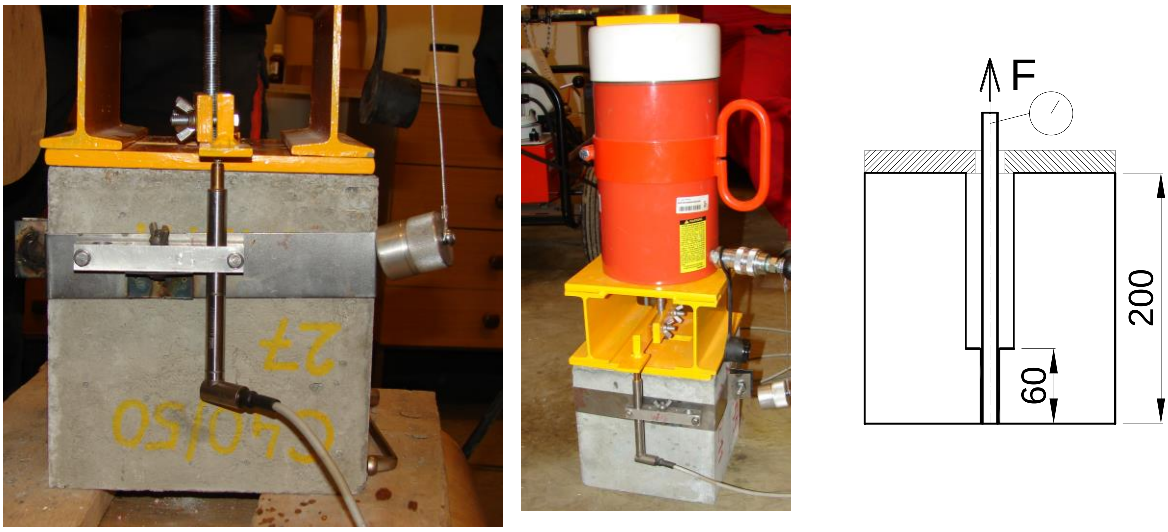

Figure 1: Bond strength experiment

Bond strength is defined as shear stresses on one of contact interfaces. It can be evaluated on interface between steel and glue or on the interface between glue and concrete, which is more suitable for description of combined concrete-bond failure mode. The experiment sample after failure is shown in fig. 2a). Fig. 2b) shows similar configuration of experiment with use of steel specimen instead of concrete. This configuration was used for determination of shear strength of hardened glue not influenced by concrete strength. Steel specimens were manufactured with internal female thread to ensure fine mechanical connection between steel and glue. The thickness of glue layer was set to 1 mm as it is usual in common bonded anchors systems.

Figure 2: a) M12 specimen after failure (epoxy resin). b) steel specimen

3 COMPARISON OF EXPERIMENTAL AND NUMERICAL RESULSTS

Folowing two graphs (fig. 3 and fig. 4) are presenting comparison of results between Atena 3d model and experiments. All data are for anchor size M12 with the length of contact 60 mm. Anchors were embedded in concrete with compressive strength 80 MPa by experimental epoxy resin based glue with shear strength 30 MPa.

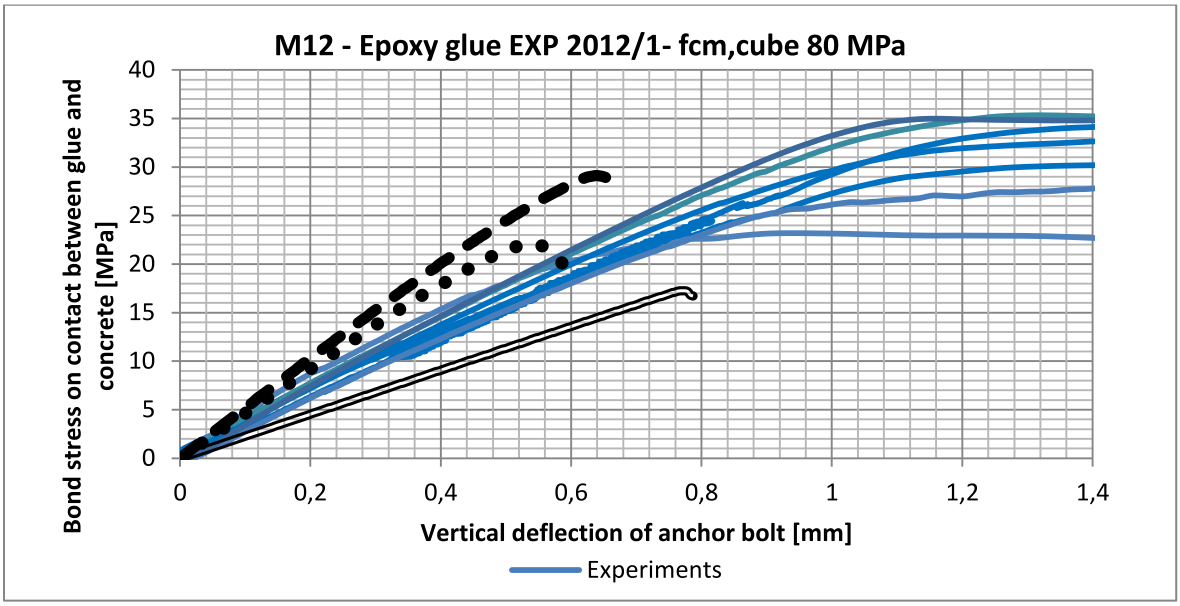

Figure 3: Model and experiment comparison (Bond strength) in dependence on initial stiffness [MN/m] for contact element size 5 mm

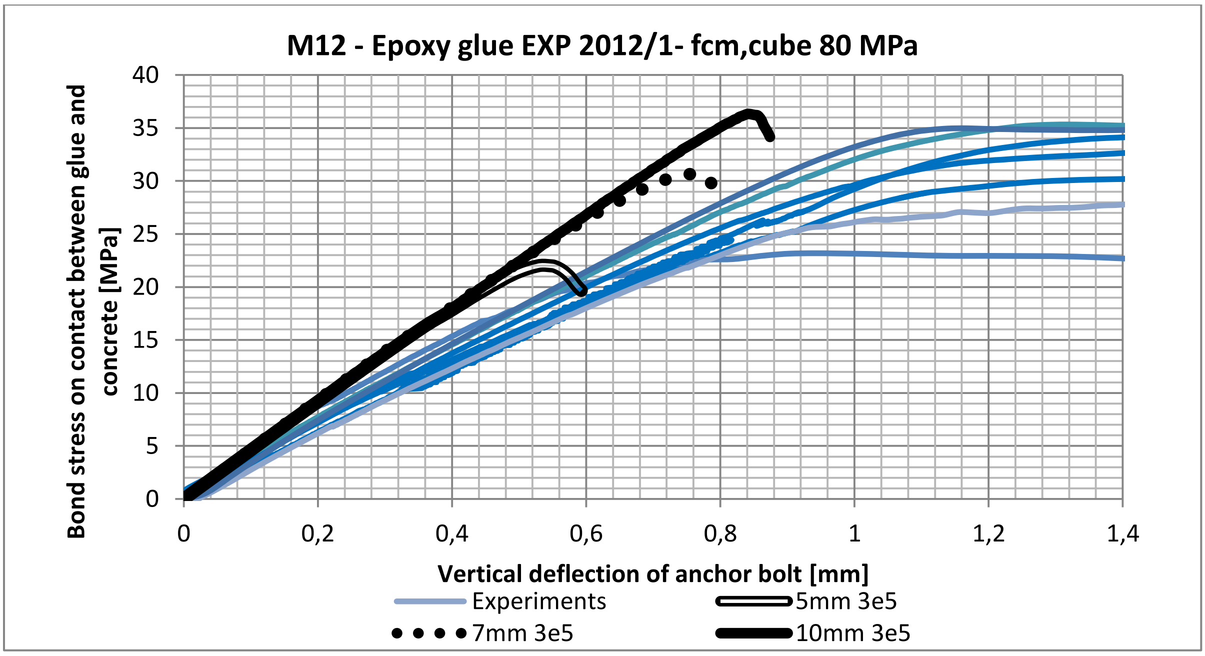

Figure 4: Model and experiment comparison (Bond strength) in dependence on contact element size and initial stiffness 3E5 [MN/m]

The contact length is 60 mm, therefore the element size in range 5-7 mm is appropriate range (in the view of cpu time and also model accuracy and stability) [5]. Fig. 3 and 4 show the dependence of model behaviour on initial contact stiffness and also element size. The stiffness of anchor in linear part of LD diagram is slightly influenced by the stiffness of whole testing system therefore smaller deformation of anchor in model cannot be regarded as inaccuracy.

Figure 5 shows results of numerical study from nine different setting of model. Experimental data in fig. 3 and 4 gives the mean value of bond strength 30 MPa. This value is also the input of cohesion parameter in contact elements. Therefore the results of model should give also value close to 30 MPa. The size of elements around the contact was set to 5, 7 and 10 mm and for all these three element sizes, the initial value of both stiffness was set to 3E4, 3E5 and 3E6 MN/m.

The black strip in fig 5a) represents the appropriate setting of initial stiffness and element size to get the result close to experiment. Sample view on model mesh with cracks propagation is shown in fig. 5b)

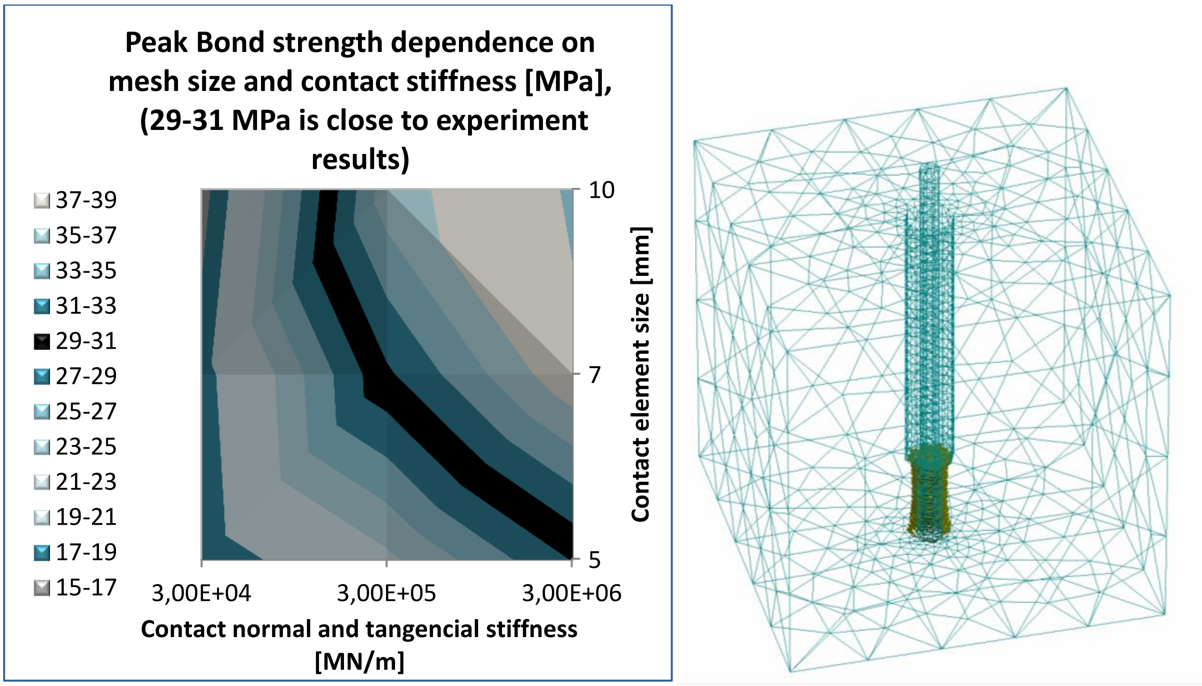

Figure 5: a) Combined dependence of results on initial stiffness and element size; b) model mesh and cracks

4 CONCLUSIONS

- Paper shows problems of modelling a small detail of composite structure, such as bonded anchor placed in high performance concrete, using Atena software for nonlinear modelling of concrete structures.
- The main problem is the mesh size dependence of model specially using GAP contact elements for simulation of glue-concrete behaviour.
- The size of elements in range of several millimetres leads together with use of typical settings of GAP elements sizes for modelling of bigger structure parts leads to model

instability and inaccuracy of results.

- Numerical study shown in fig. 5a has shown that the value initial tangent and normal stiffness of GAP elements should be optimised in dependence on element size and concrete characteristic according the approximation (2).

*K [MN/m] =500*E,concrete [N/mm] /((elem,size [mm])^(-5.3))* *(2)*

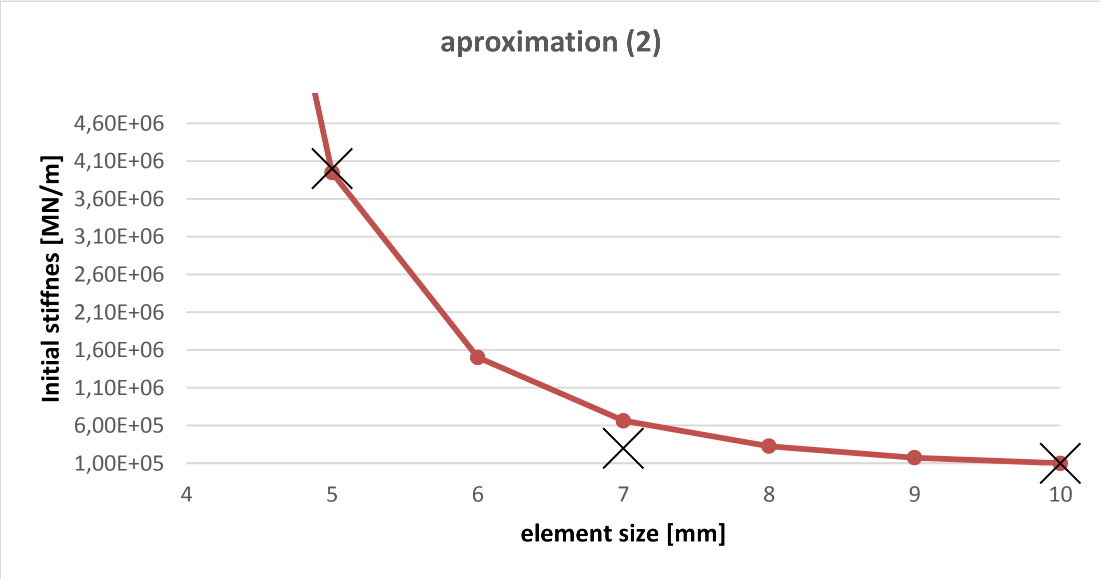

Figure 6: approximation of correlation between element size and initial stiffness

ACKNOWLEDGEMENTS

This paper was elaborated within the framework of research projects GACzR P104/11/P737 and GACzR P104/11/0703 and with the financial support of the European Union's "Operational Programme Research and Development for Innovations", No. CZ.1.05/2.1.00/03.0097, as an activity of the regional Centre AdMaS "Advanced Materials, Structures and Technologies

REFERENCES

[1] Červenka,V. *ATENA software documentation, part 2*, User‘s manual for ATENA 2D software, Červenka Consulting, Prague, Czech Republic, July 2002,

[2] Bajer, M.; Barnat, J. *The Glue-Concrete Interface of Bonded Anchors*. Construction and building materials. 2012. 34(9). p. 267 - 274. ISSN 0950-0618.

[3] Kala, J., Salajka, V., Hradil, P. Calculation of timber outlook tower with influence of behavior of “steel-timber” connection, Advanced Materials Research Vol. 428 (2012) pp 165-168, Trans Tech Publications, Switzerland, doi:10.4028/www.scientific.net/AMR.428.165, ISSN 1022-6680.

[4] Holomek, J; Bajer, M. *Experimental and Numerical Investigation of Composite Action of Steel Concrete Slab*, Procedia Engineering, Volume 40, 2012, p. 143–147, Elsevier, ISSN: 1877-7058 (1989), Vol. II, (1991).