ASSESSMENT OF FASTENERS TO CONCRETE
A TRIBUTE TO ROLF ELIGEHAUSEN

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ABSTRACT

Some examples are given of assessment of fastenings to concrete structures and the work started by Rolf Eligehausen in fib Task Group 2.9 “Fastenings to structural concrete and masonry”. Studies have been made on e.g. the influence of creep on adhesive anchors and of surface reinforcement and size effects on headed anchors.

1 Introduction

There is often a need to assess the capacity of existing structures. However, the basis for a good assessment is the knowledge of how the structures behave and can be modelled. A large step in direction of establishing this for fasteners was taken when Rolf Eligehausen in 1987 initiated a Task Group on Fastenings to Reinforced Concrete and Masonry Structures.

2 Task Group on Fastenings to Reinforced Concrete and Masonry Structures

The first meeting of the Task Group took place in Stuttgart in November 1987, see Figure 1. It was organized as Task Group VI/5 within Comité Européen du Beton (CEB). The goals of the Group were:

(a) to compile and compare the available research results on the behaviour of fastenings systems
(b) to propose a consistent approach based on current empirical and theoretical models for the design of fastenings
(c) to develop design methods that account for the effects of fastenings and the loads they carry on the behaviour of the structures to which they are attached.

The group met about twice a year and a first state of the art report was published in 1991, CEB (1991)¹,². Then a first guideline was published in 1995, CEB (1995)³. Revised versions of the guideline were published in 1997 and in 2011 by the new organization fib (Fédération internationale du béton – International Federation for Structural Concrete) in fib Bulletin 58 (2011)⁴. The new organization was a merge between CEB and FIP (Fédération Internationale de la Précontrainte - International Federation for Prestressing). The Task Group has in-between been renamed to Task Group 2.9 “Fastenings to structural concrete and masonry”. A text book was also published, first in
German and later in English, Eligehausen et al. (2006)\textsuperscript{5}. Work is now in progress to make a revision of the guide to include new aspects as assessment of existing anchors.

Figure 1. Photo from first meeting of CEB Task Group on fastenings in Stuttgart, November 4\textsuperscript{th}, 1987. From left: Lennart Elf gren, Johann Tshositsch, Rüdiger Tewes, Klaus Latenser, Werner Fuchs, Kent Gylltoft, Vicky Covert, Rolf Eligehausen, Hans-Di ter Seghezzi, Elisabet Vintzéleau, B Blache, Paul Hollenbach and Harry Wievel.

3 Anchor bolts for foundations

Works for anchor bolts in machine foundations was started in Sweden in 1978, Elfgren et al. (1980, 1982)\textsuperscript{6,7}. The idea to use adhesives for the bonding was brought up and a study visit was made to Rolf Eligehausen in Stuttgart and to producers of anchors. We then started tests on fatigue and longtime properties, Elfgren et al. (1988)\textsuperscript{8}

4 Fracture Mechanics

A way to understand the size effect in anchor bolts was to use the fracture mechanics theory. RILEM had two consecutive Task Groups on this and they arranged round robin tests and analyses of anchors, Elfgren et al. (1989, 1998, 2001)\textsuperscript{9,10,11}, see Figure 2. In the theory of fracture mechanics, the ratio of the elastic energy to the fracture energy was studied. Based on such studies Eligehausen & Sawade (1989)\textsuperscript{12} proposed a formula for the capacity $F_{\text{max}}$ [N] of an anchor to be

$$F_{\text{max}} = 2.1 \cdot (E_c G_f)^{1/2} \cdot h_v^{3/2}$$

(1)

where $E_c$ is the modulus of elasticity of the concrete [N/m\textsuperscript{2}], $G_f$ is the fracture energy of the concrete [Nm/m\textsuperscript{2}] and $h_v$ is the embedment depth of the anchor [m]. Here the exponent of the depth is reduced to 1.5 from the earlier used value of 2, to consider a size effect on the tensile capacity of anchors. The size effect predicts that at ultimate load, the tensile stresses in the concrete averaged over the fracture surface decreases as the thickness of concrete component increases (Eligehausen et al. 2006)\textsuperscript{5}. This idea was much spread later, see e.g. Ohlsson (1995)\textsuperscript{13}, Eligehausen et al. (1998)\textsuperscript{14}.

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The second RILEM group had its first meeting in Stuttgart 1993. They primarily studied tension in reinforced concrete prisms, Elfgren & Noghabai (2001)\(^{15}\).

### 5 Assessment of Structures

The assessment of structures is often divided into three phases: Initial, Intermediate and Enhanced and you stop when you get satisfying results. An example of a general procedure is shown in Figure 3, see e.g. Schneider (1994)\(^{16}\), Schneider & Vrouwenvelder (2017)\(^{17}\), SB-LRA (2007)\(^{18}\), ISO 13822 (2010)\(^{19}\) and Paulsson et al. (2016)\(^{20}\). When assessing the capacity of anchors in a special structure, e.g. in a power plant applications, there can also be a need to subdivide the phases in three steps as: (1) a global seismic analysis, (2) a local pull-out analysis of an anchor, and (3) an updated global analysis including piping and anchor stiffness.

In methods based on the reliability, the probability \(p_f\) is studied for the case that the Load Effect (\(E\)) is larger than the Resistance (\(R\)), see e.g. Figure 4. When the curves overlaps and \(E > R\) there is a certain risk for failure, see e.g. Schneider (1997)\(^{16}\), EC Reliability (2005)\(^{21}\).

The variabilities of the load effect and the resistance have a great effect on the load that can be applied to a structure. If by testing, it can be shown that the variability of the resistance can be narrowed; the load-carrying capacity can be increased considerably. This is an argument for producers and construction companies to keep track of the variability in the capacity of installed anchors by e.g. proof loading procedures.
Figure 3: Flow chart for assessment of existing bridges and other structures. Three phases are identified: Initial, Intermediate and Enhanced depending on the complexity of the questions involved, Schneider (1994)\textsuperscript{16}, Paulsson et al (2016)\textsuperscript{20}.

Figure 4: Probability variation for Load Effect (E) and Resistance (R), EC Reliability (1990)\textsuperscript{21}. 

Probability density $\varphi_x(x)$, $\varphi_R(x)$

Random variable $X$

Figure 4: Probability variation for Load Effect (E) and Resistance (R), EC Reliability (1990)\textsuperscript{21}.

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6 Recent work

Long time sustained loading tests on adhesive anchors were started in Sweden in 1981. Two types of adhesive anchors (type A and B) were exposed to various in-service conditions and subjected to sustained tension loads of 15, 30 and 45 kN (i.e. approximately 23, 47 and 70% of their mean ultimate short-time capacities, respectively) over more than 28 years. The experiments were terminated in 2013 and the final results and evaluations reported in Nilforoush et al. (2016)22. The curves of creep displacement versus time for the tested adhesive anchors are shown in Figure 5. The test results showed that the creep deformation increases by increasing the sustained load level. Results indicate that the tested bonded anchors did not fail indoors when subjected to sustained loads up to 47% of their mean ultimate short-time capacity. However, the long-term performance was substantially impaired outdoors, presumably due to temperature and humidity variations, leading to failure for sustained loads higher than 23% of the anchors’ mean ultimate short-time capacity. Based on the results of long-term experiments, the reliability and suitability of the current testing and approval provisions for qualifying adhesive anchors subjected to sustained tension loads was evaluated and several recommendations were provided (see Nilforoush et al. 201622).

![Figure 5: Creep displacement versus time for M16 adhesive anchors of type A and B exposed to various in-service conditions and different sustained tension load levels (Figures reprinted from Nilforoush et al. 201622).](image)

Work on modelling of the influence of surface reinforcement, member thickness, anchors head size and cracked concrete has recently been carried out in collaboration with Stuttgart. The full descriptions and evaluations of the numerical studies on single cast-in-place headed anchors are given in Nilforoush et al. (2017a, b)23,24. Based on these studies, it was found that the tensile breakout capacity of headed anchors increases with increasing member thickness; anchor head size and/or if orthogonal surface reinforcement is present (see Figure 6). Based on the numerical results, the CC method was refined by incorporating three modification factors to account for the influence of anchor head size, member thickness and surface reinforcement.
Nilforoush et al. (2017c) carried out also supplementary experimental studies to verify the numerical results and evaluate the validity of the proposed refined model. The experimental results showed very good agreements with the numerical results. The proposed refined model may be used for the design of new cast-in-place headed anchors as well as for the assessment of existing anchors.

Recently, Nilforoush et al. (2017d) studied the tensile behavior of single cast-in-place headed anchors in plain and steel fibre-reinforced normal- and high strength concrete base materials. The experiments showed an increase of approximately 25-50% on the tensile breakout capacity when steel fiber is present in concrete.

Figure 6. (a) Load-deflection curves of anchor bolts \( h_{ef} = 200\)mm in uncracked and pre-cracked plain and reinforced concrete slabs, (b) Load-deflection curves of anchor bolts \( h_{ef} = 200\)mm with various head sizes in plain concrete members (Figures reprinted from Nilforoush et al. 2017 a, b).

### 7 Summary

Some examples have been given for the assessment of fastenings to concrete structures and on the influence of sustained tension loads on the long-term behaviour of adhesive anchors and on influence of surface reinforcement, anchor head size and embedment depth of headed anchors.

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