ASSESSMENT OF FASTENERS TO CONCRETE
A TRIBUTE TO ROLF ELIGEAUSEN

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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 size effects in 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/6 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 consisting 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 in was published in 1995, CEB (1995)3. Revised versions of the guideline were published in 1997 and in 2011, fib Bulletin 58 (2011)4, now by the new organization fib (Fédération internationale du béton – International Federation for Structural Concrete), which 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.

![Figure 1. Photo from first meeting of CEB Task Group on fastenings in Stuttgart, November 4\textsuperscript{th}, 1987. From left: Lennart Elfgren, Johann Tshositsch, Hans Rüdiger Tewes, Klaus Latenser, Werner Fuchs, Kent Gylltoft, Vicky Covert, Rolf Eligehausen, NN, 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 a 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 fracture mechanics. 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

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

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 reflecting a smaller size effect than earlier when the load was supposed to be proportional to the square of the depth $h_v$ (proportional to the area of the break-out cone). This idea was much spread, see e.g. Ohlsson (1995)\textsuperscript{13}, Eligehausen et al (1998)\textsuperscript{14}
The second RILEM group had its first meeting in Stuttgart 1993. They primarily studied tension in reinforced concrete prisms, Elfgren & Noghabai (2001)\textsuperscript{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)\textsuperscript{16}, Schneider & Vrouwenvelder (2017)\textsuperscript{17}, SB-LRA (2007)\textsuperscript{18}. ISO 13822 (2010)\textsuperscript{19} and Paulsson et al (2016)\textsuperscript{20}. When assessing the capacity of anchors in a special structure, there can also be a need to subdivide the phases in three steps as e.g. in a power plant: (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 Figure 4. When the curves overlaps and $E > R$ there is a certain risk for failure, see e.g. Schneider (1997)\textsuperscript{16}, EC Reliability (2005)\textsuperscript{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.
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}.
6 Recent work

Long time tests on anchors were started in Sweden in 1981 and the final results were reported by Nilforoush et al (2016). Some examples are given in Figure 5. Work on modelling of the influence of surface reinforcement, embedment depth, anchors head size and cracked concrete has been carried out in collaboration with Stuttgart, see Figure 6, Nilforoush et al (2017a, b). Tests have also been carried out to calibrate the models and to check the influence of high strength concrete and fiber reinforcement, Nilforoush et al. (2017c, d).

![Figure 5. M16 anchors of type A under sustained loads of 15 and 46 kN](image)

7 Summary

Some examples have been given of assessment of fastenings to concrete structures and on the influence of creep on the capacity of adhesive anchors and on size effects in headed anchors.

8 Acknowledgements

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Figure 6. Load-deflection curves of anchor bolts in uncracked and pre-cracked concrete slabs with an embedment depth of $h_{ef} = 300$mm.

References:


