APPLICATION OF THE FINITE ELEMENT METHOD TO ANCHORING TECHNOLOGY IN CONCRETE

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Abstract

The fastening technology in the safety relevant domain for concrete substrates is mainly covered by utilizing anchors. Both the setting of an anchor in a predrilled hole and the pull-out process can be considered performing a numerical analysis based on the finite element method. A finite element program utilizing the smeared crack concept has been developed at Hilti AG for the use in anchor design.

1 Introduction

In recent years the fastening technology has become more and more important according to the increasing requirements particularly for safety reasons. Hence the anchors must be a part of the complete design process considering both safety and economic aspects.

The development of new anchors can only be optimized with an in-depth understanding of the physical processes involved during the setting and pull-out of the anchor. A helpful tool for gaining this insight is a finite element program developed at Hilti AG for the analysis of anchors.

2 Anchoring in concrete

An overview of the mechanical behavior of different fasteners is given in the literature, e.g. Rehm et al. (1991), Senkiw et al. (1991). For a better understanding of the effects occuring in the numerical examples a few principles are mentioned in the following.

In fastening technology a number of different types of fastening elements have been developed. They can be classified by the way they transmit the external forces acting on the anchor into the concrete. These different mechanisms are friction, keying or bonding (s. Fig. 1).

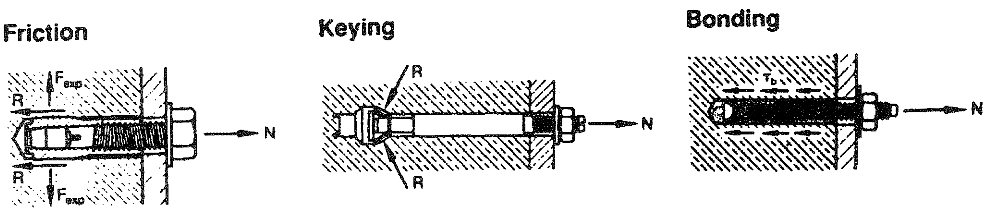

Fig. 1. Working principles of anchoring systems, Hilti AG (1993)

The application of the pull-out force up to failure leads to different failure mechanisms (s. Fig. 2): (1) break out, (2) anchor pull-out, (3) failure of anchor parts, (4) failure of edge and (5) splitting of the substrate. The occuring failure mode depends on a variety of influencing factors as for example the strength of the concrete or the type of the chosen anchor.

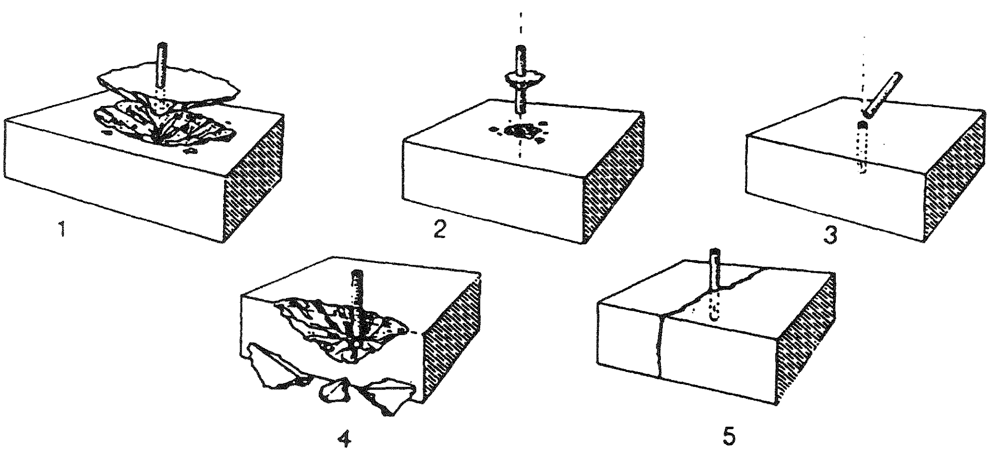

Fig. 2. Failure mechanisms, Hilti AG (1993)

3 Numerical simulation

The numerical examples presented in this chapter are based on an axisymmetric modeling of the structure. The analysis for two different types of anchors is performed: a heavy duty anchor HSL and an adhesive anchor HVA. Further examples can be seen in Jussel et al. (1994).

3.1 Heavy duty anchor HSL

The first example considered here is the heavy duty anchor HSL M16. The working principle of this anchor is the combination of the two principles of friction and keying. This anchor is expanded by a prestressing axial force applied by a tightening torque. The expansion force, caused by the displacement of the cone relative to the sleeve, permits the axial force to be transmitted to the anchor by friction. At the same time, this expansion force causes permanent local deformation of the base material. A keying action results which enables the longitudinal force in the anchor to be transmitted additionally to the base material.

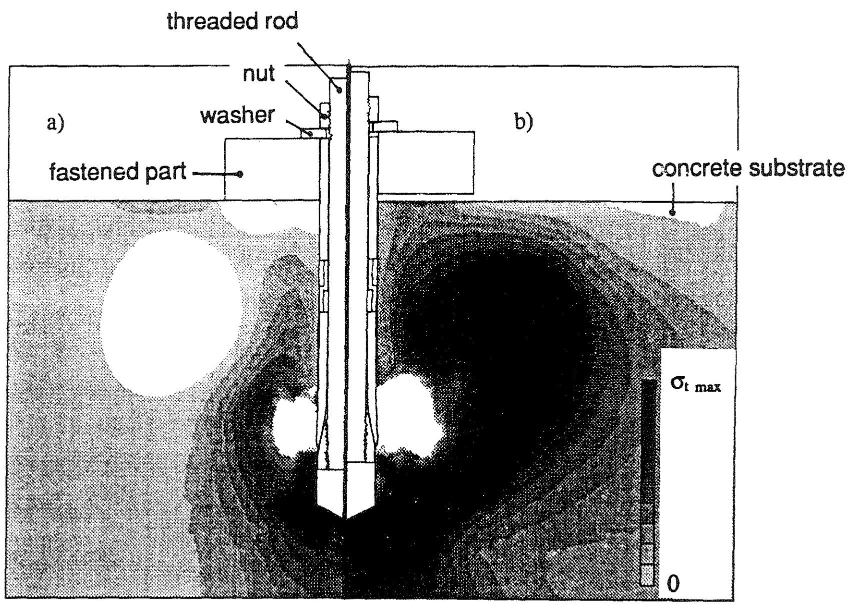

Fig. 3. Tensile stresses in the radial plane of the concrete substrate during the setting process (a) and the pull-out process (b)

Fig. 3 shows the tensile stress distribution in the base material under the loading conditions of setting the anchor, Fig. 3a, and during pull-out at half of the maximum pull-out force, Fig. 3b. $\sigma_{t\ max}$ is the tensile strength of the concrete. Fig. 3a identifies the area of largest tensile stresses at the bottom of the bore hole. Whereas Fig. 3b shows large tensile stresses in two different areas, i.e. the bottom of the bore hole and the region determining the crack tip.

The calculated final crack distribution in the post peak region utilizing the smeared crack approach shows the typical cone of a concrete break out. The cone determined in the calculation is verified in shape and size by experimental results.

The influence of different anchor sizes is illustrated in Fig. 4. Here the load/displacement curves of three anchor sizes (M8, M16, M24) are compared with each other. It should be noted that all curves show a very good agreement with the experimental results.

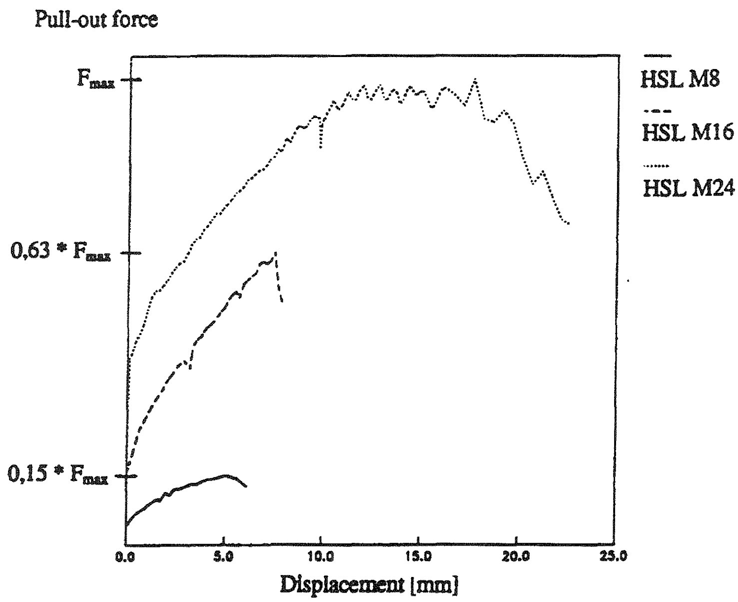

Fig. 4. Load/displacement curves of HSL M8, M16, M24

3.2 Adhesive anchor HVA

A second numerical example is carried out with an adhesive anchor. The adhesive bond between the threaded rod and the wall of the bore hole is established by a synthetic resin. Fig. 5 identifies the domain along the complete depth of the bore hole of high tensile stresses at the beginning of the pull-out process. The final failure behavior shows only a small break out of the concrete substrate in the upper part of the fastening.

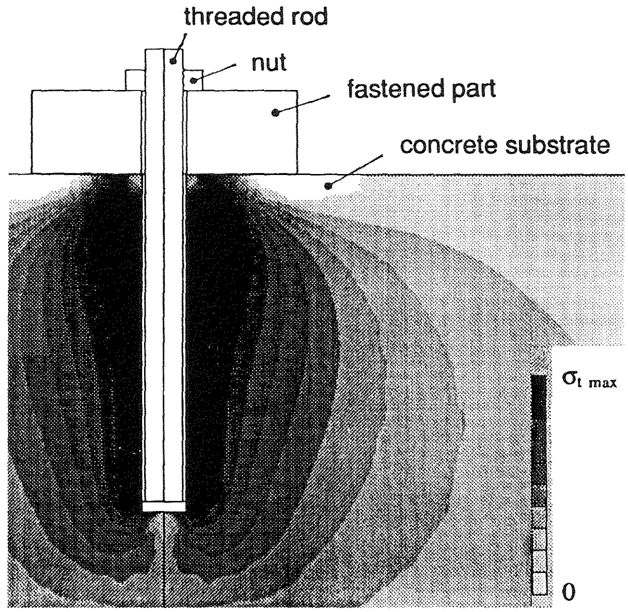

Fig. 5. Tensile stresses in the radial plane of the concrete substrate starting the pull-out process of a HVA-anchor

A comparison of the load/displacement curves for the adhesive anchors of different size is shown in Fig. 6. The different curves show a similar behavior. This is due to the fact that the failure mode is a pull-out of the threaded rod in all cases considered.

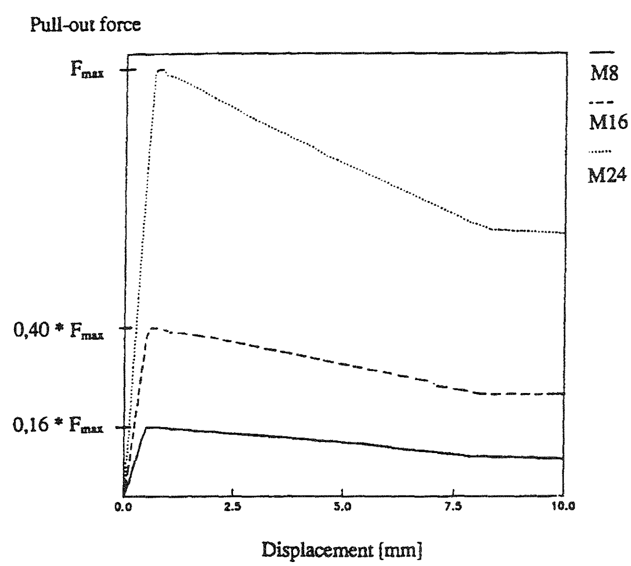

Fig. 6. Load/displacement curves of HVA M8, M16, M24

4 Summary

The smeared crack method proved to be a suitable tool when analysing anchoring systems. The developed finite element program helps in understanding the mechanisms taking place in the material, and hence it can be used for the improvement of existing anchors and for the development of new ones.

5 Acknowledgement

The authors would like to thank Prof. Dr. W.J. Huppmann, head of corporate research, Hilti AG, for his support and continuous interest in this research project. Thanks are also due R. Mattner, Dr. M. Meyer and V. Raadschelders in corporate research for performing part of the calculations.

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