VIII International Conference on Computational Plasticity
COMPLAS VIII
E. Oñate and D. R. J. Owen (Eds)

FAILURE ANALYSIS OF ANCHORING SYSTEMS IN CONCRETE

Yijun Li, Bernhard Winkler and Andreas Eckstein

New Business and Technology, Hilti Corporation
Feldkircherstrasse 100, FL-9494 Schaan, Principality of Liechtenstein
e-mail: liyijun@hilti.com, winkber@hilti.com, ecksand@hilti.com
Web page: http://www.hilti.com

Key words: Finite element, concrete modeling, anchoring system, failure analysis

Summary: *Numerical simulation has become a powerful tool for supporting the development of innovative fastening products. The inside information on the failure mechanism during the load transfer from fasteners to concrete could be easily obtained and analyzed, which offers the basis requirement for designing innovative fasteners. During last 15 years Hilti Corporation has developed a simulation tool based on finite element method and concrete material models to support the fastener design process. In this paper various simulation examples for typical anchors with different working principles are presented, in particular the numerical simulation of a concrete screw is described in detail.*

1 INTRODUCTION

The development of innovative fastening products requires an in-depth understanding of the physical phenomena involved in the complete process of setting and loading in building material, mainly in concrete. Evidently, numerical simulation can play an important role for fulfilling this challenging task. For this purpose a simulation tool based on finite element method has been developed within Hilti Corporation, which strongly supports the development process of innovative fasteners.

General speaking the fasteners in concrete can be subdivided into three different working principles according to the load transfer mechanism, namely friction, keying and bonding. For friction type anchors the tensile load is transferred from anchor to base material due to the friction created by expanded segments. Keying type anchors carry the tensile load by main keys at the end of anchor resulting in a concrete cone failure or in yielding of the steel rod. For bonding anchors the tensile load is transferred mainly due to the adhesive bond between anchor rod and concrete with a shear and concrete cone combined failure. In fact many anchors obtain their holding power from a combination of the three working principles. In this paper various simulation examples of typical anchors with different working principles are presented, especially a study on a concrete screw is described in detail.

Screw anchors belong to the type of keying anchors according to their work principle. Instead of carrying tensile load by main keys at the end of anchor, for screw anchors the tensile load is transferred to base material by several threads distributed along the anchor rod. Moreover, experimental investigations of pull-out tests on screw anchors show a shear and concrete cone combined failure, which is mostly observed for adhesive anchors. In order to get deeper knowledge on the load transfer process of screw anchors numerical simulations of pull-out tests were performed and the related results were compared with test data.

2 SIMULATION OF ANCHORING SYSTEMS

The simulation of anchoring systems includes the modeling of the anchor, the base material, mainly concrete, as well as the interface between anchor and concrete. The anchor consists of different components such as anchor rod, sleeve segments, washer and hull, respectively. The modeling should include most of components, especially when setting process needs to be simulated.

For describing nonlinear material behavior of steel an elasto-plastic material model is normally used. The concrete material is modeled by a rotating crack model for the tensile zone [1] and a plasticity model to describe the compressive regime. The softening law for tension is selected bilinear for simplicity. The smeared crack approach is adopted for simulating damage in concrete. The input parameters for the concrete model include Young's modulus, Poisson's ratio, tensile strength, compressive strength and fracture energy.

The interface between concrete and steel anchor usually is models by different contact models depending on the type of the anchor. The normal and tangential penetration is constrained by using penalties taking into account the friction and bond, respectively.

Due to symmetry most of simulations are realized whether by using axi-symmetry or in most cases only a quarter of specimen for three-dimensional problems.

According to different simulation purposes the simulation results could be the loading capacity, the load-displacement curve, the failure process and the final failure mode, respectively. Therefore, the stress and strain distribution inside the concrete near to the load introduction plays a key role for analyzing the failure mechanism as well as for optimizing the geometry of anchor components.

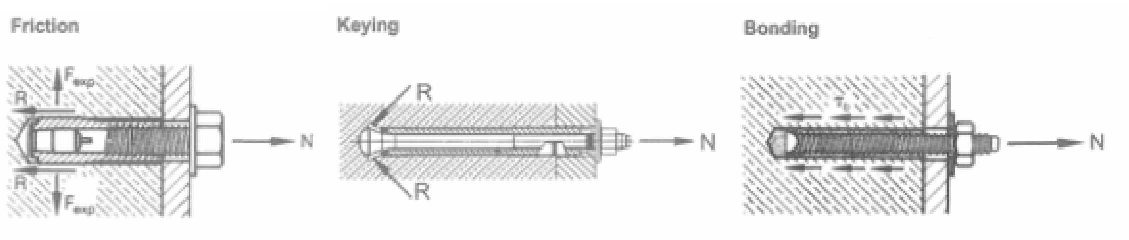

Figure 1: Three work principles of anchors [2]

3 TYPICAL SIMULATIONS EXAMPLES

As already mentioned, there are three basic work principles, which make an anchor hold in a base material. In fact many anchors obtain their holding power from a combination of these working principles. In figure 1 the load transfer mechanisms for the three work principles are plotted. In order to demonstrate the capability of simulation three anchors acting by different work principles are investigated numerically. Other examples can be found in [3]. The related anchors are the Hilti design anchor (HDA) for a keying anchor, the Hilti heavy duty anchor (HSL) for a friction anchor and finally the Hilti adhesive anchor (HVZ) representing a bonding anchor. Figure 2 shows the photos of these anchors.

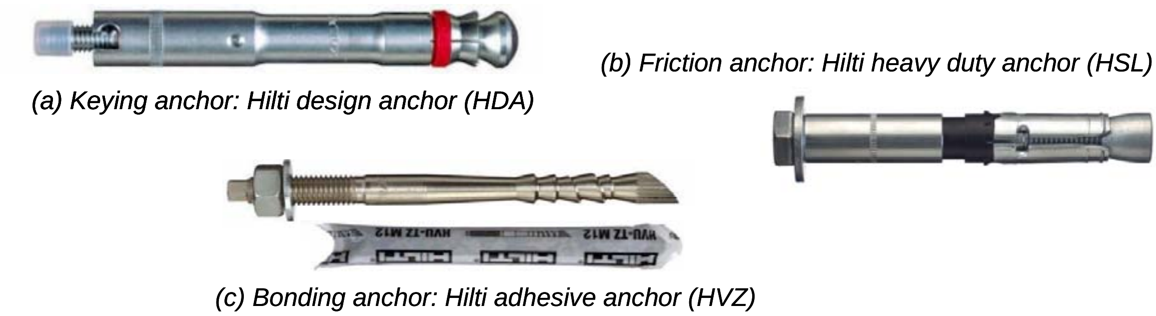

Figure 2: Typical Hilti anchors with different work principles

A lot of different simulations were performed during the development period of these products with the purpose to understand the failure mechanisms, optimizing the geometry of the anchor components and to predict the load carrying capacity, respectively. In figure 3 the different crack patterns for the anchors are plotted. From this figure the different failure modes can be clearly observed. A concrete cone failure occurred for HSL anchor, a combined shear and concrete cone failure for HVZ anchor. For HDA anchor only limited cracks appeared at the area of load introduction. The ultimate load is reached by yielding of the anchor road.

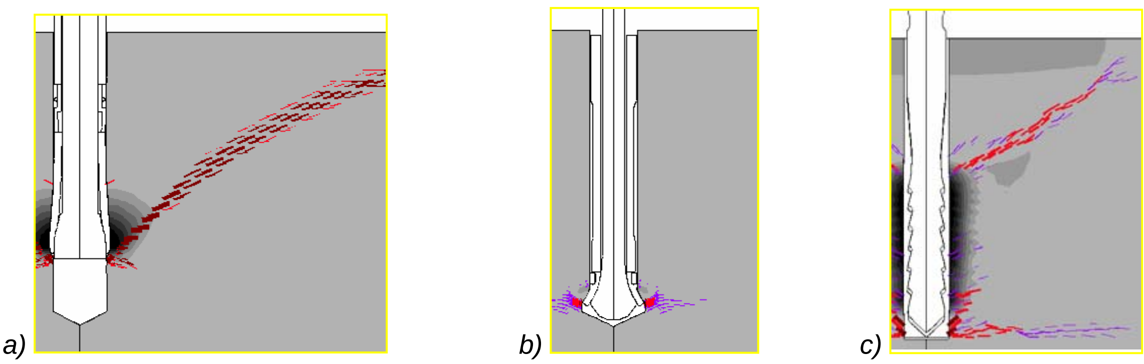

Figure 3: Crack patterns for a) HSL anchor, b) HDA anchor and c) HVZ anchor

4 FAILURE ANALYSIS OF CONCRETE SCREW

The screw is a traditional fastening technique for materials like metal and wood, to use it for concrete is relatively new. Comparing to other fastening systems concrete screws are easy to install, removable and costly low. For the installation of concrete screw a cylindrical hole has to be drilled. During the setting process the single screw threads cut into the surface of drilled hole realizing the transfer of the load into concrete by mechanical interlock. As concrete is a brittle material the concrete near the threads should be strongly damaged during the setting process and micro cracks in this zone may appear. During loading the micro cracks propagate and connect. Evidently, the information on the micro cracks initiate, propagate and connect to main crack inside of concrete could offer the basic knowledge for the development of innovative concrete screws.

Figure 4 shows the simulation results for the Hilti concrete screw (HUS) for a pull-out test. A combined shear and concrete cone failure could be observed, which corresponds well with experimental investigations. Moreover, the numerically determined load-displacement curve agrees well with the data obtained in experiments.

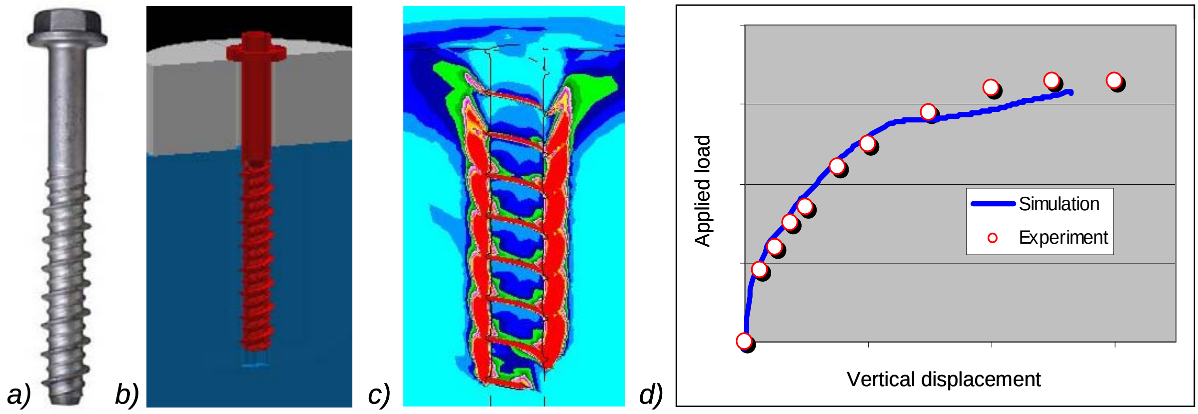

Figure 4: a) Hilti concrete screw, b) model, c) failure mode and d) load-displacement curve

5 CONCLUSIONS

In this paper the importance of numerical simulation in order to drive the development of innovative fasteners has been discussed and the simulation results of three typical anchors with respect to different work principles have been presented. In addition, a study on a concrete screw is described in detail, including the failure mode and a comparison of the related load-displacement curve with experimental data.

REFERENCES

[1] M. Jirasek and Th. Zimmermann, Rotating crack model with transition to scalar damage, *J. of Engin. Mech. ASCE*, **124**:277-284 (1998).

[2] Hilti Corporation, *Fastening Technology Manual*, Schaan, Liechtenstein (2004).

[3] J. Nienstedt and R. Mattner, Three dimensional modelling of anchoring system in concrete, *Fracture mechanics of concrete structures*, de Borst et al. (eds), Swets & Zeitlinger, Lisse, pp. 1021-1026 (2001).