

Load-Displacement Behavior of Expansion Metal Anchors under Dynamic Loading in Cracked Concrete

Daniel Schuler and Beat Erdin

Bürkel Baumann Schuler, Ingenieure+Planer AG
CH-8400 Winterthur, Switzerland

Peter Hunziker

AC-Laboratorium Spiez
CH-3700 Spiez, Switzerland

Abstract

Metal anchors used as shock-safe fastenings for shelter equipment must be capable of transferring impulse-like, transient forces into cracked concrete. To evaluate suitable anchor systems for this purpose, AC-Laboratorium Spiez conducts shock tests with anchors set in wide cracks. The results of a large number of anchor tests with varying shock loads and different types of anchors are presented. The analysis of the test results shows that anchor slip caused by the shock depends on the acting load. A simple mathematical function describing this relationship has been found.

1. INTRODUCTION

The shock resistance of shelter equipment and installations (apparatus, pipings, etc.) must be guaranteed when these components are necessary for the survival of occupants in the shelter, or if they are important for the shelter function. Shock safety can only be guaranteed if the components themselves and also their fastenings withstand shock loadings. If anchor systems are used as shock-safe fixtures, the anchors must show a small probability for pull-out failures and an adequate load-displacement behavior.

To evaluate suitable anchor systems for use in civil defence or military shelters, AC-Laboratorium Spiez has been performing shock tests with anchors set in wide cracks since 1977. Up to the present time, more than 30 types of anchors have been subjected to experimental shock tests at AC-Laboratorium Spiez. Generally, it has been found that torque-controlled expansion anchors of bolt type (Fig. 1a) or sleeve type (Fig. 1b) are suitable for transferring dynamic loads into cracked concrete. Also, undercut anchor systems basically meet the shock test requirements. Deformation-controlled expansion anchors of either wedge-down type (e.g. "drop-in anchors") or of shell-down type (e.g. "self drilling anchors") have been proven unsuitable [1]. Also no adhesive or bonded anchor system has been able to fulfill the shock test criteria so far.

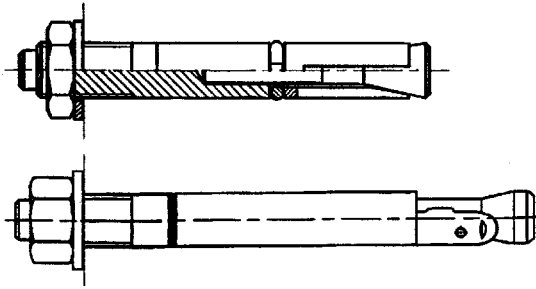


Fig. 1a: Torque-controlled expansion anchors of the bolt type

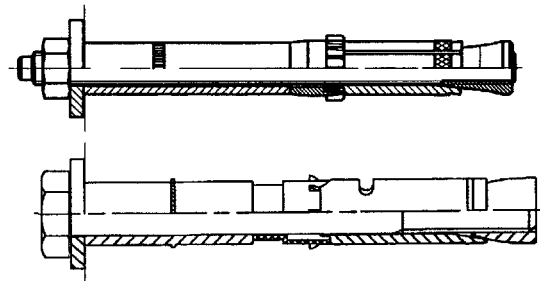


Fig. 1b: Torque-controlled expansion anchors of the sleeve type

2. SHOCK TESTING OF ANCHOR SYSTEMS

2.1 Introduction

With shock loading tests, AC-Laboratorium Spiez establishes whether an anchor system is suitable for use in shelters or not. Suitable systems must be capable of transferring dynamic loads into cracked concrete. In inelastically deformed concrete structures cracks usually pass through the anchor holes. This is the reason why pre-test cracks are produced in the concrete blocks used in the anchor shock testing. The test procedure described hereafter is also explained in detail in [2].

2.2 Test Procedure

The anchors to be tested are set in concrete blocks in accordance with the manufacturer's information and with the instructions in approvals on which the tests are based. After the anchors have been set, parallel cracks are produced in the concrete blocks with the aid of wedges. These cracks in the test members have a width (w) of 1.0 mm [2]. The prestressing of the set anchors will normally be lost after this procedure. Without previous re-expanding of the anchors, the concrete blocks are mounted on the test platform of the vertical shock testing machine, called VESPA (Fig. 2). This fully hydraulically driven machine allows simulation of a wide range of acceleration-time-histories with test objects up to ten tons [3]. For anchor shock testing the test platform will be driven with an acceleration-time-history similar to a half sine wave as shown in Fig. 3. During the motion of the test platform, the concrete test blocks are exposed to inertial forces, stressing the anchors dynamically.

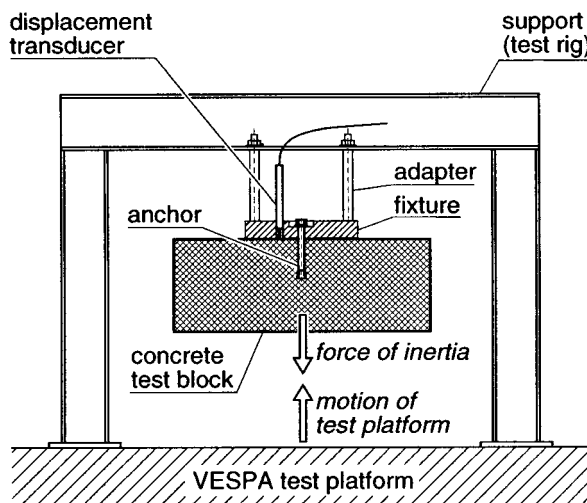


Fig. 2: Test arrangement for anchor shock testing with the vertical shock testing machine VESPA

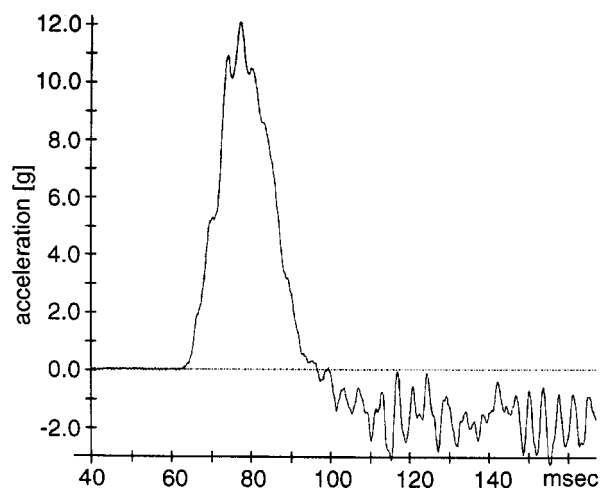


Fig. 3: Example of a measured acceleration-time-history of the VESPA test platform

For transferring the dynamic tension load, the anchors must be capable of follow-up expansion and bridging the spacing in the anchor hole caused by the crack. Therefore anchors must execute some displacement. This anchor slip (s_{dyn}) will be measured with displacement transducers fixed near the test specimen. Figure 4 schematically shows the expansion section of an anchor and the anchor displacements in different stages of the test procedure. Anchors, which are unable to undergo sufficient further expansion, are completely pulled out of their holes by the shock loading (Fig.4b). There is no anchor system known that, set in large cracks, fails by concrete-cone failure. However, pull-out is the common failure mode of shock loaded anchors in cracked concrete.

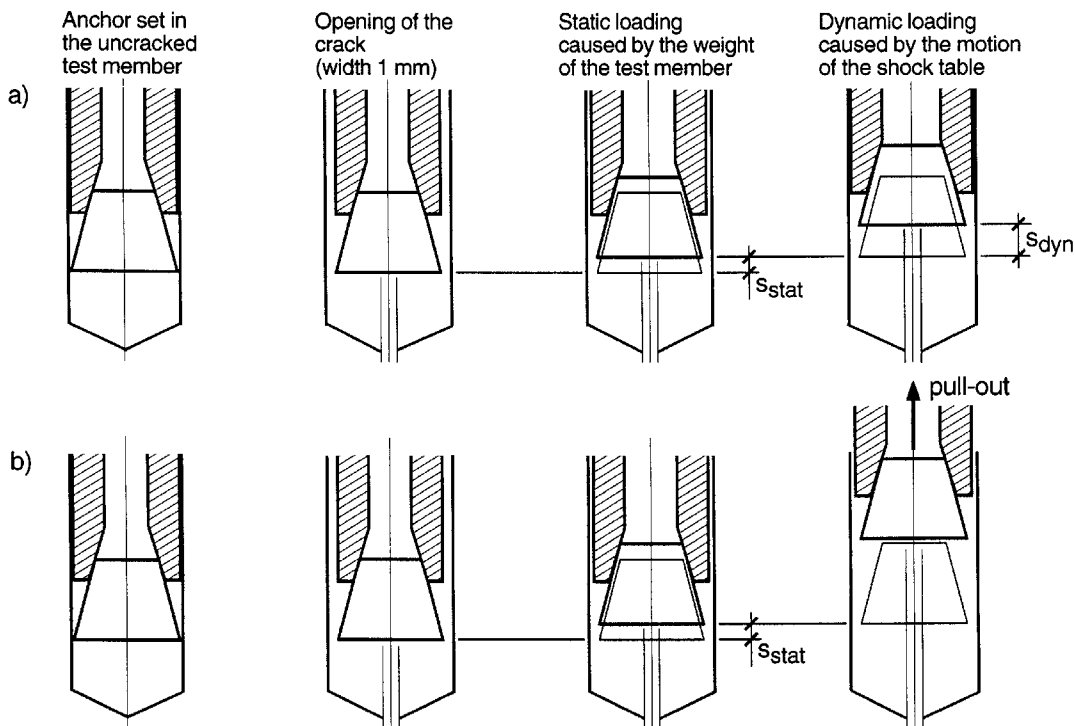


Fig. 4: Shock testing of expansion metal anchors in cracked concrete

2.3 Test Criteria

The criteria needed for the evaluation of the shock resistance of anchor systems are the pull-out probability (pf, probability of failure) and the anchor-displacement (s_{dyn}) caused by the shock loading. For the approval, the following standard limits are defined [4]:

- With a confidence level of 50% the pull-out probability must be equal to or smaller than 5% ($pf \leq 0.05$). This means that no pull-out is allowed within a test series of 14 anchors. If during a test series with 14 anchors one pulls out, the pull-out probability is too high ($pf = 0.12$). If the evaluation of shock resistance is done with 34 test specimens, one failure is tolerable.
- Anchor-displacement caused by dynamic loading may not be too big, and also the distribution of the slip values must be smaller than a certain value. The 95%-fractile ($s_{0.95}$) defines the characteristic slip. The characteristic slip corresponds to the amount of displacement which will not be exceeded by 95% of the anchors. It must be smaller than 10 mm ($s_{0.95} < 10$ mm). The standard deviation (σ), on the other hand, is a measure of scatter of slip readings. The limiting criteria for the standard deviation is $\sigma < 4.0$ mm.

2.4 Load-displacement Behavior

The evaluation of numerous anchor shock tests has shown that the anchor displacement under shock loading is most accurately described by a logarithmic-normal distribution [5]. For a torque-controlled expansion anchor of the sleeve type with a diameter of $d_{nom} = 12$ mm, Figure 5 shows as a histogram the measured slip (s_{dyn}) caused by a dynamic loading of $N_{dyn} = 3.75$ kN. With the probability density function, calculated from these readings, the 95%-fractile ($s_{0.95}$) may be calculated as 4.3 mm. The standard deviation (σ) is calculated as 1.4 mm.

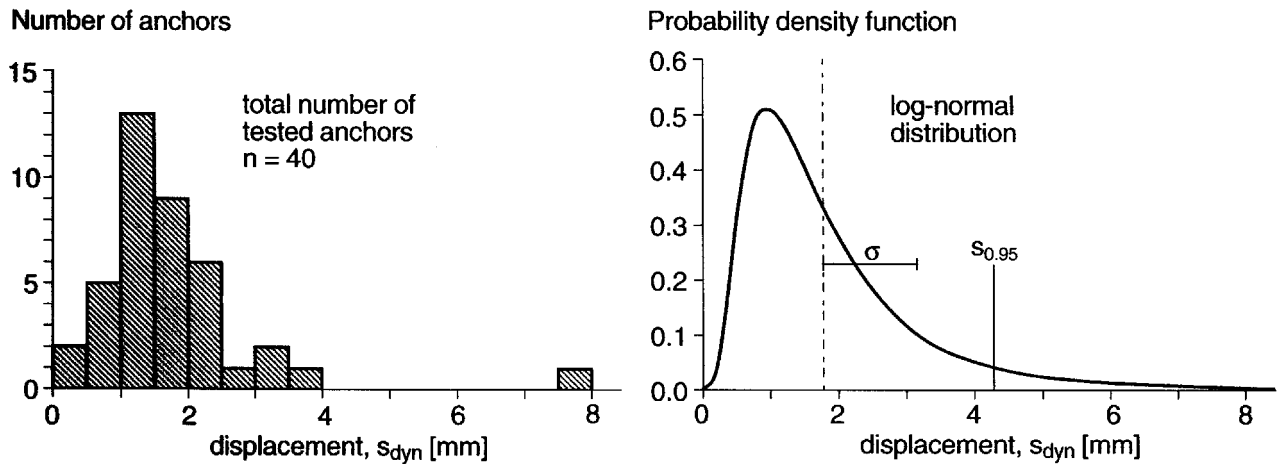


Fig. 5: Distribution of displacement caused by shock loading for a torque-controlled expansion anchor of the sleeve type

3 FACTORS INFLUENCING THE LOAD-DISPLACEMENT BEHAVIOR

3.1 Generals

The load-displacement behavior of dynamically loaded anchors is generally affected by the loading, the type of anchor construction, and the concrete base material.

- Possible influences from the loading are the amplitude of the shock load, the shape of the loading pulse (e.g. half-sine, triangular, rectangular), and the differentiation of the impact acceleration, the jerk.
- Possible influences from the anchor itself are the specific properties of the anchor construction, the type of anchor (e.g. bolt type, sleeve type), and the anchor size, i.e. the anchor diameter d_{nom} .
- Influences from the base material are primarily related to the cracking of the concrete (i.e. the location and the width of cracks). Concrete strength, however, is less important because pull-out is the decisive failure mode.

For further evaluation of the load-displacement behavior of anchors, shock tests were conducted in summer 1997 at AC-Laboratorium Spiez [6]. With these test series the influence of the amplitude of the shock loading was investigated. The tests have been performed with various types of anchors (i.e. bolt type or sleeve type) from different manufacturers. Additionally, various anchor sizes were also tested. The results and the evaluation of data from these tests are presented below.

3.2 Influence of the Loading

To evaluate the relationship between the dynamic loading (N_{dyn}) and the anchor displacement, (s_{dyn}) shock tests were conducted with torque-controlled expansion anchors with 12 mm diameter ($d_{nom} = 12$ mm). The shock load was varied in the range from 2.9 kN to 10.9 kN. The maximum acceleration of the shock pulse was 12 g, the same in all tests.

The bolt type and sleeve type anchor systems used for the tests have a maximum permissible load for quasi-permanent actions of 2.5 kN and 3.5 kN given in the approvals from the "Deutsches Institut für Bautechnik (DIBt)". For the tests, a total of 108 anchors was used. The diagram, Figure 6, shows the measured displacement values (slip s_{dyn}) in relationship to the acting dynamic tension loads (N_{dyn}) of 60 shock tests. The diagram shows that the displacements of torque-controlled expansion anchors increase with increasing dynamic loading. Furthermore, the dispersion of the log-normal distributed slip values increases.

The evaluation of these data with the methods of exploratory data analysis (see [7] and [8]) leads to more detailed statements. Figure 7 shows the same test results as Figure 6, but represented as so-called "box and whisker plots". Herein, the "whiskers" represent the smallest and the largest slip values. The "box" is built from the two quartiles (i.e. the 25%- and 75%-fractile). The medians are drawn in as dashed lines within the boxes

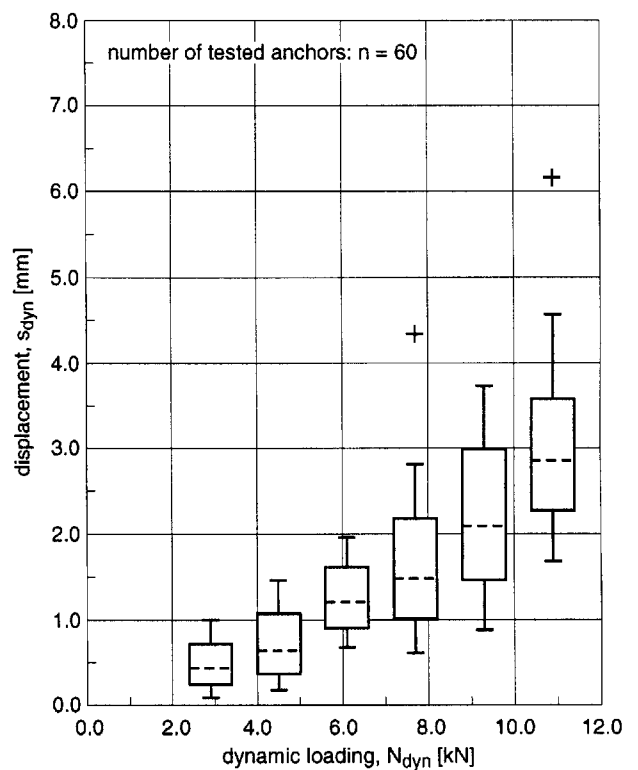
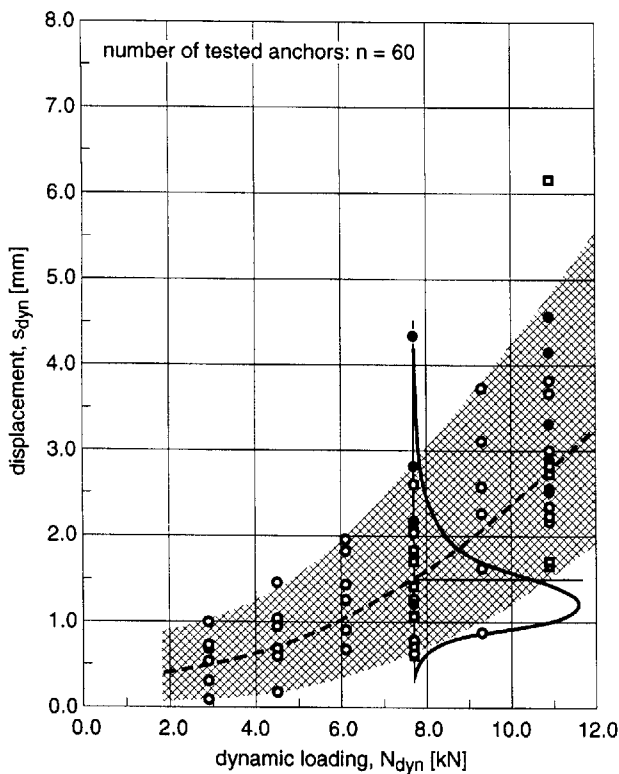


Fig. 6: Influence of the dynamic loading on the displacement of torque-controlled expansion anchors with $d_{nom} = 12$ mm set in 1.0 mm wide line cracks

Fig. 7: Box and whisker plots of the displacement for torque-controlled expansion anchors with $d_{nom} = 12$ mm, set in cracked concrete (crack width $w = 1.0$ mm)

3.3 Influence of the Anchor Type

The described investigations have been conducted with torque-controlled expansion anchors of bolt type and sleeve type from two different manufacturers, as shown in Figure 1. Out of these four anchor systems, three showed a similar load-displacement behavior. In particular, no differences between bolt type and sleeve type anchors could be established. The anchor system, which showed a significantly less stiff load-bearing behavior than the others, was of the sleeve type. However, the reasons for such differences are specific to an anchor system. There are a lot of constructive details, like the geometry of cones and spreading elements, or the friction generated within the anchor and between the expansion elements and the surface of the drilled hole, which determine the load-bearing behavior.

For the three anchor systems with identical load-bearing behavior, Figure 8 shows the measured displacements plotted against the dynamic tension loading. The represented relationship can be described in a good approach as a simple parabolic function. Herein s_{dyn} is the anchor displacement (slip) caused by the dynamic tension load N_{dyn} .

$$s_{dyn} = \alpha \cdot N_{dyn}^{\beta}$$

For torque-controlled expansion anchors with a diameter of $d_{nom} = 12$ mm, the coefficient in the formula above must be set $\alpha = 1/20$. For the mentioned anchor size the exponent is $\beta = 1.75$.

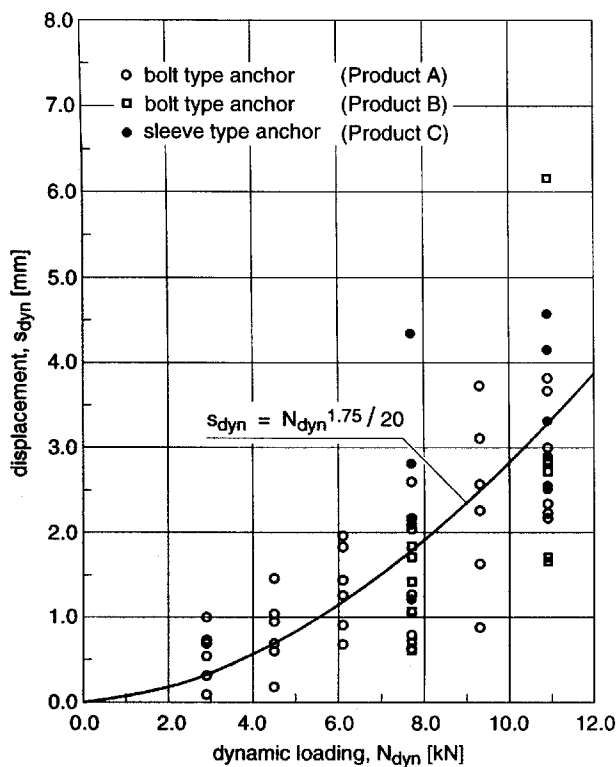


Fig. 8: Displacement of torque-controlled expansion anchors with $d_{nom} = 12$ mm as a function of shock load, for cracked concrete with crack width $w = 1.0$ mm

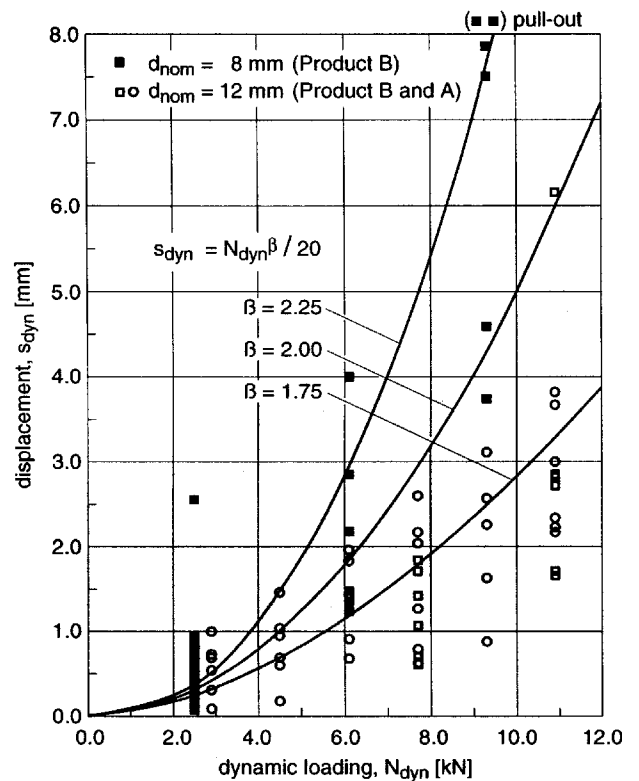


Fig. 9: Displacement of torque-controlled expansion anchors with different diameters d_{nom} as a function of shock load, for cracked concrete ($w = 1.0$ mm)

3.4 Influence of the Anchor Diameter

The range in which a further expansion of a torque-controlled expansion anchor is possible, is related to the anchor size. For anchors located in large cracks (i.e. crack width $w = 1.0$ mm) a high re-expansion or spreading is necessary for transferring the applied load. This is the reason why the anchor outside diameter d_{nom} has an important influence on the load-displacement behavior of anchors in cracked concrete.

The diagram in Figure 9 shows the slip caused by shock loading for different sized anchors with a diameter of $d_{nom} = 12$ mm respectively $d_{nom} = 8$ mm. As expected, the displacements of small anchors were significantly higher than those of the types with a larger outside diameter. Under a dynamic loading of $N_{dyn} = 9.3$ kN two small anchors failed by pull-out during the investigations.

For a mathematical description of the displacement according to the parabolic equation above, the exponent depends on the diameter of the anchor. As a result of the tests presented, the following relation between the diameter (d_{nom}) and the exponent (β) is proposed.

$$\begin{aligned}d_{nom} = 8 \text{ mm} & \quad \beta = 2.25 \\d_{nom} = 10 \text{ mm} & \quad \beta = 2.00 \\d_{nom} = 12 \text{ mm} & \quad \beta = 1.75\end{aligned}$$

4. CONCLUSIONS

In the presented study, the load-displacement behavior of dynamically loaded torque-controlled expansion anchors, set in cracked concrete, has been analyzed. For this purpose, AC-Laboratorium Spiez has conducted more than one hundred anchor shock tests with various anchor types from different manufacturers. Generally, torque-controlled expansion anchors perform well under such conditions because they are able to carry out some further expansion (re-expansion). Using expansion anchors, this is absolutely necessary for transferring impulse-like forces into concrete with large cracks.

The shock tests have been done with varying loads in a range from 3 kN to 11 kN. Thereby the maximum dynamic loading was more than four times higher than the approved static safe-working-load (permissible load) of the anchor. Nevertheless, the anchors performed very well and only two anchors with small size ($d_{nom} = 8$ mm) were pulled out. Caused by the shock loading, the anchors normally slip out of the hole a few millimeters before re-expansion takes place. This displacement has been measured. The analysis of the slip measurements has shown that the displacement clearly depends on the shock loading applied. A simple parabolic function has been found to describe this relationship in a good approach.

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