

## **LOAD BEARING BEHAVIOUR OF FASTENINGS WITH CONCRETE SCREWS**

### **TRAGVERHALTEN VON BEFESTIGUNGEN MIT SCHRAUBDÜBELN**

### **COMPORTEMENT SOUS CHARGE DES ANCRAGES AVEC VIS D'ANCRAGE**

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#### **SUMMARY**

Concrete screws are a relatively new fastening system. Their main advantage compared to traditional post-installed fastening systems is a quick and easy installation. A hole is drilled into the concrete and threads are cut in the concrete by the screw as it is installed.

Concrete screws transfer tensile loads into the base material by mechanical interlock of the threads. Due to their load-bearing mechanism, concrete screws with a technical approval of the DIBt can be used for fastenings in cracked and non-cracked concrete.

The typical failure mechanism for concrete screws is concrete-cone failure. With increasing embedment depth the ratio of the depth of the concrete failure cone to the embedment depth decreases. The failure load of concrete screws with continuous threads along the entire embedment depth increases proportionally to  $h_{ef}^{1,5}$  ( $h_{ef}$  = effective embedment depth), but it is about 20 % smaller than the failure load of expansion and undercut anchors with the same embedment depth.

In order for concrete screws to function properly, the threads cut into the wall of the drilled hole must not be damaged during the installation. This requirement is achieved by using the embedment depth defined in the Technical Approvals.

## ZUSAMMENFASSUNG

Schraubdübel sind ein relativ neues Befestigungssystem. Ihr großer Vorteil liegt in der einfachen und schnellen Montage. Es wird ein Loch in den Beton gebohrt, in das der Schraubdübel beim Setzen ein Gewinde schneidet. Schraubdübel werden in Durchsteckmontage gesetzt.

Schraubdübel übertragen eine angreifende Zuglast über mechanische Verzahnung der Gewindeflanken, die in die Bohrlochwand einschneiden, in den Untergrund. Aufgrund ihres Tragmechanismus sind bauaufsichtlich zugelassene Schraubdübel für Befestigungen im ungerissenen und gerissenen Beton geeignet.

Das Versagen erfolgt durch Betonausbruch, wobei mit zunehmender Verankerungstiefe das Verhältnis von Tiefe des Ausbruchkegels zu Verankerungstiefe abnimmt. Die Bruchlast steigt bei Schraubdübeln mit einem über die gesamte Verankerungstiefe durchgehende Gewinde proportional zu  $h_{ef}^{1,5}$  an ( $h_{ef}$  = Verankerungstiefe), jedoch ist sie unter sonst gleichen Verhältnissen ca. 20 % niedriger als die Betonausbruchlast von Spreiz- und Hinterschnittdübeln.

Damit Schraubdübel ordnungsgemäß funktionieren, dürfen die in den Beton geschnittenen Gewindegänge nicht während der Montage beschädigt werden. Diese Bedingung wird bei Einhaltung der in den bauaufsichtlichen Zulassungen festgelegten Verankerungstiefe eingehalten.

## RESUME

Les vis d'ancrage sont un système de ancrage relativement nouveau. Leur principal avantage est une installation rapide et facile. Un trou est foré dans le béton et les spires sont taraudées dans le béton par la vis lors de sa mise en place. Les vis d'ancrage transfèrent les charges de tension dans le béton par le couplage mécanique des spires. En raison de leur mécanisme porteur, les vis d'ancrage avec un agrément technique du DIBt peuvent être utilisées pour des ancrages dans le béton fissuré et non-fissuré. Le mécanisme de rupture pour les vis d'ancrage est la rupture par cône de béton. Une augmentation de la profondeur d'encrage est accompagnée d'une diminution du rapport de la profondeur du cône de béton à la profondeur d'encrage. La charge de rupture des vis d'ancrage à filetage continu sur toute la profondeur d'ancrage augmente proportionnellement à  $h_{ef}^{1,5}$  ( $h_{ef}$  = profondeur d'ancrage effective), elle est

néanmoins environ 20 % inférieure à la charge de rupture des chevilles à expansion et des chevilles à verrouillage de forme avec la même profondeur d'ancrage. Afin que les vis d'ancrage puissent fonctionner correctement, les filetages taraudés dans le béton ne doivent pas être endommagés pendant l'installation. Ceci est réalisé si l'on respecte la profondeur d'ancrage définie dans l'agrément technique.

**KEYWORDS:** concrete screw, shearing-off of threads, mechanical interlock

## **1. INTRODUCTION**

Concrete screws are a relatively new fastening system. Their main advantage compared to traditional post-installed fastening systems is a quick and easy installation. A hole is drilled into the concrete and threads are cut in the concrete by the screw as it is installed.

In Germany there are currently three different types of concrete screws from three manufacturers approved by the DIBt for fastenings with single anchors and groups in cracked and non-cracked concrete [1,2,3]. Further technical approvals exist for suspended ceilings and other comparable static systems.

During the technical approval process a large number of tests were conducted at the Institute of Construction Materials at the University of Stuttgart. Furthermore, the load bearing behaviour of concrete screws was systematically investigated through experimental and numerical studies within the scope of a research project. Important results of research reports [5, 6, 7, 8] are presented below.

## **2. CONCRETE SCREWS WITH TECHNICAL APPROVAL OF THE DIBT**

Figure 1 shows three concrete screws with a technical approval by the DIBt. The screws are intended for a drill hole diameter of  $d_0 = 10\text{mm}$  and are made of galvanised steel. They differ principally in steel strength, core diameter and thread geometry. Two of the concrete screws have small steel teeth at the end of the screw for cutting the threads into the concrete. The third concrete screw has alternating high and low screw threads. Grooves are cut into the concrete by the specially formed high screw threads.



Figure 1: Concrete screws ( $d_0 = 10\text{mm}$ ) with a technical approval of the DIBt

Concrete screws made of galvanised steel intended for a drill hole diameter of  $d_0 = 5\text{mm}$  and  $d_0 = 6\text{mm}$  are approved for suspended ceilings. Concrete screws with a drill bit diameter of  $d_0 = 8\text{mm}$  and  $d_0 = 10\text{mm}$  have a technical approval for the fastenings of statically determined and undetermined supported components in cracked and non-cracked concrete. Fastenings with single anchors and groups are allowed.

Technical approvals also exist for concrete screws made of stainless steel with drill bit diameters of  $d_0 = 6\text{mm}$  to  $d_0 = 10\text{mm}$ . To aid in the cutting of threads into the concrete, one concrete screw has an end made of galvanised steel. This end cannot be added to the embedment depth. Another concrete screw has small cutting pins made of carbon steel in the first turns to cut the threads into the concrete.

While concrete screws made of galvanised steel are only allowed for use in dry environments, the concrete screws made of stainless steel can be used outdoors, in industrial environments and near the sea.

Concrete screws made of galvanised steel are cold-rolled and subsequently tempered and heat-treated. Residual stress and incipient cracks in the steel can result from this process. To insure flawless products, special tests must be carried out during manufacturing within the scope of the internal quality control. Concrete screws made of galvanised steel, which are produced according to requirements for the technical approvals, have an indefinite lifespan in dry environments. If concrete screws made of galvanised steel are used in environments with a high corrosion risk (e.g. outdoors), a brittle failure can occur as a consequence of stress corrosion cracking. The time until failure cannot be predicted. In these cases concrete screws made of stainless steel (or other types of fastenings) must be used.

In the following section results of tests with the concrete screws type 1 to type 3 are presented. It is pointed out that the numbering of the concrete screw types is not the same as shown in Figure 1 or in the cited references.

### 3. LOAD BEARING BEHAVIOUR OF CONCRETE SCREWS

During installation, concrete screws cut a thread into the wall of the drilled hole (Figure 2). Therefore, tensile loads are transferred into the base material by diagonal struts, i.e. mechanical interlock (Figure 3a). The load transfer mechanism is similar to that of deformed reinforcing bars cast into concrete (Figure 3b) because the flanks of the screw thread function in a similar manner as the ribs of reinforcing bars. However, the laws for deformed reinforcing bars are only partially valid for concrete screws. One reason for this is that damage due to small outbreaks in the threads cut into the wall of the drilled hole can occur, which reduce the area for the mechanical interlock. Additionally, the core diameter of the concrete screw is smaller than the drill hole diameter to allow for easier installation. Consequently, the lateral restraint of the concrete is lost in the region of the highly loaded concrete consoles. To achieve sufficient load transfer into the concrete, the „relative rib area“ of concrete screws, which corresponds roughly to the ratio between the depth and the spacing of the threads cut into the wall of the drilled hole, is much larger than that of commercially available deformed reinforcing bars.



*Figure 2: Concrete screw and a thread cut into the wall of the drilled hole [9]*

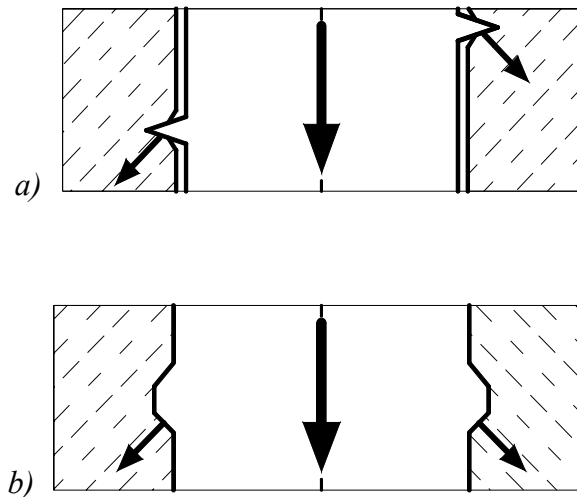


Figure 3: Transmission of tension load into concrete  
 a) Concrete screw  
 b) Cast-in-place deformed reinforcing bar

#### 4. INSTALLATION OF CONCRETE SCREWS

Concrete screws are normally screwed into the concrete using an electric-screw-gun. In technical approvals the power class [2,3] or the type of electric-screw-gun [1] is specified. The threads cut into the concrete must not be destroyed during installation. Limiting the applied torque can do this. Concrete screws can also be screwed in with a torque wrench. It cannot be excluded that concrete screws should not be screwed in using a commercial screw-wrench, because the torque necessary for tightening up after the screw head reaches the attachment can range between wide limits and therefore the threads cut into the concrete might be destroyed.

The necessary installation torque for cutting the threads into the concrete should be small in order to achieve an easy installation. Moreover, the resistance against shearing-off of the threads should be as high as possible, so that the threads cut into the concrete are not destroyed while tightening up the concrete screws.

Figure 4 shows the measured torques while screwing in a concrete screw (drill bit diameter  $d_0 = 8\text{mm}$ ) dependent on the swing angle. The failure happened by shearing-off of the threads. The anchorage material consisted of fine-grained concrete (maximum aggregate size 8mm) of the strength class B25.

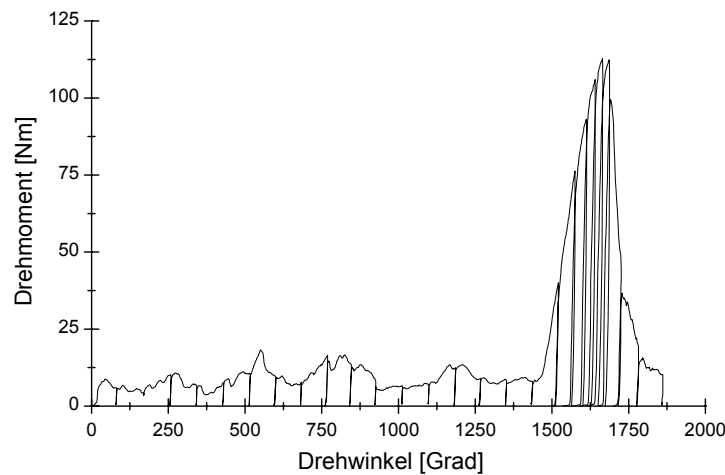


Figure 4: Typical relationship between torque moment and swing angle (Concrete B25, grading curve BC 8,  $d_0 = 8\text{mm}$ , Failure mode: Shearing-off of the thread [10])

Before the screw head reached the attachment, the necessary installation torque varied only slightly. If the concrete contains coarser aggregates, torque peaks can occur if a thread is cut into a big piece of aggregate.

After the screw head reaches the attachment, the torque on the concrete screw rises sharply to the peak value  $T_D$ . Subsequently, the shearing-off of the threads begins and the torque decreases rapidly to zero. The damage to the concrete threads after overtightening the concrete screw is shown in Figure 5. Figure 5a shows the threads after the screw head reaches the attachment (installation torque  $T_E$ ). For comparison, the threads cut into the concrete by the concrete screw ( $d_0 = 10\text{mm}$ ) at the remaining torques of  $T_{\text{Rest}} \sim 0,75T_{D,m}$  and  $T_{\text{Rest}} \sim 0,19T_{D,m}$  after reaching the peak value  $T_{D,m}$  are shown in Figure 5b and Figure 5c, respectively.

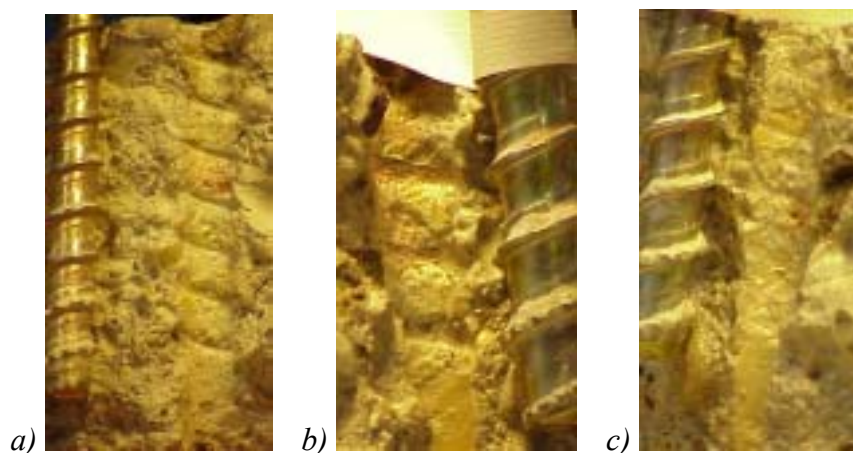


Figure 5: Threads cut into the wall of the drilled hole, concrete screw type 2 [10]

- a)  $T_{\text{inst}} = T_E$   
 b)  $T_{\text{Rest}} = 100\text{Nm} (\sim 0,75 T_{D,m})$   
 c)  $T_{\text{Rest}} = 25\text{Nm} (\sim 0,19 T_{D,m})$

### 4.1 Installation with torque wrench

Figure 6 shows the maximum measured installation torques ( $T_E$ ) of two concrete screws ( $d_0 = 10\text{mm}$ ) with a technical approval when the screw reaches the attachment. The embedment depth was chosen as  $h_{\text{nom}} = 50\text{mm}$  to achieve the failure mode of shearing-off of the threads when the screw was further tightened after coming in contact with the attachment. Figure 7 shows the measured failure torques  $T_U$ . The type of concrete screw, the cube strength ( $\beta_w \sim 20\text{N/mm}^2$  and  $\beta_w \sim 70\text{N/mm}^2$ ), the grading curve of the natural round aggregates from the Rhine valley (grading curve BC8 (maximum aggregate size 8mm) and grading curve AB 32 (maximum aggregate size 32mm) according to DIN 1045 [17]) and as well as the drill bit diameter were varied.

According to Figure 6 the installation torque  $T_E$  is not significantly influenced by the concrete strength.  $T_E$  increases, however, with an increasing aggregate size. A substantial influencing factor is the drill bit diameter, since there is an increase of the depth of the threads cut into the concrete if the drill bit diameter is reduced. Furthermore, the type of concrete screw significantly influences the installation torque.

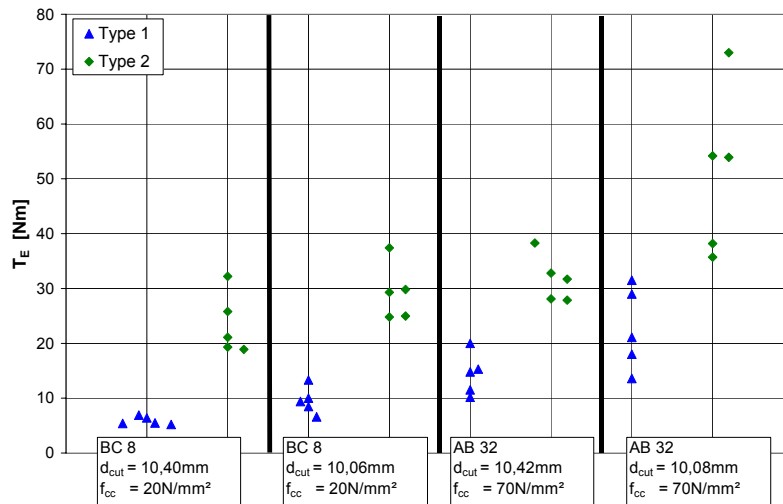


Figure 6: Influences on the installation torque moment  $T_E$  [9]

Upon further tightening after the screw head reached the attachment, concrete screw type 1 failed in all tests by twisting-off of the screw head (steel failure). Consequently the variance of the failure torques is small (Figure 7). On the other hand, concrete screw type 2 failed by shearing-off of the threads cut into the concrete except in the tests in high strength concrete  $\beta_w \sim 70\text{ N/mm}^2$  with maximum aggregate size (grading curve AB 32) and a tight drill hole. The failure



torques in case of shearing-off of the threads are barely affected by the concrete strength and the composition of the concrete. However, they increase as was the case for the installation torques, with decrease of the drill bit diameter.

The different failure modes of concrete screw type 1 and type 2 can mainly be attributed to the fact that the steel strength of concrete screw type 2 is higher than the steel strength of type 1. For that reason concrete screw type 2 needs a larger embedment depth than type 1 to reach the failure mode of steel failure.

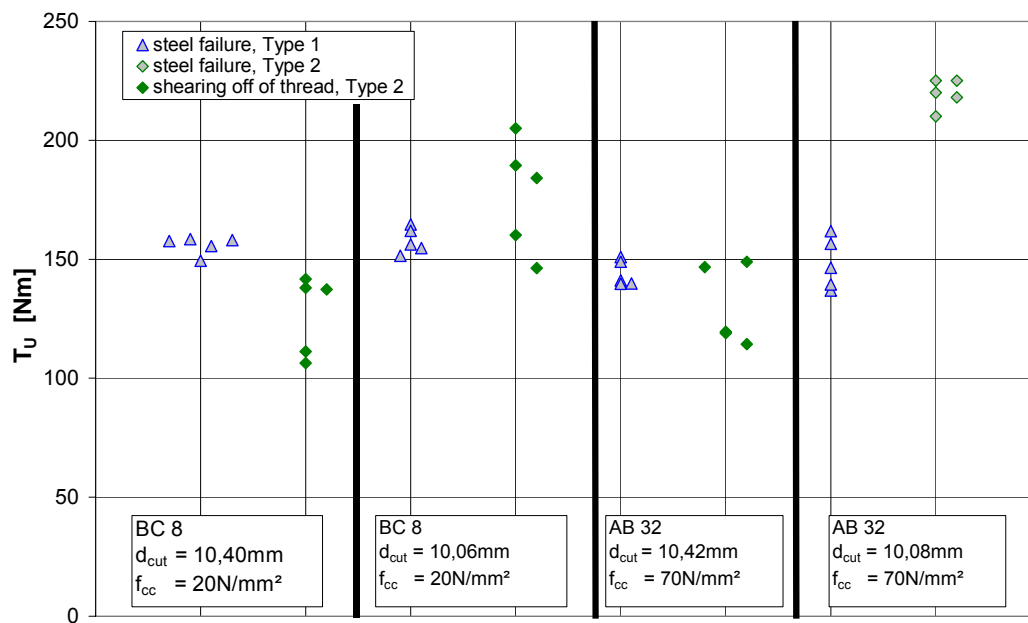


Figure 7: Influences on the failure torque moment  $T_U$  [9]

By increasing the embedment depth the installation torque increases only slightly because the threads are mainly cut into the concrete by the flanks of the screw thread at the head of the screw.

On the other hand, the failure torque in the case of shearing-off of the threads cut in the concrete increases with increasing embedment depth (Figure 8), because more threads have to be sheared off. The embedment depth required by the technical approvals with  $h_{nom} \geq 70\text{mm}$  is significantly larger than the embedment depth used in the tests shown in Figure 7. This ensures that the failure mode steel failure occurs and not the failure mode shearing-off of the threads (Figure 8) if the concrete screw is overtightened during installation.

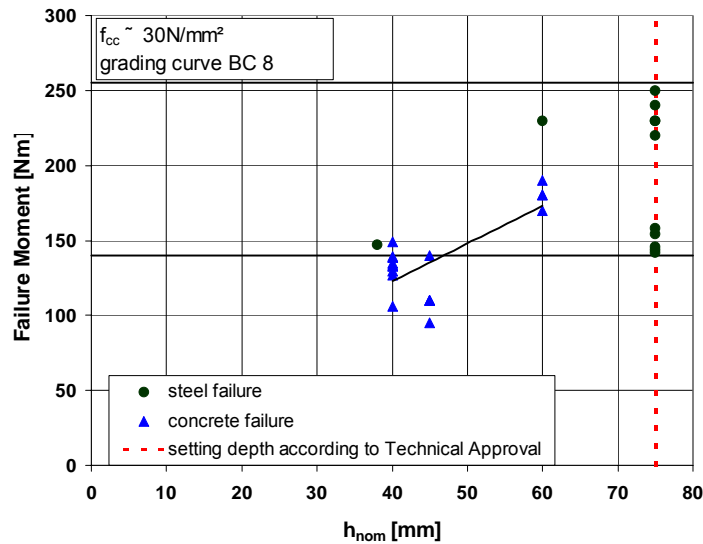


Figure 8: Influence of the embedment depth on the failure torque moments [11]

## 4.2 Installation with electric-screw-gun

While the installation of a concrete screw with a torque wrench or a screw-wrench requires more than 30 seconds for the screw head to reach the attachment, installation with a high-performance electric-screw-gun requires only one to two seconds. For this reason, in practice concrete screws are usually screwed-in with an electric-screw-gun. In the setting tests electric-screw-guns with a maximum moment higher than the steel failure torque moment of the concrete screws were used. Nevertheless, the concrete screws failed by shearing-off of the threads after the screw head reached the attachment. The time between reaching the attachment and shearing-off of the threads  $t_K$  increases with increasing embedment depth (Figure 9).

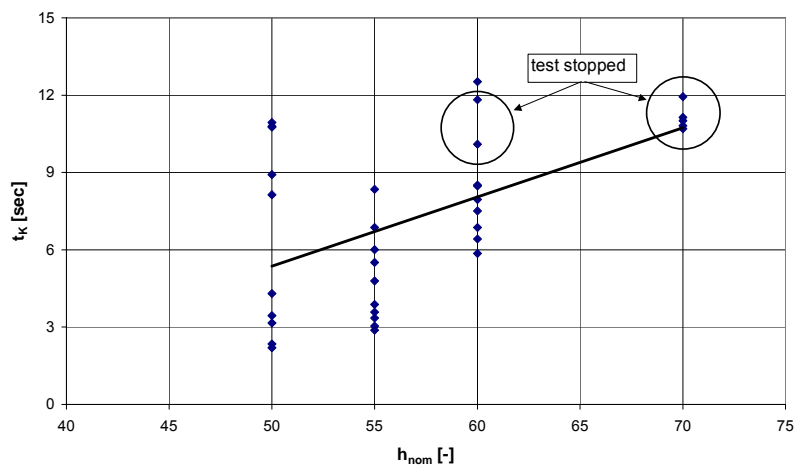


Figure 9: Influence of the embedment depth on the time until shearing-off of the threads cut into the wall of the drilled hole ( $d_0 = 10\text{mm}$ , grading curve BC 8,  $\beta_w = 26\text{N/mm}^2$ ,  $d_{cut} = 10,41\text{mm}$ , electric-screw-gun 1)

The time between reaching the attachment and shearing-off of the threads is little affected by the concrete strength and the composition of the concrete (Figure 10). It is affected significantly by the drill bit diameter, the type of concrete screw and the type of electric-screw-gun used for installation (Figure 11).

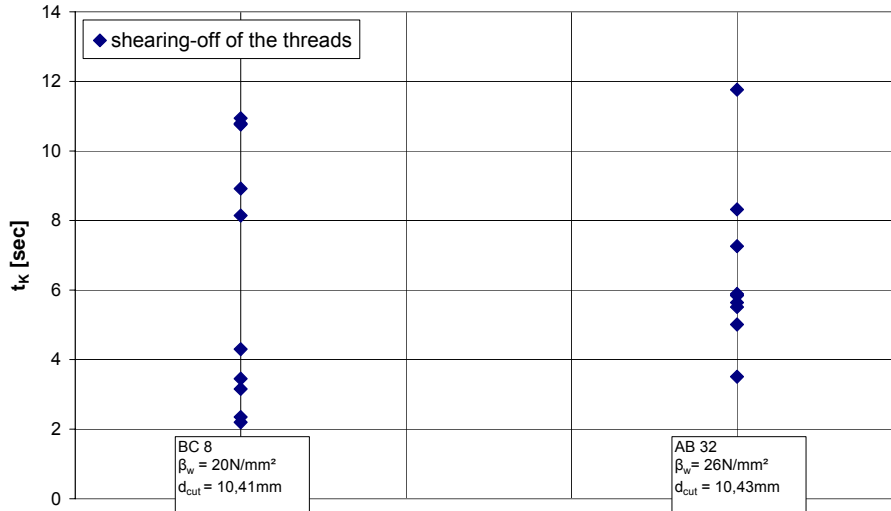


Figure 10: Influence of composition of concrete on the time until failure  $t_k$  ( $d_0 = 10\text{mm}$ ,  $h_{nom} = 50\text{mm}$ )

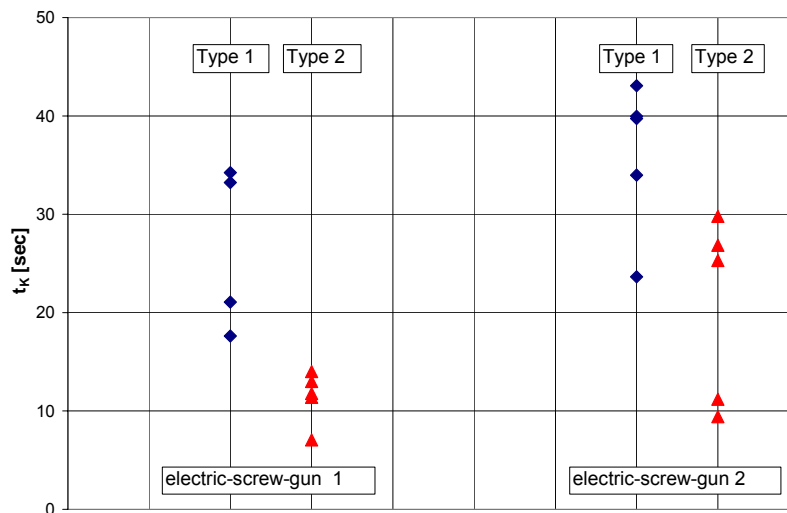


Figure 11: Influence of electric-screw-gun and type of concrete screw on the time until failure ( $d_0=10\text{mm}$ ,  $\beta_w = 20\text{N/mm}^2$ , grading curve BC 8,  $h_{nom} = 50\text{mm}$ ,  $d_{cut} = 10,41\text{mm}$ ) [9]

In practice it may occur that concrete screws are unscrewed after the screw head reaches the attachment (e.g. for easier installation of a group). Therefore, the influence of unscrewing concrete screws on the time until failure  $t_k$  was investigated. Screws without unscrewing were tested for comparison. Figure 12 shows the test results. If concrete screws are unscrewed one complete turn with a screw-wrench after the screw head reaches the attachment and then screwed in

again with an electric-screw-gun, the minimum time until failure  $t_K$  decreases in comparison with concrete screws that were not unscrewed. If the unscrewing of the concrete screw takes place with an electric-screw-gun, the time until failure  $t_K$  decreases significantly because it is not possible to unscrew concrete screws in a controlled manner with an electric-screw-gun.

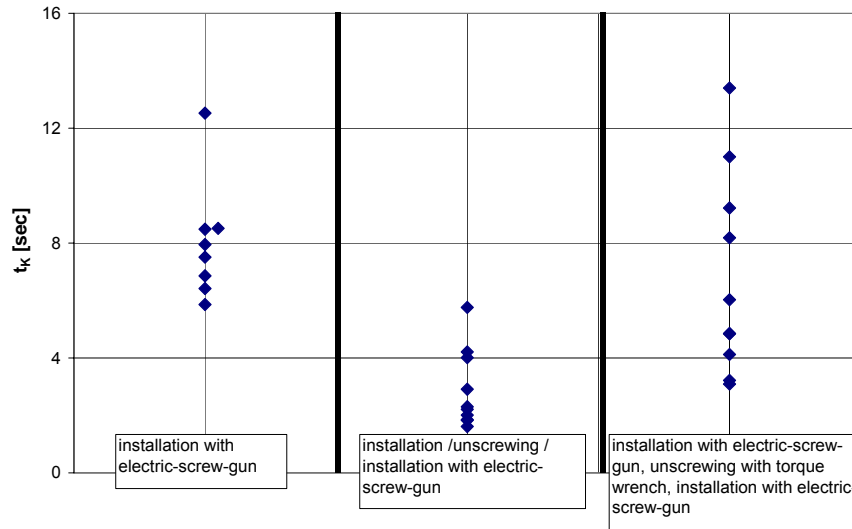


Figure 12: Influence of unscrewing of concrete screws on the time  $t_K$  until failure ( $d_0 = 10\text{mm}$ ,  $f_{cc} = 26\text{N/mm}^2$ , grading curve BC8,  $d_{cut} = 10,44\text{mm}$ ,  $h_{nom} = 60\text{mm}$ , electric-screw-gun 1)

### 4.3 Remaining load-carrying capacity

To investigate the influence of the installation torque, i. e. the over-tightening of the concrete screw, on the pull-out failure load, the concrete screws were installed until the screw head reached the attachment ( $T = T_E$ ), prestressed with  $T \sim 0,9 T_{D,m}$  or until the torque moment fell to a preset value  $T = T_{Rest}$  after reaching the maximum torque. Afterwards the concrete screws were pulled out. Figure 13 shows the measured failure loads depending on the installation torque. If the torque of the concrete screw is stopped immediately after reaching the maximum torque, the measured pull-out failure loads are in the same range like in the tests with concrete screws that were prestressed with  $T = T_E$  or with  $T \sim 0,9 T_{D,m}$ . Furthermore, the load-displacement behaviour does not differ significantly (Figure 14). If the concrete screws are turned further, the failure load falls rapidly, because the threads cutting into the wall of the drilled hole are destroyed (cp. Figure 5). Furthermore, the load-displacement behaviour is less favourable. The behaviour shown in Figure 13 and Figure 14 also applies to other types of concrete screws if they are seated with an embedment depth at which shearing-off of the threads is possible.

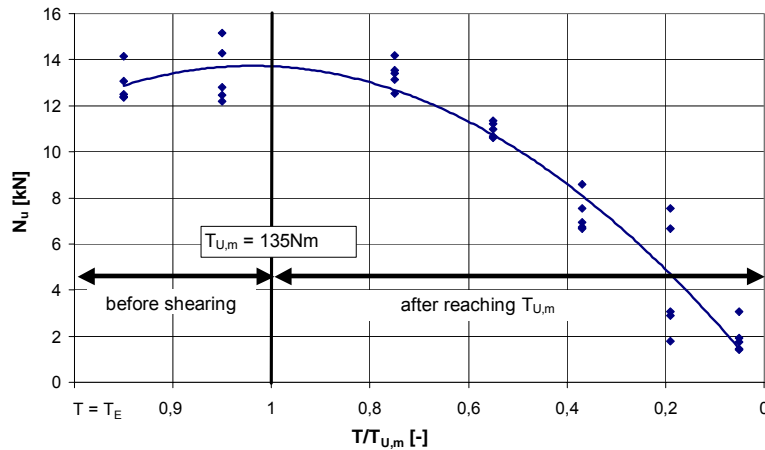


Figure 13: Influence of torque before and after reaching the failure torque on the pull-out load ( $d_0 = 10\text{mm}$ ,  $h_{nom} = 50\text{mm}$ ,  $d_{cut} = 10,42\text{ mm}$ ,  $f_{cc} = 30\text{N/mm}^2$ )

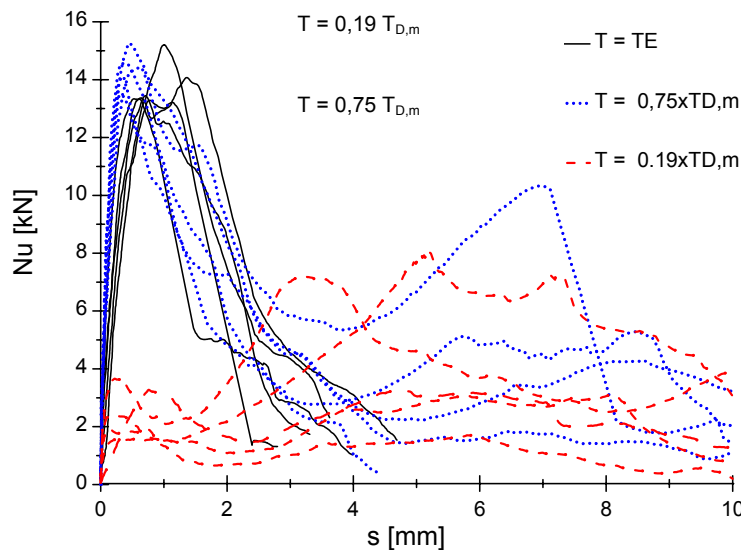


Figure 14: Influence of the torque moment before and after reaching the failure torque on the load-displacement curves

#### 4.4 Required embedment depth

In practice it cannot be excluded that concrete screws are further tightened after the screw head reaches the attachment, e. g. if the electric-screw-gun is not stopped immediately or if the attachment should be tightened against the surface of the concrete slab with a standard screw-wrench. Unscrewing of the concrete screws and screwing them in again can also occur. This may damage the threads cut into the wall of the drilled hole, if the embedment depth is not deep enough because in practice it is normally not possible to stop the installation after reaching the maximum torque  $T_D$ . This has been shown by experiences in practice. A check of concrete screws ( $d_0 = 6\text{mm}$ ) that were seated with a small embedment depth showed that shearing-off of the threads during the installation had occurred with about 15% of the screws.

To avoid damage of the threads cut into the concrete, the embedment depth of the concrete screws with a technical approval of the DIBt was defined such that steel failure and not shearing-off of the threads will occur during installation with a standard screw wrench (Figure 8). At this embedment depth a long period of time is needed to shear-off of the threads using an electric-screw-gun. It is assumed that in practice a time period as long as this is not applied.

Concrete screws with a larger core diameter than the concrete screws with a technical approval have very high torque moments in the case of steel failure. Therefore, it makes no sense to evaluate the minimum embedment depth of these concrete screws since that steel failure occurs. Presently a new concept for concrete screws with  $d_0 > 10\text{mm}$  is being developed to avoid the damage of the threads cut into the concrete during the installation.

## 5. LOAD BEARING BEHAVIOUR OF CONCRETE SCREWS

### 5.1 Load-displacement behaviour and failure mode

Figure 15 shows typical load-displacement curves measured in pull-out tests under tension load in cracked ( $\Delta w = 0,3\text{mm}$ ) and non-cracked concrete. They increase steeply and lie close together. The failure modes were pull-out and concrete cone failure.

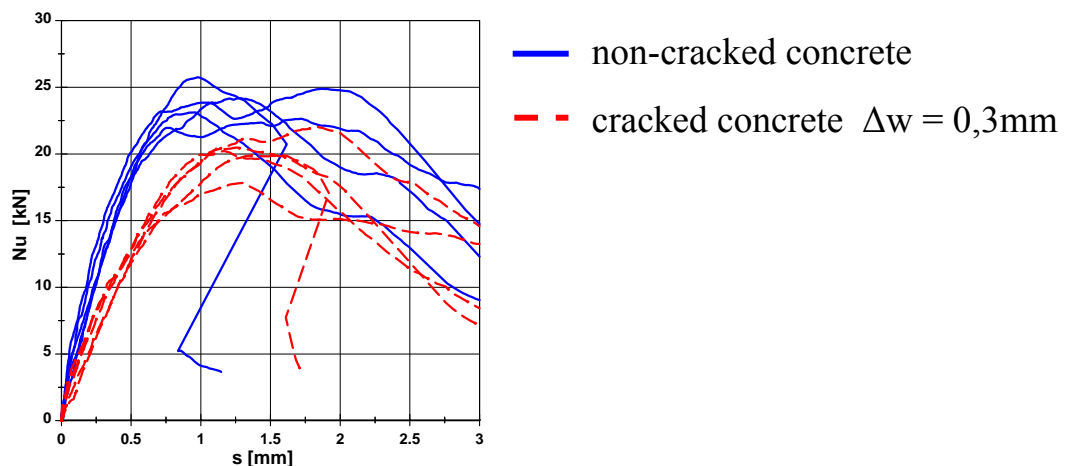


Figure 15: Typical load-displacement curves for concrete screws in cracked and non-cracked concrete ( $h_{ef} = 65\text{mm}$ ,  $d_{cut} = 10,25\text{mm}$ ,  $f_{cc} = 30\text{N/mm}^2$ , grading curve AB 16) [11]

Concrete screws with a small embedment depth fail through a concrete failure cone that starts at the first bearing thread at the tip of the concrete screw (Figure 16a). If the embedment depth increases, only the concrete at the surface breaks out and the remaining portion of the screw is pulled out (Figure 16b).

The observed failure modes differ from the failure mode of expansion anchors and undercut anchors. These anchors transfer the load into the concrete near the end of the embedment depth and the concrete cone failure begins near the end of the anchor. On the other hand, concrete screws discharge the load over the entire embedment depth into the concrete.

The failure mode shown in Figure 16 is similar to that of bonded anchors but the failure load of bonded anchors increases nearly linearly with increasing embedment depth ( $h_{ef}$ ) [12]. Whereas the failure load of concrete screws increases by  $h_{ef}^{1,5}$  (see section 5.2.1). Therefore, the failure of concrete screws is due to exceedence of the concrete tension strength in the failure cone and not to pullout as for bonded anchors.



Figure 16: Typical concrete failure cones [9]  
 a)  $h_{nom} = 50\text{mm}$   
 b)  $h_{nom} = 90\text{mm}$

## 5.2 Failure Loads

To clarify the influence of different parameters on the failure loads of concrete screws, pull-out tests in concrete slabs with a cube strength of about  $\beta_w \sim 30\text{N/mm}^2$  were performed. The concrete slabs were produced from concrete with a grading curve AB16 (aggregates with maximum size 16mm) according to DIN 1045 [17]. Natural round aggregates from the Rhine valley were used. For drilling of the holes, drill bits with medium bit diameter according to [4] were used. The measured failure loads were normalized by  $\beta_w^{0,5}$  to  $\beta_w = 30\text{N/mm}^2$  because the failure is caused by exceedence of the concrete tension strength.

## Influence of the embedment depth

Figure 17 shows the measured failure loads of concrete screws produced by manufacturer 1 for various embedment depths  $h_{ef}$ . The investigated parameter is the drill hole diameter  $d_0$ . The effective embedment depth was determined according to equation (1).

$$h_{ef} = h_{nom} - 0,5 \cdot h - h_s \quad (1)$$

with:

$h_{nom}$  = length between end of concrete screw and concrete surface

$h$  = threaded length of concrete screw

$h_s$  = length of screw without thread

Equation (1) considers that load discharge starts with a transfer from the top of the concrete screw that is dependent on the kind of thread of the concrete screw. It enables a better comparison of the test results of concrete screws from different manufacturers, i. e. with different kind of threads.

According to Figure 17 the failure loads of concrete screws increase proportionally to  $h_{ef}^{1,5}$ . That relation also applies to expansion and undercut anchors failing by concrete cone failure. Figure 17 applies to concrete screws with threads over the complete embedment depth. If concrete screws only have threads over part of the embedment depth, the failure load will not increase after reaching a certain embedment depth, because the failure mode changes to pull-out failure (shearing-off of the concrete between the screw flanks). This is similar to the behaviour of torque-controlled expansion anchors, where the failure mode changes with increasing embedment depth from concrete cone failure to pull-through failure [14].

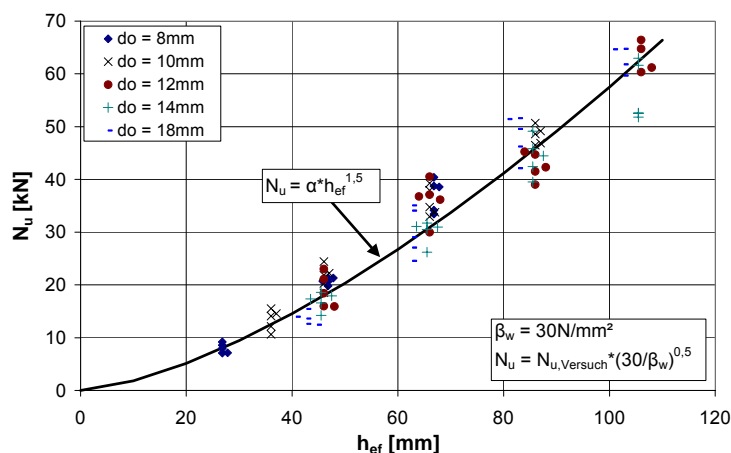


Figure 17: Influence of embedment depth on failure load



## Influence of concrete screw Diameter

For identification of concrete screws, the drill hole diameter is used because concrete screws from different manufacturers intended for the same drill hole diameter differ in their core and outside diameters. Figure 18 shows failure loads for various drill hole diameters. Parameter is the embedment depth  $h_{ef}$ . For a comparison at the same effective embedment depth the measured failure loads were normalized by  $h_{ef}^{1,5}$ . The straight lines in Figure 18 show the trends of the test results. One can see that the failure loads decrease slightly with increasing drill hole diameter at lower embedment depth and the failure loads are independent of the drill hole diameter at larger embedment depth. However, in all cases the influence of the drill hole diameter on the failure load is not significant.

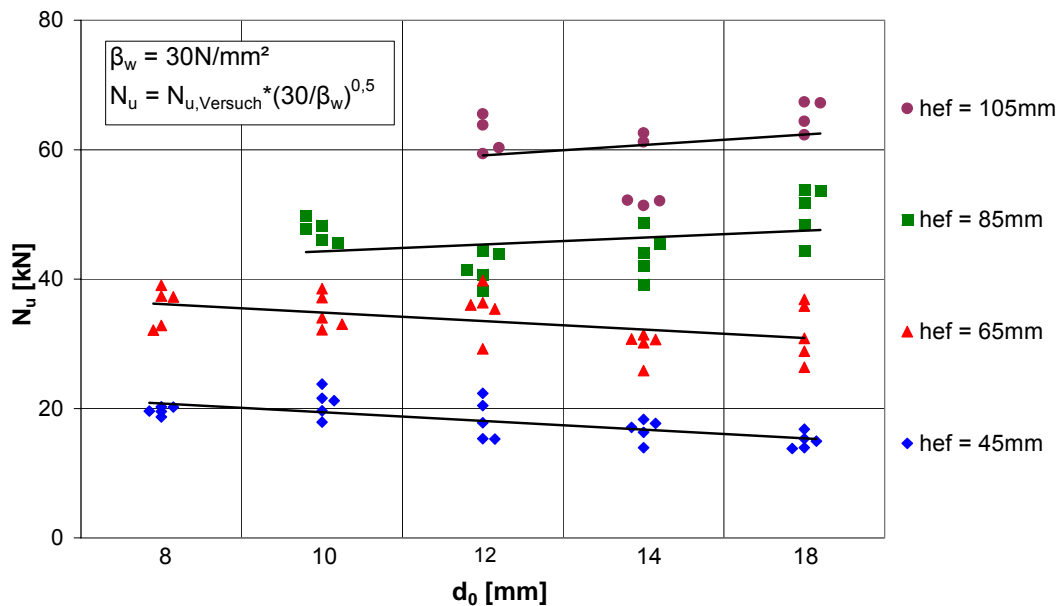


Figure 18: Influence of concrete screw size on failure load

## Influence of the concrete screw type

Figure 19 shows the failure loads of concrete screws with a drill bit diameter  $d_0 = 10\text{mm}$  to various embedment depths. The investigated parameter is the type of concrete screw. The figure shows that the failure loads of different concrete screws differ a little under similar conditions. That can be attributed to the different threads. The different load bearing performances of the concrete screws were considered when determining the characteristic resistance for concrete cone failure in the technical approvals of the DIBt.

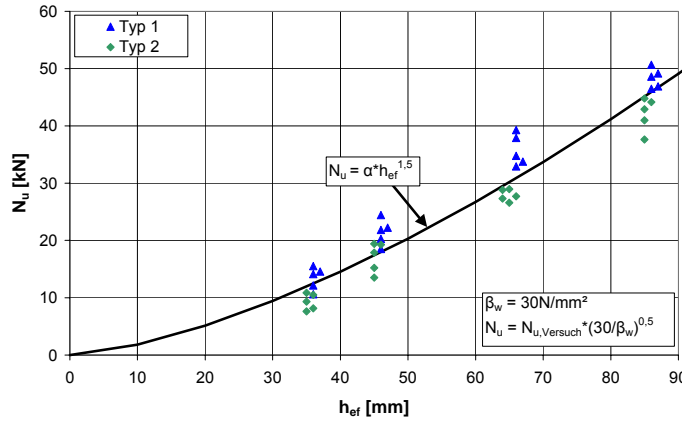


Figure 19: Influence of the type of concrete screw ( $d_0 = 10\text{mm}$ ) on the failure loads

### Influence of Screw Spacing

To investigate the influence of the screw spacing on the failure loads, groups with four concrete screws in concrete with the concrete strength near  $\beta_w \sim 30\text{N/mm}^2$  were tested. The screw spacing was varied. At small spacing the groups failed by a combined concrete cone failure (Figure 20a). At a spacing of  $s = 2 h_{nom}$  a changeover to several failure cones was observed (Figure 20b).



Figure 20: Concrete failure cone of square groups with concrete screws

a)  $s = 1 h_{nom}$  and

b)  $s = 2 h_{nom}$  ( $d_0 = 10\text{mm}$ ,  $h_{nom} = 70\text{mm}$ )

While the screw spacing does not significantly influence the stiffness at the beginning of the tests, the failure loads and the displacement at failure load increase with increasing screw spacing (Figure 21). Figure 22 shows the failure loads of square groups based on the average failure load of a single concrete screw as a function of the relationship between spacing and effective embedment depth.

The failure loads of groups increase with increasing screw spacing, but they did not reach the fourfold value valid of a single anchor at a larger spacing. The reason for this is not yet known.

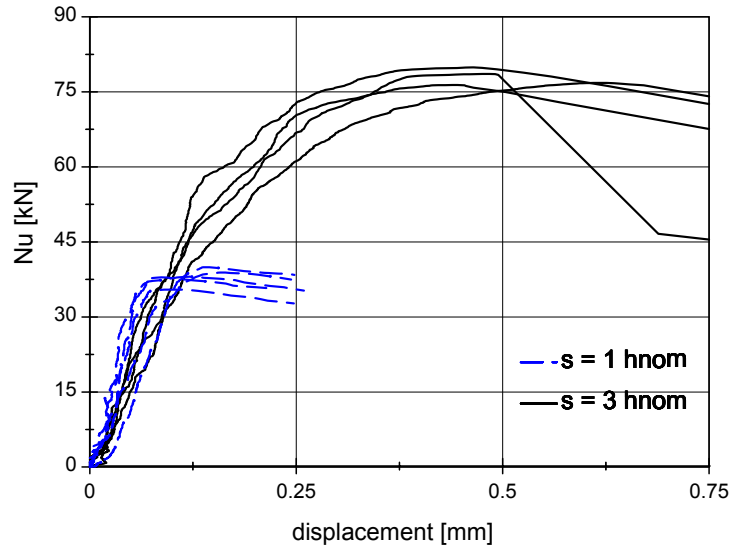


Figure 21: Typical load-displacement curves of groups of concrete screws ( $d_0 = 10\text{mm}$ ,  $h_{nom} = 50\text{mm}$ )

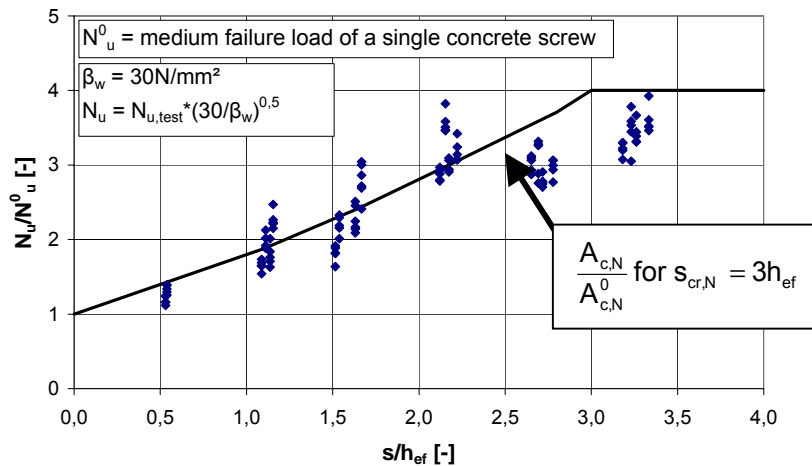


Figure 22: Failure loads of square groups of concrete screws based on the average failure load of a single concrete screw ( $d_0 = 10\text{mm}$ )

### Influence of cracks in concrete

The results shown so far apply for non-cracked concrete. In structural members of reinforced concrete one can assume that cracks in the concrete appear. If a concrete screw is anchored in a crack, the undercut area of the thread flanks is reduced in comparison to non-cracked concrete. Furthermore, the axially symmetric state of stress around the screw is disturbed by the crack. These effects cause that the stiffness of the fastening and the failure loads in comparison to non-cracked concrete are reduced (Figure 15). The decrease of the failure load averages about 30 % at a crack width of 0,3mm. This reduction is on the same order of magnitude as that for expansion or undercut anchors.

## 6. CALCULATION OF THE AVERAGE FAILURE LOAD OF SINGLE ANCHORS

Figure 23 shows the failure loads of different types of concrete screws with varying outside diameters as a function of the embedment depth. For comparison, the bearing capacity after Equation (2) is shown. The equation describes the average concrete cone failure load of expansion and undercut anchors [13].

$$N_{u,c}^0 = 13,5 * h_{ef}^{1,5} * \sqrt{\beta_w} \quad (2)$$

with

$\beta_w$  = concrete cube compressive strength (200mm)

$h_{ef}$  = effective embedment depth

The failure loads of concrete screws are below the values predicted by equation (2). This can be attributed to the different failure modes (Chapter 5.1). If the influence of the concrete screw type and the diameter is neglected, the measured failure loads can be described with adequate accuracy by Equation (3).

$$N_u^0 = 10,5 * h_{ef}^{1,5} * \sqrt{\beta_w} \quad (3)$$

with

$h_{ef}$  = effective embedment depth after Equation (1)

The values  $N_{u,test}/N_{u,calculation}$  are normally distributed around average value of 1,0 with a coefficient of variation  $v \sim 15\%$  (Figure 24). According to the test results the failure loads of concrete screws are about 20% lower than the failure loads of expansion and undercut anchors. Equation (3) does apply to fastenings in non-cracked concrete. For fastenings in cracked concrete Equation (3) has to be multiplied with the factor 0,7.

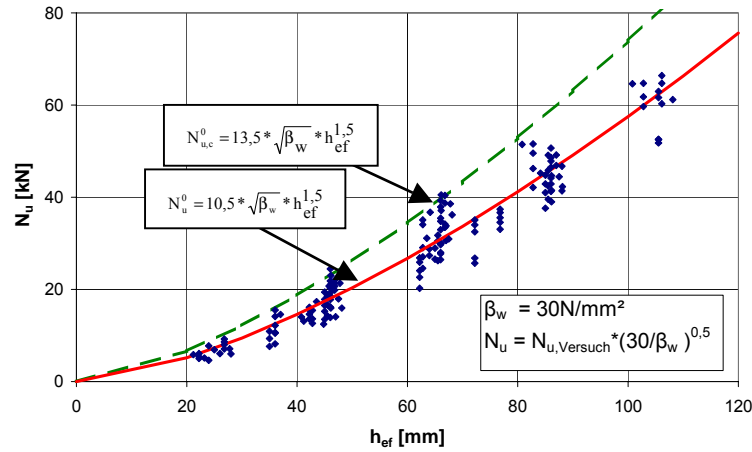


Figure 23: Maximum pull-out loads of concrete screws in non-cracked concrete as a function of the embedment depth  $h_{ef}$  and comparison with prediction by CC-method for concrete cone failure

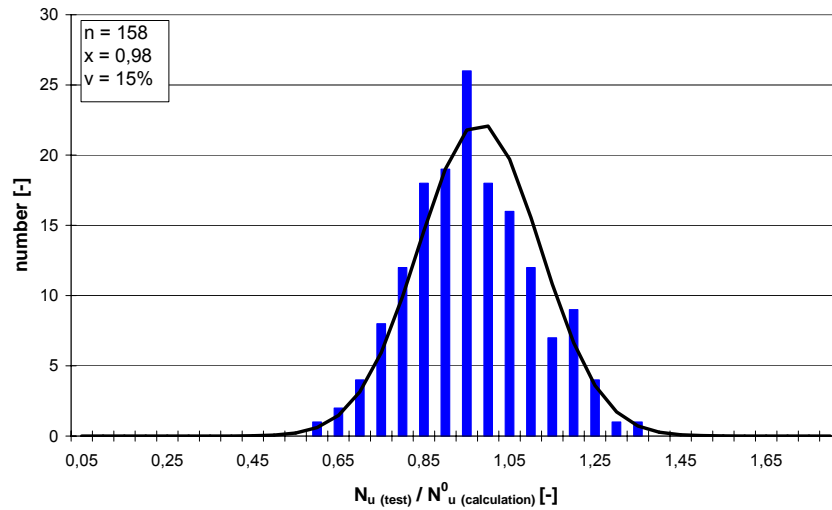


Figure 24: Histogram of the quotient of measured and calculated concrete failure load by tension tests with concrete screws

The failure load  $N_u$  of groups with concrete screws evaded centrally can be calculated according to the CC-Method (Equation (4))

$$N_u = \frac{A_{c,N}}{A_{c,N}^0} * N_u^0 \leq n * N_u^0 \quad (4)$$

with

$A_{c,N}^0 =$  area of concrete cone of an individual anchor with large spacing and edge distance at the concrete surface, idealizing the concrete cone as a pyramid with height equal to  $h_{ef}$  and a base length equal to  $s_{cr,N}$

$A_{c,N}$  = actual area of concrete cone of the anchorage at the concrete surface. It is limited by overlapping concrete cones of adjoining anchors ( $s \leq s_{cr,N}$ ) as well as by edges of the concrete member ( $c \leq c_{cr,N}$ ). Examples for the calculation of  $A_{c,N}$  are given in [14, 15]

$N$  = number of anchors of the group

For expansion and undercut anchors the critical anchor spacing is  $s_{cr,N} = 3h_{ef}$  ([14, 15]). The failure load of concrete screws at the same embedment depth is lower than that of expansion and undercut anchors. However, Figure 22 shows that the test results can be described approximately with  $s_{cr,N} = 3 h_{ef}$ .

## 7. DESIGN OF FASTENINGS WITH CONCRETE SCREWS THAT MEET TECHNICAL APPROVALS

In references [1] to [3] the design of fastenings with concrete screws takes place according to design method A in [16], which is based on the CC-Method. The characteristic values necessary for the design of fastenings with concrete screws with  $d_0 = 10\text{mm}$  under tension load are assembled in Table 1. The high characteristic resistance  $N_{Rk,s}$  at steel failure cannot be exploited because it is higher than the characteristic resistance  $N_{Rk,p}$  at pullout. The values  $N_{Rk,p}$  were determined from the tests for the technical approvals. The behaviour of the fastening in cracks with opening and closing crack widths was considered as well. The design at the failure mode “concrete cone failure” takes place according to the CC-Method for expansion and undercut anchors which is described in detail in [14, 15].

For consideration of the lower load capacity of concrete screws in comparison to expansion and undercut anchors in Equation (5) a reduced embedment depth  $h_{ef,cal}$ , in comparison to equation (1), is used to calculate the characteristic resistance against concrete cone failure for a single concrete screw. The embedment depths used are stated in Table 1.

$$N_{u,c}^0 = 7,0 * h_{ef,cal}^{1,5} * \sqrt{\beta_{WN}} * \psi_w \quad (5)$$

with

$\beta_{WN}$  = nominal value of the cube strength after DIN 1045 [17]

$h_{ef,cal}$  = nominal effective embedment depth (Table 1)

$\psi_w$  = 1,0 for fastenings in cracked concrete

= 1,4 for fastenings in non-cracked concrete

Table 1: Characteristic values for the resistances under tension load of concrete screws ( $d_0 = 10\text{mm}$ ) with a Technical Approval of the DIBt

Type of concrete screw			[1]	[2]	[3]
Drill hole diameter	$d_0$	[mm]	10	10	10
Embedment depth	$h_{\text{nom}}$	[mm]	70	75	85
Steel failure					
Characteristic resistance	$N_{\text{Rk,s}}$	[kN]	54,1	75,4	58
Pull-out failure					
Characteristic resistance in non-cracked concrete B 25	$N_{\text{Rk,p}}$	[kN]	12,0	16,0	20,0
Characteristic resistance in cracked concrete B 2	$N_{\text{Rk,p}}$	[kN]	7,5	12,0	12,0
Concrete cone failure					
Nominal effective embedment depth	$h_{\text{ef,cal}}$	[mm]	50	50	60
Characteristic screw spacing	$s_{\text{cr,N}}$	[mm]	150	150	180
Characteristic edge distance	$c_{\text{cr,N}}$	[mm]	75	75	90

## 8. SUMMARY

Concrete screws are a relatively new fastening system. Their main advantage compared to traditional post-installed fastening systems is a quick and easy installation. A hole is drilled into the concrete and threads are cut in the concrete by the screw as it is installed.

Concrete screws transfer tensile loads into the base material by mechanical interlock of the threads. Due to their load-bearing mechanism, concrete screws with a technical approval of the DIBt can be used for fastenings in cracked and non-cracked concrete.

The typical failure mechanism for concrete screws is concrete-cone failure. With increasing embedment depth the ratio of the depth of the concrete failure cone to the embedment depth decreases. The failure load of concrete screws with continuous threads along the entire embedment depth increases proportionally to  $h_{\text{ef}}^{1,5}$  ( $h_{\text{ef}}$  = effective embedment depth), but it is about 20 %

smaller than the failure load of expansion and undercut anchors with the same embedment depth.

In order for concrete screws to function properly, the threads cut into the wall of the drilled hole must not be damaged during the installation. This requirement is achieved by using the embedment depth defined in the Technical Approvals.

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