Testing and Approval of Anchor Systems


This English translation has been prepared by MKT to the best of its knowledge.

- Original version in German language
City/Date       Winterthur, 5. May 2006  
               (Edition 2017)

Contracting Authority       Federal Office for Civil Protection FOCP  
                             Spiez Laboratory  
                             FOCP Certification Office  
                             CH-3700 Spiez

Report       Testing and Approval of Anchor Systems

Report No.       BBS-7531/4

Author       Daniel Schuler  
             BBS Ingenieure AG  
             Gertrudstrasse 17  
             CH-8400 Winterthur  
             Telephone +41 52 260 07 10  
             daniel.schuler@bbs-ing.ch
Terms and abbreviations

<table>
<thead>
<tr>
<th>CSTB</th>
<th>Centre Scientifique et Technique du Bâtiment (Scientific and Technical Centre for Buildings)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIBT</td>
<td>Deutsches Institut für Bautechnik (German Institute for Structural Engineering)</td>
</tr>
<tr>
<td>EC</td>
<td>Eurocode</td>
</tr>
<tr>
<td>EOTA</td>
<td>European Organisation for Technical Approvals (Europäische Organisation für Technische Zulassungen)</td>
</tr>
<tr>
<td>ETA</td>
<td>European Technical Approval /European Technical Assessment (Europäische Technische Zulassung / Europäische Technische Bewertung)</td>
</tr>
<tr>
<td>ETAG</td>
<td>Guideline for European Technical Approval (Leitlinie für die Europäische Technische Zulassung)</td>
</tr>
<tr>
<td>FOCP</td>
<td>Federal Office for Civil Protection</td>
</tr>
<tr>
<td>VESPA</td>
<td>Vertikale Schockprüfanlage (Vertical Shock Testing System)</td>
</tr>
</tbody>
</table>
1 Introduction

The suitability of fastenings and anchor systems is tested for use in protective structures. For this reason, shock tests with anchor systems have been carried out for several decades. These types of tests - hereinafter also referred to as anchor shock tests - are used to test and prove the suitability of the anchors for fixing protective components under shock action and in cracked concrete substrate.

The shock tests are carried out by the Federal Office for Civil Protection FOCP in the testing laboratory for NBC protection material at Spiez Laboratory. The test laboratory STS 0055, accredited according to ISO 17025, has the required test methods and equipment to subject concrete anchors to a shock-like loading and to measure their load-bearing behavior during shock loads.

Protective structures are designed such that they can withstand a certain earth shock load defined by the degree of protection. For economic reasons, protective structures are designed such that they are plastically deformed by an earth shock load caused by a nuclear explosion. The resulting cracks in the reinforced concrete members of the structure are of decisive importance for the load bearing behavior of the anchorage. The anchor shock tests determine whether an anchor system is suitable for use in protective structures. Suitable systems must be capable of transmitting shock loads in cracked concrete with a crack width of 1.0 mm.
2 General

2.1 Quality management

2.1.1 General principles

In accordance with the instructions\(^1\) of the Federal Office for Civil Protection FOCP, the following entities (partners) are specifically responsible for the overall quality of a component in general and for ensuring protective function and functionality within the civil protection area.

- **Supplier / Manufacturer / Applicant / Approval holder**
  Partner who manufactures and distributes the components subject to the testing requirements and receives approval for use of the product in Swiss civil protection.

- **Certification Office**
  The FOCP Certification Office is responsible for the implementation of quality management. It specifies, among other things, the scope of testing, assigns the test work to the test center and issues the approvals.

- **Testing Laboratory**
  The accredited testing laboratories of FOCP Spiez Laboratory are responsible for technically competent, appropriate and correct testing of components subject to the testing requirements and has the necessary resources.

2.1.2 Anchor shock test procedure and participating entities

Fastening elements, anchors and anchor channels are subject to the testing requirements according to the policies of the FOCP. Since the quality of anchors with European Technical Approval (ETA) and European Technical Assessment (ETA) respectively are subject to third party inspections, they are classified as non-critical components (Model 1).

For anchors the approval is issued according to Model 1 based on the successfully passed type test. Approval is granted for ten years. An approval extension is granted for an additional ten years in each case. The extension is made by means of a technical assessment. A new type test is conducted in the event a technical assessment is not possible based on the available technical documents. Provided no changes have been made to the anchors, the approval number (BZS D yy-xxx) remains the same during the term of the approval. If changes were made to the anchors, a new type test is required and the anchor receives a new approval number once the test is passed.

\(^1\) Weisungen Qualitätsmanagement für prüfpflichtige Komponenten im Bereich Zivilschutz, Bundesamt für Bevölkerungsschutz, Bern, 10. Februar 2005
The Spiez Laboratory consults an external expert for the preparation and analysis of the anchor shock tests. The expert has extensive expertise in the fields of fastening technology, structural dynamics and protective structure engineering. The expert specifies the test program based on probabilistic principles and prepares an expert opinion on the basis of a statistical analysis of the test results. The expert is commissioned by the FOCP Certification Office. Also the document control is carried out by the Certification Office.

**Figure 1** Anchor shock test procedure and participating entities
2.2 Fundamental principles of shock safety

2.2.1 Shock testing on anchor systems

A servo-hydraulic controlled shock testing machine called the Vertical Shock Testing System (VESPA) is used for anchor shock testing at the Spiez Laboratory. The VESPA has a test platform that measures 6.0 x 4.0 metres on which a test frame made of steel girders is built for the anchor shock tests. The concrete test blocks are attached to the frame using the anchors to be tested. Due to the shock-like vertical movement of the test table upwards, the anchors are loaded with an inertial force which is dependent on the mass of the test body. Shockproof anchors should be capable of transferring this load to the cracked concrete substrate without excessively large displacements (slippage). The anchor displacement occurring due to the shock load is measured with a displacement transducer and recorded for the subsequent analysis of the test.

![Diagram of shock testing anchor systems](image)

Figure 2 Schematic representation of shock testing anchor systems

![Image of shock testing anchor systems on VESPA](image)

Figure 3 Shock testing of anchor systems on the Vertical Shock Testing System (VESPA)

![Image of installed anchor in cracked concrete test block](image)

Figure 4 Installed anchor in cracked concrete test block (crack width 1mm)
2.2.2 Function and suitability of anchor systems
The forces acting on an anchor fixing can be transmitted to the substrate via form-fit, frictional connection, material connection or a combination of these mechanisms. With regard to the supporting mechanism of the anchor systems, it has been shown that so-called force or torque controlled expansion anchors, which are based on a frictional connection as well as form-fit based undercut systems, are basically suitable to meet the test criteria. Up to now, a bonded anchor that works in cracked concrete in combination with a force-controlled expansion has also fulfilled the shock test criteria. Deformation-controlled expansion anchors have proven to be unsuited.

2.2.3 General requirements for shock resistance
Shock resistance must be ensured for installations (devices, pipes, etc.) which have functionally and survival-important tasks in a protective structure. Furthermore, less important components may only be damaged to such an extent that they do not endanger persons or other functionally important installations (passive shock protection).

2.2.4 Approval criteria for shock resistant anchor systems
The verification of the shock resistance of anchor systems includes the proof that the anchors are only pulled out with a low probability under shock loads and that shock loads do not result in large displacements (slip). Decisive for the fulfilment of these criteria is the so-called re-expansion behaviour of the anchors. Anchor systems with a favourable load-bearing behaviour can expand in cracked concrete without a large slip and still retain their load-bearing capacity even if the pretension is completely lost.

The criteria which must be fulfilled for the approval of an anchor system are described in report ACLS 9710\(^2\) of the Spiez Laboratory. In order to be granted approval, a minimum probability of failure must be verified. For purposes of this verification, the decisive factor is the number of anchors \(NF\) (number of failures) which are pulled out of the drill hole during shock loading. From this, the probability of failure \(PF\) is determined for the confidence niveau defined with \(CN = 0.5\). It must not exceed 5\% \((PF \leq 0.05)\). Where the number of tests \(NT = 14\), no anchor must be pulled out \((NF_{adm} = 0)\). For 34 tests \((NT = 34)\), the number of permissible failures is \(NF_{adm} = 1\).

As a further approval criterion, it must be demonstrated that the slip behaviour of the anchor is within fixed limits. The following criteria must be met. The characteristic 1st slip (5\%-fractile value of the slip at the first shock) must be less than 10 mm \((s_{1,k} < 10 \text{ mm})\) and the standard deviation, as a measure of the scattering of the first slip, must be less than 4 mm \((\sigma_1 < 4 \text{ mm})\). The requirements for slip stability are met if the slip at the second shock load is lower on average than it was at the first shock (slip average ratio \(s_{1,m} / s_{2,m} > 1.0\)).

The approval criteria, which take into account the probability of failure due to pull-out and the slip behaviour of the anchor system, are summarised in Figure 5.

Figure 5 Criteria for the approval of shock resistant anchor systems
2.3 Design of anchor fastenings

2.3.1 General

The design of safety-relevant anchor fastenings in structural and underground engineering or in building and installation technology is generally based on the guidelines for European Technical Approvals (ETAG) and the values given in the European Technical Approvals and Assessments (ETA) of the anchor. The design values for the load-bearing capacity are decisive for the design. These are determined with the characteristic load capacities and partial safety factors specified in ETA as follows:

\[
R_d = \frac{R_k}{\gamma_M}
\]

Where:

- \(R_d\) Design resistance
- \(R_k\) Characteristic resistance
- \(\gamma_M\) Partial safety factor for material resistance

Different failure modes of the anchor can be decisive for the design. The failure types "steel failure" and "concrete cone failure" in case of tension loading must always be proven.

2.3.2 Steel failure

The design value of the load-bearing capacity for steel failure is determined from the characteristic load-bearing capacities and partial safety factors given in the ETA as follows:

\[
N_{Rd,s} = \frac{N_{Rk,s}}{\gamma_{Ms}}
\]

Where:

- \(N_{Rd,s}\) Design value for the steel load-bearing capacity under tension loading
- \(N_{Rk,s}\) Characteristic value for the steel load-bearing capacity under tension loading according to ETA
- \(\gamma_{Ms}\) Partial safety factor for steel failure according to ETA
2.3.3 Concrete failure

The design value for concrete cone failure under tension load is determined as follows:

\[ N_{Rd,c} = \frac{N_{Rk,c}}{\gamma_{Mc}} \]

Where:
- \( N_{Rd,c} \): Design value for the concrete breakout resistance under tension loading in cracked concrete.
- \( N_{Rk,c} \): Characteristic value for the concrete breakout resistance under tension loading in cracked concrete according to the equation below.
- \( \gamma_{Mc} \): Partial safety factor for cracked concrete according to ETA.

The characteristic load-bearing capacity for concrete breakout cannot be taken directly from the ETA. For cracked concrete, it is determined in accordance with ETAG 001 as a function of the concrete strength and anchorage depth as follows:

\[ N_{Rk,c} = 7.2 \cdot \sqrt{f_{ck,cube}} \cdot h_{ef}^{1.5} \]

Where:
- \( N_{Rk,c} \): Characteristic value for the concrete breakout resistance under tension loading in cracked concrete.
- \( f_{ck,cube} \): Characteristic concrete cube compressive strength.
- \( h_{ef} \): Effective anchorage depth of the anchor according to ETA.

The characteristic values of cube compressive strength for various concrete qualities according to the standard SN 505 262\(^3\) are indicated in the following table.

<table>
<thead>
<tr>
<th>Concrete class</th>
<th>C12/15</th>
<th>C16/20</th>
<th>C20/25</th>
<th>C25/30</th>
<th>C30/37</th>
<th>C35/45</th>
<th>C40/50</th>
<th>C45/55</th>
<th>C50/60</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f_{ck,cube} ) [N/mm(^2)]</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>37</td>
<td>45</td>
<td>50</td>
<td>55</td>
<td>60</td>
</tr>
</tbody>
</table>

Concrete C25/30 is used as a basis for computing the load-bearing capacity compared to concrete cone failure.

\(^3\) Schweizer Norm SN 505 262 (SIA 262:2013), Betonbau, Schweizerischer Ingenieur- und Architektenverein, Zürich, 2013
3 Testing, approval and verification of anchors

3.1 Shock resistance

The admissible shock bearing capacity \( R_{\text{adm,shock}} \) of an anchor fixing depends on the load-bearing behaviour of the anchor system in case of strongly cracked concrete and shock loads. Due to the large crack widths (\( w = 1.0 \text{ mm} \)) occurring in a shock case, the load-bearing capacity of the system is usually decisive in relation to pull-out failure.

The European Technical Approvals (ETA) do not contain any specifications with regard to load-bearing capacity in the event of shock loads and large crack widths. For this reason, in section 3.4 load classes are specified with the shock resistance \( R_{\text{class}} \), depending on the drill bit diameter \( d_0 \) or the nominal anchor diameter \( d_{\text{nom}} \).

Usually, the shock resistance \( R_{\text{class}} \) defined with the load classes is lower than the load capacity calculated in accordance with ETA, Section 2.3. However, in the case of anchor systems with a thread cross-section that is smaller than the outside diameter of the anchor or with a low anchorage depth, steel failure or concrete breakout instead of pull-out failure can be decisive in the event of a shock. Therefore, the admissible shock resistance \( R_{\text{adm,shock}} \) is to be specified as the smallest value of the three load capacities \( N_{Rd,s} \), \( N_{Rd,c} \) and \( R_{\text{class}} \):

\[
R_{\text{adm,shock}} = \min [ \ N_{Rd,s} \ , \ N_{Rd,c} \ , \ R_{\text{class}} ]
\]

Where:

- \( R_{\text{adm,shock}} \): Admissible shock resistance
- \( N_{Rd,s} \): Design value for the steel load-bearing capacity under tension according to the ETA (section 2.3.2)
- \( N_{Rd,c} \): Design value for the concrete breakout resistance under tension loading in cracked concrete C25/30 according to the ETA (section 2.3.3)
- \( R_{\text{class}} \): Shock resistance according to the load classes specified in section 3.4

3.2 Anchor shock testing

3.2.1 Test load

Test loads with which the shock tests for anchor systems are tested correspond in principle to the admissible shock resistance of the anchor systems. The test load is a centrally applied tensile load on the anchor:

\[
N_{\text{test,shock}} = R_{\text{adm,shock}}
\]

Where:

- \( N_{\text{test,shock}} \): Test load (centric tension load)
- \( R_{\text{adm,shock}} \): Admissible shock resistance according to section 3.1.
3.2.2 Test setup
During the anchor shock test, the anchors to be tested are loaded centrically with a shock load $N_{\text{test, shock}}$. This tensile load corresponds to the inertial force $F$, which is caused by the mass $m$ of the concrete test specimen and the acceleration $a$ of the test platform. This inertia force, calculated as a product of mass and acceleration, is specified in the test report of the anchor shock test.

![Diagram showing anchor pulling force, mass of concrete test block, force of inertia, and acceleration of test platform](image)

**Figure 6** Test load $N_{\text{test, shock}}$ generated by the mass inertia of the test specimen

3.2.3 Test parameters
Within the scope of anchor testing, the smallest anchor dimensions are generally tested as the effects of cracks is greatest with the smallest dimensions. In the case of torque-controlled expansion anchors of the bolt-type, previous experience has shown that anchors with an outside diameter of $d_{\text{nom}} = 8 \text{ mm}$ can still meet the shock test criteria. Due to their design with a threaded bolt and an anchor sleeve, force-controlled expansion anchors of the sleeve type as well as undercut anchors have a larger outer diameter. With these anchor types, the smallest dimensions that can meet the shock test criteria have an outer diameter of $d_{\text{nom}} = 10 \text{ mm}$.

For the anchor shock tests, concrete test blocks with a mass $m = 25 \text{ kg}$ or $52 \text{ kg}$ are used. The drawings of these concrete test blocks can be found in the appendix. For the concrete test block 290/290/120 ($m = 25 \text{ kg}$) and an acceleration corresponding to the basic protection ($a = 12.5 \text{ g}$), the resulting shock load is $N_{\text{test, shock}} = 3.1 \text{ kN}$. When using the concrete test block 360/360/160 ($m = 52 \text{ kg}$) and a test acceleration of $a = 16 \text{ g}$ (degree of protection 3 bar), the resulting test load is $N_{\text{test, shock}} = 8.1 \text{ kN}$.

The shock test parameters for the permissible shock load capacities, which are normally applicable and correspond to the load classes in accordance with Section 3.4, are summarised in the following table.
### Table 2  Shock test parameters defined for the small dimensions of torque-controlled expansion anchors of the bolt and sleeve type as well as undercut and bonded anchors

<table>
<thead>
<tr>
<th>Anchor Type</th>
<th>M8</th>
<th>M10</th>
<th>M12</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bolt anchor</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter $d_o/d_{nom}$ [mm]</td>
<td>8</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Test block mass $m$ [kg]</td>
<td>25</td>
<td>52</td>
<td>52</td>
</tr>
<tr>
<td>Test acceleration $a$ [g]</td>
<td>12.5</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>Test load $N_{test,shock}$ [kN]</td>
<td>3.1</td>
<td>6.1</td>
<td>8.1</td>
</tr>
<tr>
<td><strong>Sleeve anchor</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter $d_o/d_{nom}$ [mm]</td>
<td>10</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Test block mass $m$ [kg]</td>
<td>25</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>Test acceleration $a$ [g]</td>
<td>12.5</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Test load $N_{test,shock}$ [kN]</td>
<td>3.1</td>
<td></td>
<td>8.1</td>
</tr>
<tr>
<td><strong>Undercut anchor</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter $d_o/d_{nom}$ [mm]</td>
<td>10</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Test block mass $m$ [kg]</td>
<td>25</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>Test acceleration $a$ [g]</td>
<td>12.5</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Test load $N_{test,shock}$ [kN]</td>
<td>3.1</td>
<td></td>
<td>8.1</td>
</tr>
<tr>
<td><strong>Bonded anchor</strong></td>
<td></td>
<td></td>
<td>M10</td>
</tr>
<tr>
<td>Diameter $d_o/d_{nom}$ [mm]</td>
<td></td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Test block mass $m$ [kg]</td>
<td></td>
<td></td>
<td>52</td>
</tr>
<tr>
<td>Test acceleration $a$ [g]</td>
<td></td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>Test load $N_{test,shock}$ [kN]</td>
<td></td>
<td></td>
<td>8.1</td>
</tr>
</tbody>
</table>
3.3 Calculated shock resistance verification

Appendix A2 of the Technical Instructions for the Shock Protection of Installation Parts in Civil Protection Buildings (TW Schock 1995) contains the basic principles and a calculation example of a simplified computational proof of a shock-proof fastening. For a shock-proof installation part, the static equivalent load $F$ acting on the centre of gravity (SP) of the installation part is determined. Afterwards, the shear force ($S$) and the tensile forces ($Z$) acting on the fastener and the resulting transverse tension force ($K$) are calculated for all load directions.

![Figure 7](image)

**Figure 7** Simplified calculated verification of shock resistant fastenings according to TW Shock 1995

The calculated proof of shock resistance is provided if the acting transverse tension force does not exceed the admissible shock resistance of the anchor.

$$K \leq R_{adm,shock}$$

Whereby:

- $K$ Anchor transverse tension force
- $R_{adm,shock}$ Admissible shock resistance according to section 3.1

3.4 Load classes

The load classes for torque-controlled expansion anchors of the bolt and sleeve type, as well as for undercut and bonded anchors, which are uniformly specified for all anchor brands are shown in the following figures 8, 9, 10 and 11. Since anchors of the sleeve type and undercut anchors have a larger outer diameter than bolt anchors due to their design, the smallest dimension of these anchor types has a lower shock resistance than a bolt anchor with the same diameter.
Testing and Approval of Anchor Systems

Figure 8  Uniform load classes for torque-controlled expanding bolt-type anchors depending on drill hole diameter or nominal outside diameter of the anchor.

Figure 9  Uniform load classes for torque-controlled expanding sleeve-type anchors depending on drill hole diameter or nominal outside diameter of the anchor.
Testing and Approval of Anchor Systems

Figure 10 Uniform load classes for undercut anchors depending on nominal outside diameter of the anchor

Figure 11 Uniform load classes for bonded anchors depending on drill hole diameter
## Parts list for reinforcement:

<table>
<thead>
<tr>
<th>Pos.</th>
<th>Qty.</th>
<th>Ø [mm]</th>
<th>l [m]</th>
<th>l_{tot} [m]</th>
<th>G [kg]</th>
<th>Outer dimension [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>6</td>
<td>0.76</td>
<td>1.52</td>
<td>0.34</td>
<td>260 x 60 x 90</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>6</td>
<td>0.70</td>
<td>1.40</td>
<td>0.31</td>
<td>245 x 60 x 75</td>
</tr>
</tbody>
</table>

**Concrete test block 290/290/120** (25 kg)

for anchor shock testing

Plan no. 981.0077  M 1:5  06.11.1985
Parts list for reinforcement:

<table>
<thead>
<tr>
<th>POS</th>
<th>Qty.</th>
<th>ø</th>
<th>Cutting length cm</th>
<th>Total length m</th>
<th>Weight kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>6</td>
<td>107</td>
<td>4.28</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>6</td>
<td>104</td>
<td>4.16</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Shape of the reinforcement – all dimensions are exterior dimensions without specific indication: bending and end hooks acc. to SIA

Concrete test block 360/360/160 (52 kg)

for anchor shock testing

Plan no. 981.0053 M 1:5 20.06.1986