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</table>
A DESCRIPTION OF THE METHOD

Purpose

The Boltometer 011 is the second version of an instrument for a non-destructive test of grouted rock bolts in situ. It has been developed to provide the mining engineer with an instrument which is capable to “look into the rock” and to indicate if a particular bolt does not fulfill its function. This will improve the knowledge of rock reinforcement in general and bolting technique in particular. Thus the Boltometer will lead to reduced costs for rock reinforcement and - last but not least - to safer underground constructions.

Principle

A specially designed sensor, containing piezoelectric crystals, is held against the free outer end of the bolt. Using the crystals as exciting unit, elastic waves are transmitted to the bolt. When travelling through the bolt some wave energy is transferred to the grouting and further on to the rock thus decreasing the amplitude of the wave. At the inner end of the bolt the waves will be reflected. The reflected waves can be monitored at the outer end of the bolt using the piezoelectric crystals as receivers. If the grouting around the bolt is of good quality and covers the entire length of the bolt, the amplitude of the reflected wave is more damped than if the grouting is porous or lacking.

A high amplitude of the reflected wave recorded by the Boltometer’s sensor will therefore indicate a grouting with reduced function. Analysing the amplitude of the recorded wave, according to calibration tests on reference bolts, the condition of the grouting - and the function of the bolts in situ - can be classified.

In addition the time interval between the moment of excitation and the moment of receiving of the reflected wave makes it possible to calculate the distance to the cause of reflection.

Application

The Boltometer is developed for test of grouted rock bolts only. It has been successfully tested on a large number of rebar and tube bolts and should be used under the following conditions to guarantee optimum function:

- borehole diameter 25 - 40 mm,
- bolt diameter 20 - 30 mm,

- bolt length greater than 0.8 m,
- length of the grouting less than 4.0 m,
- outer end of the bolt must be flat to achieve sensor contact.

Access to reference bolts with known length, optimum and/or known bad grouting conditions for the actual bolt type and actual rock conditions will considerably improve the classification.

Classification system

Based upon results from field tests with the Boltometer which have been verified by means of a hydraulic jack and/or overcoring, a proposal for practical classification of cement grouted rock bolts has been presented (Table 1). The Boltometer automatically indicates the relevant bolt class according to the proposed classification system.

<table>
<thead>
<tr>
<th>Class</th>
<th>Boltometer signal</th>
<th>Estimated bolt condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>No reflection</td>
<td>Optimum</td>
</tr>
<tr>
<td>B</td>
<td>Small flexural wave reflection</td>
<td>Reduced</td>
</tr>
<tr>
<td>C</td>
<td>Large flexural wave reflection</td>
<td>Insufficient</td>
</tr>
<tr>
<td>D</td>
<td>Compression wave echo and very large flexural wave reflection</td>
<td>Very poor or non existant *)</td>
</tr>
</tbody>
</table>

Table 1. Classification system

*) The bolt can be pulled out by means of a hydraulic jack (sometimes a blow with a sledge hammer or vibration of the bolt may be necessary to loosen the bolt).
B EQUIPMENT

Unpacking

Before unpacking check if there is any transport damage to be seen. The Boltometer 011 is shipped in a case containing:

- Main unit
- Sensor with cable and connector
- Battery charger with cable and connector
- Silicon paste
- Users manual

General description

The Boltometer is comprising a sensor and a main unit, connected by a cable. The front of the main unit is shown in Figure 1.

![Diagram of Boltometer 011](image)

FIGURE 1. The front of the Boltometer 011
The sensor (Figure 2) consists of a specially designed transducer unit, elastically supported in the sensor housing. At the rear of the sensor four LED lamps can be seen. In the middle of the LED lamps a button is placed. This button has the same function as the START button on the front of the main unit.

**Specification**

- Memory (2k RAM) for storage of signals and parameters (excitation, frequency, velocity and classification curve breakpoints). No memory loss (battery back up) during power off.

- Real time clock with date. No data loss during power off.

- 12 V, 3 Ah Rechargeable battery.

- Operation current: - Ready mode 150 mA  
  - Measurement mode 600 mA  
  - Print mode 400 mA

- Dimension: 320 * 170 * 300 mm

- Weight: - main unit 7.2 kg  
  - sensor 1.0 kg

- Printer: EPSON micro dot printer, model-160.

- Printer paper: Woodfree paper, width 57,5 mm, roll diameter less than 50 mm, thickness approximately 0.07 mm.

- Ribbon cassette: Purple or black, EPSON ERC-09

*FIGURE 2. Sensor*
C  FUNCTION KEYS

Press the following keys and get familiar with their function.

ON
Press both ON-keys at the same time. After approximately one second a picture similar to Figure 3 is present on the display.

To the left of the vertical axis there is x1 or x5 indicating the vertical magnification. Under the horizontal axis are the length marks, one mark for every 20 centimeters.

The two parallel lines over the horizontal axis are the classification lines, which are used by the Boltometer to do the classification.

OFF
To leave the READY mode press OFF, and the Boltometer is turned off.

START
After pressing the START key, CL X will change to inverse letters. The Boltometer now executes the program. The program which is executed is decided by the program-number, e.g. P1 for the standard measuring program.

To leave actual mode press START again. The different programs are discussed in chapter “Operation”.

PROG
Press the PROG-key and the P-number changes to inverse letters on the display. It’s now possible to change program number. Up arrow increases the program number. Down arrow decreases the program number. Read the Operation chapter for information about different programs. To leave the current mode press START again (or PROG). The P-number letters will change back to normal letters.

LIMIT
Press the limit-key to enter limit mode. In this mode the classification lines can be positioned. There are two lines for the flexural wave and two other lines for the compression waves. The correlation between the lines and the digits in limit mode are shown in Figure 4.
FIGURE 4. Correlation between the digits in limit mode and the break-points of classification lines for each mode.

a: Display in limit mode
b: Part of display in ready mode

Pressing the right arrow moves the blinking cursor to the right. It moves in the following order:

XC1 XC2 XC3 XF1 XF2 XF3 YC1 YC2 YC3 YC4 YF1 YF2 YF3 YF4.

With the left arrow the cursor moves to the left.

The number next to the cursor increases by pressing the up arrow. The number decreases by pressing the down arrow.

The X-values can be selected in the range 0 to 15 meters, with a resolution of 0.1 m. The value of X..1 should be less than (to the left of) X..2. And the value of X..2 must be less than (to the left of) the value of X..3.

The Y..1 value should be greater than or equal to Y..2 (higher or equal). The Y..2 value should be greater than or equal to Y..3. The value of Y..4 must also be greater than or equal to Y..3. The value Y..4 will define a second curve which is parallel to the one defined by breakpoints 1-3. The distance between the two lines will be equal to Y..4 - Y..3. The Y-values can be selected in the range 0 - 254, with a resolution of 1.

The method of classification is explained in the chapter: Interpretation of result.

To leave limit mode press the START (or the LIMIT) key.

FREQ/VELOC

By pressing the FREQ/VELOC key the display will look like Figure 5. This display tells the frequency and the velocity used when measuring compression wave and flexural wave. To change the digits, put the blinking cursor next to the digit to be changed.

COMP FC kHz
VC km/s
FLEX FF KHz
VF km/s

FIGURE 5. Display in FREQ/VELOC mode.

The right arrow moves the blinking cursor downwards. (From FC to VC to FF to VF). The left arrow moves the cursor upwards in the reverse order.
With up arrow the digit next to the cursor increases. The down arrow decreases the digit. The excitation frequency (FC and FF) can be selected in the range 0 - 102.0 kHz, with a resolution of 0.4 kHz. The velocity for compression waves can be selected in the range 0 - 10.2 km/s, with a resolution of 0.04 km/s. For flexural wave the range is 0 - 5.10 km/s with a resolution of 0.02 km/s.

The choice of frequencies and velocities will be discussed in the chapter: Operation.

By pressing the START (or FREQ/VELOC) key, FREQ/VELOC mode is left.

**SCALE**

After pressing the SCALE-key the Boltometer enters the scale mode. In this mode the meter marks on the X-axis and the scale-indication of the Y-axis will change to inverse digits.

The X-axis reaches from 0 to 30 m, and 4 m of the rock bolt is shown on the display at one time. A measurement records 10 m of the rock bolt (0 - 10 m, 10 - 20 m or 20 - 30 m can be recorded).

Which 10 m section that is recorded during a measurement depends on what is shown on the display. If a part of the first 10 m of the rock bolt is shown on the display, the next measurement will also record the first 10 m of the rock bolt. If a part of 10 - 20 m is shown, the next measurement will also record 10 - 20 m of the rock bolt and so on.

By pressing the SCALE key in scale mode a jump will be executed on the X-axis to the next 10 m section. The jump will be made from 0 - 4 m (or from any part of the 0 - 10 m) to 10 - 14 m, and then to 20 - 24 m and then back to 0 - 4 m.

By pressing the right arrow key the X-scale increases by one meter. Then passing 26 - 30 m a jump will be done to 0 - 4 m.

If the left arrow key is pressed the X-scale decreases by one meter. Then passing 0 - 4 m a jump will be done to 26 - 30 m.

The scale on the Y-axis is recorded in the range 0 - 254. If the Y-scale is indicated with *1, 0 - 254 is shown on the display. Every dot has then a magnitude of 5. If Y-scale is indicated by *5, 0 - 51 (of the recorded range 0 - 254) is shown on the display, the magnitude of the dots is 1.

With the up arrow the Y-scale will be set to *5, and with the down arrow it is set to *1. Scale mode is left by pressing the START key.

**FLEX/COMP**

By pressing the FLEX/COMP key, the flexural wave recording will be shown instead of comp wave or vice versa. The current wave mode is indicated to the left of the display by an F for flexural wave and a C for compression wave.

**PRINT**

Pressing the print key gives the following printout:

![Printout Example](attachment:image.png)

**FIGURE 6. Example of a print result.**

The first line indicates year - month - day and hours: minutes : seconds. The second line indicates the class. The sensor - bolt contact is indicated by a 1, for every LED lamp that was lit and with a 0 for every LED lamp that was not lit. Figure 7 shows the connection between LED lamps and contact condition on the printout.
FIGURE 7. The mutual relations of the sensor LED lamps position and the contact digits printout. The sensor (to the left) is drawn as it is seen by the operator when measuring. The positions of the LED lamps on the front panel are identical.

The third line indicates which part of the X-axis that was printed (in this case 0 - 4 m). The part of the rock bolt shown on the display, is also the one that will be printed. The fourth line indicates wave mode and the magnitude of the Y-axis.

PAPER
Pressing paper key executes a paper feed.

LIGHT
This is an on/off key for the background lighting of the display.

TIME
By pressing the time key the clock data will be shown on the display in following order: hours: minutes: seconds year - month - day. The blinking cursor can be put under any digit by the left arrow and right arrow keys.

The digit under-scored by the blinking cursor can be increased by the up arrow key, or decreased by the down arrow key.

The TIME mode is left by pressing the START key.

A, B, C
Keys labelled A, B and C are reserved for optional features.
D OPERATIONS

Measurement

a. Make the outer end of the bolt flat and clean (no parts on the main surface such as grades at periphery).

b. Put a thin layer of contact paste (or grease) on the end of the bolt.

c. Turn on the Boltometer.

d. Push the START-key or the key at rear end of the sensor. The class indication will then turn into inverse signs which indicates the instrument is armed.

e. Press sensor firmly against the end of the bolt. (Warning: Striking or otherwise exposing the sensor to mechanical shock can permanently damage the piezo-electric elements).

- If program one (P1 on display) is used: A measurement will be made as soon as all contact diodes have been lighted. If any diode does not light, move the sensor around slowly until sufficient contact is made.

- If program two (P2 on display) is used: the contact diodes will be lit according to the contact conditions. To make a measurement, press the START-key or the key at the back of the sensor a second time. The contact diodes will be lighted according to contact conditions during the measurement.

f. After the measurement a part of the recorded signal will be shown on the display. A classification is made and the result is also shown on the display. For explanation of signal and classification see the chapter on Interpretation of results.

g. The contents of the display can be printed by pushing the PRINT key.

h. For a new measurement push the START key or the key at the back of the sensor.

Excitation frequency

The excitation frequency is the frequency of the pulses transmitted into the rock bolt. The optimum frequency to be used depends on the rock bolt diameter. Normal values for 25 mm rock bolts are 45 kHz for flexural waves and 35 kHz for compression waves. To select frequency, see the chapter Function keys.

Wave velocity

The wave velocity is the speed at which the waves travels in the rock bolt. To get the right length indication at echoes on the meter scale, the wave velocity must be chosen right. To calibrate the wave velocity, take a rock bolt of known length, installed in a rock. The rock bolt should give an end echo, and have a length of about 2 m. Change the wave velocity, until the end echo appears on the meter scale, at a distance equal to the length at the rock bolt. Standard values of flexural wave velocity are 3 km/s and 4.52 km/s for compression wave velocity. To select the velocity see chapter Function keys.

Programs

There are 3 different programs available, all explained below.

P1: This program waits until all contact diodes are lit and then a measurement is made. If the contact diodes are still lit after the measurement the result will be shown on the display. If any contact diode is not lit on the Boltometer you will have to move the sensor until all diodes are lit.

P2: When the START key has been pressed once, the contact diodes will be lit according to the contact conditions. Pressing the START key a second time, will start measurement. The result is presented on the display. The contact diodes are lit according to contact conditions during the measurement.

P3: Test program. The diodes starts to twinkle for about 4 second. On the display a pattern of alternating dark and light dots appear, after 2 seconds the pattern is shifted one step. The test program stops automatically after about 4 seconds, and the Boltometer returns to ready mode.

Power supply

The Boltometer is supplied with a battery. To recharge the battery connect the battery charger to the right connector of the Boltometer. The battery charger LED lamp should light when charging. If the battery is completely discharged it will take about 14 hours to recharge.
Printer

To change paper, start with removing the printer cover. This is done by loosening the two screws on the printer cover and lifting the printer cover. Take a new paper roll and pull out the leading edge of the paper. The paper edge should be cut at a right angle. Insert the paper into the paper inlet of the printer. Press the key PAPER and the paper will automatically feed into the printer. Continue pressing until the paper is advanced long enough to reach the slot in the printer cover. To change ribbon cassette, push on the cassette (on the letters "push"). Remove the cassette. Place a new ribbon cassette in position. Then, press the cassette to secure it. Check that the ribbon is not twisted. If twisted, turn the round knob on the cassette.
F  INTERPRETATION OF RESULTS

Bolt class

The connection between the rock-bolt condition and bolt-class is:

Bolt-class A corresponds to a bolt with optimum function i.e. continuous cement-grouting of good quality (low water/cement-ratio) and no damage or fissures along the rod.

Bolt-class B corresponds normally to a bolt with reduced function i.e. a cement-grouting that either does not cover the entire length of the bolt or has reduced strength (high water/cement-ratio).

Bolt-class C corresponds to a bolt with insufficient function i.e. considerably reduced amount or quality of the cementgrout and/or substantial damage to the bolt.

Bolt-class D corresponds to a bolt with considerably reduced or non existant function i.e. the total length of the cementgrout will be less than 0,6 m and/or there will be at least one major damage on the bolt.

In appendix 1 there are examples of measurements on different rockbolts.

The class decision is made according to if and how the classlines are crossed by the signaltrace. There are two classlines, classline 1 (CL1) is below classline 2 (CL2). The class is determined in the following manner:

Bolt-class A is the result when both the flexural wave signal and the compression wave signal are completely below CL1 lines.

Bolt-class B is the result when one or both wave signals cross a CL1 line. Neither signal should cross their CL2 lines.

Bolt-class C will be the result if one, but only one, wave signal crosses a CL2 line.

Bolt-class D is the result if both the flexural wave signal and the compression wave signal cross their CL2 line.

The idea of the different classes is also discussed in the chapter: Description of the method.

The time history of a flexural wave signal obtained from a class A-bolt should show a high damping rate, very little noise and normally none or only one echo with low amplitude. This echo comes from the inner end of the bolt and the length of the bolt can therefore easily be estimated by means of the distance marks on the X-axis.

For class B-bolts the damping of the signals is still high, the noise level can be somewhat higher but there is still only one echo - from the inner end of the bolt. A distinct echo in class B will almost always allow a satisfactory, accurate decision of the length and the function of the bolt.

Class C-bolts figures can have several echos. First of all one can decide whether the largest echo really comes from the inner end of the bolt or - for instance - from a fissure in the grouting. In the latter case another echo can often be seen at a greater distance. Several echos could indicate a nonuniform cement-grouting.

Class D-bolts show signals with large echos. A very large compression wave echo indicates that most of the cement-grouting is missing.
Appendix 1

MEASUREMENT RESULT ON REFERENCE BOLTS

LIMITS:

<table>
<thead>
<tr>
<th></th>
<th>COMP</th>
<th>0.70</th>
<th>1.40</th>
<th>3.00</th>
<th>m</th>
<th>250</th>
<th>90</th>
<th>40</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FLEX</td>
<td>0.80</td>
<td>1.00</td>
<td>3.00</td>
<td>m</td>
<td>250</td>
<td>50</td>
<td>35</td>
<td>100</td>
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FREQ/VELOC:

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<th></th>
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<th>kHz</th>
<th>4.52</th>
<th>km/s</th>
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<tbody>
<tr>
<td></td>
<td>FLEX</td>
<td>46.8</td>
<td>kHz</td>
<td>3.00</td>
<td>km/s</td>
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- 11 -
MEASUREMENT RESULT ON REFERENCE BOLTS

**LIMITS:**

<table>
<thead>
<tr>
<th></th>
<th>COMP</th>
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<tbody>
<tr>
<td></td>
<td>0.70</td>
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<td>250</td>
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<tr>
<td>40</td>
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**FREQ/VELOC:**

<table>
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<tr>
<th></th>
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<td></td>
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<tr>
<td>4.52</td>
<td>kHz</td>
<td>kHz</td>
</tr>
<tr>
<td>km/s</td>
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