On the Influence of Casing and Backfilling on Inclinometer Tests

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1 Introduction

Vertical probe inclinometer measurements represent one of the most commonly used methods when it comes to the investigation of slope instabilities in rock and soil. The application of this method requires the in-situ installation of a defined measuring column prior to monitoring, which is in most cases done in boreholes.
The monitoring itself is conducted either by periodical readings with a probe inclinometer system or the use of a system of permanently installed so called "in-place" inclinometers. Both systems measure changes in the inclination of the column with reference to depth and orientation. These measurements allow estimations on ground movement perpendicular to the axis of the inclinometer column. Further details on the measuring method are given in the ISRM Suggested Method (ISRM, 1981), as well as in Dunnicliff (1993) and are not topic of the presented paper.

Prior to installation a suitable combination of casing and backfill has to be selected in order to allow the inclinometer readings to genuinely reflect the displacements of the rock or soil mass to be monitored. Towards this goal several recommendations are available and summarized in Table 1. It appears that there is no standardized procedure as how to select the fill material. The same applies to casings, where plastic (ABS), steel, aluminum and glass fiber composites are commonly used materials. Different diameters, lengths, diameters and connections of casing are available and documented by the manufacturers.

However, the selection of the most appropriate combination of casing and fill material remains up to the geologist or geotechnical engineer.

In order to aid with the selection a two stage research effort was launched at the Ruhr-University Bochum. Firstly, small scale displacement experiments on various casing-backfill combinations were conducted and secondly, displacement experiments in the lab on a scale 1:1 were executed with ABS casing and different fills in a synthetic rock mass.

Table 1: Compilation of recommendations about the materials used for backfilling inclinometer casings.

Source	General remarks	Granular fill	Grout
TRB (2008)	For small displacements grouting	Granular fill when measurements have to be fast after installation	Non shrinking grout
DIN 4107-3 (2011)	Select backfill according to geotechnical and measurements related requirements	Sand / gravel fill has to be compacted	Weak cement, cement bentonite slurry
RTH 301-80		Sand backfill	Weak cement grout

2 Materials

For the investigations presented in this paper the following casings were used: SISGEO type S111 aluminum alloy casing ∅ 76 mm; SISGEO type S131 ABS casing ∅ 71 mm with 3.5 mm material thickness and SISGEO Type S141 ABS casing ∅ 70 mm with 5 mm material thickness. The fills tested along with some mechanical properties are summarized in Table 2.

2.1 Small scale displacement experiments

In order to analyze the mechanical behaviour of different “model columns” consisting of specimens with differing casing-grout-combination an existing rock shear testing frame was adapted and modified with special shear boxes and deformation transducers (Fig. 1).

By use of this testing layout it was possible to directly shear specimen of 200 mm height while measuring external movement and internal deformation of the casing. The used layout is supposed to represent the shearing of an inclinometer column in a high strength hardrock formation (see Figure 2). While the outer deformation (d_O) was measured by use of the testing frame's deformation transducer, the inner deformation (d_I) was measured with two inductive transducers attached to the upper shear box and monitoring the distance to the inner wall of the lower casing part.

Table 2: Compilation of investigated materials and their relevant technical properties (all cement based materials tested after 28 days of drying)

Name	Description	Water/Solid-Factor	Density [g/cm³]	UCS [MPa]	Cohesion [MN/m²]	Friction angle [°]	Young´s Modulus [MN/m²]	Settlement value [%]
SD 0.45	Soil Dämmer™ industrial cement-Bentonite-mixture	0.45	1.58	0.05	n.t.	n.t.	100	0
ZB 1	Cement-Bentonite-mixture 5:1	1.67	0.76	0.36	n.t.	n.t.	884	8
ZB 2	Cement-Bentonite-mixture 3.3:1	1.85	0.50	0.10	n.t.	n.t.	100	16
OD 0.45	Original Dämmer™ industrial cement-Bentonite-mixture	0.45	1.58	7.0	2.64	12	2468	0
OD 0.7		0.70	1.42	1.7	5.27	18	912	0
BD 0.45	Blitz Dämmer™ industrial cement-Bentonite-mixture	0.45	1.73	23.1	7.11	27	7063	0
BD 0.55		0.55	1.52	21.0	7.93	16	5206	0
BD 0.7		0.70	1.42	12.6	5.27	10	4550	0
Z 0.5	CEM III/B cement	0.50	1.58	36.8	11.6	26	8148	6
Z 0.8		0.80	1.25	24.6	7.7	26	4474	12.5
S	Sand, medium grained	n.a	≈ 1.5	n.a.	0	32	≈140	n.a.
CP	Industrial clay pellets	n.a	≈ 1.8	n.a.	0	9	≈ 80	n.a.

n.t. = not tested, n.a. =not available

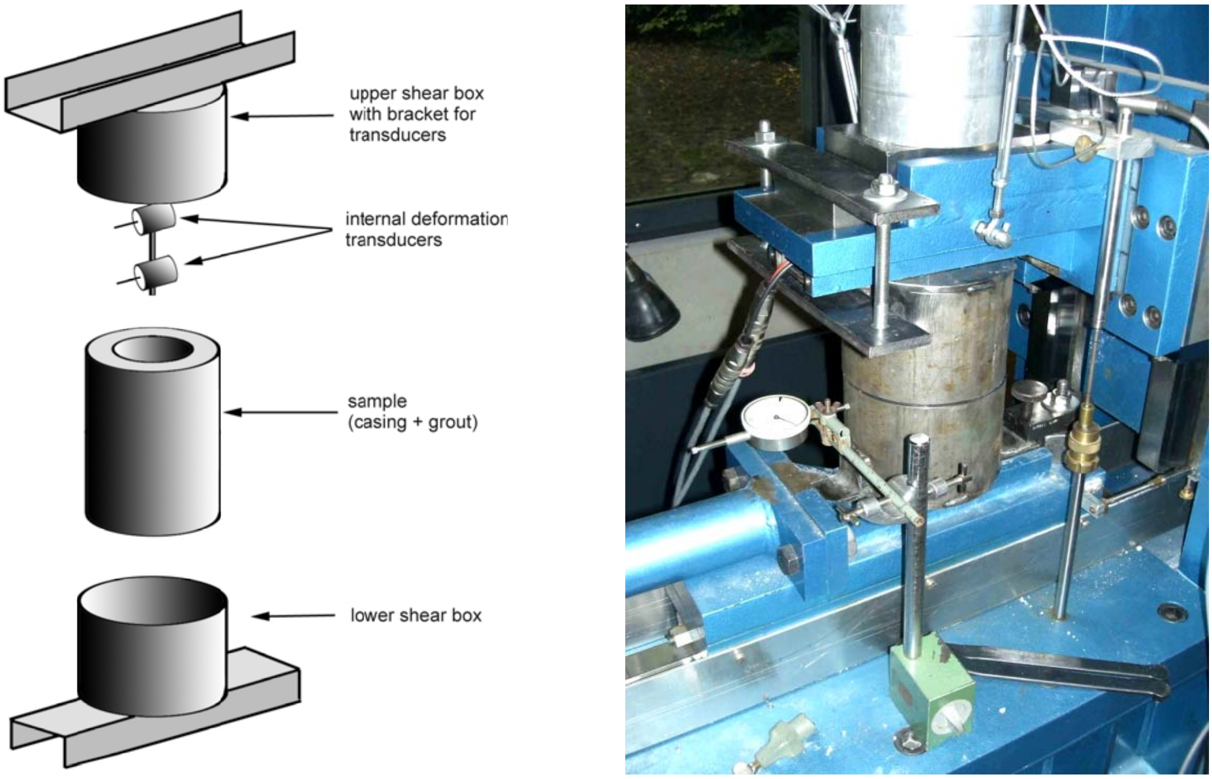

Figure 1: Testing layout of the direct shear test on model tube installations (casing-grout-combinations). Left: Scheme with internal measurements devices, right: photograph of the setup.

The tests were all carried out under a constant vertical force of F_N = 3000 N (Fig. 2), which equals the vertical stress in a borehole at a depth of about 20 m and a grout density of 1.5 to 2.0 g/cm³. The stress and deformation measurements gained from the tests were than evaluated and compiled with reference to the different materials tested. Figure 3 gives an example of a displaced sample with the sheared fill material and the deformed casing.

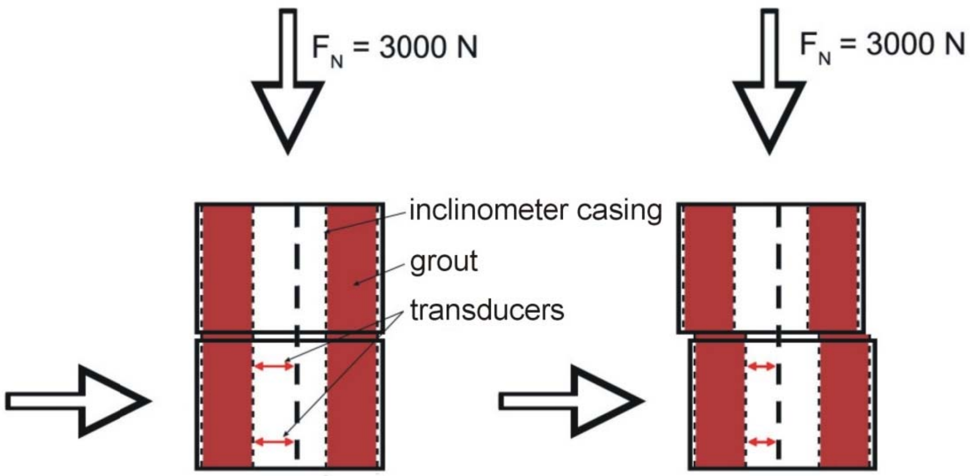

Figure 2: Schematic cross section for the direct shear tests on model columns.

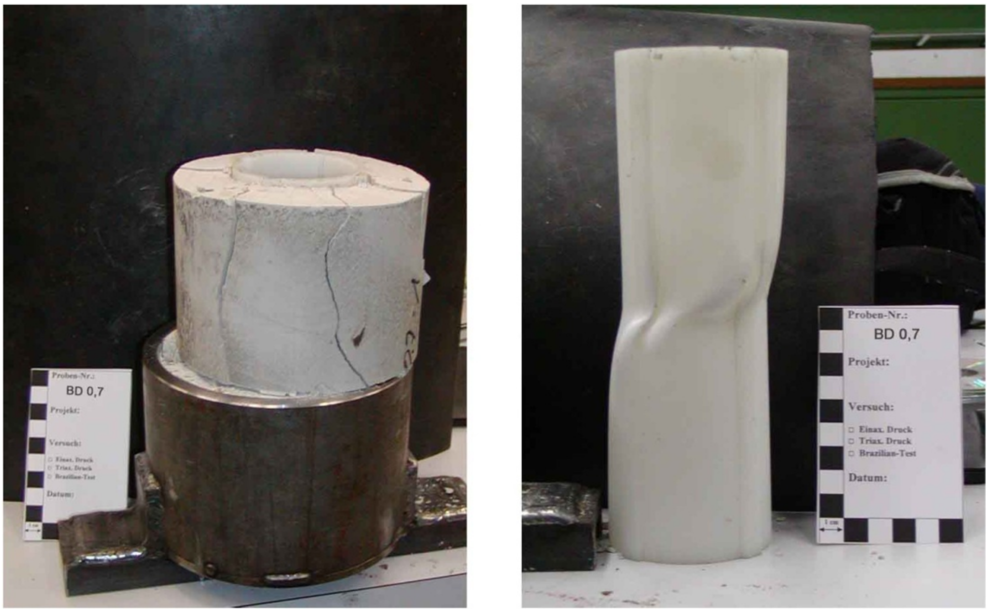

Figure 3: Specimen with type S131 ABS casing and Blitzdämmer™ industrial cement-bentonite-mixture after the shear test. Left: Complete sample after removing the upper shear box, right: deformed ABS casing after removal of grout.

The results of the small scale displacement tests may be summarized as follows: The outer displacement d_O is always larger than the measured displacement d_I at the inner rim of the casing. The ratio d_O/dI is called the damping factor F_D and serves as criteria for selecting the most appropriate combination of casing and fill material. Table xx summarizes the damping factors for the tested combinations.

Table 3: Derived “specific damping factors” F_D for the tested grout-casing-combinations.

Fill name	ABS casing, 3.5 mm (SISGEO S131)	ABS casing, 5 mm (SISGEO S141)	Aluminum casing (SISGEO S111)	grout without casing
SD 0.45	1.14	1.33	-	1.28
ZB 1	1.24	1.38	1.24	1.24
ZB 2	1.40	1.26	2.18	-
OD 0.45	1.50	1.36	3.24	1.15
OD 0.7	1.75	2.03	2.57	1.07
BD 0.45	2.15	-	3.38	1.66
BD 0.55	1.58	2.59	1.64	1.51
BD 0.7	1.89	1.87	-	1.21
Z 0.5	2.32	2.17	2.58	1.16
Z 0.8	1.61	1.39	1.78	1.87

- = test failure

The detailed results of the small scale displacement tests are published in earlier papers (Plinninger et al. 2010). It is evident that the external displacements are not fully recognized by the inclinometer and that fill-material depended damping occurred. The question whether the results are scale dependent called for further research with displacement tests on a scale 1:1.

2.2 Large scale displacement tests

An apparatus was constructed to facilitate the controlled displacement of stiff blocks in which a borehole of diameter 120 mm was inserted. In a first stage of the large scale testing, 3 mm ABS casings have been tested with various backfilling materials as specified in Table 2. For this 1100 mm long casing sections were used. After being centered in the borehole, the various backfilling materials were filled in around the casing. Grouts were cured for at least 28 days before testing. The stiff blocks of dimensions 300 mm x 300 mm x 500 mm (length x width x height) were made from reinforced concrete. The upper block remained immobile within the steel apparatus and the lower block was displaced by a hydraulic ram. The friction between the blocks was minimized by a slide band. The displacement of the lower block was measured by a mechanical dial of resolution 0.01 mm. The inclinometer measurements were conducted by use of a SISGEO biaxial servo-accelerometer probe with 0.5 m measuring base, while possible rotation of the block was parallel monitored with a SISGEO “TILLI” type Portable Tiltmeter. If tilting was observed, the inclinometer readings were accordingly corrected. A scheme of the testing setup as well as photo is shown in Figure 4.

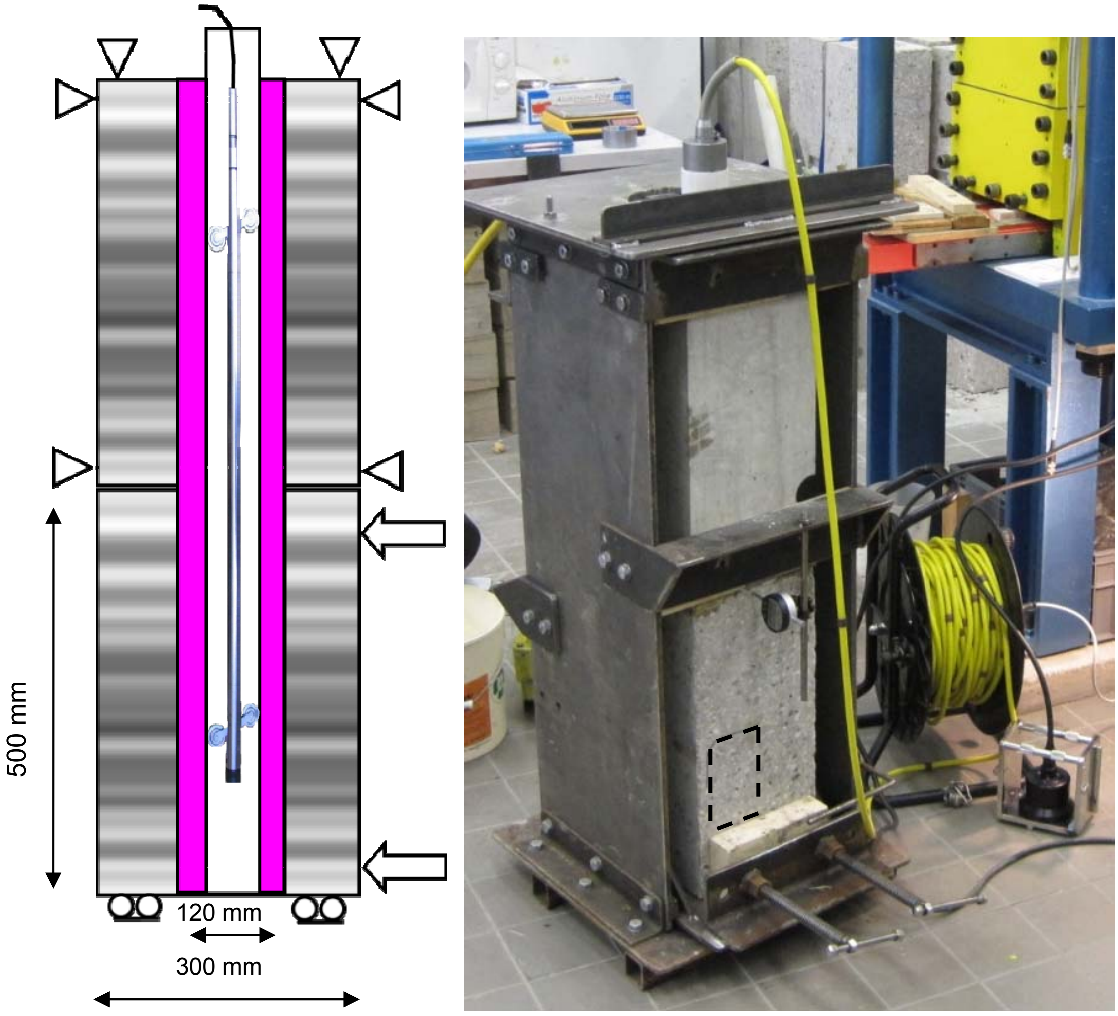

Figure 4: Left: Scheme of the test apparatus with concrete blocks (white/grey pattern), backfill (purple), ABS 3mm casing and inclinometer. Right: Photo of the apparatus during testing. The inclinometer probe is inserted into the column for measuring, portable tiltmeter to the right. The area of tilt measurement is indicated by the broken lines.

The displacement tests were carried out with a manual hydraulic pump exerting pressure to the ram. The applied oil pressures range from 10 bar to 450 bar. In preselected steps of the test, hydraulic pressure, external displacement, internal inclinometer reading and the external tilting of the lower block were recorded. From this information the acting force on the block as well as the tilt-corrected internal displacement was calculated. The tests were conducted up to 20 mm of internal displacement depending on the behavior of the fill materials and the available space for the inclinometer was recorded.

3 Results of large scale displacement tests

The comparison of outer displacements with displacements calculated from the internal inclinometer readings are given in Figure 5. As found in the small scale model tests, the internal displacements are smaller than the external ones. As summarized in Table 4, the damping factors range from F_D = 1 (no damping) for sand to FD = 3.01 for cement (Z0.5). T. Closer inspection of the data (insert in Figure 5) suggests a non-linearity of the data in the initial, low displacement range. Particularly the stronger materials such as cement grout (Z 0.5) or the cement-bentonite mixture (BD 0.55) transfer poorly the outer displacements in the beginning of the tests. When the outer displacements exceed values of approximately 6 mm - or more precisely, the forces exceed the maximum shear strength of the backfill material - then all fill materials transmit linearly the displacements although in a slightly damped way. The damping factors F_D of the large scale tests are summarized in Table 4; the non-linearity is noted.

Table 4: Compilation of investigated test results with respect to damping factor F_D.

Fill	Description	Non-linearity	F_D initial	F_D final
SD 0.45	Soil Dämmer™ industrial cement-Bentonite-mixture	Yes	1.14	1.02
ZB 1	Blitz Dämmer™ industrial cement-Bentonite-mixture	Yes	1.24	1.03
ZB 2		Yes	1.37	1.03
OD 0.7	Original Dämmer™ industrial cement-Bentonite-mixture	Yes	1.78	1.01
BD 0.55	Cement-Bentonite-mixture	Yes	3.01	1.01
BD 0.7		Yes	1.13	1.02
Z 0.5	CEM III/B cement	Yes	2.32	1.01
S	Sand, medium grained	No	1.00	1.00
CP	Industrial clay pellets	No	1.29	1.29

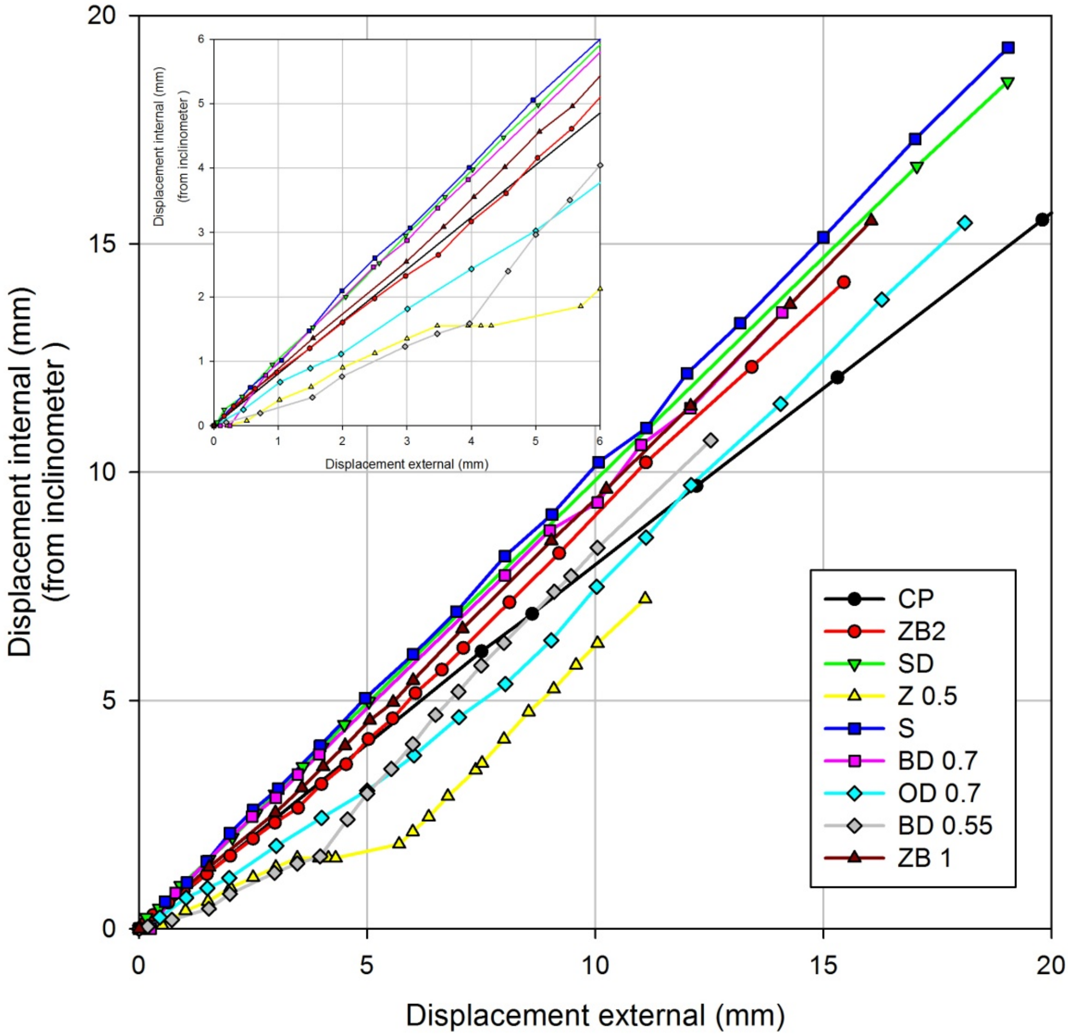

Fig. 5 Comparison of external and internal displacements for different combinations of fill materials and ABS 3 mm. The insert shows details of the initial nonlinear behavior of several materials.

4 Discussion

The displacement tests in a 1:1 scale generally support the findings from the small scale tests, published earlier. As stated before, the use of different backfilling materials will significantly influence to monitoring of lateral displacement, particularly the possibility of detecting initial displacements. The non-linear behavior of all grouts suggests material failure within the first millimeters of displacement. Particularly the stronger grouts exhibited significant “breaking” due to shear failure before reproducing the external displacement correctly. This assumption is supported by the data displayed in Figure 6, where the shear stress in the fill material is as a function of the displacement is shown. The shear stress was computed with the applied force from the ram in relation to the plane area of the filling material. The effect of the casing was neglected. The weak filling materials show rather linear shear stress-displacement relations which is reflected in damping factors between $1 < F_D < 1.8$. The stronger materials Z 0.5 and BD 0.55 with damping factor $F_D > 2.3$ may sustain high shear stresses while the mixture BD 0.7 shows unclear behavior.

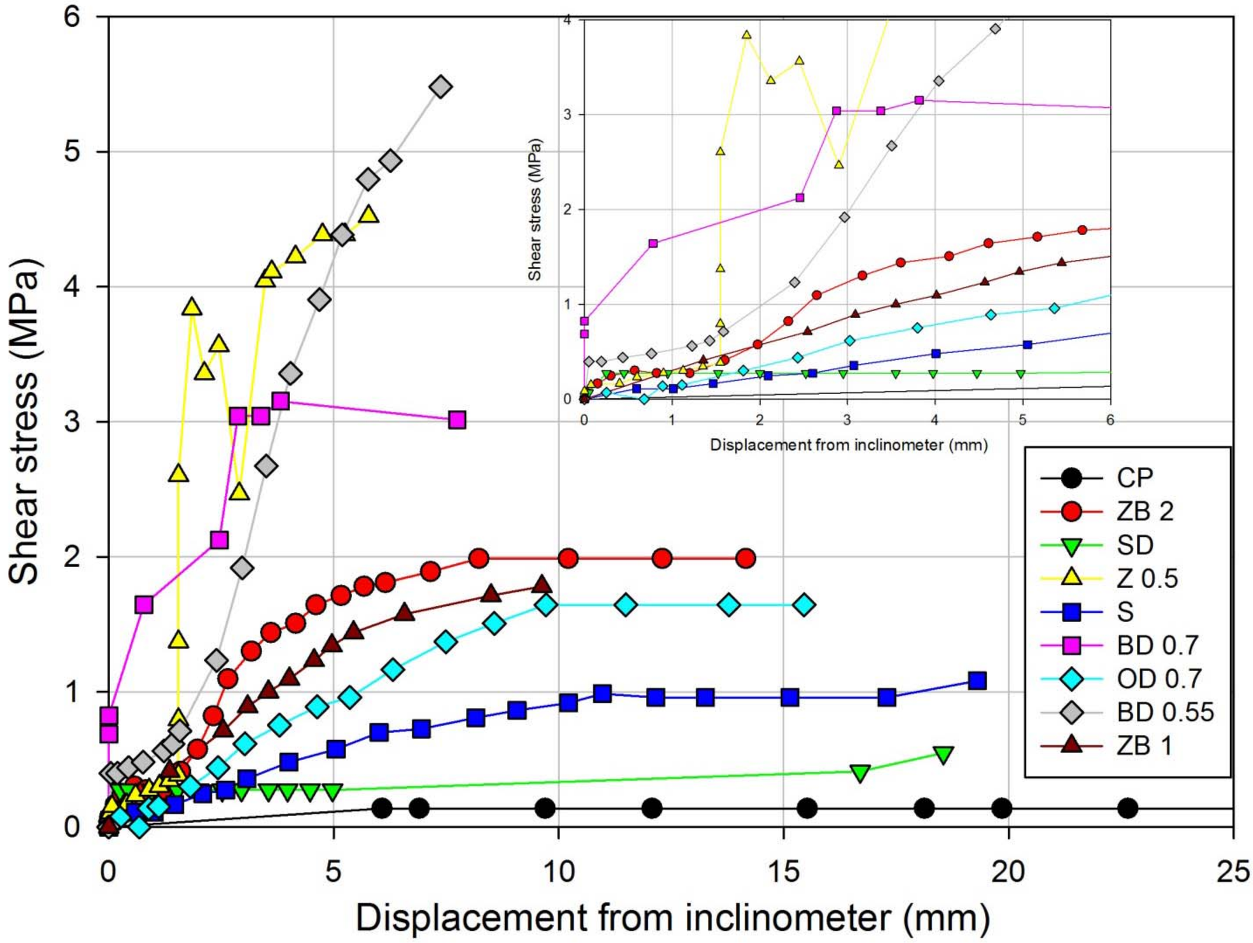

Figure 6: Shear stress vs. displacement for the various combinations of fill material and ABS 3 mm. The insert highlights the initially strong non-linear behavior of some materials.

5 Example of Application

Assume shear displacement on a rock joint which should be monitored by an inclinometer. A shear test in the laboratory was conducted under a normal stress σ_N = 0.5 MPa (≈ 20 m of overburden) and a displacement velocity of $2 \cdot 10^{-3}$ mm/s as shown in Figure 7. The strength of the discontinuity is exceeded at a shear displacement of 0.5 mm, after which residual sliding occurs. Exemplary inclinometer measurements with ABS casing ∅ 71 mm with 3.5 mm and the fill materials ZB1, OD 0.7 and BD 0.55, respectively may lead to the measurements as shown in Figure 8. The failure of the discontinuity is not reflected in the measurements and the velocity of displacements will be different for the various fills as shown in Table 5.

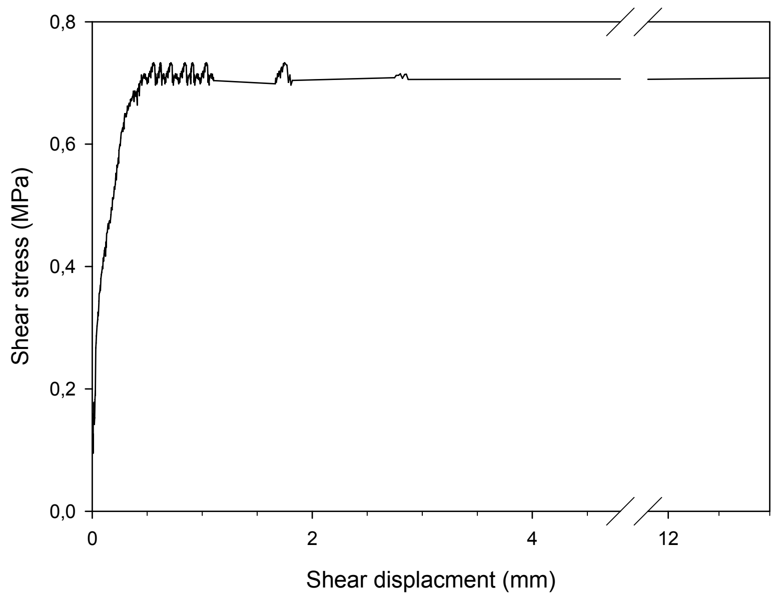

Figure 7 Result of a laboratory shear test on a sandstone discontinuity.

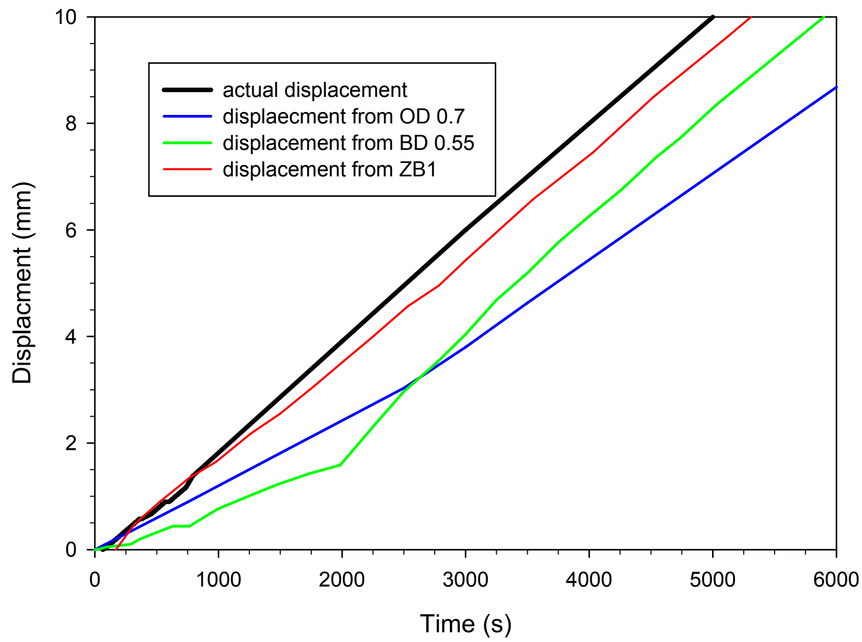

Figure 8: Exemplary displacement-time plots for different casing-fill combinations.

Table 5: Exemplary sliding velocity interpreted from 3 different casing-fill combinations.

Fill material	Initial velocity	Final velocity
ZB1	$1.9 \cdot 10^{-3}$ mm/s 95% of correct velocity	$1.9 \cdot 10^{-3}$ mm/s 95% of correct velocity
BD 0.55	$8 \cdot 10^{-4}$ mm/s 40% of correct velocity	$2 \cdot 10^{-3}$ mm/s 100% of correct velocity
OD 0.7	$1.2 \cdot 10^{-3}$ mm/s 60% of correct velocity	$1.6 \cdot 10^{-3}$ mm/s 80% of correct velocity

The fill material ZB 1 reacts with a time lag but reflects then quite closely the actual displacements and velocities. The other fill materials show in the early stage too little velocity and the rock mass may be wrongly interpreted as stable. Later on the velocities increase and one might wrongly interpret this as an acceleration of the failure process on the discontinuity in question.

6. Conclusion

The tests conducted on 3 mm ABS casing have proven the suggestion that even in hardrock conditions the best suited backfilling materials should have low shear strength. It could be demonstrated that aside sand any filling material did not properly reflect the initial displacements. Particularly for small displacements the initial damping of the “intact” fill material should be taken into account when interpreting inclinometer readings. The fact that “correct” values are available only after some mm of displacements may lead to the wrong conclusion that the displacements accelerate and the rock mass under investigation becomes instable.

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