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The influence of casing and backfilling materials on inclinometer measurements

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ABSTRACT: Vertical inclinometer measurements represent one of the most commonly used methods for the investigation of slope instabilities in rock and soil. Nevertheless, with a wide variety of casing types, grout and backfilling materials available, the choice of the best suited installation materials and the influence of the chosen materials on the testing results of a specific installation remains mostly vague. The presented paper reviews the findings of a recent research work conducted at Ruhr-University Bochum. Using different laboratory tests, the impacts of basic material properties on the result of inclinometer measurements at shear plane level resulting from different casing/grout-combinations were investigated. Additionally, the paper reviews some more findings on possible installation problems and presents practical suggestions for their solution.

1 INTRODUCTION

Vertical probe inclinometer measurements represent one of the most commonly used methods for 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 in most cases is 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 (Fig. 1). Both systems measure changes in the inclination of the column with reference to depth and orientation. These measurements allow estimations of ground movement perpendicular to the axis of the inclinometer column (Fig. 2, left). Further details on the measuring method are given in the ISRM Suggested Method (ISRM, 1981) as well as in Dunnicliff (1993) and are not the topic of this paper.

2 INSTALLATION OF INCLINOMETER COLUMN

A vertical inclinometer tube basically comprises a special inclinometer casing which is installed into a borehole or inside a pipe (Fig. 2, right).

The choice of the best suited installation materials and the correct installation of the column are of crucial importance for the monitoring results. The national German DGGT recommendation states that "… experience has shown that problems with inclinometer measurements are often connected to the choice of a wrong inclinometer casing and its wrong installation" (DGGT, 2002, p. 15).

Figure 1. Inclinometer measurements using a probe inclinometer system (left) and a chain of in-place-inclinometer transducers (right; photo courtesy of SISGEO s.r.l).

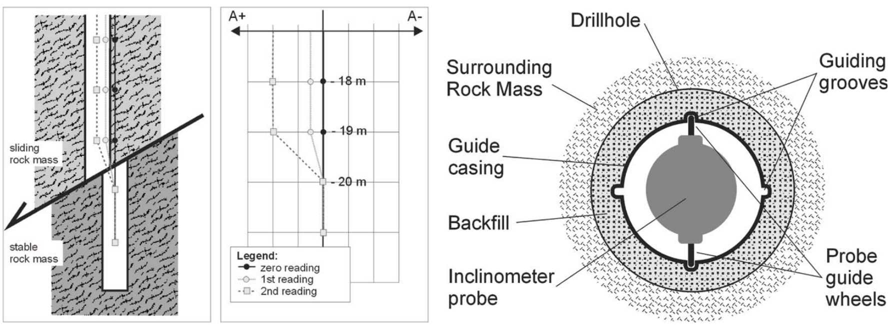

Figure 2. Left: Scheme for a rock slide and inclinometer readings gained. Right: Schematic cross section of an inclinometer tube (acc. to ISRM, 1981).

2.1 *Inclinometer casing*

The key features of an inclinometer casing are two pairs of guiding grooves that provide a guidance and orientation reference for the inclinometer probe. The various casings available on the market differ widely in casing geometry (diameter and thickness), coupling system and casing materials. Aluminium alloy, fiberglass, ABS (Acrylonitrile-Butadiene-Styrene) plastic and steel represent common materials (Fig. 3).

There are a number of technical aspects for casing choice which are described by Dunnicliff (1993) including suggestions on high precision, climatic conditions, skill of the installation personnel, longevity and depth of the installation. Additionally, the deformation characteristics of a chosen casing should represent another relevant influencing factor which has not yet been subject to systematical investigations.

2.2 *Backfilling*

In order to gain high precision measurements, it is important that the chosen material and the installation procedure carried out ensure that the backfill completely fills the annular space between the inclinometer casing and the surrounding rock mass. Poor-quality backfilling around the casing may cause scatter in readings and may not fully transfer ground movements to the casing. There are a number of materials available, which can be generally divided into granular backfilling materials and grouts (Tab. 1).

Granular backfilling materials, which are usually purchased and transported in bags, are filled into the borehole from the top of the column. Even if diameter-constant couplings are used and great care is taken during installation (e.g. by sand flushed in with water) the risk

Figure 3. Examples of different inclinometer casing types, used for the investigations presented in this paper (from top to bottom): SISGEO type S111 aluminium alloy casing ∅ 76 mm; SISGEO type S131 ABS casing ∅ 71 mm with 3.5 mm material thickness; SISGEO Type S141 flush-coupled ABS casing ∅ 70 mm with 5 mm material thickness and SISGEO type S151 ABS casing with 5 mm material thickness and quickjoint-system.

Table 1. Overview of materials commonly used for the backfilling around inclinometer tubes.

Granular materials	Grouts
Bentonite pellets	Cement grouts
Sand	Industrial cement-bentonite-mixtures (e.g. Dämmer™)
Sand-gravel-mixtures	Cement-bentonite-mixtures mixed on site

remains, that backfill may hang up on couplings or borehole and incomplete backfilling is achieved.

Consequently, most recommendations suggest the use of grouts for backfilling. The ISRM Suggested method (ISRM, 1981) only describes grouts, national German DGGT-recommendation No. 21 (DGGT, 2002) suggest the use of sand-gravel-backfilling only in special situations, for example large underground cavities (e.g. karst). Dunnicliff (1993) states: “Grout backfill is generally more effective than a compacted granular backfill” (p. 256).

But even if grouts are capable of a complete backfill of the inclinometer casing, the stability of these mixtures should be kept in mind. As grouts are mixtures of solid ingredients (cement, sand, clay minerals) with water, grouts may settle and separate during hardening. A value of 10% grout settlement will mean that for a 30 m deep installation there will be 3 m of more or less pure water “backfilling” at the top of the backfill after hardening.

Additionally, the deformation characteristics of a chosen grout should represent another relevant influencing factor which has not yet been subject to systematical investigations.

3 LABORATORY INVESTIGATIONS

In the course of a research project at the department of Engineering Geology, Ruhr-University Bochum, Germany a systematical investigation of commonly used grouts, inclinometer casings and combinations of both installation materials was carried out (Düllmann, 2008).

Table 2. Compilation summary of investigated grouting materials and their relevant technical properties (all parameters tested after 28 days of drying).

Abbreviation	Grout description	W/C-factor	Density [g/cm³]	UCS [MPa]	Young's modulus [MPa]	Settlement value [%]
SD 0.45	Soil Dämmer™ industrial cement-Bentonite-mixture	0.45	1.58	0.05	100	0
ZB 1	Cement-Bentonite-mixture 5:1	1.67	0.76	0.36	884	8
ZB 2	Cement-Bentonite-mixture 3.3:1	1.85	0.50	0.10	100	16
OD 0.45	Original Dämmer™ industrial	0.45	1.58	7.0	2468	0
OD 0.7	cement-Bentonite-mixture	0.70	1.42	1.7	912	0
BD 0.45	Blitz Dämmer™ industrial	0.45	1.73	23.1	7063	0
BD 0.55	cement-Bentonite-mixture	0.55	1.52	21.0	5206	0
BD 0.7		0.70	1.42	12.6	4550	0
Z 0.5	CEM III/B cement	0.50	1.58	36.8	8148	6
Z 0.8		0.80	1.25	24.6	4474	12.5

The investigations were conducted on a total of 10 grouts (including cement grouts, Dämmer™ industrial cement-bentonite-mixtures as well as bespoke cement-bentonite-mixtures) and 3 types of inclinometer casings (SISGEO type S111 aluminium casing ∅ 76 mm, SISGEO type S131 ABS-Casing ∅ 71 mm, 3.5 mm material thickness and SISGEO type S141 ABS-Casing ∅ 70 mm with 5 mm material thickness). All grouts were mixed with specific water-cement-factors so that a moderate viscosity and good flowing characteristics were achieved.

3.1 *Properties of investigated grouts*

In order to obtain relevant material properties for the various grouts, standard tests were carried out on each mix. Table 2 gives an overview of the tested grouts and their properties.

3.2 *Direct shear tests on grout-casing-combinations*

In order to analyze the mechanical behaviour of different "model columns" consisting of specimens with differing casing-grout-combinations an existing rock shear testing frame was adapted and modified with special shear boxes and deformation transducers (Fig. 4).

By use of this testing layout it was possible to directly shear specimens of 200 mm height while measuring external movement and internal deformation of the casing. The used layout was supposed to represent the shearing of an inclinometer column in a high strength hardrock formation (see Figure 2). The outer deformation (d_O) was measured using the testing frame's deformation transducer, and 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 (see Fig. 4, Fig. 5).

3.3 *Test results*

The tests were all carried out under a defined vertical force of $F_N = 3000$ N, 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.

A "specific damping factor" F_D was identified which describes the difference between the outer deformation (d_O) applied to the sample and the inner deformation (d_I) resulting from this and measured on the inner wall of the inclinometer casing. The "specific damping

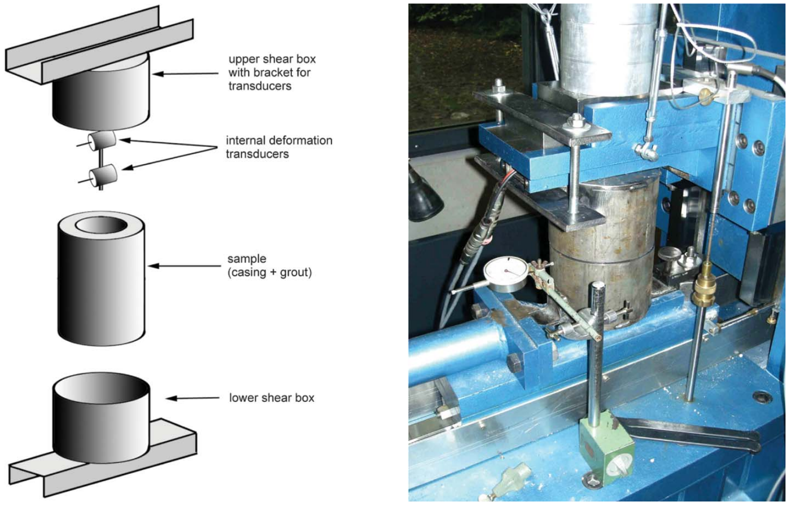

Figure 4. Testing layout of the direct shear test on model tube installations (casing-grout-combinations).

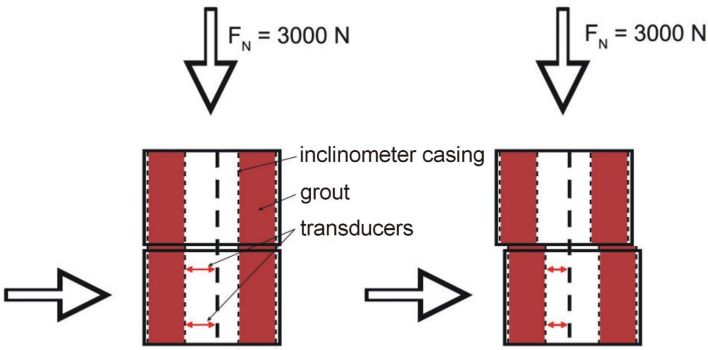

Figure 5. Schematic cross section for the direct shear tests on model columns.

Figure 6. 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.

factor" F_D was calculated for every combination tested according to equation 1. The gained F_D values are compiled in Table 3.

$$F_D = \frac{d_o}{d_I}\left[\frac{mm}{mm}\right] \tag{1}$$

where F_D = specific damping factor [mm/mm], d_O = outer deformation [mm], measured on the outside of the sample, d_I = inner deformation [mm], measured on the inside of the sample casing.

The derived damping factors showed values ranging from a minimum of 1.14 to a maximum of 3.38 and are widely distributed amongst the different combinations. However, by disregarding the grout material the following significant trends by casing type can be found:

- the thinner (3.5 mm) ABS casing type achieved F_D values of 1.14 to 2.32 and with a mean value of 1.66 show the best correlation of outer and inner deformation,
- the thicker (5.0 mm) ABS casing type achieved slightly higher F_D values of 1.26 to 2.59 and a mean value of 1.71 which is a slightly higher damping,
- the aluminium alloy casing type achieved relatively high F_D values of 1.24–3.38 and with a mean value of 2.33 show the highest damping in the system.

Further analysis was performed in a second step in order to understand the damping characteristics of the grout materials. This analysis included the comparison of the measured F_D factors and the specific material properties of the grout. As can be seen from Figure 7, the correlation of F_D factors and the material's Young's Modulus gives rise to the conclusion that the damping rises with rising stiffness of the grout materials.

Table 3. Derived "specific damping factors" F_D for the tested grout-casing-combinations.

Abbreviation	ABS casing, 3.5 mm (SISGEO S131)	ABS casing, 5 mm (SISGEO S141)	Aluminium 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.

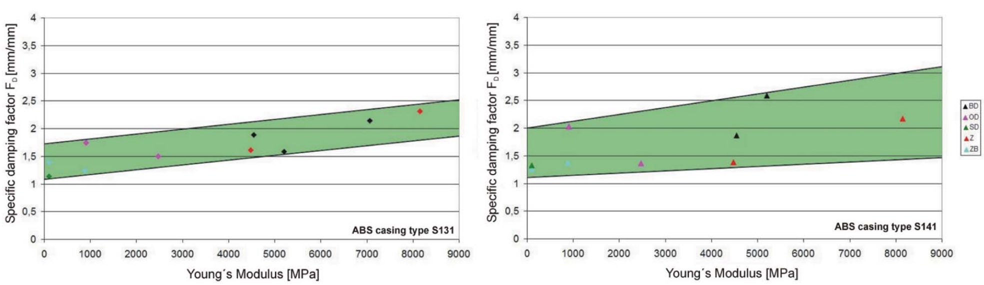

Figure 7. Damping factors F_D for ABS-casings with 3.5 mm (left) and 5.0 mm (right) material thickness, plotted against the Young's Modulus of the grouting material.

4 CONCLUSION AND SUGGESTIONS

The most important finding of the presented investigations is the fact that none of the analyzed grout-casing-combinations were able to represent the deformations applied from the outside in a 1:1 ratio. Transferred to real-scale inclinometer measurement this implies that inclinometer measurements that are caused by shear will always underestimate the real shear deformation taking place in the rock mass. This finding is of importance if the results of in-situ inclinometer measurements are used as input parameters for numerical (e.g. finite element models) in order to calibrate or back-analyze slope instability problems. However, this finding may not be applicable to measuring results that are caused only by ductile deformation or rotation of the whole column and not by shearing of the column.

Another finding of this research is that the use of different casings and different grouts will have a specific influence on inclinometer results at shear planes. Based on the experiences presented in the literature and the results of the presented investigations from the authors' point of view the following 5 conclusions can be made in order to provide a best possible measuring installation for vertical inclinometer measurements:

1. **Use ABS casings rather than aluminium alloy casings**: Aluminium casings are subject to corrosion—even if they are coated—and show higher damping than ABS casings.
2. **If possible, thin ABS casings are preferred**: If the length of the column to be installed and the differential pressures that arise during grouting allow the use of thin walled ABS casings, they should be used. These casings have shown the best deformation characteristics disregarding the used grouting material.
3. **Use grouts rather than granular backfilling materials**: Grout backfill will generally allow a better backfilling of the casing than granular backfill materials. The use of granular backfilling should be limited to special situations as, for example, in large underground cavities (e.g. karst).
4. **Use stable grouts rather than non-stable grouts**: If a grout is used, try to use stable mixtures that show no or only little settlement, i.e. separation of solid ingredients and water. If unstable grouts are used, check for the complete backfilling of the upper part of the column and re-grout if necessary.
5. **Use soft grouts rather than stiff grouts:** Softer grout backfilling has a lower damping effect in the system and will allow a more realistic reproduction of ground movements in the inclinometer casing. This recommendation not only refers to soft soils but also seems to apply to hard rock conditions.

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