Borehole Instrumentation for Groundwater Investigations in Underground and Surface Coal Mine Environments

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ABSTRACT

The paper presents details of borehole instrumentation schemes for the purposes of monitoring rock and fill deformations associated with groundwater in underground and surface coal mines. The instruments are described which measure rock mass displacements, permeability changes and alterations to hydrology. Methods of installation are detailed and the applicability of instruments discussed. Reduction and interpretation of results are detailed.

INTRODUCTION

The Department of Mining Engineering at Nottingham University have in conjunction with British Coal been involved in a number of groundwater research projects over the past 10 years. Projects have been undertaken to monitor intact strata and rockfill deformations in particular measuring permeability changes associated with such movements and the mechanical effects associated with groundwater percolation. Studies by Aston (1982) and Neate (1980) have investigated permeability changes associated with strata adjacent to longwall deep mine workings. Reed (1986) has conducted work on opencast coal mine sites measuring the permeability of backfill materials and the settlement of such masses associated with groundwater recovery. The field projects have necessitated a wide range of instrumentation techniques particularly in situ monitoring with borehole instruments.

CHANGES IN PERMEABILITIES ASSOCIATED WITH LONGWALL FACE ENDS

The majority of extraction in U.K. underground mines is by the longwall method. The process of advancing or retreating a panel is associated with collapse of overlying roof strata into the void left by coal extraction behind the face supports. This process affects permeabilities of the associated strata above, behind and in advance of the face line. If rock breakage extends to an aquiferous formation than heavy induced inflows will results with detrimental effects on the safety and economy of the operation. The aim of this investigation has been to determine the nature of the hydrological changes around the face end.

Instrumentation

In order to obtain anything more than a sketchy view of the permeability changes occurring at a face end, it is necessary to take measurements at as many points as practicable around the roadway. Suitable borehole instrumentation is provided by the tension wire extensometer (TWE) with modifications to include discrete in situ permeability testing compartments. The TWE instrument for pure rock monitoring exercises consists of three basic components;

i). Firm anchorages within a borehole in contact with the rock mass from which measurements may be taken.

ii). A tensioning device between anchors and the surface.

iii). A means of assessing any change the wires are subjected to.

This instrument can be modified to contain discrete compartments for the purposes of permeability testing. Figure 1 details the features of the instrument.

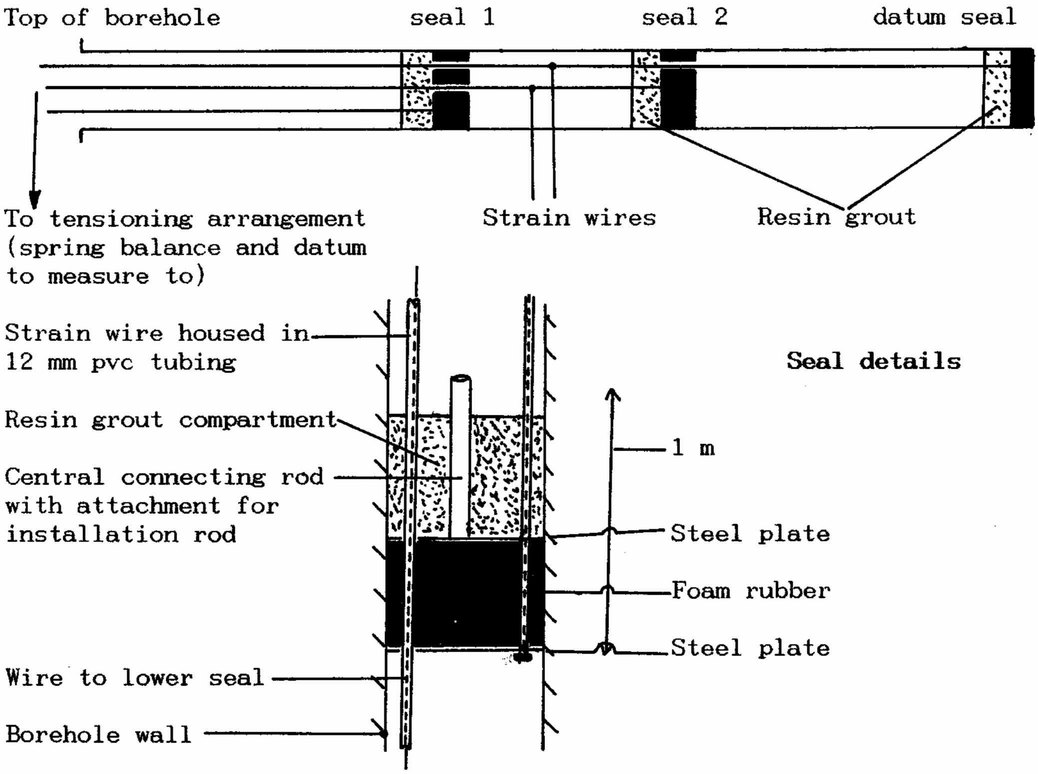


Figure 1. General details of the TWE with modifications for permeability testing.

Figure 2 details schematically how deformations can be measured. Sources of error from the instrument can be minimised by the avoidance of excessive frictional and temperature variations. Vertical boreholes can be installed with a permanent tensioning device which eliminates many sources of error. The method of installation is presented in table 1.

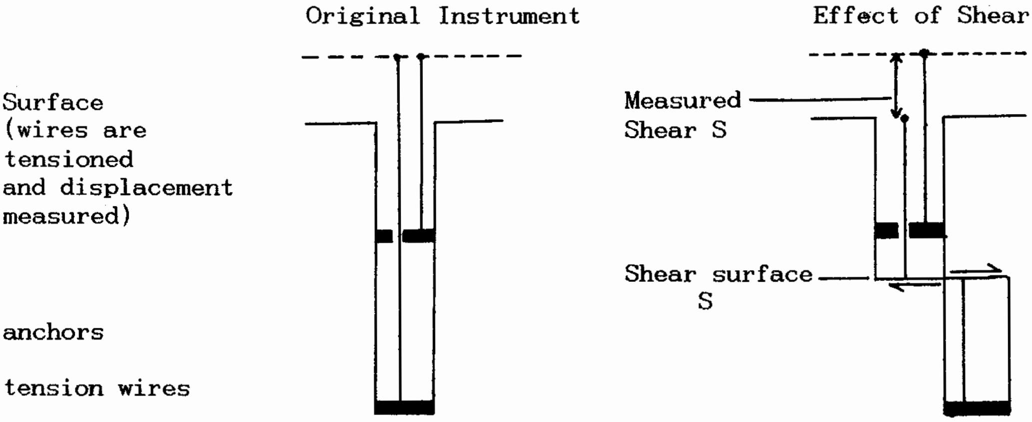


Figure 2. Measurement of shear by TWE

i). Drill and ream 100 mm borehole
ii). Insert first seal and wire to base of hole. This is pushed into place by installation rods.
iii). Pump resin grout to seal anchor in place.
iv). Insert next seal.
v). Pump resin grout.
vi). Continue process until last seal is in place.
vii). Install tensioning device if permanent, e.g. loaded weights.

Table 1. Procedure of TWE installation

The inclusion of test compartments, (fig 1) enables the conduction of permeability tests. In these instruments constant tensioning systems cannot be used. Figures 3 and 4 detail the testing manifold and reduction of pumping data to final results.

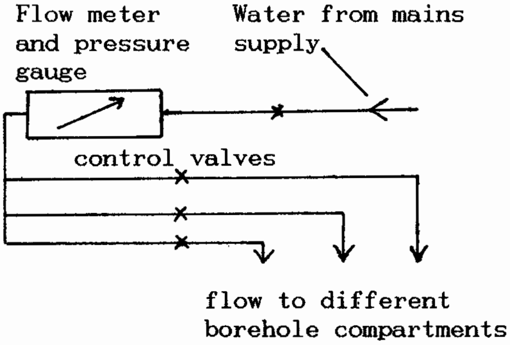
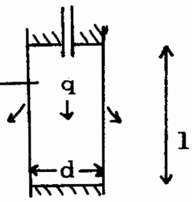


Figure 3. Testing Manifold

Permeability=k compartment

$$k = \frac{q \ln(2mld)}{2\,lH}$$



k=coefficient of permeability normal to compartment m/s
kp=coefficient of permeability parallel to compartment
q=flow rate m^3/s
l=length of test compartment m
d=borehole diameter m
$m=(k/kp)^{0.5}$
H=pressure head of water m, above original level

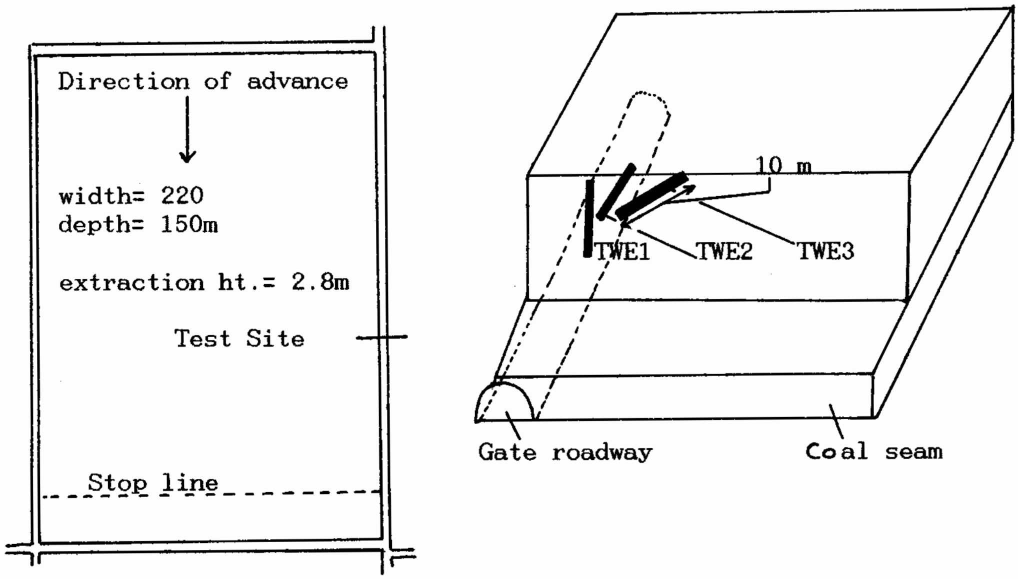
Figure 4. Reduction of data

Field Strategy.

Results are best effected by drilling several multipoint boreholes from the gate roadway. This minimises drilling and disturbance and maximises results. If this is done on standard in line advancing faces then the drilling and instrumentation of the boreholes is very difficult in the cluttered modern gate end. It is much more suitable to gain access to a face either on retreat or with gate roadways already headed out. Test holes in these situations can be installed well in advance of the face and so initial in situ data can be measured

Case Study.

Facilities for testing were made available by British Coal on a retreat face. The maingate of the face was to be maintained for re-use on an adjacent panel. Figure 5 details the face layout and the instrumentation scheme. Three boreholes were drilled to investigate the strata above the roadway, drilled at 90, 64 and 45 degrees to the roadway base. Each hole contained five compartments with seals and anchors. Boreholes were drilled at 100 mm dia. and 10 m length.



Plan of Face Layout **Isometric View**

Figure 5. Test Layout on Retreating Face

A large number of pumping tests were performed and the results were transformed into a series of vertical and three dimensional views of strata behaviour. Fig 6 details these cross sections. Inspection of the results shows that a fissured zone developed around the roadway, expanding slowly upwards. A similar zone also exists in advance of the face. The results also show that a surface can be defined as the limit of permeability changes.

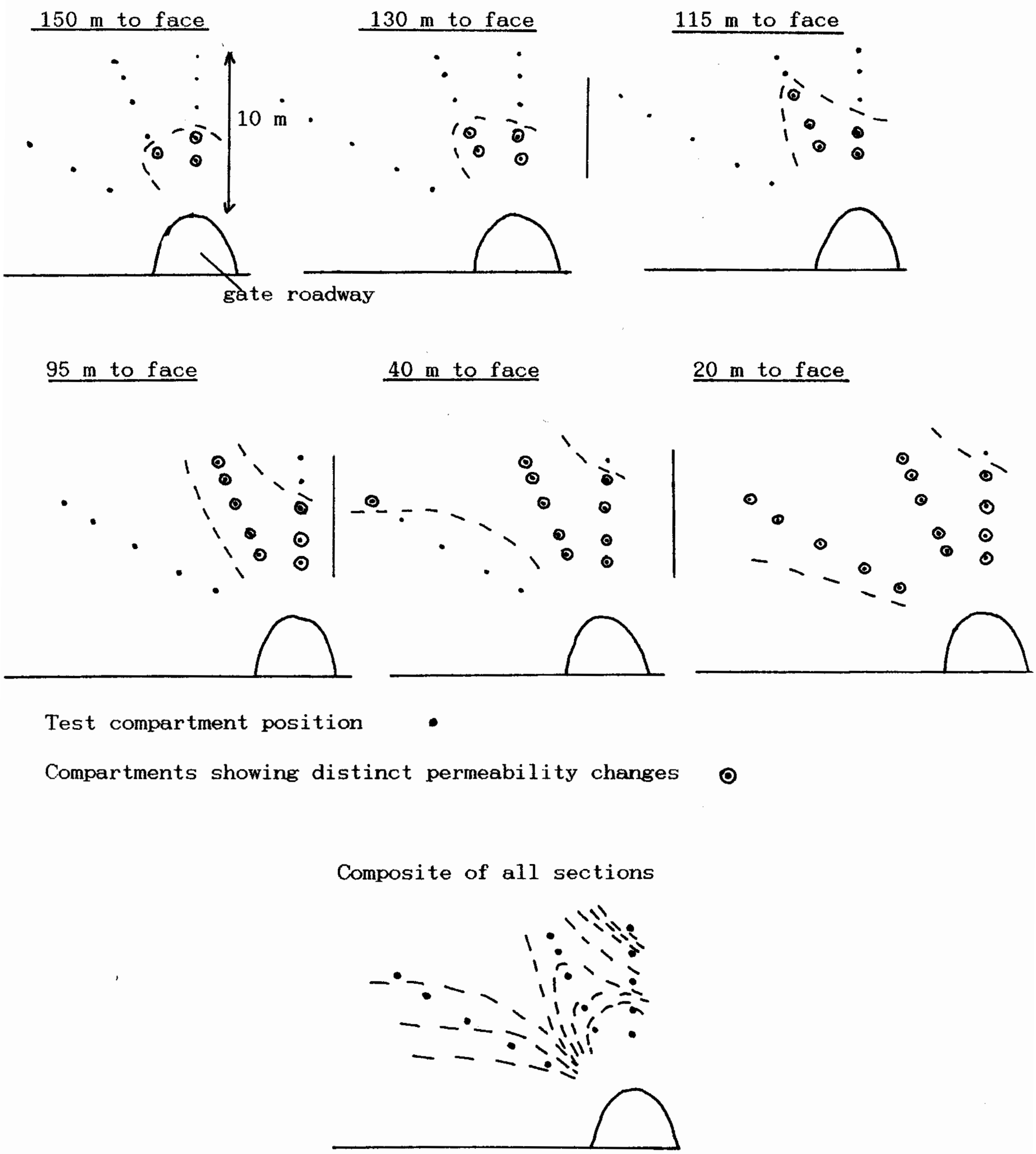


Figure 6. Field observations

The information gained in the field tests shows the effect of the approaching face line on rock deformations at the test site. This information may subsequently be used to estimate likely rock mass behaviour, and the results can be used as an aid for mine water inflow prediction as well as an indication of roadway stability.

INVESTIGATIONS CONDUCTED UPON OPENCAST COAL MINES IN THE UK.

The Department has conducted an investigation to monitor the effects of groundwater re-establishment on restored surface mine sites, ie the recovery to equilibrium levels of the piezometric surface previously depressed by pumping operations. The rates and magnitudes of groundwater recovery were measured with complimentary backfill deformations. The project formed part of a larger research objective to establish the suitability of restored opencast sites for structural development.

Opencast Mine Backfill

The extraction of near surface coal deposits in the U.K. typically involves overburden to coal ratios of 10-25:1. Restored mine sites of up to 100 m in depth are not uncommon and the maximum extraction to date has reached 250 m. The restored backfill mass has the capability to undergo significant displacements during consolidation. Typical settlement values of up to 1% of the initial fill depth can be measured unless some form of controlled backfill replacement has been used such as compaction. In the presence of a recovering water table the rate of settlement of unconsolidated backfill has been shown to accelerate.

Aims of Instrumentation

The project investigated the following areas;

i). Measurement of the rate and magnitude of groundwater recovery in both backfill and the surrounding solid strata.

ii). An observation of changes in groundwater hydrology as a result of surface mine operations.

iii). Monitoring changes in surface stability of backfilled materials associated with groundwater recovery, particularly lateral and vertical movements.

iv) To observe changes in permeability of backfill materials and relate these to stability.

The instruments used in this project are detailed in table 2.

Instrument	Function
Magnetic/Extensometer/Piezometer	Vertical settlement of backfill materials, groundwater recovery
Tension wire Extensometer with modifications for permeability testing	Lateral and vertical displacements. Permeability testing.
Multipoint Piezometer	Recovery within the fill, presence of perched water tables.
Stand-pipe Piezometer	Recovery within the fill and drawdown between solid and fill materials.

Table 2. Summary of Instrumentation.

The Magnetic Extensometer/Piezometer, MEP.

This instrument is designed to relate groundwater levels within a soil or rockfill mass to the settlement which occurs at different horizons within that mass. The instrument is detailed in figure 6. Movements are assessed by the location of magnetic targets within the borehole related to a datum installed in stable material below the base of the fill. A reed switch probe enables the magnets to be located and a standard dip meter can be used to establish water levels.

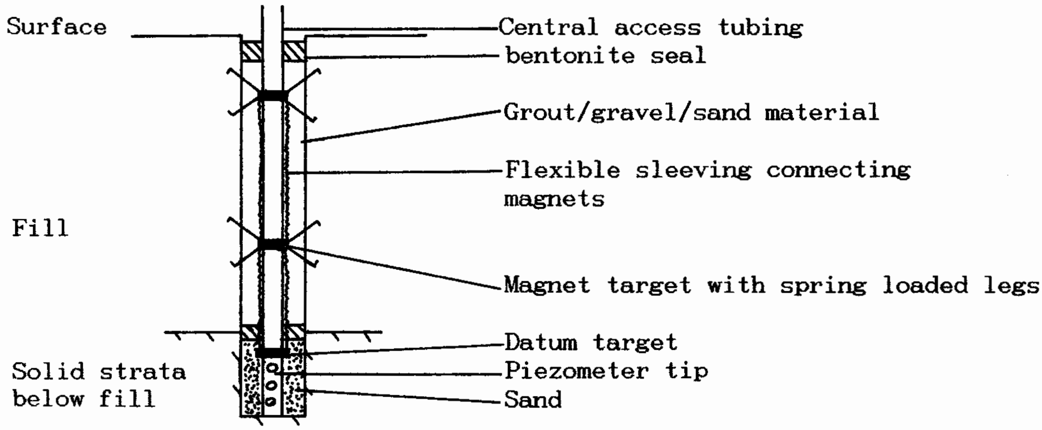


Figure 6. The Magnetic Extensometer/Piezometer Instrument

Method Of Installation

The project has involved the installation of 10 instruments, 9 of which have been successful. These 9 instrument are detailed in table 3. The failure of the 10th instrument is detailed later.

Site	No. MEP	Depths m	Borehole dia. mm	Time to Drill and install	Borehole backfill material
A	5	20-25	149	10 days	Weak grout
B	4	30-70	149	21 days	Filter sand

Table 3 Summary of MEP installations

The instrument is installed in a 149mm cased borehole in prefabricated sections of 6 m length. Spring loaded magnets are installed in the borehole in a retracted state, the spring legs held be a piece of nylon twine to which a pneumatic cutter and line is attached. Magnets fit over the 23 mm dia. access tubing and are interconnected by pvc sleeving to maintain their position in the borehole during installation. When the instrument is in place the casing is withdrawn and the spring loaded legs of the magnets fired off into the walls of the borehole by the compressed air source. The borehole is then backfilled using weak grout, gravel or sand. It is considered by the authors that sand is by far the best medium as grouts tend to have long setting times and gravel has the tendency to bridge in the borehole. Bentonite seals are applied as indicated in figure 6.

It is very important to keep control over the weight of the instrument as it is lowered into the hole, securing as necessary with ropes. If the instrument is lowered into a borehole with a relatively high water table then difficulties may be encountered in overcoming buoyancy effects.

Drilling in Fill

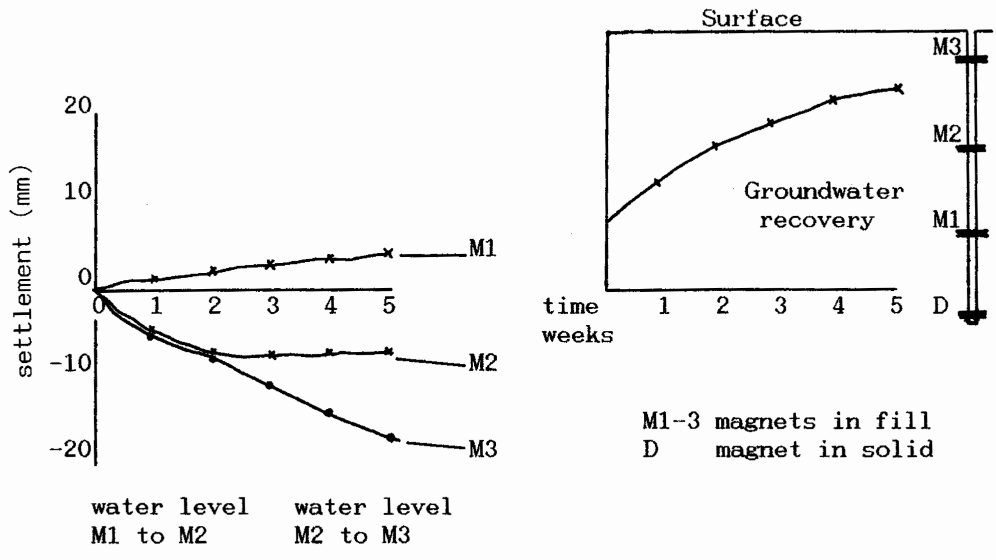
Owing to the blocky nature of backfill, hole diversion whilst drilling was a problem. This is worsened if the fill is relatively fresh lain. In several sections of the boreholes, very weak horizons were found which again led to problems with the casing operation. In the times of installation presented in table 3 it should be stressed that drilling accounted for over 75% of the periods stated.

Failure of instrument, 80m depth

A 10th instrument installation was attempted in a fill 80m deep. This instrument failed owing to the access tubing being sheared by lateral fill movements. It is recommended that installations should be restricted to say 50 m depth if installations are to have a very high success.

Use in the Field

The instrument is simple to read in the field and the results are easily reduced. Figure 7 details typical results which may be obtained from such an instrument and the interpretation of such.



Trends observed; i) slow settlement in unsaturated ground
ii) collapse settlement in presence of recovering water table
iii) heaving movements in fill following saturation

Figure 7. Typical results from MEP installation

Application of TWE to Opencast Mine Backfill

The TWE instrument with permeability testing facilities has been applied to surface mine monitoring. The instrument is of the same basic design as that previously detailed with a few minor details such as the borehole size has to be increased to 149 mm and the casing has to be installed completely prior to installation. Two installations to 75 m have been successfully completed in this project. Details of seal locations etc. are presented in table 4. The technique of installation is as follows;

i). Drill borehole and case to 149 mm diameter
ii). Install datum wire/anchor in base of hole
iii). Raise casing to just above level of first seal
iv). Install first seal/anchor/wire, grout in position
v). Raise casing to level of second seal. Continue process until last seal in position.
vi). Install tensioning unit or head unit for permeability testing applications

Instrument	Depth of datum	Depth of seals
A	71 m	42, 28, 19, 14, 10, 6, 3 m
B	73 m	20, 15, 10, 5 m

Table 4. Details of TWE installations

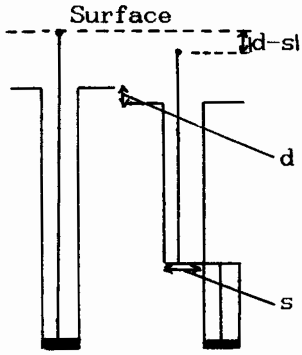
The positioning of the seals in the borehole reflects the difficulty in installing this type of instrument in backfill materials. There were several problems encountered in installation ranging from the tensioning of pipes and wires when casing was been withdrawn to the again common problem of drilling and casing deep backfill material. Despite the problems in installation which along with drilling operations took on average 5 days per instrument, the devices have worked satisfactorily.

Use of Instrument and Reduction of results

The wires on the instrument were very easy to read and it is possible to read 8 wires in a matter of a few minutes. The pumping tests however using the same type of manifold as previously described are long term tests and require a full man week to accomplish the results. The large compartments and the permeability of the backfill meant that it took a long time to achieve steady state conditions, several hours per compartment. On lower compartments tests were frequently aborted as the permeability of the material was such that steady state conditions could not be met. Reduction of the wire data requires some thought and technique, and in some cases it is only possible to obtain net shear and settlement displacements between the seals. Table 5 gives some data for 4 strain wires and demonstrates the reduction and interpretation process.

Wire	Depth m	Measured Seal Displacements Month (mm) 1	2	3	4	5	6	7	8	9	10
1	32	0	0	0	+10	0	0	0	0	0	0
2	20	0	0	-5	-5	-10	-5	+5	-5	+10	+25
3	15	0	+5	+5	0	-20	-35	-40	-40	-40	+10
4	5	0	0	+10	+15	+10	+20	+20	+40	+40	+60

Horizon	Thk. m	Net Displacements between Seals Month (mm) 1	2	3	4	5	6	7	8	9	10
1-2	12	0	0	+5	+15	+10	+5	-5	+5	-10	-25
2-3	5	0	-5	-10	-5	+10	+30	+45	+35	+50	-15
3-4	10	0	+5	-5	-15	-30	-55	-60	-80	-80	-50
4-surf.	5	0	0	+10	+15	+10	+20	+20	+40	+40	+60
Net Disp.		0	0	0	+10	0	0	0	0	0	-30 (mm)



Initial Subsequent
reading reading
d= settlement
s= shear movement

Table 5. Example of TWE results in fill material

If this instrument is combined with multipoint or stand-pipe piezometers then the level of the groundwater table can be correlated to movements in the fill. Stability of the fill can be determined as when the displacements between horizons have reached a constant magnitude. This instrument thus becomes superior to MEPs in that lateral displacements are considered as well as those in the vertical.

CONCLUSIONS

This paper has attempted to present some details on suitable borehole instrumentation for groundwater investigations in underground and surface mines. Applications may differ from site to site as may instrument structure and method of installation, however the general principles of these techniques have been proved in field studies in the U.K.

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