SPATIAL DISPLACEMENTS OF OPENCAST MINE BACKFILL ASSOCIATED WITH GROUNDWATER RECOVERY.

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ABSTRACT

The paper presents part of a research programme conducted by the University of Nottingham into the environmental effects associated with opencast mining operations. Specifically the paper describes the monitoring of three-dimensional movements in a restored mudstone/sandstone backfill of up to 80 m depth. Instrumentation and field results are presented, including permeability measurements in spoil materials.

INTRODUCTION

The surface mining of coal deposits in the United Kingdom has in recent years survived a great deal of pressure from the environmentalist lobby, which is continuing to impose more stringent regulations regarding opencast mine operations. Both environmental impacts encountered during mining, (e.g. noise, dust, vibrations, water pollution), and those which may manifest after the operation have come under scrutiny. The project has investigated the environmental effects following the completion of the mining operation, specifically those associated with the re-establishment of the local hydrological regime, when groundwater recovers from its depressed level maintained by pumping operations, to its new equilibrium position in the fill and surrounding strata. The two principal impacts have been determined as being; the effect of groundwater on the stability of the restored backfill mass, and, the pollution of groundwater as a result of contact with weathered rock fill materials.

This paper is concerned with the nature of the re-establishment, changes in hydrology and the stability of a restored backfill mass.

SITE DESCRIPTION.

The results presented in this paper were obtained over an 18 month period of field work on a dragline surface mine in the North-East of England. The area of the site investigated as in fact an extension to previous opencast operations. The depth of fill approaches a maximum of 80 metres. The restored site which covers a total area of 296 hectares is destined for use as agricultural land, however the results of this investigation will go directly towards a general assessment of surface mine sites for building purposes. The mine fill consists of a mixture of mudstones and sandstones and the mine void was infilled by both dragline spoiling and end-tipping by dump trucks over the edge of the advancing loosewall. Final restoration levels were achieved by scrapers and bulldozers.

GROUNDWATER CONDITIONS.

The groundwater levels over the locality of the mine are subject at present to one principal influence; the pumping of groundwater from a local abandoned colliery shaft. The effect is particularly marked as many of the seams which are being worked by opencast mines in the area are excavating abandoned room and pillar mine workings, forming a vast intersection of shafts and old deep mine workings. The distance between the colliery pump and the opencast mine site is approximately 4.3 km. The influence of this pumping is however restricted by semi-pervious barriers in the area such as major faults, igneous dykes and areas of solid unworked strata all having relatively lower permeabilities. Figure 1 illustrates the groundwater levels over mine site prior to excavation, and reflects what must have been near-equilibrium conditions produced by continuous pumping in the deep mine shaft. Of specific note was the high hydraulic gradient between the sites occuring at the outcrop of seams which were directly connected to the mine pump.

Groundwater levels are also affected by the presence of adjacent opencast mine sites which induce temporary effects owing to the excavation of saturated rock and on-site, pumping both of which serve to depress local groundwater levels.

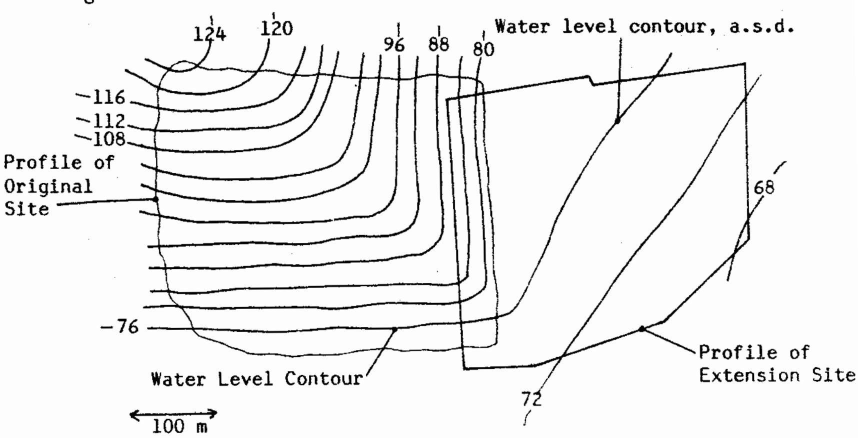

Figure 1. Original Groundwater Levels on Site.

PREDICTION OF GROUNDWATER RECOVERY.

The shaft pumping operations are expected to continue for at least until the mid 1990's, so a prediction as to the final water levels in the restored fill will be made assuming this influence. Following the termination of this pumping, water levels may be expected to rise above these estimations. Temporary effects resulting from the presence of local opencast mine sites either existing or projected are at present neglected. A standard measure on opencast mine sites with old mine workings such as these is to seal them off with clay to prevent water either entering deep mine workings or vica versa. If these seals are 100% effective then there should be a minimum of influence from the pumping shaft and water levels would rise to either the original equilibrium levels or more likely to above these. In this case it is possible to predict the minimum degrees of water table recovery in assuming that water levels will rise to the minimum level of the seam lowest in the succession to be linked to the colliery shaft. After this water levels may either remain stationary and water drain through old workings directly to the shaft, (ineffective clay seal), or the water levels will rise further. This approach also neglects drawdown within the fill towards the intersection of the old workings.

In the position of the deepest point of excavation, the level of lowest abandoned deep mine workings were 80 m a.s.d., (above site datum), about 40 m below the final restored fill surface, and this was thus deduced to be the minimum level that the groundwater level will recover to. The pre-mining water levels over the extension site stood at 70 to 75 m a.s.d, whilst over the original site they lay in excess of 100 m a.s.d. which would indicate that the predicted degree of recovery is of the right order. The minimum measurable degrees of groundwater recovery over the Extension site are presented in figure 2. This prediction is vital to the siting of instrumentation, as obviously such equipment must be sited in the deepest fill to ensure maximum degrees of measurable groundwater recovery and consequently backfill settlements.

INSTRUMENTATION.

The instrumentation of the site was aimed at recorded groundwater recovery and backfill movements. Piezometers were installed around the boundary of the site, to monitor the recovery in the solid strata as well as the recharge into the fill. Multi-point piezometers were installed in the fill, to monitor recovery and the formation of perched water tables, and extensometers were installed in the fill to monitor backfill displacements. Initially the magnetic type extensometer was installed in the fill, but failed owing to a shearing movement damaging the central access tube through which a Reed Switch Probe was passed to monitor magnet position. This type of instrument was replaced by a tension wire extensometer with facilities for permeability testing. Details of these types of instruments are presented in figure 3.

note. site datum is defined as 100 m below Ordnance Datum, (sea level at Newlyn).

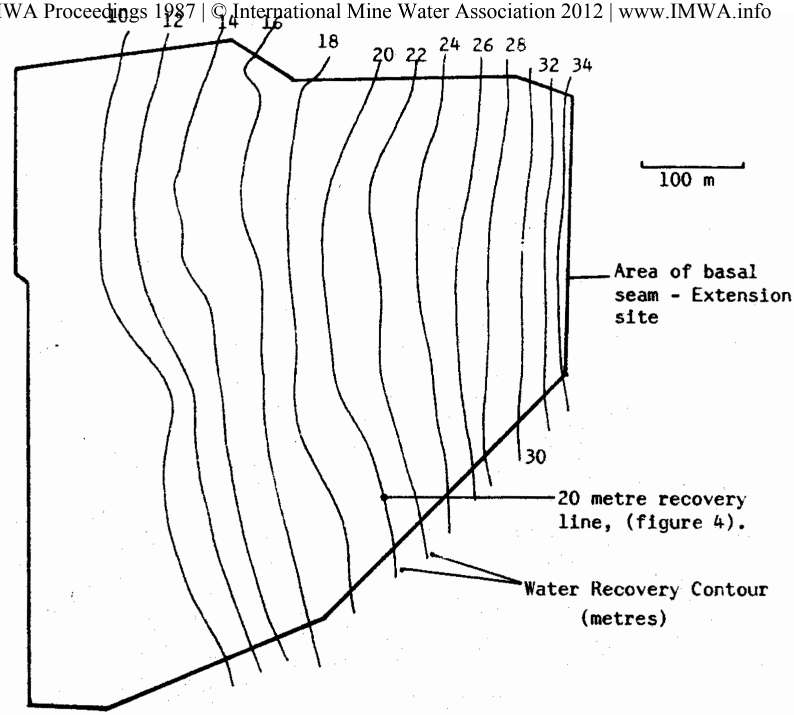

Figure 2 Prediction of Groundwater Recovery over the Extension Site.

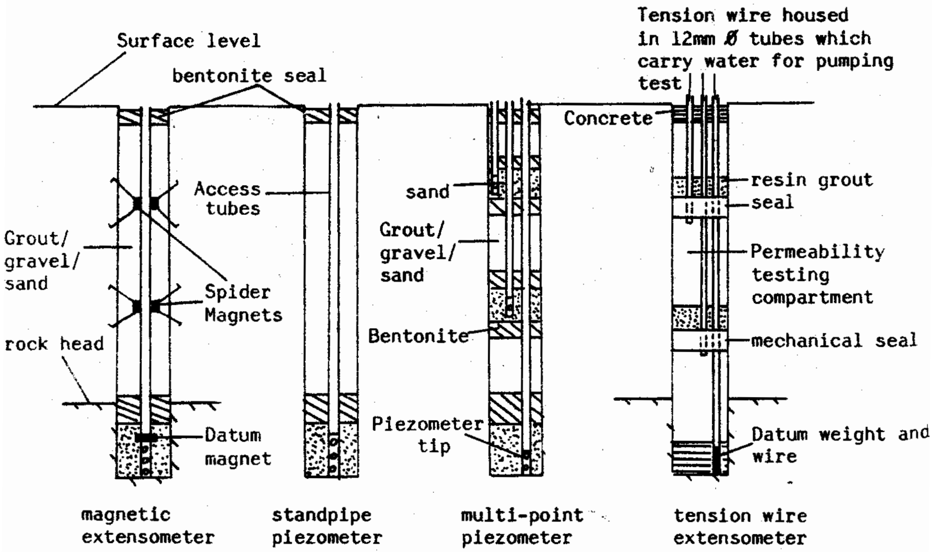

Figure 3 Borehole instrumentation

The positioning of the instruments was subject to some important site restrictions, together with the expected measurable degree of water recovery. The important criteria were as follows;

a). **The lines of installation of the proposed water courses.** To give adequate protection to the instruments it was recommended that 20 m clearance should be given to protect from moving plant which will be constructing the water course.

b). **The profile of the excavation of the basal seam,** - to ensure that instruments are placed in maximum depths of fill. The figure also shows areas of solid strata which were left intact owing to stability problems during mining. It was recommended that adequate clearance be given to these areas to compensate for any borehole deviation during drilling.

c). **The position of the final void area.** At the time of instrumentation this area was still being backfilled and in fact the area remained open for a further year until October 1985. Adequate clearance had to be given for plant operating in this area.

d). **The line of current subsoil placement.** Corresponding to the line of final overburden level. Over much of the site between 2 and 3 m of overburden were still to be replaced, so that it was considered best if instruments could be sited as close as possible to the edge of the completed restoration.

e). **The 20 m recovery line.** It was considered that the instruments should be sited so that a minimum of 20 m of groundwater recovery. This line marks the westward boundary of the instrumentation scheme.

The final plan of the instrumentation is presented in figure 4.

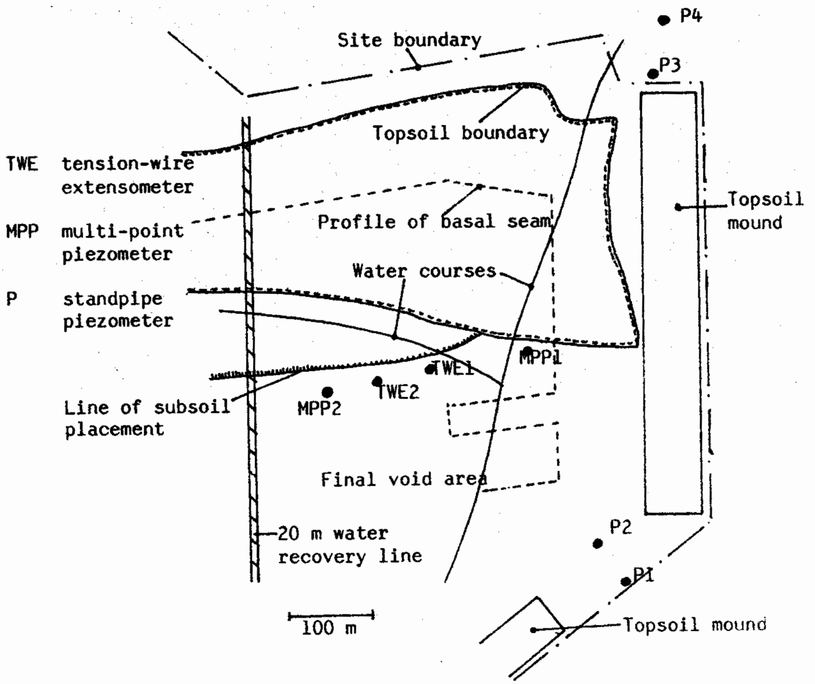

Figure 4. Instrumentation of Extension site.

APPRAISAL OF RESULTS.

Groundwater Recovery Trends.

The water levels recorded in the standpipe piezometers, P1, P2, P3 and P4, are presented in figure 4. The two piezometers on the Southern side of the backfill have shown very similar trends with water levels recovering by around 5 metres to 78 metres a.s.d. This level is particularly significant as it corresponds to the approximate position of the lowest seam, directly linked by abandoned workings to the deep mine shaft pump. A similar recovery has been recorded on the Northern instruments, P3 and P4, however the water levels themselves are much lower than in the South. In addition there is a far greater degree of drawdown between instruments P4 and P3 than there is between P2 and P1, the distance inbetween each instrument set being 25 metres. The water level in P3 stood in January 1986 at just over 68 m a.s.d with the level in P4 at 60 m a.s.d, a drawdown of 8 metres. In addition the water level in P3 is also 10 metres below the levels recorded in piezometers P1 and P2 in the south. Water recovery has appeared to have slowed considerabley over the monitoring period, (although water levels are increasing by 10-20 cm per month).

The rate of recovery is also of importance. In previous work, (Singh, Denby and Reed, 1985), a recovery of 24 metres had been recorded over 144 days in a small site recharged by old workings. On this site however the recovery in the solid strata has only being 5 metres over a period of a year. It is considered that the size of the site and thus the volumes of water required for recovery is the prime reason. In addition to this the old deep mine workings are acting as a drain for groundwater in contrast to those recharging the fill of the shallow mudstone site previously presented.

The results from the two multi-point piezometers, MPP1 and MPP2 installed in the backfill have given some indication of the characteristics of a recovering water table within such a rockfill mass, (figure 5). Water levels over the initial six months were indicated by only the lowest piezometers, i.e. those which were installed at the base of the backfill. Result indicated a recovery of 10 to 15 metres over this period to levels around 80 a.s.d in each borehole. From this point water levels began to be observed in two piezometer access tubes for both instruments. The results indicated differences in water pressures between the two point on both instruments most notably on instrument MPP2, (furthest east). Over December 1985 the difference in water levels between the two tips registering water in MPP2 was 13 metres which had increased from differences of 2 metres from the months before, and decreasing to 6 metres the month after. These results illustrate the complex nature of groundwater within such a rockfill mass. It is possible for several perched water tables to occur with numerous flow paths through the broken rock material.

Tension Wire Extensometer Readings.

Both the tension wire extensometers have appeared to be work satisfactorily over the monitoring period. A Summary of the results for both extensometers are presented in table 2, which gives the overall movement of each wire as either an effective settlement or a shear movement. Over this period the water table remained in the region between the datum and second seals. No saturation or collapse settlement due to

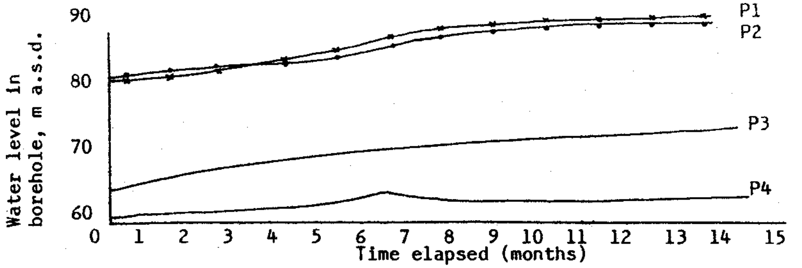

Figure 4. Groundwater recovery in solid strata around excavation

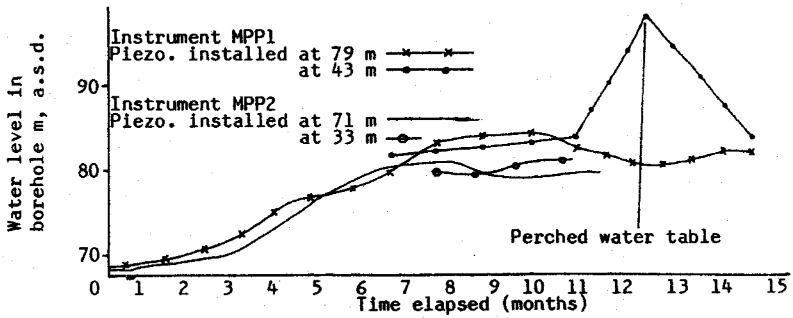

Figure 5. Groundwater recovery in backfill

Table 2 Summary of Tension-Wire Extensometer Readings
Monitoring commenced July 1985.

Instrument TWE1, (total depth of fill = 71 m).

Horizon.	Thickness (m)	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
		Total Displacements between Seals (mm)								
1-2	33	+5	-15	-15	-25	-25	-10	-5	+10	0
2-3	19	-20	+210	+215	+220	+210	+190	+190	+185	+190
3-4	5	-10	-215	-215	-215	-175	-160	-165	-170	-170
4-5	3	+25	+40	+40	+40	+10	-5	-20	-100	-100
5-6	5	+10	0	0	0	0	+15	-210	-130	-130
6-7	3	-20	+155	+155	+155	+205	+200	+445	+435	+430
7-8	2	-20	-215	-210	-215	-225	-225	-235	-230	-225
8-Surface.	1	+30	+70	+60	+70	+40	+30	+40	+45	+45
Total movement at surface (mm)		0	+30	+30	+30	+40	+35	+40	+45	0

Instrument TWE2, (total depth of fill = 73 m).

Horizon.	Thickness (m)	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
		Total Displacements between Seals (mm)								
1-2*	12	0	+5	+15	+10	+5	-5	**	+5	-10
2-3	5	-5	-10	-5	+10	+30	+45		+35	+50
3-4	10	+5	-5	-15	-30	-55	-60		-80	-80
4-Surface	5	0	+10	+15	+10	+20	+20		+40	+40
Total movement at surface (mm)		0	0	+10	0	0	0		0	0

*Owing to instrumentation difficulties the datum wire could only be installed to 32 m depth.
** Instrument inaccesible owing to surface flooding.

+ denotes shear movement, - denotes settlement.

the standing water level can be assumed to have occurred above the second seal. This does not take into account collapse settlements resulting from perched water tables. Heave movements are registered as shear displacements in this analysis.

Whilst interpretation of the actual results is complicated task with many shear and settlement occurences interacting together, the general trends from TWE1 show that shear or lateral movements are very significant. Shear zones can definitely be seen to exist and have a greater magnitude of displacement than settlement movements. It is unfortunate that these instruments cannot indicate the direction of lateral movement (as say an inclinometer can), although it is reasonable to suppose that movement is directed towards the final void area which was finally infilled by October 1986. It is these shearing movements which are judged responsible for the failure of the initial magnetic extensometer and also contributory to the problems of dipping the multi-point piezometers with a relatively large dip meter probes.

One of the most important results obtained from the observations on instrument TWE1 has been that the net overall movement of the fill surrounding the borehole has been one of shear, i.e. the magnitude of the shear movements have exceeded the degree of settlement recorded. In past studies it has always been the vertical movements which have been considered as the prime phenomena critical to backfill stability. These results however, (as in cases of longwall coal mining subsidence in underground mines), have indicated that particularly in the surface fill layers, lateral displacements more likely to be of superior importance.

As an example as to the magnitude of lateral movements occurring within the fill, the results for March 1986, (table 2), indicate a vertical settlement of at least 400 mm in the region of seals 3 to 6, i.e. in the interval 6 to 19 m below the fill surface. (This estimate is based on the net displacements for each interval; 3-4 = -170 mm, 4-5 = -100 mm, 5-6 = -130 mm). The net displacement of horizon 6-7 has been determined as a 435 mm shear movement. However this horizon must also have settled by at least 400 mm on top of the fill horizons below it. Thus the minimum shear in this horizon 6-7 must be 400 + 435 mm, or 835 mm. The overall conclusion which can be made is that a lateral movement in addition to settlement has occured in the region of seals 6-7 of at least 835 mm. The region of seals 6-7 lies 3 to 6 metres below the restored fill surface.

Considering the horizons above this zone of shear, the interval between seals 7-8 has indicated a settlement of 230 mm which has occured in 2 metres of fill, lying 1 to 3 metres below the surface. This magnitude may well be caused by infiltration of water during pumping tests, and is discussed later. The topmost layers of fill which have been most subject to the compactive load of passing plant have registered shear movements of between 30 and 70 mm. The magnitude of shear can be observed to be differential with depth. The construction of a structure with deep foundations in excess of say 3 metres say will thus be liable to severe damage if constructed on a fairly new fill surface. Of importance is to note that a large shearing movement of 245 mm occured in the region 6-7 during February 1986, 8 months after monitoring commenced and at least 24 months after the fill had been placed.

Of note are the low overall displacements in the region between seals 1-2 - the lower half of the borehole. This is the zone in which the groundwater recovery is occuring, and illustrates that saturation affects both lateral as well as vertical collapse.

The results from instrument TWE2, show little relative movement has been recorded on all the wires, the lowest wire being installed at 32 metres, in a fill depth of 70 metres. This illustrates that all the movements whch are occuring in this borehole are in the lower parts of the fill, thus tying in with water table position. No significant shear movements have been observed in the upper fill region. During the drilling of this borehole the fill was found to be quite saturated, although the standing water table corresponded to the position of that in TWE1. It may be possible that during drilling the borehole intersected a perched water table, which subsequently was allowed to drain through the borehole. This would explain the instability of the drilled hole as well as the degree of consolidation measured to date.

Permeability Test Results.

The objectives of the permeability tests in the borehole compartments are to monitor changes in permeability as related to compaction and also the changes in permeability as a function of fill depth.

The values of permeability are generally in the range of 10^{-5} m/s in the region of the near surface fill. It was generally found that it was impossible to fill the compartments which were lowest in the borehole. This implies that the permeabilities of these compartments are so great that the borehole has no capacity for holding water. This observation implies that the base of a dragline or dump truck fill consists of larger rock masses with smaller rock sizes occuring nearer surface - a result of gravitational separation on tipping.

Of importance is that on the compartments which can be measured there is a trend of decreasing permeability and increasing compaction with time. Permeability of the nearest surface layers have been found to be exceptionally low, 10^{-6} m/s, presumably owing to site plant compaction effects. An importance of this is the fact that surface runoff will be much greater and infiltration into the fill less. A danger exists that as for the mudstone truck shovel site, insufficient surface drainage may result. The rooting of the top and sub soils will for a period of time ensure that the surface does not flood, but with groundwater action the clayey nature of these materials may again form a seal which results in ponding. These observations stress the importance of good surface gradients and the introduction of drainage channels to maintain adequately drained land. The importance of seeding in the maintenance of well draining soils should also be appreciated.

In the conduction of a pumping test, the time required to fill some of the compartments in the boreholes were in excess of several hours, by water supplied from the domestic mains supply, (80 p.s.i.). This water will obviously have had an effect on the stability of the fill through which it passes. In the conduction of a test wire measurements were taken before and after pumping, in order to observe if any immediate collapse settlement had occurred - and none was measured. It is however possible that collapse settlements occured shortly after pumping ceased and after the second reading. This observation may explain in particular the collapse of 230 mm over 2 metres thickness of fill material in the upper section of the borehole. Surface infiltration may be to a certain extent ruled out owing the the impermeable nature of the surface soil layer. Over the Winter months, the surface of the site was frequently flooded with surface water. Measured permeabilities are presented in table 3.

	Coefficient of Permeability m/s	
	December 1985	April 1985
Instrument TWE1 Horizon		
Surface - 1 m	2.5×10^{-6}	3×10^{-4}
1 - 6 m	7×10^{-6}	5.1×10^{-6}
6 - 11 m	1.4×10^{-5}	6.7×10^{-6}
11 - 14 m	1.8×10^{-6}	3.2×10^{-5}
Below this level steady state test conditions could not be achieved		
Instrument TWE2 Horizon		
Surface - 5 m	5.6×10^{-6}	5.5×10^{-5}
- 10 m	4.2×10^{-5}	2.3×10^{-5}
Below this level steady state test conditions could not be achieved		

Table 3 Variation of permeability with depth for backfill materials

CONCLUSIONS.

The following conclusions may be made from an analysis of the results from this investigation.

a). On large opencast sites the rate of groundwater recovery may be very slow. Recovery was observed to be more rapid in the fill than in the solid, presumabley owing to differences in permeabilities between the two formations. The rate of recovery in the solid strata surrounding the excavation was approximately 5 metres per year. This contrasts with the rapid recovery reported in previous work, (Singh, Denby and Reed 1985), where old mine workings were discharging water into a shallow fill. This slow recovery has however being recorded on similar opencast sites of large areal extent, (Singh, Reed, Denby and Hughes 1985).

The effect of pumping in the nearby colliery shaft has been observed to have had an effect on the rate and degree of recovery. The present water levels are standing around the level of the abandoned deep mine workings. Despite the application of clay seals to these horizons, it would appear that water are draining from the site to the shaft pump. Groundwater levels are expected to rise further in the fill owing to drawdown effects occuring in the backfill towards the incrop of the abandoned mine workings.

It is expected that the pumping in the colliery shaft will continue for at least a further 10 years, and consequently dictate to a large degree the nature of water levels in the local area. When pumping ceases then once again recovery may initiate and water levels rise.

b). Perched or irregular water tables have been shown to exist in backfill materials. There need not necessarily be only one free water surface in the backfill. Perched water was indicated in both of the multi-point piezometer instruments, and may well explain the instability of the borehole which was drilled for instrument TWE2. The lack of movement in the upper layers of the fill may well be due to the fact that a perched water table had pre-saturated the area prior to monitoring. This perched water table will have been drained by the drilling of the borehole in the fill. In general the presence of a perched water table did not result in a collapse settlement, but shear displacements did tend to be of a significant magnitude in the areas of perched water.

c). Backfill lateral displacements have been found to exceed the magnitude of the vertical settlements. These shear movements are considered responsible for the damage inflicted to the original magnetic extensometer as well as being contributory to the loss of a probe in one of the piezometers installed in instrument MPP1.

Shear has been shown to be differential in magnitude in the near surface layers and consequently uncompacted backfill of such young age may be considered a hazard to the construction of structural foundations. Additional work has shown that these movements stabilise after a period of time, and the compaction of fill may remove their effects completely. A continued monitoring programme would be instrumental in determining a suitable time lapse. Owing to the slow recovery of the groundwater table it has been so far impossible to correlate settlement to recovery in the lower reaches of the fill. The lower half of the fill does however show a small net shear movement, which may imply that settlement and shear in the region of the water table are of equal magnitude.

d). Permeabilities have been measured throughout the vertical section of the borehole and have shown that the lower layers of fill are very much more permeable than those nearer surface. On the lower compartments in the borehole it was found that it was not possible conduct the tests as they were so permeable that a steady state water pressure could not be established, (at least within a reasonable time period). The upper sections of fill averaged permeabilities of 10^{-5} m/s, equivalent to intact coal measures strata encountered in the region. The uppermost metre of fill was found to have a permeability of around 10^{-6} m/s, and generally were very impermeable. The surface area of the site was frequently flooded in the period of December to May 1986, illustrating the lack of surface infiltration which was occuring into the fill through the surface layers. Surface water was eventually removed by the installation of a pump, enabling the surface of the mine to dry out for the remainder of the restoration programme, (May to October 1986), the relayering of soils. It is considered that the pumping tests themselves induced some degree of collapse settlement, notably a settlement of 230 mm in a 2 metre thickness of spoil material which lay just under the impermeable surface fill layer.

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