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THE EFFECT OF GROUNDWATER RE-ESTABLISHMENT ON THE SETTLEMENT OF OPENCAST MINE BACKFILLS IN THE UNITED KINGDOM.

R. N. Singh, B. Denby and S. M. Reed.
Department of Mining Engineering,
Nottingham University, University Park,
Nottingham. NG7 2RD,
United Kingdom.

ABSTRACT

The paper outlines the surface environmental problems associated with the re-establishment of the groundwater table on the settlement of opencast mine backfills in the United Kingdom. The factors affecting the rate of groundwater re-establishment are reviewed together with its effect on the settlement of opencast mine backfills. The research program includes investigations on two sites to monitor and evaluate recovery and settlement patterns in the mine backfills.

INTRODUCTION.

Surface coal mining operations in the United Kingdom are characterised by small output, (14 mt/y from 50-60 sites), large coal to overburden ratios, (often exceeding 30), multi-seam operations and high profitability inspite of very difficult geotechnical settings in near-urban environments. In order to mitigate the surface environmental impact, the mining operations are carried out in a planned manner followed by progressive site restoration and rehabilitation.

During the life of a surface mine, working below the level of the natural water table, the groundwater level is depressed to below that of the base of the excavation to ensure that mining proceeds in as dry surroundings as possible. On cessation of coal extraction the pumps are withdrawn as the mining excavation is backfilled with overburden or interburden. As backfilling continues the groundwater table commences to recover to its equilibrium position, percolating through the backfill to achieve this aim. As a consequence of groundwater recovery two major environmental problems accrue, (a). groundwater pollution and (b). backfill settlements. For smaller sites in wet areas of flooded old deep mine workings, the water table recharge would be expected to have finished within one year of the completion of the final restoration. On larger sites in drier areas, or in cases where deep mine activity maintains the water table on a depressed level, then the recharge period may extend over a number of years, (Ferguson 1984). The relationship between groundwater re-establishment and the settlement of opencast coal mine backfills is currently being evaluated by the Authors on two restored surface mine sites in the United Kingdom. This paper details this research, site instrumentation and the current results.

FACTORS AFFECTING THE RATE OF GROUNDWATER RE-ESTABLISHMENT.

The mining and backfilling operations alter the nature of the mined strata, from a condition of relative uniformity and competence to a disturbed, intermixed, aquiferous formation, completely altering the local hydrological regime. The rate of water recovery in this material and the level of the re-established water table is dependent on a number of inter-related factors, (Herring 1977, Traux 1965, Evangelow 1982), as follows :-

a). The Post-Mining Hydrological Regime:- The post-mining hydrological regime will govern the degree of recharge occuring within the fill. Recharge may occur solely from surface infiltration or as a result of a direct contact between the fill and a subsurface aquifer. If the mine has intersected any old workings then these may either act as a sump for the infiltrating water and thus drain the fill, or conversely may act as a source of water inflow.

b). The Nature of the Backfill:- The permeability of a backfill is largely dependent on the method of mining and restoration. Permeabilities of dragline spoils and spoil lain by dump trucks are considerabley greater than those which have received some degree of compaction as in a scraper-lain spoil. Permeability of such fills also decrease with age, following the effects of settlement and consolidation. The type of material within the backfill is also of great importance, a clayey backfill will be so much less permeable than a sandstone fill. The measured permeability of opencast mine backfill varies from between 10-4 - 10-8 m/s, depending upon the argillaceous content of the original excavated rock, (Norton, 1983). The type, thickness and extent of a fill all have great effects of the permeability and transmissivity of a given material , and consequently will greatly affect the rate and manner with which water will percolate and re-establish throughout the fill.

c). Climate:- The climate of an area affects the rate of recharge of the near-surface strata. In areas of high rainfall, the rate of recharge of these horizons, all else being equal, will obviously be much higher than in lesser rainfall areas. Effects are seasonal, ie wet and dry seasons, and at certain times of the year the groundwater may become static owing to ice or snow. In the colder months the phenomenon of frost heave within the fill may occur resulting in an increased permeability of the near surface layers.

THE SETTLEMENT OF OPENCAST MINE BACKFILLS.

The extraction of one tonne of coal may typically entail the removal of 20-30 cubic metres of overburden under British conditions, (Charles 1984). This spoil material is commonly excavated by draglines and cast to one side of the pit to form the advancing loosewall of the mine. Alternatively in the case of face shovel use, the overburden may be loaded onto dump trucks and end-tipped to form the loosewall in high lifts. The backfilling operation in this way infills the area from which the coal has just been extracted, i.e. the previous cut. As a consequence of the backfilling operation, opencast mining leaves areas where the depth of loose fill is considerable, fill which has the capability to undergo significant settlement. The degree and timescale of such settlements can be of considerable importance for in cases where opencast working has for example been situated close to centres of population, and may be subsequently required for urban development.

A serious problem as a result of groundwater recovery occured at the Whitley Bay Opencast Coal Site, (Penman, 1974), which was completed and backfilled during the late 1950's. A large housing estate was later built on top of the fill. No settlement was observed until the cessation of pumping at a nearby deep mine initiated the sequence of water level recovery. It appeared from the nature of the substantial damage that was inflicted on the buildings, that where underground services had been installed within the fill, water had gained easier access inducing larger relative settlements than elsewhere. It is these differential settlements which are of such great importance in designing structures to build on the fill.

The observed backfill settlements that have been monitored in the United Kingdom have shown in most case studies that the prime cause of backfill settlement is a recovering water table. Settlements of this nature are thought to be a consequence of the shear strength reducing properties of rockfill saturation, (Terzaghi, 1960). Terzaghi's work showed that the wetting of unpolished rock surfaces did not reduce the coefficient of sliding friction of rock on rock and concluded that settlement of rockfill material was thus not caused by any lubricating effect due to water but rather to a reduction in strength of the rock and consequently crushing at contact points, (Penman 1971).

RESEARCH PROGRAMME.

Two sites have been selected for the installation of instrumentation to monitor and evaluate groundwater recovery and settlement patterns in opencast mine backfills. The overall aims of the research are to evaluate correlations between water levels, recovery rates and settlement patterns with regard to the following criteria:-

* **Time :-** Previous work has indicated that recovery and settlement behave semi- logarithmically with time, (Kilkenny 1968).
* **Properties of the Fill :-** An evaluation of the mineral nature of the backfill, e.g. differences in behaviour between predominantly mudstone or sandstone fills.
* **Mining Methods :-** The method of working and fill emplacement has a great effect on the degree of settlement that a fill may undergo, owing to the differences in initial compaction offered by the various backfilling techniques.
* **Mining Environment :-** The effects of climate and the sources of minewater inflow will all have an effect on the rate of recharge of the fill- and consequently the time elapse before the settlement of that fill is complete.

It is aimed that the research will form the basis for establishing guidelines regarding building construction on backfilled opencast mine sites, in particular those which may undergo significant additional settlements as a result of delayed groundwater re-establishment, possibly a consequence of local pumping from adjacent surface excavations or deep mine workings.

SITE DESCRIPTIONS AND INSTRUMENTATION DETAILS.

Site A is an opencast coal site which was worked by shovel and truck methods in the Midlands coalfield. Excavated depths worked were fairly shallow averaging only 17 m over the entire site with a maximum depth in the final void area of 35 m. The site lies in a flood plain and as a consequence of this it was expected that the water recovery would raise the piezometric level to the surface.

Inflows into the active mine consisted of a total of 2,200 l/min from principally old workings together with influx from surface run-off/precipitation.

The mine backfill is predominantly mudstone, 70%, with 12% alluvial deposits. The remaining material consisting of sandstones, siltstones and seatearths.

The overburden to coal ratio finalised at 10:1 with an backfill bulkage of around 7%, which was actually much lower than was expected (10-12%). Thus to restore the site up to the required final overburden level the alluvial deposits which had previously been put aside as soil making materials were used. The vast majority of the fill had been end-tipped by dump trucks, although some compaction had been afforded to the near surface layers of the fill by scraper placement. The site was instrumentated during September 1984 at which time the restored overburden lay at its final level. Restoration was then postponed from this date until Spring 1985 when the replacement of the soils was planned.

Instrumentation on Site A:-

The following instruments have been installed on site A.

* Five combined Piezometer/Magnet Extensometers in the fill to monitor water recovery and backfill settlements.
* Four Standpipe Piezometers in the solid strata surrounding the excavation to monitor groundwater levels and recharge patterns.

The combined Magnet Extensometer/Standpipe Piezometer installation, (fig 1), is a method for relating the levels of groundwater within a fill to the settlements occuring at different levels. Settlement or heave within a soil or a rockfill mass may be assessed by the monitoring of the location of magnetic targets which have been positoned over a near vertical access tube. Location of the targets is accomplished by passing a Reed Switch Probe through the access tubing. When the probe enters the magnetic field generated by a target, an audible signal is emitted at the surface. A steel tape from which the probe is suspended is then used to read off the depth at which the probe is located. All measurements are referred to a datum magnet situated at the base of the access tubing approximately 1 m into the bedrock below the fill. A standard piezometer tip below the datum utilises the access tubing as a standpipe and consequently when a dip meter is lowered into the hole the water level in the fill can be determined.

The layout of the instrumentation on site A is detailed in plan in fig 2, which also shows the depths of fill on site, the subsoil and topsoil mound positions, excavation limits and so on. The results up to the date of this paper are detailed in the next section.

Site B is an opencast coal site in Northern England which was worked by dragline operations with end-tipping of the fill into the restoration void by dump trucks. (To the date of this paper restoration is still continuing, ie backfilling and pumping are still in operation). The fill is a mixture of mudstones and sandstones and in the area of instrumentation averages approximately 75 m deep, providing a good contrast to the shallower, predominantly mudstone environment of site A. Water recovery on this site will be determined to a great extent by pumping in a local disused colliery shaft which dictates the groundwater levels over much of the region. Groundwater recoveries will also be influenced by adjacent opencast workings. Owing to current backfilling and pumping operations the site at present is only at the stage of installation of instrumentation. When the full monitoring program is established, (March/April 1985), approximately 20 m of groundwater recovery will be monitored in the lower half fill. Groundwater levels are not expected to rise to within 35 m of the surface owing to the presence of old deep mine workings in the walls of the excavation providing a direct hydraulic link with pumping shaft.

Instrumentation on Site B.

Instrumentation on site B at present consists of the four standpipe piezometers installed in the solid strata surrounding the excavation for the monitoring of groundwater levels and the recharge patterns. Instruments in the backfill consist of two five-point piezometers for the purposes of permeability testing, the results of which will be related to the consolidation of the fill material. An extensometer of a similar type to those installed on site A was installed to a depth of 80 m on this site but this instrument was lost just after the installation to what was deduced to be shearing movements in the fill fracturing the access tubing at 20 m below the surface. This instrument is thus practically useless barring been able to monitor the top 20 m of the fill, an area in which no groundwater recovery will occur. At the time of writing this paper an evaluation is being made of the use of the tension wire type extensometers as alternatives to the unsatisfactory probe type which has been lost. The tension wire instrument is of a type which can monitor such shearing movements as those which affected the original installed instrument without incurring damage.

Two of these instruments are being installed to depths of around 75 m together with a combined facility for further permeability testing. The site results will be supplemented by surface levelling and tilt station measurements.

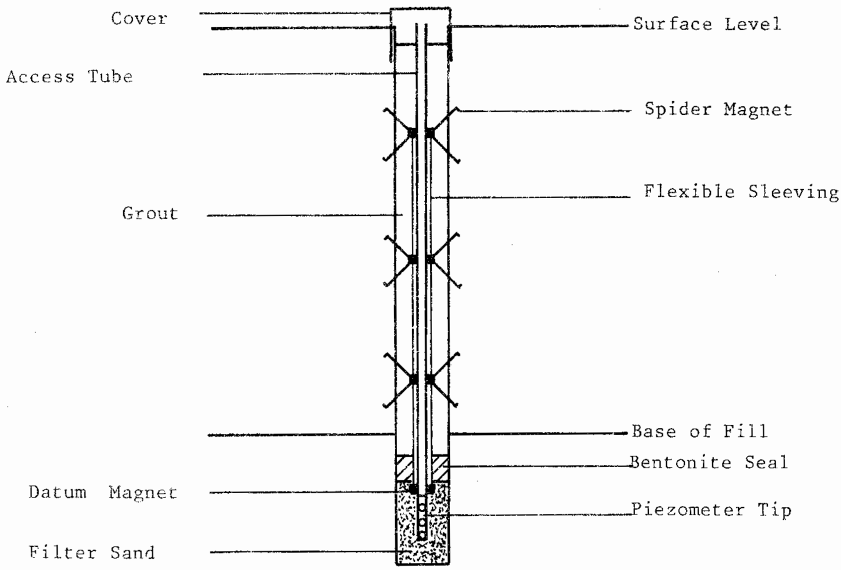

Fig. 1. The Combined Magnet Extensometer/Piezometer Instrument

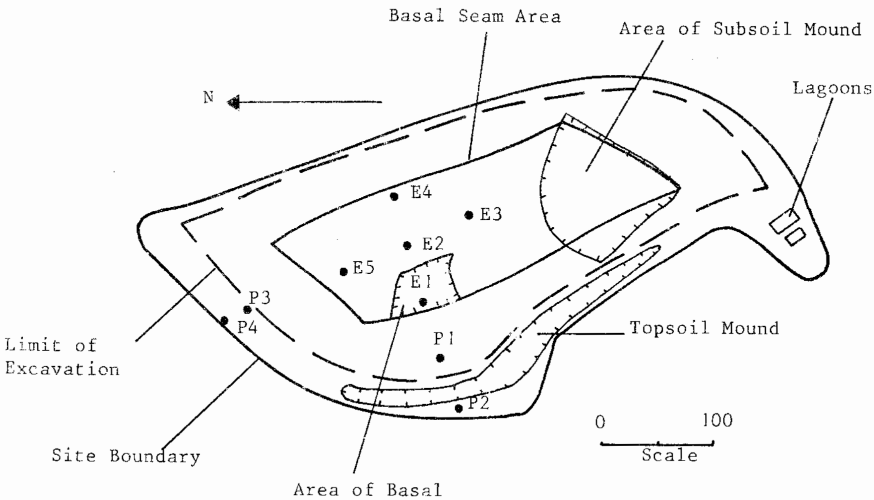

Fig. 2. Instrumentation Plan : Site A

EVALUATION OF THE INITIAL 110 DAY MONITORING PERIOD: SITE A.

Total Recorded Settlements.

Table 1 details the total settlements recorded on each of the extensometer installations on site A. Also presented are the mean depths of the fill over the monitoring period and the settlements expressed in millimetres per metre of fill depth.

TABLE 1.

INSTRUMENT	MEAN DEPTH OF FILL	TOTAL SETTLEMENT OF TOP MAGNET	SETTLEMENT mm/m fill depth.
	m	mm	
E1	19.864	0.168	8.46
E2	22.135	0.180	8.13
E3	20.666	0.135	6.53
E4	18.866	0.025	1.33
E5	23.339	0.170	7.28

These results show that four out of the five holes, (E4 that is excepted), have settlement rates expressed over the depth of the hole which correspond fairly closely. A fact that would indicate that the total settlement achieved on any one hole is greatly determined by fill depth. Of the four instruments in question, (E1, E2, E3, and E5), E1 and E2 have settlements in mm/m which correspond very closely, whilst those on E3 are slightly less, which can be explained by the fact that the fill around E3 is the older and consequently will have had additional time for settlement to have taken place. Whilst E5 is the deepest hole the settlement registered on this instrument is lower than for say E1 and E2 which are both shallower and both in older fill. One possible reason for this could be that whilst the fills around E1 and E2 were predominantly end-tipped, a fair proportion of the fill around E5 was scraper lain, thus greater compaction was offered to this area.

The most obvious quantity in table 1 is the very small settlement movements that have been monitored on E4, with a total of only 25 mm of settlement in a hole of almost 19 m depth. An explanation of such small movements as compared those that have been measured on the other holes is the fact that this instrument is situated in the line of a dump truck/scraper haul road, thus this area of fill would have been subjected to a great deal of compaction throughout the life of the mine. The future results from this instrument and their comparasion with the others will prove exceedingly useful in the evaluation of suitable techniques for the compaction of mine backfills in order to reduce differential settlements.

GROUNDWATER RECOVERY BEHAVIOUR.

Fig 3 shows the behaviour of the groundwater table during the initial monitoring period for all of the instruments in the fill, relating recovery to magnet positions. As expected, (although at a very much accelerated rate), the groundwater levels are recoverying to the surface. A period of heavy rainfall between days 50 and 70 was such that the entire site became flooded and it was impossible to take any readings on the instruments. For lengthy periods following this time two of the instruments, (E2 and E4), remained flooded with only very occasional readings being possible on these instruments. As would be expected the high period of rainfall led to a substantially increased rates of infiltration into the fill, leading to very much accelerated water recovery rate.

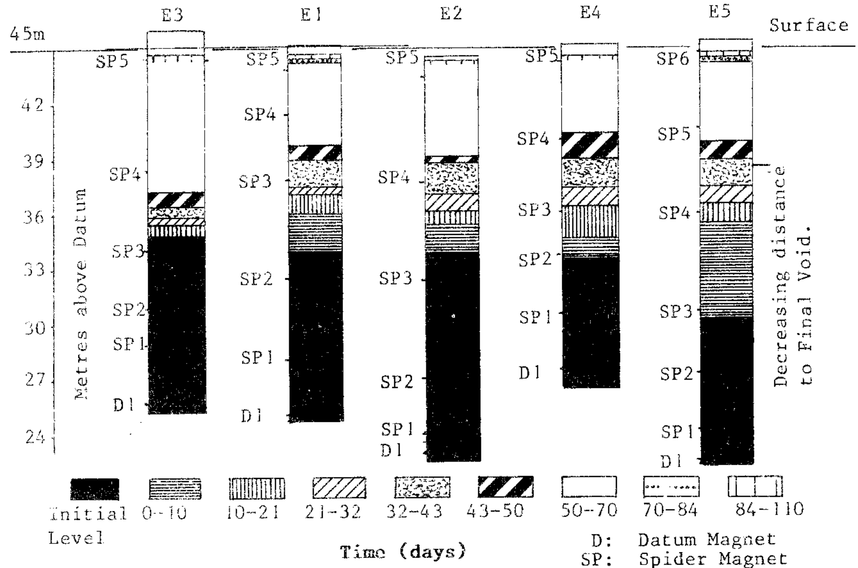

Fig. 3. Recovery Rates on Extensometer Instruments

Pumping on site ceased on 13 August 1984, one week after the termination of mining, thus initiating the sequence of groundwater recovery.

Obviously as the groundwater recovery sequence was initiated in August of 1984 and the monitoring commenced on the 1 October 1984, some degree of settlement and recovery has been unavoidabley missed. Assuming that the water level in the fill around E5 on the 13 August 1984 was at pavement level, (a fair assumption given that this hole was close to the final void/pumping area, then just under 9 m of recovery occured between this date and when monitoring commenced on the 1 October, a period of 48 days. If the first 48 days of the monitoring period are considered then it can be seen that the water table in E5 rose again by a further 9 m, rising in the next 48 day period by 5 m, a total of 23 m recovery in the period of 144 days.

The highest initial water level that was initially recorded was predictablely in E3, the instrument furthest from the final void. E1 and E2 had lower but similar water levels, a consequence of being 50 m nearer the final void than E3. E4 the instrument which was furthest away from the principal recharge zone, (the old deep mine workings on the western side of the pit), exhibited the second lowest initial water level reading.

Whilst recoveries were subsequently measured on instruments E1, E2, E4 and E5 over the initial 21 days of monitoring, little or no recovery was registered on E3, particularly in the first 15 days. Initial suspicions that the piezometer tip had being rendered ineffective owing to blockaage were however soon dispelled when recovery recommenced. The rate of recovery in this hole was initially slow but eventually after the period of high rainfall, (days 50-70), the water levels in E3 became the highest of all. It is suspected that the slow initial recovery rate in this hole was due to the rising water table encountering a retarding, relatively impermeable layer within the fill. The initial water level lay at approximately 0.5 m above the level of the third spider magnet in the hole, (fig 4) , and on day 15 commenced to slowly rise toward the fourth magnet, (SP4). Monitoring of the spider magnets showed that during the first 15 days movements had been restricted to below the level of SP3, ie in the saturated zone of the fill. On day 15 settlement commenced taking place in the region between SP3 and SP4, corresponding to the rise in the water table. The pattern of the backfill settlement during this period thus corresponds to the behaviour of the water table and thus piezometer malfunction can be ruled out and the nature of the recovery associated with the characteristics of a relatively impermeable backfill horizon.

During the initial 110 days of water level monitoring, the levels in all the instruments recovered to meet an approximate mutual position. Of especial note is the fact that the water level in the fill in E3 on day 110 stood at a greater level than the actual restored level of the fill around instrument E2. This implying that a danger existed that water levels may rise to flood the surface of the fill. (The fill surface effectively forms the base of a basin which is surrounded on three sides by intact strata, the fourth side running along the line of the outcrop. This flooding problem did actually occur on day 125, (the date of this paper), leaving all the instruments in the fill totally submerged by 1-2 m of standing water. The levels of the water in the solid strata surrounding the excavation were also lying above the level of the restored backfill. The level in P3, (fig 2), stood at 0.75 m above the level of the restored surface around E5. This severe flooding of the pit surface together with the fact that the surface water appears to have no where to drain to leads to immense problems both in future monitoring as well as in future restoration policy. As stated earlier the soils have still to be replaced, (to a depth of about 1-1.5 metres), thus pumping the surface water off-site may be required assuming that the fill will not drain. This problem at the time of writing is currently under evaluation and in the meanwhile monitoring of the solid strata water levels is continuing.

EVALUATION OF WATER RECOVERY RELATED SETTLEMENT.

In order to evaluate the effect that the groundwater recovery has on the settlement of the mine backfill it is necessary to observe the behaviour of all the inter-magnet horizons during the times that they were subjected to the rising water table, times of saturation and the periods of unsaturation. For the purposes of this paper, the settlement-recovery characteristics for E1 will be considered in detail. Instruments E2, E3 and E5 all follow similar settlement patterns, whilst the compaction that instrument E4 has received from its position in a former haul road has resulted in little settlement and none which can be related to groundwater recovery. The settlement-time curves for the magnets on E1 are illustrated in fig 4, whilst those for the other instruments are shown in figs 5-8.

ANALYSIS OF SETTLEMENT RESULTS FOR EXTENSOMETER E1, DAY 0-110.

Four distinct phases of backfill movement can be observed in the results for extensometer E1, (fig 4).

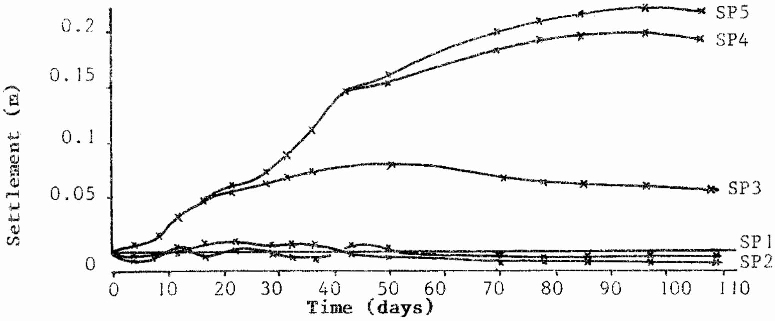

Fig. 4. Settlement Time Curves - Extensometer E1

i) Settlement occuring below SP3 :- days 0- 30
ii) Settlement occuring between SP3 and SP4 :- days 30- 50
iii) Settlement occuring between SP4 and SP5 :- days 50- 70
iv) Small, slow, heaving movements on all magnets following saturation.

Table 2 shows the periods of settlement measured on extensometer E1, with respect to time, total settlements, percentage settlements at magnet horizons and water level positions.

TABLE 2.
ANALYSIS OF RESULTS, EXTENSOMETER E1, SITE A.

	Settlements (m)					Percentage Settlements					Water Level
DAY	SP1	SP2	SP3	SP4	SP5	D-1	1-2	2-3	3-4	4-5	horizon.
0	0	0	0	0	0	-	-	-	-	-	SP2-SP3
4	-.003	-.001	-.001	.004	.003	-	-	-	-	-	"
8	0	0	.008	.009	.007	-	-	-	-	-	"
12	0	0	.022	.024	.023	-	-	91.7	8.3	-	"
15	-.001	-.001	.029	.031	.029	-	-	93.5	6.5	-	"
19	.001	.003	.039	.044	.042	-	-	88.6	11.4	-	"
21	.002	.004	.041	.045	.045	-	-	91.1	8.9	-	"
25	0	.002	.041	.045	.046	-	-	91.1	8.9	-	"
29	-.001	.001	.046	.058	.057	-	-	79.3	20.7	-	Water at SP3
32	.001	.003	.052	.072	.069	-	-	72.2	27.8	-	SP3-SP4
36	-.004	-.001	.052	.085	.084	-	-	61.2	38.8	-	"
43	.002	.002	.054	.115	.117	-	-	47.0	53.0	-	"
46	-.004	-.003	.051	.116	.118	-	-	44.0	56.0	-	"
50	0	-.001	.055	.127	.129	-	-	43.3	56.7	-	"**
70	-.002	-.005	.045	.150	.160	-	-	28.1	65.6	6.3	Water at SP5
78	-.001	-.005	.045	.151	.167	-	-	27.0	63.4	9.6	>SP5
84	-.001	-.005	.044	.151	.170	-	-	25.9	62.4	11.8	"
94	-.002	-.006	.044	.148	.173	-	-	25.4	60.1	14.8	"
110	-.004	-.009	.038	.142	.168	-	-	22.6	61.9	15.5	"

** Period of heavy rainfall between days 50 and 70

\- Symbol denotes that small movements have been neglected.

Throughout the monitoring period only small heaving movements of less than 1 cm have been recorded on the lowest spider magnets SP1 and SP2, a phenomena which has been recorded on all the installations with magnets that have been placed in saturated ground at the start of monitoring. Such movements of less than 1cm are difficult to quantify, save stating that they are most likely a result of mudstone swelling on saturation. In this stage of the analysis given that total settlement recorded on E1 is 16.8 cm they will be neglected.

An analysis of table 2 shows that on extensometer E1, between days 0 and 25, 91.1% of the total recorded settlement occured between magnets SP2 and SP3, (a total settlement of 4.1 cm). The remaining 8.9% occured in the region between SP3 and SP4. Negligible movement was recorded above the position of SP4. The water level during this period had risen from initially lying midway between magnets SP2 and SP3, to the level of the SP3 magnet on approximately day 29. Thus the majority of the settlement, ie 91.1% can be related to the area in which the water table was recovering.

From day 29 to day 50, settlement in the region of SP2 to SP3, gradually slowed down with only 0.9 cm occuring during this time as opposed to 4.9 cm which occured in the region between SP3 and SP4 during the same period. On day 50, the water levels lay midway between SP3 and SP4. The period between days 50 and 70 was as described a time of heavy rainfall, which flooded the pit surface rendering the reading of instruments impossible. On day 70, the water level was found to be at the level of SP5, (which lies 1.88 m above the location of SP4). From day 50 to 110 settlement consisted of 3.9 cm between SP4 and SP5, 1.5 cm between SP3 and SP4 and a heaving movement of 1.7 cm between SP2 and SP3- the maximum degree of settlement occuring once again in the zone of the recoverying water table.

Overall on this instrument, backfill settlement has been seen to be a direct result of the presence of the water table at a fill horizon. At any one moment in time it would appear that only one horizon is significantly moving. After the water table has saturated a section of fill, the accelerated settlements would appear to be replaced by heaving movements. A phenomenon which has been observed on all the instruments with magnets in saturated ground, probably due to the swelling of the mudstones in the fill.

RESULTS ON OTHER INSTRUMENTATION.

Figs 5-8 show the settlement-time curves for the other extensometer instruments. All bar extensometer E4 are exhibiting similar trends to those discussed on instrument E1, ie the settlement of fill occuring in the horizon of the recovering water table together with subsequent heave movements on saturation. The results for extensometer E4 are of particular interest in that this instruments lies in the position of a former dump truck/scraper haul road. Little settlement has been recorded and that which has has been unable to be related to the position of the water table. Such differential settlements in fill materials can inflict severe structural damage. It is therefore important that if a backfilled opencast mine site is later utilised for construction purposes that estimates of potential backfill settlements over the site are made and

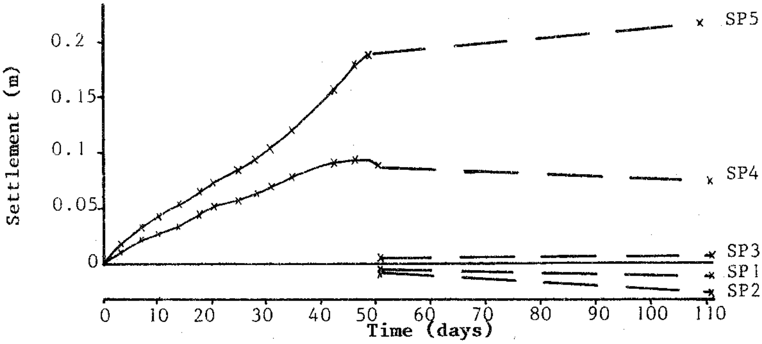

Fig. 5. Settlement - Time Curves- Extensometer E2

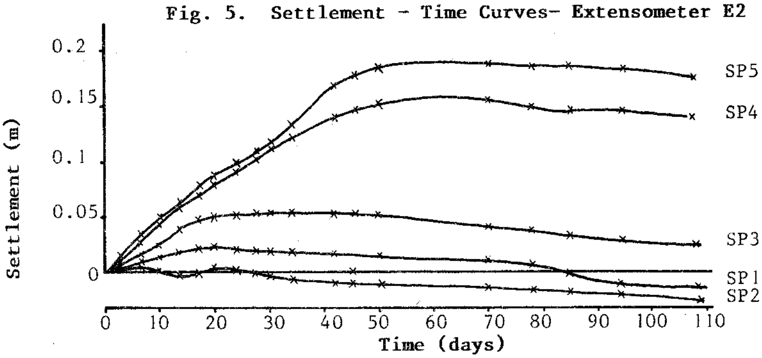

Fig. 6. Settlement - Time Curves - Extensometer E3

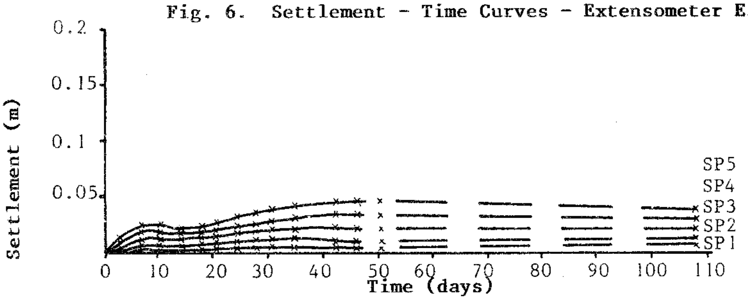

Fig. 7. Settlement - Time Curves - Extensometer E4

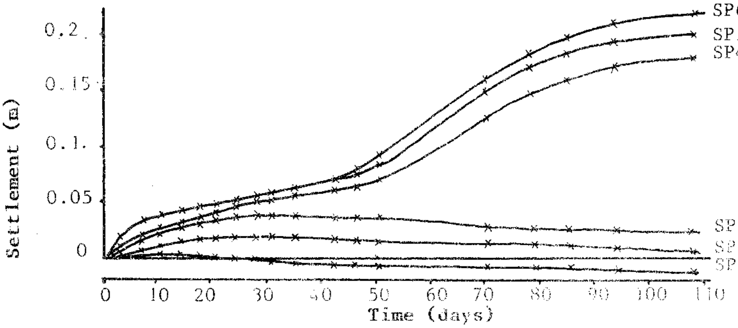

Fig. 8. Settlement - Time Curves - Extensometer E5

incorporated into the structural design.

FURTHER RESEARCH.

Site A:- Assuming that the groundwater pondage can be removed from the surface of site A, then the monitoring of backfill settlements and groundwater patterns will continue along the following guidelines.

a). To continue monitoring water levels and settlements in the extensometer instruments.
b). To monitor movements in the backfill on the removal of the on-fill subsoil mound. (Charles 1984 states that such surcharges over consolidate the fill and consequently induce heave on removal).
c). To set up survey traverses to monitor future surface settlements.

It is further hoped that if the site surface can be successfully drained or even raised above the final water level that a drop in groundwater levels will occur during the summer months. If this were to happen then the effects of secondary re-establishment may be able to be monitored.

Site B:- A full investigative procedure will be initiated on site B, consisting of permeability testing and surface settlement monitoring. Plans are been made to install tension wire extensometers in the fill to depths of around 70 m to monitoring settlement zones together with shearing movements. It is anticipated that these instruments will be modified to conduct permeability testing in addition to this.

With this degree of instrumentation it is anticipated that those criteria established in the Research Programme may be evaluated to enable this work to contribute to guidelines on the construction of structures on opencast mine backfills liable to encounter groundwater related settlements.

CONCLUSIONS

From the observations on Site A, the following conclusions can be made:-

1. Settlement of opencast mine backfill on site A has been shown to be entirely due to the effect of groundwater recovery- except in the case of one instrument which has shown that the degree of previous compaction is of significant importance.

2. The rate of recovery in a mine backfill can be extremely rapid, (on site A - circa 170-175 days), from the termination of pumping.

3. Once the fill has been saturated then settlement effectively ceases. (Although a slower rate of settlement in the form of creep movements is still thought to continue).

4. Once a horizon is saturated then heaving movements are initiated. The maximum heave movements so far registered however are only in the region of 1-2 cm.

ACKNOWLEDGEMENT.

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REFERENCES.

1. Charles, J.A.; Hughes, D.B. and Burford, D. (1984)
The Effect of the Rise of Water Table on the Settlement of Backfill at Horsley Restored Opencast Coal Mine Site. 1973-1983.
Third Conf. Ground Movements and Structures, UWIST, Cardiff, 1984.

2. Evangelow, R.D. (1982)
Factors Controlling Water Movement in Acid Spoils.
Symp. Surface Mining Hydrology, Sedimentology and Reclamation, University of Kentucky, Lexington, USA, 1982.

3. Ferguson, D. (1984)
Reclaimed and Backfilled Areas.
Third Conf. Ground Movements and Structures, UWIST, Cardiff, 1984.

4. Herring, W.C. (1977)
Groundwater Re-establishment in Cast Overburden.
Seventh Conf. Coal Mine Drainage, Louisville, USA, 1977.

5. Kilkenny, W.M. (1968)
A Study of the Settlement of Restored Opencast Coal Sites and their Suitability for Building Developments.
Bulletin 38. University of Newcastle-upon-Tyne, Civil Engineering Department, 1968.

6. Norton, P.J. (1983)
A Study of Groundwater Control in British Surface Coal Mining.
University of Nottingham, Ph.D Thesis, 1983.

7. Penman, A.D.M (1971)
Rockfill.
Current Paper 15/71, Building Research Station, Department of the Environment, 1971.

8. Penman, A.D.M and Godwin, E.D. (1974)
Settlement of Experimental Houses on land left by Opencast Mining at Corby.
Conf. on the Settlement of Structures, Cambridge, 1974.

9. Terzaghi, K. (1960)
Discussion on Salt Springs and Lower Bear River Dams.
Trans. ASCE, vol 125, pt 2, pp 139-148

10. Traux, C.N. (1965)
Water Storage Potential of Surface Mined Coal Lands.
Mining Congress Journal, Nov. 1965.