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EVALUATION AND STABILISATION OF AN EMBANKMENT AT SEBASTOPOL, SOUTH WALES, UK

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ABSTRACT

This paper introduces a slope movement and related railway track movement at Sebastopol, South Wales, UK. The monitoring results including slope movements and groundwater levels are summarised and presented. The slope at Sebastopol has a long history of instability. Because of continued gradual movement of the railway line and accelerated movement in 2004, a series of small diameter 'Grundomat' micro-piles were installed alongside the track early in 2005 to increase the shear resistance of the underlying soil and to reduce the rate of slope movement to a small but manageable amount. The slope movements have been continuously monitored since the piles were installed whilst the slope above the railway has continued creeping down-slope. In early 2007, the slope movement was accelerating and the railway itself was again involved in movements of about 20 mm per week. Given the increased movement of the bank it was considered likely that the Grundomat piles were either rotating or failing in bending. To gain further temporary stability, additional Grundomat piles were installed. Back-analyses of slope stability with and without the piles were carried out.

INTRODUCTION

This paper presents a history of slope movement and implementation of a geotechnical solution to reduce the movement rate. From an initial desk study the early history of local slope failure is tracked, changes in land use are detailed along with a review of the monitoring and investigation of the slip. The case history then follows the decision making process to determine a stabilising solution and finally details the design, construction and monitoring of the micro-piles to reduce the movement rate.

The slope is located at Sebastopol, Mid Glamorgan south Wales in the UK. Fig. 1 indicates the approximate location of the site within the UK.

Sebastopol is the name given to a very small and now demolished group of houses to the east of the Rhymney River. The Rhymney valley runs roughly north to south, and the river Rhymney flows along the bottom of the valley. Above the river, aligned along the valley are the A469 trunk road and a railway line.

The railway links the city of Cardiff to the south and the town of Rhymney to the north. The railway and the A469 Trunk Road are aligned along the west side of the roughly north-south trending Rhymney Valley.

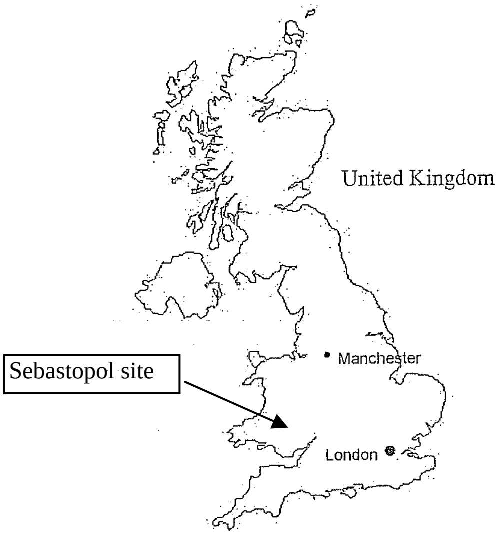


Fig. 1. Location of Sebastopol Embankment

SUMMARY OF THE PROBLEM

The railway in Sebastopol was built in 1856 for traffic between Cardiff and Rhymney with both up and down lines. It is now a single bi-directional track. The bi-direction single track railway line is located on the valley side where it traverses a slight depression in the slope profile via a low side-long embankment situated some 20 m above the Rhymney River. The A469 Trunk Road is located parallel to and about 50 m above the railway line where it is slightly incised into the valley-side. Above the road the slope continues for a further 150 m or so in height with a rocky escarpment at the crest.

At the bottom of the valley the River Rhymney River is constrained by a concrete retaining wall about 2 m high which shows signs of past movement and repair. Between the top of the retaining wall and the railway line the side slope is quite steep (slightly in excess of 30 degrees) and is covered with ash through which many small trees and shrubs are growing. The majority of the trees exhibit trunk curvature caused by slope movement and a number has fallen over the past few years.

Between the railway and the road, the landowner has undertaken earthworks to create grazing land that has involved the tipping of fill material. Water issues from the base and sides of the fill and in general flows into a small steam alongside a path on the north side of the fill that connects the site with the main road. The stream is fed by an issue close to the junction of the main road and the path down the slope although recently the path has become largely obscured by the tipped fill. Fig. 2 shows the location of the site and the study area that exhibited track movement.

There has been a history of movement which has affected both the line and an over-bridge on the line at Sebastopol. The track problems at the site were seen as a continuation of a long history of movement which is complex in its origin. Given the sidelong location of the railway on 'foundered' ground it is likely that there is local movement of the railway embankment itself together with an underlying general down-slope movement of the valley slopes at least from the A469 to the river. In November 2004 the continued track movement over a distance of about 150 m necessitated the introduction of a temporary speed restriction of 10 mph (16 kph) at the site (see Fig. 3).

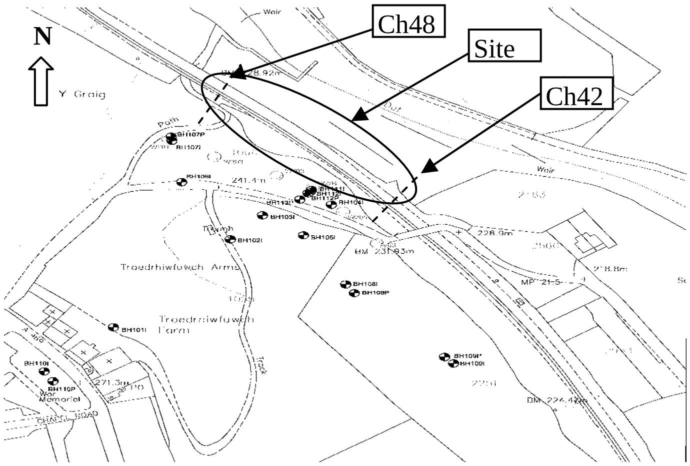


Fig. 2. Site Location indicating the study area of track movement and the location of boreholes

Fig. 3 View of track looking north, November 2004

SITE GEOLOGY

The Rhymney Valley is deeply glaciated with a cross section like a flattened 'U'. The steeper upper slopes are composed of the Brithdir and Hughes Beds being generally strong coarse and medium grained sandstones with some siltstone beds. The slopes lower down the valley side are at a flatter angle and comprise the Rhondda Beds with alternating sandstones and mudstones. Whilst the majority of the South Wales valleys are mantled with glacial till, according to Bentley (Bentley, 2000) this is not the situation at Sebastopol where the upper part is bare rock and the mid and lower parts of the slope are covered by scree and weathering products respectively.

The rock in the upper part of the slope consists of exposures of the Brithdir and Hughes Sandstones standing at steep angles where they form the back-scarps to deep slip movements. Within the sandstones are variably mined coal seams, particularly the Tillery and Brithdir Rider. The lower slopes are formed of slip detritus and solifluxion deposits that are subject to shallow debris slides. These have in the past been triggered by slope movements in the upper escarpment to form a continuation of these slips to the base of the slope.

The most recent glaciation has left the valley with over-steepened sides by undercutting which together with a high water table from melt-water caused numerous landslides. Following glaciation, the groundwater pressures reduced to a point where the movements ceased to a large extent but many relict shear surfaces remained. These can be re-activated by heavy and continuous rainfall or earthworks, mining, quarrying and other similar activities.

At Troedrhiwfuwch, on higher ground in the valley-side and immediately to the north of Sebastopol a major landslide occurred in 1906 which extended from the upper slopes of the

Hughes and Brithdir Sandstones into the weaker Rhondda Beds below and finally included the mainly soliflucted slope mantle material towards the base of the slope. The slip included the A469 trunk road and the slide apparently stopped just short of the railway. The lower slopes (below the road) have been largely re-graded and little direct evidence remains although above the road the back-scarp is clearly defined.

Immediately above Sebastopol at Troedrhiwfuwch the geomorphology is a slightly different (Bentley SP, 2000). A relatively stable buried promontory exists and as a result a small village community was situated here, unaffected by the land-slipping to the north (and in fact the south). However the danger from rockfall emanating in the exposed Hughes and Brithdir Beds above the village meant that in 1970 the school serving the local community was closed and only one or two houses now remain.

The slopes below the road are now partly obscured by the recently tipped and regraded earth spoil, but the lower natural ground immediately above the railway is very hummocky with many small slip scarps. Below the railway on the bank above the River Rhymney the steep slopes are wooded. There is evidence of considerable ash tipping from the railway as the ground is loose underfoot and mounds of ashy material are found against the upslope side of many of the trees. The trees themselves show trunk curvature that is symptomatic of slipping ground and there is what appears to be a 'toe bulge' immediately above the river retaining wall below the chainage of the effected part of the line.

RECENT GROUND INVESTIGATION

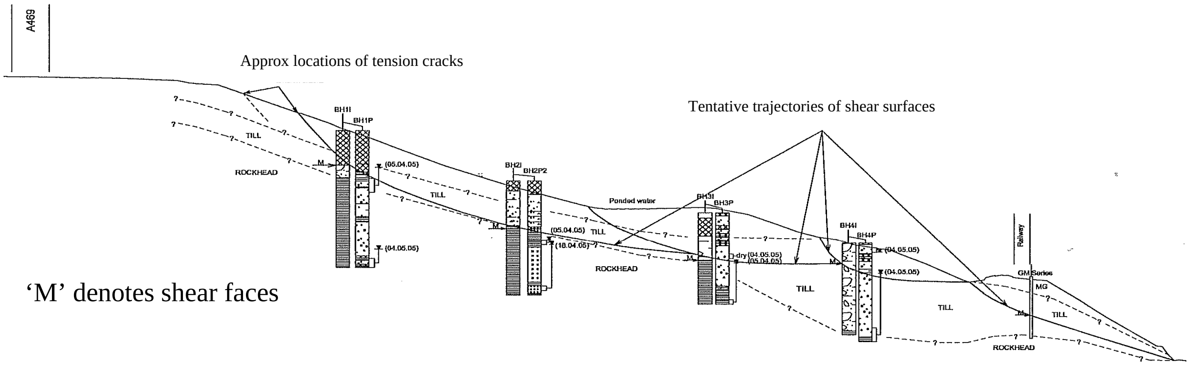
In March 2005 a ground investigation was carried out in conjunction with the embankment strengthening in the slope. Both the superficial deposits and the bedrock were investigated using cable tools and rotary diamond coring respectively. The exploratory work revealed that in the upper slope just down-slope of the road there was approximately 10 m of Made Ground (fill) reducing to zero towards the base of the slope immediately above the railway. The Made Ground comprising the railway embankment is estimated to consist of fill about 3 m thick beneath sleeper level. The drift deposits consist of sands and gravels with some clays, cobbles and boulders and is about 5 m thick in the upper slope but increasing in thickness to as much as 20 m in the lower slope down to the river. Below the drift, the rock generally consists of mudstones in the upper part but with siltstones and sandstones at depth.

The Piezometers installed in the boreholes recorded two distinct water tables. The upper one is at shallow depth, probably in hydraulic continuity with the surface water that ponds on the lower slopes above the railway embankment. The lower water table is at about 5 to 10 m below ground level and is associated with the underlying sandstones, siltstones and mudstones. Fig. 4 shows a typical cross section of the site.

INVESTIGATION OF THE PROBLEM

Given the sidelong location of the railway on 'foundered' ground it is likely that there is local movement of the railway embankment itself. It is also likely that there is an underlying general down-slope movement of the valley slopes at least from the A469 to the river.

It is acknowledged that the geomorphology at Troedrhiwfuwch differs from the immediately adjacent valley slope where the major landslip occurred in 1906, and that at about mid-slope there is a more stable buried profile. However, below the location of the abandoned houses of Troedrhiwfuwch, ie just below the level of the A469, it is probable that the overburden formed of scree and soliflucted soil increases in thickness. Instability of the lower slopes is then more likely and is evidenced by the hummocky ground that may be seen immediately up-slope of the railway line. Historical soil tipping on the slope below the A469 may be contributory to instability of the slope. Although there appears to be some under-drainage, the presence of issues and the surcharging of the slope that the weight of the spoil presents is such that it could have initiated slope movement.



Approx locations of tension cracks

Tentative trajectories of shear surfaces

'M' denotes shear faces

Fig. 4 Typical cross section of the site

In more recent times there has been some local re-profiling to reduce the weight of tipped soil in the upper part of the slope and minor drainage works so that the immediate impact of the soil tipping has been reduced. It is understood that a drainage blanket of granular material was introduced over the slope prior to the recent re-grading. Issues of water discharge from beneath the re-graded soil cover and drainage water discharges to established water courses including those forming part of the track drainage.

There are space constraints at the site that limit the options available for long term stabilisation of the slope and also limitations that are associated with the continuous running of the railway. In addition the stabilisation of the entire slope is likely to be extremely costly and as a temporary expedient it has been considered better to concentrate on local stabilisation measures to bring about some short term improvement to the railway so that the speed restriction could be removed.

Therefore to temporarily improve the condition of the railway in advance of permanent works to arrest the slippage, a line of micro-piles was driven at close centres over the location of the worst movement.

The line of piles was driven vertically approximately 2.5 – 3.0 metres from the track on both the down-slope and up-slope sides. The piles work as shear dowels across the anticipated slip zone, and penetrate a small distance into the underlying bedrock to a depth of about 12 m below ground level in order to achieve suitable fixity.

SLOPE STABILITY AND THE DESIGN OF MICRO-PILES

Having identified micro-piles as an appropriate emergency option, two phases of design were undertaken. The first involved consideration of the overall slope stability. The second stage concerned the design of the piles themselves.

The slope stability was analysed using an in-house (CL Associates) slope stability package (SLIPSYST) and later using the program SLIDE and also a TGP in-house program, SLIPPY. Circular slips using the Bishop simplified method and non-circular slips using Janbu method were analysed

The crucial factors likely to influence the slope stability were the controlling residual soil shear strength parameters and the groundwater level, especially temporary rises in the groundwater level caused by heavy rainfall.

The preliminary ground investigation was to determine the basic geology of the site. Back-analysis was then employed to provide estimates of basic soil parameters for further analyses.

Whilst monitoring of movement in the main slope was being undertaken with inclinometers, the results were not available at the time. However, the slope was assumed to be at a factor of safety (FoS) close to unity in the preliminary analysis. The preliminary analysis has suggested results of ϕ'_r of 32^o for the Made Ground, ϕ'_r of 20^o and c'_r of 1.5 kN/m^2 for the sheared overburden soil, ϕ'_r of 33^o and $c'_r = 0$ kN/m^2 for the embankment. A typical analysed slip surface is shown in Fig. 5, which passes through the area of the railway embankment.

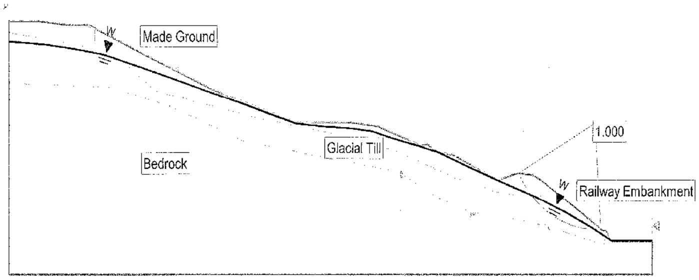


Fig. 5 Typical slip surface obtained in the SLIDE analysis

Additionally, the finite element program PLAXIS was used to analyse the strains within the embankment. There is no direct determination of a lumped factor for overall stability of the slope in the PLAXIS analysis, but zones of excessive deformation are associated with the location of a shear surface.

Fig. 6 shows the total displacement of finite element points at failure from PLAXIS analysis. The maximum soil movements are located in areas subjected to shear similar to those identified in the SLIDE analysis. The magnitude of movements can be seen from the lengths of arrows, which show large settlements in the area of the track underneath the railway.

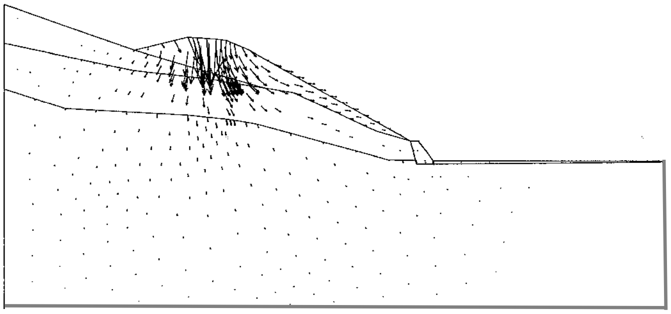


Fig. 6 Total displacements of soils in PLAXIS analysis

The preliminary design suggested that three lines of micro-piles should be installed alongside the railway, two on the river (down-slope) side and one row on the upslope side. The piles consist of grout-filled mild steel tubes approximately 10 m long and 100 mm diameter with a 3 mm wall thickness. The tubes are reinforced with a centrally located 73 mm OD flush-jointed high tensile API drill-tube. On the up-slope side, the Grundomats were installed at 1.0 m centres over a length of approximately 20 m and on the down-slope side two rows extended over 80 m generally at 1.5 m centres with the rows staggered by 0.75 m.

The piles were driven using a down-hole-hammer to a nominal depth of 12 m or a 'set' of not more than 6 mm penetration in 10 seconds of driving. If the resistance at 12 m gave more than 10 mm of penetration in 10 seconds the pile driving continued to a maximum depth of 15 m. The depth and 'set' of the piles was continuously reviewed and a driving record of each pile was produced for the depths below 5 m with rates of penetration recorded at 300 mm intervals. The piles were finished at 200 mm above ground level.

Fig. 7 shows the overall stability analysis results with spaced micro-piles using SLIDE. The FoS for the slope has been increased by the installation of the micro-piles. However, the increase in the safety factor is small of the order of 5 to 10%, which means further movement is possible in the short term. On the down-slope side, the estimated shear force on single pile is 35 kN using a plastic deformation method of analysis (Ito and Matsui, 1975). This value is lower than the lateral shear resistance of the piles.

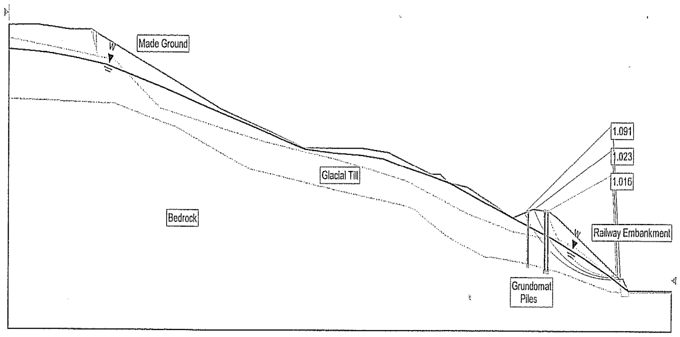


Fig. 7 The overall stability analysis using SLIDE

To provide additional understanding of the slope movement, back-analysis was carried out using the PLAXIS program for the situation with the piles in place. Fig. 8 shows the calculated soil total movement vectors plotted to the same scale as Fig. 6. It is clear that the magnitudes of soil movement vectors are smaller than those without micro-piles shown in Fig. 6.

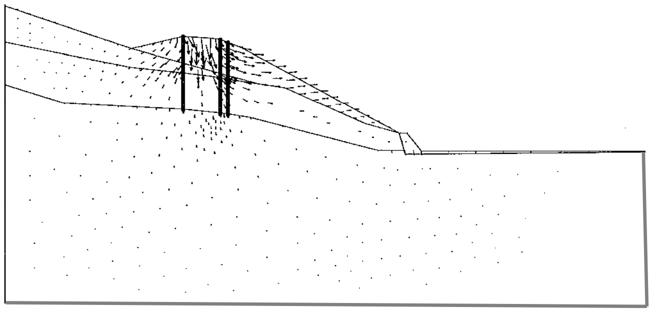


Fig. 8 Total displacements of soils with micro-piles in the PLAXIS analysis

Approximately 100 Grundomat piles were installed, six of which were fitted with inclinometers. At the time the Grundomats were installed the opportunity was taken to improve the ballast shoulders of the railway with ballast boards retained by the piles. Fig. 9 shows the finished Grundomat piles.

Fig. 9 View of finished Grundomat piles

DEVELOPMENT OF SLOPE MOVEMENT

In addition to the inclinometers installed in six of the Grundomat piles, the ground surface of the slope has been monitored by surveying targets fixed to using wooden pegs. The tops of a number of the Grundomat piles have also been monitored by survey methods.

In the main slopes piezometers were installed at the same time as the inclinometers and have been read concurrently with them. Two piezometers were installed in each borehole, one to monitor a deep water table associated with the bedrock and another shallow instrument to monitor the perched water table in the drift deposits.

There has been steady movement recorded in the inclinometers on defined shear surfaces at between about 5 and 15 m depth in the main slope but less movement has been recorded in the railway embankment where the Grundomat piles are installed. The depth of the movement is often coincides with the rock-head or a short distance into the mudstones but this is not exclusively the situation with some shear zones being within the drift deposits. The tentative trajectory surfaces obtained from inclinometers are shown in Fig. 3 (movement zones are denoted with an 'M').

If the accumulated displacement recorded in the upper 2 m of the inclinometer installation is used to represent the general slope movement, a displacement against time is obtained. Fig. 9 shows the movement of the top of inclinometer No GM3 against elapsed time. It is clear that the slope movement continues with an average rate of about 1.5 mm per month. Fig. 10 also shows that the rate of movement slowed down with time. This is consistent with the local reinforcement conferred by the Grundomat piles installed alongside the track.

At the same time however, the reduction in rainfall over the summer months led to a lowering in the groundwater levels. Fig. 11 presents the piezometric levels against time. Monitoring of the piezometers shows a relatively small reduction in groundwater level eg the water level recordered in the upper instrument in Borehole 4P fell by only about 50 mm from May to August 2005. A similar trend is present in the deeper piezometers. It may also be noted from Fig. 11 that there is sufficient distinction between the readings from the shallow and deep piezometers to indicate that the drift and bedrock strata are not in full hydraulic continuity.

The continued movement during 2005 and early 2006 meant that nearly all of the inclinometers in the main slope close to railway became sheared. Over the first 9 months the movement at the surface amounted to about 1.5 mm per month.

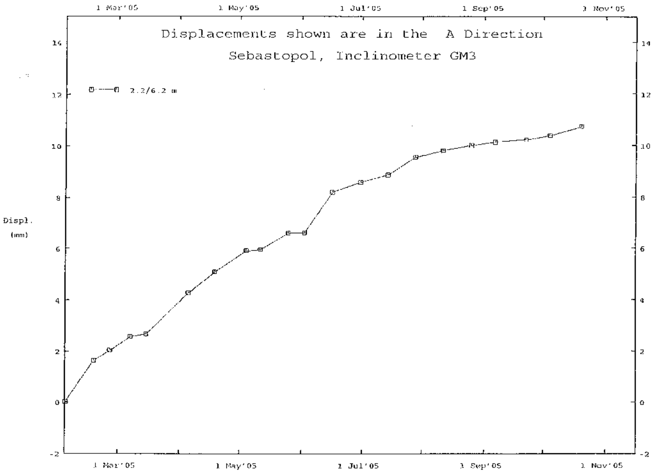


Fig. 10 Displacement against time GM3 (Feb 05 – Sep.05)
(*Courtesy of Network Rail*)

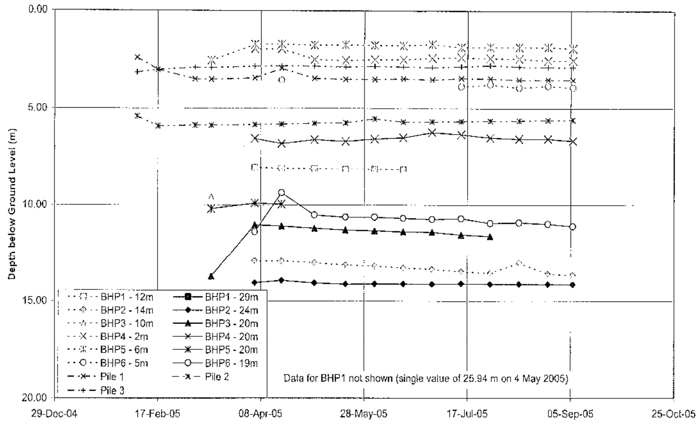


Fig. 11 Piezometric levels over 8 month period
(*Courtesy of Network Rail*)

From mid November to mid December 2005 the railway embankment movement accelerated to approximately 6 mm over this four week period. Fig. 12 shows the movement of inclinometer GM3 in the railway embankment at that period.

This acceleration of movement is thought to be associated with increased rainfall during November and early December in 2005, but the total movement is only around 10 mm over 8 months. Fig. 13 presents the piezometric levels at that time. The groundwater level is shown to have risen significantly during that period.

Fig. 14 shows the rainfall data for the period January 2005 to May 2006. The variation of rainfall data has been compared with movements of three of the monitoring pegs (C6, D5 and E1 installed in the upper slope). The rainfall data shows a clear increase from mid November to mid December 2005. The increase in the piezometric levels reflects the increase in rainfall.

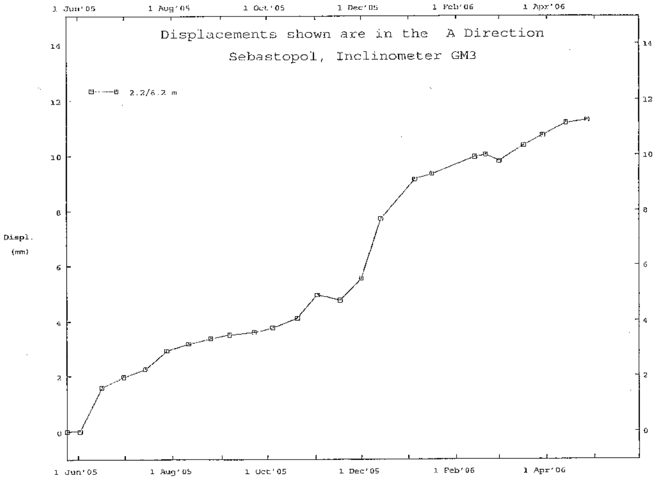


Fig. 12 Displacement against time GM3 (Jun 05 – Apr.06)
(*Courtesy of Network Rail*)

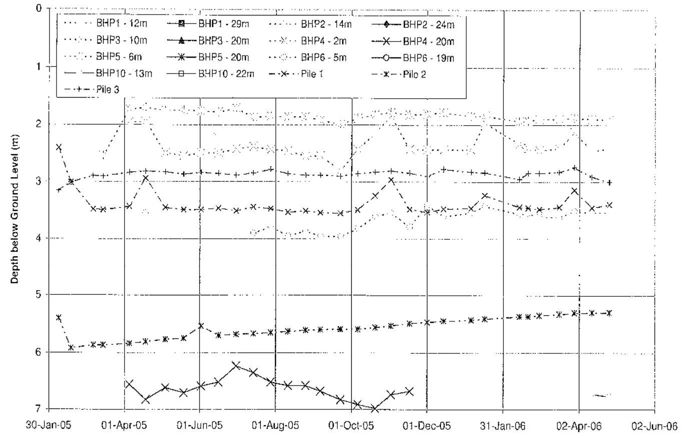


Fig. 13 Piezometric levels over 16 month period
(*Courtesy of Network Rail*)

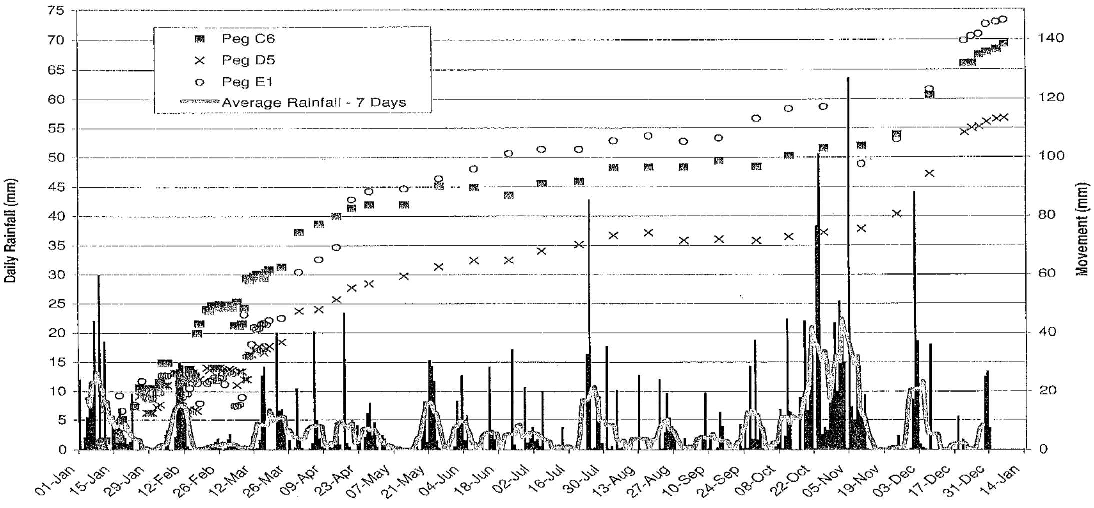


Fig. 14 Rainfall data and slope movement January to December 2005 (*Courtesy of Network Rail*)

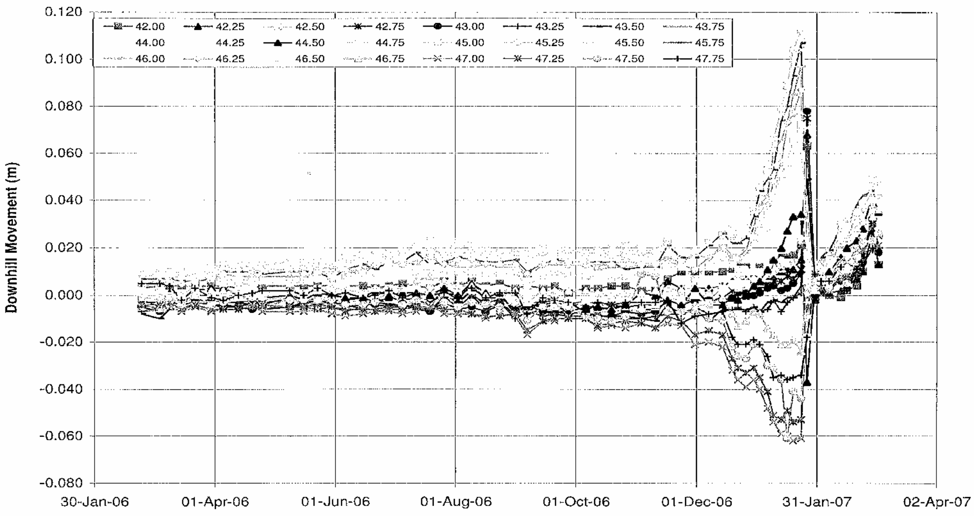


Fig. 15 Track horizontal movement of upslope rail monitoring from January 2006 to February 2007 (*Courtesy of Network Rail*)

Whilst there was some slow creep of a few mm per month in the railway embankment, the movement accelerated abruptly in December 2006 due to the heavy rain at that time. Fig. 15 shows the horizontal track movement of upslope rail during that period. The large movements suggested that some of the Grundomat piles were over-stressed in bending or had become detached at rockhead. Therefore the continued ability of the Grundomats to stabilise the embankment was considered to be of limited duration, perhaps 1 or 2 years.

It also became apparent during the monitoring of groundwater levels and movement at Sebastopol that the initiation and cessation of slope movement depends upon quite small changes in groundwater level, of the order of a few hundred mm.

FURTHER STABILISATING SCHEME WITH MICRO-PILES

Whilst the installation of the piles initially allowed the train speed to be restored, the accelerated movement of the railway forced the train speed to be reduced to 10 mph (16 kph) late in 2006. From an engineering view point, it is probable that the slope at the base of the railway embankment is becoming overstressed by the continued movement of the slope above it. Of some concern is that if a significant proportion of this overstress is being transferred to the Grundomat piles, should these fail, any movement could be more sudden than that associated with straightforward re-activation of long term shear surfaces.

Whilst the need for improving the overall stability of the slope is being considered, a requirement for further temporary emergency restraint became clear. It was decided that as the

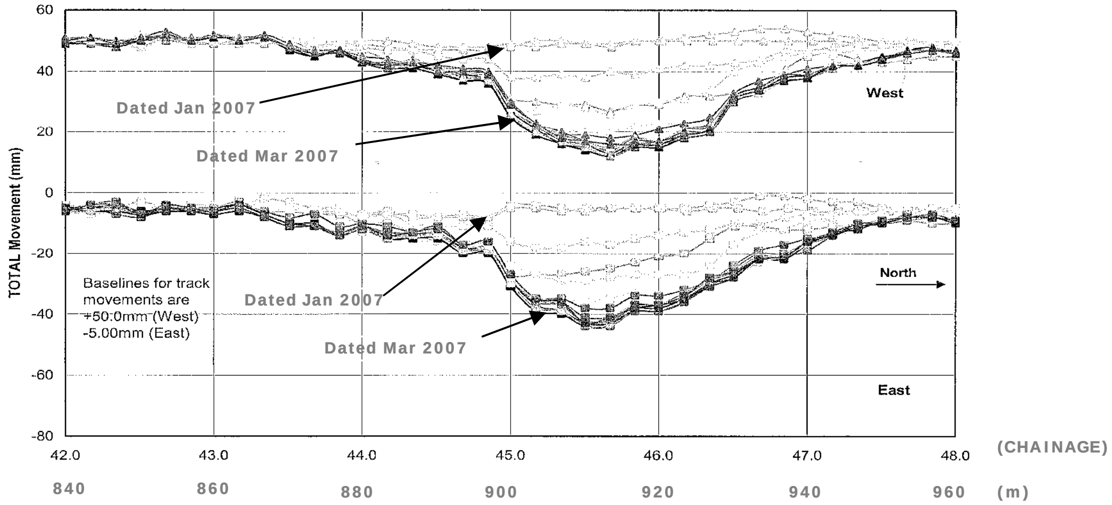


Fig. 16 *Track horizontal movement monitoring from January to March 2007*

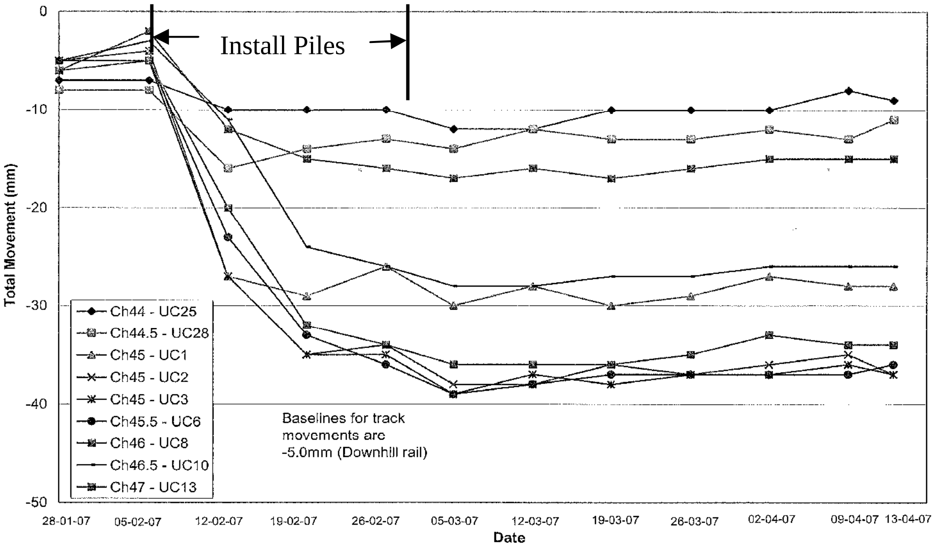


Fig. 17 Down-slope track horizontal movement against elapsed time

micro-piles appear to have a service life of about 2 years further piles were installed to provide a temporary reduction in track movement.

The additional Grundomat piles were installed to a similar specification as the previous piles. A total of 144 piles were installed in February 2007. Given the presence of the existing piles, the layout of the piles had to be modified locally to preserve optimum equidistant clearance. On the up-slope side, the Grundomats were installed at 1.0 m centres over 20 m and on the down-slope side two rows extended over 70 m generally at 1.0 m centres with the rows staggered by 0.5 m.

During and after the progress of the work the track movement was surveyed. Fig. 16 shows the track movement from January to March 2007. The track movements were mostly concentrated in the area from 880 m to 960 m. The track length to be strengthened using Grundomat piles was defined based on the initial track monitoring results.

Fig. 17 presents the down-slope track lateral movement against elapsed time. The track movements before the installation of the Grundomat piles are clearly large, but the rate of movement slowed down after the installation of the micro-piles in February 2007 and line speed has again been restored.

Currently, further ground investigation and instrumentation is being carried out at the site. A dewatering trial forms part of the works with an array of wells in the lower slope. These extend down into the bedrock and are to be pumped for a period of time so that the drawdown can be monitored. This trial is intended to provide an evaluation of the potential use of dewatering as a means of slope stabilisation at the site.

SUMMARY AND CONCLUSIONS

The case history of the Sebastopol slope movement shows clearly what the key factors influence the slope stability. The continuous monitoring survey provided invaluable information on the location of the slip surface and the rate of movement of the slip. It was also a valuable tool to confirm the performance of the temporary stabilising measures using micro-piles.

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