THE PERFORMANCE OF RAILWAY EMBANKMENT STABILISATION MEASURES

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ABSTRACT

Degradation and instability of railway embankments leads to high maintenance requirements and poor ride quality. A range of remedial techniques is available to improve the performance of embankment earth structures. The selection of remedial techniques will inevitably be constrained by available capital budgets and the balance between initial capital outlay and the cost of ongoing maintenance. However, there is little data on the performance improvements achieved by the different remedial techniques. As a result, comparison between schemes on a whole life cost basis is difficult.

This paper presents track movement data for a number of embankments where different types of remedial solution have been implemented. A relationship is shown between the stiffness of the remedial scheme, the initial capital cost and the subsequent reduction of differential track movement. This data may help asset managers in Client organisations to assess the relative cost effectiveness of different embankment stabilisation solutions.

In addition, future research requirements into track performance are highlighted.

INTRODUCTION

Earth Structure embankments comprise approximately one-third of the UK rail network and were mostly built over 100 years ago, with very little engineering control. Occasionally, areas of slip failure and collapse have occurred with resultant safety implications and service penalties. However the most significant aspect of the, by modern standards, poor construction is ongoing embankment deformation and hence high maintenance costs. Figure 1 shows generic embankment "failure mechanisms" which frequently cause poor track performance. Systematic methods of appraising earth structure assets and implementing remedial works are now widely practised; (Egan and Snell, 1998; McGinnity et al, 1998 and Perry et al, 2000). Due to the complex "failure mechanisms" and inhomogeneous nature of railway embankments, no routine design methods are currently available to predict the degree of improvement in embankment deformation performance achieved by the different types of remedial works, and this situation is unlikely to change in the near future.

Over the past 5 years or so Keller Ground Engineering have undertaken approximately 13 km of earth structure stabilisation and have amassed a considerable body of data on the performance of different remedial measures. Data for three of these sites on the London Underground Ltd (LUL) network have been assessed with Ove Arup & Partners to provide a quantitative insight into the typical track deformation performance achieved by different remedial techniques, as listed in Table 1.

(1) Track bed / formation (and ponding).
(2) Shallow slope instability (e.g. at ash fill / ballast shoulders).
(3) Deep seated slope instability.
(4) Seasonal desiccation / swelling from tree roots / vegetation.
(5) Settlement from inadequate compaction and inhomogeneous fill.
(6) Poor foundation.
(7) Internal erosion / burrows.
(8) Inadequate cess.

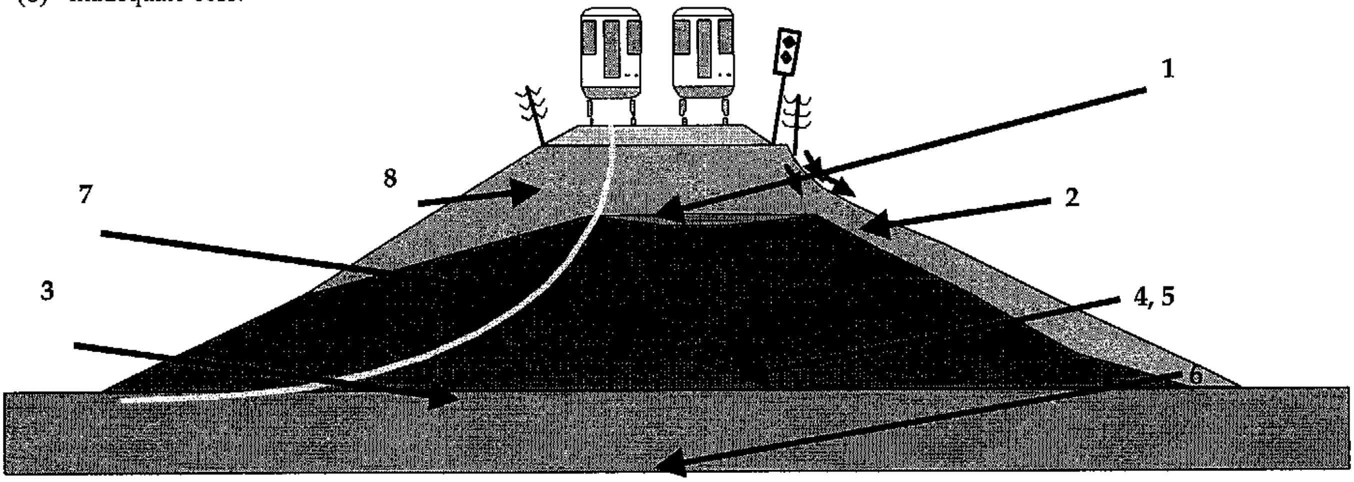


Figure 1 Generic embankment 'failure mechanisms' (After McGinnity, Fitch, Rankin 1998)

Location	Remedial Solution/Embankment Height	Monitoring Period	Maximum Rail Movement (Settlement -ve)	
			Cess Rail (mm)	6ft Rail (mm)
Burnt Oak				
Section 2 Northbound	Tied minipile wall/5.2m	August 1996 to July 1997	- 4	- 9
Section 2 Southbound	Tied minipile wall 4.8m		- 4	- 3
Section 6 Northbound	Tied minipile Wall/ 4.6m		- 16	- 17
Section 6 Southbound	Tied minipile wall / 3.9m		- 15	- 9
Arnos Grove				
Eastbound Section	Gabion toe wall & regrading/2.5m	July 1998 to February 1999	- 18	- 10
Westbound Section	Propped minipile wall/ 5.5m		- 10	- 9
Theydon Bois				
Eastbound Section	Reinforced soil & Regrading/8.0m	July 1998 to July 1999	+ 10	+ 8
Westbound Section	Reinforced soil & regrading/8.0m		+ 23	+ 22

Table 1 – Summary of stabilisation projects and maximum recorded post construction rail movements .

DESIGN REQUIREMENTS

Adequate performance of an earth structure asset may be defined in terms of Ultimate Limit State (ULS) requirements (such as factor of safety against slope instability) and Serviceability Limit State (SLS) or movement / deformation requirements.

The ULS usually equates to the relatively rapid rupture or collapse of an embankment. The margin of safety against this Limit State is typically analysed by limit equilibrium methods and expressed as a factor of safety on soil strength.

The SLS requirements are usually related to track alignment requirements (relative rail gradients and cant etc.) associated with the operational line speed. Track alignment requirements are specified in the railway standards of the Operator. For example, LUL Standard E 8404 A2, 1998 gives a track alignment maintenance target (that is, the quality threshold which the operator requires to be achieved or bettered) of a 5mm relative deviation between consecutive levels on any rail at 5m intervals (relative gradient of 1:1000) and ± 10mm deviation from the marked cant. Similarly, Railtrack Line Specification RT/CE/S/104, 1999, gives track geometry quality in terms of maximum and target standard deviations for every eighth and quarter mile, together with unacceptable isolated track geometries. A maintenance limit on twist of 1:300 over a 3m length is specified.

The rate at which track levels change with time may be measured by optical levelling of the track. The overall performance of the earth structure / track bed can then be evaluated in terms of the rate of deterioration of track alignment with time. Rail levelling data obtained from the sites listed in Table 1 have been analysed to give quantitative assessment of the rate of track level change for different types of remedial solution.

PRESENTATION OF DATA

Burnt Oak

This embankment, ranging in height from 4m to 7.3m high, is located on the Northern Line between Colindale and Burnt Oak Stations and was constructed in 1924. A circular slip occurred in January 1994 over a section of the earth structure which was repaired using sheet piling. Further remedial works comprising a bored cast in place minipile retaining wall and capping beam with raking piles (Egan & Snell, 1998) were constructed by Keller Ground Engineering as Design & Build Packages in two later phases.

The performance of the embankment has been reviewed at two typical cross sections (annotated as Section 2 and Section 6).

Figures 2 and 3 show the pre-remedial works monitoring data around Section 6, obtained by optical levelling the end of the sleepers adjacent to the 6 ft, (unfortunately similar data for Section 2 are not available). For the twelve months prior to construction of the remedial works the maximum recorded deviation sleeper level ranged from –17mm (settlement) to +12mm (heave) as shown in Figure 3.

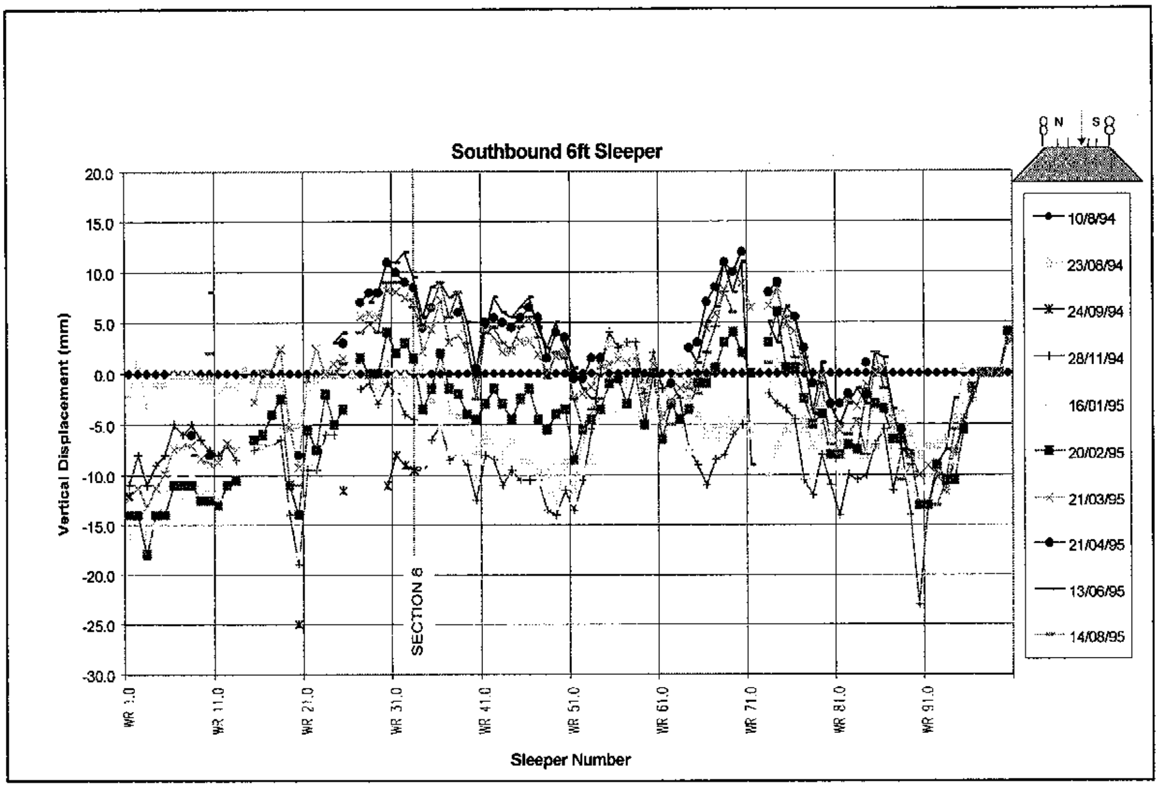
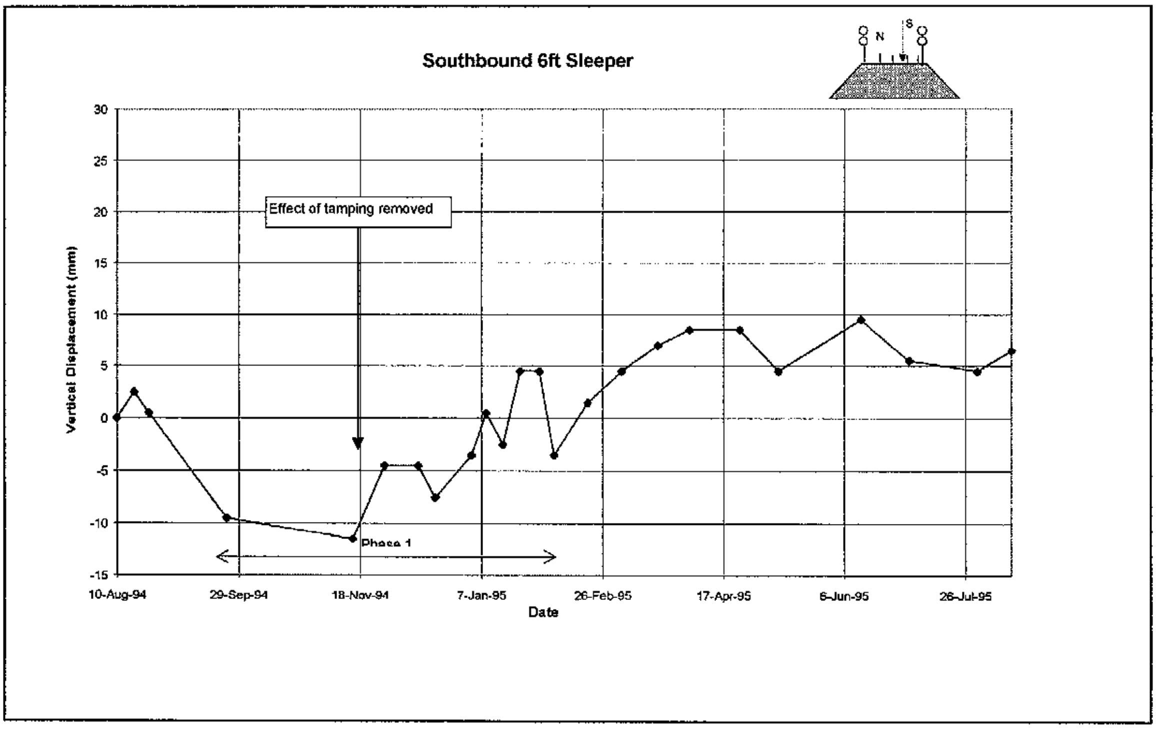


Figure 2 Burnt Oak Pre-remedial works track levelling data (Movement of Southbound Rail with time)

Figure 3 Burnt Oak Pre-remedial works change in Southbound sleeper level with time at Section 6



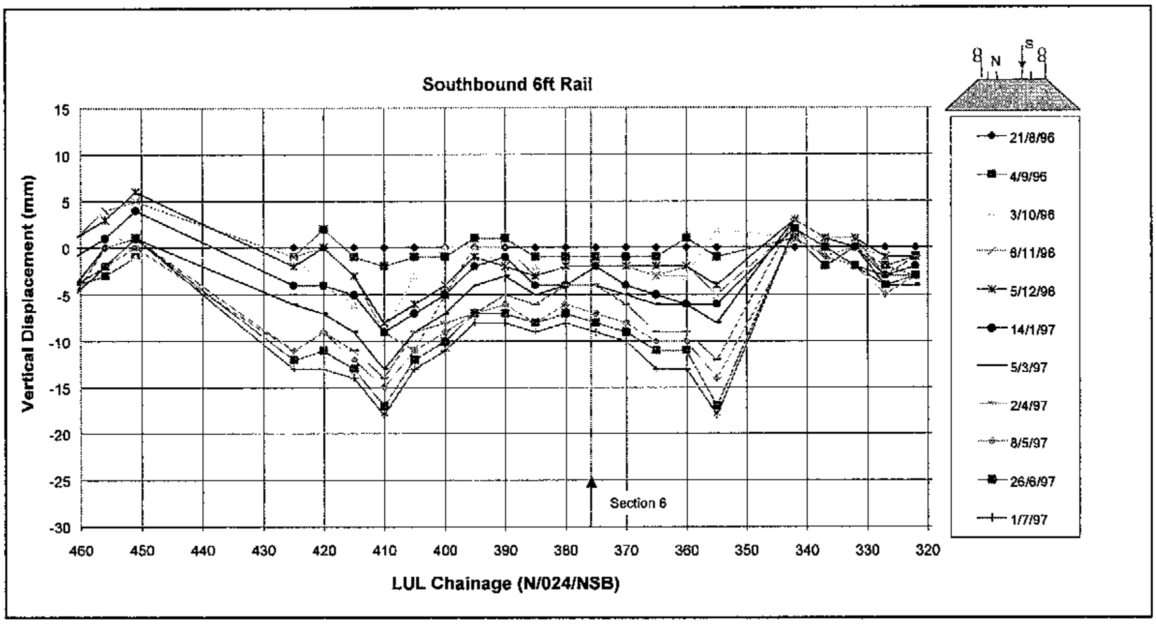


Figure 4 Burnt Oak Post-remedial works track levelling data
(Movement of Southbound Rail with time)

Post construction monitoring was carried out on a monthly basis by levelling the top of the rails at 5m intervals of chainage. Figure 4 shows the recorded rail levels with time on the Southbound. Figure 5 shows the recorded change in rail level with time for both North and Southbound track at Section 6.

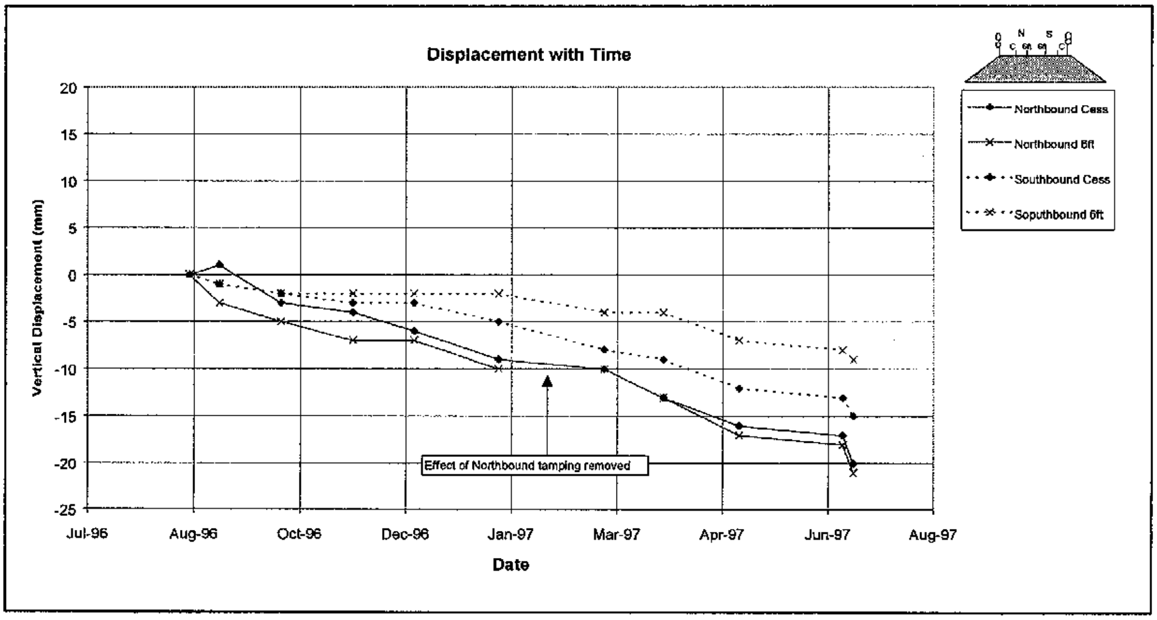
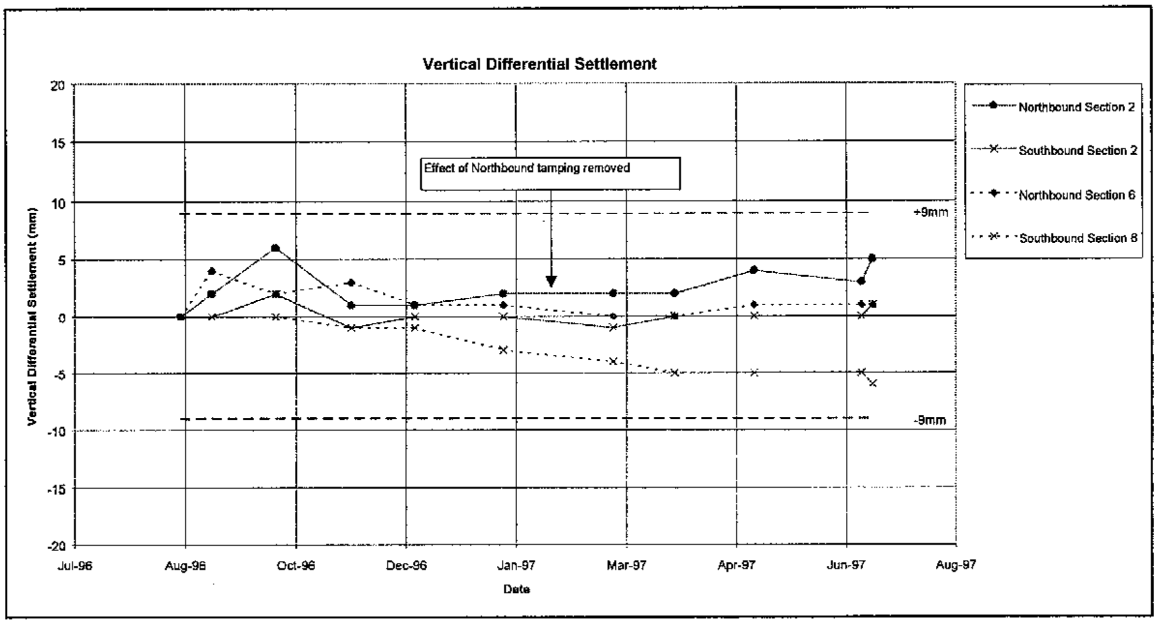


Figure 5 Burnt Oak Post-remedial works change in rail level with time at Section 6

It should be noted that these data have been corrected to remove gross displacements resulting from re-ballasting, tamping and associated track works. Data for Section 2 has been omitted due to spec restrictions here, but at both sections the tracks showed a general trend of settlement of the order of 9mm to 20mm at Section 6 and 4mm to 9mm at Section 2.

Figure 6 shows the differential settlement of the cess rail with respect to the 6ft rail (i.e. change in cant) with time for the two sections. For these data negative differential settlement indicates the cess rail is settling with respect to the 6ft rail. All data show the observed deformation to be within the LUL track geometry requirements.

Figure 6 Burnt Oak – Post –remedial works change in cant with time at Sections 2 and 6.



Arnos Grove

This site is located on the Piccadilly Line between Arnos Grove and Southgate stations and comprises an approach embankment to a viaduct over Arnos Park. The embankment is constructed out of London Clay fill on sidelong ground rising in height from grade at Arnos Grove Station to 5.5m high (Westbound) and 3.5m high (Eastbound) adjacent to the viaduct. On the Westbound, the remedial works comprised a minipile retaining structure and capping beam with either horizontal ties or raking piles. On the Eastbound, a 40m length of tied minipile retaining wall was constructed adjacent to the viaduct, and a gabion toe retaining wall with and regrading where the embankment height dropped below 2.5m.

As part of the pre remedial works construction site investigation rail levelling was carried out on both the eastbound and westbound tracks for a period of 9 months concluding in March 1997. Track settlements up to - 37mm and - 55mm were recorded on the Eastbound and Westbound tracks respectively during the 9 month monitoring period. The maximum settlement was recorded on the Westbound track adjacent to the viaduct structure. On both sides of the embankment the cess rail was recorded to be settling more than the 6 ft rail with a maximum differential settlement (change in cant) of approximately 26mm developing during the 9 month period.

Post construction rail levelling was undertaken for a 12 month period after construction of the remedial works commencing in July 1998.

Figure 7 Arnos Grove – Post remedial works change in rail level with time on Eastbound and Westbound.

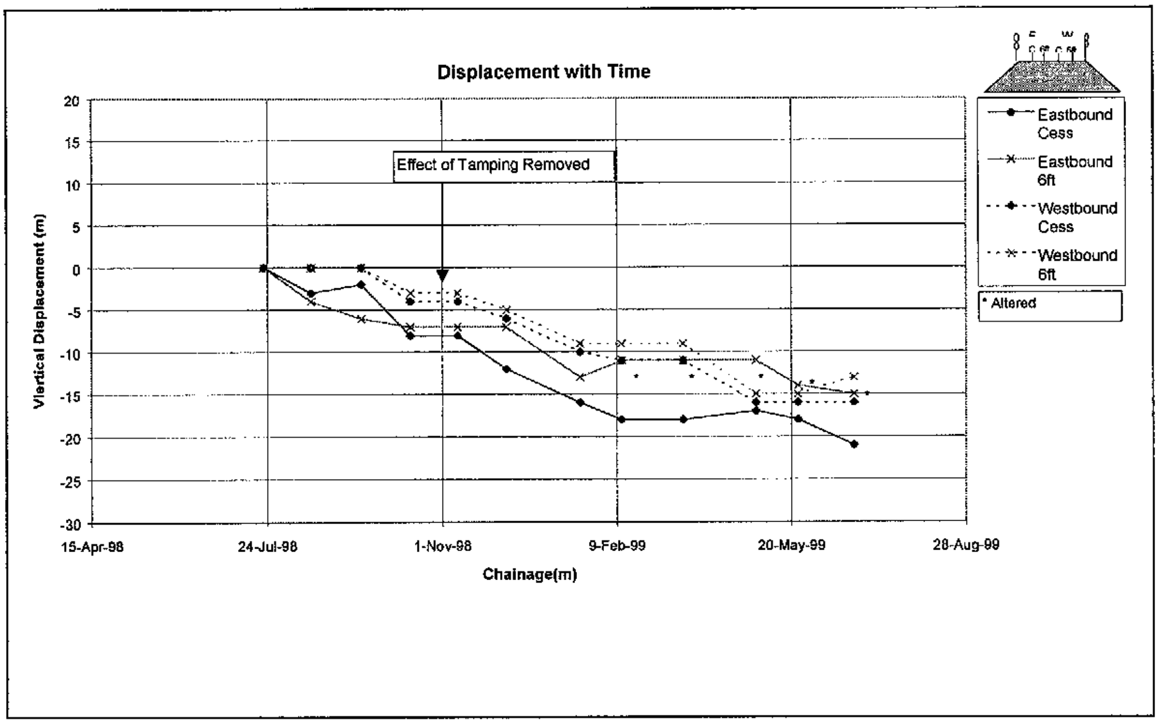
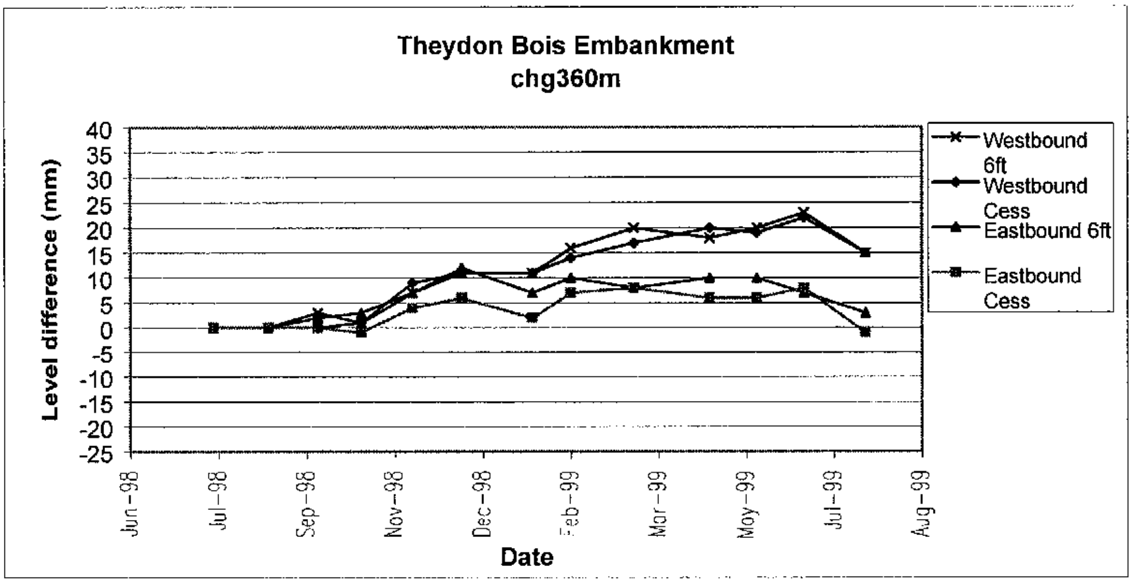


Figure 7 shows the change in rail level with time for typical cross sections through the propped mini pile structure on the Westbound and the gabion/regrading solution on the Eastbound. These data show a trend of settlement of approximately 20mm settlement of the embankment occurring over the 12 month monitoring period. However, the maximum differential settlement (change in cant) during the 9 month period was only about 4mm on the Westbound (mini-pile wall) and 8mm on the Eastbound (Gabion /regrading).

Theydon Bois

Located approximately mid-way between Debden and Theydon Bois stations on the Central Line, this embankment is approximately 800m long rising to a maximum height of 8m from cuttings at either end of the structure. Due to the rural setting of this embankment greater space within the LUL boundary enabled the construction of a reinforced soil toe berm to address deep seated instability. An engineered fill shoulder was also placed to create a 4m wide cess walkway and provide lateral restraint to the track (Egan & Snell, 1998). The remedial works commenced in November 1997 and were completed in July 1998 with post construction rail levelling undertaken until July 1999

Figure 8 Theydon Bois, Post remedial works change in rail level with time on Eastbound and Westbound



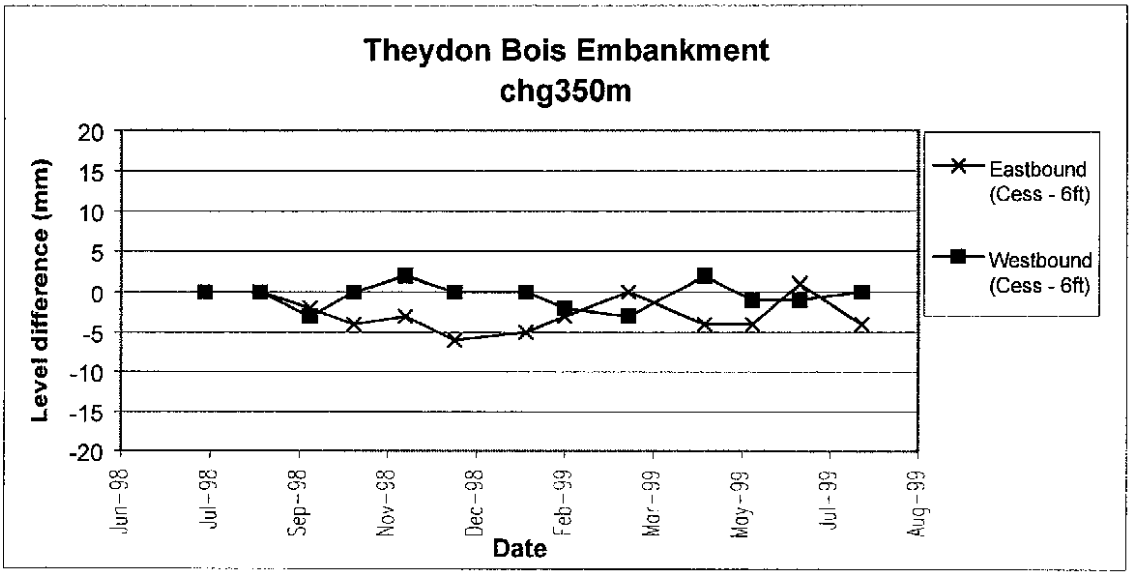


Figure 9 Theydon Bois – Post remedial works change in cant with time on Eastbound and Westbound

Figure 8 shows the change in rail levels over the post construction monitoring period for a cross section taken midway along the length of the embankment. This data shows a heave of approximately 20mm and 10mm for the Westbound and Eastbound tracks respectively. Figure 9 shows the vertical differential settlement of the outer rail with respect to the inner rail (i.e. change in cant) with time at the same cross section.

DISCUSSION

London Underground Performance Criteria

In general the SLS Performance criteria adopted by LUL for remedial works is:

"to restrict the differential settlement of the outside rail to 1:500 along the track over any 10m (± 20mm) interval and 1:300 (± 5mm) across the rails"

Allowing for a ± 2mm accuracy in the optical rail levelling the above data show the performance of the embankments after construction of the stabilisation works to be within the specified requirements.

Relative Performance of the Remedial Works

Post construction monitoring indicates that at all the sites there was still some ongoing settlement / heave of the tracks even after construction of remedial works. It is thought that this reflects the fact that the schemes address the primary causes of instability / movement but movement due to secondary causes (see Figure 1) cannot be fully eliminated.

The five minipile retaining wall sections show an apparent maximum settlement during the year after completion of the works, ranging from 3mm to 21mm (Table 1). The average settlement for the 6ft and cess rails for the five sections is not significantly different at 12.4mm and 12.8mm respectively although the spread of data is quite wide.

In the case of the minipile schemes, embankment vegetation is typically cleared within 7m wide corridor adjacent to the cess. Furthermore drainage is provided under the edge of the cess at the base of the capping beam. This would be expected to promote a reduction in groundwater levels within the clay core consequent shrinkage over time. The disturbance due to pile installation may also cause some relaxation of track support, although if this were the case the cess rail would be expected to settle more than the 6ft rail, being closer to the area of ground disturbance. This is not generally borne out by the data.

At Burnt Oak Section 6 the Northbound remedial works were undertaken 1994 /1995 with the Southbound mini pile wall being installed about one year later. From the track monitoring there is evidence that the performance of mini-pile solutions improves with time as the work 'beds-in'.

Data obtained adjacent to the gabion / regrading solution at Arnos Grove shows the cess rail settling by up to 8mm with respect to the 6ft rail during the 12 month monitoring period. This is more than observed adjacent to the structural mini pile solution (4mm). While both solutions achieved the requirements of the LUL specification, the monitoring indicates that gabion and earthworks solutions are more flexible and do not offer the same degree of support as the structural solution. Similar conclusions could be drawn from Andrei (1999), who published data for a site at Rayners Lane on the LUL network.

The behaviour at Theydon Bois is notably different to the other sites, as shown in Figure 8, with both the Eastbound and Westbound tracks recording heave during the post construction monitoring. While the cause of this difference in behaviour might be related to a number of factors it is likely that the effect of removing all of the mature tree cover that existed on both sides of the embankment prior to the construction works at this site is significant. It is well known that high plasticity soil are prone to swelling where trees have been removed.

CONCLUSIONS

The changes in the rail levels a six section of embankment where stabilisation works have been undertaken have been evaluated. In general the implementation of remedial solutions incorporating minipile retaining walls provided enhanced cess support limiting differential transverse settlements (changes in cant). A reinforced earth solution is also shown to have adequately controlled rail movements at a comparatively wide rural site where space permitted this solution to be adopted. In contrast a site where a low height gabion toe retention structure and regrading, while achieving the requirements of the performance specification, appeared to give less control of rail movements. These observations appear to be consistent with data published by Andrei (1999).

When seeking to control track movements on embankments located within narrow sites exhibiting poor performance, structural solutions are likely to achieve a higher degree of restraint compared to softer earthwork type solutions and may provide greater whole life benefits.

RECCOMMENDATION FOR FURTHER WORK

To date little comprehensive quantitative data on the improvement in embankment performance achieved by remedial works has been published. Systematic acquisition of track performance data over a sufficiently long period to allow evaluation of seasonal effect both before and after the remedial works construction phase is recommended to provide feedback on scheme performance. In addition, no routine design methods are currently available to predict the degree of improvement in embankment deformation performance achieved by different types of remedial works. Further work linking the degree of track restraint provided by different remedial solutions to the operating requirements of the asset owners would allow the evaluation of schemes on a whole life cost basis and enable best value to be identified.

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