

# Effects of vegetation on earth structures on the London Underground network

N. Saffari<sup>1</sup>, M. Alhaddad<sup>1</sup>, J Kennedy<sup>1</sup>

<sup>1</sup>*Department of Earth Structures and Geotechnical Engineering, Transport for London*

**ABSTRACT:** Earth structures on the London Underground (LU) network are over 80 years old, with some as old as 150 years. Most of the cuttings are formed in the London Clay Formation, and the embankments were generally formed from the excavated material from London Clay cuttings. The original construction of these earth structures was not scientifically undertaken, with over-steepened cuttings and poorly compacted embankment fill. Many of them have been showing signs of movement and past instabilities since the early 1990s. By the late 1960s, LU had introduced electric trains, which led to a reduction in the maintenance of vegetation on the earth structures, and the development of dense vegetation, including large mature trees. Over the last decade, the impact of climate change and extreme weather events have also become more frequent. This has led to severe flooding and disruption of rail infrastructure, including some injuries and a few fatalities, as well as impacting serviceability of transport operation. Detailed and deep monitoring of earth structures has provided improvements in the understanding of the behaviour of earth structures, as well as managing the risk of instability. This paper presents the scope of the long-term monitoring undertaken on the LU earth structures, with a focus on the effects of vegetation. The results of the monitoring demonstrate the impact of vegetation on the porewater pressure regime within heavily overconsolidated London Clay cutting and embankment slopes, along with the associated slope and track deformation. Removal of vegetation can lead to increases in porewater pressures, which in turn result in reduction in operating factors of safety. The results also show the shrink-swell seasonal movements due to the presence of mature vegetation and the potential impact on track serviceability and performance.

**Keywords:** Root Cohesion; Vegetation; Porewater Pressure; Slope Stability; London Underground; Monitoring; Climate Change

## 1 INTRODUCTION

The London Underground (LU) railway system consists of approximately 463 route kilometres (km) of track, of which 239 km is supported by earth structures. The earth structures comprise 116 km of cuttings, and 123 km of embankments. The cuttings are mostly formed within the London Clay Formation, and the embankments are predominantly constructed of fill derived from London Clay excavations. These earth structures are over 80 years old, with some as old as 150 years and showing some signs of movement and past instability.

LU has developed and operated a proactive risk-based asset management regime since the late 1990s for earth structures. This management system broadly comprises the following:

- Condition Appraisal
- Monitoring
- Maintenance
- Repair and Renewal

Monitoring is seen as an essential and important component of the asset management regime. The objective of the monitoring is to understand the behaviour and performance of these structures, and particularly the

porewater pressures within the slopes, along with associated deformations, as well as to safely manage the condition of the assets.

The effect of vegetation on the stability of earth structures is well reported in the literature (Powrie, W., Smeethurst, J., 2019; Scott, 2006). Vegetation can be beneficial, but it can also have detrimental impacts on slope stability and earthwork performance. The affects are highly dependent on the type of vegetation and the geology of the slope. The monitoring undertaken on LU earth structures has, in part, been utilised to investigate the effects of vegetation.

## 2 EFFECTS OF VEGETATION

During the steam era and the operation of coal fired trains, vegetation was regularly maintained on LU railway, to reduce the risk of track-side fires.

However, with the introduction of electric trains, the risk of trackside fires reduced, resulting in vegetation maintenance being cut back and finally terminated by the late 1960s. This resulted in the growth of significant mature and over-mature trackside vegetation, causing various service-related problems.

The problems caused by the increased trackside vegetation included:

- Seasonal track movement.
- Tree, branch and leaf fall.
- Loss of visibility.
- Fires.
- Damage to drainage and adjacent structures – often leading to 3rd party claims.

However, removing vegetation as a mitigation measure can have detrimental effects such as:

- Reducing slope stability by removing the beneficial effects of roots that control porewater pressures and provide reinforcement near surface against shallow instability.
- Loss of biodiversity, screening and noise attenuation.
- Heave in London Clay by eliminating the water uptake of the root system.

It should also be noted that removal of lineside trees may reduce seasonal shrink-swell cycles, but does not immediately eliminate ground and track movements, which may continue for at least four years (Briggs et al, 2013). Hence, a whole life vegetation management policy was needed, to optimise the vegetation across the network and achieve the right balance between the safe operation of the railway and the provision of a natural and green environment, in line with the mayor's transport strategy. This policy is dispatched through the LU Standard S1165, Landscaping and Vegetation.

### 3 EFFECTS OF CLIMATE CHANGE

LU has conducted research on the effects of climate change and inclement weather on its earth structures. As part of this study, five modes of instability were identified:

- Flow failure
- Prolonged rainfall and low SMD
- Frost shattering
- Scour erosion
- Seasonal shrink-swell

As part of the study, all assets susceptible to these failure modes were identified and divided into categories of High, Medium and Low risk. High risk assets have been added to the LU Weather Action Plan and are now managed accordingly.

The impact of climate change on porewater pressure regimes for the design and assessment of clay earthworks, has been studied by Wengui Huang, et al., 2023. This study shows that climate change will potentially lead to increases in the magnitude of dry-wet cycles. This will drive greater shrink-swell behaviour and may increase desiccation cracking. This also means that the rate of weather driven deterioration of soil strength is likely to increase.

The increase in the amplitude of the swell-shrink movements of embankments will cause increased serviceability concerns leading to deformation of track and

associated infrastructure (Figures 1), as well as increasing the rate of strength deterioration over time.



Figure 1. Typical photo showing presence of mature vegetation and seasonal deformation of track and lineside services

Figure 2 shows a plot of Track Recording Vehicle (TRV) data, together with the SMD variation over the period of July 2024 to October 2025. The TRV is a specialised rail vehicle that uses sensors to measure the condition of railway tracks at normal speed without obstructing regular traffic. TRV runs on a regular basis to measure particular track parameters, in order to classify the track performance against condition thresholds. Based on the results, mitigating actions are taken to maintain the track to within its safe operational limits. The graph shows a clear decline in track quality over the period of prolonged hot and dry summer experienced between May and September 2025. This decline has occurred mainly in the areas of the network underlain by London Clay (in cuttings or at-grade sections) or London Clay fill embankments. Presence of mature vegetation has also been a significant contributing factor.

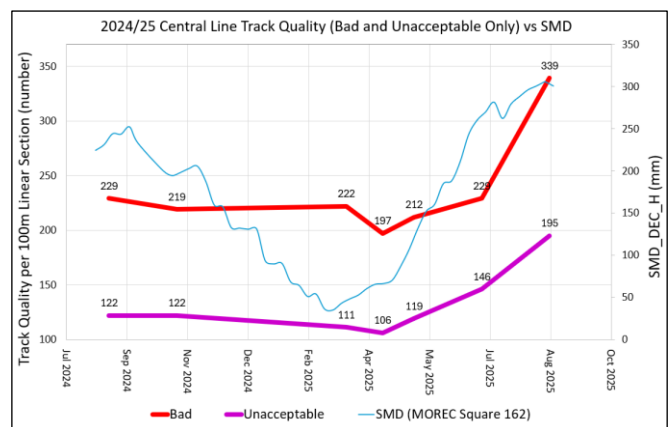


Figure 2. Track Quality on the Central Line (Bad and Unacceptable) vs SMD for 2024/25

The shrink-swell behaviour is greatly impacted by the presence of deciduous and mature vegetation (Figure 3). Therefore, the vegetation management strategy of earth structures on the LU network needs to be reviewed in the context of climate change.

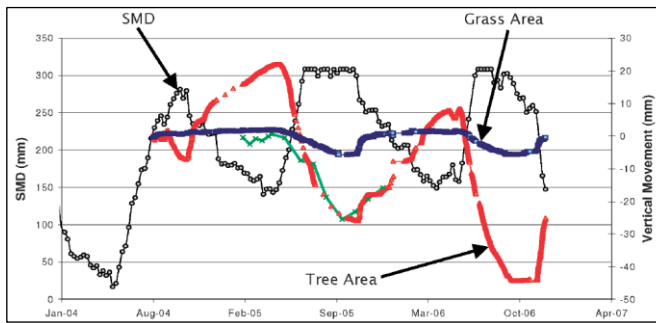


Figure 3. Embankment Deformation, Grass Covered versus Mature High Water Demand Tree Covered Slope (after Scott, 2006)

## 4 INSTRUMENTATION AND MONITORING

### 4.1 Objectives

The key objectives of the earth structure monitoring are as follows:

- Obtain data for slope stability analysis and design.
- Observe the asset performance.
- Manage the safety risk.

### 4.2 Observational Monitoring

In some cases, the results of analytical assessments may indicate that an asset does not meet the minimum criteria of the LU standard in terms of the calculated factors of safety for slope stability. However, in contrast, the physical condition of the asset through inspection does not show any signs of potential instability. In this case the calculated factors of safety are considered to be perhaps too conservative and not representative of the actual condition of the assets, taking into consideration the impact of vegetation on the slope.

For these assets, a monitoring regime is established in order to measure the actual porewater pressures within the slopes and the slope movements over a long period of time, which is often many years, to ensure that a representative sample of climate and seasonal responses is recorded. The monitoring is continued until adequate data is collected to establish trends and demonstrate that the worst credible conditions and slope behaviour have been established.

At this stage either a re-assessment is carried out to upgrade the condition classification for the asset, or monitoring is continued as a means of managing the asset in the longer term, until such time that the data indicates the need for remediation. This method can result in potentially significant cost savings compared to the cost of the remedial works.

### 4.3 ALARP Monitoring

Assets that through analytical assessment fail to meet the minimum condition for the railway to operate without

restriction are normally included in a work-bank for remediation. However, in order to manage the risk to the operation of the railway at ALARP (As Low As Reasonably Practicable) level, these assets are placed into a “deep” monitoring regime, in order to detect development of any early signs of instability, until remedial works are completed.

The LU Earth Structures team has been involved in the design, procurement, data acquisition and interpretation of the data from comprehensive monitoring systems for a number of assets over the last 18 years. The results of the monitoring are utilised to re-calculate the factors of safety on a regular basis in order to check that adequate margin of safety is available, until remedial works are completed. This is particularly important during enabling works prior to construction, when vegetation is typically cleared, and the earth structure stability could be at its most critical.

Mitigation measures are put in place to ensure appropriate actions are taken in case the margins of safety are reduced below critical levels. For assets that are considered to be more critical an Emergency Preparedness Plan (EPP) is put in place with allocated actions when trigger levels are exceeded.

### 4.4 Typical Instrumentation and Monitoring

Typical instrumentation and data sources used for monitoring of slopes within the LU network consists of the following:

- Standpipe & flushable hydraulic piezometers
- Inclometers & survey targets
- Soil Moisture Deficit (SMD) & rainfall
- Track Recording Vehicles (TRV)

## 5 CHIGWELL CASE STUDY

The cutting located between Chigwell and Grange Hill on the Central line is 500m long and up to 10m deep, with slope angle of generally 20°, although locally it is over-steepened to between 35° and 40°.

Several transects have been monitored on this cutting for approximately 10 years using inclinometers and piezometers. There was a significant amount of vegetation, including mature and semi-mature trees covering the slope which was entirely removed in December 2018 in preparation for the cutting stabilisation works. Figure 4 shows vegetation cover before and after the clearance.



Figure 4. Chigwell Cutting Vegetation Clearance Before and After

The results from a standpipe piezometer, a flushable piezometer and an inclinometer are shown in Figure 5. Before removal of vegetation the results show a cyclic seasonal response in both the inclinometer and the piezometers. Higher porewater pressures are experienced in the wet winter season, due to higher rainfall and lower water demand from the trees. In the dry summer season, lower porewater pressures are measured due to the reduced rainfall and higher moisture uptake from the trees.

The near surface movements before the removal of vegetation seems to be consistent with the seasonal cyclic changes in porewater pressure. It can also be seen that the removal of the vegetation from the cutting has resulted in a significant increase in the porewater pressure and the near surface downward movements. The shallow movements are shown to be less cyclic after removal of the mature vegetation, due to absence of water demand from the mature vegetation.

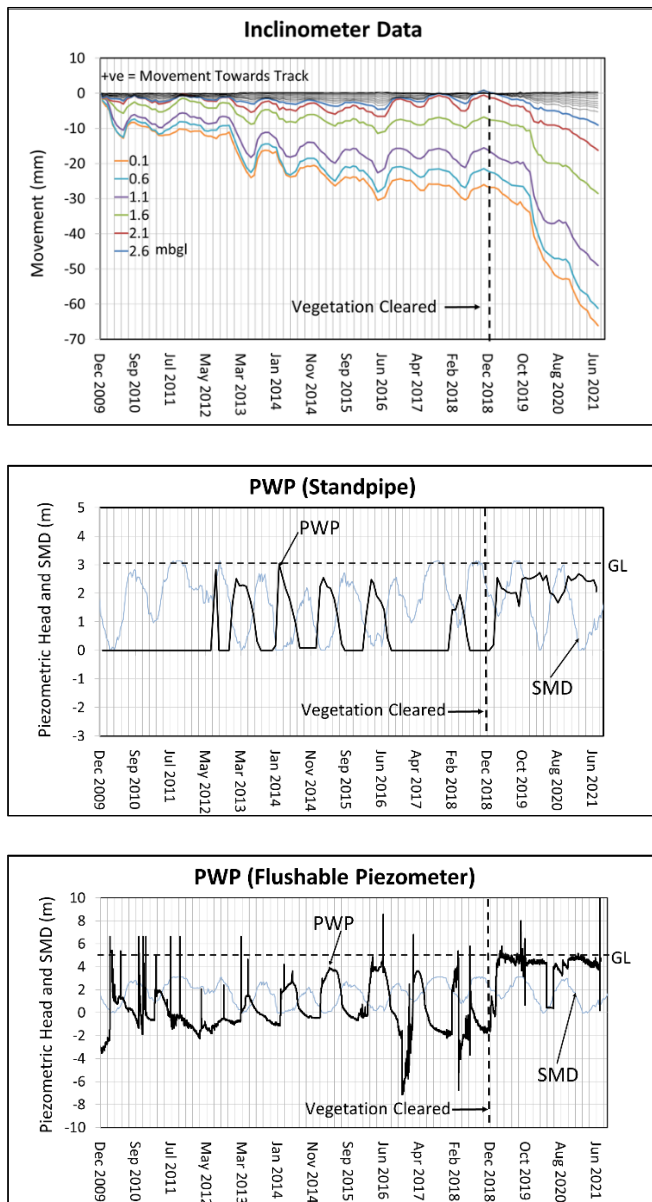


Figure 5. Incliner Shallow Movements vs Porewater Pressure (PWP) and Soil Moisture Deficit (SMD)

## 6 CONCLUSIONS

Long-term monitoring of earth structures on London Underground network shows a clear and measurable relationship between vegetation cover, porewater pressure, and shallow slope movement within overconsolidated London Clay formations.

Track performance and quality could be significantly impacted by the effects of vegetation and climate change leading to greater shrink-swell behaviour. Therefore, the vegetation management strategy of earth structures on the LU network needs to be reviewed in the context of climate change.

## 7 ACKNOWLEDGEMENTS

The authors would like to thank Geotechnical Observations who have managed the field installation and data collection and management of the monitoring systems over many years.

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