Background

Deterioration of railway embankments and trackbed occurs naturally over time. However, there has been a marked increase in embankment and trackbed deformation on the railway network in Great Britain over the last 20 years, sometimes resulting in failure, such as the failure of the embankment at Mottingham in Kent during 2001.

Network Rail has observed an increase in deformation associated with an increase in railway traffic loading, resulting from higher axle loads and increased train frequency. Currently, there is no means of assessing the potential deformation of embankments and the trackbed, where an increase in railway traffic loading is anticipated.

To confirm the observed relationship between load and deformation within embankments and the trackbed RSSB, in conjunction with Network Rail (NR), commissioned a programme of applied research on behalf of the Vehicle/Structures System Interface Committee (V/S SIC).

Initially, the research programme was to be progressed through 3 phases:

1. Desk study
2. Site instrumentation and laboratory testing
3. Analytical model development

However, the findings from the desk study phase indicated that a modified strategy, involving initial development of the analytical load model from the desk study phase plus the addition of laboratory testing, would provide earlier benefits for the industry. Phase 2 consisted of laboratory testing and the initial development of the analytical model. The further work to validate the model and carry out site instrumentation will be carried out by Network Rail.
Aims

On behalf of the V/S SIC the primary objective of the industry programme is to develop an analytical model for assessment of deformation within an embankment of clay core construction, in response to railway traffic, which is:

- Effective, reliable and simple to use.
- Embraced by the railway industry.
- Compatible with the current route availability system for classification of bridges. Bridges provide a benchmark system on which embankment classification can be based.
- To support the development of budgets for embankment remediation due to deformation from railway traffic.

In light of the revised scope, the aim of this research was to develop an analytical model based upon current asset and maintenance records with the support of laboratory and full scale testing.

Findings

Previous research into the impact of dynamic train loading on the degradation of embankments has considered mainly straight track conditions and at grade conditions; only a few studies have considered embankments subject to railway traffic.

A review of embankment failures identified that they occur predominantly for medium to high plasticity clay fill embankments, 3 to 6 metres in height, and with a slope angle greater than 25°. The available Network Rail records of embankment failures focussed only on the relatively large scale classical geo-technical slope stability failures, which are dependent upon physical and environmental factors, or failure resulting from scour or washout, rather than traffic loading. The failure and deformation mechanisms associated with railway traffic loading are derived from repeated loading (fatigue-type behaviour) that results in the need for increased track maintenance. The deformation will be concentrated in the upper layers of the embankment below the subgrade. A review of case studies for track maintenance identified that embankments tend to require significantly more track maintenance than cuttings.

Prior to failure, embankment deformation as a result of railway traffic loading, becomes evident through the need for increased maintenance of the track. The investigations identified 4 principal factors as the causes of such traffic induced deformation of embankments:
Train axle load  
Plasticity of the embankment clay fill  
Trackbed configuration (ballast thickness)  
Effective track drainage

Railway traffic loading is generally expressed in terms of the overall tonnage applied to the railway line - million gross tonnes (MGT). This research demonstrated that the key variables, axle load and the number of load applications, N, should be identified separately, and not just the overall tonnage. Axle load is the primary parameter affecting embankment deformation, with N having a smaller impact.

High plasticity clays are subject to much greater levels of permanent deformation under repeated loading compared to low plasticity clays.

For a given plasticity classification (low, medium or high), this trend is illustrated in Figure 1, and also the effect of the number of load cycles (solid line: deformation after 1 year; and dashed line: the deformation after 5 years). The effect of load magnitude can also be seen, with passenger trains causing stresses in the ground below the track in the range 10 to 20 kPa and for freight traffic, within the range 30 to 40 kPa.

**Figure 1 - The effects of clay plasticity**

Track alignment and local structural features ('hard spots') are regarded as secondary factors which contribute to increased deformation. Embankment height, shoulder width, and slope angle will have no significant impact, beyond particular critical thresholds. An increase in ballast thickness reduces the level of stress within the embankment and trackbed, and therefore has a
significant impact on the development of permanent plastic deformation.

The analytical modelling has shown that for clay soils, whilst loading under any given cycle is largely recoverable, after a large number of cycles the permanent plastic component of the deformation can become significant. A commonly used predictive model for determination of the cumulative plastic strain for given a number of applied stress cycles is empirical and based on a power law relationship proposed by Li & Selig (1996).

Two load scenarios were found to be appropriate for assessment:

1. **Reload** - the embankment clay fill has previously been subject to the level of stress being imposed.
2. **Virgin** - the embankment clay fill is to experience a level of stress for the first time.

For each load scenario 2 assessment lines were defined - median and upper bound (see Figure 3). It was concluded that in most cases it will be the reload load scenario that should be considered together with the median assessment line. The upper bound assessment line will usually provide a worst case estimate of the deformation of the embankment.

**Figure 2 - Plastic strain accumulation**
Method

The desk study included a review of Network Rail maintenance records and analysis of trackbed composition across the GB rail network, to establish a link between track maintenance activity and embankment and trackbed deformation due to railway traffic loading.

Two fundamentally different types of laboratory testing were undertaken to provide the data required for development of the analytical model. Using 30 tonnes of clay extracted from Tumpy Green in Gloucestershire, the testing programme comprised:

1. Testing of small soil samples to assess soil behaviour under a wide variety of cyclic loading regimes covering stress ranges that are both remote from and close to failure.
2. Testing of a large scale model embankment (see Figure 4) to assess the response to loading, on a model of the whole system (track, ballast, and embankment fill).

Figure 3 - Large-scale model test setup

The development of an 'analytical model' for assessment of strength and deformation within an embankment of clay core construction, has involved the following steps:

1. Preparation of 3-dimensional numerical models of the large scale model test set-up, that are able to simulate the train elements testing, and a report which describes the site instrumentation to be used as part of the next phase of work.
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loading, track and underlying response of the ballast and fill layers.

2 Calibration of the numerical model against the large scale model test results.

3 Extrapolation of the 3-dimensional numerical model to full-size, followed by parametric studies undertaken to ensure compatibility with the large scale model response to loading.

4 Determination of scale factors using numerical analysis to rigorously back analyse the large scale model tests, to reflect the non-linear stress-strain behaviour exhibited by clod and matrix embankment clay fills.

The numerical modelling and testing have been used to develop an assessment methodology (see Figure 4) for prediction of the impact of a change in railway traffic loading on clay core embankments.

Figure 4 - Embankment deformation assessment methodology

Other known contributions to track deformation are ballast degradation because of load, and seasonal shrink-swell effects caused by drying and wetting of the embankment and trackbed. When the track deformation reaches the maximum set out in GC/RT5021 (intervention limit) maintenance of the track to reinstate the required vertical alignment is necessary.
Next Steps

Significant steps have been taken to provide an improved understanding of the complex relationship between the train (axle load, speed, and frequency of travel), and embankment and trackbed deformation; and importantly to provide the means of assessing it.

The V/S SIC has accepted the findings and outputs of this research, and that further work remains to be undertaken to confirm the validity of the assessment methodology; and that this is best developed through implementation within Network Rail.

Network Rail has agreed to take forward the next stages of the work. This work will enable calibration of the models against deformation data obtained from instrumented sites, to be undertaken. Account will be taken of ballast thickness and drainage conditions, and their influence on the predicted stress changes.

This will allow future development of the models, taking into account the significance of particular train load models and specific vehicles, to ensure the validity of the predicted stress changes applying the T679 embankment damage assessment methodology.

Contact

For more information please contact:

Head of Engineering Research
R&D Programme
RSSB
enquirydesk@rssb.co.uk