Overview

Rail and road embankments are integral components of transport networks, comprising a significant proportion of the rail and road networks. In the case of rail networks, embankments and cuttings comprise approximately 5,000km of the total 16,000km route length.

Embankments are the foundation upon which the rail track and the road pavement are built. The growth in demand for rail and road transport contributes to increased damage from traffic and imposes tight restrictions on the time available to inspect embankments and to carry out maintenance. Unplanned inspection and maintenance, as a result of undetected damage, is expensive, results in significant traffic disruption, and can have a significant impact on adjacent infrastructure (bridge foundations for example).

In terms of infrastructure management and reliability of train services, there are considerable advantages to be gained from the ability to: inspect embankments without disrupting traffic, identify those embankments most at risk; and then plan for inspection and maintenance with minimum disruption to train services. On behalf of the Vehicle/Structures System Interface Committee, RSSB engaged as a project partner providing financial and technical support to two EPSRC supported research projects led by Newcastle University.

The first project, BIONICS (BIOlogical and eNgineering Impacts of Climate change on Slopes), involved the construction of full size trial embankments that are representative of UK infrastructure. This facility, built at Nafferton Farm, Northumberland, is designed to support and improve the understanding of the long-term impact of climate change on infrastructure embankments; and inform industry and stakeholders of the adaptation strategies needed to mitigate the effects. This facility is now complete and has established a database of high quality embankment performance data that is supporting further research into the interaction of climate,
vegetation, and engineering on the behaviour of infrastructure earthworks.

The second research project has undertaken a trial application of an embankment inspection methodology which involved the remote collection of embankment data using photographic imaging techniques on the BIONICS facility and an 8km test corridor of rail and road infrastructure. The results have demonstrated the capacity of airborne survey techniques, including lidar (airborne laser scanning) and multi-spectral aerial imagery, to deliver high quality information on key slope stability parameters, such as local slope gradient, vegetation type, and soil moisture distribution. In addition, these techniques are capable of supporting analysis at very high spatial resolutions, improving overall understanding of localised slope behaviour.

**Aims and Objectives**

The specific aims and objectives of the two projects were:

**BIONICS**
- To monitor embankment and foundation movement
- To monitor seasonal water pressure variation
- To plant and monitor representative vegetation subject to variable climate
- To measure the amount of water from rainfall that affects the embankment
- To create a climate control system for the embankment for regulation of rainfall
- To develop a methodology for identification of UK infrastructure that requires further investigation

**Remote asset inspection**
- To trial the collection of embankment data remotely using helicopter-mounted photographic imaging techniques (lidar, multi-spectral aerial imagery and terrestrial scanning)
- To identify and extract parameters that have a controlling influence on slope stability
- To develop a strategy for semi-autonomous identification of the symptoms of instability and risk in transport corridors
- To develop and validate a risk assessment tool for supporting investment decision making processes for the management of embankment assets in transport corridors
Deliverables

As well as the physical construction of the full-scale research embankment, with the facility to create an artificial climate over part of its length using a system of sprinklers and covers, the outputs of the two research projects have been used in numerous ways. These include the production of PhD theses, academic papers, presentations, and reports. Further information on each project may be found at the Newcastle University hosted project websites:

BIONICS: http://research.ncl.ac.uk/bionics/
Remote asset inspection: http://www.ceg.ncl.ac.uk/pls/linearsurvey.html

Method

To ensure the full size trial embankments were representative of UK infrastructure, both modern, designed embankments, typical of highway embankment construction, and heritage embankments, typical of early railway construction methods were built on land outside Newcastle. The railway embankments were constructed in 1m layers, with light compaction (poorly compacted), and the highway embankments were constructed in 0.3m layers, with compaction according to the Highways Agency Specification for Roads and Bridgeworks (well compacted).

Embankment modelling has been based on setting extreme boundary conditions to represent the range of extremes, ('summer' and 'winter' conditions), based on the application of a static pore water pressure to the geotechnical model, to define the range of pore water pressure variation. Analysis was then run for six months until equilibrium conditions were established; for each condition the mechanical response, including slope failure, was modelled. The effects of variation in weather, for example due to climate change, are modelled independently, and the impact on pore pressures is assessed for input to the Fast Lagrangian Analysis of Continua (FLAC) model. In this way the impact of weather variation on progressive slope failure, today and in future, could be assessed.

The trial embankment has supported several follow-on projects, including the development of a hybrid hydrological-geotechnical model that has been used to predict the behaviour of embankments over their design lives. The model was validated against the data from the embankment and from a series of centrifuge models provided by another project partner. A biological project has also examined the colonisation of the newly
constructed embankment by new species of flora and fauna, and monitored the effects of the controlled climate on growth.

For the purpose of the remote asset inspection a trial site was identified to the west of Newcastle, near Haltwhistle where the A69 Haltwhistle By-pass and the Newcastle to Carlisle railway line run parallel to each other. The overall trial corridor was 8km long, but the section of most interest was the 2km section of railway corridor adjacent to Melkridge.

Figure 1 - Map of the test corridor area

The Melkridge section offered a section of railway line that is adjacent to the River South Tyne, is susceptible to failure and instability, is representative of problems affecting the GB rail network, and includes extensive stretches of embankments. For this section of the railway network geotechnical records were available which provided not only information about the physical properties of the embankment, but also indicated problems with poor drainage and rabbit activity.

The activities to be undertaken in connection with the work may be summarised as:

- Acquiring data on: slope stability parameters, the presence and location of vegetation, and soil moisture condition, from aerial survey.
- Development of a numerical model to utilise the slope stability parameters obtained from aerial survey and to make an assessment of the risk of embankment instability.
• Regression analysis to assess the reliability of the risk assessment data for use with a GIS-based risk mapping tool.
• Consideration of the options for taking into account future climate change impacts within the slope stability risk assessments.

Aerial surveys were undertaken in 2007 to obtain the slope stability parameters required:
• Slope height and width, aspect and wetness (LIDAR - July 2007)
• Vegetation cover (Multi-spectral aerial imagery - September 2007)

This information was abstracted from the aerial survey data and provided for numerical modelling. The numerical model was developed using proprietary finite element software, FLAC, to provide a geotechnical model of the embankment. This model was coupled with a hydrological model (SHETRAN) to provide estimates of pore water pressure variation over time within the finite element cells. The combination of the physical properties (estimated or based on site investigation records) of the embankment and the ability to predict changes in pore water pressure over time, allow an estimation of the physical response of the embankment (for example an estimation of the factor of safety against failure), as well as the ability to predict how this might change over time due to the impact of climate change (for example an increase or decrease in pore water pressure).

The risk assessment strategy may be conveniently summarised in diagrammatic form as shown in figures 2, 3, 4, and 5.

Summary of Results

A large amount of test data has been generated from the trial embankment facility. Some key findings were:
• Based on tests in accordance with BS1377, the soil has been classified as a clay of medium plasticity ie less plastic than a highly over consolidated clay like London Clay.
• Deformation data for the embankment indicates settlement in the range 26-33 mm, levelling off by the end of 2007, for the railway (poorly compacted) embankments, and settlement in the range 12-16 mm, with settlement ongoing, for the highway (well compacted) embankments.
• Pore pressure variation affects slope stability and variation in the upper layers is more marked for the 'poorly compacted' embankments compared to 'well compacted'
embankments. This reflects the difference in the speed of response to change in water content, for example due to wetting and drying, in the upper layers of the embankment. Vegetation affects the pore pressure variation in the embankment.

The second research project has demonstrated that remote risk assessment may be applied to provide the following information along a transport corridor:

- High resolution aerial laser scanning (lidar) for analysis of the topographical characteristics (slope, aspect, wetness).
- An aerial image of vegetation cover, including classification of type (accuracy of 77%).
- An assessment of slope stability using numerical modelling techniques and hazard mapping for particular route sections.

Next Steps

The test embankment built for the BIONICS research remains in operation and, in conjunction with the database of high quality embankment performance data, it enables further research into the interaction of climate, vegetation, and engineering on the behaviour of infrastructure earthworks to be undertaken.

The remote asset inspection research has demonstrated that such techniques may be applied to assess the risk of failure of railway embankments along a particular route.

As a result of the project, LIDAR data, Digital Terrain Models, and geological data, have been used by Network Rail to develop a 'water concentration features' database. This database is used to identify surface water concentrations that will contribute to the risk of cutting scour and earthflow failures and, to support the examination of earthworks in accordance with Network Rail standard NR/L3/CIV/065. Access to the 'water concentration features' database is also being used by the Futurenet Project, which is looking at the development of models of weather- or climate-induced failure mechanisms of transport systems, together with climatic trigger levels likely to be experienced up to 2050.

The BIONICS project will help with studies on the effects of climate change on Network Rail embankments. The BIONICS data is being provided to partners in the 'Adaptation and Resilience to a Changing Climate' programme. BIONICS data will also help to extend the use of Soil Moisture Deficit classification data to areas other than southern England (where it is already in use).
Figure 2 - The risk assessment strategy

Figure 3 - Lidar survey, topographic data
Figure 4 - Aerial images, classification of vegetation

Figure 5 - Numerical modelling, coupled SHETRAN/FLAC models

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