# Forecasting transportation infrastructure slope failures in a changing climate

JH Wilks
*Department of Civil and Building Engineering, University of Loughborough, UK*

ABSTRACT: The changing climate will influence the way the UK transport network performs. An aspect of this are potential changes in the modes and frequency of slope failures, both natural and constructed. Forecasting the future behaviour of infrastructure slopes will allow development of maintenance and management strategies that will result in increased resilience of the of the transport network .

## 1 CLIMATE CHANGE AND TRANSPORT

As the climate changes it impacts many areas of our lives. The UK is dependent on transport for both business and leisure activities. The climate impacts a wide variety of aspects of the UK transport network which are being investigated in a collaborative approach.

As winters get wetter and summers get hotter and drier (Jenkins *et al*. 2009) the climate to which the network's earthworks and natural slopes are subjected is changing and will continue to change. An investigation is underway to forecast the impact of climate change on the incidents of slope failures impacting on the transport network in the future

## 2 FUTURE RESILIANT TRANSPORT NETWORKS (FUTURENET)

Future Resilient Transport Networks (FUTURENET) is a 4 year EPSRC funded project assessing the resilience of the UK transport network in 2050. Collaborative in approach, the project draws on expertise from its partners and stakeholders: the Universities of Birmingham, Nottingham and Loughborough; the British Geological Survey, TRL, HR Wallingford; Highways Agency, Network Rail, WSP and Institute of Mechanical Engineers.

FUTURENET is considering potential modes of failure on the transport network. These will include the social concept of a failed journey, road rutting, rail buckling and earthworks failures. With the aid of a study corridor, each type of failure is being modelled at a detailed level and these models will be combined to produce integrated models of particular areas of the network prone to failures, these in turn will allow assessment of the whole network (Figure 1). The study corridor chosen is between London and Glasgow which covers a wide range of geology and has climate variation within it. The transport networks being considered are road, rail, and air.

As part of the study at Loughborough University, the author is considering slope instability in collaboration with the British Geological Survey. This research project commenced in December 2009.

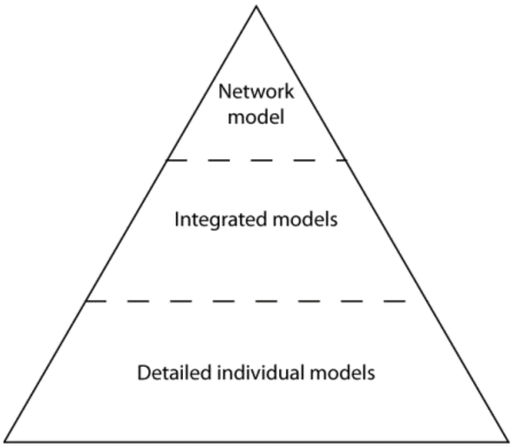

Figure 1. FUTURENET project structure.

## 3 EARTHWORKS ASSETS

The UK has a large network of earthworks (Table 1) which provide the road and rail routes linking the major cities. Rail earthworks are often over a hundred years old stemming from a peak of construction in the late 19th and early 20th century. In comparison, highways earthworks were constructed with the introduction of motorways and hence are now around 50 years old.

| Owner | Route Length (km) | Length of cuttings (km) | Length of embankments (km) |
|---|---|---|---|
| Network Rail | 16000 | 5000 | 5000 |
| Highways Agency | 10500 | 3500 | 3500 |
| London Underground Limited | 400 | 60 | 60 |

Table 1. UK owners of earthworks assets. Source: Perry et al. (2003a; 2003b).

## 4 VULNERABILITY OF TRANSPORTATION INFRASTRUCTURE SLOPES TO FAILURE

The UK transport network earthworks are constructed from a variety of materials, using different construction methods and are of different ages. This variability leads to a complex assessment of potential failure. The geology of the UK is diverse, leading to construction in materials with a variety of properties, generally locally available to the construction site.

When placed, the method of construction and compaction depends upon the construction practices of the time. During the 19th and early 20th centuries many rail embankments were constructed using the 'end-tipping' method with little compaction onto unprepared ground; modern practices, used in modern highway construction, have a much higher level of compaction (Skempton. 1996).

Slopes can fail in several ways. Natural slopes are a product of the environment they were formed in, whereas earthworks are designed for a purpose, but failures do still occur. Failures can be for the first time, where peak strength has been mobilised; or failures can be reactivated along existing planes of weakness.

Slopes are subjected to a seasonal wetting and drying which results in a cycle of pore pressure increase and decrease, and hence cycles of effective stress. The older an earthwork, the more cycles it will have undergone. A series of cyclical changes can contribute towards progressive failure (Potts *et al*. 1997). An extreme seasonal increase in pore water pressure can cause a significant reduction in strength and trigger failure. Time is also a factor in the equilibration of pore pressures following a cutting excavation where delayed failure can occur. The seasonal cyclical pattern of wetting and drying can cause shrinking and swelling of the slope materials, resulting in volume changes and possible serviceability failures

Therefore, the predicted changing climate pattern to have wetter winters and hotter drier summers (Jenkins *et al*. 2009) will increase the magnitude of these cyclical processes and contribute to a changing pattern of infrastructure slope failures. Whilst wetter winters brings more precipitation which could cause a rise in pore water pressure, hotter, drier summers will result in drier slopes at the end of summer, hence these drier conditions will have to be overcome to produce pore water pressure that could trigger failure. However hotter, drier summers could result in cracking of slope surfaces, allowing higher rainfall infiltration rates. This coupled with wetter winters could result in more instances of failure. Hence there is a need to investigate the effect of climate change on slopes.

## 5 RAINFALL TRIGGERED LANDSLIDES

The most common triggering mechanism for landslides is loss of strength through an increase in pore pressure. Pore water pressure increase within a slope can occur from above through rainfall infiltration and percolation, or from below through a rise in a perched water table or the groundwater table (Terlien. 1998).

The amount of rainfall triggering a slope failure is a relatively easy to measure and widely available parameter, which is often used as a proxy to critical pore water pressures in the slope. This, however, neglects the infiltration rate which differs between geologies.

The pore water pressure conditions within a slope prior to a triggering rainfall event is important and several studies consider the critical antecedent rainfall conditions that produce these conditions. In developing a model of earthworks failure, the concept of a triggering threshold is often adopted, above which the conditions exist for failure to occur. This project aims to develop threshold values for potential slope failures on the transport network and to investigate the probability of exceeding the thresholds under predicted climates.

## 6 IMPLICATIONS OF EARTHWORKS FAILURE

The maintenance of earthworks is expensive. In 2007/2008 Network Rail spent approximately £80 million on earthworks; of this approximately 3.5% was spent on inspection, evaluation and assessment processes; of the rest 8.8% was used for emergency and reactive works, but the majority (approximately 87.7%) was used for planned proactive preventative measures (RAIB. 2008).

It is therefore prudent to obtain the best knowledge regarding earthwork assets and their potential to fail, in order that the maintenance is planned and executed efficiently.

## 7 CONCLUSIONS

There is a need for a better understanding of the behaviour of earthworks under extreme weather conditions, particularly in the light of climate change. A fundamental understanding of climate change is that static assumptions are not valid and so, in order to produce models that forecast future slope response, it must be considered that the mechanisms of failure may change.

FUTURENET is investigating the resilience of the UK transport network in 2050 using London to Glasgow as a case study. As part of this, models are being developed that describe the climatic trigger(s) for failure in earthworks and natural slopes. There is a need for understanding of the behaviour of earthworks in the future such that the assets can be managed and maintained in an appropriate manner.

## REFERENCES

Jenkins, G. J., Murphy, J. M., et al. 2009. *UK Climate Projections: Briefing Report.* Met Office Hadley Centre.

Perry, J., Pedley, M., et al. 2003a. *Infrastructure Cuttings-Condition Appraisal and Remedial Treatment.* CIRIA C591.

Perry, J., Pedley, M., et al. 2003b. *Infrastructure embankments–condition Appraisal and Remedial Treatment.* CIRIA C592.

Potts, D. M., Kovacevic, N., et al. 1997. Delayed collapse of cut slopes in stiff clay. *Géotechnique,* 47, 953-982.

RAIB. 2008. *Network Rail's Management of Existing Earthworks.* Rail Accident Investigation Branch, Department for Transport 25/2008.

Skempton, A. W. 1996. Embankments and cuttings on the early railway. *I.C.E. Proceedings, Construction History,* 11, 33-49.

Terlien, M. T. J. 1998. The determination of statistical and deterministic hydrological landslide-triggering thresholds. *Environmental Geology, Springer Verlag,* 35, 124-130.