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28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

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STABILISATION OF FORMER TRUNK ROAD EMBANKMENT USING COMBINED STRUCTURAL AND ECO-ENGINEERING STRATEGIES

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Abstract

Mass wasting events and failures on the earthworks adjacent to trunk roads are becoming more frequent as a result of climate change and increased volume of transport. This paper describes the geotechnical aspects of stabilisation of a 750 m long and up to 55 m high coastal slope in Scotland bisected by a former trunk road with a history if instability and subsidence. Ground investigations, monitoring, specimen and detailed design considerations are discussed in the light of geo-environmental, financial, temporal, sustainability and risk considerations. The geotechnical design had to consider the local and global stability of the slope as well as the effect of potential climate change, land use and traffic volume changes. Additionally, the stabilisation options for the earthworks supporting the road were constrained by the requirements of the local authority and statutory undertakers. The detailed design for landslide and erosion prevention comprised extensive drainage measures and soil nailing designed to be installed within the existing slope surface, utilising an innovative head assembly, recessed within the slope and covered with pre-seeded biodegradable 'grow bags' making them 'invisible', providing a green slope finish, and minimising the visual impact of the works on the natural surrounding. The sustainable use of vegetation for slope stabilisation is highlighted through the use of eco- and ground bio-engineering strategies in the design and construction of stabilisation measures against shallow slope instability and erosion.

Keywords: sustainability, eco-engineering, soil nailing, slope stability, asset management

1 Introduction

A trunk road is a major road, usually connecting two or more places, which is the recommended route for long-distance and freight traffic. In the UK, trunk roads were first defined in the Trunk Roads Act 1936 when the Minister of Transport took direct control of 30 major roads (7,200 km, including bridges). Additional roads were 'trunked' either following the Trunk Roads Act (1946) or after being constructed as such. Trunk roads can be 'de-trunked', e.g. with construction of a motorway following a similar route, and then they become ordinary 'A' roads. The trunk roads in Scotland (currently 3,405 km or 6% of the total road network, carrying 37% of all traffic and 63% of heavy goods vehicles), have been managed separately since 1998. The trunk road and motorway network in Scotland has a gross asset value of approximately £18 billion. It is Scottish Ministers' single biggest asset.

Large number of embankments and cuttings not only on the trunk road network in UK are exhibiting signs of distress because of their age and historical lack of investment in maintenance and repair. The transportation and local authorities who own the assets are faced with decisions on balancing limited funding for maintenance and repair with investment for keeping up with the raising environmental standards and climate changes that threaten the assets'

stability [1,2]. Additionally, the lack of resources and understanding of the wider aspects of road maintenance and repair usually result in poor asset management and increase in the risk of failure of the slopes associated with a road [3, 4].
Slope instability events (landslide, translational slips, erosion) are natural events and can occur above or adjacent to sections of trunk roads. Major instability events such as landslides are most likely to occur during and immediately after periods of very heavy rainfall, especially if the heavy rain follows an extended rainy period. In Scotland, landslides are most prevalent in the periods July to August and October to January [5]. It is of critical importance that good quality information on the asset condition and their behaviour especially immediately before and after an instability event is needed to maintain their sustainability.
Traditional slope instability prevention and mitigation measures involve the use of structural elements and materials such as concrete and steel to provide safety against failure of the slope [3]. Recent trends in civil engineering also consider the use of live or living material for slope stabilisation such as vegetation. This approach, termed eco-engineering or ground bio-engineering [6] is based on a sustainable geotechnical design where the vegetation, apart from fulfilling an engineering function, contributes towards positive environmental and social impact at a relatively low cost.
In this case study, the stability of a former trunk road embankment in Scotland is investigated from the aspect of provision of sustainable geotechnical solution and the considerations informing the detailed design. Environmental and socio-economic aspects of the geotechnical design are outlined and the findings and obstacles associated with the design process are discussed.

2 Case study background and methodology

2.1 Site description and Background

The Bervie Braes comprises a coastal slope which lies immediately to the west of the old harbour in Stonehaven, Aberdeenshire. The Braes extend for approximately 850m and reach a maximum height of 55m. The former trunk road connecting Stonehaven to Dunnottar Castle and A94/A957 road runs sidelong and generally northwest-southeast across the slope, rising from the northwest end towards the at the far south-eastern end where it turns inland (Fig.1). Around 60 residential properties lie towards the toe of the slope with the residents using the vegetated road embankment for pedestrian access to the road and the nearby tourist attractions. The slope profile above the road is made up of a series of hollows, mounds, and bulges which represent washouts from ephemeral springs, failed material and areas of ongoing creep, respectively. The overlapping of old apparently inactive and active areas of slope instability provides the slope with a hummocky appearance.
The geological setting comprises alluvial raised beach deposits of gravel and sands overlying Glacial Till and, locally sands and gravels, of glacial origin. As a result of being on the periphery of a considerable fault (Highland Boundary Fault) the rock strata underlying Bervie Braes (Devonian conglomerates and sandstones) are deformed and reported as being highly inclined over the vast proportion of the Braes and vertical at the south end of the site. A number of ephemeral springs with a distinguishable seepage line exist on the embankment.
The Braes have a history of slope instability which is detailed on Fig 1. After the event of 2009, the local authority who owns the road commissioned a forensic study to determine the relationship between the local groundwater regime, including perched water levels, the locations of weak, sensitive soils and the movement and progressive failure of the road [7]. Based on this study, the specimen and detailed design for a stabilisation solution commenced in 2010.

2.2 Geotechnical design rationale

Structural stability aspect: The geotechnical design had to be based on provision of stability for the slope in both short- and long-term. Additionally, the slope stabilisation solution had to cater for both shallow and deep seated slope instability due to the complex geological setting and the fact that both of them have been observed as failure mechanisms on the slope in the past.

To inform the geotechnical design, a range of ground investigations (GI) were carried out and compared to the results of historic ground investigations on the site. The GI included non-intrusive and intrusive techniques described in detail elsewhere [7]. From these, the ground model including the characteristic values of the soil strength parameters was produced for a number of characteristic cross-sections of the slope. The GI also included the installation and monitoring of vibrating wire piezometers, standpipes and inclinometers. With these, the spatio-temporal characteristics of groundwater levels and movements within the soil mass could be observed and analysed. Potential failure modes were postulated [7] and a number of potential solutions (soil nailing, reinforced earth, retaining wall, drainage and combinations) investigated against the potential construction costs.

Environmental aspects: The environmental aspects informing the geotechnical design included consideration of the effects of the water and vegetation. Groundwater, on the other hand, was identified as the major cause of potential deep seated slope instability and had to be managed together with the surface water that would cause erosion or shallow slope instability. Hydrological and hydrogeological studies were carried out in order to ascertain if the amount of surface and ground water which is protected in the area [8] that would potentially have to be drained from the slope and discharged either into the existing surface water network or directly into the sea. This was followed by a video and geophysical survey of the existing drainage along and adjacent to the road which revealed disjointed pipes, blockages and a number of level and size irregularities which did not feature in the records of the local authority or the utilities company.

Year	Event	Consequence	Action
1958	Major slip above the south pier of the harbour	Collapse of a road section	Anchored sheet pile wall installed
1980s	Slope failure at far north-western end	Major damage to residential property	Debris cleared, damage reinstated
1992	Distortion of the carriageway surface	Cracked pavement	Temporary single carriageway operation introduced
1993		Localised bulging of the slope and development of longitudinal cracking along the footpath on the embankment	Permanent closure of road in one direction (uphill)
1994	Slope failures above and below the road due to heavy continuous rainfall over a period of four days	Road blockage	Debris cleared; full road closure between February and July
2009	Surface washouts and mud flows at the south-east end (circled); major slip at the far north-western end	Undermined road embankment; major damage and abandonment of residential property	Full road closure; forensic study commissioned

Figure 1 Satellite and historical aerial view of Bervie Braes (source Google Maps), together with an overview of historical slope instability events

The road embankment is part of the Stonehaven Conservation Area and major changes to the existing environment including the aesthetics are not permitted. To establish the baseline environmental conditions, ecological and dendrological surveys were undertaken. The ecological survey did not find evidence of protected species on the slope but noted that the trees and shrubs present on the slope host bird nests during the nesting period and construction should avoid this period. It was also noted that large parts of the slope are covered by seasonal vegetation which often leaves the ground exposed during the winter. The dendrological survey revealed relatively low variety of trees of low value on the slope which are liable to overturning.

Socio-economic aspects: The local authority who owns the road since it has been de-trunked consulted with Stonehaven Community Council who voted for the most acceptable stabilisation solution. This was important because the residents are one of the major groups that use the Braes for recreational purposes or access. Access was important for the residents as it brings tourists to Stonehaven while visiting the War Memorial (0.5 km south of the Braes) and Dunnotar Castle (3 km south) but also because this road is one of only 3 providing access to the town and the other two also are also threatened by slope stability problems. It should be noted that approximately 500 people live in the properties at the toe of the slope and have been at immediate risk of slope instability which motivated them to participate in the consultation. The majority of residents voted for the soil nailing solution for both the upper and lower slope, preferring full re-opening of the road after stabilisation.

After the events of 2009, the Scottish Government provided a grant which when combined with the funds available to the local authority could not provide stabilisation of the whole slope as voted for by the residents. A risk analysis resulted in a strategic decision to stabilise only the most critical sections of the road embankment leaving the slope above the road in its present condition [9].

3 Results – detailed geotechnical design

The detailed design was guided by the stability principles placed within a sustainability framework. Deep seated instability required stabilisation and anchoring into the more competent, deeper soil horizons while the short-seated instability required retention and protection of the ground surface. These objectives were achieved by designing soil nails toeing in the Glacial Till with concrete head assembly that would retain the more erodible sands near the surface (Fig.2). This structural solution also ensured the long-term stability of the slope with a design life of 120 years.

In the area that exhibited most distress and failure in the past (Fig 1 circled, inset), the carriageway was designed to be excavated together with the road base and subgrade down to beyond the failure surface and replaced with locally sourced suitably compacted material over which the new road base and wearing course will be constructed. With this, the design ensured that the risk of settlements due to internal erosion and washout of the subgrade will be significantly decreased.

The short-term stability of the soil around the soil nails which is exposed to erosion from surface water was ensured by the innovative design of the head assembly which is recessed into the slope and covered with bio-degradable bags containing soil and selected grass seeds. Additionally, the slope was hydroseeded after the completion of the soil nailing works with a selected mixture of seeds of native grass and herb species. This design, based on evidence and experience [6, 10] envisaged that the grass roots will grow quickly, reinforce the top layer of the soil while using water with their roots and thus provide protection against shallow seated instability.

Water as the major factor that potentially could cause slope failure was controlled by installation of raking drains near the toe of the slope whose function was to drain excess groundwater and discharge it, together with the surface water from the slope, into a contour drain channel running along the toe of the slope and discharging into a piped drain that runs along the existing surface water drain and discharges in the open sea at levels that would ensure self-cleansing but also protection from flooding. New road drainage system was designed to capture the surface water from the slope above the road and thus limit the amount of surface water that could potentially reach and erode the road embankment. The drainage systems were designed with sustainability and resilience in mind with an increase in peak water quantities due to the effects of climate change taken into account.

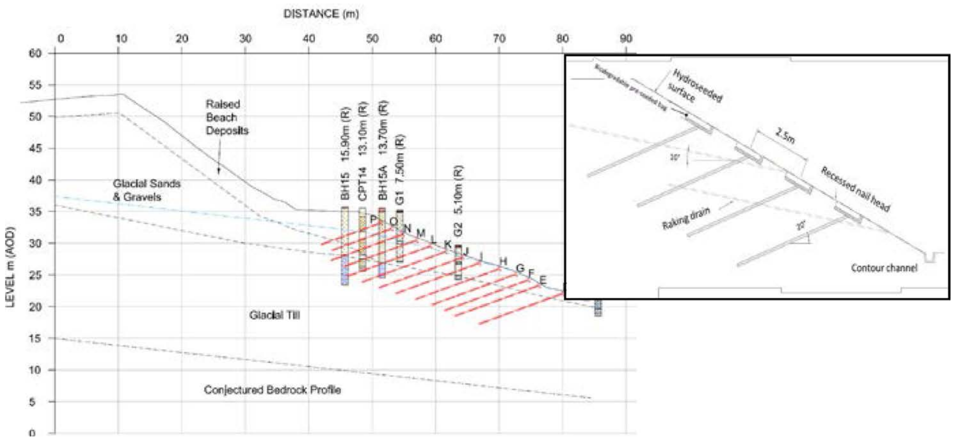

Figure 2 Detailed design of slope stabilisation measures: soil nailing with 'green' surface finish due to recessed soil nail head assembly. Drainage measures such as raking drains and contour channel (inset) also part of the detailed design

Another aspect of sustainability in the design was the requirement to cut the existing trees which were at risk of infection or failure and replace them with native species which will in long-term perform an engineering function such as soil reinforcement and water extraction form the soil with evapotranspiration. Additionally, the design envisaged planting of new 120 trees of native species to increase the biodiversity, provide wild bird habitat and increase the vegetation cover over the areas which could be exposed in the winter.

The detailed design considered the socio-economic constraints and specified phased construction in order to ensure partial access to the Braes for the residents and tourists with the choice of construction method left to the contractor in order to finish the construction within the set time period which, in turn, coincided with the non-nesting period for the birds. The design and specification were formulated using an innovative approach where the contractor was stimulated to achieve savings during the construction which are then used to procure more stabilisation works [9].

4 Discussion

The case study showed that the geotechnical design could not be disassociated from the wider environmental and socio-economic milieu. Although the close connection between geotechnics and sustainability exited in the past, only few studies have been published on sustainable design showcasing good (or bad) practice and increasing the profile of the profession [10]. It is hoped that this study will contribute towards the motivation of the geotechnical engineers to publish on the subject and actively work and collaborate in increasing the impact of sustainable geotechnical design.

The geotechnical design for this study was complex and time consuming. The complexity was demonstrated through the subtle interplay between structural stability issues and sustainability issues. While the structural issues could be resolved by numerical modelling and analysis, they required a number of parameters as an input which originated outside the strictly geotechnical domain. Parameters such as groundwater levels, precipitation patterns and quantities, creep movements required longer-term monitoring in order to reveal patterns and allow selection of critical values as an input into the geotechnical model or analysis. During the time these parameters were monitored, the risk of failure of the embankment and potential damage to life and property had to be managed by avoiding access to the slope and remote monitoring, almost real-time analysis of the remote monitoring data and issuing warnings to the residents and tourists. This process required resources and planning in addition to the investment for the equipment. However, the safety of the public and employees was very important for the local authority and the designer and the investment into the monitoring and warning system was negligible when compared to the cost of stabilisation works. Such system may be used on a temporary basis [4, 5] where risks can be calculated and a procedure exists for management of different levels of risk.

The approach of combining non-intrusive and intrusive GI was beneficial for the design as it provided good coverage of the site and correlation between the mechanical and physical properties of the soils on site. Proper planning of the GI within the budgetary restraints was critical as very little relevant historical data existed despite the history of failures on the site and the number of investigations carried out in the past. A shortcoming of this approach was the data resolution: a stonemasonry structure supporting the road in the most distressed section was not detected by the GI and caused problems and minor delay during construction. Similarly, geophysical survey was not able to clearly show a number of services running very closely together which, again, caused problems during construction. This issue could be efficiently resolved by combining the geophysics with video surveys where possible (as it was done with the drainage runs in this case study) but caution should be exercised when interpreting them together.

An interesting point was that vegetation was found to have a stabilising effect on the slope while back-analysing the existing conditions [7]. This encouraged the eco-engineering considerations in the geotechnical design and designing with vegetation which will perform some engineering function in the short- or long-term [6]. This approach contributed towards more lean and resilient design and also improved the aesthetics and ecological diversity in the conservation area. While recommending this approach, it should be noted that it should be followed by regular inspections and monitoring in order to ensure both engineering and environmental functions of the vegetation are performed.

The socio-economic constraints resulted in risk based design and an innovative use of NEC3 for procurement of stabilisation works with a limited budget [9]. The design and the coverage of the stabilisation measures had to be curtailed to within the budget limits which meant the areas with the highest risk of failure on the embankment supporting the road were stabilised first. This approach allowed good coverage of stabilisation measures on the embankment but left the upper slope in its existing state and several areas on the embankment without any stabilisation measures which still pose a risk of failure.

While the financial constraints dictated the magnitude of the works [4], it was the public who actually selected this remedial option which may not have been the most financially viable. In similar cases in the future, it may be interesting to question and record the motivation and concerns of the public when making such a decision as well as the way the options are presented to them. In the future, it may be more appropriate to assess and manage the risks using risk registers with quantified risks of failure and identification of criticality in order to provide a more solid basis for prioritisation and investment.

Lastly, the availability of critical information for the design was of great importance in this study. Although a number of studies with different foci were carried out on the site in the past 20 years there were no systematical inspection, maintenance or repair records available. The availability of such records and the easiness of access to them would have sped up the design process and decreased the number of assumptions made which, in turn would have resulted in lowering the factors of safety and getting more form the limited budget [3,4]. During the current study, new information was revealed and all the changes were recorded in a systematic way; however, the questions remain over the management and update of this data in the future within a modern asset management system [1,3].

References

[1] Meyer M.D., Amekudzi, A., O'Har, J.P.: Transportation Asset Management Systems and Climate Change, Transportation Research Record 2160, pp. 12-20, 2010.

[2] The Scottish Executive: Scottish Road Network Climate Change Study, eds. R.M. Galbraith, D.J. Price & L. Shackman. The Scottish Executive, Edinburgh, 2005.

[3] UKRLG Highway infrastructure asset management: UK Roads Liaison Group 2013.

[4] Fwa, T. & Farhan, J.: Optimal Multiasset Maintenance Budget Allocation in Highway Asset Management, J. Transp. Eng., 138(10), pp. 1179–1187, 2012.

[5] Transport Scotland: Scottish Road Network Landslides Study – Implementation, eds. M. Winter, F. Macgregor & L. Shackman. TS, Edinburgh, 2008.

[6] Norris, J.E., Stokes, A., Mickovski, S.B., Cammeraat, E., van Beek, R., Nicoll, B.C., Achim, A. (Eds.): Slope Stability and Erosion Control: Ecotechnological Solutions, Springer, pp. 290, 2008.

[7] Currie, C., Murdoch, W., Sallis, D., Smith, M.: Forensic investigation of a failed road at Bervie Braes, Stonehaven – models and mechanisms. In: Forensic Engineering – From Failure to Understanding, B. Neale (ed.), Thomas Telford , London , pp. 325-334. 2009.

[8] Natural Scotland: The river basin management plan for the Scotland river basin district 2009–2015, The Scottish Government, 2009.

[9] Mickovski, S.B., Black, J.D., & Smith, M.J.: Innovative use of ECC (NEC3) for procurement and management of infrastructure projects with limited funding: Bervie Braes case study In: Procs 29th Annual ARCOM Conference, 2-4 September 2013, Reading, UK, eds. S.D. Smith & D.D. Ahiaga-Dagbui, Association of Researchers in Construction Management, pp. 799-808, 2013.

[10] Mickovski, S.B.: Why is the future ready for environmental geotechnics?, Environmental Geotechnics [Accepted for publication], 2014.