

Geotechnical Asset Data to Enhance Road Network Resilience

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Abstract

Transport Scotland is responsible for the 3,739 km Trunk Road and Motorway Network (TRN) in Scotland. Contained within that are extensive earthworks and other geotechnical assets. The consequences of climate change present major hazards to Scotland's transport infrastructure including floods and landslides, which, in turn, present major risks. Climate projections for the next 30 years, indicate that the hazards and impacts are currently seen are likely to escalate. A managed adaptation of these assets is required, not least to ensure that they are sufficiently resilient to ensure we maintain a transport system that is safe, reliable, and resilient. This includes the specific targeting of geotechnical and drainage and environmental hazards to ensure that adjacent slopes are stabilised where necessary, that third-party slope instability is managed, surface water controlled, and the potential for flooding is reduced. Identifying the locations of vulnerable assets and environmental hazards, reviewing the effectiveness of management and maintenance processes, and developing appropriate adaptation, and hazard and risk reduction measures is essential to the avoidance of undue and increased failure and associated disruption and risk. In recognition of the challenge of climate change and the consequent need for adaptation and enhanced resilience at asset, route and network levels, work is ongoing to address the above issues using a data-led approach. In this paper we will report on ongoing work to: assess the impact of climate change on our geotechnical assets, and outline the current technical approach to managing and maintaining such assets. This paper sets out the background to this need.

Keywords: Geotechnical, Geohazards, Assets, Data, Management.

1. Introduction

The consequences of climate change present major hazards, including floods and landslides, to Scotland's transport infrastructure. Such infrastructure is vulnerable to these hazards, and therefore major risks are presented to the operation of the network. Projected climate trends show future impacts are likely to be more severe than experienced to date. Further, the UK Climate Change Risk Independent Assessment (CCRA3, 2021a) identifies seven key climate risks that relate to transport infrastructure, many of which directly relate to geotechnical assets. Therefore, a managed adaptation of the assets is required, not least to ensure that the transport system is maintained and is sufficiently safe, reliable and resilient.

Scotland's transport infrastructure networks are fundamental to our nation's communities, businesses, and visitors. They offer critical connections between people and places and are vital in providing access to economic opportunities and vital services. The 3,739 km Scottish Trunk Road Network (TRN) is one of the most critical transport networks and is illustrated in Figure 1.

Road infrastructure geotechnical assets (e.g. retaining walls, strengthening systems, embankments, and cuttings), are often viewed as secondary, ancillary or 'child' assets in the portfolio. While this view recognises their essential function in supporting the primary assets (e.g. the road pavement) it could be argued that it fails to recognise their fundamental role in ensuring the resilience and accessibility of the TRN. While drainage and the effects of flooding are being taken forward under separate arrangements, the important link between the performance of geotechnical assets and the provision of adequate drainage must be borne in mind.

Building on the Scottish Road Network Landslides Study (SRNLS) (Winter et al. 2005; Winter et al., 2008) and the Scottish Road Network Climate Change Study (Galbraith et al., 2005), the National Transport Strategy (NTS2) (Transport Scotland, 2020) committed to taking climate action, including adapting the transport system to the impacts of climate change.

In this context, there is a need to specifically target geotechnical assets on the TRN to ensure that their maintenance is subject to targeted procedures that are underlined by an in-depth knowledge of their behaviour,

condition and performance. This would allow a proactive approach to preventative maintenance to be adopted, rather than the present reactive approach to asset failure.



Figure 1: Map of Scotland's Trunk Road Network, depicting Operating Company (OC) areas and DBFO Agreements.

This will help to ensure that consequential risks are minimised by:

- stabilising adjacent earthworks slopes where necessary,
- ensuring the stability of the earthworks on and in which our pavement assets are constructed, and of other geotechnical assets that support the pavement, structures and earthworks assets,
- addressing third party, natural slope instability as necessary.

Identifying the locations of vulnerable geotechnical assets, reviewing the effectiveness of our management and maintenance processes, and developing appropriate adaptation, and risk reduction measures is essential to the avoidance of undue and increased failure, and associated disruption and risk. Work is ongoing to:

- Assess the impact of climate change on geotechnical assets, their adaptation and resilience, and Transport Scotland's approach to addressing such impacts.
- Review the current technical approach to managing and maintaining our geotechnical assets, including the collection of asset register data and the technical approach to managing and maintaining geotechnical assets.
- Review the role of the management of geotechnical assets in the context of the current approach while seeking opportunities for improvements that will enable a more effective and proactive response to potential failures of the asset.

2. Climate Change

Key changes to Scotland's climate are highlighted in the bullets below and in Table 1 (CCRA3, 2021b):

- Scotland's 10 warmest years on record have all occurred since 1997. The average temperature in the last decade (2010-2019) was 0.69°C warmer than the 1961-1990 average, and the warmest year on record was 2014.
- There has been an increase in rainfall over Scotland in the past few decades (with an increasing proportion of rainfall coming from heavy rainfall events). The annual average rainfall in the last decade (2010-2019) was 9% wetter than the 1961-1990 average, with winters 19% wetter.

• Mean sea level around the UK has risen by approximately 1.4mm a year from the start of the 20th century.

It is important to understand that these predictions are based upon potential increases in the global temperature anomaly and are probabilistically based, emphasizing the uncertainty that is inherent in the resulting forecasts.

Table 1. How the climate could change in the future based on UKCP18 probabilistic projections (central estimate for 30-year average change in each variable from a 1981-2000 baseline) (Source: CCRA3., 2021b).

	2050s	2050s	2080s	2080s
	RCP2.6 (50 th	RCP6.0 (50 th	RCP2.6 (50th	RCP6.0 (50 th
	Percentile)	Percentile)	Percentile)	Percentile)
Annual Temperature	+1.1°C	11.0°C	+1.1°C	+2.0°C
Summer Rainfall	-7%	-6%	-12%	-16%
Winter Rainfall	+7%	+7%	+7%	+13%
Sea Level Rise (Edinburgh)	+12cm	+18cm*	+23cm	+54cm*

* CP8.5 scenario, as for marine projections this is closer to a +4°C global warming scenario.

In addition to these temporal changes, the spatial variation of climate and consequently weather also needs to be considered.

Although climate models are not best suited to predicting storm events, the available evidence for climate change does point to an increase in such short duration, high intensity rainfall events, even in summer (Winter et al., 2019).

While precipitation is the dominant factor in influencing geotechnical failure and geohazard triggering or initiation, higher temperatures and winds can also have an influence through, for example, soil drying and cracking. These factors were, for instance, specifically highlighted as modes that could allow rapid inundation of water and the rapid onset of instability in the SRNLS (Winter et al., 2005; 2008).

3. Climate Impacts

The CCRA3 (2021a) identifies seven key risks, which are, in the current context, sources of risk, or hazards, from climate that relate to transport infrastructure including those related to flooding and erosion, slope and embankment failure, and subsidence. The transport system and its networks regularly face challenges from weather related impacts, which as a result of climate change are projected to increase. This reiterates the need for additional adaptation and resilience to avoid an increase in costly disruption and loss of service on transport networks.

The relatively long lifespan of transport infrastructure assets in relation to climate changes must be considered for existing and new infrastructure. This will be important as Scotland moves toward Net Zero emissions, presenting an opportunity to build climate resilience into future infrastructure.

These changes to climate clearly signal the increased potential for instability and landslides, for example. While the increased hazards are likely to exhibit the greatest increases in the winter months, when the land is already saturated and unable to adsorb any further water, the SRNLS (Winter et al., 2005; 2008) and successor documents particularly highlighted the increase in such hazards as a result of drier summers.

The impacts of climate change are already seen to cause significant delay to road users as a result of landslides, and fluvial, pluvial and coastal flooding. The coastal floods experienced on the A78 are significant and lead to diversions of significant length as well as damage to the ageing infrastructure. Such effects are forecast to increase, and increased traffic will exacerbate their effect. This is readily demonstrated by considering the A83 Rest and be Thankful. Up until 2014 the event frequency was around 0.9/year with a typical magnitude of less than 1,000m³ (Winter & Wong, 2020) whereas current evaluations suggest that in 2020 the total amount of debris that reached the road was around 20 times that in any previous year.

Drainage assets provide a vital function, including supporting the effective shedding of water from and removal of water within geotechnical assets, however the TRN has been impacted by floods, for example, for approximately 200 days in the past three years with restrictions/closures affecting Scotland's economic output.

While the effects of climate change are manifest, the current situation, even without such consideration, indicates that action to mitigate hazards and improve the TRN is required.

An unpublished study by AECOM found that the number of routes with the highest level of vulnerability to flooding will more than double by the 2030s. Without significant investment in drainage assets these figures are likely to increase significantly. Analysis of the available climate and climate change trends along with their impacts suggest that landslide hazards and risks are also likely to increase considerably (Winter et al., 2010; Winter & Shearer, 2013).

As part of the climate change adaptation process it seems likely that additional investment in the operation and maintenance of trunk roads and bridges will be required. This will help in the mitigation of the key risks associated with the previous baseline investment levels.

Current design standards generally include an allowance for the effects of climate change, but these allowances are unlikely to be sufficient for the future changes. This report helps to inform changes to design, specification and construction to accommodate the likely future changes in climate. It should be noted that this process is one that requires constant review.

4. Adaptation and Resilience

More investment will be needed to ensure that projected increases in, for example, heavy rainfall are factored into maintenance, adaptation, and longer-term renewal programmes. Additional adaptation actions were proposed by CCRA3 (2021a) including data-led monitoring, inspection, analysis and characterisation programmes; greater use of 'soft' engineering techniques; and enhanced drainage capacity. Such actions are particularly relevant to geotechnical assets and geohazards that are particularly vulnerable to the action of water and therefore to the effects of increased rainfall, whether by runoff and erosion, infiltration and strength reduction, or the action of flood water.

It is widely accepted that improving resilience constitutes both increasing the ability of infrastructure to withstand potential threats and also the capability of the system to rapidly recover from disruptive events and Figure 2 defines the four components of resilience. Of the four essentials for resilience, redundancy applies to the network as a whole resistance, or physical robustness, reliability, or the ability to operate under a variety of conditions, and recovery, the ability to respond to and recover from disruption, are most relevant to geotechnical assets and geohazard events.

The importance of resilience, and the potential negative effects of a lack of resilience, on infrastructure and its availability for use are exemplified at a conceptual level in Figure 3. The effects of changing event patterns are illustrated in Figure 3, for successive events for which a constant magnitude is assumed for clarity. While Figure 3 is conceptual, it clearly illustrates that when the time required for recovery is less than the recurrence interval events it is straightforward to maintain the resilience of the infrastructure at a constant level and opportunities are even available to increase the resilience (Figure 3, top). However, as the frequency of events increases, and the recurrence interval decreases towards the recovery time then opportunities to increase resilience are removed and it becomes possible only to maintain the current level of resilience (Figure 3, middle). Ultimately, as the frequency of events increases, the recurrence interval becomes less than the time needed for recovery the level of resilience cannot be maintained and resilience decreases over time (Figure 3, bottom).

The change in the recurrence period, allied with increased event magnitude, at the A83 Rest and be Thankful has been such that the situation is threatening to become one of reduced resilience and much larger scale actions are planned with a new route currently in procurement. In addition, larger scale actions where hazards, and especially risks, are extreme, such as at the A83 Rest and be Thankful, where a new route is proposed through Glen Croe, will need to be considered where appropriate.

One of the purposes of this work is to begin the process of assessing need and placing values and costs on the required interventions to increase the resilience of the TRN through a managed adaptation plan applied to the geotechnical asset base and to set the scene for prioritisation of these actions. It is Transport Scotland's responsibility to ensure the network is fit for the future with adaptation to the climate emergency and increased resilience playing a key part. The route from adaptation to resilience through Transport Scotland's key activities is shown in Figure 4.

Transport Scotland's asset management practices include the asset register, which is regularly reviewed and updated, tools and techniques for identifying and planning works that provide best value for money, procedures for assessing and mitigating risk, and tools and techniques for assessing the short (one to three year) and long term (up to 20 years) maintenance needs of the TRN.



Figure 2. Components of resilience (after Reeves et al. 2019 based on Roads Liaison Group, 2016).



Figure 3. Changing resilience potential in the light of the relation between event frequency, or recurrence interval, and the time required for recovery, from a series of events of the same magnitude (adapted from Reeves et al. 2019, Milne et al. 2016 and Dijkstra & Dixon, 2010).



Figure 4. Adaptation whether through maintenance and renewal, new construction or other opportunities leads to increased resilience. *Opportunities allows for those interventions that are beneficial to the TRN independent of climate change but that may receive a higher priority due to their wider benefits.

The Transport Scotland asset register is well-developed but, in the case of geotechnical assets, some work is required to ensure that is adequately populated facilitating further work within the new Asset Management Performance System (AMPS).

The TRN depends on geotechnical assets, including earthworks, for resilience. The division between geotechnical assets and structures is rather indistinct, and for good reason; many such assets whose behaviour and performance are governed by geotechnical principles fulfil a structural function. The primary purpose of classifying such assets as geotechnical, structural or both is to ensure that the correct expertise is brought to bear in the inspection, management and maintenance regime.

The behaviour and performance of earthworks is complex, and other geotechnical assets are particularly complex, and the determination and prediction of their condition is similarly so. This complexity is reflected in the most important long-term asset management objective of ensuring that the asset is:

- managed and maintained such that its condition remains fit-for-purpose,
- the deterioration is detected and quantified, and
- that intervention occurs prior to failure.

Such proactive responses, in advance of failure, can avoid reactive or responsive interventions and the associated unplanned disruption and other risks associated with failure.

Guidance on achieving effective adaptation for resilience is relatively thin on the ground. Indeed, it is important that asset adaptation works retain a strong focus of network and infrastructure resilience. A number of studies have outlined the vulnerabilities of, and risks to, various infrastructure (e.g. Willway et al. 2008; Milne et al. 2016) while others have attempted to define the current level of resilience (e.g. Reeves et al. 2012) and the costs of increasing the resilience of assets (Reeves et al. 2013). Relatively few studies have developed practical guides to incorporating and enhancing resilience in road networks but Reeves et al. (2019), for example, offer such guidance at a strategic level while Winter (2014) and Winter (2016) demonstrate the functional approach to resilience from a strategic risk reduction perspective.

It is only relatively recently that studies have begun to emerge that illustrate at a practical level how resilience might be achieved. Reeves et al. (2018), for example, illustrate this as part of a wider project funded by the World Bank for the mains roads company of the Federation of Bosnia & Herzegovina (JP Ceste).

In this context it seems highly likely that guidance will need to be provided to Transport Scotland's Operating Companies and other agents to ensure that full value is achieved from adaptation interventions. Such guidance should not be prescriptive but indicate the framework and form of adaptation measures that are considered to provide acceptable levels of increased resilience. Such guidance should draw upon successfully implemented examples from the TRN and the wider national and international context and consider design, specification, maintenance and operation of geotechnical assets and especially focus on their interaction with drainage.

5. Vulnerable Locations

In order to facilitate the adaptation of the TRN to climate change the Transport Scotland Approach to Climate Change Adaptation and Resilience (ACCAR) will, as the name suggests, inform and implement the direction of travel and define both the focus on directly controlled infrastructure and services and provide recommendations on areas where influence can be exerted, and leadership provided on decision-making within the wider sector.

The purpose of the ACCAR is as follows:

- Review Transport Scotland's current climate change adaptation and resilience activities, through identification and baselining of on-going work across all modes.
- Provide recommendations on how to further enhance adaptation and resilience across the Transport Scotland portfolio.
- Set the strategic direction for adaptation and resilience activity for Transport Scotland and outline supporting actions for those areas where we have an influence and/or can provide leadership.
- Enable the establishment of an appropriate and proportionate governance structure to oversee adaptation and resilience activity within Transport Scotland.

It is envisaged this work will outline the current position and provide recommendations on how to progress adaptation and resilience activities for the Transport Scotland portfolio. However, it is not intended that it will set out a plan or programme of specific actions for individual directorates. The Vulnerable Locations Group (VLG) was set-up to drive Transport Scotland's strategic approach to climate change and adaptation. The Vulnerable Locations Operations Group (VLOG) is, in turn and as the name suggests, to implement the direction(s) determined by the VLG on the Trunk Road Network.

This work in in progress with a number of sites having been identified and proposals are in development to allow their further assessment, remediation and adaption to provide enhanced local and network resilience.

6. Summary

Geotechnical assets fulfil an essential function in supporting the primary assets, such as the road pavement, as well as playing a fundamental role in ensuring the resilience and accessibility of the TRN. This role, while already of critical importance, will become more crucial as climate change increases the pressures on such assets.

Transport Scotland currently operates an effective asset management regime that is primarily focussed on pavements, structures and ancillary assets. If the challenge of adapting the TRN to ensure adequate resilience is to be met, then a greater focus on geotechnical assets will be required.

An effective approach will need to fully recognise the interactions between geotechnical and structures assets, and between geotechnical and drainage assets. Collaboration between those responsible for each asset type will need to be fostered in order to ensure that, for example, both the structural and geotechnical aspects of retaining walls are catered for and that the drainage of slopes is adequately assessed.

The new asset management tool, AMPS, allows information from structures, drainage and geotechnical assets to be combined with flood and landslide susceptibility, hazard and risk, and historic flooding and landslide events – once the geotechnical asset data is populated. This will enable a significant step forward in terms of identifying vulnerable, or at risk, areas and assets and ranking those risks in order to provide an effective prioritisation for adaptation to achieve greater asset and network resilience.

At present sites and features in need of major adaptation due to their major potential adverse impact on the safe, reliable, and resilient operation of the TRN are in the process of being identified and plans developed to take forward specific actions.

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