

A Geotechnical Resilience Assessment Framework for England's Strategic Road Network

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Abstract

National Highways would like to make better informed decisions on the requirement for geotechnical interventions on the Strategic Road Network. This arises from the need to enhance the resilience of geotechnical assets against a likely increase in events associated with climate change. This supports the organisation's aim to ensure its roads are more dependable, durable, safe, and serviceable. It also aligns with objectives in the company's licence, which includes the requirement to "Adapt its network to operate in a changing climate, including assessing, managing and mitigating the potential risks posed by climate change to the operation, maintenance and improvement of the network".

To ensure a consistent approach, decisions to improve resilience should be made within a framework that provides decision makers with reliable information. Through the Arup/AECOM consortium, National Highways has developed a Resilience Assessment Framework for use alongside its existing geotechnical processes. The framework sets out a staged approach to risk and resilience assessment and adaptation, so that the organisation can better manage and mitigate the impact of ground-related hazards.

This paper provides an overview of the Resilience Assessment Framework. It focusses on the risk-based assessment of resilience and aims to provide the organisation with a better understanding of its *existing* ability to anticipate, resist, absorb, and recover from geotechnical events. It also considers decision making around resilience measures to *improve* the organisation's ability to adapt to events. Outputs may be used to determine actions to eliminate, manage and/or communicate risk levels. Actions are then prioritised and implemented based on urgency, appropriateness and the effect on residual risk and the resulting resilience.

Keywords: Resilience, Risk, Climate Change, Geotechnical Assets, Geotechnical Events

1. Introduction

National Highways, formerly Highways England, was created from the Highways Agency in 2015 as the government owned company responsible for the operation, maintenance, and improvement of England's Strategic Road Network (SRN). The SRN comprises about 36,000 lane-kilometres of motorways and main arterial roads and over 13,500 kilometres of geotechnical assets (National Highways, 2022). The term geotechnical asset describes the major and minor earthworks, including cuttings, embankments, and bunds, where major and minor are defined by a limiting height of 2.5 metres (Highways England, 2020a).

National Highways aims to manage asset risk effectively, considering the whole life of the asset and making efficient use of resources to undertake timely interventions that optimise cost, risk, and performance. The organisation manages its geotechnical assets in line with its broader approach to asset management (National Highways, 2022) through the Design Manual of Roads and Bridges standard, CS 641 Managing the maintenance of highway geotechnical assets (Highways England, 2020a), and through its Geotechnical Asset Class Strategy (Shires et al, 2022).

2. Geotechnical asset management in National Highways

The organisation undertakes regular principal inspections on all its geotechnical assets, using trained and experienced geotechnical professionals, to proactively identify defects and predict the likely consequences of geotechnical events, in terms of location and criticality. The results of these inspections are collated and managed, alongside other geotechnical information, within National Highways' geotechnical records repository and asset management system, Geotechnical & Drainage Management Service (GDMS) (Daly et al, 2020).

The geotechnical information in GDMS is used alongside local knowledge and engineering expertise to identify the need for, and determine the nature of, geotechnical interventions. These might be as little as an increased inspection frequency or visual monitoring, or they may involve a more physical presence, such as temporary traffic management or engineering based preventative, or remedial, construction works (Highways England, 2020a). A summary of completed and planned geotechnical activities, including inspections, monitoring, and interventions, is provided with a description of known ground-related hazards and any geotechnical events that have occurred, within a Geotechnical Asset Management Plan (GeoAMP). These reports are developed on a regional basis and are updated annually.

Although National Highways' geotechnical decision-making processes are based on robust information and seem to have been effective to date, the company would like to make *better* informed decisions on the requirement for geotechnical interventions. This arises from the need to enhance network and asset resilience against geotechnical events associated with the changing climate, which is tied to its commitments to the UK government, to road users and to the taxpayer.

3. The need for a resilient Strategic Road Network

Resilience is a term that is used in many disciplines and consequently there are many definitions of resilience (Hickford et al, 2018). In infrastructure, engineering and geotechnics, the term is used to describe the integrity of assets and networks, but also extended to the organisational management processes that exist to allow those components to operate effectively. In many definitions of resilience there are several common principles: anticipate; absorb; recover; and adapt, and these principles form the basis of the definition of resilience used by the Cabinet Office (2011) and used in the context of this paper.

Resilience is "The ability of assets, networks and systems to anticipate, absorb, adapt to and/or rapidly recover from a disruptive event"

National Highways' government licence, issued by the Secretary of State (Department of Transport, 2015), recognised the need for a resilient network, stating that "...the licence holder should take all reasonable steps to ensure the continued availability and resilience of the network...". The licence also recognised the role of climate change in resilience, stating that the holder should "Adapt its network to operate in a changing climate, including assessing, managing and mitigating the potential risks posted by climate change to the operations, maintenance and improvement for the network".

In 2018, the government tasked the National Infrastructure Commission (NIC) with exploring the necessary steps to make the UK's infrastructure more resilient to future challenges. Their study noted that although UK infrastructure has broadly been able to withstand shocks and stresses in recent years, it would be prudent to prepare for new problems, which may be more severe than anticipated. The NIC's report (2020) presented a framework for resilience (Figure 1) and set a timeline for infrastructure operators to implement a series of actions based around improving resilience.



Figure 1: The National Infrastructure Commissions' framework for resilience (2020).

Since 2015, National Highways has sought to improve the resilience of geotechnical assets to weather and climate change related geotechnical events through investment in a series of research and development activities. These have been undertaken through two programmes of work that have been aligned with the wider organisational requirements and the emerging national policy, i.e., the Geotechnical Resilience Programme (between 2015 and 2020) and the subsequent geotechnical Climate Change Adaptation Programme (since 2020).

4. The impact of climate change on geotechnical asset performance

When compared to other asset owners and other transport networks in the UK, National Highways has experienced relatively few geotechnical events in recent years (Figure 2), i.e. a total of 36 geotechnical events have been reported through GDMS within the last 10 years. However, geotechnical events are often preceded by defects, and studies have shown a causal link between drainage related problems and geotechnical defects. Specifically, 74% of National Highways' geotechnical defects have been shown to be a result of either a lack of drainage infrastructure or the poor performance of it (Lane et al, 2020).



Figure 2: Some geotechnical events that have occurred on the SRN in the last 10 years include a denehole on the M2 (top left); a washout failure on the M4 near Bradfield (top-right); solution features on the A38 near. Ashburton (middle-left); a rockfall on the A590 north of Ulverston (middle-right); a rockfall and debris slide on the A259 near Winchelsea (bottom left) and shrink-swell induced pavement cracking on the A27 between Lewes and Eastbourne (bottom right).

Other recent research, undertaken though National Highways' geotechnical Climate Change Adaptation Programme, has developed a series of deterioration models for highway geotechnical assets and then applied uplift factors representing climate change predictions. These models show a significant increase in the predicted number of new defects per year, rising from 97 in 2020 to somewhere between 152 and 229 in 2080 (Power et al, 2022), and demonstrate a clear need to adopt a resilience framework for UK highway geotechnical assets.

5. The Resilience Assessment Framework

To ensure a consistent approach across the SRN, decisions to improve resilience need to be made within a common framework that provides decision makers with access to clear, accurate, timely, and reliable information. Through the Arup/AECOM consortium and using stakeholder feedback from the wider Geotechnical Resilience and geotechnical Climate Change Adaptation Programmes, National Highways has developed a Resilience Assessment Framework for use alongside its existing geotechnical standards, processes, and tools.

The framework sets out a two-staged approach to risk and resilience assessment and adaptation (Figure 3), to allow the organisation to better manage and mitigate the impact of ground-related hazards (Arup/AECOM, 2020a & 2020b). It has been designed to be used at either a regional scale, at a link scale, e.g., between 2 or more junctions along a route, and/or at an asset scale. It assists in the understanding of risks from geotechnical events, in terms of performance and considers preparedness as an extra measure to identify and prevent additional threats. Finally, the framework informs adaptation and recovery, in the occurrence of a geotechnical event, to facilitate a return to usual asset and network services. Each stage of the process is informed by an input, or a series of inputs, and results in an output that is used to either inform subsequent actions or better inform and improve earlier stages in the process.

5.1 Part 1: Assessment of current resilience

Part 1 of the Resilience Assessment Framework focusses on the risk-based assessment of resilience and aims to provide the organisation with a better understanding of its *existing* ability to anticipate, resist, absorb, and recover from geotechnical events.

The steps in this initial part of the process are outlined as follows.

- 1. <u>Define performance objectives</u> Once spatial and temporal limits are set, an assessment is undertaken to define National Highways' requirements for the part of the network or asset(s), based on the timeframes being considered. This may be informed by information sources such as the Roads Investment Strategy (RIS), other strategies and strategic business plans, as well as local knowledge.
- 2. <u>Hazard identification</u>, where "hazard" is defined as a source of potential harm, loss or failure (Highways England, 2018) This stage includes the identification and description of ground-related hazards that have the potential to impact on performance. It may be informed by local geological knowledge and experience and should include a review of desk-based information such as GeoAMPs, hazard maps, hazard guidance notes, and geotechnical asset inventory and condition information available through GDMS. Descriptions should include a summary of the magnitude and rate of onset of a hazard event, determined by the hazard type, previous events, inspection and monitoring records, and local or regional environmental conditions. Where information is not available, knowledge gaps, assumptions and levels of confidence should also be recorded.
- 3. <u>Risk estimation</u>, where "risk" is defined as the *product of the likelihood of a disruptive event occurring and the consequence it would have* (Cabinet Office, 2011). Risk may be assessed either qualitatively or quantitatively, recognising uncertainty, and decisions should typically be cautious where levels of uncertainty are high or where information is lacking. This assessment may be informed using geotechnical risk matrices and registers, such as those in Highways England (2020b), where;

Risk = Likelihood x Consequence

- <u>Likelihood</u> is defined as the *potential for an event to occur*. The assessment of likelihood should consider hazard properties and characteristics, legacy issues, existing mitigation measures and potential triggers, including weather related triggers that may be exacerbated by climate change.
- <u>Consequence</u> is defined as *the outcome of an event affecting objectives* (British Standards Institution, 2018). The assessment of consequence should consider the type of assets affected,

including non-geotechnical assets, their vulnerability or degree of harm/damage and criticality, as well as that of the network proximate to the assets affected. The critical loss or partial loss of an affected asset is assessed in terms of cost, safety, delays, and environmental factors, whereas network criticality is assessed in terms of the route importance, along with the potential damage to highway and other services and businesses (including reputational damage). Potential sources of information might include experience, government safety statistics, environmental and network mapping, traffic records (e.g., average annual daily flow), and agreed diversion routes.

4. <u>Ability to respond</u> – The organisation's ability to respond to and recover from the consequences of the hazard event should be determined. This will be informed by resources and knowledge such as emergency response plans, the availability of resources (e.g., personnel, equipment, plant, and materials), diversion routes, monitoring, network and crisis/disaster management plans, severe weather plans etc. The ability of the organisation to respond to a hazard event will influence the consequence and it may be appropriate to reassess the consequences to determine residual risk and inform future decision making (in Part 2).



Figure 3: The Resilience Assessment Framework is divided into two parts, with Part 1 focussing on the assessment of current resilience, and Part 2 focussing on the assessment of options to improve resilience.

5.2 Part 2 Assessment of options to improve resilience

Part 2 of the Resilience Assessment Framework considers decision making around resilience measures and the way that those measures are planned and implemented, to *improve* the organisation's ability to adapt to events.

The necessary steps in this next part of the process are as follows.

- 5. <u>Risk evaluation</u> Part 1 of the framework comprises an assessment of the current residual risk level, for each ground-related hazard considered and for each area or asset assessed. This informs the need to implement additional measures, or other actions to reduce, control and/or communicate risk levels.
 - <u>Risk acceptability</u> is the level of risk that an organisation will tolerate, and it will depend on statutory requirements, e.g., to reduce risks as low as is *"reasonably practicable"* (HM Government, 1974), and the expectation of its stakeholders, including national and local governments and those of its users. Risk acceptability can be defined using thresholds and descriptions to categorise or classify risk and determine the need for action, in a similar way to those used in traditional geotechnical risk registers (Highways England, 2020b).
 - <u>Temporal change in risk</u> is an important consideration in risk evaluation. There are several factors affecting the likelihood or consequences of an event occurring, which are more susceptible to change than others. Those that should be reviewed regularly include the effect of climate change on the frequency of weather-related triggers and the effect of deterioration on the condition of a geotechnical asset. Deterioration may also affect the magnitude of a geotechnical event and the rate at which it occurs, as well as the resulting degree of damage or harm. Similarly, the availability of resources relating to mitigation measures, such as personnel, plant, equipment, and diversion routes, will affect the organisational ability to respond to events and consequently the residual risk level. Other factors are less likely to change regularly, such as asset and network criticality, although they should still be reviewed periodically.
- 6. <u>Identification of potential actions</u> Traditional approaches to risk mitigation often focus on actions to eliminate reduce or control risk and these may include inspections and interventions when certain thresholds are reached. A resilience-based approach takes this a step further and considers other actions such as the development of communication plans, response and recovery planning, and adaptation and learning. Actions should align with the Cabinet Office (2011) model, which defines the components that need to be considered in building infrastructure resilience (Figure 4). These four components have also been adopted by the UK Road Liaison Group (2016)



Figure 4: The Cabinet Office (2011) components of infrastructure resilience (from Reeves et al, 2019)

These four components are outlined in the context of this Resilience Assessment Framework below.

- Resistance represents the prevention of the hazard event or engineering of assets and systems to withstand events without causing harm, damage or disruption. This could include the reconstruction or regrading of an earthwork or the installation of a special geotechnical measure, such as a slope reinforcement or drainage.
- Reliability defines the ability of the affected asset to function as required during a hazard event, even in a deteriorated condition. Actions to determine reliability include inspections and monitoring, to provide a warning of changes in asset condition to limit the impact on performance.
- Redundancy is the ability of a road network to function without the affected asset, possibly with a reduced level of performance. An example of redundancy could be providing additional lanes of traffic or ensuring diversion routes are in place. In some locations it might not be possible to provide redundancy due to spatial constraints, for example.

• Response and recovery

The Resilience Assessment Framework also adopts the hierarchy of interventions used by New Zealand's national highway authority in their Resilience Response Framework (Waka Kotahi NZ Transport Agency, Unknown). This sets out a series of response categories ranging from acceptance (alongside monitoring), through improvements in preparedness, reduction through maintenance or improvements, to the prevention/removal or avoidance of resilience risks.

- Accept (monitor)
- o Preparedness
- Reduce (maintain or improve)
- Prevent/remove/avoid
- 7. <u>Resilience based decision making</u> Outputs from the earlier stages of the Resilience Assessment Framework are used to determine a long-list of actions to eliminate, reduce, manage and/or communicate risk levels. These are then prioritised based on urgency; appropriateness in terms of network criticality, potential road-user disruption, resources (including cost and time); the combined effect on residual risk; and the resulting enhancement of the resilience of assets and/or the road network to geotechnical events. The prioritisation exercise should determine if an action needs to be implemented in the short-term, long-term or if it is not currently required. Given the inherent uncertainty in risk management over time, it might be necessary to make decisions for different scenarios and schedule further decision points in the future. Planning for climate change requires a move away from traditional planning approaches and the use of adaptation pathways can help to consider multiple future scenarios.
- Plan and implement prioritised actions are then planned, to minimise disruption to existing operations, within the constraints of the budget, to maximise safety, environmental and socio-economic benefits. Residual risks should be communicated to stakeholders and actions should support existing processes, e.g., the scheduling of principal inspections, other geotechnical interventions and the production of GeoAMPs and the management of geotechnical risk (Highways England, 2020a & 2020b).
- 9. <u>Ability to adapt and learn</u> Adaptation and learning through feedback loops (shown in Figure 1) is an essential part of this and other processes, particularly given the uncertainty in climate change predictions and the uncertainty in risk management. Following the first use of the Resilience Assessment Framework, the process should continue to be used proactively, with a frequency that will depend on the residual risk levels. It may be necessary to assess some types of hazard event more regularly than others. As a minimum, the assessment should be reviewed as part of the annual GeoAMP production process.

6. Next steps

The Geotechnical Resilience Assessment Framework was produced as a series of documents and implemented in the summer of 2020, for use in the 2020/2021 and subsequent GeoAMPs. Its role has since been formalised through its inclusion in National Highways' (2022) Geotechnical Asset Class Strategy. National Highways is implementing an Asset Management Transformation Programme, which has made increasing the maturity of the Resilience Assessment Framework an objective.

Feedback on its application, from Geotechnical Maintenance Liaison Engineers, Asset Needs Managers and other users, will be crucial in determining its place within the established suite of mandated geotechnical processes. The upcoming review of geotechnical standards within the Design Manual for Roads & Bridges, currently scheduled to begin in late 2023, will need to place greater emphasis on the need for asset and network resilience in the changing climate. The inclusion of the Resilience Assessment Framework within mandatory standards should form part of that update.

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