Engineered Rock Slopes Hazard on the Strategic Road Network of England

This guidance note is intended for non-specialists of ground-related hazards and describes the potential for Engineered Rock Slopes to impact the safety and performance of the Strategic Road Network (SRN). Together with the Slope Hazard Rating map and Rock Slope Hazard Index map, plus corresponding hazard assessment notes on Highways England's Geotechnical Data Management System / Geographical Information System (HAGDMS / HAGIS), the products support effective management of the Engineered Rock Slopes risk to the network.

This guidance note does not replace the need for local and site-specific assessment by Highways England's geotechnical specialists.

How to use this guidance note:

Part I: provides an overview of Highways England's risk management of Engineered Rock Slopes hazards
Part II: outlines steps in the risk management framework to enhance the network resilience to Engineered Rock Slopes
Part III: provides further background information specific to Engineered Rock Slopes, its relevance to the SRN, and key sources of reference

Part I Highways England's approach to managing Engineered Rock Slopes risks

Areas adjacent or in close proximity to Engineered Rock Slopes are susceptible to impacts caused by the failure of the slopes. Engineered Rock Slopes have usually been formed by cuts through surface rock formations. The background of Engineered Rock Slopes and their impact on the SRN is summarised in Part III.

A separate hazard guidance note is available for Engineered Soil Slopes.

The risk presented by Engineered Rock Slopes is not new to Highways England. Any new assessment of the risk should make due consideration of the following factors:

- At the time of construction of the SRN or at the time of undertaking improvement schemes, Engineered Rock Slopes and related risks should have been investigated and mitigated appropriate to the standards or advice that applied at the time. Where available, relevant records are held in HE's geotechnical database held on HAGDMS.
- The Geotechnical Risk Management procedures were introduced in the 1990s. Specifically, *HD22 Managing Geotechnical Risk* was first published within the *Design Manual for Roads and Bridges* (DMRB) in 1992. It is therefore reasonable to assume that for schemes post 1992 there is an improvement in the reliability of information captured and retained, along with increased standardisation in investigation, design, and mitigation methodologies across schemes.
- A Rock Slope Hazard Index (RSHI) evaluation was carried out in 2011 for Engineered Rock Slopes nationally. The assessment represents the most detailed assessment of rock slope condition to-date.

Rockfall on M6, Lune Gorge, 1997. Source: HAGDMS

Rockfall damages road sign. Source: Unknown

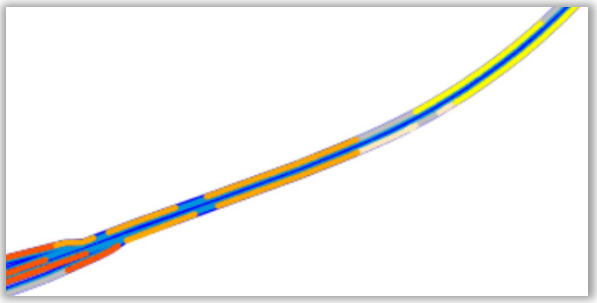
1.0 Current ground risk management requirements:

HD22/08 (DMRB Volume 4) presents a framework for geotechnical risk management and is a mandated requirement on all highway schemes where a ground investigation or geotechnical design is required. It establishes the principles of early risk identification and continuity of the geotechnical risk register through the project life cycle from concept to handover.

HD41/15 (*Maintenance of Highway Geotechnical Assets*) provides guidance on the identification and management of 'At Risk Areas' including those of potential Engineered Rock Slopes related risk. Consideration of the hazard posed by Engineered Rock Slopes to the existing SRN should form a part of the GeoAMP (Geotechnical Asset Management Plan) process. The GeoAMP is prepared by the Operations service provider, reviewed on an annual basis (at a timeframe agreed with Highways England), and is submitted for agreement by HE.

For guidance on the application of current requirements please refer to the Advice contacts below.

2.0 The Highways England rock hazard maps



Section of the Slope Hazard Rating map (2017)

Two HE specific hazard maps have been produced:

- the Slope Hazard Rating map* – includes both rock and soil slopes for a generalised slope assessment
- the Rock Slope Hazard Index map – based directly on the specialist Rock Slope Hazard Index assessment (RSHI)

These maps can be accessed on HAGDMS and their derivation is explained in detail in the hazard assessment notes available on the HA GDMS download page.

The maps are intended as high level hazard awareness maps only. **They do not replace the need to seek expert advice** from within Highways England and undertake site-specific studies. As noted above, consideration of Engineered Rock Slopes along with all other ground-related hazards is an inherent part of risk management within Highways England's geotechnical standards.

3.0 Further advice

To obtain further advice on the hazard Engineered Rock Slopes poses to the Strategic Road Network, or for any other issues associated with ground-related hazards, please contact one of the Geotechnical Advisors available within Highways England's Geotechnics and Pavement Group.

Role of Highways England's Geotechnical Advisors:

- Technical oversight of schemes, to ensure the technical input is appropriate, complies with HE standards and delivers good value.
- Cascading local knowledge and good or bad experiences from other projects
- Evaluating and supporting innovation opportunities to promote efficient delivery.
- Providing asset data and information management services.
- Managing knowledge improvement for the geotechnical discipline, including Standards and Advice Notes and supporting Integrated Asset Management in Highways England.

* The latest version of the Slope Hazard Rating map should be used. Superseded versions will continue to be available on HAGDMS for reference only.

Part II Using the Slope Hazard Rating map and the Rock Slopes Hazard Index map to enhance resilience of the SRN

Resilience of the Strategic Road Network comes from both adequate design and maintenance, mitigation of hazards, and having appropriate response and recovery measures in place should the hazard occur. Selection of appropriate mitigation (proactive, pre-event) measures versus response and recovery (reactive, post-event) cannot be prescriptive, but the guidance below can be used to support risk-based decision making.

1. Define the hazard event

A hazard 'event' can be defined as '*the event that could occur due to the presence of the hazard*'. The following are different hazard events related to the presence of Engineered Rock Slopes along the SRN, and these present different risks to the network:

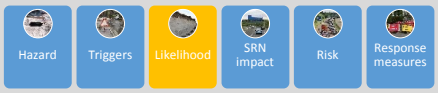
- Incursion of rockfall / vegetation mantle material onto carriageway – potential obstruction and damage
- Subsidence of part or all of a carriageway, structure or other asset
- Impact damage to structures and above-surface SRN asset due to rockfall / falling slope debris

2. Consider potential external triggers of the hazard event

There may be little or no warning immediately prior to an Engineered Rock Slopes failure, but if specific triggers have been identified, these can be monitored to improve the management of the risk. The following are potential external triggers of an Engineered Rock Slopes hazard event:

- Freeze-thaw cycles
- Weathering and erosion
- Degradation / loss in performance of any stabilisation measures such as rock bolts and anchors (also see the Aggressive / Corrosive Soil and Groundwater hazard guidance note)
- Vegetation issues e.g. root action or wind forces on trees anchored to the slope

Note that the above weather related triggers may be exacerbated by climate change.



3. Assess the likelihood of the hazard event occurring

The *hazard rating* given on the Slope Hazard Rating map and the RSHI categories given on the Rock Slope Hazard Index map are not absolute indicators of the likelihood of a hazard event occurring, but a relative condition indicator of the slopes, compared to the rest of the network. It should also be noted that the slope hazard rating is not directly comparable to hazard ratings derived for other hazard types.

To undertake a qualitative assessment of the likelihood of a rockfall, the following factors are relevant:

(A) The inherent likelihood of an Engineered Rock Slope failure

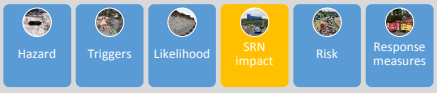
- Refer to the Slope Hazard Rating map and the Rock Slope Hazard Index map
- Evidence of movement (e.g. monitoring or any evidence recorded in Geotechnical Asset Database – GAD, or in Geotechnical Asset Management Plans for known rockfall areas)
- Poor slope condition / low inherent stability as indicated a geotechnical slope examination (HD 41/15) or Rock Slope Hazard Index (RSHI) – for slope-specific indication of condition
- Age of slope - supplementary condition indicator where a geotechnical examination is not available or not recent

(B) Presence of any mitigating / exacerbating features

- Presence, condition and effectiveness of slope improvement / stabilisation measures – as installed during construction / maintenance of the SRN or by third parties
- Size (height / volume) of slope and distance of slope from the SRN – to indicate the context and proximity of the carriageway relative to a potential landslide, and the likelihood that a rockfall would interact with the road network

(C) Indicators that a triggering action (as listed in Step 2: Triggers) is likely to occur

- Observed / forecast periods freezing temperatures
- Observed / forecast heavy or prolonged rainfall
- Water/wastewater pipes in poor condition, e.g. aged or damaged through construction-induced ground movements, such that they may leak
- Presence of service ducts or poorly compacted backfill – granular backfills may act as a localised source reservoir (if exposed at the surface / have connectivity with other water sources)
- Blocked / insufficient / absent drainage



4. Consider the potential impact on the safety and/or performance of the SRN

A quantitative assessment of impact on a national scale is not possible. Note that rock slope failures are considered to represent a greater likelihood of impacting on safety due to the common location above and adjacent to the highway. At a local level, the following factors should be considered to understand the potential impact:

(A) Factors specific to the hazard event:

- The rate of failure and the amount of warning available – a rapid, catastrophic event presents the highest safety consequence.
- The size of the potential failure – a large failure presents a much higher safety risk to potentially many more users of the network than a small one would. Estimation of failure size requires local consideration and expert input.

- The location of the potential failure, and slope geometry – the slope angle, height affects and hardness of material the lateral horizontal travel of debris. Where material reaches a main running lane it presents both higher safety impact, and higher performance impact than one that affects a hard shoulder / remote from the carriageway.
- Consideration of potential investigation and remedial works – the longer these could take, the longer the performance impact.
- The serviceability and effectiveness of any control measures such as nets and ditches to limit the consequence of any falling material.

(B) Factors specific to the location of the hazard event on the network:

- The speed and volume of traffic using the road – where higher it typically correlates to an increased safety impact.
- The type of pavement – a sudden/catastrophic failure is more likely where there is loss of support beneath by a rigid pavement whereas a flexible pavement show early signs of a failure (where rock slope supports the SRN)
- The type of road – smart motorways being the most important in terms of performance, down to All Purpose Trunk Roads (APTR) being the least.
- Presence of technology – smart motorways could be assumed better able to respond to an event in terms of traffic management.

5. What is the risk (considering likelihood and impact) that Engineered Rock Slopes presents to the SRN?

This can be qualitatively assessed, and should inform subsequent decision making. Uncertainty should be recognised and decisions should typically be cautious, particularly where there are high levels of uncertainty (or lack of data).

6. Select appropriate measures to mitigate risk and enhance resilience

Measures taken to mitigate risk and enhance resilience may be either proactive or reactive. Typically, the greater the safety or performance risk to the SRN in terms of both likelihood and impact of an event, the greater the benefits of undertaking proactive mitigation. When selecting appropriate measures, there should be early engagement with Geotechnical Specialists from Highways England, service providers and land owners (where the slope is outside the SRN boundary).

High level risk management measures are likely to be specific to both the hazard event and whether it is a construction and/or on-going operations risk, but all measures would fall into one of the following categories:

- **Investigation:** To understand the current condition and therefore likelihood of the hazard event. Investigation may reduce the uncertainty and hence reduce the need for additional mitigation measures.
- **Intervention:** Where there is an evident cost-benefit in implementing measures (barriers) to prevent the hazard event from occurring, or mitigating measures to limit the impact should it occur.
- **Monitoring:** To allow appropriate operational responses to be implemented in anticipation of a potential hazard event.
- **Response and recovery:** To respond rapidly to a potentially unexpected hazard event, development of response plans is recommended for areas of known Engineered Rock Slopes risk. Response plans should include:
    i. Engagement with Highways England technical specialists – named focal points (and responsibilities) should be clearly identified.
    ii. Identification of third party land owners where the slope is located outside the SRN boundary, or that will be potentially impacted should an HE-owned slope fail. Also procedures for gaining access where required to third party land.

iii. Being prepared to close lanes and/or implement diversions, and have an understanding of the potential duration of these measures until the SRN may be fully operational – this includes a broad range of communications, such as Highways England's suppliers, road users and the general public. These should be linked to Incident Response Plans (IRPs).

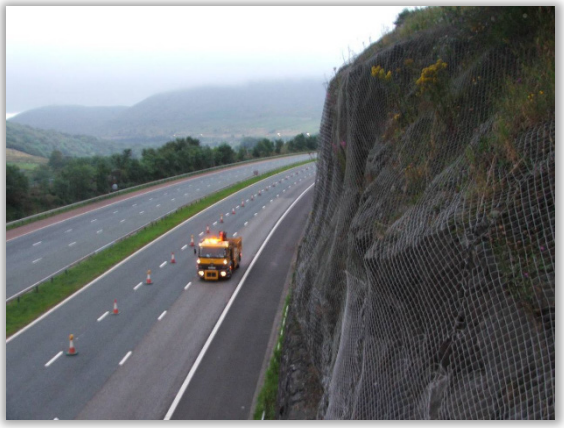
iv. Likely response options should be identified – based on the particular hazard events and anticipated consequences. The time and resources that would be required to implement the options should also be considered.

v. Incident recording – following initial recovery, a full record of the mitigation works (as part of Health and Safety file recording), the cause of the event assessed, the risk of similar events occurring elsewhere on the network evaluated, and appropriate actions taken to manage the incident should be recorded. All geotechnical events must be recorded on HAGDMS. Note that the origin of rock slope hazards may be on 3rd party land.

Part III An overview of Engineered Rock Slopes in England

1.0 Engineered Rock Slopes

Engineered rock slopes along the road network are typically formed by cutting through surface or near surface rock formations. The rock cut is either self-stable against a design factor of safety or is stabilised through specific measures such as tension rock anchors or spraying shotcrete on the surface. This earthwork type is distributed along the SRN but primarily concentrated in the northern part of the country.



Rock Face south of Jeffrey's Mount, M6. Source: HAGDMS

HAGDMS presents two maps relevant to the hazard posed by Engineered Rock Slops:

- the Slope Hazard Rating map
- the Rock Slope Hazard Index map

The Slope Hazard Rating map is based on an analysis that has been carried out into the performance of the major geotechnical assets of Highways England, both rock and soil. The latest available version of this map should be used as it will reflect the most current analysis; however, HAGDMS also retains previous versions of the map for historical reference only (e.g. the 2014 map is available but is superseded.) The derivation of the Slope Hazard Rating is based on the slope shape and geology. This is explained in detail in the Slope Hazard Rating data description note on HAGDMS.

The Rock Slope Hazard Index map presents the results of a Rock Slope Hazard Index (RSHI) examination carried out in 2011, as described in the accompanying data description note. The RSHI examination is a detailed inspection of a rock slope and can provide a good indication of slope condition. It has been used previously by HE to aid geotechnical engineers assess the appropriate level of resilience management and maintenance regime. However, the examinations were carried out as a one-off exercise only, and so there is a risk that the results no longer reflect current condition. Therefore, the Rock Slope Hazard Index map may be used as a guide to support an assessment of condition and likelihood of failure, alongside the Slope Hazard Rating map that is based on more recent but less detailed slope data.

2.0 Engineered Rock Slopes and the Strategic Road Network

The hazard posed can be considered to arise from the potential for Engineered Rock Slopes failure on the Highways England estate with the potential to impede the highway, damage assets or cause injury. These hazards could be present due to:

- inadequate design and/or stabilisation methods (compared to current practice/guidance), which may correlate to the age of the slope
- the stabilisation measures or barriers employed have deteriorated since works were undertaken (e.g. chemical, groundwater or surface flooding) or have reached the end of their serviceable life

The risk that the presence of Engineered Rock Slopes that are susceptible to failures presents to the SRN is directly related to the size of the failure (e.g. size of the fallen rock) and its proximity to the network.

3.0 Key references and further information

Rock Slope Hazard Index map, 2017, HAGDMS / HAGIS

HAGDMS Rock Slope Hazard Index data description, 2017

Acknowledgement and contact details

This work has been informed by two tasks currently being undertaken as part of HE's Innovation Programme: Task 1-085 *Resilience enhancement measures for geotechnical assets* and Task 1-062 *Geotechnical Hazard Knowledge*.

For further information, queries or comment please contact David Patterson david.patterson@highwaysengland.co.uk