Aggressive / Corrosive Soil and Groundwater Hazard on the Strategic Road Network of England

This guidance note is intended for non-specialists of ground-related hazards and describes the potential of Aggressive / Corrosive Soil and Groundwater to impact the safety and performance of the Strategic Road Network (SRN). Together with the Corrosive (ferrous) and Sulfate and Sulfide maps and corresponding hazard assessment note on Highways England's Geotechnical Data Management System / Geographical Information System (HAGDMS / HAGIS), the three products support effective management of the Aggressive / Corrosive Soil and Groundwater 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 Aggressive / Corrosive Soil and Groundwater hazards
Part II: outlines steps in the risk management framework to enhance the network resilience to Aggressive / Corrosive Soil and Groundwater
Part III: provides further background information specific to Aggressive / Corrosive Soil and Groundwater, its relevance to the SRN, and key sources of reference

Part I Highways England's approach to managing Aggressive / Corrosive Soil and Groundwater risks

The potential presence of naturally occurring aggressive soil and/or groundwater introduces a chemical hazard to the SRN as materials, structural elements and assets can become corroded or damaged. The background of Aggressive / Corrosive Soil and Groundwater and its impact on the SRN is summarised in Part III.

Concrete that has been affected by sulfate attack

The risk presented by the distribution of Aggressive / Corrosive Soil and Groundwater 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, Aggressive / Corrosive Soil and Groundwater 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 Highways England's geotechnical database held on HAGDMS.
- The Geotechnical Risk Management procedures were introduced in the 1990s. Specifically, *CD 622 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.

1.0 Current ground risk management requirements:

CD 622 (formerly HD22/08) 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.

CS 641 (formerly HD41/15) '*Maintenance of Highway Geotechnical Assets*' provides guidance on the identification and management of 'At Risk Areas' including those of potential Aggressive / Corrosive Soil and Groundwater related risk. Consideration of the hazard posed by Aggressive / Corrosive Soil and Groundwater 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 Highways England.

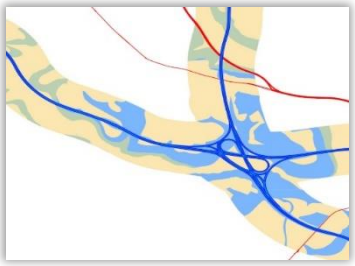
For guidance on the application of current requirements please refer to the Advice contacts below.

2.0 Aggressive / Corrosive Soil and Groundwater mapping

There are currently two map layers available on HAGDMS that show the susceptibility of the network to Aggressive / Corrosive Soil and Groundwater. These include the following layers, as part of the British Geological Survey's BGS Civils engineering properties datasets package:

- **Sulfate and sulfide** – an assessment of the presence of oxidising materials in the uppermost 2m of natural ground. The derivation of this map by the BGS is explained in detail in a hazard assessment note available on the HAGDMS download page: *BGS Civils: Sulfate/Sulfide data description.*

Section of the Sulfate and Sulfide map



Section of the Corrosivity (ferrous) map

- **Corrosivity** – an assessment of the corrosivity of the natural ground to ferrous materials. The derivation of this map by the BGS is explained in detail in a hazard assessment note available on the HAGDMS download page: *BGS Civils: Corrosivity data description*.

These map layers can be found in the HAGDMS mapping legend at *Base mapping* > *British Geological Survey* > *BGS Civils*. Both layers are for a 1km corridor around the Strategic Road Network.

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 to undertake site-specific studies. As noted above, consideration of Aggressive and Corrosive Soil and Groundwater 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 Aggressive / Corrosive Soil and Groundwater 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.

Part II Dealing with Aggressive / Corrosive Soil and Groundwater 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.

The Resilience Assessment Framework, developed by Arup (2020a and 2020b), can also be used to help you inform this part of the assessment. This is available on HAGDMS through 'Help>Downloads>Geotechnical Supporting Documents', and is provided in two parts, that include:

- Resilience Assessment Framework: Part 1 – Assessment of current resilience.
- Resilience Assessment Framework: Part 2 – Assessment of options to improve resilience.

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 Aggressive / Corrosive Soil and Groundwater beneath the SRN, and these present different risks to the network:

- Deterioration and corrosion of the materials of SRN assets or structural components (e.g. foundations, earthwork materials, pavement, steelwork, pipes and utilities) – also see other hazard guidance where there is reliance on the effectiveness of intervention works (measures such as soil nailing) that are potentially affected by corrosion.
- Ground heave – caused by the growth of pyrite/thaumasite crystals

2. Consider potential external triggers of the hazard event

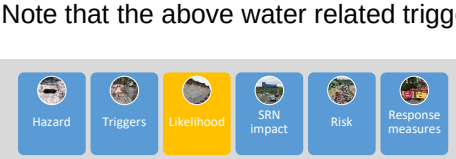
There may be little or no warning of an Aggressive / Corrosive Soil and Groundwater-related event, particularly with buried features, but if specific triggers have been identified, these can be monitored to improve the management of the risk. The following are potential external triggers of an Aggressive / Corrosive Soil and Groundwater hazard event:

- Development of a corrosive or aggressive environment and the proximity of vulnerable materials – such as sulfides combined with anaerobic conditions adjacent to buried concrete containing dolomitic limestone aggregate
- Development of an oxidation environment of pyrite/thaumasite

In general, the development of environments needed for the above chemical environments relates to the mobility of the naturally occurring minerals and the presence of water. The following events may therefore be considered exacerbating triggers:

- A surface flooding event
- Leakage from nearby water mains, sewerage or drainage
- Groundwater regime change (refer also to the Groundwater Flooding hazard guidance note)

Note that the above water related triggers (surface or groundwater, flooding etc.) may be exacerbated by climate change.



3. Assess the likelihood of the hazard event occurring

The *hazard rating* given on the Corrosive (ferrous) and Sulfate/Sulfide maps are not an absolute indicator of the likelihood of a hazard event occurring, but a relative indicator of the potential presence of Aggressive / Corrosive Soil and Groundwater, compared to the rest of the network. The Sulfate/Sulfide and Corrosive (ferrous) rating are not directly comparable to hazard ratings derived for other hazard types.

To undertake a qualitative assessment of the likelihood of deterioration and corrosion of the SRN, the following factors are relevant:

(A) The likely presence of Aggressive / Corrosive Soil and Groundwater

- Corrosive (ferrous) and Sulfate/Sulfide maps.
- Local evidence of corrosion / chemical-related attack
- History of corrosion / chemical-related repair maintenance
- Winter maintenance policy and use of salting or de-icing technologies
- Proximity to mine workings (and mine water), landfill or a coastal environment

(B) Presence of any mitigating / exacerbating features

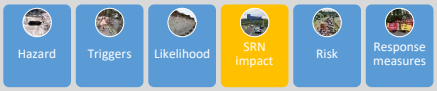
- Age or construction/maintenance records of the SRN – indicative of the types, current effectiveness (including age degradation) and completeness of any investigations and measures undertaken to identify and treat adverse chemical environments, and selection of appropriate materials for resistance to chemical attack
- Use of pyritic material as fill – thereby introducing the risk of potential sulfate crystal growth

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

As most chemical attack on construction materials requires a degree of moisture, these are predominantly considerations of transport mechanisms of potentially aggressive groundwater to the site / level of vulnerable SRN assets or components:

- Recent / forecast heavy or prolonged rainfall
- A history of flooding (including groundwater flooding)
- Blocked / insufficient / absent drainage
- Water/wastewater pipes in poor condition, e.g. aged or damaged through construction-induced ground movements, and may leak or cause local flooding

An understanding of the likelihood of an Aggressive / Corrosive Soil and Groundwater hazard event occurring may also be assessed from historical records and frequency of similar problems on the strategic road network and the surrounding area. Regional strategies are available in some areas.



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, but at a local level, the following factors should be considered to understand the potential impact:

(A) Factors specific to the hazard event:

- The rate and extent of corrosion or deterioration and the amount of warning available – a rapid, catastrophic event presents the highest safety consequence.
- Consideration of potential investigation and remedial works – the longer these could take, the longer the performance impact.

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

- The type of SRN element affected – the safety impact of a corrosion-induced element failure will depend on the role of that element and the consequences of its failure. Corrosion of a soil nail may lead to a sudden slope failure, whereas corrosion of barrier fencing would have minimal to no safety impact.
- 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 Aggressive / Corrosive Soil and Groundwater 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 and service providers.

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 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. Note that evidence may be from inspections undertaken for other assets e.g. Structures and Pavement Surveys.
- **Response and recovery:** To respond to a potentially unexpected hazard event, development of response plans is recommended for areas of known Aggressive / Corrosive Soil and Groundwater risk. Response plans should include:
    i. Engagement with Highways England technical specialists – named focal points (and responsibilities) should be clearly identified.

ii. 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).

iii. 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.

iv. 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.

Part III An overview of Aggressive / Corrosive Soil and Groundwater in England

1.0 Soil and groundwater chemistry

Particular soil / groundwater chemistries can be 'aggressive' to materials used within the SRN environment, causing corrosion or deterioration. In recognition of this, the BGS has available for purchase within its suite of geological engineering properties maps (the 'BGSCivils bundle') the following:

- The 'Corrosivity (ferrous)' map
- 'The Sulfate / Sulfide potential' map

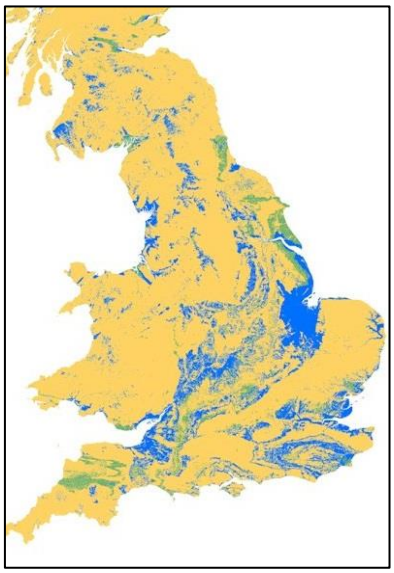
For iron / steel, the Corrosivity (ferrous) map (see below, left) presents the results of a national assessment to categorise which geographical areas would be more prone to corrosion. The assessment is based on a scoring methodology of the following combination of factors: water content, redox status, pH, sulfates/sulfides and electrical resistivity.

Concrete corrosion – subjected to sulfate (thaumasite) attack

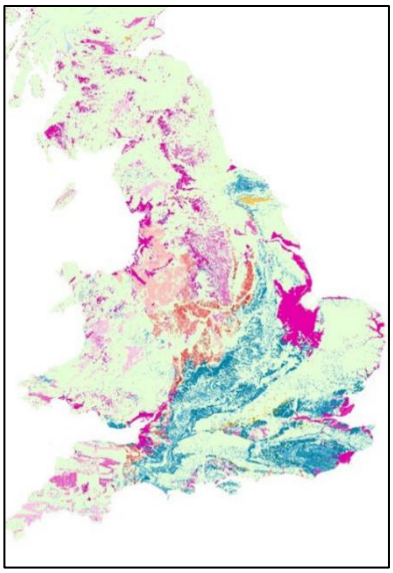
For concrete / cement, the presence of Sulfate/Sulfide formations map (see below, middle) indicates the likely presence of sulfur in soil and rocks which can give rise to aggressive ground conditions and associated concrete expansion and softening. It has been standard in the UK for over sixty years to design concrete to be resistant to these conventional attacks, however in the late 1980s deterioration of concrete due to thaumasite sulfate attack was also identified. This can occur in cases where anaerobic conditions are combined with concrete that contains carbonates e.g. calcium carbonate aggregates or bicarbonate dissolved in groundwater.

A further hazard linked to sulfur-rich minerals such as pyrite (iron sulfide) is crystal growth. In aerobic conditions, sulfides can oxidise to form sulfates and the associated volume expansion can become significant – sulfate crystals can push up and through concrete as they grow.

The maps shown are potentially useful to indicate where there is a particular soil / groundwater chemistry hazard along the SRN. These maps are available on HAGDMS, for a 1km corridor for the entire SRN.



Corrosivity: Blue shows a higher likelihood of corrosive conditions. Source: BGS Civils Database: Corrosivity (Ferrous)



Sulfate/Sulfide potential. Source: BGS Civils Database: Presence of Sulfate/Sulfide formations

2.0 Aggressive / Corrosive Soil and Groundwater and the Strategic Road Network

The hazard posed by Aggressive / Corrosive Soil and Groundwater arises from the potential for:

- corrosion, degradation or damage to SRN assets and structural elements by potentially aggressive soil / groundwater (corrosion of iron and steel, or sulfate/sulfide attack on concrete or earthwork materials). The subsequent impact upon the SRN depends on what components are affected.

- Ground heave, caused by sulfate crystal growth, that can damage pavement and ground slabs of structures

These hazards could be present due to:

- unidentified, and hence untreated chemical exposure
- inadequate treatment methods (compared to current practice/guidance), which may correlate to the approximate date of treatment
- the treatment measures employed have deteriorated subsequently due to changes unforeseen at the time of treatment (e.g. surface flooding) or have reached the end of their serviceable life

Whether or not the presence of aggressive soil and groundwater constitutes a hazard to the SRN depends on a variety of factors including the chemical types present, their concentration, availability and scope for replenishment and the extent of exposure.

As with all geotechnical assets, it is reasonable to assume that design and construction after the introduction of HD22 in 1992 would have been subject to a greater level of assurance and rigour, including measures to minimise chemical degradation. In particular, in 1998 the first Interim Advice Note (IAN 15/98) was published to address the issue of thaumasite attack. As of 2014, this is addressed within Series 1700 (Structural Concrete) of the MCHW. These dates may indicate approximate likelihoods of how well mitigated that particular risk would have been at time of construction.

3.0 Key references and further information

BGS Civils Corrosivity map, 2019, HAGDMS / HAGIS

BGS Civils Sulfate / Sulfide map, 2019, HAGDMS / HAGIS

BGS Civils: Corrosivity (ferrous) data description, HAGDMS, 2019

BGS Civils: Sulfate and Sulfide potential data description, HAGDMS, 2019

British Geological Survey, User Guide for the BGS Soil Chemistry Data for Environmental Assessments - Open Report OR/14/031, 2014

British Geological Survey, Environmental chemistry, www.bgs.ac.uk, 2017

British Geological Survey, Corrosivity (ferrous), www.bgs.ac.uk, 2017

Building Research Establishment, Special Digest 1:2005 Concrete in Aggressive Ground, 2005

Arup, Resilience Assessment Framework, Part 1 – Assessment of current resilience, 2020a (HAGDMS Report Number 31685)

Arup, Resilience Assessment Framework, Part 2 – Assessment of options to improve resilience, 2020b (HAGDMS Report Number 31686)

Contact details

For further information, queries or comment please contact the geotechnical team:
geotechnicsteam@highwaysengland.co.uk