Dissolution Features 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 Dissolution Features to impact the safety and performance of the Strategic Road Network (SRN). Together with the Dissolution Features Hazard Rating map 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 Dissolution Features 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 Dissolution Features hazards
Part II: outlines steps in the risk management framework to enhance the network resilience to Dissolution Features
Part III: provides further background information specific to Dissolution Features, its relevance to the SRN, and key sources of reference

Part I Highways England's approach to managing Dissolution Features risks

Dissolution Features occur when water passes through soluble rocks such as limestone, chalk, dolomite, gypsum or halite and creates voids or cavities. An overview of Dissolution Features and its impact on the SRN is summarised in Part III.

Subsidence sinkhole due to a dissolution feature in chalk, located on the M2

For hazards associated with mining of rock-salt, refer to the Brine Extraction and Non-Coal Mining hazard guidance notes.

The risk presented by Dissolution Features 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, Dissolution Features 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.

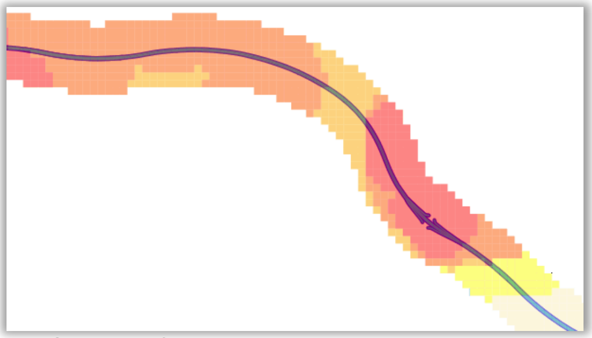
1.0 Current ground risk management requirements:

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 Dissolution Features related risk. Consideration of the hazard posed by Dissolution Features 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 Dissolution Features Hazard Rating Map



Section of the Dissolution Features Hazard Rating map

An HE specific Dissolution Features Hazard Rating map for a 1km corridor centred on the Strategic Road Network has been prepared. This can be accessed on HAGDMS / HAGIS. Version 1 of the hazard map is a synthesis of information relating to Dissolution Features obtained over several years from organisations including British Geological Survey, and Peter Brett Associates. The derivation of this map is explained in detail in a hazard assessment note available on the HA GDMS download page: *HAGDMS Dissolution Features Hazard Rating data description (April 2017).*

The map is intended as a high level hazard awareness map only. **It does not replace the need to seek expert advice** from within Highways England and undertake site-specific studies. As noted above, consideration of Dissolution Features 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 Dissolution Features 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.

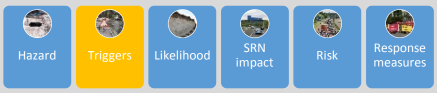
Part II Using the Dissolution Features Hazard Rating map to enhance resilience of the SRN

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 Dissolution Features beneath the SRN, and these present different risks to the network:

- Collapse of dissolution feature void (sudden)
- Subsidence associated with near surface cavities or washout of the infill within a dissolution feature (could be either sudden or progressive)



2. Consider potential external triggers of the hazard event

There may be little or no warning of a dissolution-related 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 a Dissolution Features hazard event:

- A surface flooding event
- Change in surface water flow and changes in drainage
- Groundwater regime change (refer also to the Groundwater Flooding hazard guidance note)
- Heavy or sustained rainfall
- Change in surcharging or loading
- Vibration, e.g. due to traffic, construction activities
- Leakage from nearby water mains, sewerage or drainage

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 Dissolution Features Hazard Rating map is not an absolute indicator of the likelihood of a hazard event occurring, but a relative indicator of the potential presence of Dissolution Features, compared to the rest of the network. The Dissolution Features hazard rating is not directly comparable to hazard ratings derived for other hazard types.

To undertake a qualitative assessment of the likelihood of either a cavity collapse or related subsidence, the following factors are relevant:

(A) The likely presence of Dissolution Features

- Refer to the Dissolution Features Hazard Rating map
- Locations of high water flow (groundwater or surface water) – more mobile water has a higher dissolution action on susceptible rock types.
- Groundwater aggressivity – where groundwater is acidic it has a greater dissolution action on susceptible rock types.

(B) Inherent properties and characteristics

- Geology of the underlying ground – is a key factor in understanding susceptibility to dissolution features. Geology gives an indication of rock solubility.

(C) Presence of any mitigating / exacerbating features

- Depth to any potential Dissolution Feature – shallow cavities are generally more sensitive to loads applied at the surface compared to deeper cavities. Deeper cavities are less likely to have been mitigated during construction of the SRN.
- Type and compressibility of any fill material within dissolution pipes – affects the potential formation of sinkholes / differential movement at the surface.
- Presence and effectiveness (condition) of any ground improvement measures implemented to mitigate cavities or inhibit the flow of water through potential Dissolution Features
- Presence, condition and effectiveness of drainage systems – also soakaways could inadvertently direct water towards soluble rock

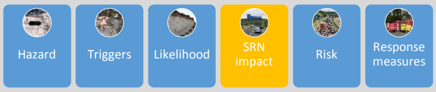
(D) Indicators that a triggering action (as listed in Step 2: Triggers) is likely to occur

These may be considered by the type of triggering mechanism:

- Destabilisation through cavity growth, as may be indicated by:
    - Ongoing dissolution action from existing groundwater flows (i.e. requiring no separate triggering event)
    - Recent prolonged rainfall
    - A history of flooding (also refer to the Groundwater Flooding hazard guidance note)
    - Blocked / insufficient / absent / inappropriate drainage. Also, water/wastewater pipes in poor condition, e.g. aged or damaged through construction-induced ground movements, and may leak or cause local flooding
    - Groundwater extraction / dewatering, soakaways, irrigation
- Destabilisation through additional loading, as may be indicated by:
    - Traffic loading (volume) increases – causes an increase in stress cycling and vibration
    - Construction / demolition activities, excavations, and temporary plant
    - New structures and permanent loads

An understanding of the likelihood of a cavity collapse or related subsidence occurring may also be assessed from historical records and frequency of similar problems on the strategic road network and the surrounding area. Where

HAGDMS contains report records* demonstrating that this hazard was assessed in accordance with current risk management procedures and standards it is reasonable to assume a lower likelihood of a hazard event. There is planned research and development into the use of sensing techniques and other data to identify the presence of ground-related hazards, which could support the likelihood assessment described above.



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:

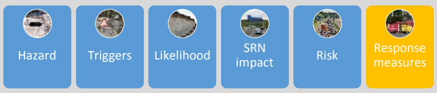
- The rate of failure and the amount of warning available – a rapid, catastrophic failure presents the highest safety consequence.
- The size of the potential failure – a large feature presents a much higher safety risk to potentially many more users of the network than a small collapse would. Estimation of feature size requires local consideration and expert input.
- The location of the potential failure – ground movement directly beneath a main running lane presents both higher safety impact, and higher performance impact than beneath a hard shoulder or beyond.
- 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 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.
- 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 Dissolution Features 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

* The Topic Search tool within HAGDMS facilitates a search across several of the system's databases for information related to a particular topic, for a chosen location. Topics are pre-defined by the System Administrator and currently cover a number of ground-related hazards and therefore the databases searched are focused on geotechnics rather than drainage.

undertaking proactive mitigation. When selecting appropriate measures, there should be early engagement with Geotechnical Specialists from Highways England and service providers.

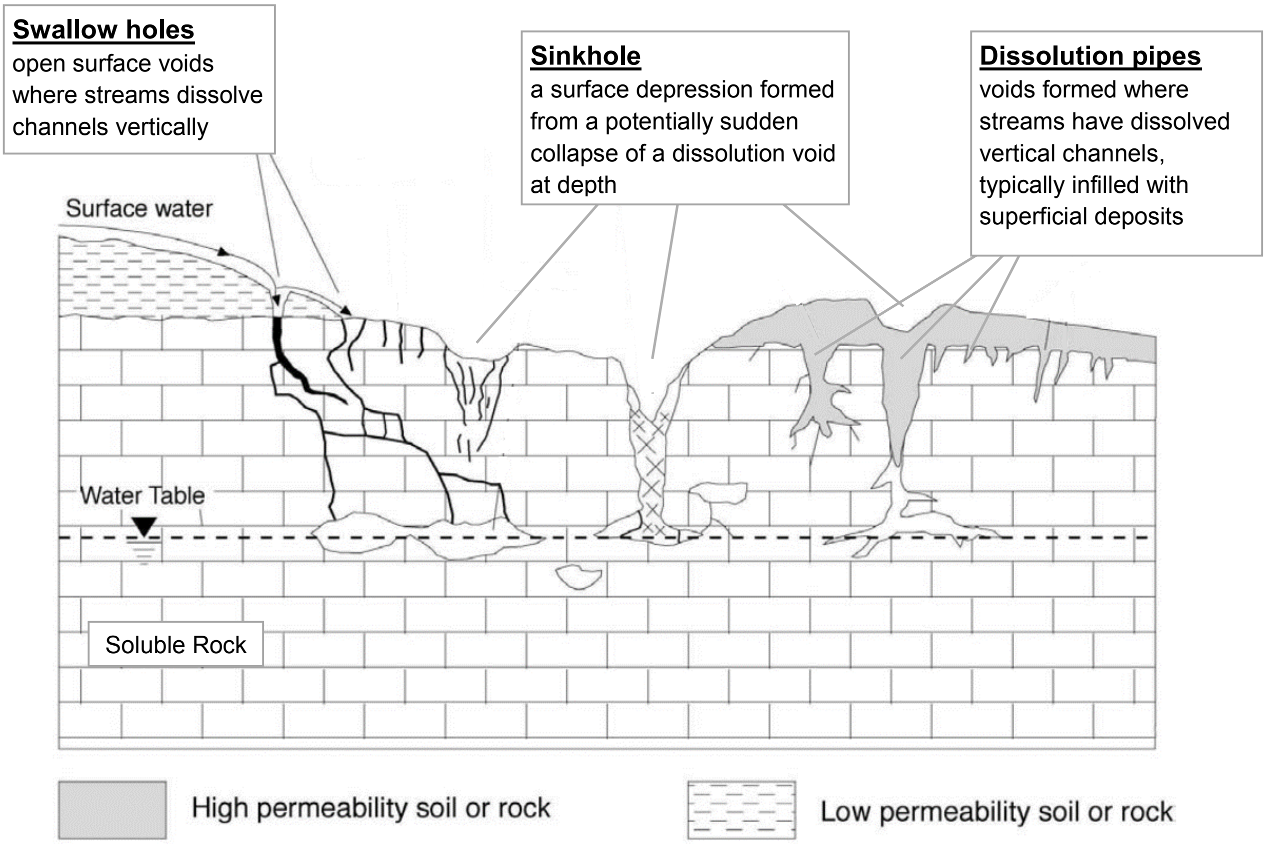
High level risk management measures are likely to be specific to both the hazard event and whether it is a construction and/or on-going operations risk, but all measures would fall into one of the following categories:

- **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.
- **Response and recovery:** To respond rapidly to a potentially unexpected hazard event, development of response plans is recommended for areas of known Dissolution Features 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 Dissolution Features in England

1.0 Formation of Dissolution Features

There are three key types of dissolution features: sinkholes, dissolution pipes, and swallow holes as illustrated in the figure below.



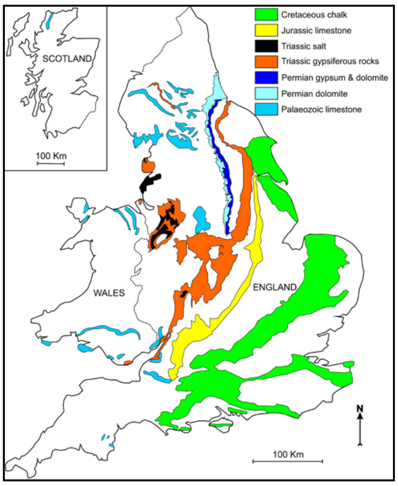
Schematic of common dissolution features in chalk (adapted from CIRIA C574)

- **Sinkholes** are closed depressions that are typically cone, bowl or pipe shaped in cross section, and circular or elliptical in plan. They can appear suddenly or progressively.
- **Dissolution pipes** are cone or pipe shaped in cross section and are typically partially or completely infilled with overlying deposits. It is not usually possible to see them from the ground surface. The hazard associated with dissolution pipes is a localised area of lower strength with greater potential for subsidence. These can become voids again if the groundwater flow in the area changes e.g. due to changes in drainage.
- **Swallow holes** are a surface feature where a void 'swallows' a surface stream. These are likely to have been remediated on the SRN but if in the locality of an asset it could indicate potential future dissolution feature issues.

2.0 Distribution across England

The distribution and type of soluble rock geology varies across the country, with mainly chalk in the south east and east, limestone and gypsiferous rocks in the midlands, rock-salt in the east and limestone in the north, as shown by geological mapping. To confirm the presence of soluble rocks at a particular site a geotechnical investigation using trial pits or boreholes and subsequent testing of samples can be carried out. It may also be possible to identify this hazard using geophysical methods. Some structures in a known high risk area may have monitoring equipment installed. Often the exact location of features may only become apparent when construction is underway but plans are usually in place to deal with features when found.

A cavity due to dissolution on A2 (Highways England)



Distribution of soluble rocks in England and Wales (BGS)

3.0 Dissolution Features and the Strategic Road Network

The hazard posed by Dissolution Features arises from the potential for voids beneath the Highways England estate to either collapse suddenly and catastrophically, or to cause subsidence. These voids could be present due to:

- unidentified, and hence mitigated, dissolution features
- new solution features formed since the construction of SRN
- inadequate mitigation methods (compared to current practice/guidance), which may correlate to the approximate date of works
- the mitigation measures employed have deteriorated subsequently due to changes since the time of treatment (e.g. ageing, chemical, groundwater or surface flooding) or have reached the end of their serviceable life
- inadequate, inappropriate or poorly maintained drainage

This note focuses on the potential for voids and subsidence, but the potential for other effects such as rapid groundwater flow should not be ignored.

The type of hazard that the presence of these voids presents to the SRN is further significantly influenced by geology. Broadly speaking, the hazard type can be grouped as follows:

- **Chalk:** this is the most widespread of rocks prone to dissolution in England. Features resulting from the dissolution prone nature of the rock include dry valleys, permanent or seasonal springs, caves, sinkholes and dissolution pipes. Issues arising from dissolution of chalk include cavities, irregular rockhead and localised subsidence related to infilled cavities. Areas that are particularly vulnerable include those where there is material such as gravel or sand overlying the chalk, which can leave the cavities at a few metres depth.
- **Limestone**: this rock consists of calcium carbonate. The longest cave systems in England are associated with limestone, including in the Yorkshire Dales the Peak District and the Mendip Hills. The typical problem associated with limestone is sinkholes. Cavities formed in limestone can be larger than in other geologies due to the generally higher strength of limestone.
- **Dolomite** deposits pose similar risks to limestone, and areas where it is present can be susceptible to sinkholes.
- **Gypsum** is a highly soluble rock. Cave systems can form over a much shorter timescale (<100 years) than cave systems in other geologies and can cause subsidence over large scale areas. A case in Ripon in Yorkshire reported that a van-sized block ($3m^3$) of gypsum that fell from a cliff into the river below dissolved within just 18 months.

- **Rock-salt** – salt can dissolve quickly, leading to salt springs such as those prevalent in Cheshire. These can then become centres for brine extraction - see the Brine Extraction guidance note. Issues are common at the interface between the rock-salt and overlying strata, where fresh water has the potential to dissolve salt from the rock it comes in to contact with, leading to dissolution.

4.0 Key references and further information

Dissolution Features Hazard Rating map, 2017, HAGDMS / HAGIS

HAGDMS Dissolution Features Hazard Rating data description, 2017

CIRIA, C574 Engineering in Chalk, 2002.

British Geological Survey, Soluble Rocks, www.bgs.ac.uk, 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*.

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