Shrink/Swell Susceptible Soils 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 Shrink/Swell Susceptible Soils to impact the safety and performance of the Strategic Road Network (SRN). Together with the Shrink/Swell Hazard Rating maps and corresponding hazard assessment note on Highways England's Geotechnical and Drainage Management System / Geographical Information System (HAGDMS / HAGIS), the three products support effective management of the Shrink/Swell Susceptible Soils 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 Shrink/Swell Susceptible Soils hazards
Part II: outlines steps in the risk management framework to enhance the network resilience to Shrink/Swell Susceptible Soils
Part III: provides further background information specific to Shrink/Swell Susceptible Soils, its relevance to the SRN, and key sources of reference

A detailed commentary on the history and distribution, geography and hazards presented by Shrink/Swell Susceptible Soils in the UK can be found in 'UK Geohazard Note, Ground Shrinking and Swelling May 2012 by BGS' and 'BRE 1993 Low-rise buildings on shrinkable clay soils: BRE Digest, Vols. 240, 241 and 242. CRC, London' publications.

Part I Highways England's approach to managing Shrink/Swell Susceptible Soils risks

Shrink/Swell Susceptible Soils refers to material with high potential to decrease/increase in volume associated to when its moisture content decreases/increases. Shrinking or swelling may occur as the result of a single event, or repeatedly through cyclical (seasonal) variations. The background of Shrink/Swell Susceptible Soils and its impact on the SRN is summarised in Part III.

Crack in clay slope on M11
Source: HAGDMS

The risk presented by Shrink/Swell Susceptible Soils 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, Shrink/Swell Susceptible Soils 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:

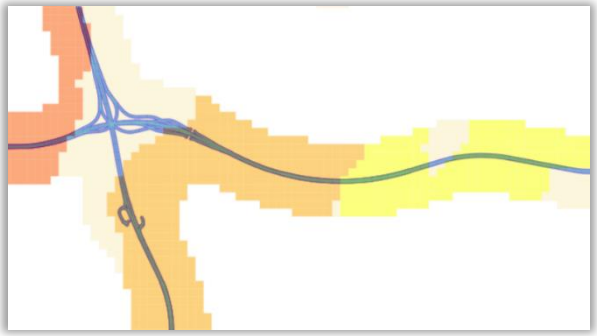
CD 622 (formerly HD22/08) *'Managing Geotechnical Risk'* presents a framework for geotechnical risk management and is a mandated requirement on all highway schemes where a ground investigation or geotechnical design is required. It establishes the principles of early risk identification and continuity 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 Shrink/Swell related risk. Consideration of the hazard posed by Shrink/Swell Susceptible Soils 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 Highways England Shrink/Swell Hazard Maps

2.1 Shrink/Swell Hazard Rating Map



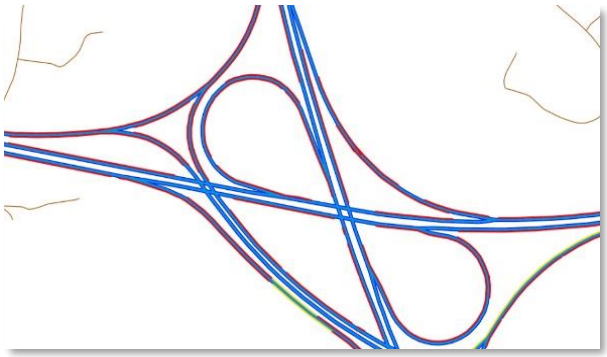
Section of the Shrink/Swell Hazard Rating map

A Highways England specific Shrink/Swell 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 Shrink/Swell Susceptible Soils obtained from the British Geological Survey. The derivation of this map is explained in detail in a hazard assessment note available on the HAGDMS download page: *HAGDMS Shrink/Swell Hazard Rating data description (April 2017).*

2.2 Shrink Swell Potential Map

A Highways England specific shrink/swell potential map has been produced. This map has been split into two individual layers:

- Shrink/swell potential of **cuttings** and **at grade** geotechnical assets
- Shrink/swell potential of **embankments** and **bunds**.



Section of the Shrink/Swell Potential map

These map layers can be accessed on HAGDMS. The map has been derived from an assessment of the geological materials comprising the assets and a large database of collected geotechnical parameters for these materials (from literature and sources on HAGDMS). These are then combined to give an assessment of the potential for shrink swell, which is presented on the map using the extents of each of the geotechnical assets held in the HAGDMS Geotechnical Asset Database. The derivation of this map is explained in more detail in a hazard assessment note available on the HAGDMS download page: *HAGDMS Shrink Swell Potential Data Description (October 2019)*.

These 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 Shrink/Swell Susceptible Soils 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 Shrink/Swell Susceptible Soils 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 Highways England 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 Shrink/Swell 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.

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

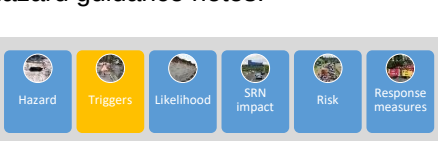
- Resilience Assessment Framework: Part 1 – Assessment of current resilience.
- Resilience Assessment Framework: Part 2 – Assessment of options to improve resilience.

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 Shrink/Swell Susceptible Soils along the SRN, and these present different risks to the network:

- Embankment or cutting deformation and cracking
- Soil creep on steep slopes
- Heave/settlement damage to pavement structure foundations, or buried utilities

Shrink/Swell behaviour is also a potential trigger to a natural slope or engineered soil slope landslide – see corresponding hazard guidance notes.



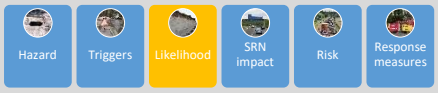
2. Consider potential external triggers of the hazard event

By identifying specific triggers of a hazard event, they can then be monitored to improve the management of the risk. The following are potential external triggers of a Shrink/Swell hazard event:

- Groundwater regime change (refer also to the Groundwater Flooding hazard guidance note)
- Change in surface water flow, drainage and landscaping (including paving)
- Leakage / flooding from water mains, sewerage or drainage
- Water ingress from service duct backfill which may act as a water reservoir
- Prolonged periods of drought

- Seasonal variations in rainfall and vegetation growth
- Planting, removing, or severe pruning of trees, (particularly relevant to high water demand trees)
- Dynamic loading of pavement (when combined with other triggers)

Note that the above weather-related triggers (surface or groundwater flooding, hot/dry summers etc.) may be exacerbated by climate change.



3. Assess the likelihood of the hazard event occurring

The *hazard rating* given on the Shrink/Swell 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 Shrink/Swell Susceptible Soils, compared to the rest of the network. The Shrink/Swell hazard rating is not directly comparable to hazard ratings derived for other hazard types.

To undertake a qualitative assessment of the likelihood of a Shrink/Swell related hazard, the following factors are relevant:

(A) The likely presence of Shrink/Swell Susceptible Soils

- Refer to the Shrink/Swell Hazard Rating and Shrink/Swell Potential (for both Cutting/At Grade and Embankment/Bund) maps.
- Presence of 'high plasticity' clays* – that is identified by the Shrink/Swell Hazard Rating map (e.g. that may have been used in the construction of embankments).

(B) Inherent properties and characteristics

- Slope gradient – steeper slopes have a greater tendency for soil creep through Shrink/Swell cycles
- Depth to Shrink/Swell Susceptible Soils – deeper soils are less affected by seasonal variations, and there is less impact for surface assets
- Former vegetation (type, density, age) – where the SRN built is on top of formerly vegetated soil, the water demand of the removed vegetation indicates the extent to which the soil may swell.

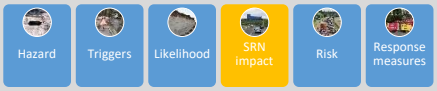
(C) Indicators that a triggering action (as listed in Step 2: Triggers) is likely to occur

- High seasonal weather variations including unusually dry summers (and which are likely to become more extreme with climate change).
- A history of flooding (also refer to the groundwater flooding hazard guidance note).
- Planned / ongoing construction activities that affect soil moisture, e.g. significant excavation or dewatering, vegetation management.
- Presence of drainage in poor condition (e.g. aged or damaged through construction-induced ground movements) and therefore may leak or cause local flooding.
- 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).
- Presence of other artificial ground water management, e.g. soakaways, irrigation.

An understanding of the likelihood of a Shrink/Swell hazard event 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

* Plasticity is a geotechnical property of cohesive materials indicating the variation of moisture content the soil can hold. 'High plasticity' soils have a greater capacity to absorb or expel water (and thereby swell or shrink) than 'low plasticity' soils.

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 size of the potential impact e.g. the extent of the susceptible soils or extent of high water demand tree or hedge line. Former tree or hedge boundaries are also susceptible to swell behaviour.
- The location of the potential impact and the type of asset (earthwork, pavement, structure, buried utility) affected – pavement deformation and cracking in a main running lane presents a 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 potential disruption impact on the SRN.
- Reduction in effective service life of pavement – through (cyclic) softening of the pavement foundations.

(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 shows 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 Shrink/Swell Susceptible Soils 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 (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 manage the Shrink/Swell Susceptible Soils hazard, development of response plans is recommended for areas of known 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. Changes are unlikely to be rapid and this should influence the responses proposed. 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 Shrink/Swell Susceptible Soils across England

1.0 Shrink/Swell behaviour in soils

The BGS provides the following context relating to the hazard of Shrink/Swell Susceptible Soils:

Shrink-swell occurs as a result of changes in moisture content of clay-rich soils. This is reflected in a change in volume of the ground through shrinking or swelling. Swelling pressures can cause heaving, or lifting, of structures, whilst shrinkage can cause differential settlement.

The amount by which the ground can shrink and / or swell is determined by the water content in the near-surface and the type of clay. Fine-grained clay-rich soils can absorb large quantities of water after rainfall [or other water inundation events] *becoming sticky and heavy. Conversely they can also become very hard when dry, resulting in shrinking and cracking of the ground. This hardening and softening is with associated volume change, is known as shrink-swell.*

The south-east of the country is significantly more susceptible to shrink/swell due to their relatively younger 'clayey' formations (e.g. London Clay, Oxford Clay, Gault Clay, Kimmeridge Clay). In contrast, other parts of the country have older clayey formations that have become much stronger 'mudstones' which are less able to absorb/lose moisture.

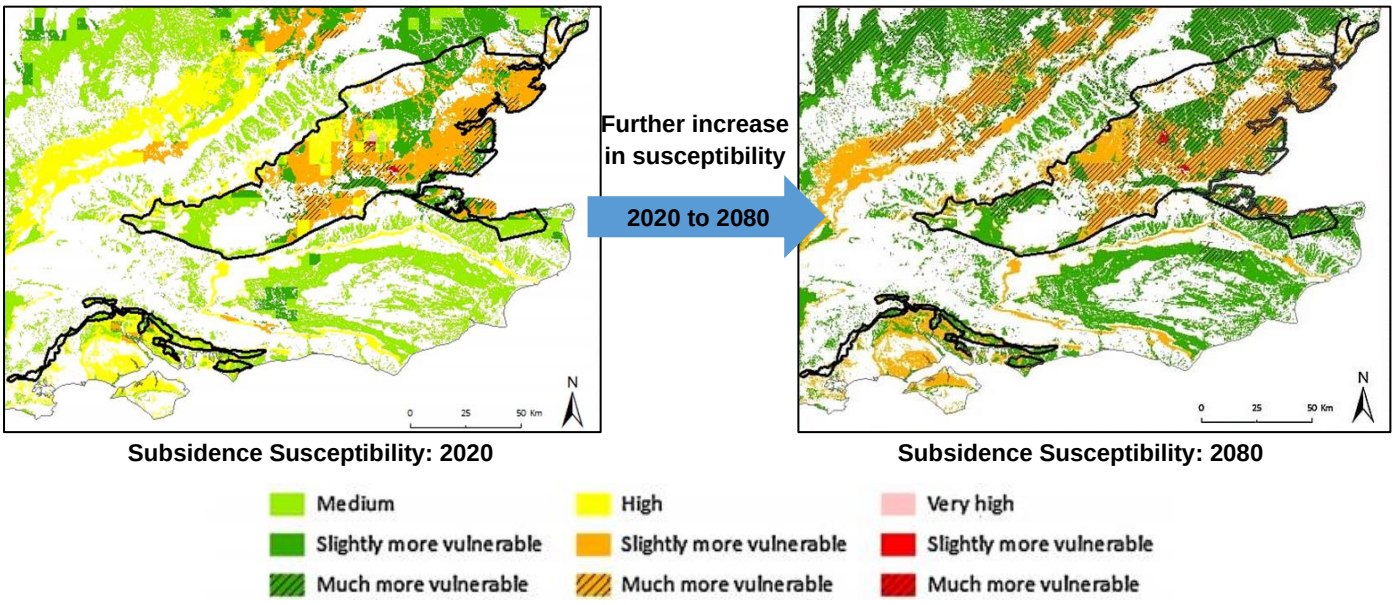
Shrink / Swell damage to A2, Canterbury, 2015. Source: HAGDMS

The presence of shrinkable clay does not always present a hazard. As described by BGS, in some areas such as The Wash and under the Lancashire Plain, these deposits are buried deep beneath other soils that are not susceptible to Shrink/Swell behaviour. However, other superficial deposits such as alluvium, peat and laminated clays can be susceptible to soil settlement and heave (e.g. in the Vale of York, Pennine valleys and the Cheshire Basin).

2.0 Climate change

The impact of climate change is predicted to be significant in the UK climate. Extreme weather in today's climate is likely to become much more commonplace in the near future. Summers will be drier and hotter, and with greater rainfall variability, so the magnitude, the frequency and the impact of the Shrink/Swell hazard is likely to increase.

Harrison et al. (2012) produced model maps for the south-east of England by combining the BGS GeoSure dataset, and applying the UK Climate Projections (UKCP) scenarios for rainfall and temperature changes for the next century. The maps (below) predict the potential increase relative to 2011 in the degree of susceptibility of the region to Shrink/Swell Susceptible Soils and subsidence/settlement for the years 2020s (left) and 2080s (right) that may be caused by the climate change. It suggests that in the future there will be increasing susceptibility to Shrink/Swell behaviour.



Increase in Subsidence susceptibility relative to 2011 (UKCIP02 climate prediction high emissions scenarios)
Contains public sector information licensed under the Open Government Licence v1.0. UKCIP 2011. Coastline courtesy of The Digital Chart of the World (DCW); from: Harrison et al., 2012.

3.0 Shrink/Swell Susceptible Soils and the Strategic Road Network

The hazard posed from the potential of Shrink/Swell Susceptible Soils ground beneath the Highways England estate is that it may cause desiccation cracking, leading to water ingress and slope failure. In addition in can also cause damage to the road surface, foundations, or buried utilities. These Shrink/Swell deformations could be caused through:

- unidentified (at time of construction), and hence unmanaged areas susceptible to Shrink/Swell
- 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. changes in water content) or have reached the end of their serviceable life

Shrink/Swell is typically a gradual phenomenon and causes damage gradually. There are usually visible indications of an issue long before any large-scale failure occurs. However, it is important that signs are recognised and addressed as, if left unchecked, they may develop into larger slope failures – see the Engineered Soil Slopes hazard guidance note.

The hazard that Shrink/Swell Susceptible Soils presents to the SRN is further significantly influenced by the geology, soil properties and water regime of the area. Broadly speaking, the hazard type can be influenced by the following factors:

- Type of material – all clays are susceptible to some shrinkage and swelling due to changes in moisture content. However, those with a higher proportion of expansive clay minerals, such as smectite, are more prone. This is indicated by a high ‘plasticity index’ (a geotechnical property of clays derived from laboratory testing)
- Thickness of the susceptible soils
- Cover to the susceptible soils – shallower soils are more prone to Shrink/Swell volume changes. High plasticity soils when at depth can exhibit little change and not necessarily constitute a hazard
- The potential change in groundwater levels, and the amount and distribution of rainfall (climate change will lead to a significant increase in the damage done by the shrinking and swelling behaviour at susceptible areas).
- Type of vegetation – extraction of water from the soil by vegetation depends on the species, size and density of the trees / other vegetation. Trees with higher water demand exacerbate seasonal variations because, in periods of dry weather, as the natural soil moisture lowers they draw still more water from the ground, yet in the wetter

winter months when the soil has higher moisture content, their water demand is much reduced, being out of their growing season

- Vegetation management – where vegetation has been removed and water is no longer being drawn up through roots, soil susceptible to Shrink / Swell will heave as it establishes a new moisture equilibrium. In addition, the decay of the root system also creates additional pathways for water ingress within the soil, encouraging further and more rapid swelling.

4.0 Key references and further information

Shrink/Swell Hazard Rating map, 2017, HAGDMS / HAGIS

HAGDMS Shrink/Swell Hazard Rating data description, 2017

Shrink/Swell Potential – Cutting/At Grade map, 2019, HAGDMS / HAGIS

Shrink/Swell Potential – Embankment/Bund map, 2019, HAGDMS / HAGIS

HAGDMS Shrink Swell Potential Data Description, 2019

Harrison, A M, Plim, J F M, Harrison, M, Jones, L D, and Culshaw, M G. The relationship between shrink–swell occurrence and climate in south-east England, 2012, Proceedings of the Geologists' Association, Vol. 123, 556–575.

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British Geological Survey, Shrink-swell and climate change, www.bgs.ac.uk, 2017

Buildings Research Establishment, BRE Digest 240: Low-rise buildings on shrinkable clay, 1993

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

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