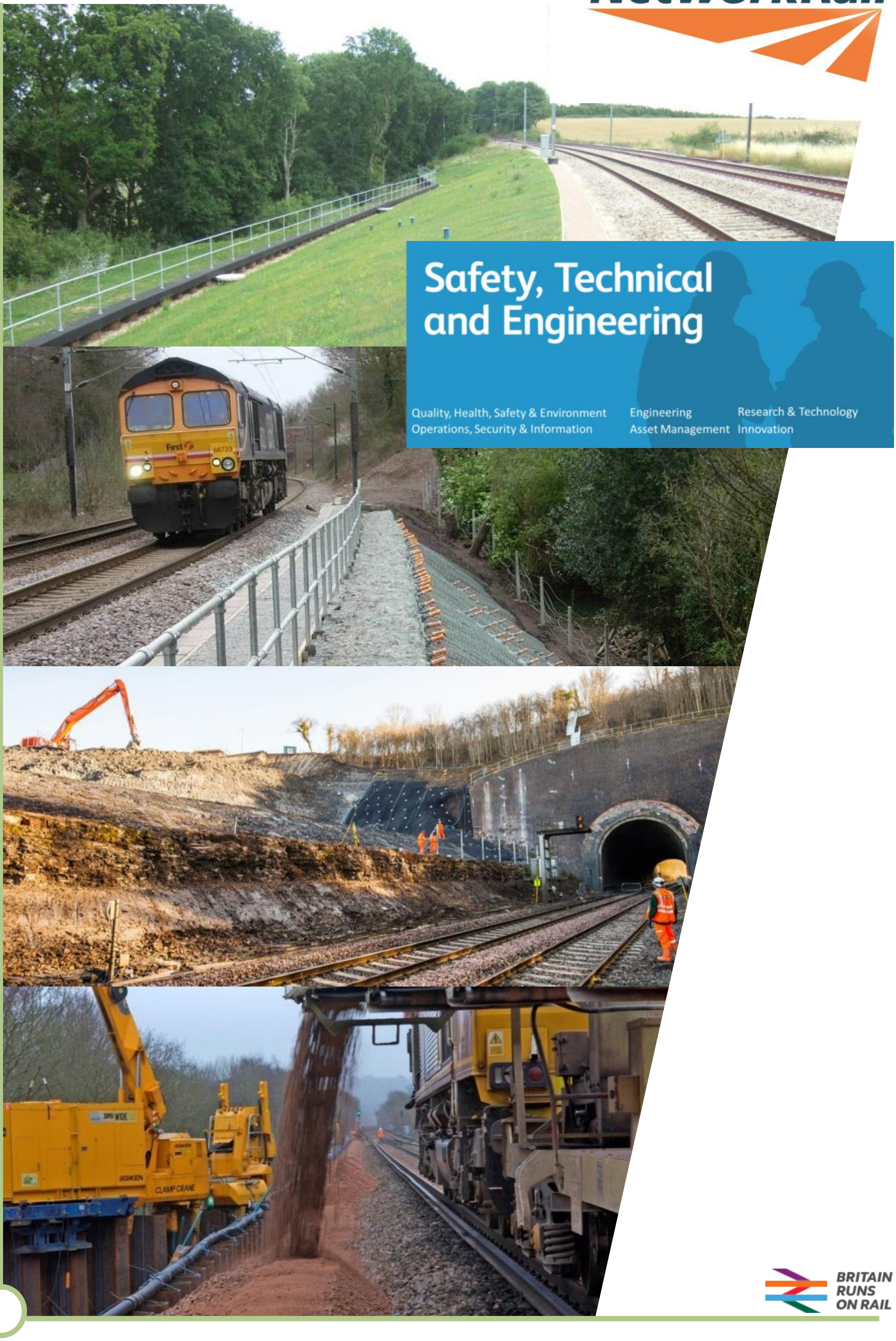
# Earthworks Technical Strategy

*June 2018*

NetworkRail



## Safety, Technical and Engineering

Quality, Health, Safety & Environment
Operations, Security & Information
Engineering
Asset Management
Research & Technology
Innovation

BRITAIN RUNS ON RAIL

**Tips:**
Reading: best viewed as a dual page PDF; select *view* > *page display* > *two page view*
Printing: *print pages: 1,3-65* (to remove this page) for correct alignment of pages on A4 double sided printing

**WARNING: Any survey using UAV on the network MUST BE authorised by Network Rail Air Operations. For further information or advice about the use of drones on, over or near to the rail infrastructure, please contact droneenquiries@networkrail.co.uk**

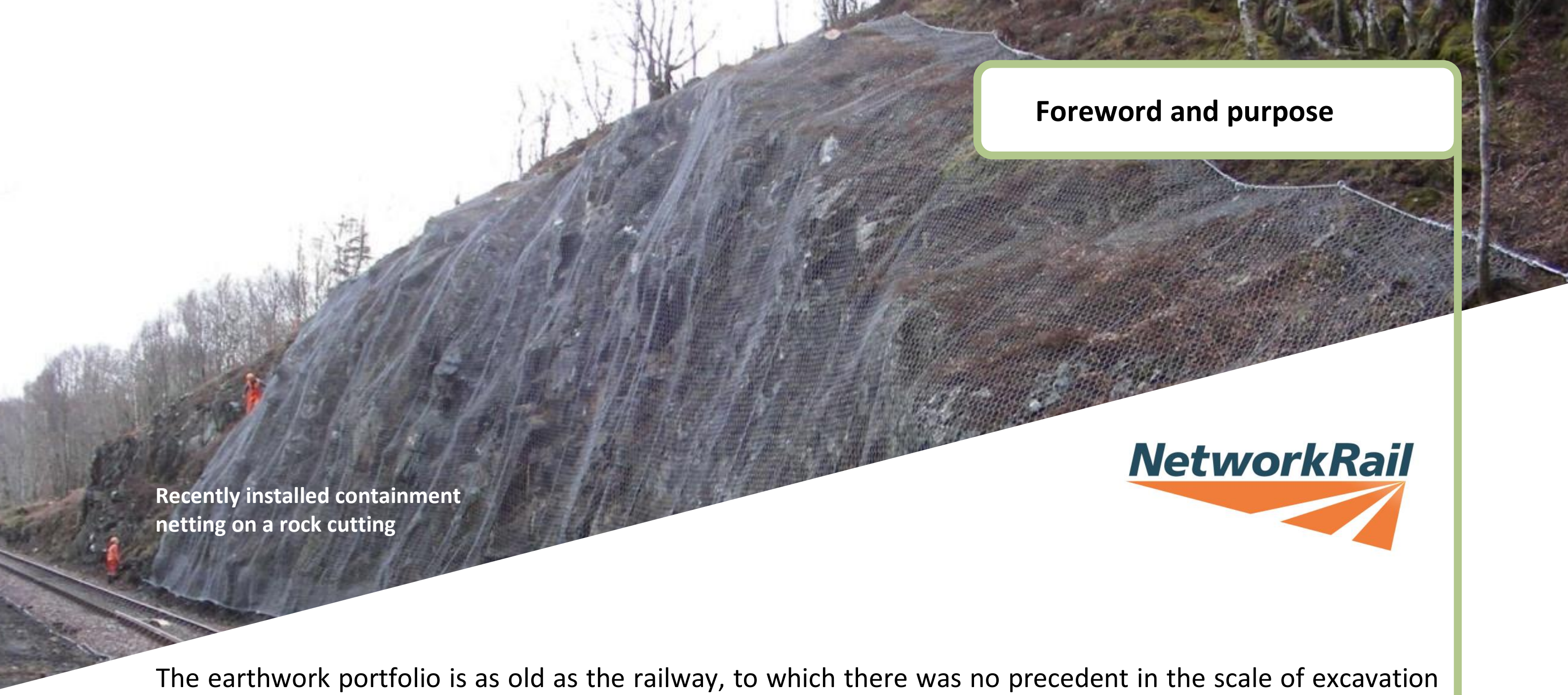
## Contents

*“Amongst the many important works connected with the construction of a railway, it is doubtful whether any require more attention, experience and knowledge than the earthworks”*

*“The hidden and insidious enemy - water. Wherever water is known or suspected to exist, its immediate source should be traced, and every possible means adopted of diverting it from slopes”*

**Railway Construction (2nd Edition) 1864**
*Available from the Institution of Civil Engineers (ICE) library*

# Foreword and purpose


Recently installed containment netting on a rock cutting

The earthwork portfolio is as old as the railway, to which there was no precedent in the scale of excavation to create cuttings, or in the placement of material to build embankments. It was a feat of Victorian engineering to undertake ground works in this order of magnitude and all whilst using empirical techniques.

There is a complex arrangement between the array of diverse assets that make up the railway system. Today we aspire for a safer, more reliable, efficient and sustainable infrastructure that continually improves. This requires a well developed capability in asset management with an appropriate and proportionate management of risk, whilst recognising there is a degree of risk that is tolerable.

We have to continually develop better technology at reducing cost and steadily evolve more efficient methods for moderating risks. Every aspect of engineering will involve risks which we must understand, prioritise and moderate in order to utilise our resources appropriately.

The purpose of this strategy is to articulate our priorities and key activities to enable long term improvements in safety performance. We have matured significantly in the last 15 years and are committed to continuous improvement in earthwork management. Whilst longer term trends in earthwork safety events continue to reduce we recognise we cannot be complacent.

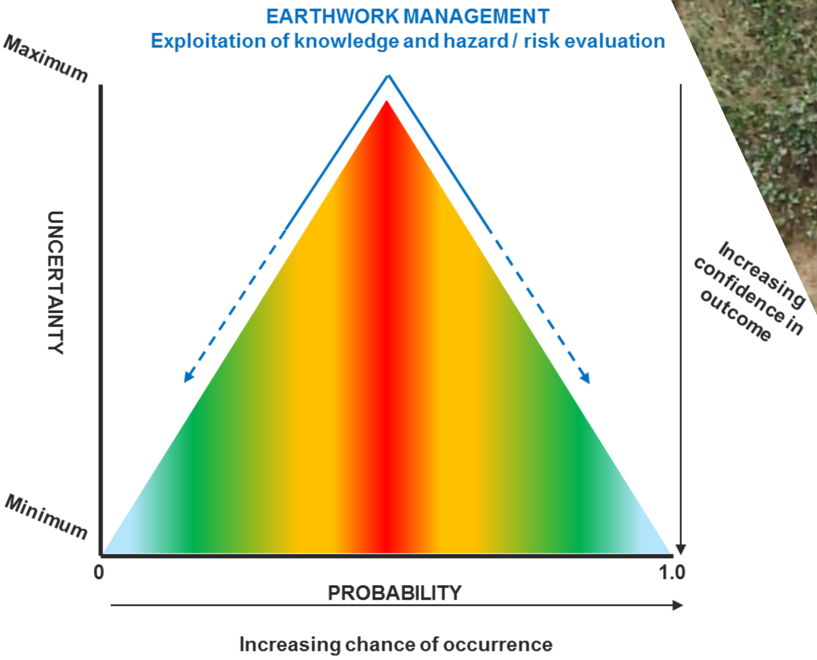
Communicating the challenges posed by railway earthworks and potential techniques that could further enhance the management techniques is in itself challenging. I do hope that this document will assist people to understand the strategic initiatives for improvement, in particular the topics of focus in our research and development.

This is not an exhaustive document articulating everything we do but will provide an insight into the world of geotechnical asset management and our strategy to continually improve through the use of technology. I hope you find this document, along with references to the published technical literature, useful.

**Simon Abbott**
Professional Head of Geotechnics


Failing embankment undergoing emergency repair

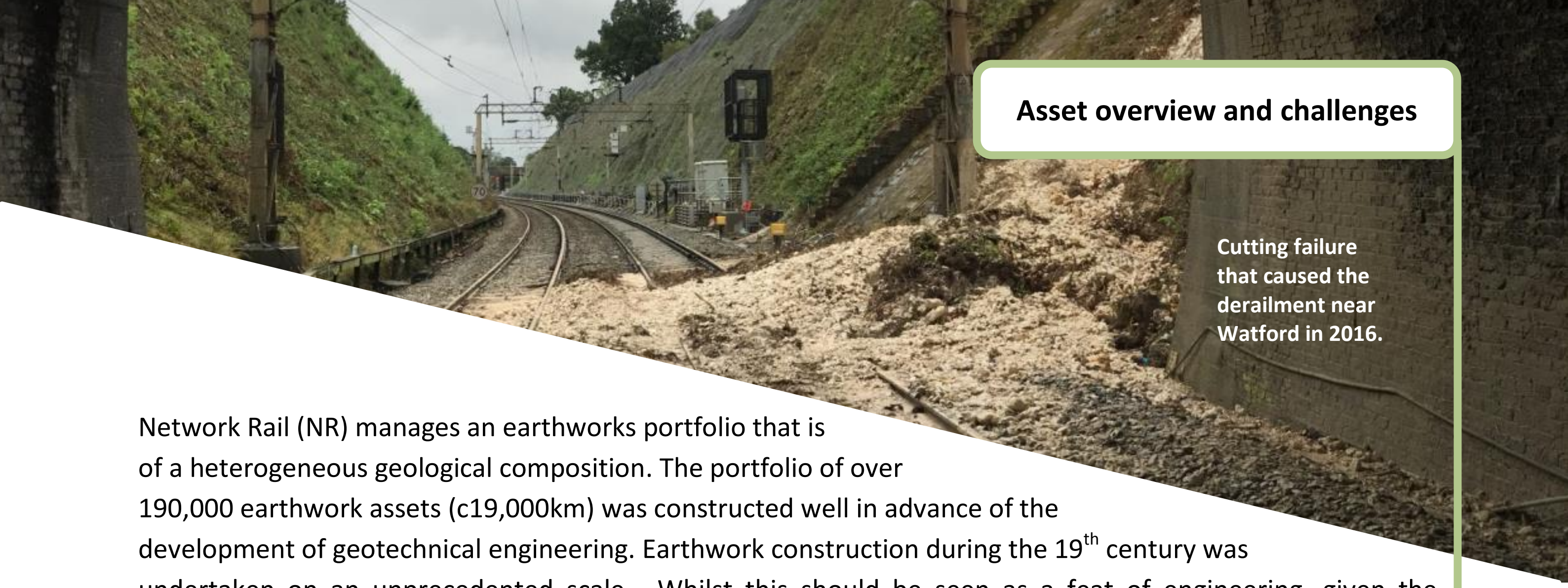
*The communication of hazard, consequence and risk when associated with geotechnical infrastructure can be very challenging. The probability and uncertainty in slope failure or a landslide event is demonstrated in the diagram below (modified after Lee 2009). It may be considered uncomfortable to have uncertainty in the performance of infrastructure slopes. However, the diverse portfolio of over-steep slopes of a heterogeneous composition provides a significant challenge for Network Rail. It is unwise to ever truly consider that the probability of a slope failure or landslide event to ever be zero (will not happen) or one (will happen).*



Above: Reduction in uncertainty of slope behaviour achieved by earthwork management (modified after Lee 2009)

Failure at Hooley ‘fasts’ in Sussex during winter 2013/14

## Asset overview and challenges



**Cutting failure that caused the derailment near Watford in 2016.**

Network Rail (NR) manages an earthworks portfolio that is of a heterogeneous geological composition. The portfolio of over 190,000 earthwork assets (c19,000km) was constructed well in advance of the development of geotechnical engineering. Earthwork construction during the 19th century was undertaken on an unprecedented scale. Whilst this should be seen as a feat of engineering, given the construction methods available, it has also resulted in a legacy of over-steep embankments and cuttings across the network. When compared to infrastructure constructed with the benefit of modern design codes and techniques, the portfolio we manage is inherently disadvantaged. The asset count, age, degradation, and current rate of strengthening provide a unique management challenge on a macro scale.

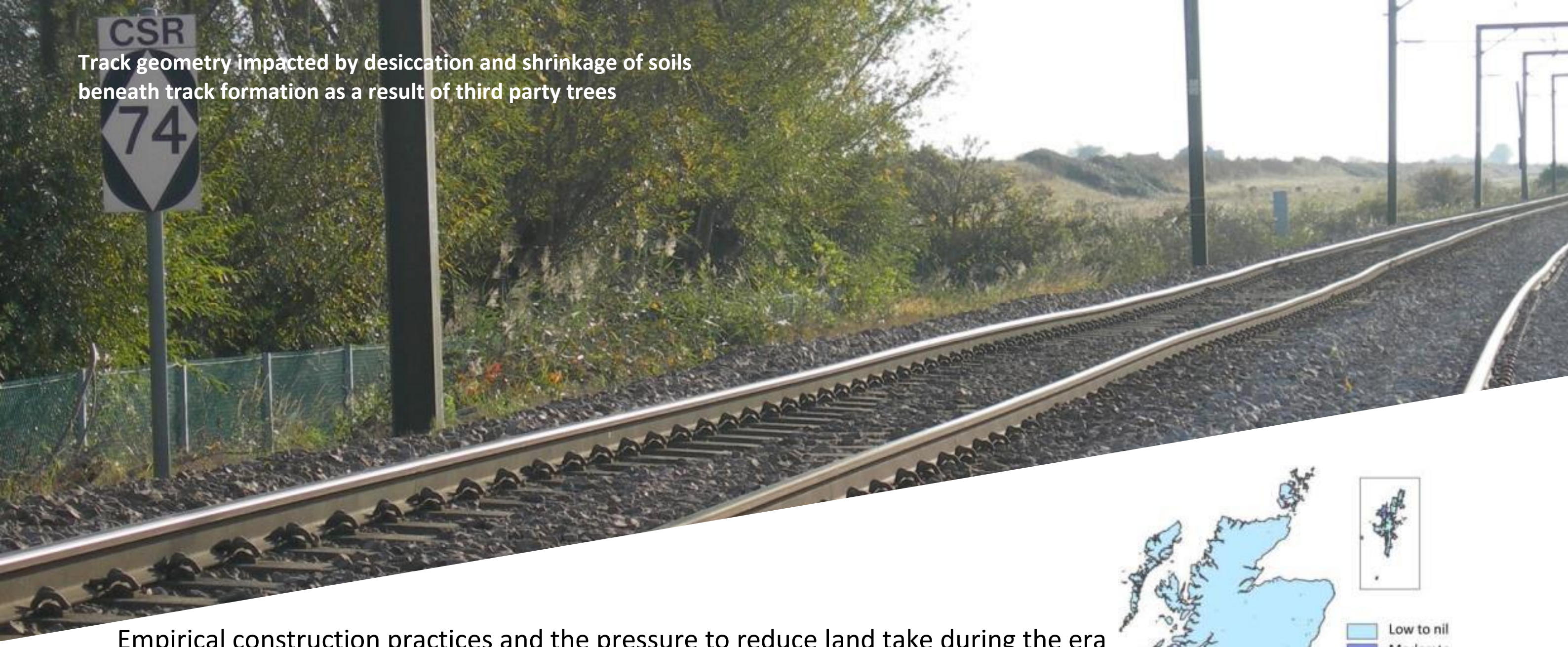
A common understanding of hazards and risks posed to any organisation can only be achieved through effective communication. The terms hazard and risk are used in different ways by different organisations and it is difficult to find an unequivocal definition. ISO 55000 & 31000 both define risk as the *"effect of uncertainty on objectives".* The Health & Safety Executive define risk as "*The likelihood that a hazard will actually cause its adverse effects, together with a measure of the effect".* The International Society of Soil Mechanics and Ground Engineering (ISSMGE) technical committee on risk assessment and management define landslide risk as "*a measure of the probability and severity of an adverse effect to life, health, property or the environment*".

Our organisation's approach to risk management is determined by risk appetite and tolerance. It is important to communicate effectively when talking about risk, as our risk position and future trajectory allow us to find the right compromise when there are competing needs from different asset groups.

We are committed to maintaining and improving both safety and performance. The benefits of continuous improvement since the inception of formal earthwork management are now starting to appear (table page 6).

Basic knowledge and appreciation in geotechnics can often lead to inaccurate conclusions on failure causes, asset capability and rates of portfolio degradation. Perceptions of the asset base and expectations of its ability to perform will often need careful management, particularly at times of heightened potential for failure during prolonged wet weather. Recent events during the winters of 2013/14 and 2015/16 continue to highlight the susceptibility of the asset base to failure (inherently disadvantaged with steep profiles from construction).

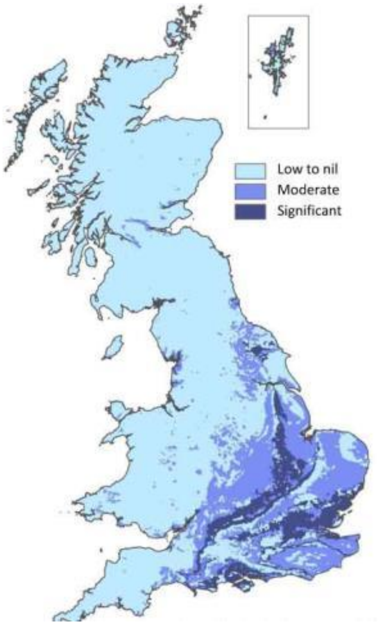
**Below:** Cutting slope failure adjacent to previous strengthening scheme, despite a functional crest drain. One challenge in capital investment schemes can often be determining where to curtail the extent of remediation.



**Track geometry impacted by desiccation and shrinkage of soils beneath track formation as a result of third party trees**

Empirical construction practices and the pressure to reduce land take during the era of establishing new railways are both preparatory factors in many of the challenges that exist today. In contrast to railway earthworks, the design of highway embankments and cuttings benefitted from experience gained during railway construction, from the development of modern soil mechanics and from an improved understanding of the soils used in construction.

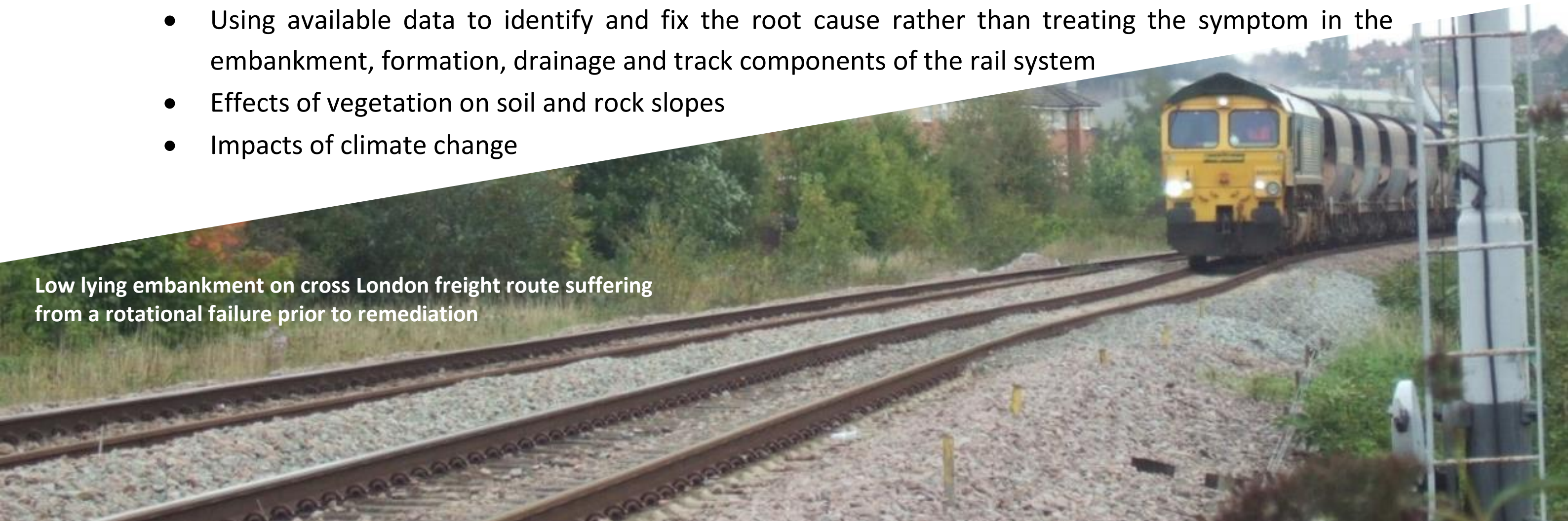
The UK geology plays an important role in understanding the range of problems and the potentially hazardous nature of these to different areas of our business. As a general rule the oldest and hardest materials are found in the north-west, with materials becoming younger and softer further towards the south-east. This is partly represented in the image to the right that depicts the outcrops of clay soils (geologically young deposits), with those having moderate and significant potential for swell-shrink predominately located in the south-east quadrant of the UK.



Map of potential swell-shrink in clay soils courtesy of the British Geological Survey

There are a broad array of technical challenges we face today, including:

- Improving the capability of the asset base to be more weather resilient (i.e. asset resistance as a component of infrastructure resilience) at an acceptable pace for industry
- Prolonged periods of wet weather that increase pore water pressures and reduce effective stress within clay slopes, reducing the factor of safety and increasing the likelihood of asset failure
- Management of the infrastructure during short duration adverse / extreme weather events that can lead to rapid washout failures in granular slopes
- Rapid failures that develop and occur within a matter of minutes to hours
- Increased embankment traffic loading and tonnage growth
- Seasonal shrink-swell (desiccation) of embankments causing serviceability issues to track geometry
- Peat wastage of sub-surface soils that result in subsidence
- Natural third party slopes beyond our infrastructure where potential hazards may exist
- Using available data to identify and fix the root cause rather than treating the symptom in the embankment, formation, drainage and track components of the rail system
- Effects of vegetation on soil and rock slopes
- Impacts of climate change



**Low lying embankment on cross London freight route suffering from a rotational failure prior to remediation**

Botley embankment in Wessex following catastrophic failure during the 2013/14 winter

> *“The national railway network suffered significant damage and disruption from the extreme weather of last winter, with large numbers of passengers experiencing disruption to their normal service, in some cases for prolonged periods”*
>
> **DfT (2014) Transport Resilience Review**

> *“The DfT should review, and at the earliest opportunity modify or replace, the 1842 legislation governing Network Rail's ability to access neighbours' property, with more explicit powers to deal with both potential threats to the safe operation or resilience of the railway and for planned maintenance.”*
>
> **DfT (2014) Transport Resilience Review**

> *“Thomas Telford’s report (1829) on the works, clearly show they were formed by end-tipping at the full height; a process, moreover, of which Telford specifically disapproved on the grounds of delayed consolidation and an increased tendency for slipping”*
>
> *“Shortly after opening the line another very similar slip occurred… as a quick first-aid measure Brunel had a row of timber piles driven at the toe of the slope, penetrating 8ft into undisturbed ground”*
>
> **Skempton (1996) Embankments and cuttings on the early railways**

**Above:** Historical images from the 19th century showing end tipping techniques to build an embankment and a chalk cutting with un-remediated slope hazards

> *"The key variables affecting track deformation are axle load and the number of load applications, N, and these should be considered separately, and not the overall tonnage; the axle load is the primary parameter, N having a relatively smaller impact, as for a given tonnage (i.e. Million Gross Tonnes), a line subject to a larger axle load will be far more vulnerable to deformation than a line exposed to a smaller axle load and a proportionately larger N value"*
>
> **RSSB & Mott MacDonald (2011) The effects of railway traffic loading on embankment stability**

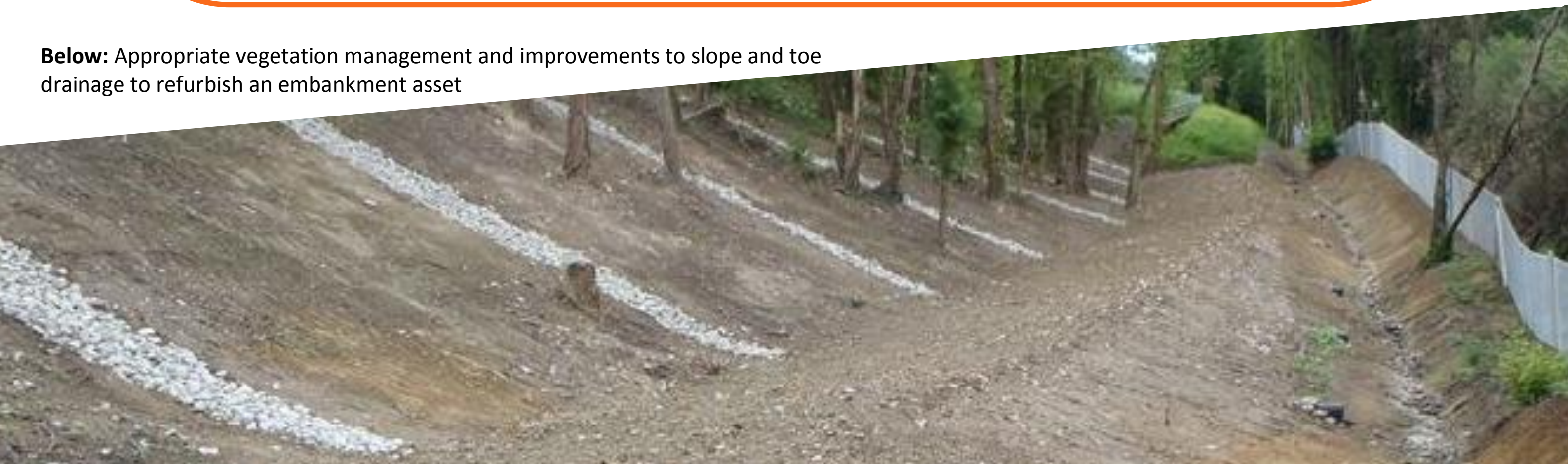
> *"The balance between reducing seasonal track movement and maintaining embankment stability might best be achieved by selectively removing high water demand tree species within a defined distance of influence, rather than clearing all trees from an embankment slope"*
>
> **Smethurst et al (2015) Mechanical & hydrological impacts of tree removal on a clay fill railway embankment**

**Table showing key performance and safety metrics by regulatory control periods.** Safety ***KPI's*** are improving but all failures and ***TSR*** numbers are relatively stable (varying with weather trends). First time Earthwork specific asset policy was issued in 2012 during the planning process for CP5.

| Control Period | Date Range | **Earthwork TSR's (% of all TSRs)** | **All Earthwork Failures** | **Potentially high consequence earthwork failures** | **Earthwork attributable derailments** |
|---|---|---|---|---|---|
| CP1 | 1994/95 – 98/99 | No data | No data | No data | 7 |
| CP2 | 1999/00 – 03/04 | 273 (7.3%) | No data | No data | 8 |
| CP3 | 2004/05 – 08/09 | 135 (3.8%) | 477 | 41 | 8 |
| CP4 | 2009/10 – 13/14 | 441 (4.8%) | 528 | 32 | 8 |
| CP5* | 2014/15 – 18/19 | 290 (3.4%) | 381 | 18 | 2 |
| CP6 | 2019/20 – 23/24 | | | | |
| Trend | | relatively stable | relatively stable | reducing | reducing |

*Data for 4yr period 14/15 to 17/18 ***TSR*** = Temporary Speed Restriction ***KPI*** = Key Performance Indicator

**Below:** Appropriate vegetation management and improvements to slope and toe drainage to refurbish an embankment asset



Slow failing embankment requiring excessive track maintenance prior to capital renewal

Continual improvements to safety, performance, reliability, capability and capacity are challenges that we and the industry are working to address. Expectations regarding the capability of the earthworks portfolio will need to be continually managed due to the legacy factors associated with the asset base.

The winter of 2013/14 was the wettest winter on record and caused significant transport disruption in the UK. In response, the DfT reviewed the resilience of transport infrastructure to extreme weather events. Published in July 2014 the report recognised that Network Rail needed a sustained level of progressive strengthening to improve the resilience of the earthwork portfolio. Whilst there were no earthwork attributable derailments in the winter of 2013/14, several key London commuter lines were severed for a number of weeks following multiple catastrophic earthwork failures.

Given the asset age, rate of deterioration and vulnerability to weather, the improvements through capital investment can be divided into three categories:

- **Planned Renewal;** Strengthening of asset to improve slope Factor of Safety (FoS) to modern day standards; providing increased resilience and improving reliability.
- **Actively Failing Asset;** Accelerated intervention (renew) to prevent catastrophic failure from taking place following an inspection report and / or detection through installed monitoring equipment
- **Catastrophic Failure;** Asset Recovery Post Failure

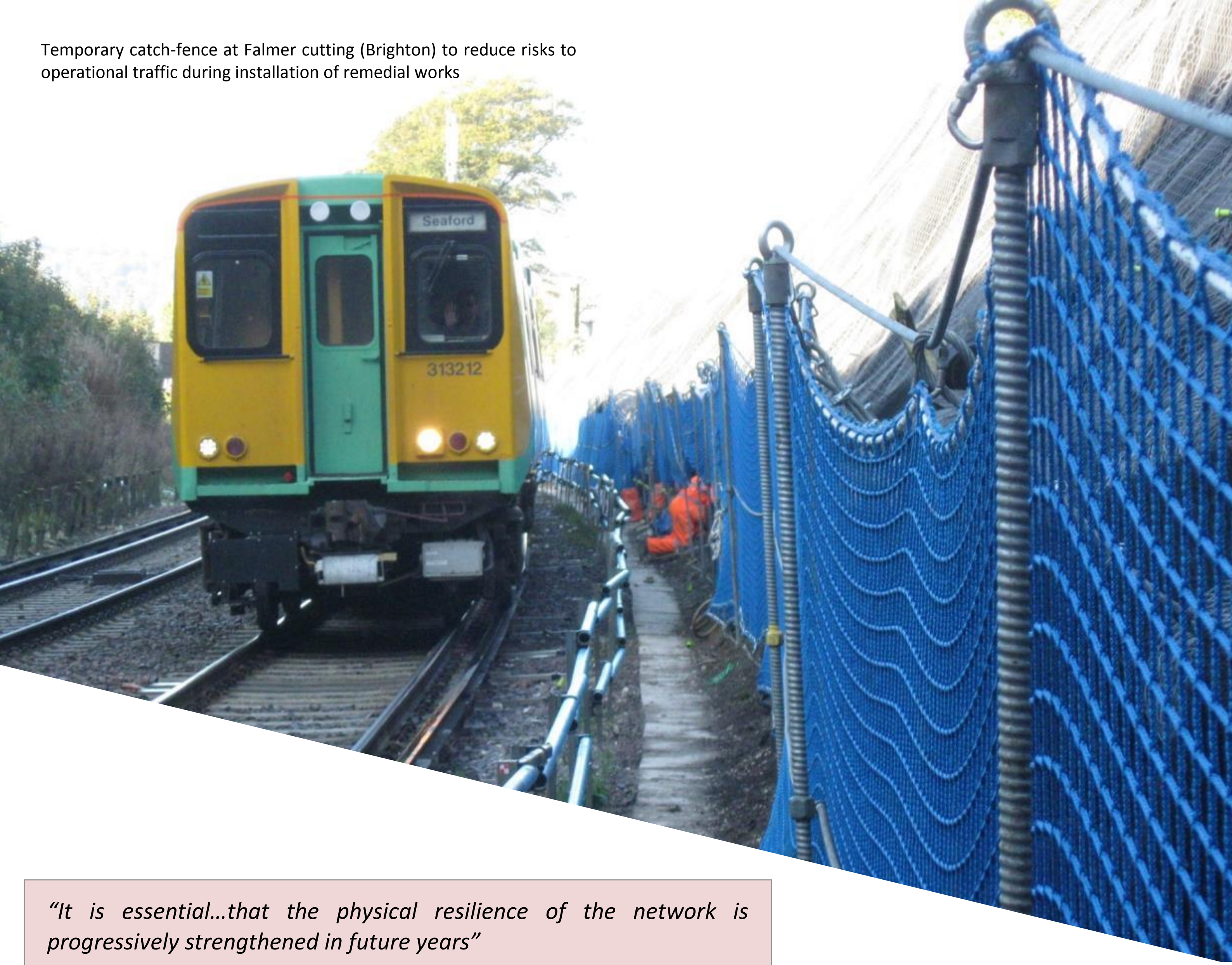
The majority of capital investment prior to Control Period 5 has typically been spent on arresting actively failing assets or in the recovery of assets following catastrophic failure. We are now becoming more pro-active than ever before in the targeting of capital investment. The first version of a specific Earthwork management policy was issued in 2012 and the benefits of this policy are now starting to yield improvements in safety indicators (see table opposite).

Despite improvements to safety performance, the preparatory factors associated with a legacy network will continue to provide a unique management challenge for our organisation well into the 21st century.

> *"The seasonal, shrink-swell volume change of railway embankments has been shown to reduce the strength of the clay fill soil and promote the progressive failure of embankment slopes"*
>
> **Briggs et al (2017) Failures in transport infrastructure embankments**

**Below:** Catastrophic embankment failure in Sussex during 2014 and repaired slope following extensive piling and rebuilding works

Temporary catch-fence at Falmer cutting (Brighton) to reduce risks to operational traffic during installation of remedial works



*"It is essential…that the physical resilience of the network is progressively strengthened in future years"*

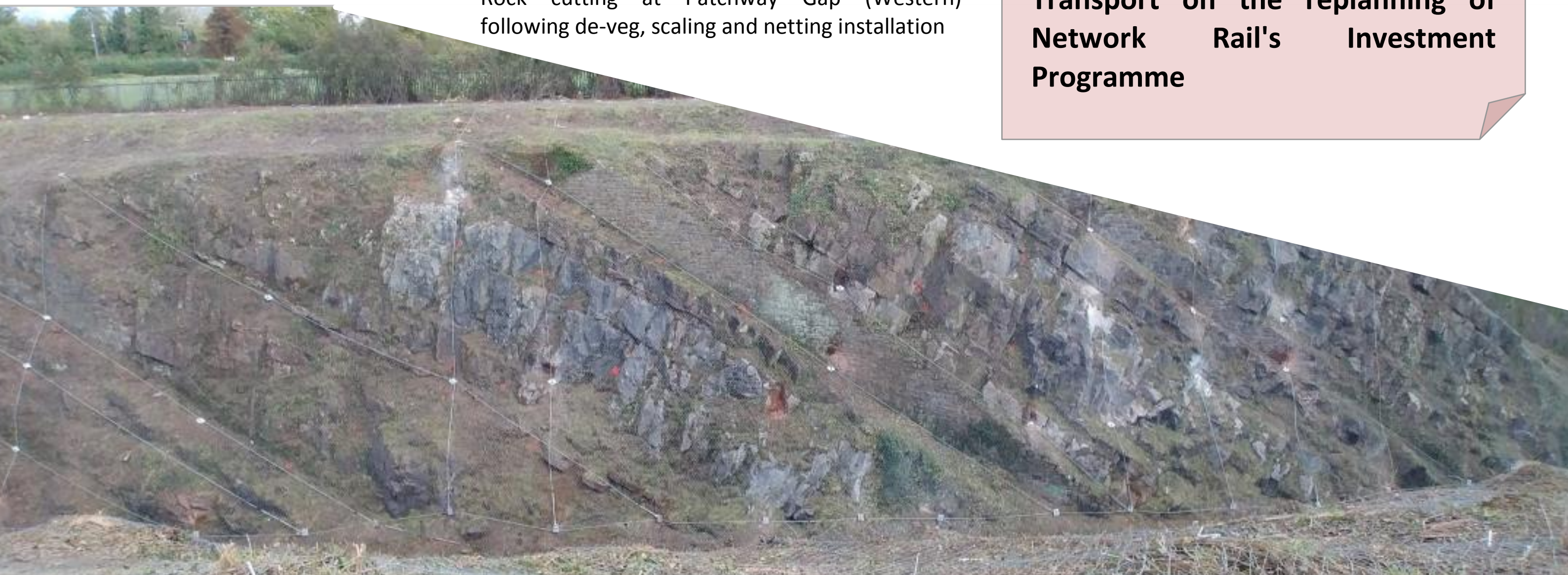
*"Network Rail should maintain a strong focus on trialling newly available condition monitoring and slope stabilisation technologies, working with academic and other researchers and with other railway administrations, to improve its ability to identify and anticipate slopes that will fail and target remedial work as efficiently as possible. In addition Network Rail should continue to commission academic research into possible slope stabilisation techniques"*

**DfT (2014) Transport Resilience Review**

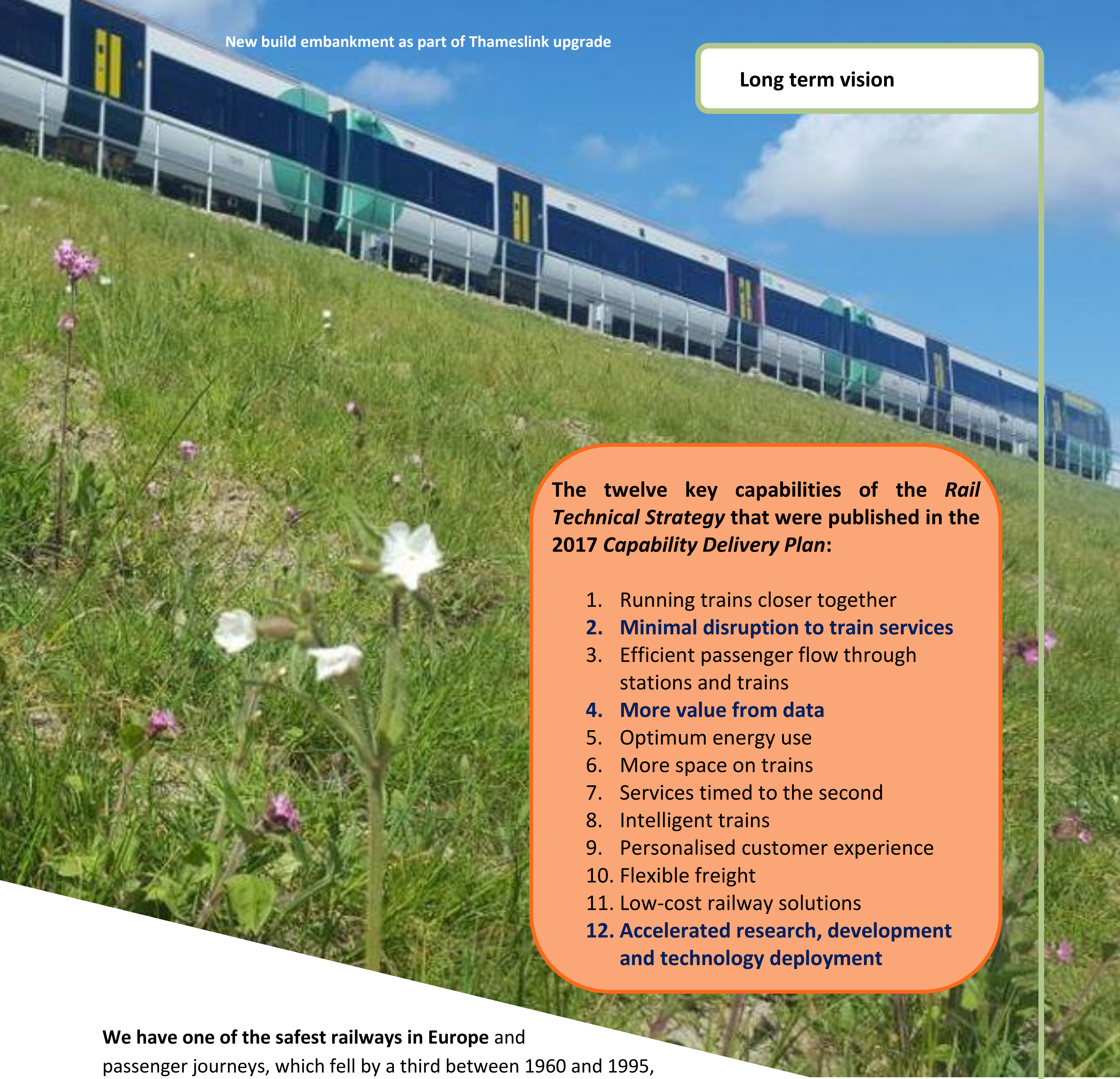
*"There will be an increase in renewals expenditure in CP6, particularly relating to structures and earthworks assets"*

**Sir Peter Hendy Report (2015) to the Secretary of State for Transport on the replanning of Network Rail's Investment Programme**

Rock cutting at Patchway Gap (Western) following de-veg, scaling and netting installation



# Long term vision



New build embankment as part of Thameslink upgrade

**The twelve key capabilities of the *Rail Technical Strategy* that were published in the 2017 *Capability Delivery Plan*:**

1. Running trains closer together
2. **Minimal disruption to train services**
3. Efficient passenger flow through stations and trains
4. **More value from data**
5. Optimum energy use
6. More space on trains
7. Services timed to the second
8. Intelligent trains
9. Personalised customer experience
10. Flexible freight
11. Low-cost railway solutions
12. **Accelerated research, development and technology deployment**

**We have one of the safest railways in Europe** and passenger journeys, which fell by a third between 1960 and 1995, have since doubled (DfT 2017). This growth has brought its own challenges, with Britain having some of the most congested and intensively used railway lines in Europe. Rising demand is putting significant pressure on the railway infrastructure. Intensive use and ageing assets put service reliability at risk.

Up to £34.7bn will be spent in the five years from 2019 to 2024 to fund an overhaul of the network, including a huge increase in asset renewals which will improve reliability and reduce disruption (DfT 2017).

We will embrace the twelve key capabilities of the Rail Technical Strategy (above), focussing on accelerated R&D, harnessing more value from existing data sets (to better focus safety interventions) and minimising the disruption to train services from increased and better targeted capital interventions. A key enabler to this vision is continued recognition to the 2014 DfT report, which identified the need to progressively strengthen the physical resilience of earthworks on the network.

**We want to be established as globally recognised experts in earthworks asset management through harnessing knowledge, continuous improvement and exploiting emerging technologies.**

Soil nail installation on an embankment in Anglia as part of a strengthening renewal scheme

We are building on the incremental improvement that have been made over the last 20 years in managing a unique and challenging asset base.

We aspire to see an infrastructure that is free from service affecting earthwork failures, and one where the directly interfacing drainage and vegetation assets are sustainably managed. This is a long term vision that can only be delivered over multiple control periods. We recognise that we need to strengthen the asset base and balance this correctly to find the right compromise when there are competing needs from different asset groups. Putting this into context our current rate of strengthening via renewal / refurbishment is typically between 0.5% and 1.0% of the asset base every 5 year control period.

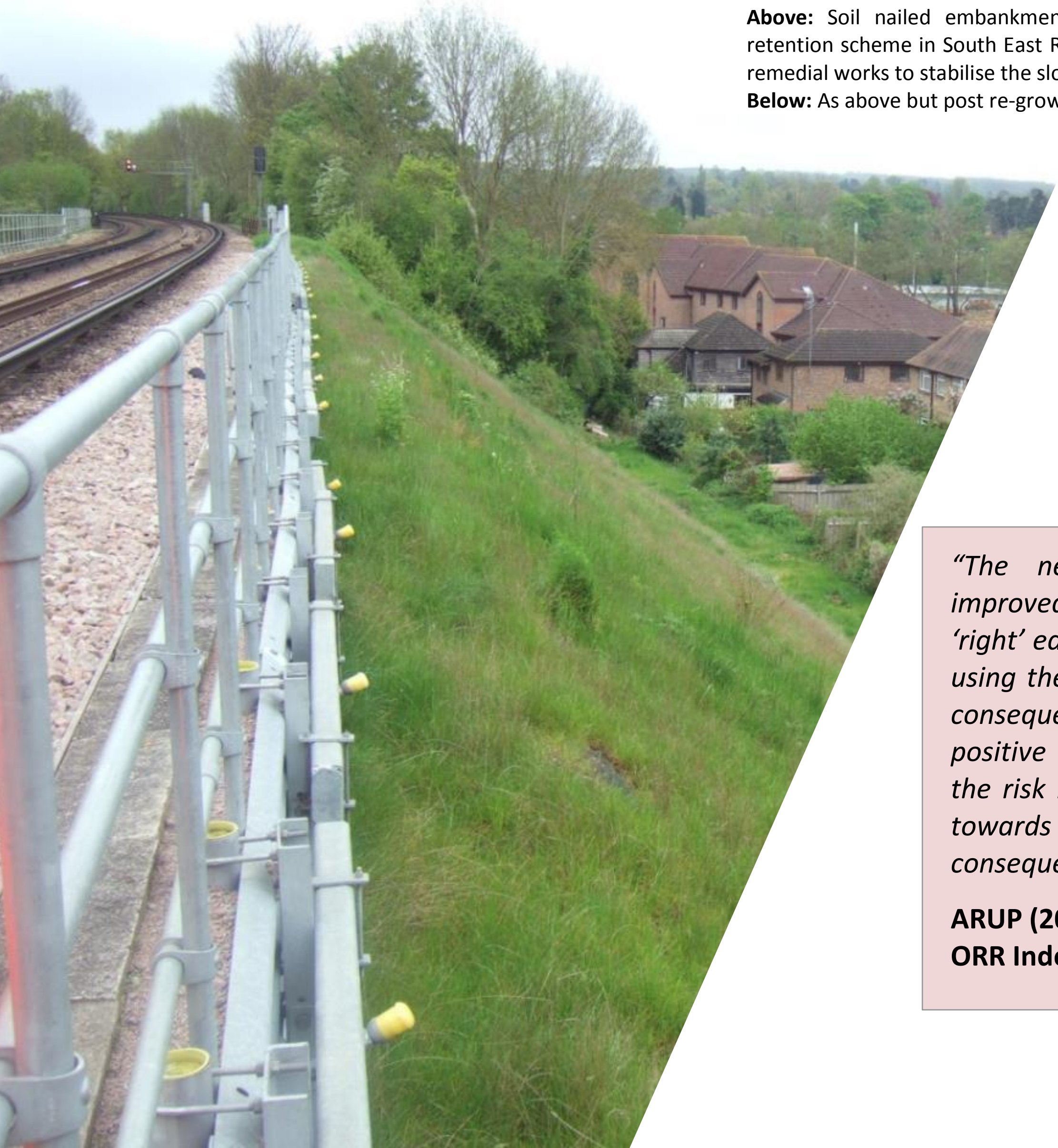
Advances in technology are fast and we are fully committed to engaging with other industries to explore emerging innovation as we recognise the benefits that uptake could potentially deliver. We are committed to researching, developing and trialling new capabilities where they align to our objectives and strategy.

Specifically the short and long term visions of the earthworks asset include:

- *Maintaining and improving the current levels of safety and performance*
- *Provide people in our engineering and asset management communities the opportunity to do what they are best at every day, enabling them to add the most value in the available time*
- *Coherently articulating the vulnerability from legacy design and how the capability / resilience of the geotechnical portfolio should be compared against modern infrastructure / design codes*
- *Improving asset capability through progressive strengthening from commitments in funding, to improve the resilience and reliability of the asset base to perform in a changing and evolving climate*
- *Standardising and increasing the deployment of condition monitoring, failure detection alarms and the process for analysing data to implement mitigation controls*
- *Planning for automation from available technologies to improve the quality, efficiency, repeatability and reproducibility of asset inspections and evaluations*

**Rail infrastructure running parallel to highway infrastructure**

New cutting slopes appropriately designed and constructed on the Stafford enhancement programme, a £250m upgrade between Stafford and Crewe, that included the construction of new 100mph railway over six miles. Image from March 2016.

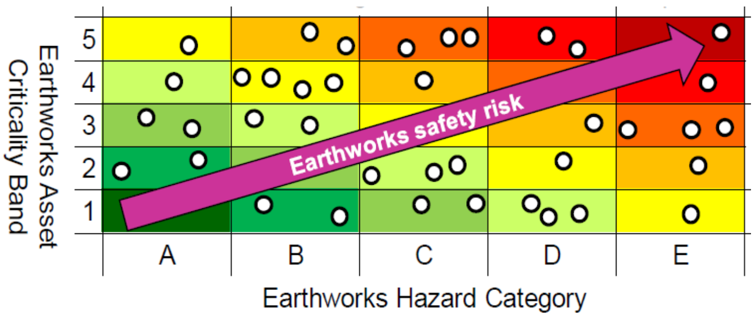


**Above:** Soil nailed embankment with a micro piled crest retention scheme in South East Route following completion of remedial works to stabilise the slope.
**Below:** As above but post re-growth of lineside vegetation.

> *"The new policy…provides an improved way of selecting the 'right' earthworks for intervention using the new EHC index and the consequence scale. It is very positive that NR have extended the risk based principles to move towards a common 'cross-asset' consequence scale."*
>
> **ARUP (2015)**
> **ORR Independent Reporter**

Asset Management is defined as *“the coordinated activity of an organisation to realise value from assets”*, where an asset is an *“item, thing or entity that has potential or actual value to an organisation”*

**ISO 55000 (2014)**
**Asset Management – Overview, principles and terminology**



Earthworks Safety Risk Matrix (ESRM) formed from asset condition data (hazard category) and consequence (criticality band) data

People are the key to successful asset management. We enable good decision making through the development of good quality engineers who are assessed through a competency framework. In 2012 we published an asset specific Earthworks Policy for the first time. The policy has continually improved and gone through independent assurance as we mature in our journey towards asset management excellence.

The policy is centred on the management of safety risk, which can be measured by the distribution of assets within the Earthworks Safety Risk Matrix (ESRM). The policy specifically recognises embankments, soil cuttings and rock cuttings as sub-sets of the earthwork portfolio. The key objectives of the policy are to:

- Prevent portfolio level condition degradation or risk growth
- Prioritise sites with highest safety risk (informed by the ESRM)
- Optimise the number of assets improved in condition for a given level of funding
- Adopt a lowest whole life cost approach balancing operational and capital investment
- Focus primarily on assets that pose the greatest likelihood of derailment, targeting works on rock cuttings over soil cuttings and soil cuttings over embankments
- Adopt a proactive approach to intervene prior to reduction in level of service

Through satisfying the above objectives, we aspire to maintain and incrementally improve the earthwork asset resistance to the threat from adverse and extreme weather.

Whole life cost models are used to forecast and inform work volumes, outputs and expenditure at portfolio level. Whilst forecasting and uncertainty go hand in hand we continue to update our degradation modelling from asset inventory data to best inform modelling rules.

Currently Route businesses produce the specification of physical interventions in tactical decision support tools (DSTs) and with refinement these requirements are consolidated into Route asset management plans.

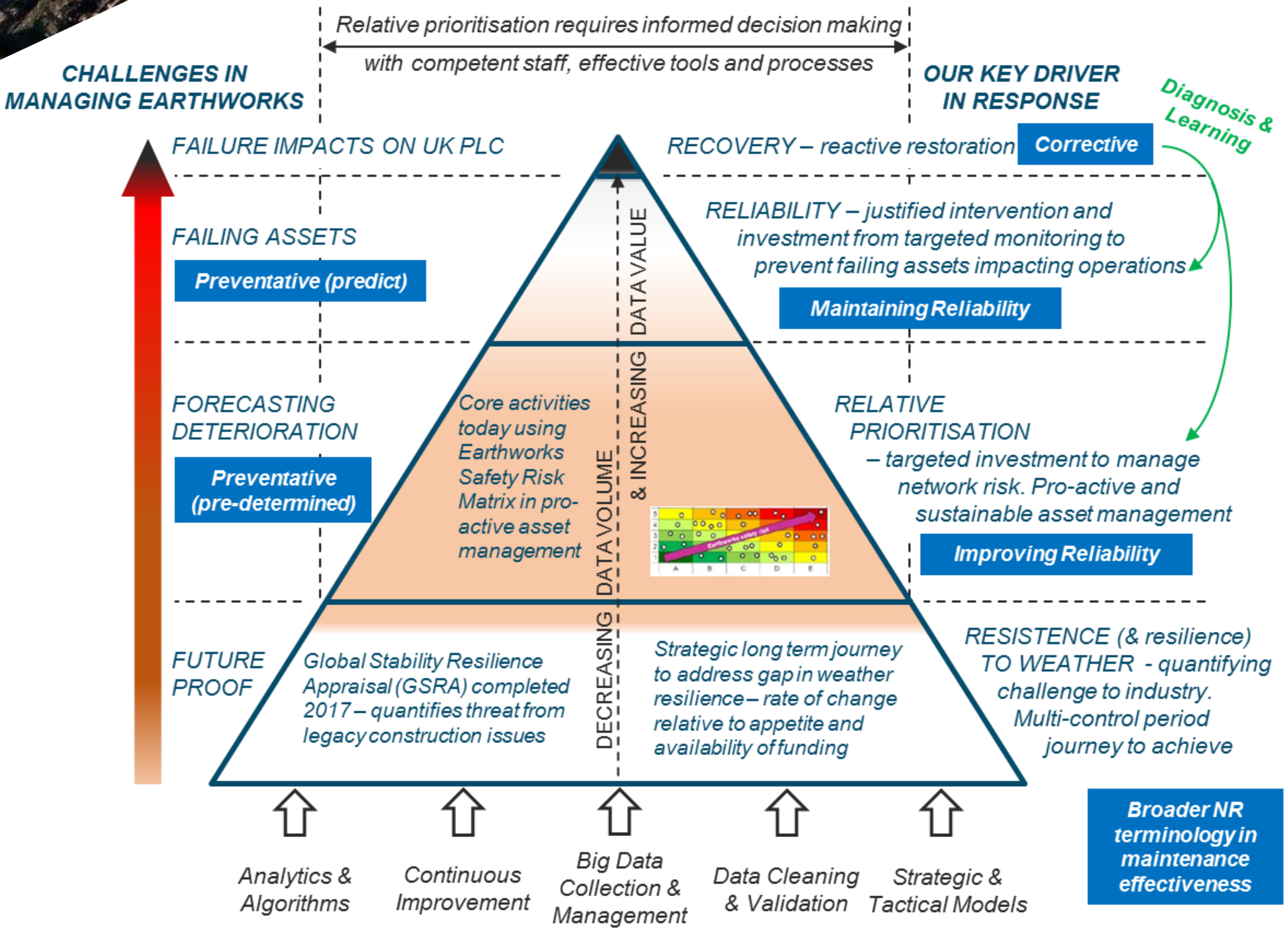
Management plans within the Routes consist of a range of intervention types; renewal, refurbishment and maintenance on embankments, rock cuttings and soil cuttings. Policy provides guidance on the type of capital investment that would be applicable to the relative risk within the portfolio. Strategic whole life cost models are used to provide guidance on activity levels to deliver the policy objectives.

*“In making asset management decisions, it is important to find the right compromise between competing interests”*

**Anatomy of asset management (2015), Institute of Asset Management**

Installation of soil nails into the upper slope of an embankment using a specially developed rig for operating on steep ground. Note blue covers on slope protecting borehole that were commissioned to obtain soil samples, material parameters and the installation of sub-surface monitoring.

**Figure below:** Challenges associated with managing the earthwork portfolio, the key drivers in Network Rail's response and the high level processes to allow effective decision making.



Relative prioritisation requires informed decision making with competent staff, effective tools and processes

RECOVERY – reactive restoration

RELIABILITY – justified intervention and investment from targeted monitoring to prevent failing assets impacting operations

RELATIVE PRIORITISATION – targeted investment to manage network risk. Pro-active and sustainable asset management

RESISTENCE (& resilience) TO WEATHER - quantifying challenge to industry. Multi-control period journey to achieve

Core activities today using Earthworks Safety Risk Matrix in pro-active asset management

Global Stability Resilience Appraisal (GSRA) completed 2017 – quantifies threat from legacy construction issues

Strategic long term journey to address gap in weather resilience – rate of change relative to appetite and availability of funding

*"The Asset Policy is underpinned by inventory, condition and failure data. It is very positive that NR are continuing to develop their earthworks asset knowledge and are taking measures to improve data quality."*

*"Since December 2012, NR have spent considerable effort in reviewing the earthwork examination data (for soil slopes) to investigate and improve on the relationship between condition and failure. This has involved detailed statistical analysis to try to better represent the likelihood of failure by weighting particular key condition features. This is very positive."*

*"We consider that the development of the 'common consequence tool' (CCT) to support cross-asset safety investment trade-off decisions is a very significant step forward. The potential benefit was indicated in our SBP Review, where we identified that cross-asset trade-offs were an area for future development."*

**Arup (2015)**
**Office of Rail Regulation. Part A Reporter Mandate AO/049: Review of updated Earthworks Asset Policy for CP5 years 3-5**

Definition of infrastructure resilience, Cabinet Office (2011)

Capital investment in earthworks improves safety, reliability and weather resilience. The legacy issues associated to asset construction will continue to be a root cause of failures across the portfolio.

NR has previously published Route Weather Resilience and Climate Change Adaptation (WRCCA) plans. These predominantly focus on short term initiatives to drive local improvements in resilience. Aside from identifying areas where work over and above policy is required these plans focus on business case investments that can be evidenced from analysis of historical events.

Achieving weather resilience for the earthworks portfolio is a long term journey that will require investment over multiple control periods. Recent outputs from continuous improvement (delivery of Global Stability Resilience Appraisal) enable us to start quantifying the gap in capability between our portfolio and that which we would expect from modern designed infrastructure slopes.

Resilience is the ability of assets, networks and systems to anticipate, absorb, adapt to and / or rapidly recover from a disruptive event. The cabinet office define infrastructure resilience as having four components; resistance, reliability, redundancy and response & recovery. The DfT (2014) suggested "*that the physical resilience of the network is progressively strengthened in future years*" following multiple catastrophic earthwork failures in the winter of 2013/14.

Hence resilience of infrastructure is provided through (a) good design of the network and systems to ensure it has the necessary resistance, reliability and redundancy (spare capacity), and (b) by establishing good organisational resilience to provide the ability, capacity and capability to respond and recover from disruptive events.

We are committed to regularly reviewing the effectiveness of our policy and adding new components that better the policy's ability to inform and deliver improvements. The trajectory for achieving resistance for infrastructure resilience / weather resilience is a multi-control period journey. The figure opposite shows that the majority of challenges from failures, failing assets and forecasting deterioration are met today with rapid corrective recovery, maintaining existing reliability and improving reliability. The challenge to future proof, if desirable, is yet to be fully augmented into policy for what can only be a multi-control period journey. Quantifying what is achievable and communicating this in our policy will be an important step.

**Above:** Hooley cutting within South East Route nearing completion of significant renewal works; consisting of slope regrading, soil nailing and a beam and grillage installation with micro piles. The extensive cutting experienced multiple failures since 2000 with two resulting in train derailments.

## Selected events that have enabled an increasing exploitation of knowledge and continue to enable the evaluation of risk and development of proportionate treatments

- *1990's – British Rail Soil Mechanics divisions sold off. Drainage knowledge lost*
- *1995 – Fatality at Ais Gil landslip (last attributable fatality directly related to earthworks)*
- *2000's – Recruitment of first specialist Area / Territory geotechnical engineers*
- *2001/02 – Earthwork TSR reporting commenced*
- *2003/04 – Earthwork volume reporting commenced*
- *2004/05 – Earthwork Failure reporting commenced*
- *2005/06 – Electronic data capture of defects commenced during earthwork inspections*
- *2007/08 – RAIB report 'Management of Existing Earthworks'; identifies good practice and opportunities to transform*
- *2011/12 – Devolution of functional engineering into route based teams. Project Darwin identifies shortfall in critical roles to manage civils assets and provides catalyst for increasing templated roles in geotechnics and drainage*
- *2012/13 – Asset specific Earthwork Policy Issued for the first time (based on risk)*
- *2013/14 – RAIB report 'Class investigation into landslips affecting NR between June 2012 and February 2013'; identifies further opportunities for improvement*
- *2013/14 – Network Rail's delivery plan for CP5 published. Contains earthwork specific volumes for the first time and KPI's for reliability and sustainability*
- *2014/15 – Evidence based statistical examination system deployed into business*
- *2015/16 – Restructuring of technical authority. Role of Chief Civil Engineer created, into which five Professional Heads report.*
- *2016/17 – Asset inventory complete*
- *2017/18 – Publication of updated standards following comprehensive overhaul*
- *2017/18 – Launch of British Geological Survey Outside Party Slope Hazards for trial*
- *2017/18 – Launch of GSRA into the business for trial*
- *2018/19 – Planned deployment of Civils Strategic Asset Management Solution (CSAMS)*
- *2018/19 – Planned completion of Intelligent Infrastructure 'remote failure detection' pilot*
- *2019/20 – Commencement of CP6 with fully populated 5 year capital and operational investment plans aligned to deliver policy objectives within constraints of available funding*

# Continuous improvement

**Above:** Site investigation taking place within a possession to obtain material properties of a cutting slope and install sub-surface monitoring instrumentation

Since the fatality at Ais Gil in 1995 we have continually improved our management processes. Earthwork assets are now recognised in their own right as an asset group that require maintenance and renewal to provide the levels of service that we aspire to deliver from the railway system.

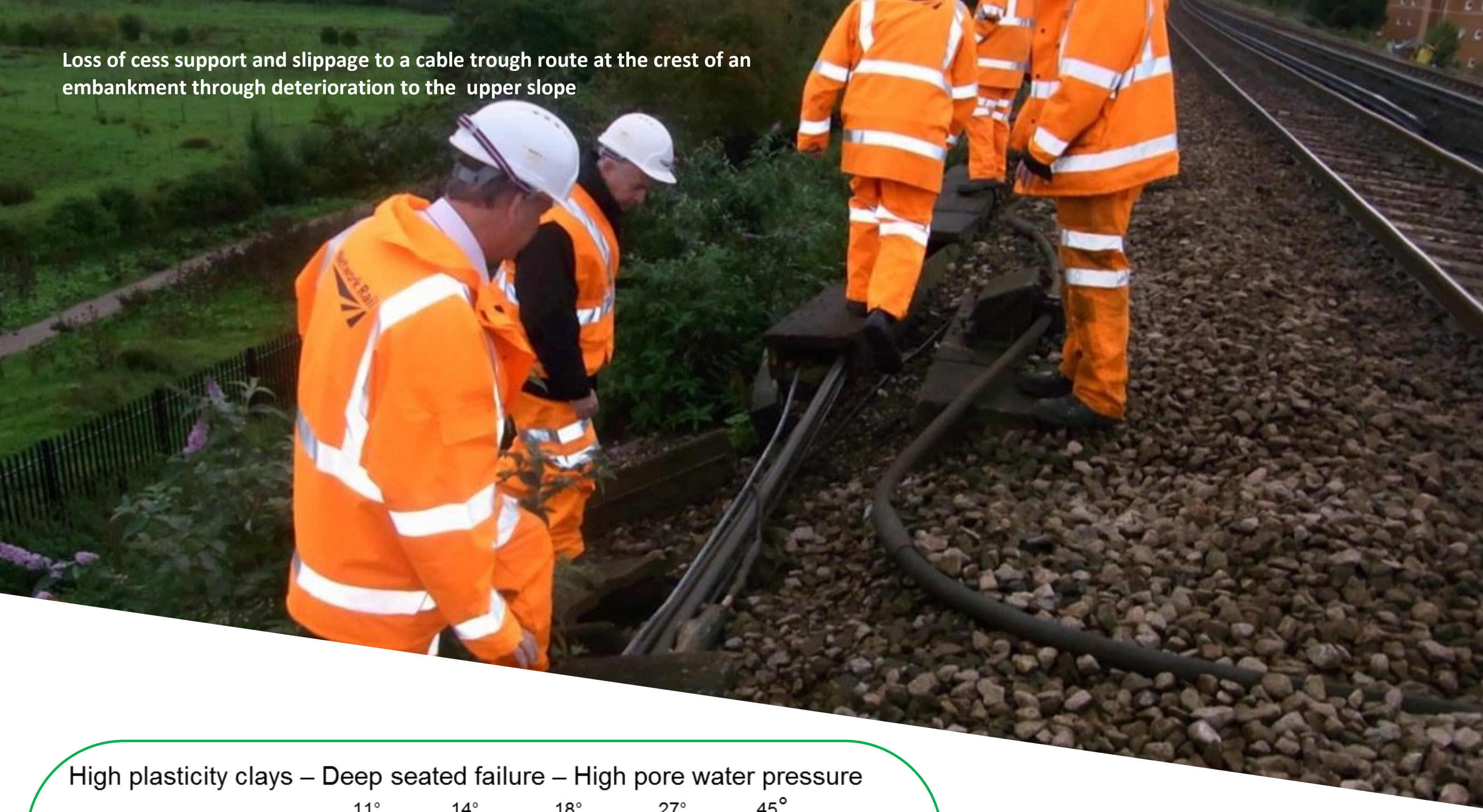
Managing our earthwork assets is challenging and we recognise that uncertainty is at its greatest when it is not possible to differentiate between the relative likelihoods of an event occurring or not (Lee 2016). We recognise the value in continuous improvement to enhance our performance, minimise inefficient use of resources and to reduce uncertainty.

We are committed to reviewing the effectiveness of our controls and seeking out improved approaches.

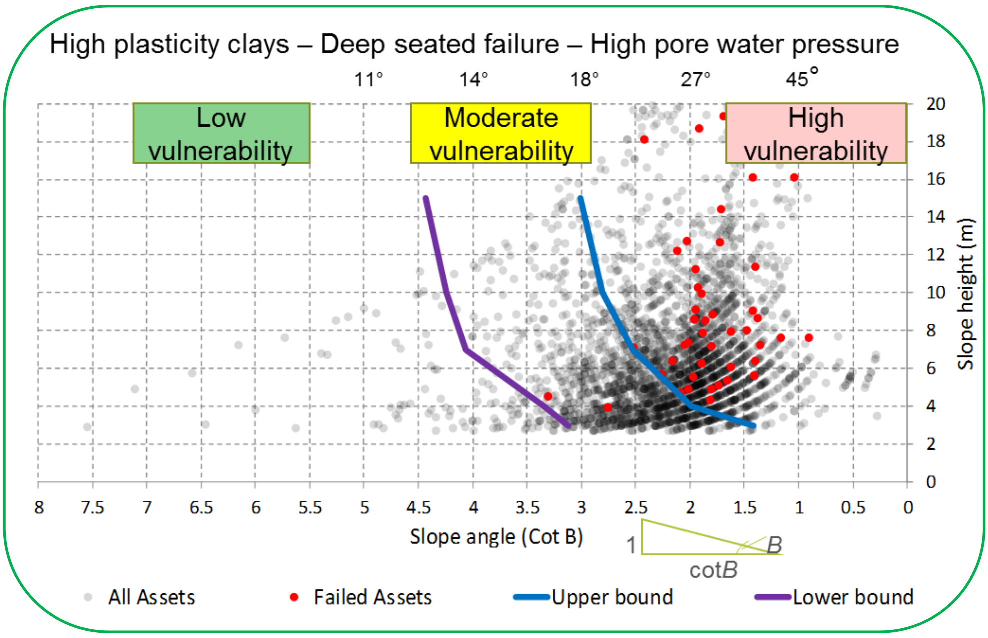
One of the most important improvements was the recalibration of the examination system and launch of an evidence based statistical approach in 2014/15. This improved the capability of the core examination tool to identify those assets most likely to fail. This work replaced a qualitative model, where earthworks were described as ‘poor’, ‘marginal’ and ‘serviceable’. These emotive terminologies were difficult for the wider business and industry to understand. Quantitative probability scales now allow the objective and clear articulation of the expected likelihood of a slope failure from within each category of hazard classification.

Recent improvement and further exploitation of knowledge also include:

- The Classification of Hazards from Outside Party Slopes (CHOPS), an initial desk based assessment in conjunction with the British Geological Survey for enabling potential threats to be quantified
- Quantification of the portfolio against modern design codes via the Global Stability and Resilience Appraisal (GSRA) study, which is discussed next.

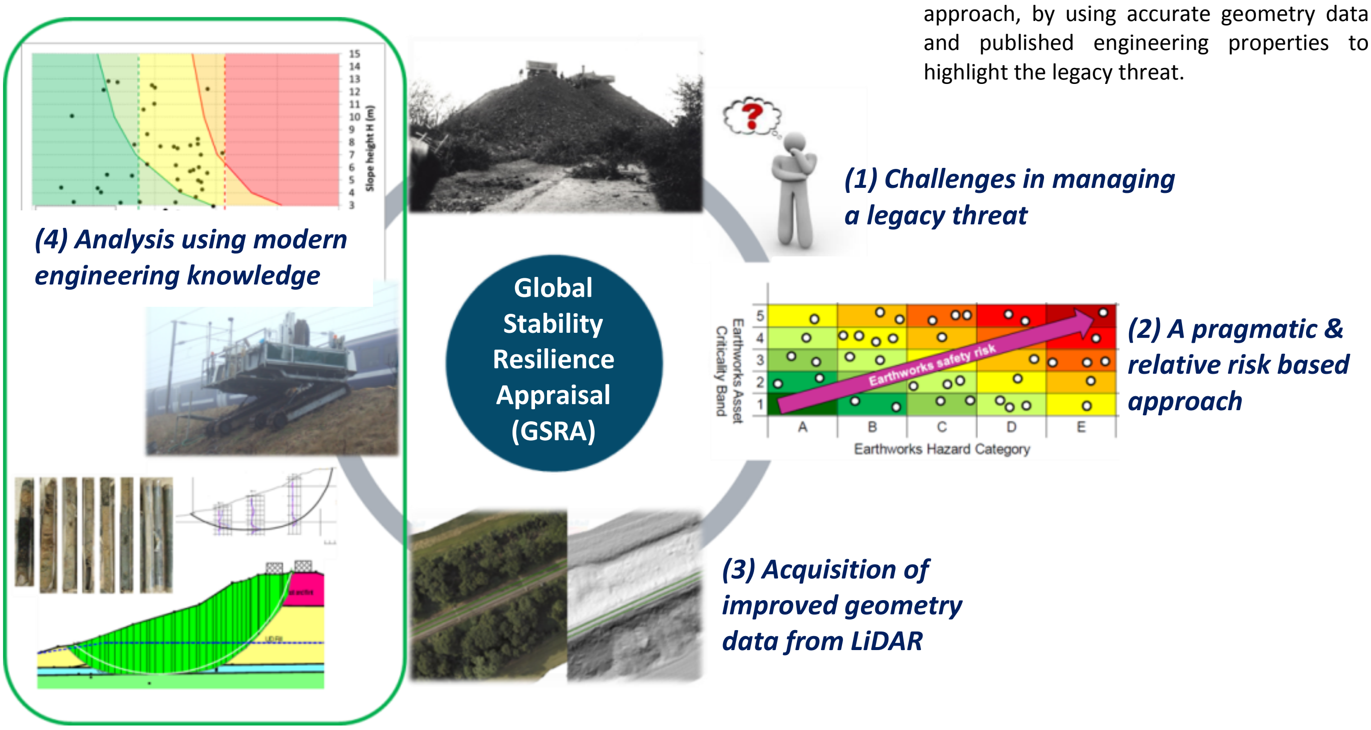


Loss of cess support and slippage to a cable trough route at the crest of an embankment through deterioration to the upper slope



**Left:** GSRA plot for the grouping of high plasticity clays. Distributions of asset population shows majority of slopes contain a legacy threat of inadequate geometry design. Upper bound line represents a Factor of Safety (FoS) of 1.0 using best credible parameters. Lower bound line represents a FoS of 1.0 using worst credible soil parameters. The distribution of failed assets points to the root cause being legacy geometry design.

**Below:** How LiDAR data has enabled the development of GSRA to build on a risk based approach, by using accurate geometry data and published engineering properties to highlight the legacy threat.




Reinstatement of cess support with a micro piled retaining wall and handrail

The development of a Global Stability Resilience Appraisal (GSRA) was undertaken to improve our strategic understanding of the resilience (or resistance) of the earthwork portfolio across the network. It will support Network Rail in articulating the capability of the earthworks portfolio and will assist in providing realistic expectations to the industry of the vulnerability of the earthwork asset base.

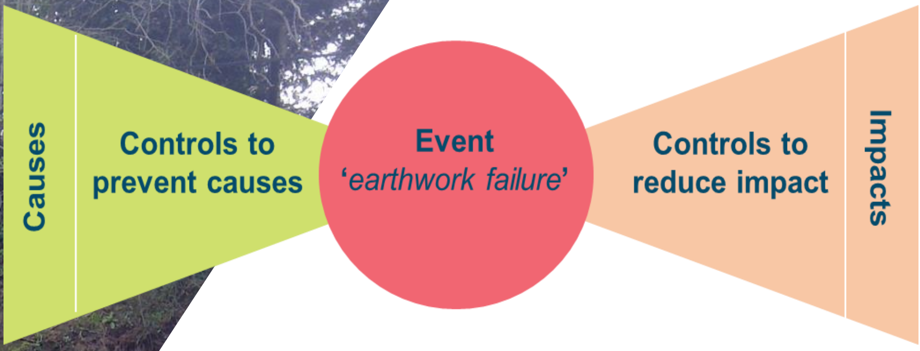
With GSRA we are now moving towards a capability where we can readily define the difference between the stability that would be provided by a modern engineered slope against any slope from within our infrastructure portfolio. The continuous improvement in data utilisation allows for the articulation of capability that has frequently been discussed and qualitatively reported but not yet objectively defined.

Tactically the initial outputs from GSRA have been deployed into the asset management community for visibility and use alongside existing tools. We are already focussing on how we can refine this tool as we move towards future systemisation and feedback will play an important part. Improvements will consider:

- How data will be used and visualised during evaluations
- Usage in diagnosing failures and the validation of capital investment plans
- Integrating improved vegetation metrics, noting vegetation type and coverage have a direct impact on pore water pressures and soil suction; factors in slope stability
- Identifying historical interventions
- Facilitating the filtering of modern interventions

Whilst the catalysts for continuous improvement will often come from failure investigations, we are committed to regularly challenging how we can better ourselves. We believe in continuous improvement and will regularly review our performance by assessing the effectiveness of our controls and seeking out improved approaches for all aspects of managing our portfolio. GSRA is one way in which we are continuing to better ourselves by exploiting data for improved capabilities in decision making.

Earthwork inspection by rope access



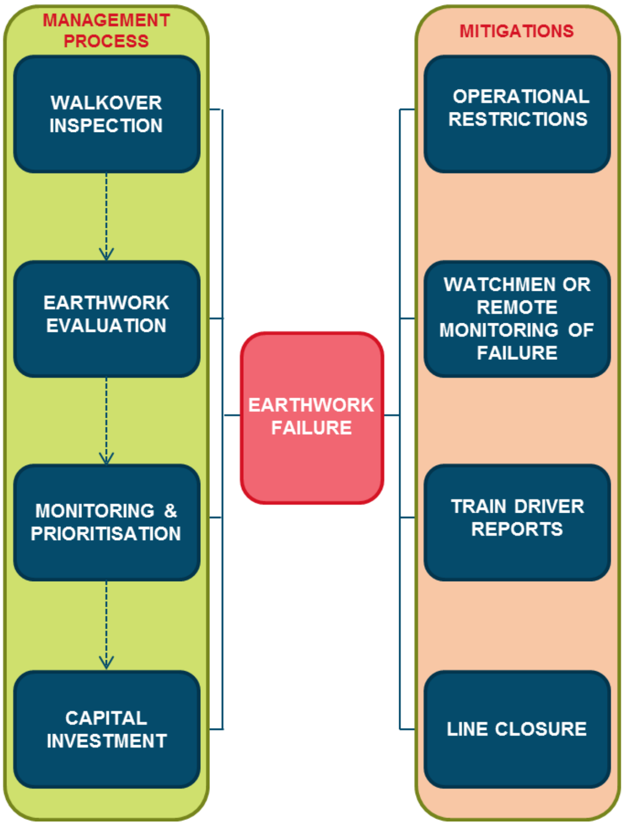
> *"The source of geotechnical risks are geotechnical hazards. It is important to recognise that the specific locations of certain ground hazards would require an unrealistic and unreasonably large amount of site investigation to locate"*
>
> *"There are some geological conditions that are 'unforeseeable', and when those conditions are encountered there will inevitably be some undetectable variations in the geology that can never be completely investigated within practical limits"*
>
> **Baynes (2010) Sources of geotechnical risk**

> *"Perceptions of risks do not provide sound bases for ethical judgements…or for proper husbanding of resources"*
>
> **Hanby (1994) Risk evaluation and realism**

**Below:** Simplified earthwork bow tie showing causes to failure events, management processes to reduce threats / prevent causes, and mitigations (controls to reduce impacts from an earthworks failure)

**Causes to events include:**

- Adverse / extreme weather
- Inadequate legacy design
- Asset degradation
- Surface water / groundwater
- Scour
- Impact from other NR functions
- Outside party activities
- Vegetation
- Increase in traffic loading
- Geological solution features
- Animal burrowing
- Climate Change
- Rock mass characteristics
- Peat wastage



**Impacts from event include:**

- Fatality
- Injury or trauma
- Derailment
- Performance delay
- Financial
- Damage to NR assets
- Damage to third party
- Reputational
- Environmental

# Geotechnical risk management

Geotechnical risk is something associated with the ground that would have an adverse consequence were it to occur. Geotechnical risk management aims to reduce uncertainty enabling us to make informed decisions and best utilise resources. Certain types of hazard may require an unreasonably large amount of investigation to locate and these can never be completely investigated within practical limits.

Bow tie risk management tools can be used to present the causes and impacts from a top event (i.e. a landslip), alongside the accompanying controls to prevent events and reduce the consequences. We have adopted bow tie techniques to improve our processes in managing the risk from and to operational assets.

A simplified bow tie diagram is shown on the opposite page. The first step in our management process is the walkover inspection, where features of slope instability such as soil creep, slumping, cracking or bulging are recorded. Known as geomorphological mapping this is a recognised and reliable method for early recognition of earthwork deterioration (Laimer 2017).

We recognise that we shall continue to experience asset failures as a result of the legacy asset we manage. It is not currently reasonably practicable to prevent all asset failures, so we are continuing to focus on improving mitigation techniques on the right hand side of the bow tie to reduce the consequence of a top event.

When we identify that an event could occur, there will be uncertainty about the timing and magnitude. Uncertainty in our knowledge and within the geotechnical engineering profession is normal. Sources of uncertainty include (after Lee, 2016):

- *Model uncertainties*, reflecting the extent to which particular stability models provide accurate representations of the slope behaviour; this arises from the approximations required in the development of a conceptual ground model
- *Parameter uncertainties*, often arising from time and resources constraints on the site investigation sampling and testing programme, measurement errors or sampling that is unrepresentative of actual conditions
- *Expertise uncertainties*, reflecting the expertise and biases of the experts involved and the way in which particular methods of analysis are selected, such as a probabilistic assessment approach
- *Unacknowledged uncertainties*, where the possibility of an event is not even considered, including so-called 'black-swan events' that are highly improbable

**Images: partially blocked culvert (top), rotational failure within an embankment (middle) and an inspector walking the track (bottom)**

**Images:**

- ***Above left:*** Material on track following debris flow at Lochailort during August 2016 following 75mm of rain in 24hours. Main source of material originated several hundred metres from NR boundary.
- ***Above right:*** Installation of rock netting anchors following failure post refurbishment intervention. Unforeseeable geological details (as described in the table below) resulted in large limestone block detaching from the cutting face several weeks after extensive scaling
- ***Opposite left****:* Inspection and de-vegetation of an earthflow failure near Killiecrankie tunnel in Scotland during January 2016
- ***Opposite right***: Remote track monitoring installed at a problematic / failing embankment in Western Route whilst awaiting intervention

| Type of Geotechnical Risk | | Hazard | Source |
|---|---|---|---|
| Project management | | Poor management of part or all of geo-engineering process | An *inadequate understanding of the importance of ground conditions* resulting in poor management of geo-engineering project processes |
| Contractual | | Poor management of site investigation and contract documentation | An *inadequate understanding of the importance of ground conditions* resulting in poor acquisition, understanding and/or communication of site investigation information; this often leads to claims based on contractually unforeseen ground conditions |
| Technical (Project level) | Analytical | Unreasonable analytical model chosen | An *inadequate understanding of ground conditions* and analytical methods, resulting in an unreasonable choice of analytical models |
| | Properties | Unreasonable design values chosen | An *inadequate understanding of ground conditions* and field and laboratory testing, resulting in an unreasonable choice of design values |
| | Geological | Unforeseeable geological details | *Geological conditions* that are very variable, and because investigation of all geological details in impractical |
| | | Inherently hazardous ground conditions | *Geological conditions and geological processes* that involve hazards such as large ground movements, voids, aggressive chemistry, erosion, etc. |
| | | Unforeseen ground conditions | An *inadequate understanding of geological conditions* resulting in unforeseen ground conditions being encountered during construction, often because of an inadequate site investigation due to poor project management |
| Asset management (Portfolio level) | | Inherent infrastructure profiles of both condition and risk | An *inadequate level of investment to manage in accordance with corporate appetite*; often as a result of high level decisions, a lack of resources and limitations associated with understanding portfolio behaviour. |

**Sources of Geotechnical Risk Table;** modified after Baynes (2010).

The different types of geotechnical risk in existence are summarised in the table opposite. We recognise there are many challenges not immediately associated with the physical asset in its operational state. These issues or types of risk are commonplace across the wider geotechnical industry, particularly as engineering projects evolve. It is suggested (Baynes 2010) that geotechnical risks associated with cost and time over-runs might occur in 20-50% of projects. It is also reported that physical failures will occur in around 0.1-1% during construction and up to 20% in mines and quarries, reflecting a greater appetite for risk in the mining sector.

Our main purpose is geotechnical risk management and it is therefore imperative that we continue to:

- Implement our Earthworks policy and seek to continually improve our risk control framework
- Support, coach and develop our people
- Communicate asset capabilities, uncertainties and requirements to meet corporate expectations
- Enhance the engineering competency and capability framework
- Maintain and seek to improve the established engineering assurance processes
- Deliver functional audit plans (FAP) and engineering verifications (EVs)
- Provide suitable and frequent opportunities for sharing knowledge and issues of concern
- Use risk registers for overall management and for documenting residual risks
- Comprehensively investigate ground conditions using a multi-staged approach as necessary
- Adequately value geotechnical data and store it appropriately for future use
- Undertake appropriate diagnosis to yield learning from failures and incidents
- Explore opportunities to peer review key project milestones in complex ground conditions
- Support research and apply learning to evolve and continually improve

*"New digital tools allow for more options to be considered when looking for the best solutions to the challenges facing the railway. One of the options ready to be deployed are new traffic management systems, which can be installed in signalling centres to help drivers and control staff keep trains running on time, and speed up recovery from service disruption. These systems are a priority because of their ability to reduce delays and maximise the efficiency of our existing infrastructure"*

*"The use of digital technology is a huge opportunity for rail. These technologies will help the railway of the future make better use of the existing infrastructure and capacity…, and find much more sustainable solutions which are lower cost for rail users and taxpayers"*

*"The benefits of c-DAS are based on getting a train to arrive at a given location at the correct point in time, travelling at the most efficient speed. This can avoid timetable conflicts with other trains, and it can avoid the need to brake at signals, reducing wear and tear on the train and the track, saving money and improving reliability"*

*"In addition to Traffic Management and c-DAS we plan to bring forward a new generation of digital signalling (European Train Control System) to our railway, moving signals from the side of the track into the driver's cab on the train. This transition will be targeted as current signalling systems come to the end of their useful life, or earlier if it is the most cost-effective way to deal with capacity and reliability challenges"*

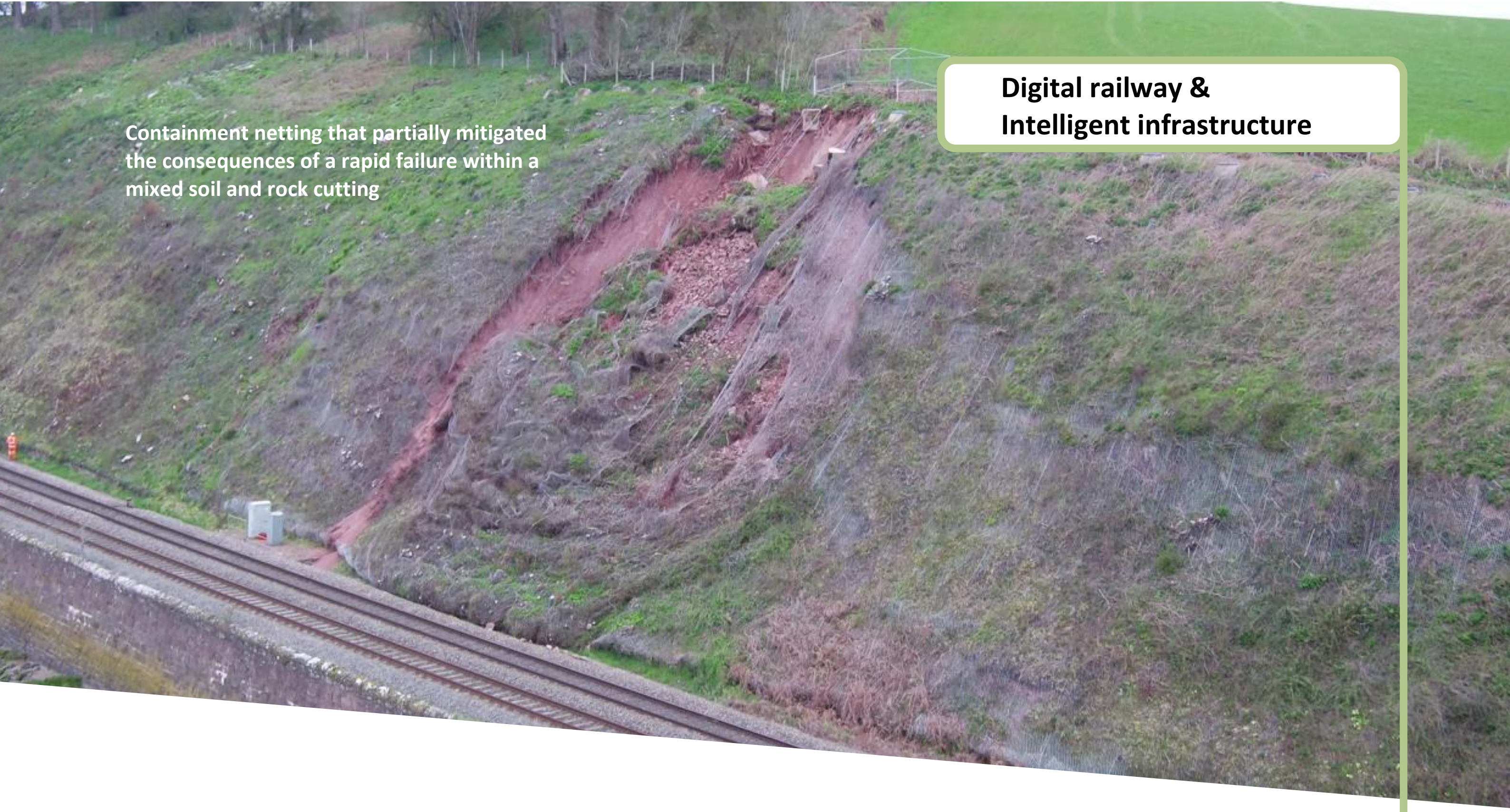
**Digital tools will make journeys better for passengers**

**Traffic Management:** The "brain" behind digital signalling. It maximises the throughput that existing track can support, and adapts the timetable in real-time as operational conditions change, aiding a rapid recovery.

**Connected-Driver Advisory Systems (c-DAS):** Provides decision support to drivers, aiding performance, safety, and fuel efficiency.

**European Train Control System (ETCS):** Removes signals from the trackside, and places them in the driver's cab. Allows trains to run closer together, at their optimum speed, while maintaining safety.

**DfT (2017) Connecting people: a strategic vision for rail**



Containment netting that partially mitigated the consequences of a rapid failure within a mixed soil and rock cutting

The primary focus for the Digital Railway programme is to deliver sustainable asset costs whilst switching to digital technologies to deliver targeted improvements to capacity, train performance and safety. This principally includes addressing the capacity challenge by the closer running of trains through digital train control and driving down the cost of conventional signalling renewals to head off a crisis of unaffordability to renew existing railway assets.

Intelligent Infrastructure (II) will improve asset management across Network Rail; eliminating the majority of failures through product and maintenance regime design and capturing, analysing and exploiting asset data to make better planning decisions about investment in our assets. Improving the availability of our infrastructure by understanding what is likely to go wrong, when it will occur and the impact on the operational railway will allow intervention to prevent disruption to train services.

The II programme will apply Research, Development and Technology to improve existing capabilities, especially in the areas of monitoring assets, 'big data' analytics and work planning. This will be achieved by:

- Embedding reliability engineering into products and maintenance regimes
- Optimising embedded monitoring coverage
- Evolving train-borne monitoring / maintaining existing vehicle monitoring capability
- Transforming analysis and analytic capabilities
- Exploiting information systems, making Ellipse the core of all asset management activity
- Industrialising autonomous systems

## What does Intelligent Infrastructure mean for earthworks?

Fully embedded monitoring (which would be disproportionately expensive across the portfolio) is still unlikely to enable intervention in advance of all failures because of the variety of failure modes and velocities of slope collapse. The biggest opportunity that can be realised from these initiatives is for the integration of binary data (from remote failure detection technologies and train-borne monitoring) into operational procedures. With standardisation in data feeds and data platforms we could see improvements to safety and performance. Embedded sub-surface monitoring is a costly method of condition assessment and only installed where necessary. The process of predict and prevent is in use today and the majority of capital investment is already targeted towards assets that are known to be actively failing.

Rebuilt embankment following catastrophic failure in 2013/14 with an anchored sheet pile wall. South East Route

**Mobile**

## 'My Work' App (Fieldreach)

- Allows for receipt and completion of varied Ellipse 'work orders tasks' on site
- Allows for data capture , review and update on site
- Allows for access to asset information, including previous exam reports (as PDFs)

## 'My Site' App (Geofield)

- Mobile CSAMS Rail Infrastructure Network Model (RINM) viewer - functions offline
- Allows for download of maps to use offline
- Allows for search and view of all civils assets across the network on site
- Allows for defect capture/ review on site

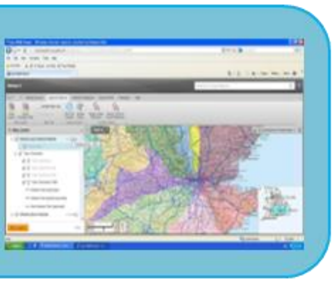
**Desktop**

## Ellipse

- Master inventory of Civils data
- A holistic, integrated, single view of information
- Work management tool
- Multiple search/filter options for data and exam reports
- Enables forecasting and tactical short/long term planning

## CSAMS Viewer

- Desktop CSAMS RiNM viewer
- Allows for search and view of all civils assets across the network
- Allows for defect capture/review
- Additional mapping to provide asset, defect and work context



## Dashboards & Reporting

- Multiple dashboards for data and trend analysis
- Metrics, statistics, asset count
- Presentation tools to display data and interactive filters to drill down
- Compliance and KPI reporting capability

Above: Visualisation of the key components that are part of the Civils Strategic Asset Management Solution (CSAMS).

**Face plates and connecting surface mesh following soil nail application to strengthen an embankment slope**

The information we extract from the data we hold as an organisation is a key enabler to intelligent decision making across the breadth of our asset management activities. Good data management enables successful strategic planning through long term demand analysis and whole life cost modelling. Building on our existing data management capabilities will facilitate improvements to our decision making, whilst reducing the uncertainty associated with determining long term capital and operational funding requirements.

The ORBIS* programme in CP5 set about revolutionising the way in which front line maintenance staff record, report and visualise data. This included the rollout of smartphones, tablets, apps and DSTs to unlock efficiencies in the planning and execution of work, including a reduction in the reliance of paper.

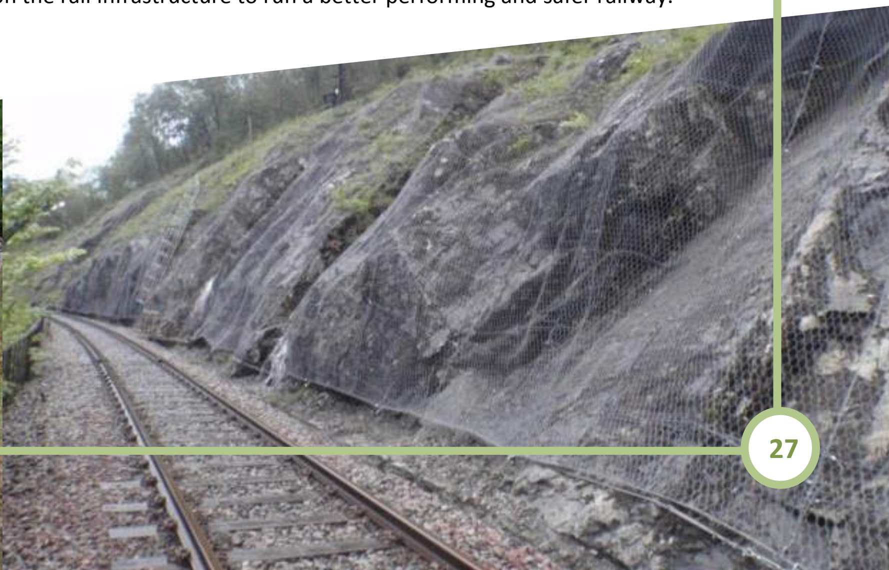
Earthworks were ahead of the ORBIS curve in relation to using technology to replace paper, with mobile handheld computing introduced in 2005/06 for the examination of earthworks. Structured data acquired in software is today synchronised onto a web based geographic information system (GIS). This system is used to undertake the examination and evaluation management phases.

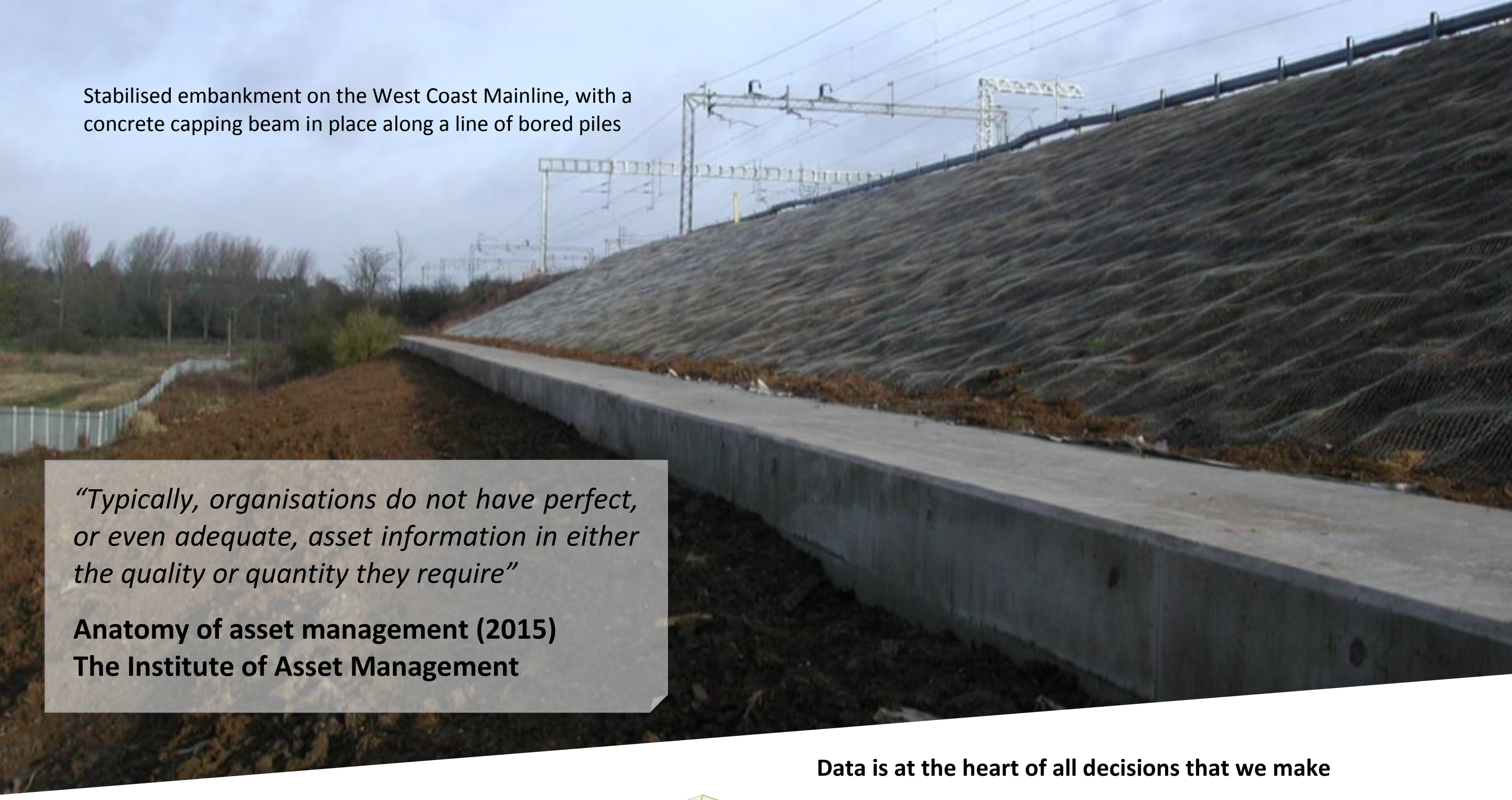
Our organisations dependency of the existing earthworks database is a good measure of its ability to deliver the functionality it was designed for. However, we recognise that this system is reaching life expiry, is not synchronised to the NR asset data store and does not provide the capability of work bank development.

We are committed to the delivery, rollout and successful uptake of a new integrated asset management system that will provide data storage facilities in a central corporate repository. A key driver for this change to the wider Civil Engineering community came from a tripartite review between ORR, NR and Arup in 2011. The Civils Strategic Asset Management Solution (CSAMS), see opposite page, will fundamentally change and improve the way our engineers work and interact with data. The integrated desktop components will provide structured facilities for the storage of data that is currently deposited in disparate locations. CSAMS will not solve every problem associated with data management but will be a step change to enable renewed focus on good asset data management that will benefit us today and those in future generations.

*Offering Rail Better Information Services (ORBIS) is a transformation programme designed to deliver digital solutions to improve how NR collects, joins and exploits accurate asset data on the rail infrastructure to run a better performing and safer railway.

**Below:** Testing of installed soil nails (left) and a rock slope with draped protection netting to prevent material reaching the track (right)

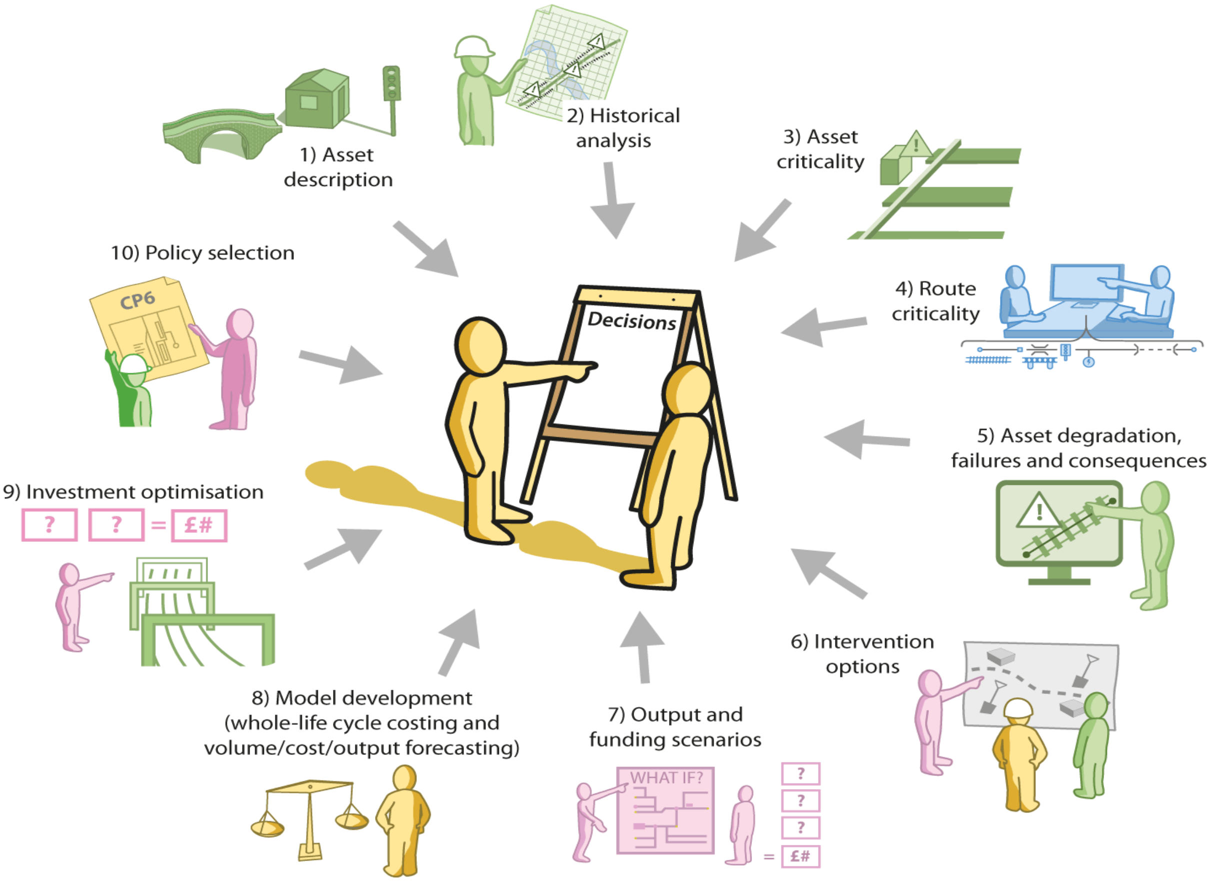




Stabilised embankment on the West Coast Mainline, with a concrete capping beam in place along a line of bored piles

> *“Typically, organisations do not have perfect, or even adequate, asset information in either the quality or quantity they require”*
>
> **Anatomy of asset management (2015)**
> **The Institute of Asset Management**

**Data is at the heart of all decisions that we make**



**Below:** Slope repairs on a cutting beneath a natural depression where water accumulates (left) and construction works taking place with temporary support to excavation (right)

## Data management

Geotechnical data is generated during various phases of an investment project. This may be as part of a wider programme of works such as an enhancement, in the development of a non-earthwork renewal or as part of investment directly related to earthwork improvement schemes. Geotechnical data associated with the ground is often expensive to acquire and will be generated at various times of a project, including:

- Site investigation and in-situ test results
- Laboratory results (strength tests etc)
- Monitoring information from sub-surface instrumentation
- Design stage (failure models and assessments)
- Construction data (pull out tests, compaction records, grout take etc)
- As built information (soil nails, rock netting, soil mixing etc)
- Maintenance (non-destructive testing etc)

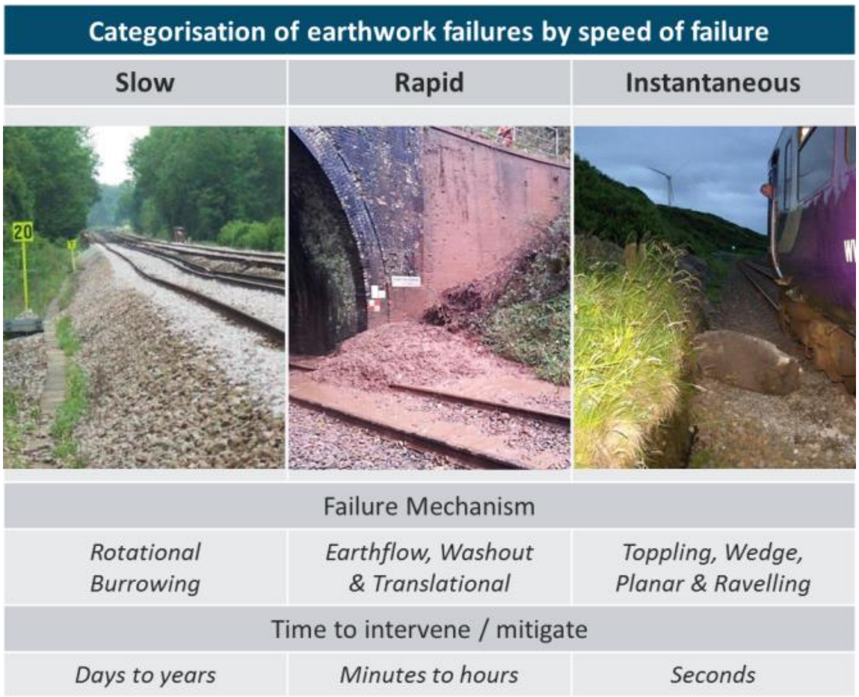
Standardised formats for the supply and transfer of geotechnical data in the UK are only formalised for the initial site investigation phase. The AGS data format allows easier sharing of information and is becoming increasingly common. It is an Network Rail policy requirement for all geotechnical data to be procured, transferred and stored in the electronic format of AGS.

We recognise that poor data management will create uncertainty and risk. This is no more evident than in well-planned and well-executed site investigations that are poorly documented. Deficiencies in adequate data storage will lead to difficulties in the future assessment and communication of ground conditions and hazards. We recognise this is one area for improvement throughout the organisation and it will require a cultural change for all engineers to put greater value on AGS data, protecting it for future generations.

Good data management enables many improvements to our business and we are committed to:

- Working with industry in appropriate forums to standardise data formats to allow interoperability between proprietary systems to enable easier sharing of geotechnical information
- Maximising NR's benefit of digital BIM by-products that are created and used during the design and construction phase of renewals to enable the delivery of efficiencies
- Defining appropriate detail for the exchange of asset information at the handover and handback of projects for the ORBIS technology programme planned to go live in 2018/19
- Developing an inventory of specialist geotechnical measures (i.e. rock netting components, soil nailing) and the associated structured data that should accompany particular types of engineering for future enhancements in the exchange of asset information between contractor and client

**Below:** Example of a specialist geotechnical measure installed on a rock cutting and attached with anchors (left) and a pull out test been undertaken on a ground anchor at the crest of a cutting following installation and grouting (right)



**Categorisation of earthwork failures by speed of failure**

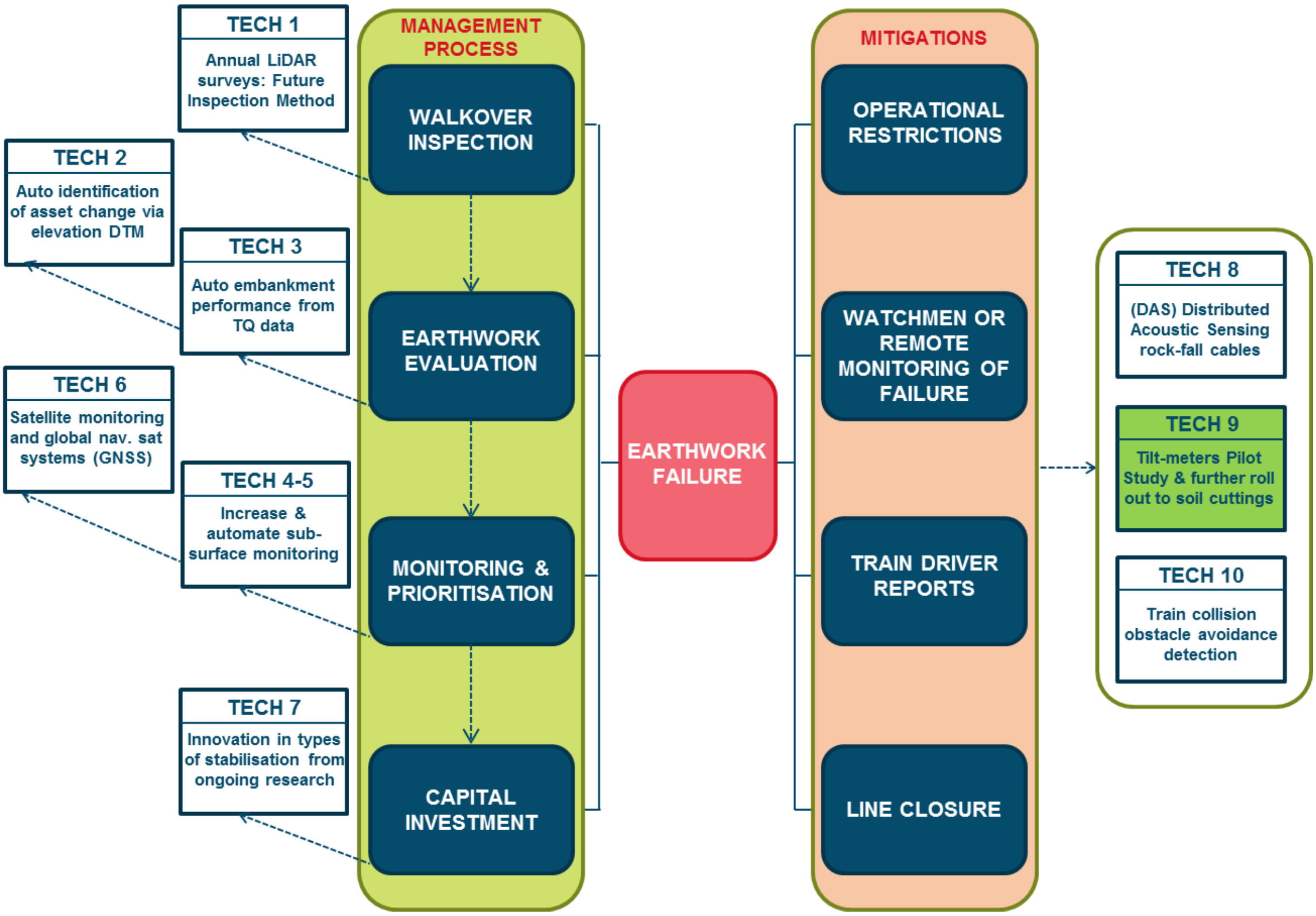
| Slow | Rapid | Instantaneous |
|---|---|---|
| Failure Mechanism | | |
| *Rotational Burrowing* | *Earthflow, Washout & Translational* | *Toppling, Wedge, Planar & Ravelling* |
| Time to intervene / mitigate | | |
| *Days to years* | *Minutes to hours* | *Seconds* |

**Above:** Construction of a sheet pile wall at the crest of an embankment on the Brighton mainline in CP4 using the silent and vibration-less *GIKEN* technique.

**Left:** Simple classification of earthwork failure type by speed. Slow, rapid and instantaneous are used to classify the applicability of technologies identified in the bow tie below and the table opposite.

**Below:** Simplified earthworks bow tie (as per page 20) augmented with potential technologies that could enhance and potentially improve existing processes. Potential technologies are assessed against the applicability to detect failures by speed of failure, as shown in the table opposite.

*NB - Tech 9 (Tilt metre pilot) shaded green in the bow tie below is a key R&D initiative*



# Technology roadmap

Installation of rock anchors for a stabilisation netting renewal scheme

Ever increasing technological developments are enabling NR to deploy more equipment to monitor the condition and performance of assets. The technology roadmap below shows a snap shot in time of known technologies that could potentially enhance and maybe one day even replace the current management or mitigation controls used in the stewardship of the earthwork portfolio.

The roadmap illustrates our commitment to embracing emerging techniques and considering the opportunities that may arise for our business. The economic attractiveness from a cost-benefit analysis of these technologies is often difficult to quantify. It is considered that there are not currently any stand out candidates for full augmentation into our business to replace existing processes of today.

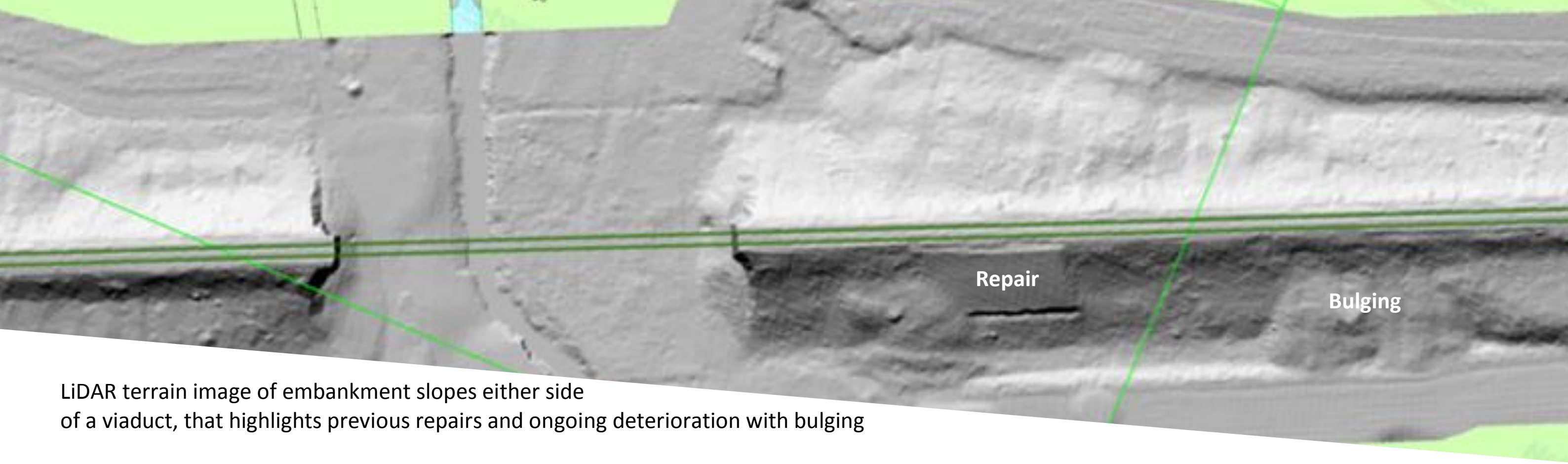
We do not know what the technology of tomorrow will be but we can and will continue to horizon scan, trial products and undertake pilot studies. The work with our academic partners and support that we offer for research bids to NERC and EPSRC will continue to remain important. Technology is seen as a key enabler to further enhance our capabilities in managing risk. We recognise that it is likely to be an array of technologies that assist our journey into the future rather than a single concept or technique.

***TECHNOLOGY ROADMAP***

| Technology (Refer to Bow Tie ref#. opposite) | Business Process that could potentially be improved | Indicative Programme | | | Application to Failure Category | | |
|---|---|---|---|---|---|---|---|
| | | CP5 | CP6 | CP7 | S | R | I |
| 1. Annual LiDAR surveys | Walkover Inspection | ⬜ | ⬜🟦 | 🟦 | 🟩 | 🟧 | 🟥 |
| 2. Elevation change DTM | Earthwork Evaluation | ⬜ | ⬜🟦 | 🟦 | 🟩 | 🟧 | 🟥 |
| 3. Embankment deg. From TQ trend | Earthwork Evaluation | ⬜ | ⬜🟦 | 🟦 | 🟩 | 🟧 | 🟥 |
| 4. Probe Inclinometers (manual) | Monitoring (sub-surface) | in use today when and where it is necessary | | | 🟩 | 🟧 | 🟥 |
| 5. In place inclinometers (auto) | Monitoring (sub-surface) | | | | 🟩 | 🟧 | 🟥 |
| 6. Satellite monitoring & GNSS | Monitoring (surface) | ⬜ | 🟦 | 🟦 | 🟧 | 🟥 | 🟥 |
| 7. Innovative stabilisation methods | Capital Investment (techniques) | horizon scanning | | | 🟧 | 🟧 | 🟥 |
| 8. Distributed Acoustic Sensing (DAS) | Mitigations | ⬜🟦 | 🟦⬜ | ⬜ | 🟥 | 🟧 | 🟩 |
| 9. Surface mounted tilt metres | Mitigations | 🟦 Pilot | 🟦 | 🟦 | 🟧 | 🟩 | 🟥 |
| 10. Collision obstacle avoidance | Mitigations | ⬜ | ⬜ | ⬜🟦 | 🟧 | 🟧 | 🟧 |

**Images below show examples innovative capital investment techniques that have arrived in the geotechnical industry:**

- Below left: Flexible rock fall catch fence installed to protect infrastructure in Wales
- Below middle: Geotextiles used in embankment reconstruction
- Below right: Soil mixing in Anglia



LiDAR terrain image of embankment slopes either side
of a viaduct, that highlights previous repairs and ongoing deterioration with bulging

> *“Geotechnical monitoring is usually applied only to earthworks or natural slopes that are causing or showing specific problems, often in the form of excessive displacement. Accessing steeply sloping ground to drill boreholes for instrumentation can be costly, and monitoring of this type can be applied only to slopes causing significant hazard”*
>
> *“Monitoring of data is commonly used to make a range of decisions about infrastructure slopes, including assessing risk of failure, and the need for interventions”*
>
> *“Setting or choosing appropriate thresholds against which to assess monitoring data can be difficult, as many infrastructure slopes are unique in construction history, geometry and geological conditions”*
>
> *“Predicting the transition from slow acceptable movement to rapid catastrophic movement is difficult”*
>
> **Smethurst et al (2017) Current and future role of instrumentation and monitoring in the performance of transport infrastructure slopes**

| *Monitoring Categories (Mazzanti 2017)* | | | Reasons for monitoring & detecting slope deformation | |
|---|---|---|---|---|
| | | *Knowledge* | **Health check:** Holistic health check in first step of management to check condition / performance | **CONDITION MONITORING via Geotechnical Instrumentation Arrays (GIA)** |
| | *Control* | | **Input into design:** Intervention design can be optimised with actual failure depth / rate | |
| | | | **Rate of change:** Rate of actual movement; for example on a shear plane at depth, can be determined to monitor against pre-determined trigger levels. Allows portfolio prioritisation. | *Pre-failure intelligence* |
| *Emergency* | | | **At failure:** Detection of rapid loss of functionality with asset unable to perform | **FAILURE DETECTION & REACTION via Alert / Alarm Systems** |
| | | | **Intelligence:** Data from site is turned into information and can alarm for mitigation deployment via intelligent infrastructure. | *Failure response* |

**Increasing importance of data quality, confidence levels and utilisation**

**Above:** Table summarising the reasons and categories for why slope deformation monitoring is undertaken, in conjunction with the level of importance in data quality, confidence levels and utilisation. Definitions of Geotechnical Instrumentation Arrays (GIA) and Alert / Alarm Systems are defined in NR control standards and shown opposite for reference. Mazzanti (2017) defines three categories of monitoring, that are integrated to aid in understanding:

| | |
|---|---|
| Knowledge: | design phase, standard maintenance and screening after events (floods etc.) |
| Control: | construction phase, advanced maintenance, verification of higher risk areas |
| Emergency: | construction phase (high risk), early warning systems for operation in highest risk areas |

Reconstruction of Langley embankment in Western route c.2006

There are a range of reasons why monitoring is undertaken and these are summarised in the table opposite. A key factor in the success of asset monitoring is careful consideration of its purpose to clearly define why monitoring is needed and what measurements are required. Three main monitoring categories can be considered (after Mazzanti 2017) for why monitoring is required; (1) knowledge monitoring; (2) control monitoring and (3) emergency monitoring.

As shown on our high level bow tie in the ‘geotechnical risk management’ section, monitoring and prioritisation play an important role in managing the asset base. Choosing the correct type of monitoring is often challenging but a greater challenge can also be communicating the capabilities of slope deformation techniques / emerging technologies and what can be considered reasonably practicable across a portfolio. The suitability of slope deformation monitoring techniques are dependent on the specific temporal and spatial monitoring needs and the applicability to the envisaged failure type (categorised by speed of failure).

Our standards currently define two different types of monitoring techniques (shown below). These can be summarised as condition monitoring (operating on the left hand side of a bow tie to inform actions to prevent landslips) and failure detection and reaction (operating on the right hand side of a bow tie to reduce the consequences from a potential landslip).

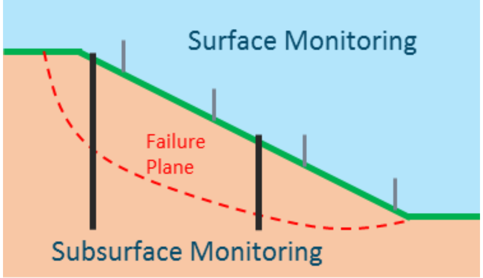
***Geotechnical instrument arrays (GIA)*** *are used where ground movements are anticipated to be slow and there is a warning which utilises periodically retrieved data or where an increase in the rate of slope movement may not pose an immediate hazard to the running line. GIA systems consist of bespoke monitoring devices (e.g. inclinometers) that assist in determining the condition and sub-surface performance of a slope. Data acquisition may be remote from automated capabilities.*

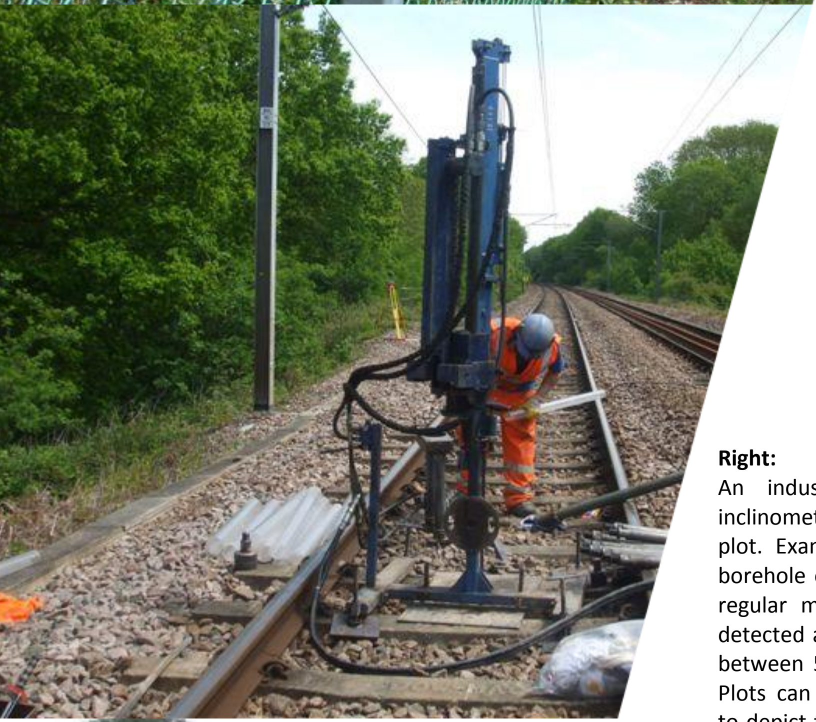
***Alert/Alarm Systems*** *are adopted on earthworks where there is a high likelihood of rapid deterioration or failure and such movements are likely to have an immediate impact on the safe operation of the railway. An alert system consists of a mechanical, electrical (or other) system that can automatically detect an earthwork failure with reference to a pre-determined hierarchy of trigger levels.*

> *“Control monitoring is probably one of the most used in the management of transportation geotechnical assets. The aim of this type of monitoring is to quantitatively check the evolution of well-known problems that affect geotechnical assets, in order to help define service levels and the management of risk associated with failures”*
>
> *“The aim of the emergency monitoring is to continuously control transportation routes and provide an alert (often automatic) in case the risk becomes unacceptable”*
>
> **Mazzanti (2017) Towards transportation asset management: what is the role of geotechnical monitoring?**

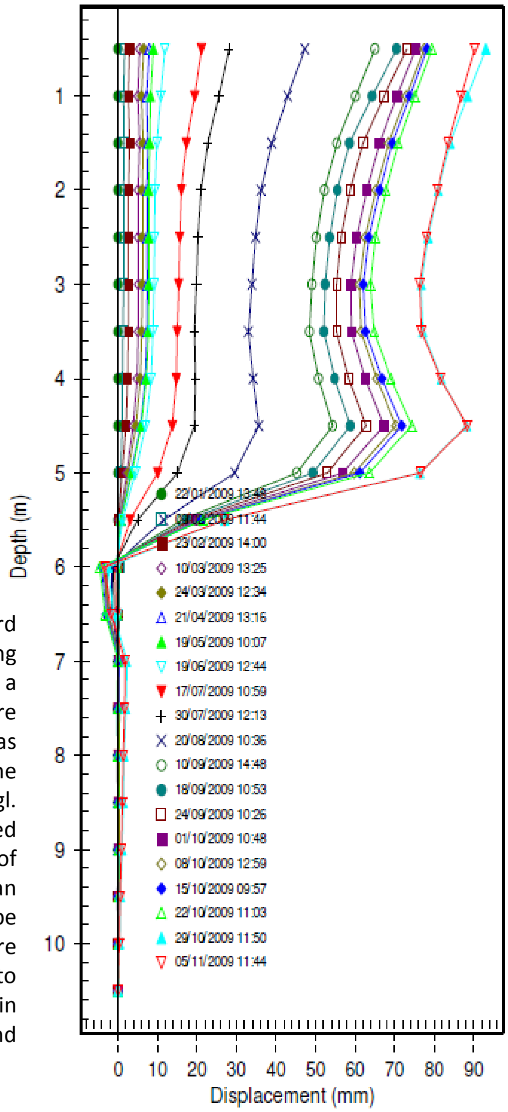
**Top Left:** Surface mounted geotechnical alert / alarm system to remotely detect failures at Folkestone Warren (Kent).

**Bottom three images:** exploratory drillings rigs and a sub-surface monitoring borehole as part of an array of geotechnical instrumentation to monitor slope condition.





**Right:**
An industry standard inclinometer monitoring plot. Example shows a borehole of 10m where regular monitoring has detected a failure plane between 5 and 6 mbgl. Plots can be converted to depict the velocity of the failure, allowing an assessment of slope condition and failure rate in response to seasonal variations in rainfall and ground conditions.



*"Monitoring of earthworks is difficult. They can be variable in terms of geometry and material properties, there can be local defects, they are often covered with vegetation that can make assessment and condition monitoring difficult, and there are multiple modes of failure, some of which are complex"*

**Smethurst et al (2017) Current and future role of instrumentation and monitoring in the performance of transport infrastructure slopes**

Visual inspections have limited usefulness in determining the condition of a slope or the objective measurement of instability, as they provide little information on sub-surface processes. Slopes will not always show signs of distress and can fail with limited, if at all any, indication of service loss prior to rapid failure.

The European geotechnical monitoring standard (BS EN ISO 18674-1:2015) guides engineers in the use of appropriate instrumentation to meet the specific objectives of a monitoring scheme.

Condition monitoring requires an understanding of subsurface processes through the deployment of a geotechnical instrumentation array (GIA), as defined previously. We recognise that new innovative surface mounted techniques are becoming more economically attractive and will often offer improved spatial and temporal resolutions in data.

We consider failure detection to be the deployment of an alert / alarm system, where the aim of the instrumentation is to detect rapid failure (see section on failure detection pilot study) and allow the consequence of an earthwork failure to be controlled on the right hand side of our risk bow tie.

We do not consider surface technologies to be condition monitoring to allow intervention prior to service loss. It is not clear how parameters such as surface displacement should be used as an indication of incipient failure (Smethurst 2017) as there will be insufficient knowledge about slope processes. These technologies do offer potential for the detection of failure for which we recognise there are opportunities to improve the mitigations side of a bow tie and reduce the consequences from asset failures.

Transport operators want safe and disruption free systems. Emerging technologies offer the potential to monitor at a greater spatial and temporal resolution. When capabilities are demonstrated the economic attractiveness of rolling out will always need to be assessed against what is reasonably practicable.

We shall continue to use sub-surface condition monitoring where applicable. Recognising that it is not reasonably practicable to embed sub-surface monitoring across our portfolio we shall continue to investigate emerging capabilities targeted for the shallow surface and surface of infrastructure slopes.

Right: Slow moving deep seated rotational failure in a cutting slope at Chipping Camden in Western route (2013). Slope suffered a delayed failure c.165 years post excavation / construction.

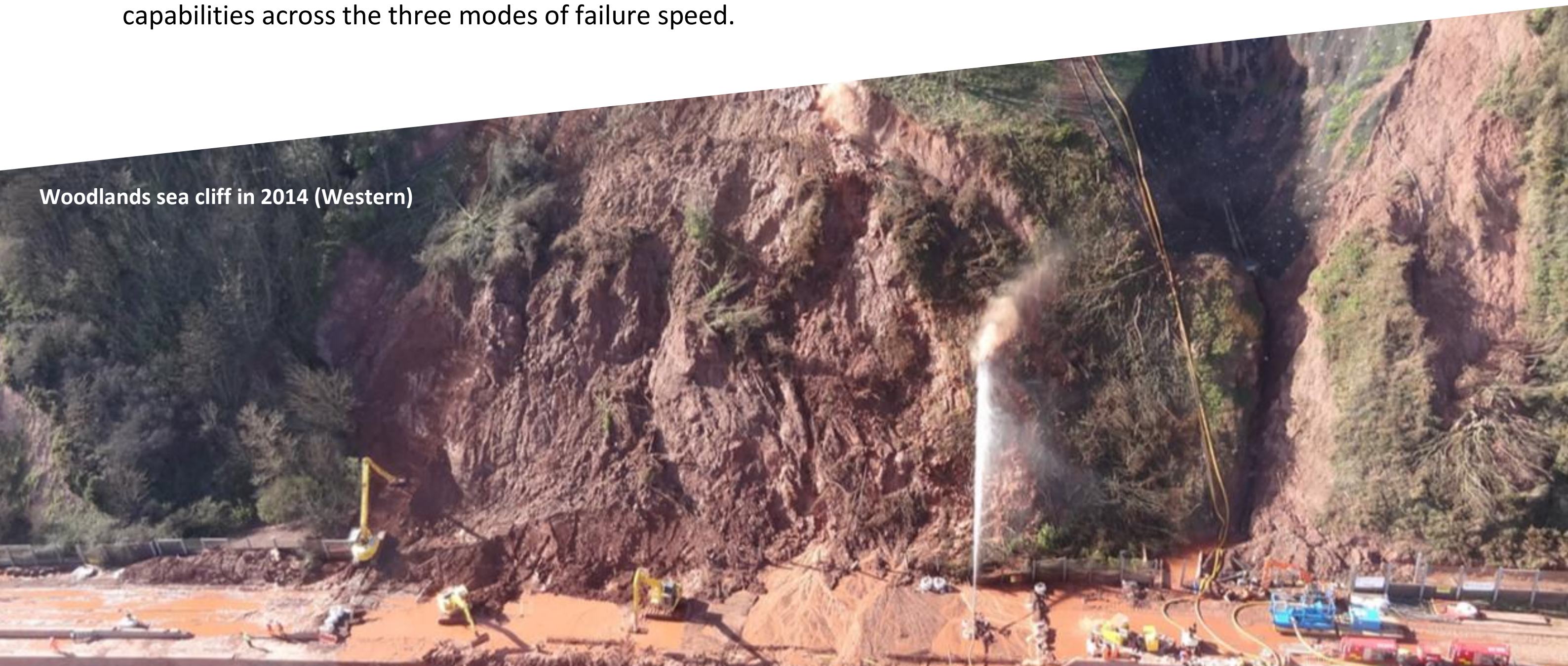
| Monitoring Technique | Description & Comments | *Failure Category | | |
|---|---|---|---|---|
| | | S | R | I |
| ***Surface deformation monitoring*** | | | | |
| Global positioning system (GPS) | GPS system receives time signals from orbiting satellites and positioning is based on signal travel times. Limited reception in topographic depressions and accuracy issues in forested areas (signal scatter) | 🟨 ● | 🟨 | 🟥 |
| Photogrammetry | 3D reconstruction of surface topography from overlapping at least 2 photographs taken from different positions. Complex post processing of data. Application limited by high cost and time requirements. | 🟨 | 🟥 | 🟥 |
| Remote Sensing (InSAR, LiDAR) | Terrestrial, aerial or satellite based recording of reflected electromagnetic energy from the Earth's surface, Positional reflectors required to overcome vegetation. Complex and expensive data processing | 🟨 ● | 🟥 | 🟥 |
| Distributed acoustic sensing (DAS) | Optical fibres used as a sensing device to measure acoustic energy generated by noise and vibrations; identifying threat events from normal background activity (i.e. rock falls). | 🟥 | 🟨 | 🟩 ● |
| Accelerometer & Geophones | Recording of ground surface velocity or acceleration.in response to rapid movements and earthquakes. Limited detection capability of low velocity ductile movements. Post-processing is complex. | 🟥 | 🟨 ● | 🟨 |
| Electrode tracking using ERT | Electrical resistivity tomography (ERT). Measured resistivity can be inverted to track electrode / slope movement. Readings sensitive to sensor spacing. Complex installation and post-processing. | 🟩 ● | 🟨 | 🟥 |
| Surface mounted tiltmeters | Microelectronic sensors capable of detecting changes from the vertical. Typically installed on the end of a pole inserted with suitable embedment. Wireless network required to create an array across an asset. | 🟨 | 🟩 ● | 🟨 |
| ***Subsurface deformation monitoring*** | | | | |
| Time domain reflectometry (TDR) | Deployment of cables in boreholes, locating displacement faults by measurement of reflections along conductor. No direct measurement of deformation or deformation rate. Sold as commercial systems. | 🟨 | 🟨 | 🟥 |
| Shape acceleration array (SAA) | Comprise a string of microelectronic sensors at regular intervals and installed inside boreholes. Measures 3D displacement. High costs of instrumentation and processing. SAA string recoverable from borehole. | 🟩 ● | 🟨 ● | 🟥 |
| Acoustic emission monitoring | Deformation of angular backfill in a borehole, creates high energy acoustic emission on a steel conductor waveguide. Most applicable to slopes failing along a defined shear surface. Sensitive to slow rates. | 🟩 ● | 🟨 | 🟥 |
| Electrical resistivity tomography (ERT) | Moisture content mapping in 4D of earth structure via electrodes placed below ground level, using soil resistivity. Complex installation and post-processing. Readings sensitive to sensor spacing. | 🟩 ● | 🟨 | 🟥 |
| Porewater suction / soil moisture probes | Variety of probes available for detailed measurement of soil and water interaction and soil water retention. Does not directly detect deformation. Careful calibration required and specialist expertise. | 🟩 ● | 🟨 | 🟥 |
| Ground penetrating radar (GPR) | Measurements based on the propagation of electromagnetic waves in the subsurface. Commonly used to establish ballast depth in railway formations. Requires complex post processing. | 🟨 ● | 🟨 ● | 🟥 |
| In place inclinometers and extensometers | Tubing installed into boreholes to detect zones of disturbance and determine whether movement is constant, accelerating or responding to remedial intervention. Possible to automate but expensive. | 🟩 ● | 🟩 ● | 🟥 |

● Technology that NR either use, have researched or plan to trial

* Failure Categories; Slow (S), Rapid (R) and Instantaneous (I)

**Monitoring Technologies Table;** Modified after Smethurst et al (2017).

Table showing slope monitoring techniques split by (i) surface techniques and (ii) subsurface techniques for monitoring deformation. Applicability to Network Rail slopes and to the slow, rapid and instantaneous failure categories is based on a qualitative (red, amber, green RAG) assessment, against the technology as either a geotechnical instrumentation array (GIA) or an alert / alarm system. Few technologies offer strong capabilities across the three modes of failure speed.



Woodlands sea cliff in 2014 (Western)

# Applicability of slope deformation technologies (new & existing)

Appearance of a significant defect at the crest of an embankment following deterioration in condition

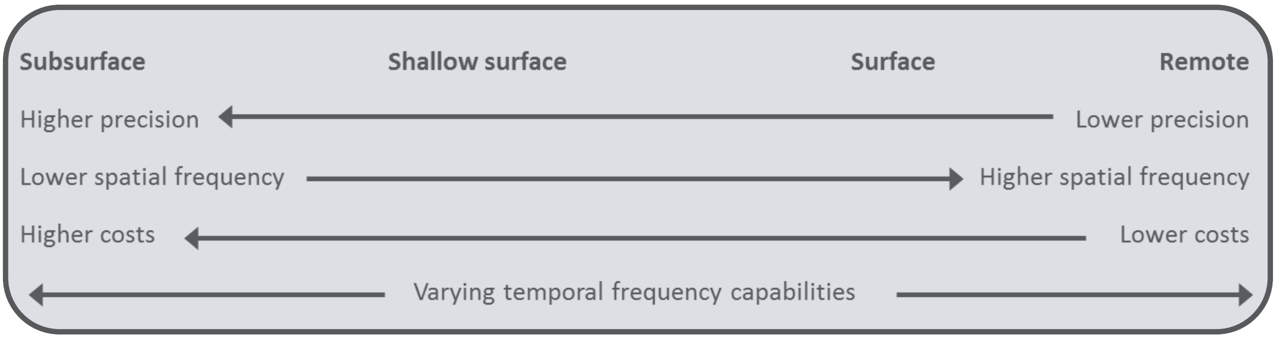
There are a wide variety of slope deformation technologies providing a range of capabilities to detect the onset of slope instability or failure (see table opposite). New technologies are starting to offer greater potential to monitor more slopes at an increased spatial and temporal resolution. Here we aim to provide an overview of how these technologies could assist Network Rail and how different techniques could assist us in predicting slow failures and mitigating the consequences of rapid and instantaneous failures. Industry will often embellish technological capabilities and their applicability – our view as Network Rail is presented.

Our Earthworks Policy focuses our capital investment on cuttings over embankments and on rock cuttings over soil cuttings. The instantaneous nature of rock falls from cut slopes is difficult to detect and almost impossible to predict when a failure may occur. We are less tolerant of the potential for rock-fall and our relative investment reflects this; thus our need to monitor rock slopes is limited. The population size of soil cuttings and their susceptibility to rapid failure during adverse weather provides one of our greatest challenges.

We consider ourselves to be very good at detecting, monitoring and intervening at slow failure locations using our management processes and traditional sub-surface inclinometer monitoring. The table opposite shows that limited techniques offer opportunities to detect rapid or instantaneous failures. Of those techniques that do offer potential we consider them as failure detection techniques and not condition monitoring.

The selection of any instrumentation needs to meet the specific objectives and consider the precision, reliability and resolution of the technique (factors illustrated in the schematic diagram below).

We shall continue to research and pilot technologies that offer potential improvements to decision making for slow moving failures. However, our principal interest will be to investigate and assess emerging technologies that can be applied to rapid moving failures. Demonstrated capabilities in the identification of rapid failures are a key NR geotechnical challenge. Whilst we have less tolerance for instantaneous failures from rock slopes, we only have a limited interest in capabilities built around techniques such as acoustic sensing.



Above: Qualitative capability assessment of general monitoring technologies (subsurface to remote) by spatial and temporal resolution, monitoring precision and cost of techniques.

**Left:** Washout at Foxhills Tunnel following a deluge of 90mm of rainfall within an 8 hour period (August 2006).
**Bottom left:** Installation of intervention works following a failure on the approach to a tunnel portal in Scotland (2016).

TOP GEOTECHNICAL CHALLENGE
*Detection of asset failure by means other than train drivers*

**Above:** Passenger train derailment on the Fort William to Mallaig line (January 2018) following the collision with material from a debris flow. Originating from the adjacent mountainside the debris flow mobilised rapidly and was encountered by a passenger train with the driver unable to stop in advance of the failed material.

**Broad array of technical challenges (see page 4):**

- Improving the capability of the asset base to be more weather resilient (i.e. asset resistance as a component of infrastructure resilience) at an acceptable pace for industry
- Prolonged periods of wet weather that increase pore water pressures and reduce effective stress within clay slopes, reducing the factor of safety and increasing the likelihood of asset failure
- Management of the infrastructure during short duration adverse / extreme weather events
- Rapid failures that develop and occur within a matter of minutes to hours
- Increased embankment traffic loading and tonnage growth
- Seasonal shrink-swell (desiccation) of embankments causing serviceability issues to track geometry
- Peat wastage of sub-surface soils that results in subsidence
- Natural third party slopes beyond our infrastructure where potential hazards may exist
- Using available data to identify and fix the root cause rather than treating the symptom in the embankment, formation, drainage and track components of the rail system
- Effects of vegetation on soil and rock slopes
- Impacts of climate change

To understand our challenges it is important to understand what we are doing or have undertaken previously to make improvements. We face a broad array of technical challenges (shown opposite) and our top challenge requires industry to recognise that all earthwork failures cannot be prevented; we have to improve our failure detection capabilities using technology to improve our safety performance. This in itself will bring more challenges.

The most significant event we aim to prevent is a train derailing at high speed from an earthwork failure. Whilst the trend of earthwork derailments is reducing we recognise there is no room for complacency for rapid soil cutting failures during short duration storm events (that may also destabilise slopes beyond our land ownership).

Progressive strengthening will continue to improve the network resilience but this rate will be dependent on corporate and industry appetite. Earthwork failures are not going to be eradicated in the next 20 years.

**Recognising the general lack of infrastructure resistance to weather events we need to be able to detect asset failures, principally soil cuttings, before they are encountered by train drivers.** This is a key driver for undertaking the remote failure detection pilot study.

The ability to monitor more slopes at greater spatial and temporal resolution requires handling, processing and analysis of significantly more data. Whilst automated systems that analyse large quantities of data are desirable, having human judgement of the data in major decision making processes (e.g. before stopping trains) is important.

As described by Smethurst (2017) this introduces the need to have enough suitably trained people to understand and review situations and make good and consistent decisions, and where appropriate, the use of standardised monitoring (avoiding having large numbers of bespoke systems) and centralised control. The human influence in decision making requires careful processes and clear risk, decision and response plans are an essential part of major monitored systems.

In summary there are many challenges but the area we need most assistance is with the detection of rapid soil cutting failures. We recognise that sensor technology will continue to advance at speed, to improve challenges such as battery life. We await the arrival of energy harvesting technologies to further revolutionise smart sensors.

The Network Rail challenge statements are published online and the link can be found in further information (p61).

**Right:** Controlled blasting on the Conway Valley Line to remove an unstable column of rock. Storm Doris (Feb 2017) brought down mature trees from the slope, weakening the rock mass and necessitated emergency intervention.

*Evolution of plant technology for drilling boreholes; from temporary scaffolding*

Images at the top of this page are courtesy of Geotechnical Engineering Ltd.

> *"To have a chance of carrying out the 'right' investigation, the planning needs to be made by suitably qualified professionals. Too many investigations are planned by non-specialists with the wrong questions asked and therefore answers not being received to the right questions"*
>
> **Norbury (2017) Standards and quality in ground investigation**

**The skills shortage is a critical issue for the UK engineering sector. To deliver the world class infrastructure that our economy depends on requires suitable access to a high standard of engineering skills. Geotechnical engineers are in high demand and the profession appears in the UK occupational shortage list published by the government.**

**NR is a corporate member of *EngineeringUK*, a not for profit organisation, which works in partnership with the engineering community to promote the vital role of engineers and engineering to inspire the next generation. NR also has a number of STEM ambassadors who are knowledgeable role models and volunteer to inspire young people in the world of science, technology, engineering and maths (STEM).**

> *"my experience is that the sequence of acceptance of technical innovation into general practice is likely to take ten, perhaps even twenty or more years to come into clear focus"*
>
> *"Technical innovation must stand the test of time in order to prove its worth….nevertheless, new ideas, test or analytical procedures or new materials, such as grouts, soil stabilisers or geotextiles, may be developed and marketed without proof of their long lasting abilities."*
>
> *"A way forward...lies in the continuing development of site investigation practice and the understanding of surface and sub-surface processes of importance to engineering and for the assessment of hazard and quantification of risk"*
>
> **Professor Peter Fookes FREng – First Glossop lecture (1997)**

**Below:** Cutting slope stabilisation scheme consisting of a partial installation of soil nails and mesh around the scar of a historic failure

# UK geotech industry challenges

*with access ramps to slope climbing rigs with working platforms for operatives*

The UK geotechnical industry covers a wide breadth of capabilities from site investigation and specialist contractors through to consulting design engineers and infrastructure asset managers. NR is a corporate member with the Association of Geotechnical & Geoenvironmental Specialists (AGS) and the Construction Industry Research and Information Association (CIRIA). The forums that these bodies facilitate allow NR to engage with wider industry initiatives in the ground engineering sector and understand commonly faced challenges. NR is also a founding member of the UK Geotechnical Asset Owners Forum (GAOF).

**A skills shortage and lack of diversity** are recognised by industry and the professional institutions. We have a strong graduate programme and are committed to fair transparent recruitment, providing our people with appropriate training and the opportunity to learn about and understand unconscious bias.

**Climate change coupled with ageing assets** is a concern for members of the UK GAOF. Climate change clearly presents an increased likelihood of slope failure but quantitative assessments are currently not feasible. Research is starting to investigate the impact of climate change on transport slopes. Research has modelled the cycles of drying/wetting that soils are subjected to and demonstrated that changes to micro-structure over time, are accompanied with a loss of strength. Future phases of research are supported by NR.

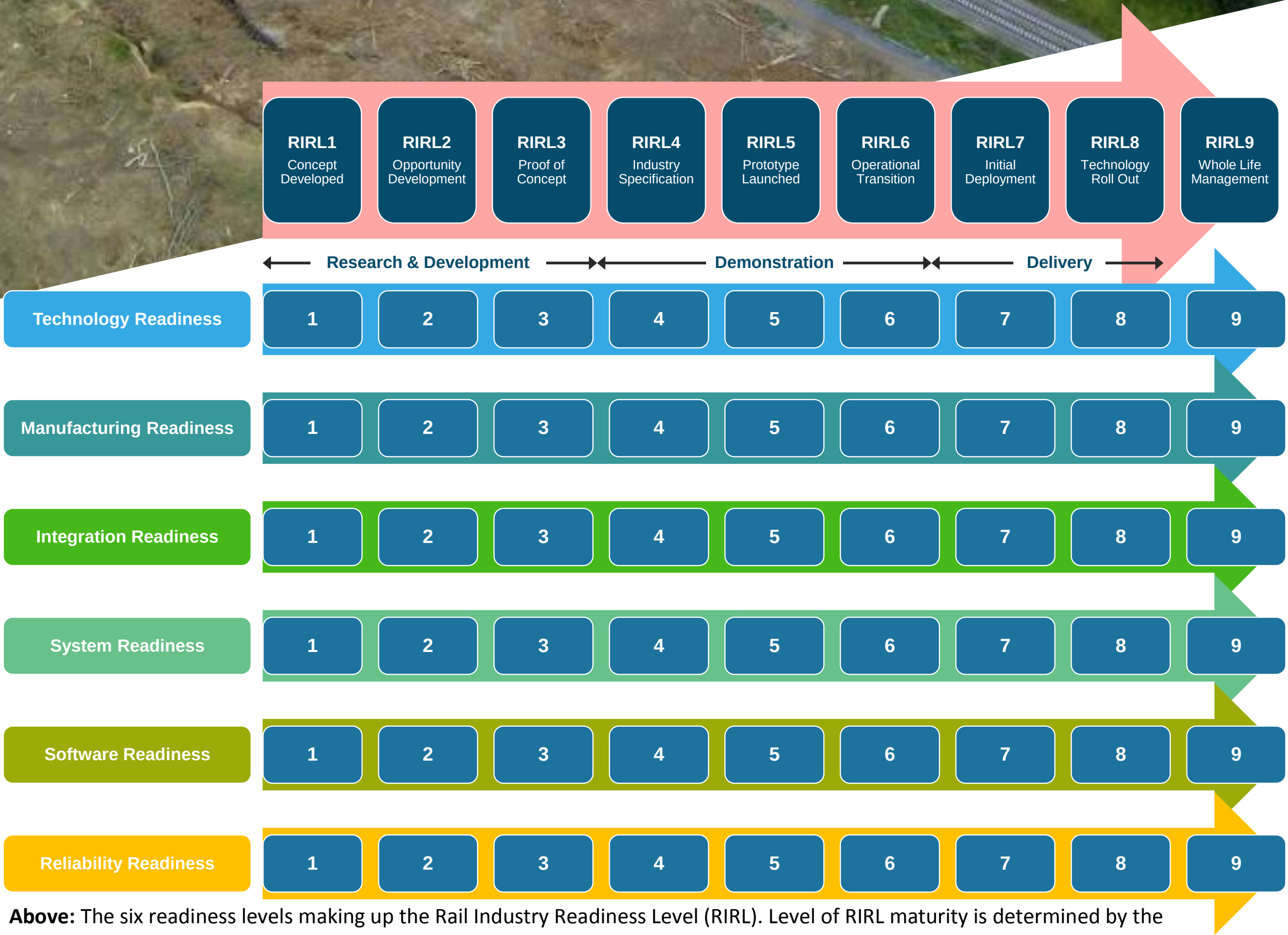
**The lessons learnt from significant incidents in the past are often as relevant today.** We recognise that we need to embed lessons learnt and revisit incidents to refresh our understanding. The Carsington Dam failure in 1984 had several lessons that are as relevant to us today as they were to industry back then; (1) limited expertise was input into the design, (2) unrealistic slip surfaces were analysed, (3) the ground model was technically flawed and (4) data from instrumentation was not utilised appropriately.

**Improvements to site investigation practice, including data transfer, would enhance the ability to understand the sub-surface.** There has been innovation in both intrusive and non-intrusive techniques, yet there is a need for industry to develop new techniques and improve those which are tried and tested. As noted by Fookes (1997) the continuing development of site investigation will only improve the assessment of hazards and we aspire to see industry make more efficient rigs, capable of improved exploratory sampling.

**The development of improved construction techniques is always sought to improve our safety performance.** Industry has and continues to innovate processes to allow slope stabilisation to take place during normal railway operations. We are committed to working with contractors to innovate and develop safer ways of undertaking construction on slopes that are often steep. We are prepared to assist in developing technical innovation that arrives in the form of a new technique or product.

Chipping Camden cutting failure from above pre stabilisation

> *"Quantum sensors will enable quick and accurate gravity mapping: detecting minute differences in gravity to reveal underground features. There is much buried beneath our feet, including different soil and rock types, utilities, tunnels and old mineshafts…Quantum devices could enable us to see around corners, map hidden underground hazards, and easily solve problems that would stump any existing supercomputer"*
>
> **Government Office for Science (2016) The Quantum Age: technological opportunities**



| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **RIRL1**<br>Concept Developed | **RIRL2**<br>Opportunity Development | **RIRL3**<br>Proof of Concept | **RIRL4**<br>Industry Specification | **RIRL5**<br>Prototype Launched | **RIRL6**<br>Operational Transition | **RIRL7**<br>Initial Deployment | **RIRL8**<br>Technology Roll Out | **RIRL9**<br>Whole Life Management |
| | ← Research & Development → | | | ← Demonstration → | | | ← Delivery → | | |
| Technology Readiness | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Manufacturing Readiness | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Integration Readiness | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| System Readiness | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Software Readiness | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Reliability Readiness | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

**Above:** The six readiness levels making up the Rail Industry Readiness Level (RIRL). Level of RIRL maturity is determined by the lowest scoring readiness level applicable to the innovation.

> *We will work with industry and academia to ensure that the newly established UK Rail Research Innovation Network (UKRRIN) delivers improved performance in the sector. With £28m of higher education funding being matched by £61m of funding from the private sector, UKRRIN will future-proof the UK rail industry by supporting research in the key areas of digital systems, rolling stock, and infrastructure innovation.*
>
> **DfT (2017) Connecting people a strategic vision for rail; moving Britain ahead**

The railway needs to exploit Research, Development and Technology (R,D&T) to make train travel more comfortable, more accessible, more reliable and more affordable. The Rail Technical Strategy Capability Delivery Plan (CDP) provides a blueprint for R,D&T investment to develop prototype systems and equipment that will transform the railway.

Earthworks will benefit from UKRRIN and NR will be able to collaborate more closely with the Universities of Southampton, Loughborough, Sheffield, Heriot-Watt and Nottingham in a centre of excellence model. Access to the Rail Innovation and Development Centre (RIDC) at Melton will continue to provide the opportunity to deploy emerging technologies onto infrastructure that is primarily used for the integration testing of new rolling stock. An example of using the RIDC for infrastructure research is the deployment of the emerging technique of electrical resistivity tomography (ERT) by the British Geological Survey (BGS) to monitor water content in 4D across a soil cutting asset.

A set of readiness levels to assess the stage of development a product or system is at have been developed and agreed with industry. Rail Industry Readiness Level (RIRL) will provide a common language to better enable R,D&T. Consisting of six readiness components (shown opposite) RIRL will reduce re-engineering and speed up development cycles. Projects will need to focus on progressively maturing along the constituent readiness levels of the RIRL and this will enhance the control in developing products for deployment.

We remain committed to supporting a wide breadth of R,D&T to keep us at the cutting edge of geotechnical management and to harness potentially applicable initiatives from other sectors. NR is a member of the Manufacturing Technology Centre (MTC) and is represented on the steering group of the Cambridge University Centre for Smart Infrastructure and Construction (CSIC). We have also published our challenge statements to provide industry with the visibility of our needs, providing a clear purpose to enable the best chance for successful research to be applied.

The following pages expand on a number of topical areas in R,D&T that are at the forefront of our immediate interest and needs, albeit not exhaustive. We shall continue to support projects that look towards the UK Research Councils (specifically EPSRC & NERC) for funding and provide assistance to secure the required finances and to implement new research. We are also active members of the Construction Industry Research and Information Association (CIRIA), who work collaboratively across the construction industry to identify best practice, develop new approaches and identify and enable innovation.

**Below:** Stabilisation mesh draped and anchored to a rock cutting to prevent spalling material from encroaching onto the line (right) and pre-auguring to soften ground conditions prior to the installation of sheet piling as part of an embankment rebuild following collapse (left)

**Above:** Rapid failure of a soil cutting at Murthat in Scotland on the West Coast Main Line (Nov 2015). Asset showed no evidence of failure prior to slumping towards the track after a period of relatively normal rainfall. Failure identified by the driver of a passenger train travelling at 125mph.

## TOP GEOTECHNICAL CHALLENGE
## *Detection of asset failure by means other than train drivers*

**Above:** Example of a rapid failure within a soil cutting in response to short duration high intensity rainfall event and sign advising lineside operatives that a cutting slope contains a live monitoring system.

**Below:** A rapid debris flow failure from an adjacent hillside which caused a passenger train to derail. The detection of such rapid failures is our top geotechnical challenge, recognising we cannot instrument all hazardous or all high consequence locations (i.e. deployment of technology has to be risk based).

**Above:** Successful deployment of standardised failure detection instrumentation, consisting of regularly spaced tiltmeters and infra-red cameras, to detect the occurrence of a rapid failure before being encountered by a train driver.

We consider failure detection to be the deployment of an alert / alarm system, where the aim of deploying instrumentation is to identify rapid failures and allow the consequence of an earthwork failure to be reduced using appropriate mitigations.

Grouping the deterioration of an asset by failure speed allows three types of problem to be considered; slow, rapid and instantaneous failures. These failure modes are explained on page 30. From January 1995 to January 2018 there were 33 earthwork attributable derailments on the UK mainline network. Of these derailments, 73% (24) are considered to be the result of earthworks that have deteriorated with minimal precursors and the speed of failure classified as rapid. All other derailments are from instantaneous rock falls 18% (6) or embankments that have failed during intervention activities 6% (2) or under live loading 3% (1).

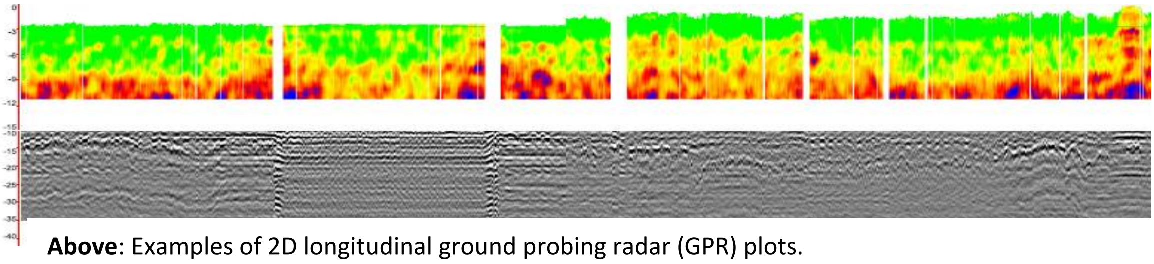
Focussing on readily available surface mounted instrumentation we believe we can deploy technology onto an asset and link data alerts / alarms into operational control centres. The production of binary data for rapid failure mechanisms should allow us to take data from a network of sensors and make operational decisions. To enable this suitably designed processes and trained operatives (flight controllers) are required.

Many other asset groups that are fitted with remote condition monitoring will fail safe. It is recognised that earthworks do not fail safe and that the aim of readily deployable surface instrumentation is to detect rapid failures. More expensive condition monitoring (inc. RCM) is undertaken on earthworks as and when it is required to proportionally manage risk; but our need to detect rapid failures can be achieved more economically than traditional and expensive sub-surface instrumentation (such as inclinometers).

We are committed to delivering a pilot study to a small proportion of soil cutting assets. The aim is to demonstrate the end to end process for failure detection and move forward the integration, system, software and reliability readiness levels. The readiness level of the technology we are using is considered mature.

The pilot study will see the deployment of product approved equipment in a standardised way to a selection of assets across four Routes. Earthwork alarms will be prioritised with the highest importance by flight controllers as they would potentially represent a wrong side failure.  We recognise that to enable the vision of deploying more failure detection alarms, the pilot study has to successfully demonstrate an efficient process for responding to alerts and alarms. Demonstrating and then providing this capability will allow routes to sustainably deploy more standardised instrumentation, integrated into one operational platform.

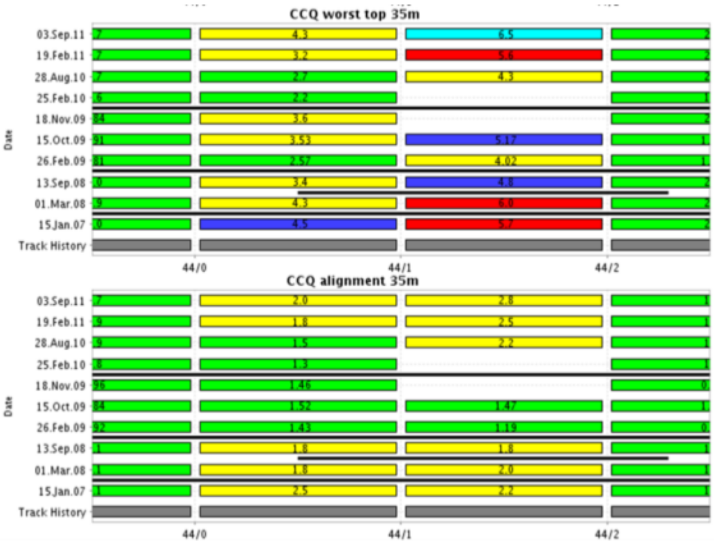
## Sample of data visualisation capabilities to show track condition



**Above**: Examples of 2D longitudinal ground probing radar (GPR) plots.

- Shallow 2GHz (coloured) GPR showing ballast contamination from formation pumping

- Deeper 400Hz (grey shade) GPR showing some deeper interface variability

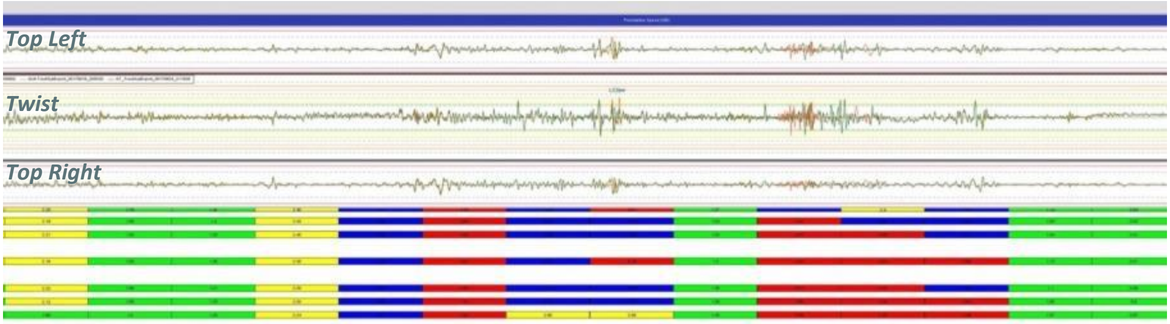


Good
Satisfactory
Poor
Very Poor
Super Red

**Left:** Colour coded quality (CCQ) charts displaying historical standard deviation (SD) values over one eighth of a mile. CCQ bands are dependent on the line speed and are one of the factors used to determine the required track maintenance in order to maintain performance within acceptable limits.

**Below:** Extract from NR Linear Asset Decision Support(LADS) tool showing CCQ and top left, top right and twist measurements, where:

- *Top (Left/Right): Variations in the vertical profile of the left/right rail in the direction of travel. Measurements are made of wavelengths up to 35 metres.*
- *Twist: The difference between the cross level at the point of measurement and the cross level at a point 3m prior*
- *Cross Level: The height of the crown of the left rail above that of the right at the point of measurement, i.e., at the point where the measuring wheels contact the rails.*



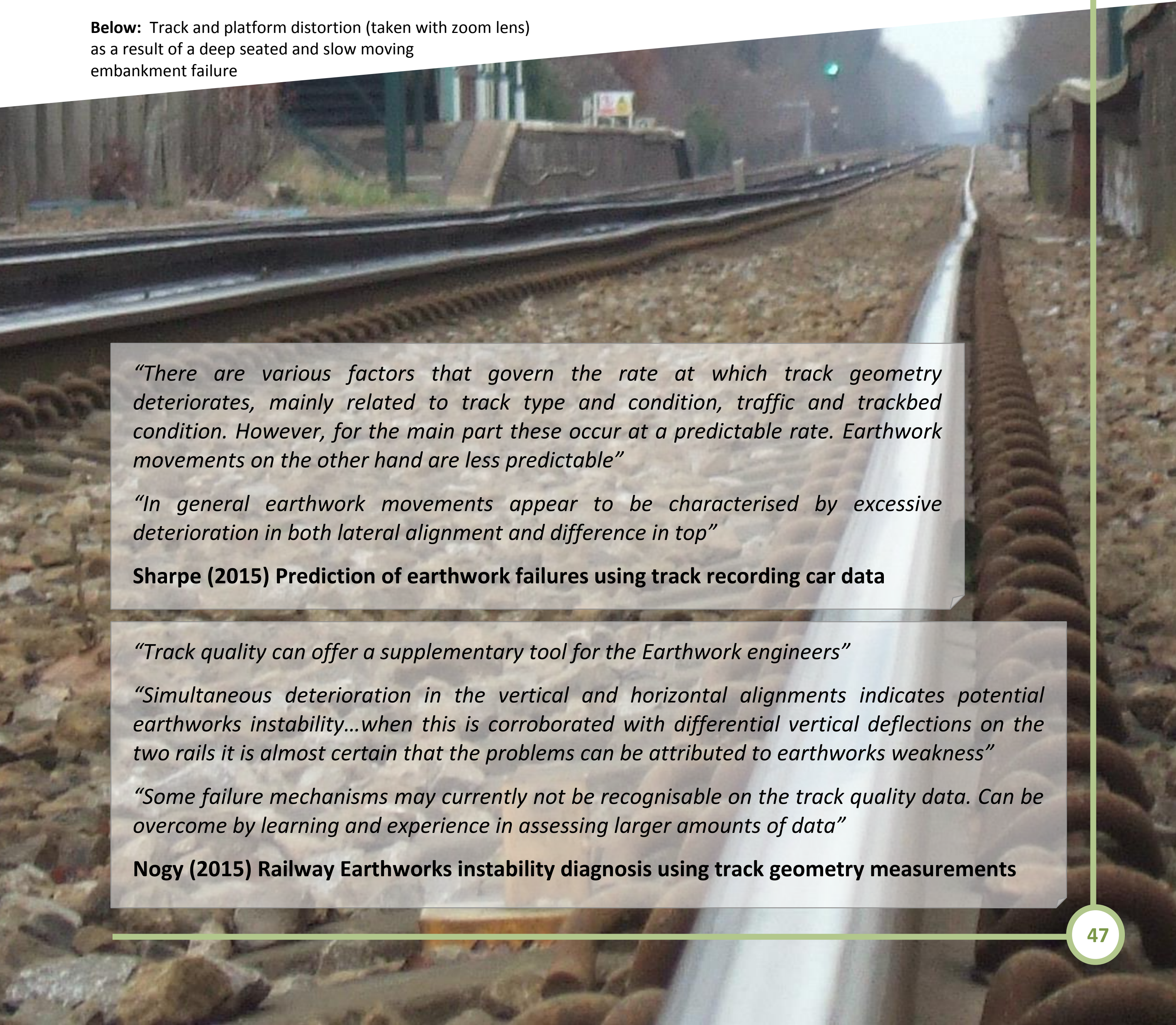
**Below left:** Presence of a significant track defect as a direct result of an active deep seated slow moving failure. **Below right:** NR measurement fleet train collecting data.

Track geometry data from the NR measurement fleet provide millimetre precision in the recording of rail positions. The frequency of collection is dependent on route criticality and the availability of data in some parts of our network maybe insufficient for trend analysis. Nonetheless it is considered that there is healthy potential for greater exploitation of the data that is currently recorded and held by NR.

Causal analysis has identified relationships between railway formation, track and earthworks in the recent past. Published work in the technical literature demonstrate trends in data for a selected number of earthwork failures that have been analysed following loss of ultimate limit state (i.e. failure). Data visualisation tools have evolved to provide improved access to detailed data sets for those staff involved in the tactical and strategic planning of track work. More recently these tools are now starting to be used by the geotechnical engineers to assist in earthwork management. The page opposite shows an insight into these sources of data.

We aspire to improve our capability to identify potentially problematic embankments from these data sources such that we identify and plan to remediate the root cause of issues rather than continue to fix the symptoms. We recognise this will require more sophisticated signature analysis at portfolio level to calibrate against other data sets (i.e. geology groupings). Our vision is to produce an evidence based relative method of prioritisation that is capable of dovetailing into our existing policy, standards and capabilities in predicting asset failure.

**Below:** Track and platform distortion (taken with zoom lens) as a result of a deep seated and slow moving embankment failure



*“There are various factors that govern the rate at which track geometry deteriorates, mainly related to track type and condition, traffic and trackbed condition. However, for the main part these occur at a predictable rate. Earthwork movements on the other hand are less predictable”*

*“In general earthwork movements appear to be characterised by excessive deterioration in both lateral alignment and difference in top”*

**Sharpe (2015) Prediction of earthwork failures using track recording car data**

*“Track quality can offer a supplementary tool for the Earthwork engineers”*

*“Simultaneous deterioration in the vertical and horizontal alignments indicates potential earthworks instability…when this is corroborated with differential vertical deflections on the two rails it is almost certain that the problems can be attributed to earthworks weakness”*

*“Some failure mechanisms may currently not be recognisable on the track quality data. Can be overcome by learning and experience in assessing larger amounts of data”*

**Nogy (2015) Railway Earthworks instability diagnosis using track geometry measurements**

## Satellite Industry Challenge 2016

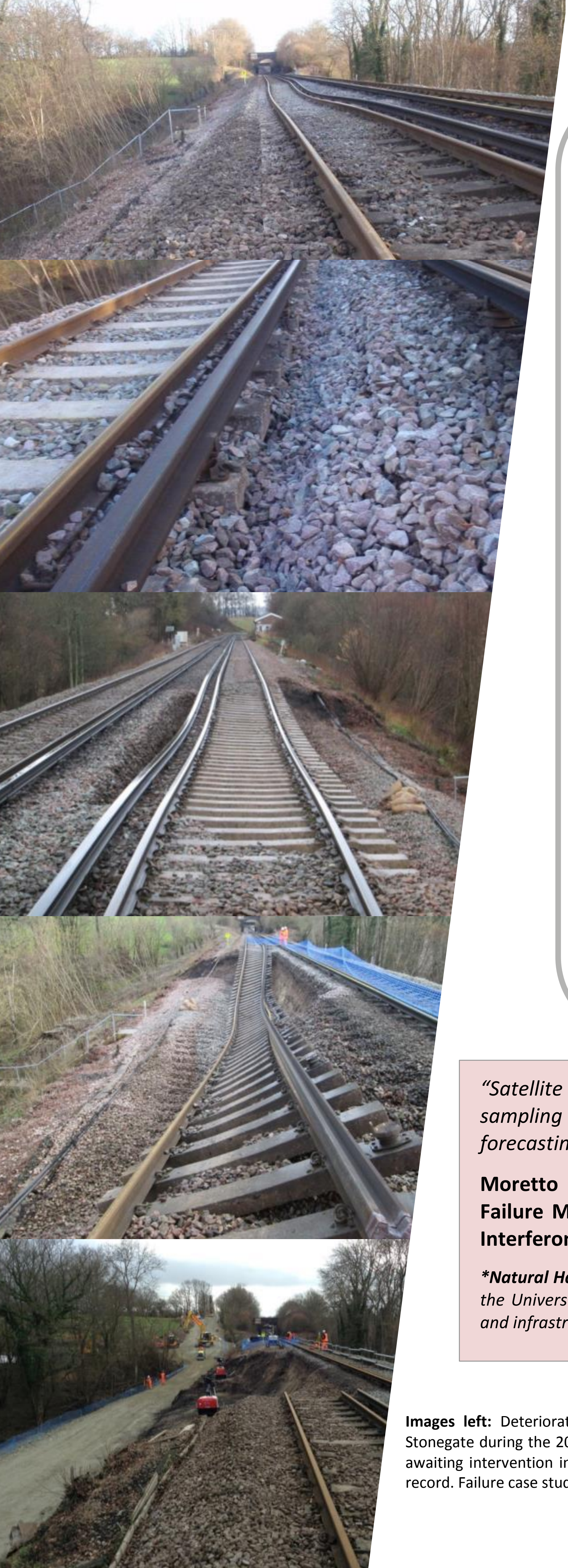
In conjunction with Innovate UK and the Satellite Applications Catapult Network Rail launched an industry challenge in October 2016. We were seeking to investigate whether early identification of increased movement and likelihood of failure would have been possible in hindsight at a number of network locations.

The challenge was facilitated by Innovate UK and data from the Sentinel-1 satellite was made available via the Satellite Applications Catapult, free of charge (under terms and conditions).

The challenge was to demonstrate solutions, using satellite data, which could have alerted Network Rail to conclusive asset deterioration and serviceability loss in advance of failure at the locations of the challenge examples. This included the catastrophic embankment collapse at Stonegate (images left). Two days of demonstrations and presentations took place to an expert panel in December 2016.

This was an incredibly useful exercise to test the actual market capabilities for the specific needs that we have. We concluded that satellite capabilities are useful for regional deformation (i.e. isostatic rebound) and in urban environments (i.e. response to tunnelling). However, the challenge clearly demonstrated our needs cannot currently be met and a thin linear infrastructure, consisting of slopes predominantly covered in vegetation cannot yet be adequately monitored from space.

> *"Satellite interferometry cannot provide, at present, the sampling frequency required for a reliable failure forecasting method for early warning purposes"*
>
> **Moretto et al* (2017) Assessment of Landslide Pre-Failure Monitoring and Forecasting Using Satellite SAR Interferometry.**
>
> ***Natural Hazards Control and Assessments (NHAZCA);** spin off from the University of Rome; analysis and monitoring of natural hazards and infrastructure for the management and mitigation of risks.*



**Images left:** Deterioration and catastrophic embankment failure in SE Route at Stonegate during the 2013/14 winter. Asset was known to be deteriorating and was awaiting intervention in CP5 but deteriorated rapidly during the wettest winter on record. Failure case study was included in the satellite industry trial (2016).

DTM image from Central-Alliance

Image above & inset: Slope failure at Farnley Haugh in LNE route during January 2016 (following wettest December on record). The digital terrain model, captured by UAV, shows a clearly defined failure within slope benching that was undertaken during previous enhancement works (widening and realignment in the 1960s).

Traditional in-situ deformation monitoring is typically expensive and also limited in spatial coverage and temporal frequency. Remote sensing techniques, such as light detection and ranging (LiDAR), synthetic aperture radar (SAR) and multi-temporal interferometry (MTI) are capable of delivering high quality information for many engineering applications. Good case studies exist in the published literature to show where these techniques have been used to monitor the long term performance of airport runways, reservoir dams, off-shore breakwaters, ground behaviour from tunnelling / mining and large natural landslides.

We recognise that the speed of emerging capabilities will require us to regularly horizon scan and potentially undertake trials where new technology exists to potentially improve our business processes. The most attractive and reliable contribution provided by remote sensing techniques lie in the possibility of wide-area qualitative distinctions between stable and unstable areas (Colesanti, 2006) and the zonation of large landslides and regional ground deformation through on the identification of slow movement rates.

*“MTI provides information on distance changes between the on-board radar sensor and the ground target (whether it be a building or the ground surface)”*

*“MTI is based on processing of long temporal series of radar images (typically >15) to remove the atmospheric disturbance, and on the selection of targets on the ground that provide a backscattered phase signal coherent in time”*

*“The MTI technique is particularly effective in urbanised settings, where a large number of human made objects can be exploited as good radar targets”*

*“MTI can deliver very precise (mm resolution), spatially dense information (from hundreds to thousands measurements point/km2) on slow (mm-cm/year) deformations affecting the ground”*

**Wasowski (2017) High resolution satellite multi-temporal interferometry for monitoring infrastructure instability**

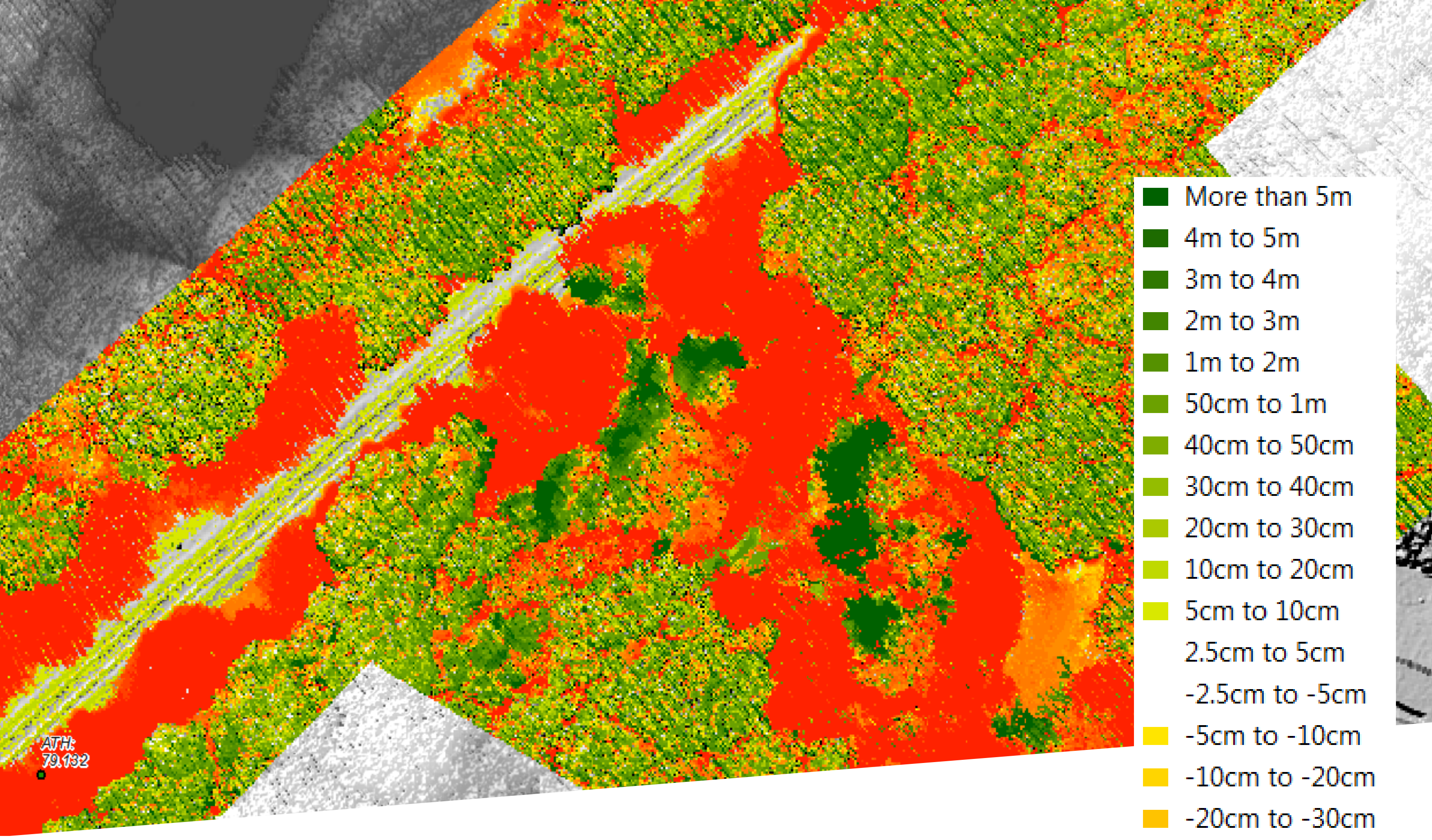
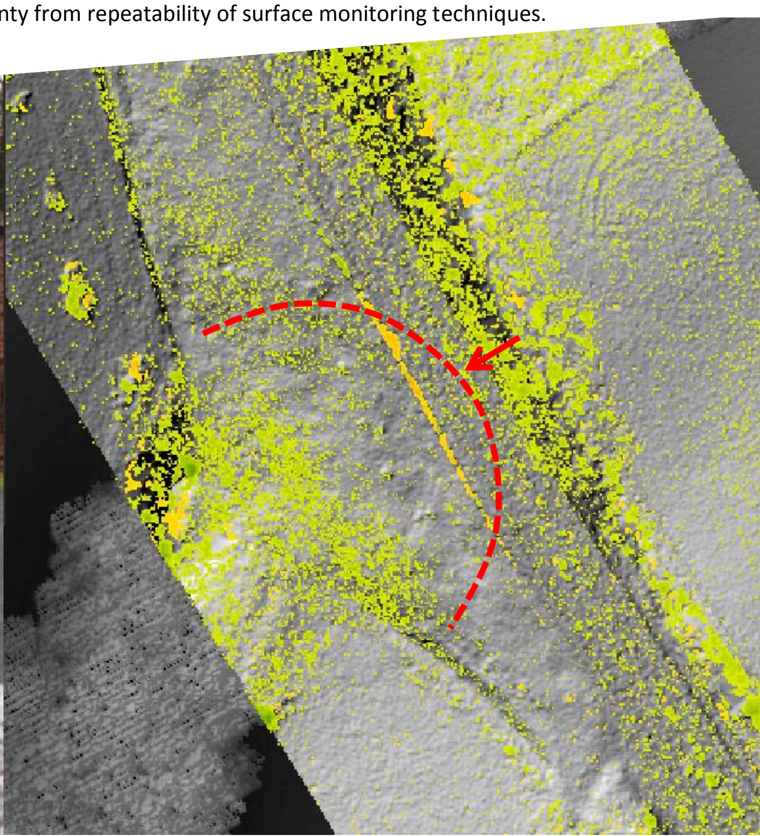


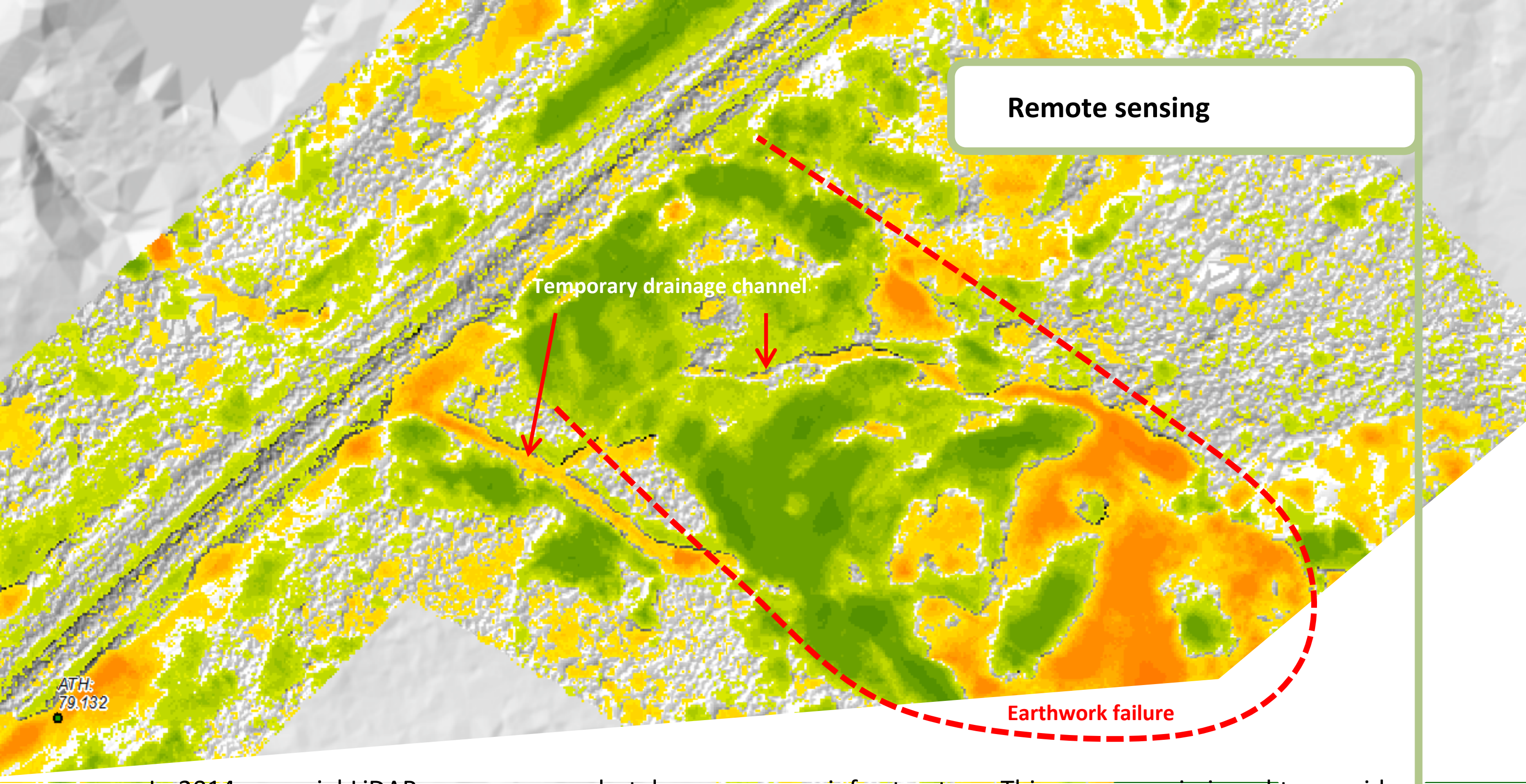
**Image Above:** elevation change surface model (tree canopy etc) from LiDAR surveys undertaken in 2014 and 2017 of a deep seated rotational failure within a soil cutting in the South East route. Notable vegetation clearance has been undertaken along the track to prevent encroachment into the 'immediate action zone'. The location of the slope failure is evident from vegetation works undertaken on the slope as part of the enabling works prior to remediation.

**Image Opposite**: elevation change terrain model (ground profile only) of LiDAR surveys in 2014 and 2017 of the same rotational failure as described above. Notable settlement is evident at the crest of the failure (amber) with uplift and heave associated at the bottom of the cutting slope closest to the track (green). Temporary slope drainage channels are also evident running along the edge of the failure and cutting across the mid-slope. Background noise within the surrounding areas highlights the issues of uncertainty from repeatability of surface monitoring techniques.

**Images Below**: Results from elevation change modelling (of the terrain) following repeat LiDAR surveys undertaken in 2016/17. Subsidence along crest (orange) and upheaval at the toe of the slope (green) are known to be occurring as a result of a deep seated failure (monitored by a sub-surface technique). Changes in the elevation model in the known problematic area are clear, but background noise within the surrounding areas highlight the issues of uncertainty from repeatability of surface monitoring techniques.



# Remote sensing



In 2014 an aerial LiDAR survey was undertaken across our infrastructure. This was commissioned to provide greater intelligence to a range of assets and enhance existing data sets. Today the post processed data is available through the company GIS viewer Geo-RINM. Digital terrain models (DTM) and digital surface models (DSM) can be toggled on and off to respectively analyse / view the ground profile and vegetation canopy. Data tiles are available for projects to utilise and integrate cloud point data into feasibility and design deliverables.

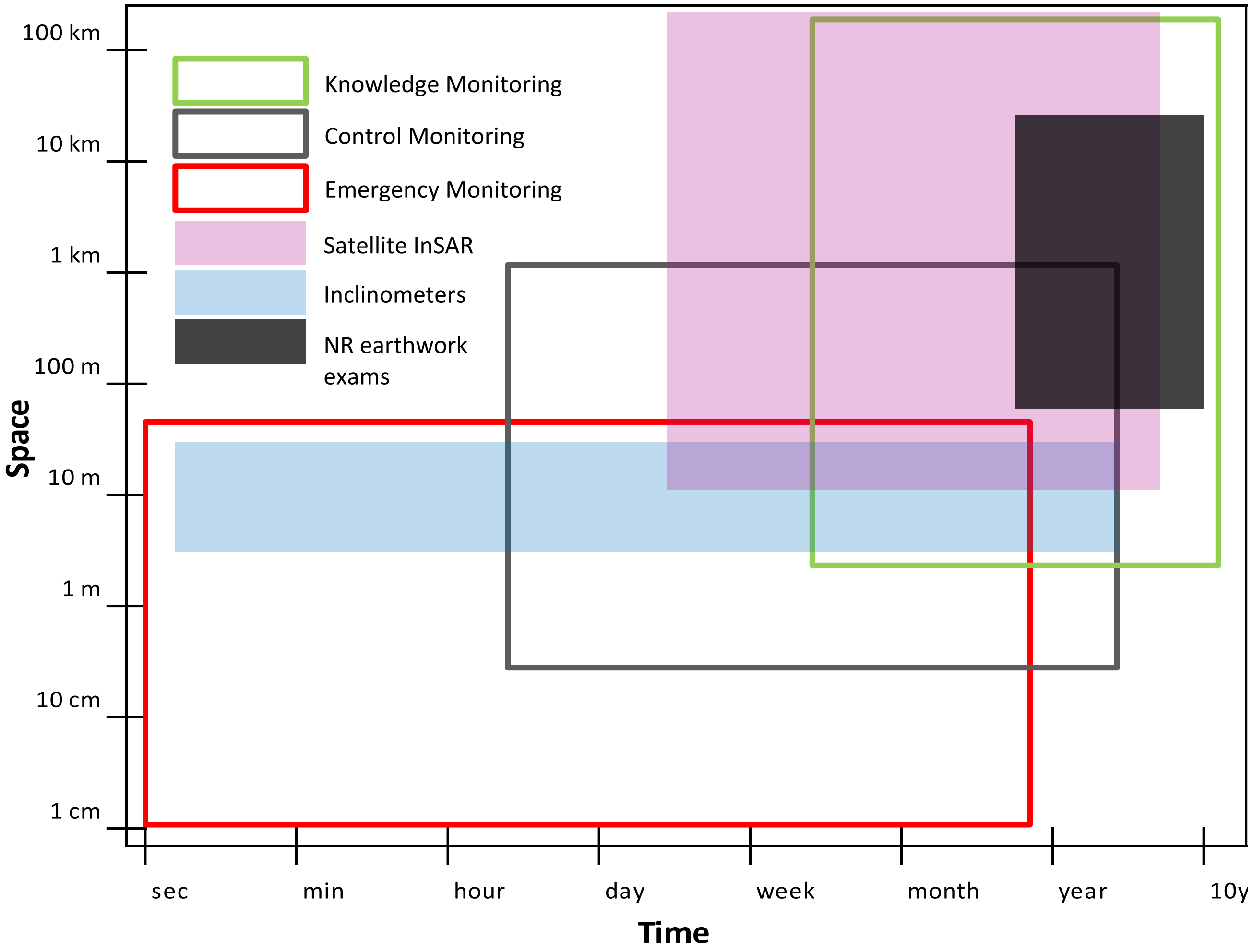
In earthworks management such data is commonly used to review geomorphological features, provide the geometry input into slope stability models and form a baseline for topographical surveys. We have undertaken a number of repeat LiDAR surveys on a selection of problematic assets to demonstrate the potential capabilities from augmenting DTM survey data and calculating elevation difference. Images on this page demonstrate some of the opportunities and challenges in creating elevation change models (ECM).

Corporate plans for CP6 include updating the aerial survey data across our portfolio to include:

- Data processing to develop and produce DTM's and ETM's that are visible within Geo-RINM
- Asset data linkage of 'change' between surveys with assets identified from the Asset Data Store

Investment is planned in CP6 to unlock intelligence from the repeat survey. We recognise that this would require significant data processing and storage for which we are working with the business to enable. A previous recommendation from a deep dive on behalf of the company Safety, Health and Environment (SHE) committee was to ***specify, construct and <u>update regularly a digital ground model</u> to detect slope movements*** with the aim to improve asset information to detect precursors prior to catastrophic failure. Updating these models should also enable more intelligence to be obtained on changes in land use adjacent to our infrastructure.

> *"Although techniques are considered to have already reached the operational level, it is apparent that in both research and practice we are at present only beginning to benefit from the high resolution imagery that is currently acquired by the new generation radar satellites"*
>
> *"It is very difficult to measure displacements exceeding few tens of cm/year and strong non-linear deformations"*
>
> **Wasowski (2017) High resolution satellite multi-temporal interferometry for monitoring infrastructure instability**



**Above:** Modified space-time-need (STN) schematic diagram after Mazzanti (2017). Illustrative chart showing the position of different types of geotechnical monitoring (described further on p32). The remote sensing technique of satellite InSAR is shown to demonstrate the capabilities that are possible in optimum terrain and conditions. NR earthwork examinations are shown for context, as is sub-surface inclinometers that are typically installed when control monitoring is required.

*"With the exception of urban and bare rock slopes…the density of radar targets suitable for interferometric measurements…introduces considerable uncertainties in the assessment of ground motions"*

*"The interpretation of the exact geological/geotechnical significance of millimetre to centimetre (per year) displacements can be very challenging because very slow ground surface deformation may arise from a wide variety of causes and, therefore, their presence on slopes may not always reflect shear movements or occurrence of landslides"*

*"The highly variable sensitivity of SAR systems to down-slope displacements can represent a considerable limitation in landslide investigation"*

*"Lack of natural, coherent radar targets in areas by dense vegetation and steep and adversely orientated slopes with respect to satellite line of sight geometry"*

*"Usually unable to detect strong non-linear deformation signals and high velocity displacements (e.g. exceeding few tens of cm/yr)"*

*"Difficult to set a single, generally applicable value for minimum velocity threshold to distinguish stable and unstable slopes (or active and inactive landslides)"*

**Wasowski (2014) Investigating landslides and unstable slopes with satellite Multi Temporal Interferometry: current issues and future perspectives**

**Above:** Remedial works at Farnley Haugh in LNE route following slope failure in January 2016.
Local granular replacement, in comparison to typically vegetated slopes, would provide suitable conditions for InSAR measurements.

We recognise that remote sensing techniques using airborne and satellite-based sensors can provide a very cost effective means of acquiring high resolution information for the ground surface over very large areas. The chart opposite demonstrates the different types of monitoring utilised by geotechnical asset owners.

Whilst remote sensing provides excellent opportunities for knowledge / control monitoring, our infrastructure is far from the ideal conditions that many technical publications suggest are necessary for good results (in particular satellite InSAR). For infrastructure slopes the spatial resolution is often impeded by the presence of dense vegetation. Therefore traditional instrumentation (like inclinometers) will still be required to manage assets that are degrading and starting to actively fail at depth.

We shall continue to horizon scan and investigate remote sensing techniques that may:

- Allow intelligence on change to be identified quickly (including change beyond the boundary fence)
- Improve the reliability and reproducibility (R&R) of earthwork inspections
- Enable a step change in the earthwork examination process and reduce the number of individuals working alone on uneven ground inspecting infrastructure slopes
- Provide indications of ground saturation and hydrophilic vegetation
- Offer intelligence using instrumentation fitted to rolling stock about the condition of gauge clearance

**Above:** Products from the national aerial LiDAR survey. Vertical aerial imagery (left) and the accompanying digital terrain model (DTM) showing geomorphological features on the embankment (right).

**Above:** Ultimate Limit State (ULS) failure of an embankment in Kent during the 2013/14 winter. Site was exposed to high maintenance frequency as a result of Serviceability Limit Sate (SLS) failures over several years.

***Demand Analysis*** *"The process an organisation uses to both assess and influence the demand for, and level of service from, an organisation's assets. It typically includes the analysis of future demand for the product or services being offered and the requirements this demand will place on the asset portfolio"*

**Anatomy of asset management (2015) - The Institute of Asset Management**

*"It is considered that the 'failures' which are directly attributable to train loading (a fatigue type of mechanism) would not be reported in the current NR reporting system, where the emphasis is on the recording of classical ULS* embankment failures. Furthermore, a prolonged time period would need to elapse before obvious signs of deterioration become apparent. Such SLS** failures would typically manifest themselves as local track settlement and generally lead to the need for increased track maintenance. In order to assess the impact of such failures on the rail network, it is recommended that a detailed analysis of track maintenance records is carried out"*

*"A preliminary assessment of the distribution of potentially load sensitive embankments across the UK railway network has been conducted on the basis of embankment fill properties and the results presented geographically… On the basis of the initial vulnerability classification, about 1100km of track is classified as high, and 628km is classified as very high, with the majority (60-70%) being located in the South East Area Territory***. This is consistent with expectations due to the nature of the geology across the network. It should be emphasised that this classification of vulnerability to railway traffic loading, is based solely on the anticipated clay fill plasticity index.... Nevertheless, the above vulnerability classification provides an initial basis for planning purposes"*

**RSSB & Mott MacDonald (2011) The effects of railway traffic loading on embankment stability**

** ultimate limit state   **serviceability limit state   ***now the three devolved Routes of Wessex, Anglia and SE*

**Above:** Robust embankment repair of an ultimate limit state (ULS) failure on the approach to a viaduct

Typically the more we use something the more it will deteriorate and approach the anticipated end of life. Changing the frequency of use or increasing the demand per use will also change the predicted date of renewal. Demand analysis is therefore a key process to understand the future requirements that may be placed on an asset and how these demands coupled with rates of deterioration will impact an assets life. Future forecasting of deterioration comes with uncertainty. For homogeneous materials and assets this uncertainty is less than for heterogeneous assets, like embankments, that have a wide range of factors impacting their deterioration.

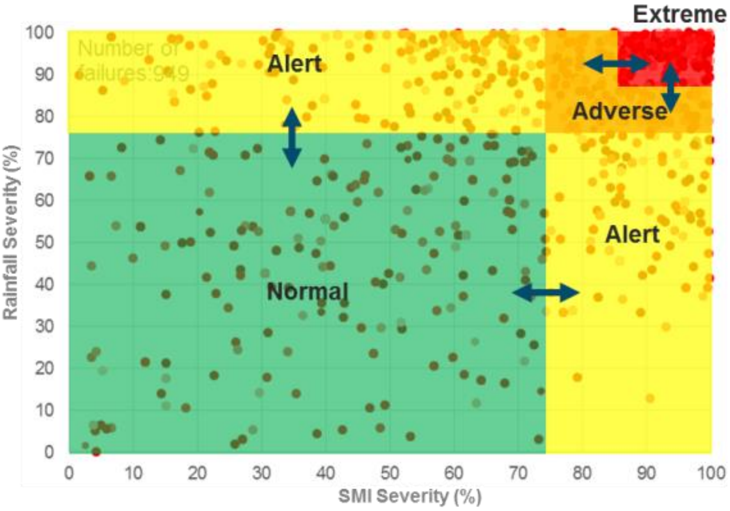
Joint studies with RSSB have shown that the key variable affecting track deformation is the axle load and the number of load applications. A classification for load sensitive embankments was developed and based on the plasticity index of clay fill. In order to assess the potential damage from railway traffic loading additional factors also need to be considered, such as ballast / ash thickness, track geometry, drainage, clay fill strength and local structural features (adjacent/underlying “hard spots”), such as culverts and retaining walls.

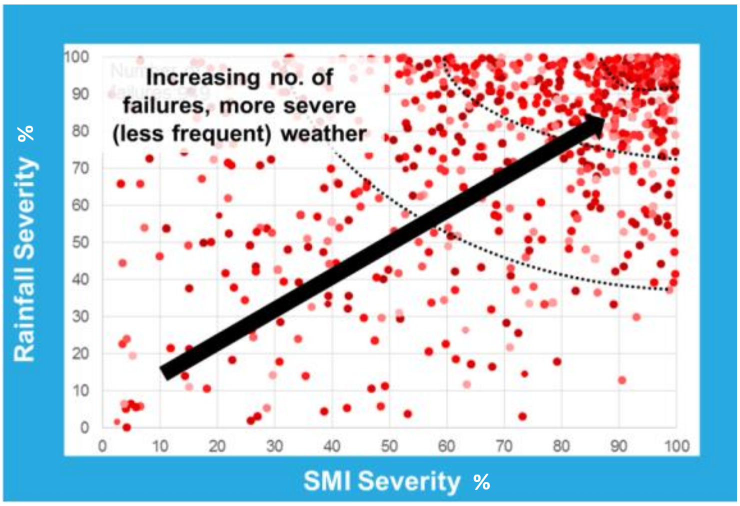
The previous review into the effects of railway traffic loading on embankment stability (RSSB, 2011) concluded that from the data available there was no correlation between the occurrence of large scale catastrophic embankment failures and a change in traffic loading. However the report recognised that fatigue type serviceability limit state (SLS) failures would be induced by train loading and manifest in poor trackbed performance. It is likely that the development of embankment SLS failures will be a slow and progressive process which will initially become evident through an increasing frequency of track maintenance. Without a reliable means of prediction, it is possible that works to renew track or formation components will not address the root cause of the problem within the embankment below the track.

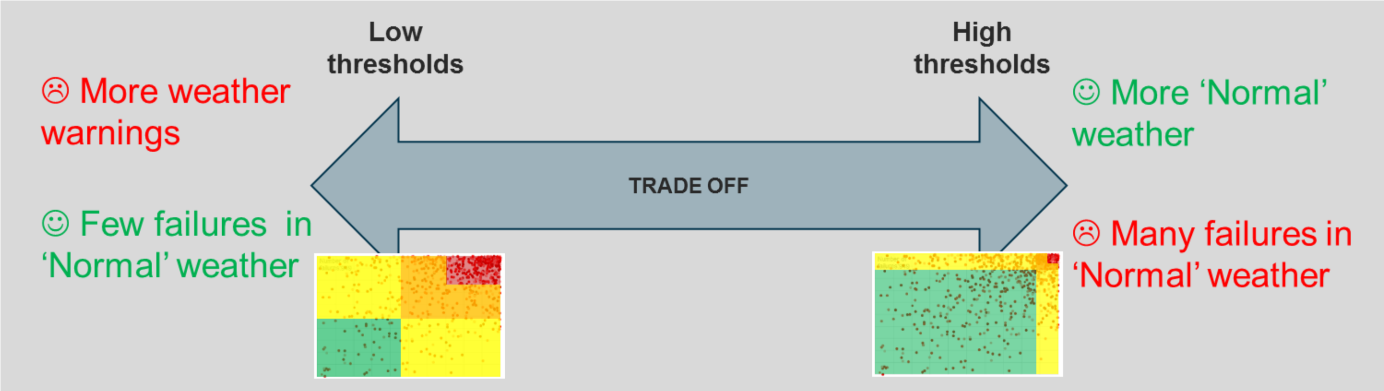
We recognise that further work is required in this area and we are committed to:

- Providing a capability to the geotechnical teams to formally record SLS failures for future analysis
- Identifying trial sites and suitably instrumenting, with long term monitoring to compare modelled predictions against actual deformations over a large number of cycles comparable to the asset age
- Undertaking further material testing representative of embankment fill in the UK
- Further studying the distribution of increased maintenance activities on embankments across the UK and linking this work with our studies into embankment track quality research

**Above:** Typical earthwork failures within the NR database that was used to undertake a correlation with weather data.







**Above:** Extracts from work undertaken by Arup on behalf of NR in using a data driven approach to identify drivers of earthwork failures. In total some 427 million weather data points were analysed against the earthwork failure database. Relative severity (a proxy for return period based on the data history availability) of rainfall and SMI* are shown for each earthwork failure since 2003/04. This combination shows the strongest correlation of ground conditions and rainfall, such that there is an increasing number of failures as the weather becomes more severe (and less frequent). Warning thresholds and triggers can then be assigned based on combinations of ground conditions and forecasted rain; recognising that there will always be a trade-off with the operational impacts. The clustering of failure dots towards the top right demonstrates that proportional to the extent of extreme weather more failures occur within these conditions, but highlights that failures will occur in other conditions (i.e. as a result of asset age). Extensive analysis has shown many earthwork failures have occurred in weather conditions where it is deemed to not be reasonably practicable to mitigate, given the low occurrence of earthwork failures in highly frequent weather conditions (i.e. non adverse / extreme).

**SMI: Soil moisture index; measure of moisture developed for agricultural purposes, a computed measure of saturation from the European Centre for Medium Range Weather Forecasting (ECMWF), provided twice daily at four different levels (up to 255cm bgl).*

Catastrophic embankment failure in Sussex during 2013/14

The main driver for slope failure is often rainfall, and it is predicted that a hotter future European climate will see rainfall arrive in more intense storm events. However, we also manage an asset base that is in parts greater than 170 years old, degrading and originally built quite poorly without the knowledge we have today of soil mechanics and geotechnical engineering.

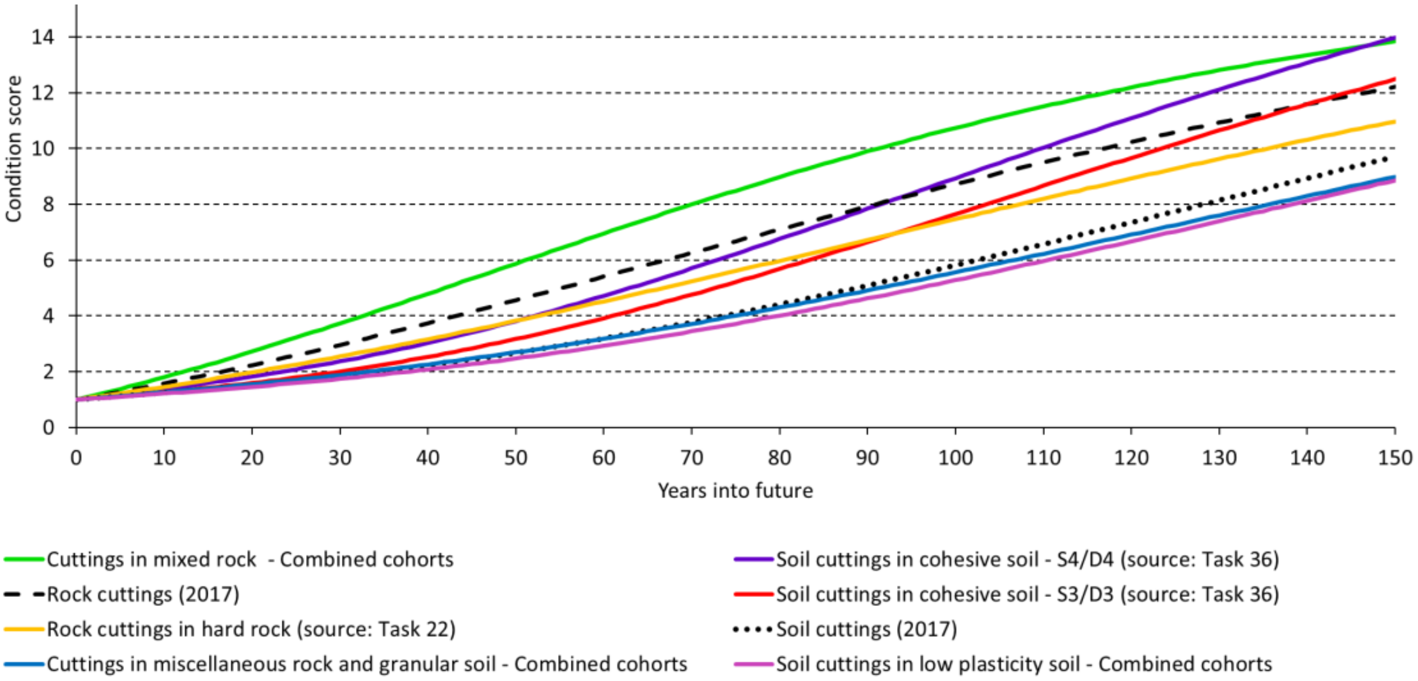
Our infrastructure experiences a relatively stable number of failures over a five year control period. Perception as to the root cause of earthwork failures is often flawed by a lack of awareness of other possible explanations. The belief that an event such as a landslip is more predictable after it became known, than it was before it became known can be referred to as hindsight bias (Roese 2012). Hindsight bias in the field of slope stability can lead an individual to believe that an incident was more predictable and less uncertain than it actually was (Lee 2015).

When there is a need to understand failure events as they were experienced, hindsight bias can thwart sound appraisal, as there is often an inability to recapture the feeling of uncertainty that preceded a failure. This can result in missed learning opportunities and poor recommendations that add little value.

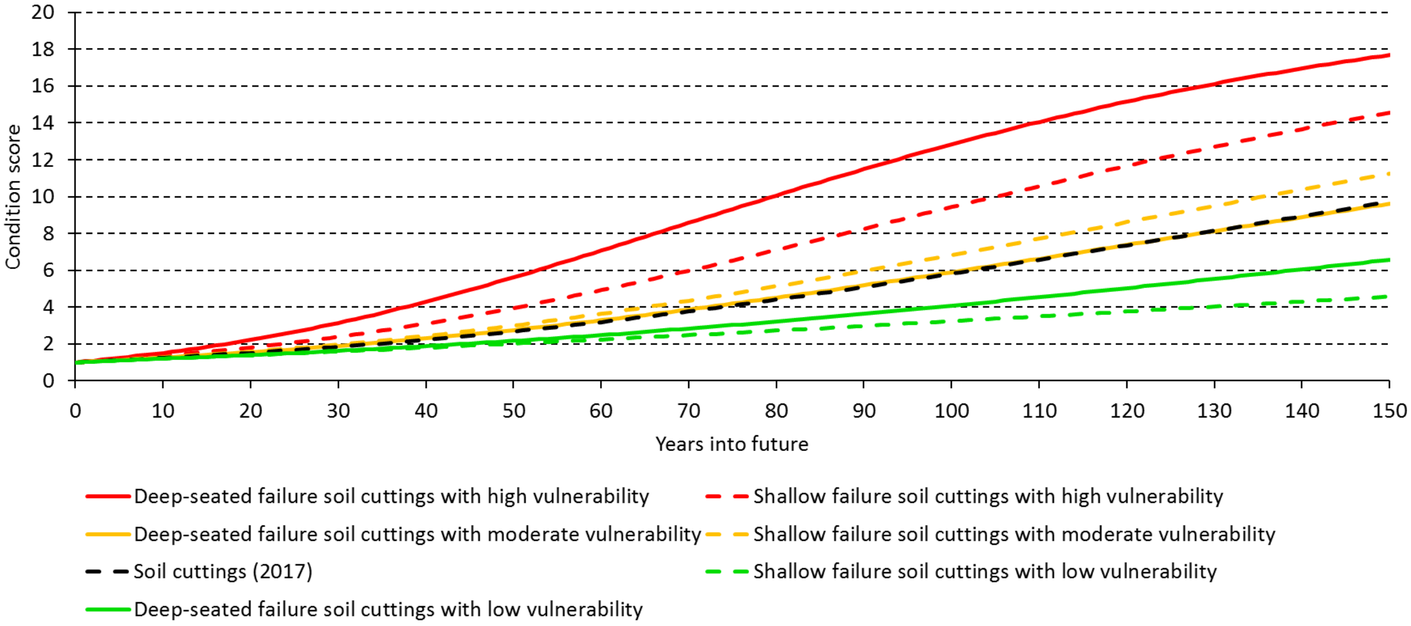
An effective strategy to reduce hindsight bias involves raising a person's awareness of other possible explanations and cause-effect linkages (Roese 2012). This is now more feasible following the completion of a national Global Stability Resilience Appraisal (GSRA) and outputs from the rainfall data driven analysis of earthwork failures (opposite). GSRA compares the capability of our slopes against modern design codes and highlights a delta that is not apparent in a relative condition or risk based management approach.

To continually move forward and progress our understanding of asset failures we are committed to:

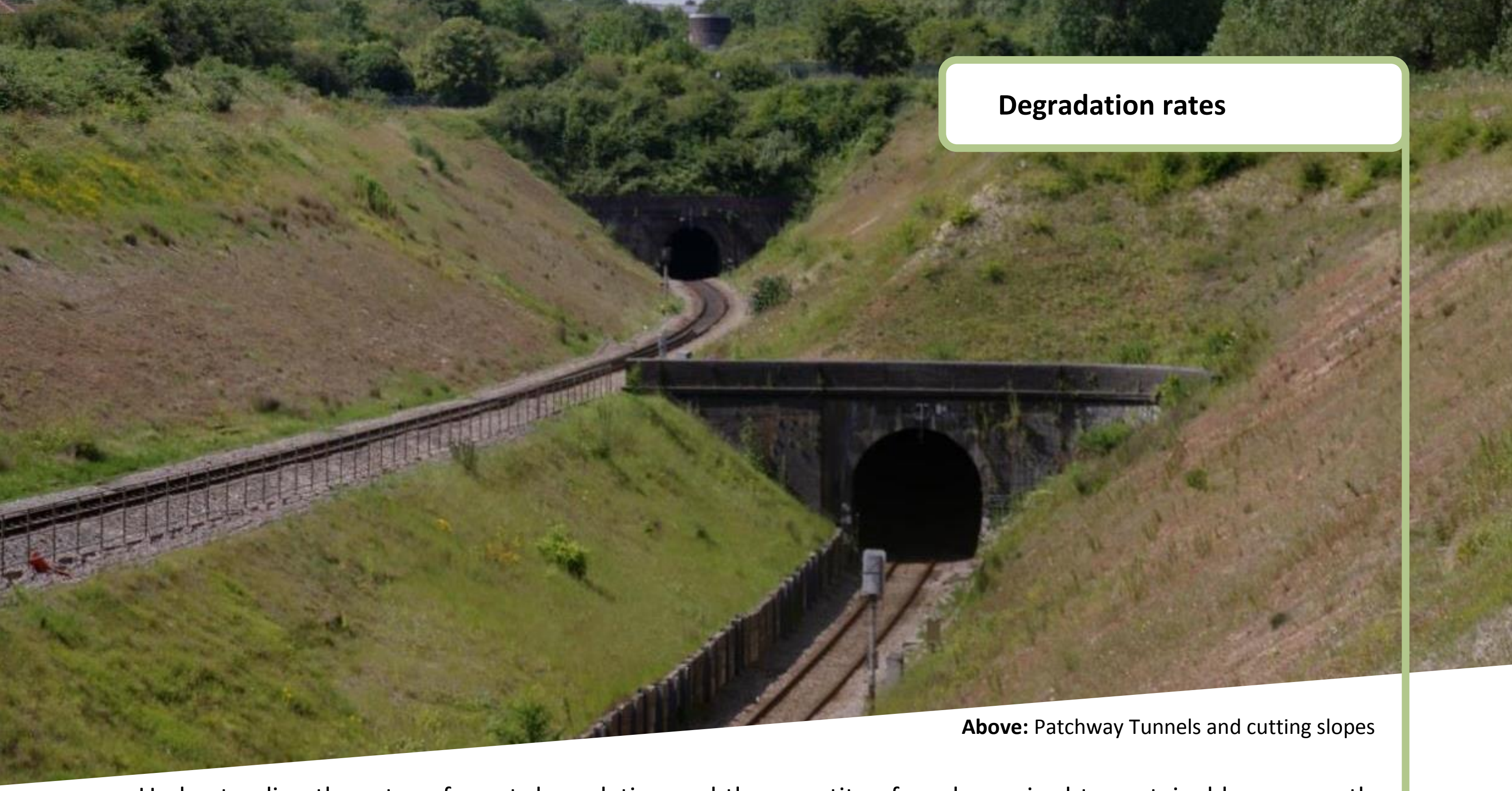
- Peer reviewing all failures and independently reviewing potentially high consequence failures
- Continuing to improve our understanding of relationships between ground saturation, rainfall and asset failures to improve trigger levels for mitigating risk during extreme weather
- Further developing our knowledge of asset degradation; for degradation and geometry characteristics are often the root cause of many failures that occur in normal conditions
- Enhancing systems to make the outputs of GSRA more readily available to the business



**Above:** Data driven deterioration curves for cutting slopes extrapolated 150 years into the future. The y-axis metric is a portfolio condition score where an increasing number represents a worsening portfolio. Generation of curves is based on real condition data but applied to an artificial portfolio of assets that all start in earthwork hazard category A.
Six geology cohorts are shown in addition to the grouped rock cutting and soil cutting assets. Data indicates that cuttings in mixed rock (e.g. interbedded coal measures) are typically degrading quickest. In contrast soil cuttings in low plasticity clay soil are typically degrading the slowest. Relative to the low plasticity soils our data suggests greater rates of degradation in S3/D3 cohesive soils (liquid limit of 40-60%) and then S4/D4 cohesive soils (liquid limit of >60%). The sequencing within the clay cutting portfolio as described and evidenced through a data driven process aligns to a qualitative engineering assessment.



**Above:** Data driven deterioration curves for cutting slopes extrapolated 150 years into the future. The y-axis metric is a portfolio condition score where an increasing number represents a worsening portfolio. Generation of curves is based on real condition data but applied to an artificial portfolio of assets that all start in earthwork hazard category A.
Global Stability Resilience Appraisal (GSRA) cohorts, see page 18-19, are shown against the grouped soil cutting asset population. GSRA assesses the vulnerability of assets by taking LiDAR derived geometry data and published geotechnical parameters to model deep seated and shallow surface stability. When degradation is assessed by GSRA groupings the data indicates that there is a logical order of degradation for assets that are most vulnerable from a first principles assessment of slope stability. This sequencing as evidenced through data aligns to a qualitative engineering assessment.



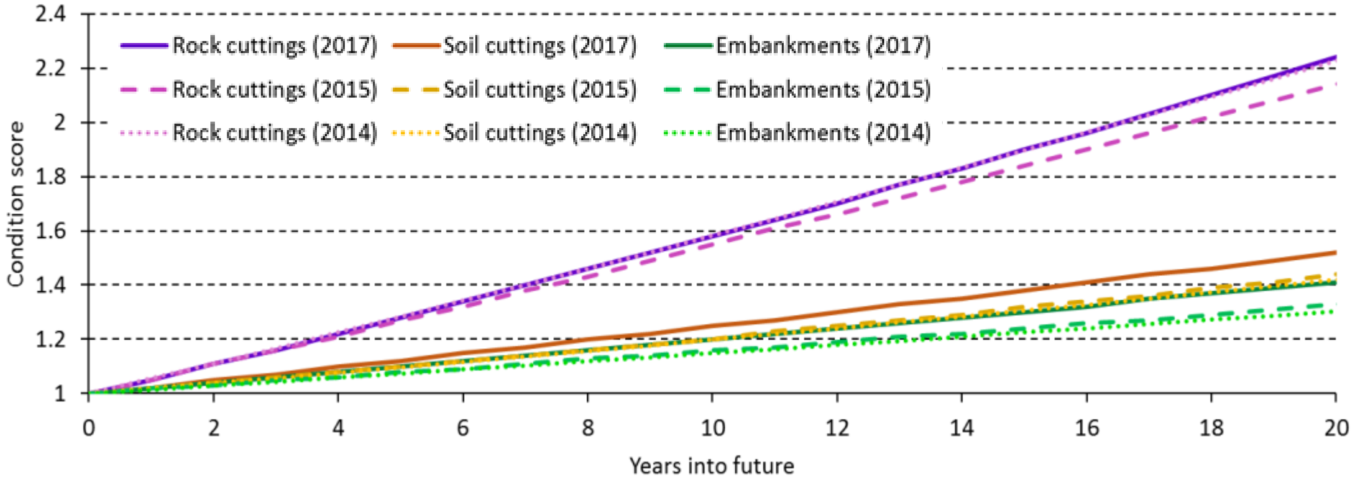
# Degradation rates

**Above:** Patchway Tunnels and cutting slopes

Understanding the rates of asset degradation and the quantity of work required to sustainably manage the portfolio has been a key focus. The development in our understanding of condition state change over time has only been possible because of the quantity of structured examination data that has been consistently recorded for nearly 15 years.

Whole life cost modelling depends on a variety of inputs and one of the most important is the degradation profiles for the asset. Improving the data quality and refining the granularity of how we measure asset degradation will remain a key focus of development.

We are now able to combine the outputs from the Global Stability Resilience Appraisal (GSRA) work, see pages 18 & 19, to assess degradation by asset type (rock cuttings, soil cuttings and embankments) and more recently geology based cohorts of increased granularity. Whilst data allows us to demonstrate that of the three principal asset types it is rock cuttings that are degrading the fastest, see chart below, we are now able to show that clay (cohesive) cuttings are degrading more slowly than for example mixed rock cuttings, see chart at the top of opposite page. We will continue to refine our understanding of degradation and in time this may lead to refinements in our policy by placing greater emphasis on particular cohorts of asset type. Continued research through modelling will enable an improved understanding of long term performance and enable better asset management and decision making through improved intelligence.



**Above:** Degradation curves for 2014, 2015 and 2017 data sets. Rate of increase in condition score for the different asset groups show asset degradation is occurring most in rock cuttings and then soil cuttings ahead of embankments. Generation of curves is based on real condition data but applied to an artificial portfolio of assets in hazard category A.


Rock slope examination taking place by rope access

> *"Risk management is a process of identifying, understanding, managing, controlling, monitoring and communicating risk. This ensures investments are considered across the range of options and choices, and are proportionate to the risks. Effective risk management is the key to facilitating and building resilience, particularly when driven at the corporate level to create a culture where resilience and business continuity management is embedded in operations. This creates 'organisational resilience' – the ability of an organisation to anticipate, plan and respond to uncertainties and disruptions to business operations,"*
>
> **Cabinet Office**
> **Keeping the Country Running: Natural Hazards and Infrastructure (2011)**

We want to be established as globally recognised experts in earthworks asset management through harnessing knowledge, continuous improvement and exploiting emerging technologies. Embracing the Rail Technical Strategy we shall focus on accelerated R&D, harnessing more value from existing data sets and aim to reduce the disruption to train services from increased and better targeted capital interventions. A key enabler to this vision is recognition of the 2014 DfT report, which identified the need to progressively strengthen the physical resilience of earthworks on the network.

A reducing number of potentially high consequence earthwork failures is the result of continuous improvement, the introduction of an asset specific policy and an increase in staffing numbers of engineers managing the portfolio. Whilst this is positive we are cognisant that the impacts from earthwork related events will continue to cause challenges and disruption to the rail network.

We recognise that continued capital investment is required to progressively strengthen our infrastructure slopes. The rate of this investment will depend on the needs of other asset groups and the difficult decisions that are continually made for the benefit of the whole railway system. We recognise various criteria need to be considered for the optimum trade-off between cost, risk and performance.; (1) safety risk, (2) impact on train performance, (3) impact on the environment, (4) life of the infrastructure and (5) weather resilience.

Our infrastructure slopes, most of which are in excess of 150 years old, are simply not comparable to the levels of capability and resilience that can be offered by modern engineered slopes. There are many more geotechnical hazards across our network than may be perceived from the tools we use and the way in which data is structured to provide a relative prioritisation of risk. Earthwork failures will continue to occur as it is simply not economically viable to strengthen all sub-standard infrastructure slopes. Technology must therefore play a greater part in the future.

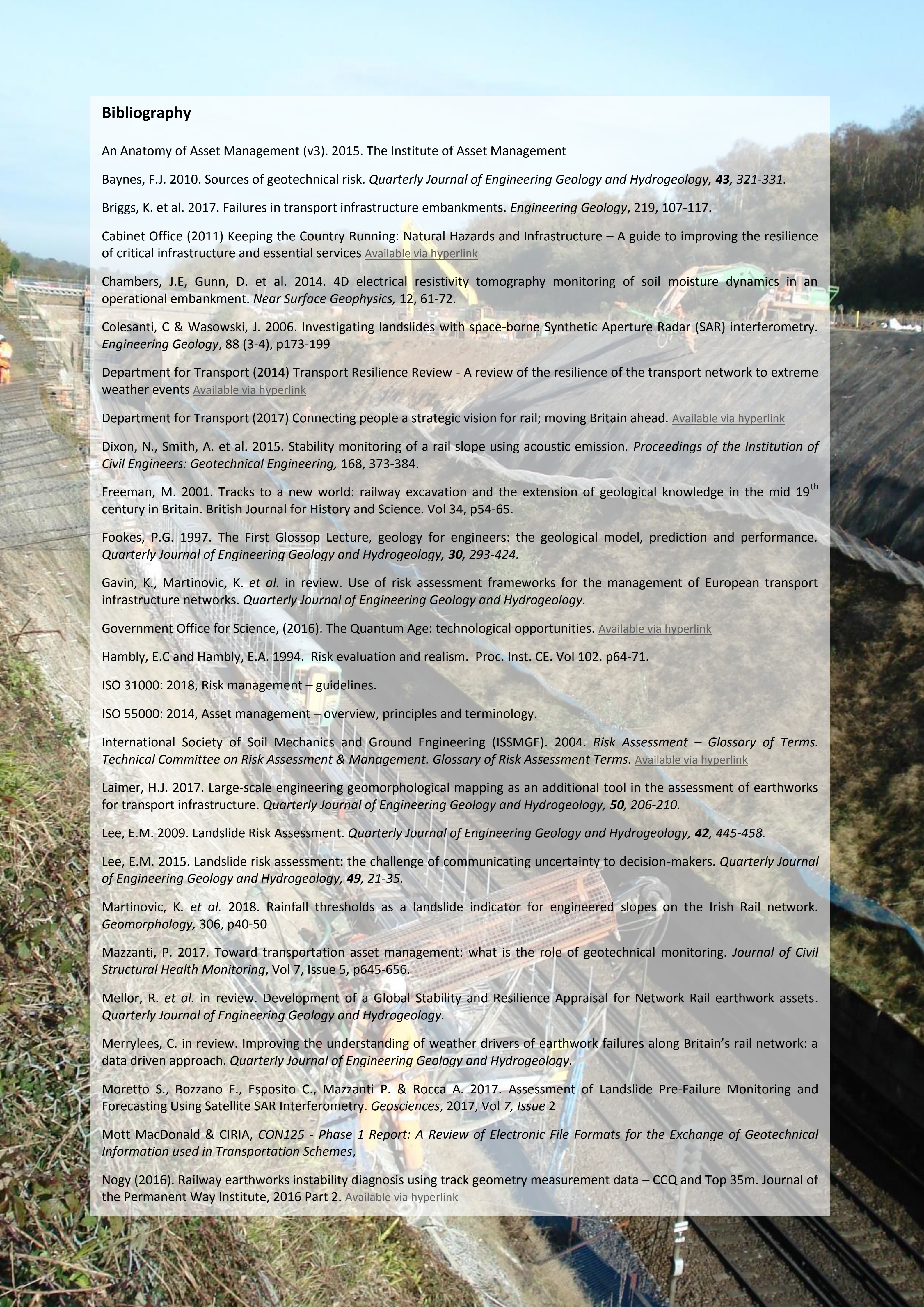
Stopping trains from finding failed earthworks that have rapidly lost the ability to perform is our top geotechnical challenge. Improving our mitigations to reduce the consequence of asset failure is an area we will continue to work at enhancing. We are very good at forecasting slow failures and intervening before a global loss of stability and collapse. The rapid failure of soil cutting slopes across the infrastructure is difficult to predict and the acceleration of deformation is often the result of local rainfall events. These events can be difficult for meteorologists to forecast accurately enough to be of use to us.

We do not know what the technology of tomorrow will be but we will embrace innovation, horizon scan and invest appropriately in R&D. Simultaneously continued capital investment is required to progressively strengthen the portfolio at a proportional rate to meet the varying demands across the network.

The relationship between cost, risk and performance is dynamic and changes over time. Earthworks are a long life asset and will benefit from the longer term strategic plans which Network Rail is now developing to span multiple control periods.

Both climate change and increased demand for greater usage on the network will provide longer term risks for which we shall continue to work with academia and research groups to further our knowledge and understanding.

A grounded appreciation of the challenges and capabilities of the portfolio will allow the future trajectory in earthwork management to remain looking positive.



## Bibliography

An Anatomy of Asset Management (v3). 2015. The Institute of Asset Management

Baynes, F.J. 2010. Sources of geotechnical risk. *Quarterly Journal of Engineering Geology and Hydrogeology,* ***43****, 321-331.*

Briggs, K. et al. 2017. Failures in transport infrastructure embankments. *Engineering Geology*, 219, 107-117.

Cabinet Office (2011) Keeping the Country Running: Natural Hazards and Infrastructure – A guide to improving the resilience of critical infrastructure and essential services Available via hyperlink

Chambers, J.E, Gunn, D. et al. 2014. 4D electrical resistivity tomography monitoring of soil moisture dynamics in an operational embankment. *Near Surface Geophysics,* 12, 61-72.

Colesanti, C & Wasowski, J. 2006. Investigating landslides with space-borne Synthetic Aperture Radar (SAR) interferometry. *Engineering Geology*, 88 (3-4), p173-199

Department for Transport (2014) Transport Resilience Review - A review of the resilience of the transport network to extreme weather events Available via hyperlink

Department for Transport (2017) Connecting people a strategic vision for rail; moving Britain ahead. Available via hyperlink

Dixon, N., Smith, A. et al. 2015. Stability monitoring of a rail slope using acoustic emission. *Proceedings of the Institution of Civil Engineers: Geotechnical Engineering,* 168, 373-384.

Freeman, M. 2001. Tracks to a new world: railway excavation and the extension of geological knowledge in the mid 19th century in Britain. British Journal for History and Science. Vol 34, p54-65.

Fookes, P.G. 1997. The First Glossop Lecture, geology for engineers: the geological model, prediction and performance. *Quarterly Journal of Engineering Geology and Hydrogeology,* ***30****, 293-424.*

Gavin, K., Martinovic, K. *et al.* in review. Use of risk assessment frameworks for the management of European transport infrastructure networks. *Quarterly Journal of Engineering Geology and Hydrogeology.*

Government Office for Science, (2016). The Quantum Age: technological opportunities. Available via hyperlink

Hambly, E.C and Hambly, E.A. 1994. Risk evaluation and realism. Proc. Inst. CE. Vol 102. p64-71.

ISO 31000: 2018, Risk management – guidelines.

ISO 55000: 2014, Asset management – overview, principles and terminology.

International Society of Soil Mechanics and Ground Engineering (ISSMGE). 2004. *Risk Assessment – Glossary of Terms. Technical Committee on Risk Assessment & Management. Glossary of Risk Assessment Terms.* Available via hyperlink

Laimer, H.J. 2017. Large-scale engineering geomorphological mapping as an additional tool in the assessment of earthworks for transport infrastructure. *Quarterly Journal of Engineering Geology and Hydrogeology,* ***50****, 206-210.*

Lee, E.M. 2009. Landslide Risk Assessment. *Quarterly Journal of Engineering Geology and Hydrogeology,* ***42****, 445-458.*

Lee, E.M. 2015. Landslide risk assessment: the challenge of communicating uncertainty to decision-makers. *Quarterly Journal of Engineering Geology and Hydrogeology,* ***49****, 21-35.*

Martinovic, K. *et al.* 2018. Rainfall thresholds as a landslide indicator for engineered slopes on the Irish Rail network. *Geomorphology,* 306, p40-50

Mazzanti, P. 2017. Toward transportation asset management: what is the role of geotechnical monitoring. *Journal of Civil Structural Health Monitoring*, Vol 7, Issue 5, p645-656.

Mellor, R. *et al.* in review. Development of a Global Stability and Resilience Appraisal for Network Rail earthwork assets. *Quarterly Journal of Engineering Geology and Hydrogeology.*

Merrylees, C. in review. Improving the understanding of weather drivers of earthwork failures along Britain's rail network: a data driven approach. *Quarterly Journal of Engineering Geology and Hydrogeology.*

Moretto S., Bozzano F., Esposito C., Mazzanti P. & Rocca A. 2017. Assessment of Landslide Pre-Failure Monitoring and Forecasting Using Satellite SAR Interferometry. *Geosciences*, 2017, Vol *7, Issue* 2

Mott MacDonald & CIRIA, *CON125 - Phase 1 Report: A Review of Electronic File Formats for the Exchange of Geotechnical Information used in Transportation Schemes,*

Nogy (2016). Railway earthworks instability diagnosis using track geometry measurement data – CCQ and Top 35m. Journal of the Permanent Way Institute, 2016 Part 2. Available via hyperlink

## Further information

**We are always keen to hear** from the supply chain to assist in the development of ideas, solutions and products. Please do get in touch and if your idea or proposal sparks interest we will invite you in to present to our engineers in Milton Keynes.

R&D@networkrail.co.uk

Our challenge statements are published on our website and are available via hyperlink

Our asset management policy and strategy documents are published on our website and available via hyperlink. Effective asset management supports the current and future timetable safely, efficiently and sustainably and should be read in conjunction with this technical strategy.

Norbury, D. 2017. Standards and quality in ground investigation; squaring the circle. *Quarterly Journal of Engineering Geology and Hydrogeology,* ***50****, 212-230.*

Office of Rail Regulation, Arup & Network Rail. 2011. Part A Reporter mandate AO/007: review asset policy, stewardship and management of structures. Final report – Review and benchmarking Available via hyperlink

Office of Rail Regulation, Arup & Network Rail. 2015. Part A Reporter mandate AO/049: review of updated earthworks asset policy for CP5 years 3-5 Available via hyperlink

Power, C. et al. 2016. Development of an evidence-based geotechnical asset management policy for Network Rail, Great Britain. Procedia Engineering 143: 726–733, Available via hyperlink

Rail Technical Strategy: Capability Delivery Plan Available via hyperlink

Roese, N.J., & Vohs, K. 2012. Hindsight Bias. *Perspective on Psychological Science,* 7(5), p411-426

RSSB & Mott MacDonald. 2011.The effects of railway traffic on embankment stability

Sharpe, P & Hutchinson, D. 2015. Prediction of earthwork failures using track recording car data. 2015 13th International conference in Railway Engineering. Edinburgh. Available via hyperlink

Skempton, A.W. 1996. Embankments and cuttings on the early railways. *Construction History,* ***11****,33-49* Available via hyperlink

Smethurst, J.A., Briggs, K., Powrie, W., Ridley, A., & Butcher, D. 2015. Mechanical and hydrological impacts of tree removal on a clay fill railway embankment. *Geotechnique,* 65 (11), p869-882.

Smethurst, J.A., et al. 2017. Current and future role of instrumentation and monitoring in the performance of transport infrastructure slopes. *Quarterly Journal of Engineering Geology and Hydrogeology,* **50**, 271-286, Available via hyperlink

Wasowski, J. & Bovenga, F. 2014. Investigating landslides and unstable slopes with satellite Multi Temporal Interferometry: current issues and future perspectives. *Engineering Geology,* 174, p103-138

Wasowski, J. et al. 2017. High resolution satellite multi-temporal interferometry for monitoring infrastructure instability hazards. *Innovation infrastructure solutions.* Volume 2, Issue 1, Article 27, Available via hyperlink

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