ARUP AECOM

WP 1-086(PPRO 4/45/12) - Application of Remote Survey Data for Geotechnical Asset Condition & Performance

Phase 2 Report

22 August 2017

Version 4.0

Document Control

Document Title	WP 1-086(PPRO 4/45/12) Application of Remote Survey Data for Geotechnical Asset Condition & Performance Phase 2 Report
Owner	Work Package Manager
Distribution	David Patterson, Dennis Sakufiwa (for information only)
Document Status	DRAFT

Revision History

Version	Date	Description	Author
0.1	30/06/17	Initial Draft	ÁNB, AM, GC, MW, SC
1.0	05/06/2017	Draft for comment	ÁNB, AM, GC, MW, SC
2.0	31/07/2017	Final addressing Client's comments	ÁNB, SC
3.0	11/08/2017	Issue without comments visible	ÁNB, SC
4.0	22/08/2017	Final issue	Ánb, SC

Reviewer List

Name	Role
Jason Manning	Senior remote sensing specialist
Michael Devriendt	Arup Project Director
Tony Daly	Asset management specialist

Signoff List

Name	Role
James Codd	Project Sponsor

Table of Contents

1. Introduction

This task, 1-086 '*Application of Remote Survey Data for Geotechnical Asset Condition & Performance*', was awarded by Highways England (SES directorate) to Arup AECOM under the SPaTS research framework to evaluate the potential and realisable benefits that remote surveying techniques could bring to Highways England's geotechnical asset management.

The project brief states that the objective of the work was to:

> *"Understand the potential roles of land and aerial based remote sensing techniques within geotechnical asset management, specifically in developing knowledge of asset condition and performance and application in the fields of asset deterioration modelling, maintenance and renewal."*

This report presents work carried out under Phase 2 and how the project's objectives have been met.

The work has been carried out in two phases:

- Phase 1: review of potential remote sensing techniques – summarised below in Section 1.1, and reported in full separately in *Phase 1 Report, January 2017*
- Phase 2: application of remote sensing techniques to Highways England geotechnical asset management

For the purpose of this work, *remote surveying* is defined as gathering of data at a distance e.g. collected via satellite, plane, vehicle etc. It does not include data collected via on-slope instrumentation such as inclinometers, piezometers or sensors that can be connected wirelessly.

1.1. Summary of work undertaken in Phase 1

Phase 1 (September 2016 to January 2017) researched and reviewed remote surveying techniques that have a potential geotechnical application. The review addressed techniques already procured by Highways England as well as others not currently utilised, and emerging remote sensing technologies. Phase 1 built upon Highways England's previous research (2000-2011), which highlighted that remote sensing techniques and their applications in asset management have evolved significantly in the last six years.

The techniques reviewed under Phase 1 were:

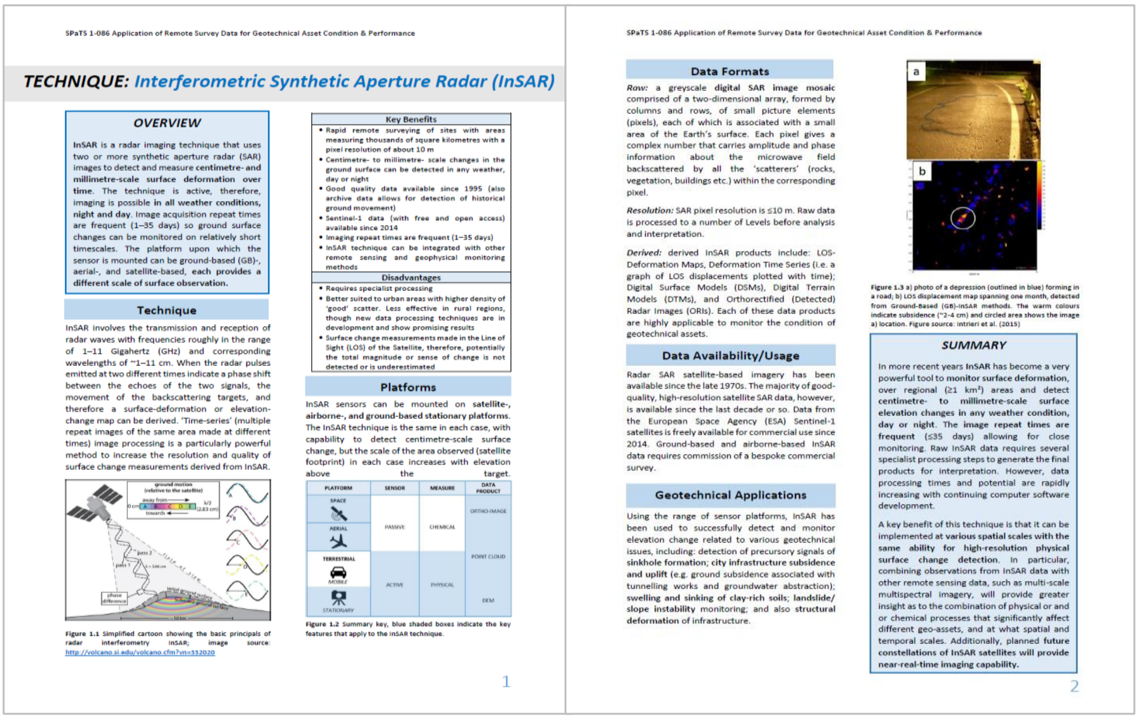
Technique		
Previously and/or Currently Procured		**Not yet Procured**
Mobile Mapping System (vehicle-mounted):		Interferometric Synthetic Aperture Radar (InSAR)
Digital Imagery	LiDAR	Multispectral imaging
Airborne (Fixed and rotary wing)[1]		Thermal Scanning
Orthoimagery[2]	LiDAR	Microwave Radiometry
Traffic Speed Condition Survey (TRACS) **Ground Penetrating Radar (GPR)[3]**		Structure from Motion (SfM)
		Hyperspectral imaging

1. Fixed *wing LiDAR surveys were trialled in the previous phase of research (2000-2011). After a pilot undertaken in 2016, Rotary Wing LiDAR surveys are now been procured as part of the National Rotary Wing Surveying Project.*
2. Orthoimagery is an aerial photograph geometrically corrected ("orthorectified") such that its scale is uniform.
3. TRACS and GPR datasets are currently procured by Highways England's Pavement group. GPR dataset has not been reviewed as part Phase 1.

Two-page research summary sheets were also developed for each of the techniques researched (see Figure 1). These sheets provide a concise review of each technique and high level applicability to geotechnical asset management.

The Phase 1 study report describes how improved methods of data collection, post-processing of data, and data-fusion are developing rapidly, and show promise for employing remote sensing techniques to monitor condition and performance of geotechnical assets. It was found that these remote sensing techniques could all be suitable for geotechnical applications and should be considered in Phase 2, subject to data availability. Six of these were shortlisted for researching further for their applicability to geotechnical asset condition monitoring.

It was recommended that Highways England should initially seek to exploit remote sensing datasets that are already available within the business (LiDAR and imagery), having been procured previously, primarily for building asset inventories. Considering the geographic coverage and history of these existing datasets it was also estimated that they could be exploited to monitor condition change in assets over time.



SPaTS 1-086 Application of Remote Survey Data for Geotechnical Asset Condition & Performance

TECHNIQUE: *Interferometric Synthetic Aperture Radar (InSAR)*

OVERVIEW

InSAR is a radar imaging technique that uses two or more synthetic aperture radar (SAR) images to detect and measure **centimetre- and millimetre-scale surface deformation over time**. The technique is active, therefore, imaging is possible **in all weather conditions, night and day**. Image acquisition repeat times are frequent (1–35 days) so ground surface changes can be monitored on relatively short timescales. The platform upon which the sensor is mounted can be ground-based (GB)-, aerial-, and satellite-based, **each provides a different scale of surface observation.**

Technique

InSAR involves the transmission and reception of radar waves with frequencies roughly in the range of 1–11 Gigahertz (GHz) and corresponding wavelengths of ~1–11 cm. When the radar pulses emitted at two different times indicate a phase shift between the echoes of the two signals, the movement of the backscattering targets, and therefore a surface-deformation or elevation-change map can be derived. 'Time-series' (multiple repeat images of the same area made at different times) image processing is a particularly powerful method to increase the resolution and quality of surface change measurements derived from InSAR.

Figure 1.1 Simplified cartoon showing the basic principals of radar interferometry InSAR; image source: http://volcano.si.edu/volcano.cfm?vn=332020

Key Benefits

- Rapid remote surveying of sites with areas measuring thousands of square kilometres with a pixel resolution of about 10 m
- Centimetre- to millimetre- scale changes in the ground surface can be detected in any weather, day or night
- Good quality data available since 1995 (also archive data allows for detection of historical ground movement)
- Sentinel-1 data (with free and open access) available since 2014
- Imaging repeat times are frequent (1–35 days)
- InSAR technique can be integrated with other remote sensing and geophysical monitoring methods

Disadvantages

- Requires specialist processing
- Better suited to urban areas with higher density of 'good' scatter. Less effective in rural regions, though new data processing techniques are in development and show promising results
- Surface change measurements made in the Line of Sight (LOS) of the Satellite, therefore, potentially the total magnitude or sense of change is not detected or is underestimated

Platforms

InSAR sensors can be mounted on **satellite-, airborne-, and ground-based stationary platforms.** The InSAR technique is the same in each case, with capability to detect centimetre-scale surface change, but the scale of the area observed (satellite footprint) in each case increases with elevation above the target.

PLATFORM	SENSOR	MEASURE	DATA PRODUCT
SPACE	PASSIVE	CHEMICAL	ORTHO-IMAGE
AERIAL			
TERRESTRIAL MOBILE	ACTIVE	PHYSICAL	POINT CLOUD
STATIONARY			DEM

Figure 1.2 Summary key, blue shaded boxes indicate the key features that apply to the InSAR technique.

1

SPaTS 1-086 Application of Remote Survey Data for Geotechnical Asset Condition & Performance

Data Formats

Raw: a greyscale **digital SAR image mosaic** comprised of a two-dimensional array, formed by columns and rows, of small picture elements (pixels), each of which is associated with a small area of the Earth's surface. Each pixel gives a complex number that carries amplitude and phase information about the microwave field backscattered by all the 'scatterers' (rocks, vegetation, buildings etc.) within the corresponding pixel.

Resolution: SAR pixel resolution is ≤10 m. Raw data is processed to a number of Levels before analysis and interpretation.

Derived: derived InSAR products include: LOS-Deformation Maps, Deformation Time Series (i.e. a graph of LOS displacements plotted with time); Digital Surface Models (DSMs), Digital Terrain Models (DTMs), and Orthorectified (Detected) Radar Images (ORIs). Each of these data products are highly applicable to monitor the condition of geotechnical assets.

Data Availability/Usage

Radar SAR satellite-based imagery has been available since the late 1970s. The majority of good-quality, high-resolution satellite SAR data, however, is available since the last decade or so. Data from the European Space Agency (ESA) Sentinel-1 satellites is freely available for commercial use since 2014. Ground-based and airborne-based InSAR data requires commission of a bespoke commercial survey.

Geotechnical Applications

Using the range of sensor platforms, InSAR has been used to successfully detect and monitor elevation change related to various geotechnical issues, including: detection of precursory signals of **sinkhole formation; city infrastructure subsidence and uplift** (e.g. ground subsidence associated with tunnelling works and groundwater abstraction); **swelling and sinking of clay-rich soils; landslide/ slope instability** monitoring; and also **structural deformation** of infrastructure.

Figure 1.3 a) photo of a depression (outlined in blue) forming in a road; b) LOS displacement map spanning one month, detected from Ground-Based (GB)-InSAR methods. The warm colours indicate subsidence (~2-4 cm) and circled area shows the image a) location. Figure source: Intrieri et al. (2015)

SUMMARY

In more recent years **InSAR** has become a very powerful tool to **monitor surface deformation,** over regional (≥1 km²) areas and detect **centimetre- to millimetre-scale surface elevation changes** in any weather condition, **day or night. The image repeat times are frequent** (≤35 days) allowing for close monitoring. Raw InSAR data requires several specialist processing steps to generate the final products for interpretation. However, data processing times and potential are rapidly increasing with continuing computer software development.

A key benefit of this technique is that it can be implemented at **various spatial scales with the same ability for high-resolution physical surface change detection.** In particular, combining observations from InSAR data with other remote sensing data, such as multi-scale multispectral imagery, will provide greater insight as to the combination of physical or and or chemical processes that significantly affect different geo-assets, and at what spatial and temporal scales. Additionally, planned **future constellations of InSAR satellites will provide near-real-time imaging capability.**

2

Figure 1 Example of research summary sheet for InSAR

To do this effectively, a combination of remote sensing techniques would be the best approach, and all potentially suitable techniques identified above should be considered. The optimal combination of techniques would depend on technical requirements, value for money and potential cross-asset application. A cost/benefit analysis would help inform investment decisions regarding remote sensing data.

A stakeholder workshop was also held in December 2016 which brought together 30 people from across industry (including representation from asset owners: TfL, Network Rail, HS2), the supply chain and academia.

The event highlighted that the desirable future applications for the remote surveying techniques include physical and chemical change detection, condition monitoring and soil moisture assessment. Potential opportunities were also identified for ''proof-of-concept'' pilots and future trials. In order for the pilots/trials to have the greatest impact and value, collaboration between industry and academia would be important. This collaboration will be a strong enabler for innovation and implementation of these data and processing techniques in asset management.

1.2. Selection of key geotechnical applications

The findings of the Phase 1 and feedback from the stakeholder workshop were discussed at a stage gate review meeting held in January 2017. It was agreed that four key geotechnical applications focussing on business-critical elements would be taken forward to Phase 2. These are:

1. **Monitoring high risk soil and rock slopes** – exploring whether remote sensing techniques can complement, decrease frequency or, potentially, replace ground based alternatives.
2. **Monitoring strengthened earthworks** – particularly for assessment of displacements, snagging and 'face' deterioration of Special Geotechnical Measures (SGMs).
3. **Monitoring areas with identified ground hazards** (e.g. mining, solution features, alluvial crossings, areas prone to flooding) that may pose a significant risk to the Strategic Road Network (SRN).
4. **Reducing the need for physical inspections –** particularly for routine inspection of low risk earthworks

1.3. Scope of Phase 2

The aim of Phase 2 (February to July 2017) was to identify how the remote sensing techniques currently procured by/available to Highways England can be exploited to support selected geotechnical applications. Specific activities were as follows:

- 'Proof-of-concept' pilot studies, applied to the shortlisted geotechnical applications (Section 2 and Appendix A)
- Producing Technical Guidance Notes (TGNs) for selected geotechnical application and advice on the most appropriate/effective combination of selected remote sensing techniques (Section 3 and Appendix B)
- Further stakeholder consultation (Section 4)
- Review of the current business case for remote sensing techniques and qualitative cost-benefit analysis (Section 5)
- Conclusions (Section 6) and recommendations (Section 7), including considerations on future remote survey trials and pilots

2. ‘Proof-of-concept’ pilots

2.1. Purpose of pilots

The ‘‘proof-of-concept’’ pilots aimed to investigate how existing Highways England remote sensing datasets and, where available, new freely procured remote sensing data can be exploited and applied to monitor condition and performance of geotechnical assets.

Additionally, the pilots aimed to identify how the collected datasets could be of potential use to other Highways England parties, beyond geotechnical asset management e.g. drainage and vegetation management.

The following sections present the format of the pilots (Section 2.2), the sites that were selected and the data sources used (Section 2.3) and key findings on capabilities and limitations for each of the remote sensing techniques investigated in this report (Section 2.4).

2.2. Pilot format

Seven ‘proof-of-concept’ pilot studies were undertaken during this phase of work.

A standalone report has been prepared for each pilot (see Appendix A2). The format is broadly the same for all pilots, as follows:

1. Site Location and Description
2. Geotechnical Risk
3. Data Review
4. Data processing and analysis
5. Conclusions and Recommendations

For ease of reference, a shortened summary version of each pilot comprising description, summary of findings, conclusions and recommendations is provided in Appendix A1.

2.3. Site selection and data sources

Discussions were held with Highways England to identify appropriate sites for the pilot studies. In order to maximise benefits the pilot sites have been selected based on the following criteria:

- known ‘problem sites’, i.e. with past or ongoing geotechnical issues;
- where multiple remote sensing datasets were available to allow comparison; and
- whether the pilot outcomes would support development of guidance for the four selected geotechnical applications (see Section 2.1)

Data used in the pilots was a combination of the information available from:

- Highways England Geotechnical Data Management System (HAGDMS);
- Geotechnical Asset Management Plan (GeoAMP) for Area 4;
- Asset Visualisation and Information System (AVIS version 1.0) online viewer;
- Remote sensing datasets owned by Highways England (including Mobile Mapping System LiDAR and imagery, hyperspectral imagery, rotary wing LiDAR and orthoimagery); and
- Remote sensing datasets owned by others (e.g. multispectral data from the European Space Agency, InSAR data from the National Physical Laboratory, aerial and street view photography from Googlemaps/ Google Earth Pro).

Potential application of datasets from pavement surveys such as Traffic Speed Condition Surveys (TRACS) and Ground Penetrating Radar (GPR) were not examined as part of this task. Review undertaken in Phase 1 indicated that the imagery captured using the Mobile Mapping System was more suited for geotechnical application than the video imagery from TRACS surveys and therefore preference was given to the former in selecting pilot studies. Stakeholder engagement undertaken as part of Phase 2 found that Highways England had been procuring GPR surveys since 2016 and some datasets were available. However, it was too late to include these in Phase 2 pilots. The applicability of TRACS and GPR datasets to geotechnical asset management should be examined as part of future work.

Site selection was challenging due to limited data availability, the need to cross-check with other data sources and identify sites with known geotechnical issues.

Table 1 overleaf summarises each pilot, giving the focus of the specific trial together with location details, known geotechnical issues and datasets currently available for investigation.

2.4. Key findings on remote sensing techniques

The ‘proof-of-concept’ pilots have allowed some conclusions on technical capabilities and limitations to be drawn of the remote sensing techniques investigated in Phase 2. Table 2 presents the key findings on remote sensing techniques, whilst their suitability to monitor the condition and performance of geotechnical assets is further explored in the TGNs (Section 3 and Appendix B).

Table 1 Selected sites and summary of available data

Pilot No.	1	2	3	4	5	6	7
Pilot Name	**M11 J5-6**	**M40 Stokenchurch Gap**	**M40 Hyperspectral**	**A259 Tanyard Lane and A21 Lamberhurst**	**M2 Dissolution Feature**	**Use of AVIS for Remote Inspection**	**Use of AVIS for SGMs**
Area	DBFO (AREA) 5 - M25 Berks, Bucks, Herts, Essex, Kent & Surrey	DBFO (Area) 30 - M40 [J1-15] Denham to Warwick	DBFO (Area) 30 - M40 [J1-15] Denham to Warwick	Area 4 - Kent, Surrey, West and East Sussex	Area 4 - Kent, Surrey, West and East Sussex	Various	Area 12 - Yorkshire & Humberside Ports Motorways
Network Section	M11	M40 J5-6	Various	Southeast England	M2 between Junction 5 & 6	Various	M1 J34-35
Description of geotechnical issue (where applicable)	Tension cracks, slip, terracing	Chalk cutting ravelling	Embankments & cutting slip	Natural slope and embankment slope instability	Sink hole on carriageway	Various	SGMs
Relevant Application(s)	- High risk* soil slope	- High risk* rock slope - SGM - Reduced frequency of inspections	- High risk* soil slope -drainage detection (SGM?)	- Ground hazard (landslide)	- Ground hazard (dissolution feature)	- Reduced frequency of physical inspections	SGMs
Primary aim	Investigate use of InSAR for monitoring subsidence/uplift of earthworks in rural areas. And slope instability? (this was main issue not subsidence / uplift)	Test change detection for deep rock cuttings using multiple LiDAR datasets	Trial use of hyperspectral data for assessing soil moisture content, vegetation change, slope instability, drainage detection	Slope change detection using rotary wing LiDAR dataset	Use of AVIS, high resolution orthoimagery and LiDAR data collected at different times to assess for evidence of precursory signs	Determine whether AVIS can be used to perform remote asset inspection as per HD41/15	Determine whether AVIS can be used to inventory and assess condition of SGMs
Asset Type	Embankment	Cutting	Various	Natural slopes	At grade	Various	Various SGMs
Soil/Rock	Soil	Rock	Soil	Soil	n/a	Various	n/a
Datasets:							
Rotary wing LiDAR	Y	Y	Y	Y	Y	N	N
Orthoimagery	Y	Y	Y	Y	Y	N	N
InSAR	Y	N	N	N	N	N	N

Mobile Mapping System LiDAR	Y	Y	Y but not assessed in this pilot	Y	Y	Y	Y
Datasets (continued):							
Sentinel-2 Multispectral Imaging	Y	Y	Resolution too coarse	Resolution too coarse	Resolution too coarse	Resolution too coarse	Resolution too coarse
Hyperspectral Imaging	N	Y	Y	N	N	N	N
Thermal Infrared Imaging (freely available)	Resolution too coarse	Resolution too coarse	Resolution too coarse	Resolution too coarse	Resolution too coarse	Resolution too coarse	Resolution too coarse

** 'High risk' sites are identified in the relevant GeoAMP report and/or have a 'High'/ 'Very High' slope hazard rating according to the 2017 classification included in HAGDMS.*

Table 2 Summary of capabilities and limitations of the remote sensing techniques investigated in the pilot studies

Remote sensing technique	Capabilities	Limitations
Mobile Mapping System LiDAR	High point density on the carriageway and immediately adjacent carriageway furniture to detect small scale features of geotechnical interest that repeat scans could remotely monitor over time. Mobile Mapping System LiDAR could be used to verify the location and, potentially, observe the condition of 'surface visible' SGMs (e.g. catch fencing, gabion walls, etc.). It shows promise for change detection if repeat surveys are available. In combination with Mobile Mapping System imagery it could be used to pre-populate some of Annex C of HD41/15 in support to physical inspections.	Classification of the point cloud limited to the carriageway and 'everything else', which is less informative than having additional classes such as (high and low) vegetation, bare ground etc. that can be filtered depending on feature of interest. LiDAR sensor line of sight can limit data collection particularly on embankments, deep cuttings and narrow densely vegetated slopes. Gaps in data coverage have been observed. Point cloud spatial coverage is more closely limited to a narrow corridor surrounding the carriageway than rotary wing LiDAR surveys.
Aerial (rotary wing/fixed wing) LiDAR	Good penetration through vegetation canopy to map slopes below. Point cloud data better classified than the Mobile Mapping System data means that vegetation can be easily filtered from data to view bare ground slope geometry of highly vegetated parts of network Broader spatial ('fence to fence') coverage than the Mobile Mapping System data enables additional asset groups such as drainage to be captured. Fixed wing LiDAR corridor up to 1 km wide, but with lower point density. It could be used for change detection if repeat surveys are available (although not part of pilot studies due to lack of data). Multiple outputs possible from point cloud data (contours, 3D surfaces, shaded relief, elevation etc.)	Lower point density than the Mobile Mapping System data along the carriageway. Reduced application for deeper, steeper slopes due to vertical features.
Rotary wing Orthoimagery	High resolution (~5 cm) can delineate small features, such as terracing and tension cracks, burrowing etc. All resolutions can be used to complement Mobile Mapping System surveys and remote surveys that collect 3D topographic data such as LiDAR	Survey time of year should be planned so that light and vegetation conditions are favourable for imaging.

Remote sensing technique	Capabilities	Limitations
Mobile Mapping System digital imagery	Could be used to provide asset information such as location, vegetation, direct and indirect features, and drainage and reinforcement structures. Can help identify location and observe condition of ‘surface visible’ SGMs. In combination with Mobile Mapping System imagery it could be used to pre-populate some of Annex C of HD41/15 in support of physical inspections.	Some of the Mobile Mapping System images are too shadowy or over-exposed due to direct sunlight. Some geotechnical features may be obscured due to height, light conditions, or cutting orientation. Limited use for embankment observations. Smaller features cannot be distinguished easily.
Hyperspectral imaging	It has the potential to remotely identify the location of buried Special Geotechnical Measures such as counterfort drains. Further research is needed but it may also be possible to monitor their performance. It can identify areas of high/low soil moisture content. It is potentially useful for other asset groups (drainage) and applications (e.g. vegetation management)	Survey time of year should be planned so that light and vegetation conditions are favourable for imaging ~1m resolution pixel imagery (as trialled) is suitable for larger feature monitoring, smaller feature monitoring would require high resolution imagery (0.25-0.5cm pixels).
Sentinel-2 multispectral	Measures surface reflectance spectral information about different materials such as healthy and distressed vegetation.	Data spatial resolution is generally too coarse to resolve soil and rock slopes across the network
InSAR	It can accurately measure millimetre-scale subsidence/uplift in urban areas. It can measure the variation of subsidence/uplift over time, not only as an average motion. Possible applications for monitoring wider area subsidence from coal mining, groundwater extraction or brine pumping	Technique is not yet developed enough to apply to earthworks traversing rural areas, which have few strong reflectors. Point density very low in rural areas. Requires technical knowledge and expertise to process and interpret.

3. Technical Guidance Notes

3.1. Purpose of the Technical Guidance Notes

A series of Technical Guidance Notes (TGNs) has been developed to communicate the potential application of remote surveying methods in the management of geotechnical assets to both Highways England and the supply chain. They are included in Appendix B.

3.2. Content and format of the Technical Guidance Notes

Technical guidance for the use of the selected techniques has been developed as a joint effort by specialists and experts with the appropriate knowledge of the technical subject, existing processes within the business and implications for end-users. The TGNs summarise the findings of the research and are complemented by the Research Summary Sheets developed for each technique during Phase 1. Pilot scale studies have also been carried out at a number of sites (see Section 2) and findings from these studies have contributed to the content of the TGNs.

These technical notes have been based on research and a limited number of pilots studies. They may need to be updated or developed further if techniques are reviewed against a wider range of sites and geotechnical features.

Each TGN is entitled with the application for which guidance of the remote sensing techniques have been developed. Each note then provides a concise 'Background' section of the previous Highways England research on the remote sensing techniques as appropriate and summarises what techniques and data are already procured and how and where these data can be accessed.

Technical guidance for the selected techniques is then provided based on the context of the application covered by the note. A number of figures have been included from relevant pilot studies to illustrate different practical examples appropriate to the context of each TGN. The overall guidance is then summarised into a matrix in which the range of remote sensing techniques investigated are set out against a number of practical parameters such as: data coverage, data availability, ease of data analysis etc. and given a rating of applicability/suitability in terms of high medium or low. The aim of the matrix is to provide a simple and concise summary of the most complementary techniques for a certain application in quick reference visual form. The final section provides key references and contact details for further information.

4. Stakeholder engagement

Further consultation activities with a number of stakeholders both within Highways England and externally were undertaken as part of Phase 2. Findings from the stakeholder engagement activities are summarised in the following sections.

4.1. Consultation with Highways England stakeholders

A series of consultations with stakeholders representing other groups and disciplines within Highways England was held to explore cross-asset synergies related to the use of remote sensing techniques, particularly looking at the cost-benefit implications for wider application of data outputs.

Table 3 Summary of consultation with Highways England stakeholders

Discipline/ Group	Relevance to this task	Outcomes
Pavement	The Pavement Group undertakes remote sensing surveys that could be useful to complement other techniques considered in this study. Conversely, data currently being captured by AIG could be used to improve pavement asset information.	TRACS surveys and - more recently - Ground Penetrating Radar (GPR) surveys are undertaken annually and they could be a useful dataset to investigate in future pilots, particularly for monitoring of areas with known ground hazards, such as sinkholes.
Asset Information Group (AIG)	AIG procures asset data capture surveys and manages their outputs on behalf of the business. AIG is the custodian of AVIS online viewer.	This project provides feedback on the usability of remote sensing data as currently procured and makes recommendations for improvement/future developments. Review of current business case for procurement of remote surveys.
Soft Estate/ Environmental Management	Pilot studies undertaken as part of this task have shown that there is potential for remote sensing to be used for detection and monitoring of vegetation. Other applications of remote sensing for environmental management can include support to contractual obligations, monitoring of landscape commitments, integrity of noise barriers	The focus of Soft Estate management is the biodiversity metric that is reported in RIS1. CEH Landcover data 2015 has been purchased to enable assessment of health (condition) of soft estate assets. Further feasibility work: looking at Earth Observation data which Natural England have used to elicit condition data on some European sites as we need to develop a means of doing efficient condition assessment
Structures	Potential synergies e.g. use of imagery and LiDAR for structure	Stakeholder engagement not undertaken as part of this task.

Discipline/ Group	Relevance to this task	Outcomes
	condition monitoring, particularly structures retaining earthworks.	
Drainage	Potential synergies e.g. defective drainage assets often cause issue to supporting earthworks. Use Mobile Mapping System LiDAR and imagery and hyperspectral imagery for drainage condition monitoring.	Stakeholder engagement not undertaken as part of this task.

4.2. External consultation

During Phase 2 the project team consulted with stakeholders from industry, academia and data suppliers on the use of data acquired with identified remote sensing techniques for geotechnical asset management applications. Collaboration and cross-fertilisation with industry and academia will be a strong enabler for innovation and implementation of these techniques in asset management.

Table 3 Summary of consultation with external stakeholders

Consultee	Relevance to this task	Outcome
National Physics Laboratory **CGG**	Collaboration on the M11 InSAR pilot with CGG who are partners in the PLIMM research project	Access to InSAR datasets and data processing capabilities from the PLIMM project Opportunity to investigate use of PSInSAR and DSInSAR for geotechnical applications
Queens University Belfast) **BGS**	NERC research project 'InSAR for geotechnical infrastructure: enabling stakeholders to remotely assess environmental risk and resilience' It would be very beneficial to compare results of the M11 InSAR pilot with the NERC project outputs	Email correspondence and high level information exchange but no formal meeting held during this task. Findings from this task can be found here. InSAR, orthoimagery and Structure from Motion have shown benefit to detect localised deformation and indicator of ground instability.

Consultee	Relevance to this task	Outcome
Network Rail (NR)	NR has recently undertaken a LiDAR repeat surveying project to investigate change detection capabilities Knowledge share would be very helpful to inform future trials for Highways England and to foster cross-industry collaboration	Ongoing knowledge share and potential opportunity for collaboration. E.g. LiDAR coverage of areas where railway is next to SRN. Some good results but also some challenge in interpreting and automating change detection using repeat UAV LiDAR surveys. Flight path, lighting conditions have an impact on data capture.
Cyient (formerly Blom)	Cyient were the data suppliers for the M40 hyperspectral dataset captured in January 2016 Cyient helped with the processing and interpretation of outputs	Collaboration with Cyient enabled the research team to draw initial conclusions on the capabilities of hyperspectral imaging for assessment of earthworks
Michigan Technological University (MTU)	MTU has undertaken an extensive study on applicability of remote sensing techniques to geotechnical asset management. 'Sustainable Geotechnical Asset Management along the Transportation Infrastructure Environment Using Remote Sensing'	Established relationship with international stakeholder Raised awareness of respective projects Very useful exchange of information on current state of research and future initiatives
Strukton Rail **European Space Agency** **Network Rail**	Strukton Rail leads on an ESA funded research project called RailSat looking to apply InSAR to rail asset management. One of the applications of interest considered in the project is to investigate overall large scale terrain movement and correlation with geotechnical data (risk assessment of earthworks, landslides, mining, etc.)	Identified as interested stakeholder in the RailSat project Knowledge share

5. Review of current business case for procuring remote survey data

This section summarises the review of the current business cases used by AIG to procure remote survey data for the following projects: the National Asset Data Capture (ADC) Surveying Project and the National Rotary Wing Surveying Project.

5.1. Review of business case for National Asset Data Capture Surveying Project

Since 2012, the Asset Information Group (AIG) has developed its use of Asset Data Capture Surveying (Mobile Mapping System (MMS) surveys for surface visible assets) due to the amount of data that can be captured quickly and efficiently together with enhanced data capture and improved data quality assessment techniques.

To date 98% of the strategic network has been surveyed as part of the current AIG National Asset Data Capture (ADC) Surveying Project. The Northern half of the SRN was surveyed in 2016-2017 and the Southern half will be surveyed in 2017-2018.

This surveying has resulted in a large volume of good quality surface visible asset inventory data which requires a sterile storage environment with easy access to the survey data. AVIS is used to house both imagery and LiDAR data for use by the business to make enhanced intelligent operational practices and strategic decision making.

Deliverables

Asset inventory (to support network management and future investment strategy) through data collected from:

- LiDAR point cloud (for network measurement and mapping)
  - Can be used for multiple further applications, e.g. topographic mapping, asset measurements for scheme design and design work for Smart Motorways and renewals programmes.
  - Secondary processing can be undertaken for a range of applications (e.g. slope angle, DEM)
  - Geospatial references are more accurate and the level of contextual information for certain assets is significantly more detailed

- High definition imagery from vehicle mounted cameras

5.2. Review of business case for National Rotary Wing Surveying Project

In July 2014 the Department for Transport (DfT) published its Transport Resilience Review (a review of the resilience of the transport network to extreme weather events) in which it states: (3.1.21) “The Highways Agency should carry out the necessary work to complete its drainage asset inventory and if appropriate should make the case, in the process of establishing the new government owned company, for funding of the survey work necessary to significantly improve its understanding of the condition of its drainage assets and the interfaces with adjoining drainage networks”. To meet the requirements of this review AIG has commenced a National Drainage ADC Surveying Project to supplement the current surface visible asset dataset within AVIS with underground and offline drainage assets to offer a comprehensive integrated asset picture for the Strategic Road Network.

The National Rotary Wing Surveying Project was trialled on the M40 in January 2016. The trial also captured hyperspectral imagery. At the time of writing the project is underway and will deliver national coverage by 2018.

Data captured with rotary wing surveys can provide Highways England with some condition data for some asset classes. For example in the case of geotechnical assets, high resolution orthoimagery and LiDAR-derived contours can be used to identify small scale slips (see Section 2.4). It can also offer support in the maintenance of drainage assets, and can be used in scheme design, for both new build preliminary and detailed design as well as SMP design. The data is also useful in Soft Estate Management and structural integrity of concrete structures.

Hyperspectral imagery could be useful for providing land cover data, soil moisture/surface water data, vegetation mapping and mineral detection.

Deliverables

- LiDAR point cloud (for network measurement and mapping).
  - In one pass it is able to collect LiDAR data in a 200m swathe, so covering the highway area from 'fence to fence'.
  - Rotary Wing LiDAR is able to 'penetrate' the vegetation to show not only the ground but also any features under the canopy.
  - The system is 'remote' and requires no access to the carriageway while still providing a greater detail of accuracy of 30mm.
  - Rotary Wing airborne LiDAR can be quality controlled using the data delivered through the ADC and incorporated into AVIS to provide a complete dataset.

- High definition orthoimagery to support completion of surface visible asset and drainage system inventories

5.3. Benefits

Benefits delivered by remote surveys are both quantifiable ('cashable') and non-quantifiable ('non-cashable'). Identified benefits are, but not limited to, as follows:

- *Cashable benefits*: cost savings as compared to traditional survey methods leading to reduced survey time, traffic management and labour cost, reduction of duplication across schemes.
- *Non-cashable benefits*: reduced worker exposure, improved asset data, new approaches to performance measurement, support incident management, support to better decision making and alignment with the organisation's strategic objectives.

5.4. Considerations on the business case for remote surveys

Remote survey data (LiDAR and imagery) have so far been captured mainly for inventory purposes and, more recently, to provide topographic mapping to SMP schemes. There is now a large holding of archive LiDAR and imagery of the entire network, which presents an unprecedented opportunity to potentially exploit these datasets for geotechnical asset management.

This work has identified recommendations on the specification, processing and accessibility of LiDAR and imagery dataset that would enable wider use for geotechnical applications. Further discussions have been held with IBI Group, in particular the IBI team responsible for SPaTS vehicle based imagery and LiDAR data capture and the AVIS software. It is understood that some of the limitations identified by this project (e.g. quality of imagery) have now been resolved. Relevant findings from this task should be communicated to AIG for consideration in procuring future surveys.

The current forward programme of planned surveys should be disseminated to all interested stakeholders in the business and, ideally, should inform planning and optimisation of information flows in support of asset management activities and performance reporting. The asset information captured and managed by AIG should ultimately facilitate cross-asset geospatial referencing and visualisation in existing asset management systems.

Going forward, cross-asset consultations should be held with AIG to ensure that synergies and requirements across the different disciplines are captured. A cross-asset joined-up approach is needed to strengthen the current business cases for procurement of remote surveys data. Demonstrating better value for money and stronger alignment with business processes (e.g. performance reporting) could lead to more regular and better targeted data acquisition.

6. Conclusions

Highways England commissioned Arup AECOM under the SPaTS framework to deliver a study considering the potential advantages of using remote survey data to assess geotechnical asset condition. As part of Phase 2, available methods were reviewed for their applicability to geotechnical asset management, specifically focussing on four key applications and with the aim of developing knowledge of asset condition and performance. The following conclusions have been drawn from the various activities undertaken in this phase of work:

- Application of remote surveys to monitor condition and performance of geotechnical assets has shown improvement since previous research. Improved capability is due to advances in sensor technology and processing methods. Highways England is now procuring more remote surveys covering most of the network, which offers **better opportunities for data application.**
- Four shortlisted geotechnical applications have been the focus of this study (see Section 3). For each application a **Technical Guidance Note (TGN)** has been developed to summarise the findings of the research and to raise awareness of the potential application of these already procured datasets for earthworks management. The TGNs may need to be updated or developed further if techniques are reviewed against a wider range of sites and geotechnical features.
- **Pilot studies** have been carried out at a number of sites and findings from these studies have informed the content of the TGNs. The pilots have helped identify capabilities and limitations of the remote sensing techniques currently procured by Highways England (see Table 2 in Section 3.4).
  - **LiDAR datasets** (both Mobile Mapping System and rotary wing) have been found particularly useful for assessing condition and performance of geotechnical assets. **The combined LiDAR and imagery datasets currently been procured by AIG could be exploited for management of geotechnical assets**, especially at the time when there will be national coverage of the network.
  - It is important that **repeat surveys** are undertaken using the same platform and point clouds need to have at least approximately the same spatial coverage, point density, and point classifications. This is currently a barrier to the use of historical LiDAR datasets for change detection. Frequency of repeat survey should be defined based on purpose of the survey e.g. one-off for inventory, high (<1 year) for monitoring of high risk sites, medium (1-3 years) for routine monitoring of asset condition/deterioration, *ad hoc* for emergency surveys post-event.
  - Whilst satellite (InSAR and multispectral) imagery seems to be still not ready for geotechnical asset management application, **hyperspectral imagery** showed potential, particularly for identification and assessment of performance of slope drainage features which may not otherwise be identified.

- **AVIS has proven to be a useful tool for geotechnical applications** and its capabilities should be disseminated more widely to Highways England’s geotechnical community and supply chain. AVIS permits general observations about geotechnical assets and can support ‘remote inspection’ (as per HD 41/15) of cuttings. This can save time for undertaking physical inspections and could support reducing their frequency. However, if detailed observations are to be made with high confidence the system requires additional and improved datasets. Image quality of the Mobile Mapping System imagery is such that only relatively large slope features can be identified. Imaging of pavement features is much better, and this can be useful where these may be linked to slope instability (e.g. cracking in the hard shoulder, leaning barriers etc.)
- There seems to be incompatibility between inventory of earthworks assets (cuttings) held in AVIS and HAGDMS. AVIS can be a very good tool for confirming asset information, but it is very important that inventory data is collected using the business rules set out in HD41/15 and geotechnical asset information is held on the primary asset information system.

- LiDAR point cloud data shows promise for carrying out **automated change detection**. It offers a relatively rapid way of assessing geotechnical asset condition at high levels of detail and, if comparable surveys are undertaken on a relatively regular basis, then appropriate change detection algorithms can be implemented. Imagery, captured at the same time as the LiDAR surveys, is fundamental to understanding what changes are occurring. However, change detection techniques could be used for looking at 'hard' features from the imagery and understanding condition change between successive surveys. This is particularly the case if the image quality can be sufficiently improved.
- Additional datasets to those used in the pilot studies are available, some of which may be of use to geotechnical asset managers. For example, pavement surveys such as TRACS and GPR could be used in combination with other remote sensing datasets, particularly with regard to detecting issues that have little warning, such as dissolution features.
- Based on the pilot study undertaken for this task, the best combination of remote sensing data to assess **high risk embankments** over time would be a combination of rotary wing LiDAR data and high-resolution orthoimagery.
- For **high risk rock cuttings,** it was found that the high-resolution orthoimagery could delineate geotechnical features such as rock falls. However, particularly in the case of steep cuttings, oblique surveys would be more appropriate to make useful observations of the steep rock cutting face. Terrestrial static (tripod) LiDAR is likely to be a much more accurate system for use on large discrete rock slopes
- More work is needed to ascertain capabilities of remote sensing techniques to monitor areas of **known ground hazards**. From the limited pilot studies, it can be observed that for areas prone to natural landslide hazard rotary wing LiDAR is recommended

over the terrestrial Mobile Mapping System LiDAR system. Rapid rates of movement preceding cavity collapse of dissolution features means that they are hard to detect by means of remote sensing surveys. Sinkholes are not usually that large in scale – typically 2-4m across, or larger ones up to around 20m. The multispectral resolution of 10 m is insufficient. InSAR would require scatterers - DSInSAR may be possible. Some success in identifying mine shafts and sink-holes has been achieved with thermal infra-red techniques but the current research has not had access to this dataset, nor suitable sites to trial.

7. Recommendations

Based on the work undertaken in both phases of work of this project, the following recommendations are made:

- The work undertaken as part of this task has shown that remote sensing datasets currently held and being procured by Highways England can have useful geotechnical (and other) applications. However, remote sensing is only one of a larger suite of methods that can be used to assess and proactively monitor asset condition and performance of the geotechnical asset. These methods include geotechnical investigations, geophysical surveys, site inspections and geotechnical instrumentation. Future work should focus on developing a Proactive Monitoring programme for Highways England's geotechnical assets, which will entail using one or a combination of these methods as appropriate.
- In the longer term remote survey techniques could be used for semi-automated assessment of changes in the geotechnical asset base. This automation could feed into the Proactive Monitoring programme and combined with data collected via traditional methods in order to get a better understanding of the *bigger picture* of asset performance. The outputs will inform Highways England's geotechnical advisors decision making and allow interventions before assets witness significant performance issues. Better knowledge of asset condition and performance will support application in the fields of asset deterioration modelling, maintenance and renewals. Ultimately, this will not only make the organisation more efficient in terms of their geotechnical asset management approach, but it will importantly mean a safer, more resilient and more free flowing network, which aligns with Highways England business objectives.
- Coordination of activities between AIG and potential users in other asset groups is recommended. The forward programme of planned surveys should be disseminated to all interested stakeholders in the business and, ideally, should inform planning and optimisation of information flows in support of asset management activities and performance reporting. The asset information captured and managed by AIG should ultimately facilitate cross-asset geospatial referencing and visualisation in existing asset management systems.
- Regular repeat surveys are necessary to enable meaningful change detection in the future. A cross-asset joined-up approach is needed to strengthen the current business cases for procurement of remote surveys data. Demonstrating better value for money and stronger alignment with business processes (e.g. performance reporting) could lead to more regular and better targeted data acquisition.
- Cross-asset consultation undertaken as part of this task showed potential synergies. However more consultation is needed. It is recommended that a cross-asset workshop is held to discuss current and potential uses of remote sensing, synergies and requirements across the different disciplines.

- For future LiDAR data procurements and to maximise benefits for geotechnical applications, Highways England should consider the following:
  - LiDAR survey data are classified to define ground surface, structures, and vegetation, for example, rather than purely carriageway and all other features grouped together as a second single class. This will also improve information and make it more usable for other asset groups/applications.
  - LiDAR data are be collected using the same surveying platform and methodology (e.g. rotary wing, with consistent altitude, flight lines and flight speed as this affects point sampling density) in order to compare survey data collected at different times.
  - Mobile Mapping System camera surveys are undertaken in more optimal conditions to reduce over-, or under-exposure of imagery
  - Improvement of image quality could yield additional benefits in terms of condition change of hard features such as retaining walls and pavements can suggest developing problem with the adjacent earthwork.
- If Highways England are to use LiDAR data for change detection associated with condition monitoring, the data capture frequency should be increased to medium (1-3 years). Mobile Mapping System appears to be a useful tool for this application and it is recommended that this is taken forward as the primary tool for change detection of selected slopes with appropriate geometry.
- The following improvements are suggested for AVIS in the context of use for geotechnical applications:
  - Standardise notation and expansion of Map Query inputted data;
  - Mobile Mapping System and rotary wing LiDAR point cloud are placed side-by-side;
  - LiDAR data displayed as Digital Surface Model (DSM);
  - Rotary wing LiDAR contour dataset is included ; and
  - Possible inclusion of high resolution vertical aerial photography.

7.1. Considerations on future work

The significant advances in remote surveying technologies made in the last decade can support Highways England's vision for a proactive management of their geotechnical assets and, ultimately, of a more resilient SRN. Higher spatial and temporal resolution data is becoming more routinely available, which offers the potential to improve existing asset management approaches if combined with a suitable programme for data acquisition. As such, further investigation is required into available methods and their applicability with particular focus on supporting whole life assessments and proactive monitoring of geotechnical assets.

The following recommendations are made in terms of future work in this space based on the opportunities highlighted by the work undertaken in Phase 1 and Phase 2 of this project that show promise for supporting Highways England's future programme for proactive management of performance. Further consideration is recommended for both pilots utilising recently acquired datasets and trials of new techniques (e.g. hyperspectral images), as discussed below.

Trial site selection

Careful consideration should be given to the selection of the most appropriate test sites for maximising potential benefits. Sites should be selected on the basis of available historical records/ remotely sensed data but also take into account the remote surveys currently being undertaken (National Rotary Wing Surveying Project) and/or procured (National Asset Data Capture Surveying Project (North)).

Generally, trial sites should be known problem sites where more than one technique can be tested in order to investigate their complementarity and effectiveness. Trials should be undertaken at similar time/season and repeated to allow detection of change.

It is recommended that user requirements by Highways England should also consider how the collected datasets could be of potential use to other Highways England interested parties, beyond geotechnical asset management. This would make for a stronger business case and it could influence the specification for any trials and surveys.

At the time of writing LiDAR trials using an Unmanned Aerial Vehicle (UAV) platform are being undertaken at Leys Bends landslide site ahead of installation of a geophysical monitoring system (PRIME). These datasets may present opportunities for broadening this research and they should be reviewed when available.

Hyperspectral trial

Highways England procured a rotary wing hyperspectral survey of the M40 motorway in January 2016. This dataset was made available to the research team for review and to identify any potential application for geotechnical asset management.

Working with Cyient (formerly Blom, who were the data suppliers) and in consultation with known academic experts on hyperspectral imaging, the hyperspectral dataset has been reviewed and some initial conclusions on its capabilities for earthworks assessments were formed (see Section 3.3.3. Pilot 3 M40 Hyperspectral). The study was affected by unfavourable light and vegetation conditions and by the fact that there are limited asset information records available for the M40 DFBO. However, findings from Pilot 3 have shown promise, in particular for inventory and performance assessment of drainage assets, some of which are also classified as SGMs.

It is therefore recommended that further trials of this technique are undertaken as it could usefully support proactive monitoring of geotechnical assets, as well as other assets.

The business case for trialling this technique would be strengthened by its wider application (e.g. drainage assets, vegetation management). In addition, stakeholder engagement undertaken as part of this task has shown that there are potential opportunities for collaboration with other asset owners (e.g. Network Rail) who are interested in trialling this technique. Trials should be undertaken in a different area of the network and the survey should be planned taking into consideration the most appropriate time of the year. Ground truthing surveys would be a key part of any further research.

Strengthened Earthworks pilot

Building on the findings of Pilot 7 (see Section 3.3.7), AVIS could be used to validate locations and inventory of 'surface visible' SGMs using the outputs of Task 594: *Strengthened Earthworks.* This activity should be complemented by a consultation with the Geotechnical Maintenance Liaison Engineer (GMLE) from the area of study. This should be considered for inclusion in the research task focusing on whole life assessment of geotechnical assets.

Validated SGM locations could then be used to create a GIS layer in HAGDMS and – potentially – include associated Mobile Mapping System imagery. Availability of repeat Mobile Mapping System surveys could support condition assessment of SGMs, thus reducing the need for physical inspections.

In addition to this and to support the development of a proactive monitoring programme, a full scale trial should be carried out using data from repeat Mobile Mapping System LiDAR surveys to detect change (see Section 6.3 below). In particular, SGMs such as gabion walls and other retaining walls, facing solutions e.g. for rock slopes, would be good candidates for change detection. Consideration should be given to the placing of targets on the front of the SGMs to assist detection of any deformation.

Hyperspectral imagery could complement this pilot by helping improve knowledge of location and performance of non-visible drainage assets, see Section 6.2.

LiDAR change detection capability pilot

Change detection has been attempted in the various pilot studies undertaken in Phase 2 (see Section 3). Whilst the pilots have shown that Mobile Mapping System (ground-based) and rotary/fixed wing (airborne) LiDAR cannot be easily used together for change detection, the newly acquired LiDAR datasets for both Mobile Mapping System and rotary wing national surveys can offer opportunities to further investigate change detection capabilities using the same platform, data classification and point density.

A further pilot study should be undertaken as part of future work to develop a proactive monitoring programme to compare Mobile Mapping System LiDAR data from two separate time points on an area that is known to have deteriorated. The aim should be to understand the scalability of automated change detection using the LiDAR datasets on a larger section of the network. These LiDAR datasets are most suited for cutting slopes.

Rotary wing LiDAR datasets should be used to undertake change detection in embankments. It is recommended that 25cm contours, where available, are used rather than processing differences in point clouds or 3D derived surfaces.

In addition, stakeholder engagement undertaken as part of this task has shown that there are potential opportunities for collaboration with other asset owners (e.g. Network Rail) who are interested in exploring change detection using LiDAR.

Ground hazards monitoring pilot

Pilot 5 (M2 dissolution feature, see Section 3.3.5) and Pilot 4 (A259 Tanyard Lane and A21 Lamberhurst, see Section 3.3.4) have investigated the use of LiDAR and orthoimagery to detect and monitor natural landslide hazard and sinkhole hazard respectively. A definitive assessment was not possible, for various reasons, and further research is required to understand how remote sensing can support monitoring of areas with known ground hazards.

Change detection using LiDAR, provided the dataset is well classified and captured using the same platform and resolution, and showed potential for natural landslide hazard. Change detection with respect to dissolution features is likely to be difficult as pre-failure deformations are not usually significant and failure is typically by sudden collapse following rapid infiltration of water.

Therefore it is recommended that a future pilot is focused on an area of more gradual ground movement (e.g. mining subsidence) than that associated with cavity collapse. The most suitable locations would be informed by outputs from other research tasks (resilience enhancements, geohazard mapping and SGMs).

In addition to LiDAR other datasets should be considered as follows:

- It is recommended that pavement surveys currently procured by Highways England such as TRACS and GPR are investigated with respect to detecting ground movements under the carriageway in areas with known ground hazards.
- Findings from the NERC project investigating use of InSAR to monitor geotechnical assets (see Section 4.2) have shown that the technique can be useful to detect signs of instability. Building on this work, InSAR should also be considered as its suitability is more towards detecting deformations over wide areas than at the earthwork scale. This could be by both differential InSAR and PS / DSInSAR.

Structure from Motion trial

Structure from Motion (SfM) is a relatively recent technique that has evolved with recent advances in computer science and algorithm-based digital data processing. This technique is not currently procured by Highways England but literature review undertaken in Phase 1 has identified potential for geotechnical asset management applications.

Photo datasets are collected using a consumer compact or professional camera and a network of ground control points, GCPs, (points at which the exact geographic co-ordinate and elevation is known). Consumer cameras can be mounted on aerial platforms including UAVs, or on ground-based platforms. Outputs include centimetre-resolution shaded relief Digital Elevation Models (DEMs), orthorectified (undistorted) high-resolution colour photo mosaics, contour and slope maps. SfM data can be used in conjunction with existing datasets such as LiDAR, or aerial-/satellite-based optical or multispectral imagery.

Structure from Motion was used in the NERC project (see Section 4.2) in conjunction with other techniques and has shown promise in monitoring geotechnical assets. Cameras of appropriate resolution could be used in conjunction/as part of the Mobile Mapping System surveys. If proven successful, could usefully feed into a proactive monitoring programme.

It is therefore recommended that this technique is trialled to investigate its potential for assessing and monitoring condition of geotechnical assets over time. This technique would also be useful to monitor condition of structure assets, particularly retaining walls (also classified as SGMs).

8. REFERENCES

Arup AECOM, 2016, Task 1-086 Phase 1 Report

Highways Agency, 2014, Remote Sensing Review

Highways England, 2014, Specialist Project Services Framework (SPSF) Business Case for National Asset Data Capture Surveying (North)

Highways England, 2015, Specialist Project Services Framework (SPSF) Business Case for National Rotary Wing Surveying Project

Wolf, RD; Bouali, EH; Oommen, R; Dobson, R; Vitton, S; Brooks, C; Lautala, P; Michigan Tech University 2015, Sustainable Geotechnical Asset Management along the Transportation Infrastructure Environment Using Remote Sensing

Appendix A – 'Proof-of-concept' pilots

.

8.1. Appendix A1 – Summary of 'proof-of-concept' pilots

Pilot 1 - M11 J5-6

Pilot 1 investigates the application of various remote sensing datasets to assess change of high risk soil slopes over time. The site investigated is located in Area 5 of the network, on the M11 between Junctions 5 and 6 (Figure 2).

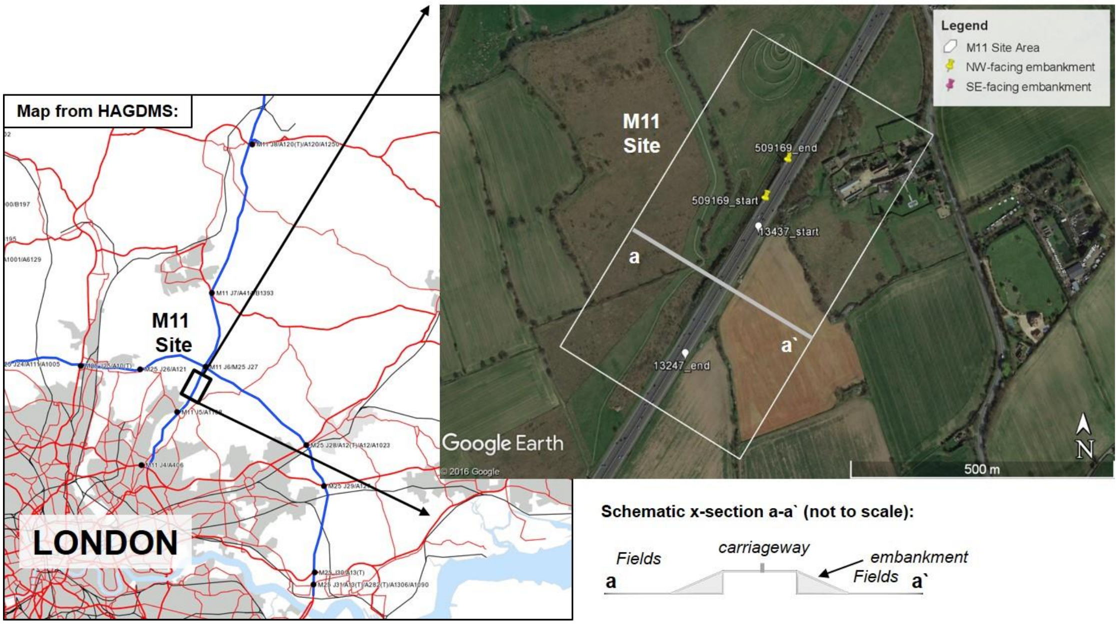


Figure 2 Site location of M11 pilot

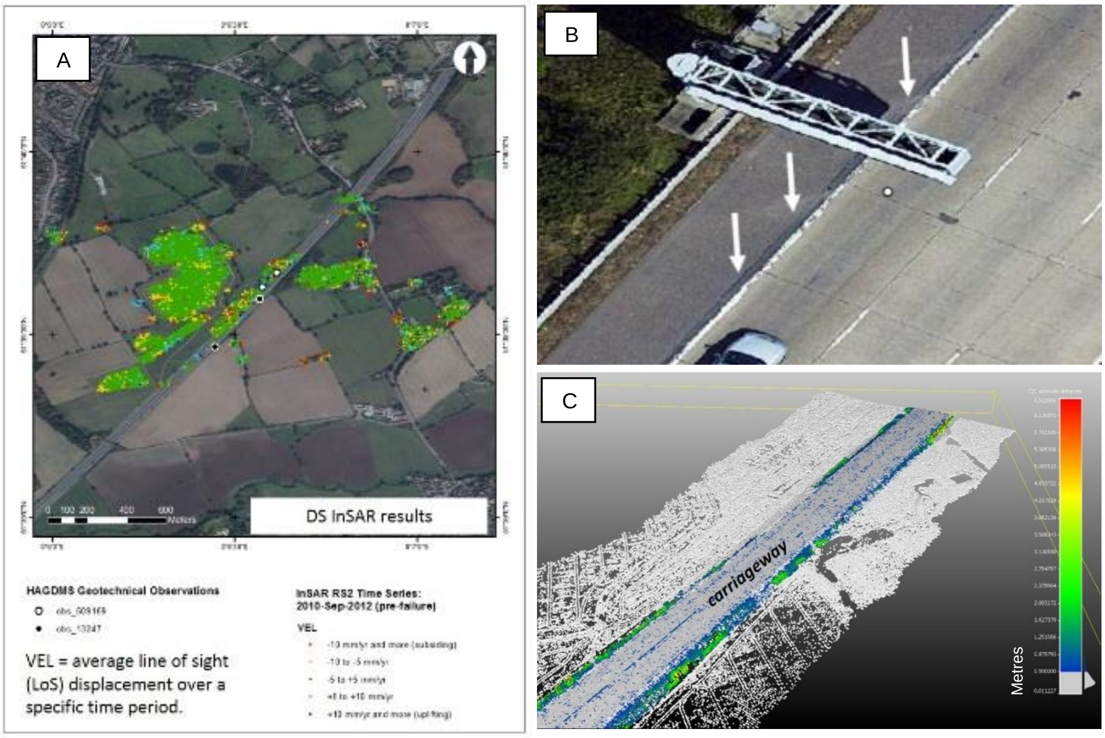


Figure 3 A) Distributed Scatter (DS) InSAR results for the M11 Site; B) 5cm orthoimagery, cracks on the pavement (indicated by the white arrows); C) Preliminary results from the change detection technique applied to the M11 LiDAR datasets.

Summary of findings:

- Orthoimagery:
    - The 5 cm resolution images typically provided sufficient detail to delineate (or detect) geotechnical features such as terracing on soil slopes or indirect features such as cracks in the pavement (see Figure 3B).
    - The 25 cm and 12.5 cm resolution images proved too coarse to delineate / detect the same scale of features.
- Multispectral satellite imagery (freely available from European Space Agency (ESA) Sentinel-2) – at its highest image resolution of 10 m pixels is too coarse to be used for soil and rock slope assessment.
- LiDAR – the 2004 aerial LiDAR survey and the 2013 Mobile Mapping System survey were compared and assessed for evidence of change in terms of geotechnical failures/ slope erosion/degradation/deposition over time. The following was noted:
    - The fixed wing LiDAR dataset has a lower point density but better spatial coverage than the Mobile Mapping System LiDAR.
    - The fixed wing LiDAR dataset is better classified and distinguishes bare soil from vegetation, structures, etc., than the Mobile Mapping System LiDAR dataset, which only separates out carriageway points. This has implications for what features can be interpreted within the Mobile Mapping System LiDAR dataset. However, the differentiation is a matter of data processing rather than data capture technology.
    - Height calibration and correct referencing is essential when evaluating change between different types of LiDAR datasets. Change (of height) detection using the fixed wing and Mobile Mapping System LiDAR datasets was not possible as there were calibration inconsistences that did not allow direct comparison of these datasets. However, through further work this may be possible and theoretically could reveal useful results.
- InSAR
    - The Persistent Scatterer (PS) InSAR data had poor spatial coverage and low point density (typical for rural areas). As there were limited persistent scatterers identified along the earthwork, it was not possible to associate the data with any type of geotechnical change over time.
    - The Distributed Scatterer (DS) InSAR data had much greater spatial coverage and point density than Persistent Scatterer data (see Appendix A2 – Full pilot reports). However, at this stage, it is still not possible to relate the height changes recorded by the InSAR points to geotechnical features.

Conclusions & recommendations

- The combination of high resolution orthoimagery and LiDAR data shows most promise for detecting geotechnical asset change over time.
- Comparison of aerial and Mobile Mapping System LiDAR has proven difficult. Change detection should be undertaken using datasets captured from the same platform with similar point density and resolution.
- Multispectral imagery and InSAR data are currently of limited use for monitoring geotechnical assets. The latter is particularly attractive for its frequency of capture and coverage and because of its potential for monitoring ground / structure deformations to mm scale (as reported for urban areas). However, the technique is not yet developed enough to apply to rural areas, as it currently relies on strong reflectors such as building corners. It is considered likely that future developments in technology will allow exploitation of this technique for monitoring of geotechnical assets.

Pilot 2 – M40 Stokenchurch Gap

Stokenchurch Gap is a steep-sided chalk cutting, constructed through the Chiltern Hills near to the village of Stokenchurch. It was excavated during construction of the M40 motorway in the early 1970s and is situated between junctions 5 and 6. The cutting is approximately 1,200 m long and 47 m in depth at its deepest point. A two by three lane carriageway passes through the cutting, which links the M42, Oxford and Warwick with the M25 and London.

For the purposes of this pilot study, the datasets investigated were:

- Rotary wing orthoimagery (5 cm)
- Digital imagery (captured from Mobile Mapping System survey and viewable in AVIS)
- LiDAR – Mobile Mapping System and rotary wing platforms.
- Multispectral imagery
- Hyperspectral imagery

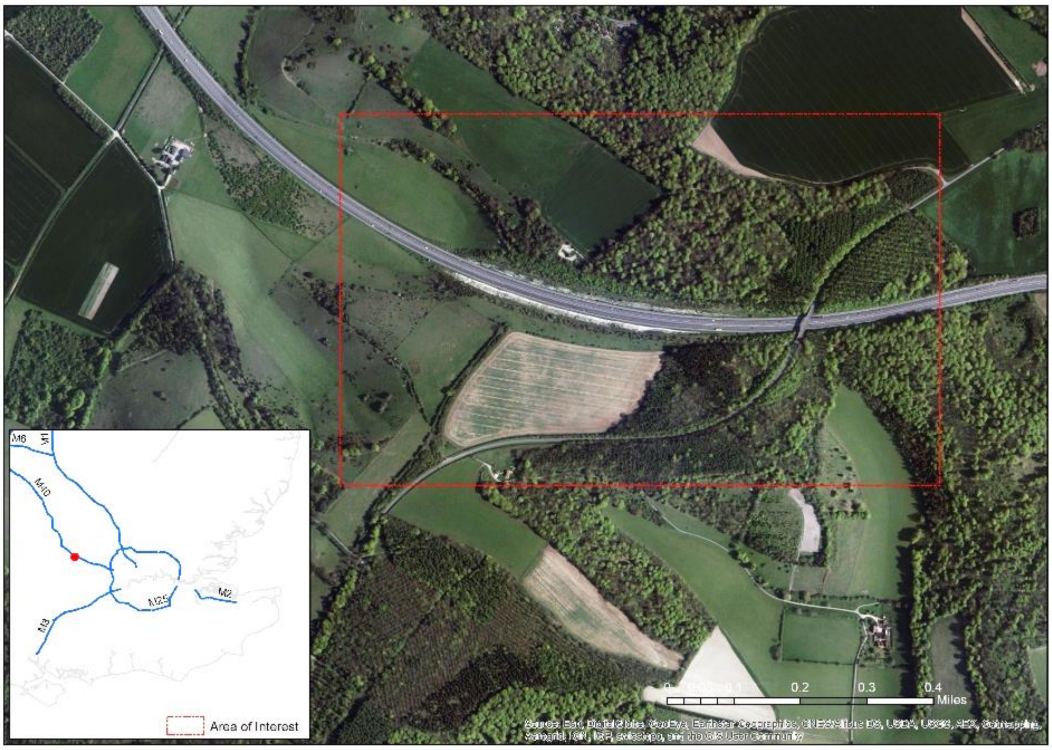


Figure 4 Location of Stokenchurch Gap on the M40

Summary of findings:

- The 5 cm resolution orthoimagery provided high enough resolution to identify geotechnical features such as rock falls and it is useful to complement the Mobile Mapping System remote surveys. But because of the vertical viewing geometry it was more challenging to make useful observations of the steep rock cutting face.

- AVIS imagery captured with the Mobile Mapping System survey is a useful roadside view of geotechnical assets from which qualitative assessments can be made. However, the quality of the image is dependent upon lighting conditions and often may be difficult to distinguish detailed slope characteristics.
- The top of the cutting was not captured by the Mobile Mapping System survey, but was captured by the rotary wing survey.
- LiDAR data were able to show:
  - The surface of the chalk cutting and the presence of any rock falls
  - The presence of catch fencing (classified as a SGM under Task 594), and in sufficient detail to determine whether it was broken or missing (condition information)
- Three different LiDAR datasets (2013 and 2014 Mobile Mapping System and 2015 rotary wing) were analysed and change detection algorithms applied to try to detect any deformation or other slope changes over time (slope retreat) – for condition assessment . Findings included:
  - Mobile Mapping System LiDAR point classification is limited to carriageway and ‘everything else’.
  - Mobile Mapping System and rotary wing LiDAR could not be compared for change detection to a high degree of accuracy. This is due to the different sensor viewing geometries and resulting point cloud point densities and differing spatial coverage.
  - Change detection between the Mobile Mapping System datasets showed promise in terms of understanding small-scale condition changes (e.g. vegetation growth) but without any slope morphology changes between the surveys it was not possible to determine whether change detection can be used for this purpose
  - Mobile Mapping System LiDAR could be used to identify any significant movements (rupture, etc.) in the catch fencing. However, no deterioration was observed.
- The Sentinel-2 multispectral imagery at its 10 m spatial resolution is too coarse to identify the same scale of geotechnical features.
- The hyperspectral trial data available for this site was not captured at the optimum time of year and affected by shadowing. No conclusion can be reached about this dataset for the steep chalk cutting. .

Conclusions and recommendations:

- A combination of terrestrial and rotary wing LiDAR datasets and high resolution orthoimagery (though of more limited use at this particular site due to the cutting geometry) appears to be most suitable for analysis of deep rock cuttings.
- There are a limited number of deep chalk cuttings along the network. Other remote techniques may also be suitable including static (tripod) terrestrial LiDAR scanning, but this data was not available during the pilot trials.
- AVIS is useful for fast remote qualitative analysis, however, the suitability of the imagery for geotechnical asset assessment is limited. Specifically, certain geotechnical features may be obscured due to height, light conditions, or cutting orientation. However, AVIS provides a good view of the pavement and roadside assets – including in this case, the SGM (catch fencing).
- LiDAR change detection has the potential to identify changes to the cutting slope face and SGMs. It may be possible to undertake this in a semi or fully automated way in future. Repeat surveys should be undertaken using the same type of sensor.
- For future LiDAR data procurement, it is recommended that Highways England increase the range of point classifications in the specification to distinguish between ground surface, structures and low-medium-high vegetation, rather than purely carriageway and all other features grouped together. This type of detailed classification would increase the usefulness of the datasets for geotechnical assessments and would be required to enable more automated analysis.

Pilot 3 – M40 Hyperspectral

A number of sites along the M40 were selected following a drive through followed by a review of Googlemaps Street View imagery and Google Earth Pro satellite imagery. These included six cutting slope sites (Sites 2 to 7) and one embankment site (Site 8) – see Figure 5. Site 1 is the Stokenchurch cutting in the previous section.

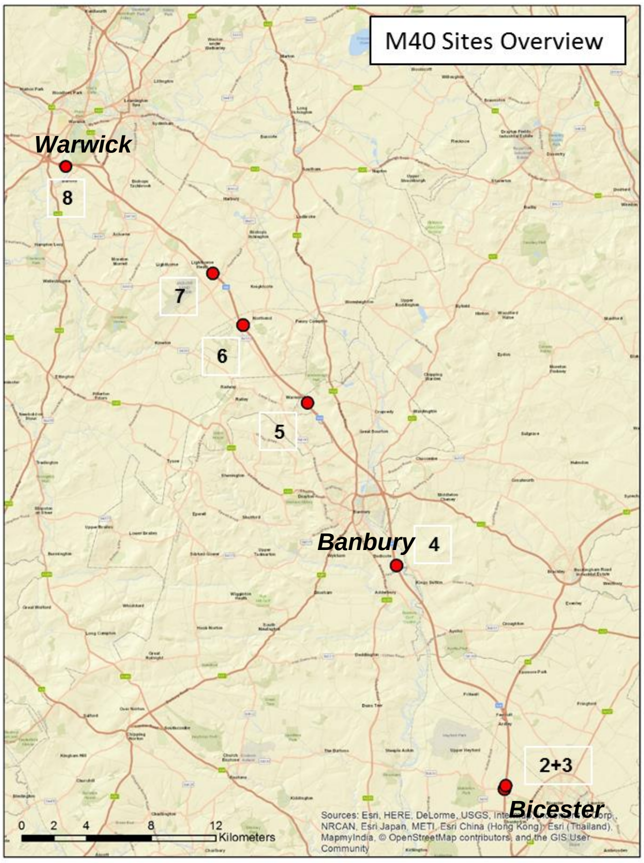


Figure 5: Overview of the M40 Pilot Site Locations

The sites selected have a range of features and the aim was to assess whether these were detectable with the hyperspectral imaging dataset.

The rotary wing LiDAR contour dataset, at 25 cm intervals, was also reviewed along a section of the M40 between the Stokenchurch cutting and j8 to try to detect any embankment slope slips for further assessment with the hyperspectral imagery, but none were identified. The rotary wing LiDAR contours were also viewed for Site 5, where a cutting slope slip was identified in the Googlemaps StreetView imagery.

The 2016 rotary wing survey datasets are of particular interest in this pilot as this survey is planned as to be carried out across the entire network. The hyperspectral scanner was flown on this rotary wing survey as a trial. It is understood that this is the first time the hyperspectral imagery (which has recorded surface reflectance in over 300 different wavelength bands) has been displayed and interrogated. Of particular interest is its potential capability to measure the spectral signature soil moisture content, as elevated soil moisture content can be a precursory sign for slope failure.

Summary of findings

- Several band combinations for highlighting vegetation health and soil moisture content were tested. The Short Wavelength Infra-Red (SWIR, ~1500-2500 nm) bands were able to highlight wetter areas, such as flooded or highly water-saturated fields.
.

- The above features were not clearly identifiable from the orthoimagery alone. Therefore there is value in the hyperspectral dataset and it could benefit asset identification and monitoring efforts, and reduce network asset mapping by ground methods.
- In terms of monitoring, the example of the counterfort drains provided promising information regarding asset performance. Where the counterfort drains were installed at Site 7 the spectral signatures showed the slope had lower moisture content than the part of the slope without drains. Such information could reduce manual inspection commitments.
- The 0.75 to 1m pixel resolution of the hyperspectral imaging is too coarse to inform detailed feature mapping, but may be sufficient for regional / network-wide geotechnical asset monitoring.
- The coarse pixel resolution also means that the pixel provides the average surface reflectance properties, which will be a combination of different materials within the pixel area (e.g. both soil and vegetation for example). . Further work, including ground truthing, is required before the usefulness of the hyperspectral dataset can be understood better.

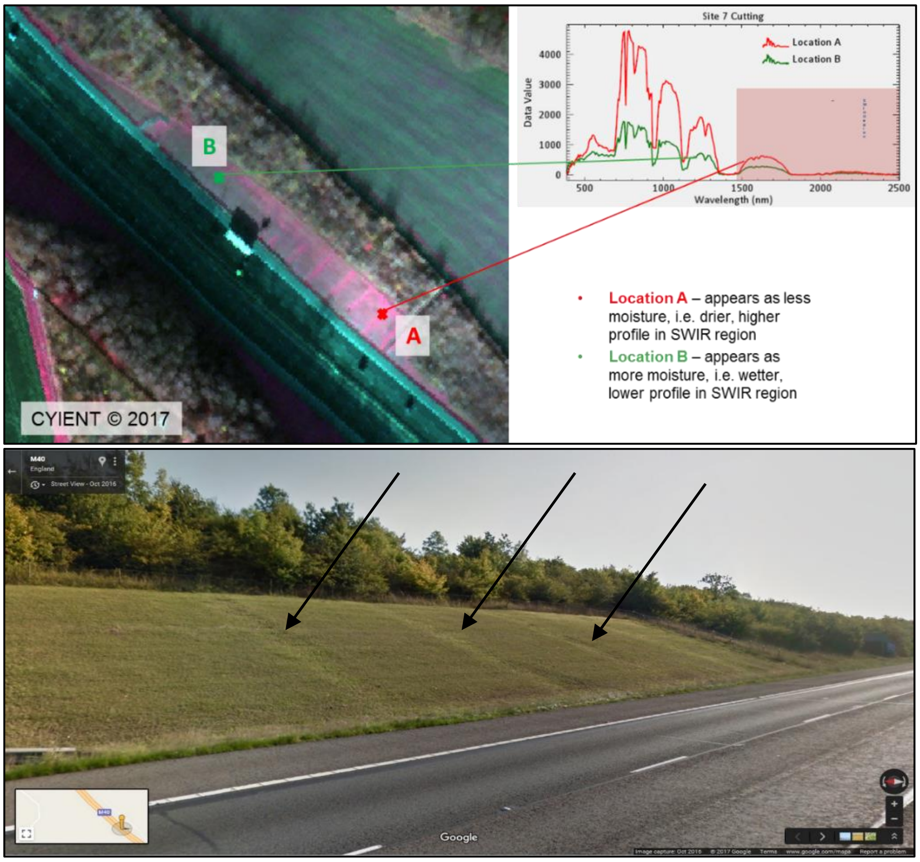
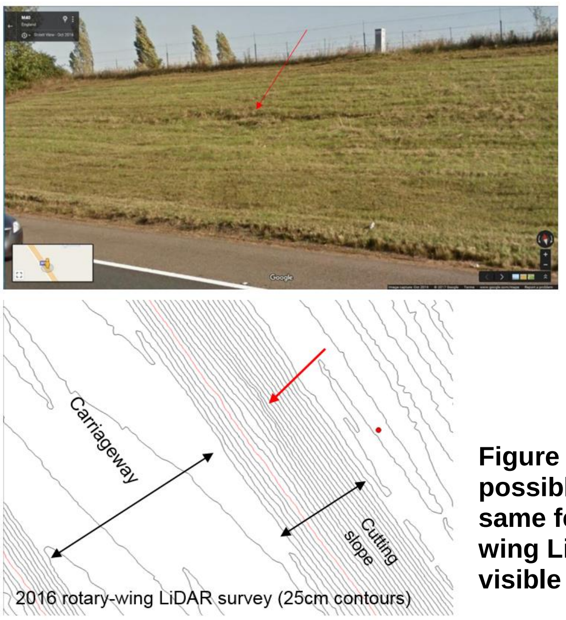


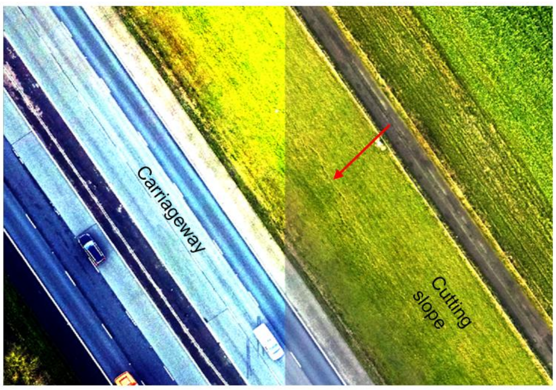
Figure 6 Hyperspectral imagery showing counterfort drains highlighted as brighter red pixels (Site 7). The top image shows the CIR (Colour Infra-Red) Band Combination.

- The time of year and time of day the survey is carried out is important because dense vegetation and long shadows from trees, tall steep cuttings, and hilly relief can obstruct the other surface signals of interest. Illumination is stronger in the summer and this provides a stronger reflectance signal.
- Using vegetation as a proxy for soil moisture content is unlikely to be useful because there is not a straightforward relationship between these two variables (high soil moisture content does not necessarily equal denser or healthier vegetation).
- The 2016 rotary wing orthoimagery quality (contrast, brightness, shadowing) is variable and image quality was found to be poor across many sites.
- Orthoimagery resolution is 5 cm. Small features of geotechnical interest can be delineated, but only when the lighting conditions are favourable.
- In this pilot the LiDAR contours at 25 cm spacing proved useful to quickly review long stretches of the M40 and enabled easy identification of slips in soil slopes that were previously unknown. This could help reduce the need for physical inspections and it has potential for automation if repeat surveys were available.

Conclusions and recommendations

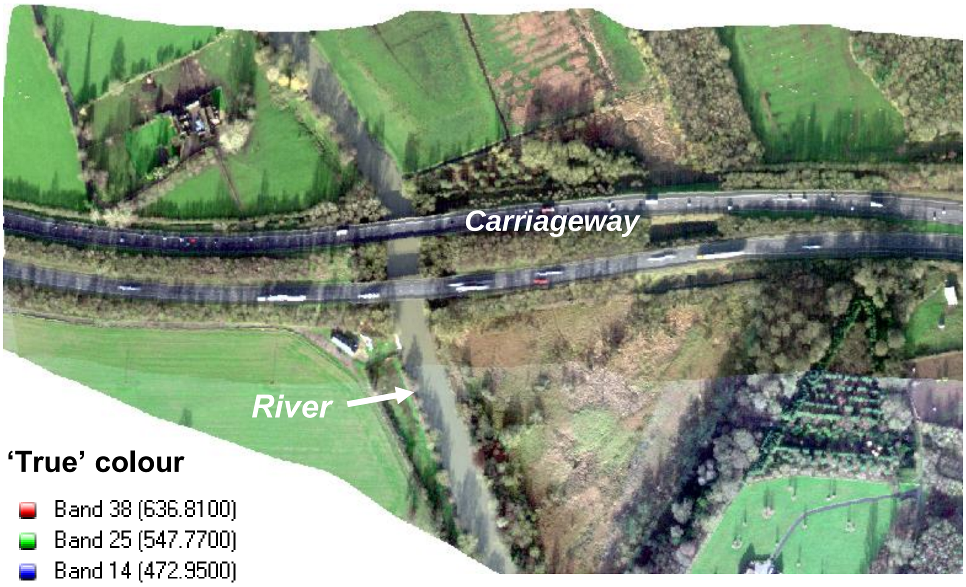
- The hyperspectral imagery showed promise for remotely identifying drainage assets, in addition to potentially monitoring their performance. It is therefore recommended that further trials are undertaken.
- The hyperspectral survey time of year should be planned so that light and vegetation conditions are favourable for imaging. This also applies to orthoimagery.
- Hyperspectral pixel resolution needs to be appropriate for the scale of features that are to be mapped/monitored (e.g. 0.25 m or 0.5 m may be more appropriate).

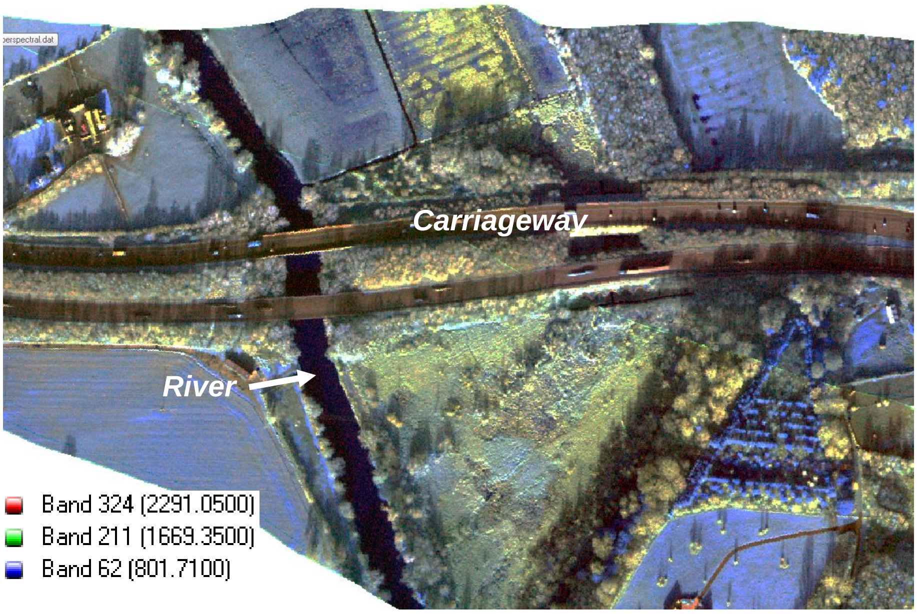




2016 aerial orthophotos

Figure 7 Google street view image (top left) of a possible cutting slope failure developing (Site 5), same feature clearly detected in 25cm rotary wing LiDAR contours (bottom left), but less visible in the orthoimagery (top right).





SWIR & IR (Short Wave Infra-Red and Infra-Red) Band Combination

Figure 8 Two hyperspectral images of the carriageway where it insects with a river and surrounding floodplains (Site 8). The SWIR & IR bands (bottom image) clearly highlight areas (brighter or darker blue pixels) of high soil moisture content (marked by red arrows) that are otherwise not obviously visible in the true colour image (top).

Pilot 4 – A259 Tanyard Lane and A21 Lamberhurst

Pilot 4 focussed on two high risk soil slopes in Area 4, Tanyard Lane on the A259 (Location 1 on Figure 9) and Lamberhurst on the A21 (location 2 on Figure 9). These sites were identified as 'high risk' in the Area 4 GeoAMP and at both sites slope failures had been reported on HAGDMS. Both rotary wing LiDAR and Mobile Mapping System LiDAR data and imagery were assessed for use of remote asset assessment. Both slopes are situated on the Ashdown Formation (mudstone) are densely vegetated.

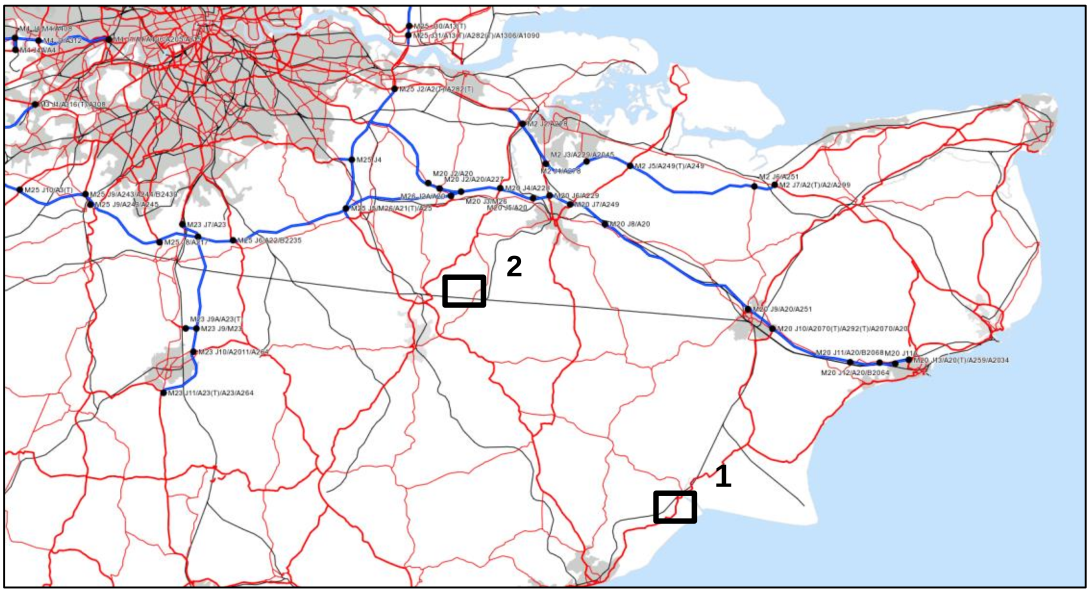


Figure 9 Locations of A259 Tanyard Lane (1) and A21 Lamberhurst (2)

Figure 10 shows 3D perspective views of the 2016 rotary wing LiDAR point cloud and the surfaced slope for the Tanyard Lane site. The slip failure at this site occurred on the natural slope.

Figure 11 shows photos of the embankment slope failure at the Lamberhurst site taken from HAGDMS (this site has a sidelong ground profile). This failure occurred in winter 2014 due to prolonged rainfall, and because of poorly constructed older earthworks. Emergency remedial works including granular replacement were carried out in 2014 and a gabion wall was put in place to remediate a deep seated failure in 2016.

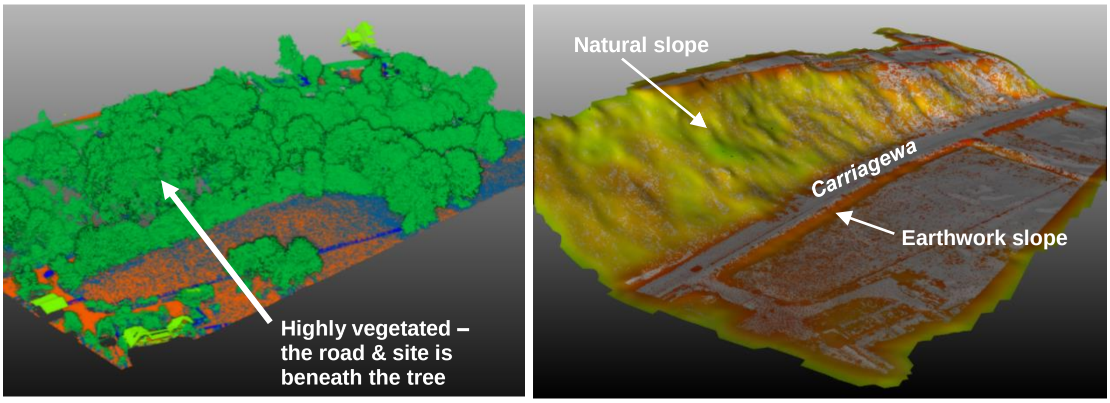


Figure 10 3D perspective views of the Tanyard Lane site showing the full rotary wing LiDAR point cloud (left) and the surfaced slope of only the ground points, revealing the geometry of the natural slope, and carriageway earthwork slope.

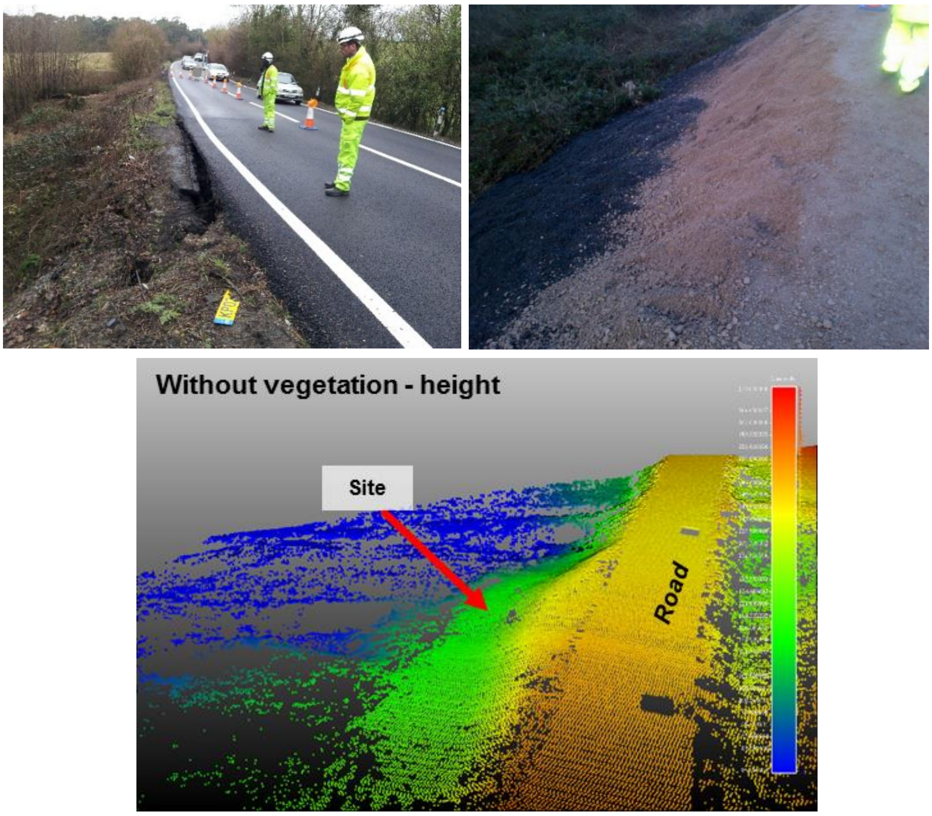


Figure 11 Lamberhurst site photos from HAGDMS showing the failure (left) and completed remedial works (right). The bottom panel shows the 2016 rotary wing LiDAR point cloud at the site with vegetation filtered

Summary of findings

- The 2013 Mobile Mapping System imagery is often too shadowed to remotely observe geotechnical issues along narrow densely vegetated roads, particularly in the summer months when vegetation is densest.

- The 2016 rotary wing orthoimagery is often shadowed and earthworks cannot be observed beneath the dense vegetation. Steep slopes are also difficult to observe in the orthoimagery.
- Mobile Mapping System LiDAR data has high point density particularly on the carriageway, but the returns from the ground surface beneath dense vegetation are more limited/less dense. Low or missing point density is also an issue on embankment slopes due to the line of sight of the sensor.
- The 2016 rotary wing LiDAR data:
  - has better spatial coverage (covering entire cutting slope, top surface and bottom surface) than the Mobile Mapping System LiDAR
  - is better classified than the Mobile Mapping System LiDAR, therefore it is easy to filter vegetation and produce a bare ground or surface model, which is necessary for assessing slope failure potential.
  - Has better point density on the earthwork slopes than the Mobile Mapping System LiDAR.
  - The 25cm LiDAR contours prove very useful for making slope assessments for slips, slumps, and drainage, even with dense vegetation and shadowing.
  - Additionally, the spatial coverage is such that additional asset classes such as drainage can be mapped in addition the various slopes.

Conclusions and recommendations

- LiDAR is best combined with AVIS vehicle imagery, but this needs to be collected under optimal lighting conditions and, ideally, at a time of the year when vegetation is less dense.
- Similarly to previous pilot studies, recommendations for better LIDAR classification of the Mobile Mapping System survey and repeat surveys with the same surveying platform and methodology for change detection can be made

Pilot 5 – M2 Dissolution feature

The section of the M2 between junctions 5 and 6 is located in Kent, between the towns of Sittingbourne and Faversham. The M2 is a dual lane motorway with hard shoulders that has a speed limit of 70mph. The carriageway links Canterbury with the M25 and London.

The geology of the area is ‘Clay with Flints’ over Chalk.

This area has experienced a number of subsidence related problems over the last two decades. Events summarised by Balfour Beatty Mott MacDonald (2015) include:

- M2 Subsidence, 1994
- M2 Denehole, 2001
- M2 Solution feature, 2002

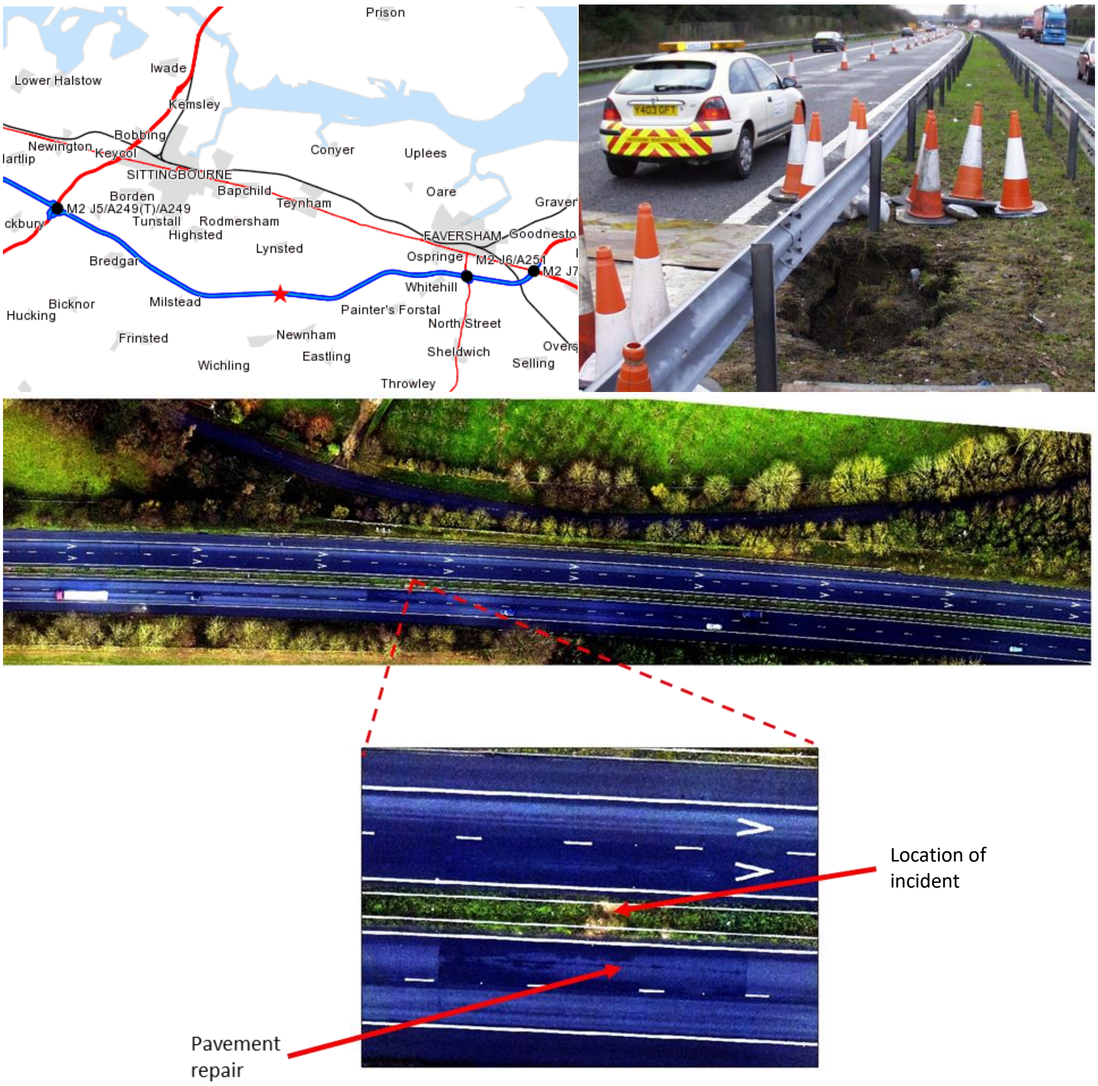


Figure 12 Solution feature location on the highway network (red star, top left-hand image) and sinkhole failure (top right-hand image), orthoimagery showing the in-filled remediated cavity collapse.

Summary of findings

- High resolution orthoimagery was useful when interpreting other datasets and is good for observing features on, along, and immediately surrounding the carriageway where there is either no or limited vegetation.
- Mobile Mapping System LiDAR has superior point cloud density to rotary wing LiDAR along the carriageway surface.
- For change detection to be carried out it needs to align in time with the known geotechnical issue.
- Available multispectral data is too coarse for small scale geotechnical issues such as a cavity collapse.

Conclusions and recommendations

- Highways England should consider changing the specification for Mobile Mapping System LiDAR to one in which pavement, vegetation and structures are classified separately.
- Other surveys that Highways England carry out including TRACS and ground penetrating radar should be investigated with respect to detecting dissolution features. They could complement the methods used in this pilot study. However, it should be noted that change detection with respect to dissolution features is difficult due to the rate of movements involved and, at times, the little warning that is associated with it.
- If Highways England is to use LiDAR data for change detection associated with condition monitoring, the data capture frequency should be increased. Mobile Mapping System appears to be a useful tool for this application and it is recommended that this is taken forward as the primary tool for change detection. A further pilot study should be carried out that compares Mobile Mapping System LiDAR data from two separate time points on an area that is known to have deteriorated. The initial study should be focussed on an area of more gradual ground movement than that associated with cavity collapse.

Pilot 6 - Use of AVIS for remote inspection as per HD41/15

This specific study focuses on the use of the AVIS online viewer tool to improve the knowledge of condition and performance of Highways England's geotechnical assets. AVIS is currently utilised as a network asset inventory tool and remote survey data are not used for geotechnical applications. The AVIS system contains Mobile Mapping System imagery and LiDAR remote sensing data. The system has been reviewed to ascertain if it can be used to undertake remote inspections of geotechnical assets with the aim to complement and, potentially reduce the frequency of physical inspections.

The capability of AVIS as a tool to aid pre-population of the geotechnical asset inspection form (HD41/15 Annex C) using Mobile Mapping System derived photographs and LiDAR point clouds was assessed for a rock cutting, a soil cutting and an embankment.

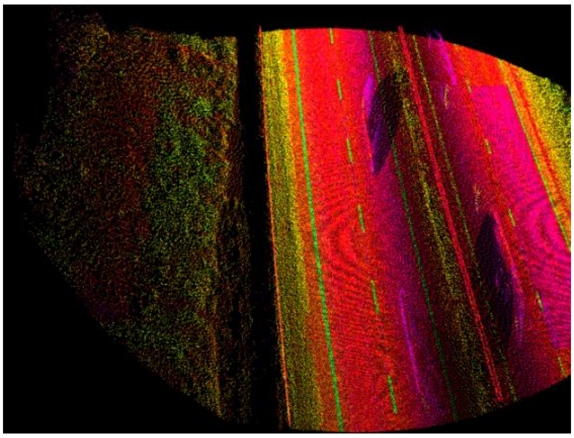


Figure 13 Ravelling of Rock Cutting on A38 Area 01. Source: AVIS

Summary of findings

- Generally, AVIS can provide geotechnical asset information relating to location and observations on vegetation, direct and indirect features, drainage and reinforcement structures.
- Water features such as marshy ground, ponding, erosion and hydrophilic vegetation may be observed. For example, water seeping from a slope is unlikely to be directly visible but may be visible if wet rock/soil appears darker below the seepage point than the surrounding drier slope face.
- Direct and Indirect features (Annex C-4) of asset instability including slips, slope bulges, distorted trees and terracing are visible along soil and rock cuttings. Reinforcement structures such as geogrid, gabions and rock bolts can be detected as long as they are surface visible features.
- A number of limitations of the AVIS tool were also determined - in particular many Mobile Mapping System photographs are either shrouded in shadows or over-

exposed due to direct sunlight such images that are not usable. Small geotechnical features such as steel mesh are not visible and LiDAR point clouds can take up to twenty seconds to load. Further limitations are described in the more detailed account of the pilot study in Appendix A2.

Conclusions and recommendations

- In its current state, AVIS permits general observations about geotechnical assets to be made. However, if detailed observations are to be made with high confidence the system requires additional and improved datasets.
- AVIS is capable of recording information for many of inspection fields in the C-2, C-3 and C-4 sections of Annex C of HD41/15. However, this is dependent on the size of the feature of interest.
- It would be useful to be able to view other remote sensing datasets in AVIS, in particular:
    1) High resolution orthoimagery and rotary wing LiDAR dataset to improve the capacity to inspect and characterise embankments;
    2) Hyperspectral imaging or airborne Thermal Infra Red (TIR) imaging to improve the detection of seepage and high moisture contents within earthworks and, potentially, locate and monitor non-visible drainage assets.
- The following recommendations for improving the capability of the AVIS System are given:
    - Standardise notation and expansion of Map Query inputted data;
    - Mobile Mapping System and LiDAR point cloud displayed side-by-side;
    - LiDAR data displayed as 3D digital surface model (DSM) and as 25 cm interval contours;
    - Mobile Mapping System surveys should be performed in more optimal conditions to reduce over-, or under-exposure of photographs.

Pilot 7 - Use of AVIS for inventory and condition of SGMs

This pilot also focuses on the use of the AVIS tool but with respect to remote inventorying and condition monitoring of Special Geotechnical Measures (SGMs). This method could help improve knowledge of location and condition of SGMs, reduce frequency of and target physical inspections.

The pilot study makes use of geotechnical assets from across the highway network but focuses in detail on the M1 near Sheffield, South Yorkshire. This section of the network was selected because it presents a wide range of geotechnical assets and it is currently being upgraded as part of the motorway widening and Smart Motorway Programmes (SMPs). Therefore, the sites reviewed represent earthworks at different stages of their lifecycle.

Summary of findings

- AVIS can be used to locate 'surface visible' SGMs (e.g. retaining walls, rock netting and bolts, visible drainage). Features and structures that suggest the presence of SGMs are often visible e.g. safety fence at the top of concrete retaining walls.
- Generally, AVIS is capable of identifying features that can give an indication of the SGM 'face' condition e.g. damaged brickwork in retaining wall.
- Observation of the full extent of SGMs located on embankments is not possible due to the limitation of the Mobile Mapping System survey method.
- Other features of interest can be observed:
  - Vegetation type present on at grade and cutting slopes;
  - Seepage from cut slopes, manifesting as wet soil or wet hard shoulder.

Observation ID: 290401
Obs Desc: seepage & dislocated trees and erosion p208-11. Running water observed. Slope benched at 16m, seepage at 10m on 1st slope.
AVIS Obs: ***Seepage is not visible in slope due to vegetation.***
Verge appears to be wet top soil. Top soil and grass has encroached onto the hard shoulder by ~0.2 m.

Figure 13 Seepage and top soil slippage observation on AVIS

Conclusions and recommendations

- AVIS could be used to verify the location of surface visible SGMs using the outputs of Task 594 Strengthened Earthworks and the results could be used to create a layer in HAGDMS of all verified SGMs and associate imagery. The above, in conjunction with consultation with the Managing Agents, would substantially improve Highways England's knowledge of SGMs.

- Condition monitoring could be supported by making repeat remote surveys of SGMs accessible to geotechnical asset managers, thus potentially reducing the need for physical inspections. Repeat surveys to the same specification may have the potential to allow changes to the SGMs to be detected. Automation of change detection would help to reduce manual assessment of the Mobile Mapping System data in AVIS.

8.2. Appendix A2 – Full pilot reports

A259 Tanyard Lane and A21 Lamberhurst

Phase 2 Pilot Study 2017

SPaTS 1-086 Application of remote survey data for Geotechnical asset condition and performance

1. Introduction

This document represents one of a series of pilot studies undertaken for Phase 2 of the SPaTS 1-086 project '*Application of remote survey data for geotechnical asset condition and performance*'.

These studies present an evaluation of the use of available selected remote-sensing survey data in both management and condition monitoring of Highways England geotechnical assets.

This specific study focuses on **Area 4 of the network, first, A259 Tanyard Lane and, second, A21 Lamberhurst**. These sites have been identified as geohazards – natural unstable/ high-risk slopes.

The focus of this Pilot is to assess the potential of the **newly acquired 2016 rotary-wing LiDAR survey** data for monitoring geotechnical assets, in particular for the natural landslide hazard present at the sites of interest.
This LiDAR dataset in itself is a pilot of a proposed national network-wide rotary-wing LiDAR survey that is been undertaken at the time of writing.

This document covers both sites and it is structured as follows:

Please see other supporting documents for further information.

Click on the 'Home' button to get back to this slide

2. Data Review

Two **high-risk soil slope** sites were selected from 17 shortlisted high-risk sites in Area 4 of the network. The shortlisted sites were selected from a review of the GeoAmps Report for Area 4.

The two sites investigated in this Pilot are:

<table>
<tr><th rowspan="2">Site</th><th rowspan="2">Carriageway (HAGDMS observation reference)</th><th rowspan="2">Geotechnical Risk (HAGDMS/GeoAmps Report 2016-17*)</th><th colspan="5">Data</th></tr>
<tr><th colspan="3">LiDAR/ Survey</th><th colspan="2">AVIS</th></tr>
<tr><td rowspan="2">Tanyard Lane</td><td rowspan="2">A259 (555772)</td><td rowspan="2">‘Slip, toe debris’ (2015). Photos (2015) describe and indicate tree dislocated in slip.</td><td colspan="2">Terrestrial (vehicle)/ Mobile Mapping System</td><td>Aerial/ Blom</td><td>Imagery</td><td>LiDAR</td></tr>
<tr><td>2013</td><td>2015</td><td>2016</td><td>Available</td><td>Not possible to view</td></tr>
<tr><td>Lamberhurst</td><td>A21 (544255)</td><td>Soil slip/ cracked pavement. Remedial work proposed: Granular replacement/ gabion wall</td><td>2013</td><td>2015</td><td>2016</td><td>Available</td><td>Available</td></tr>
</table>

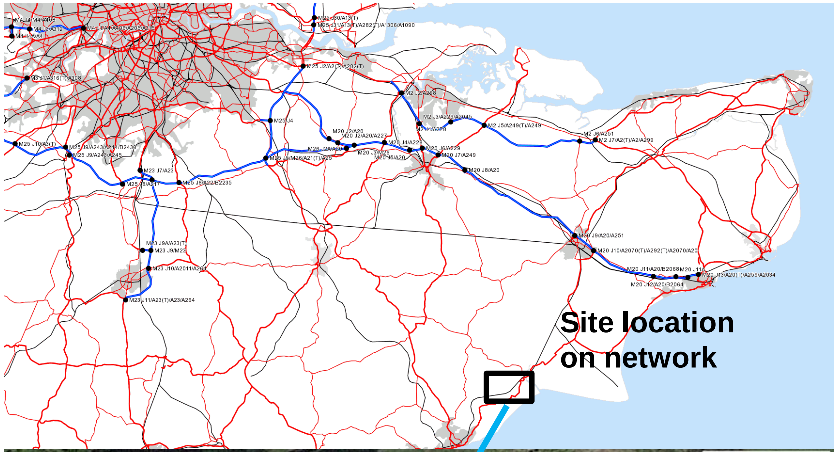
*GeoAmps Report Area 4 Geotechnical Asset Management Plan (GeoAMP) 2016-17 Part 1 Date: April 2016 (HAGDMS Reference 29040).

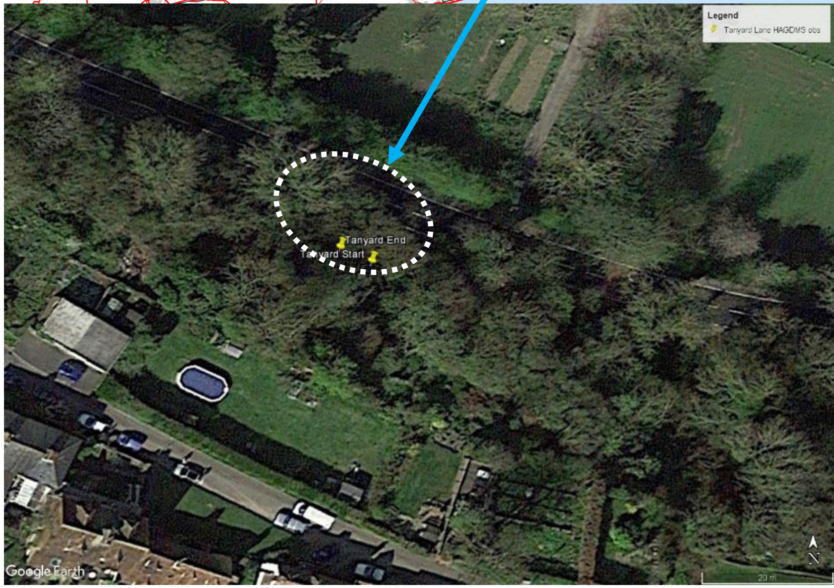
3. Site Location & Description

Tanyard Lane, HAGDMS observation 555772:

- Dense vegetation (trees, shrubs, grass), natural slope failure. Survey details in Table 1:

Location	GPS Easting	GPS Northing	Earthwork Chainage	Angle	Length	Height
Start	590439	117649	190	43.0	23.0	15.7
End	590434	117651	184	43.0	23.0	15.7





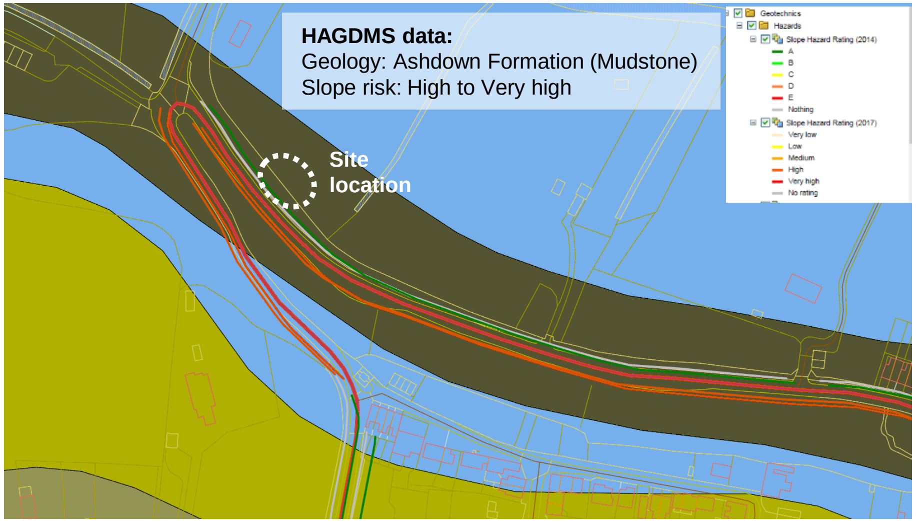


Table 2: Geotechnical Risk & Data Survey Timeline

Mobile Mapping System1	Failure (reported HAGDMS)	Remedial works	Mobile Mapping System2	Aerial LiDAR
2013	2014	2015	2015	2016

4. Geotechnical Risk

Tanyard Lane, observations of geotechnical failure:

- HAGDMS: “Mudslide over the whole height of the slope on the south-side of the road. This is a natural slope not an earthwork. The mudslide has not reached the carriageway but has deposited mud on the verge. Slope immediately adjacent appears unstable.”

2015 - FAILURE

2017 – POST-FAILURE

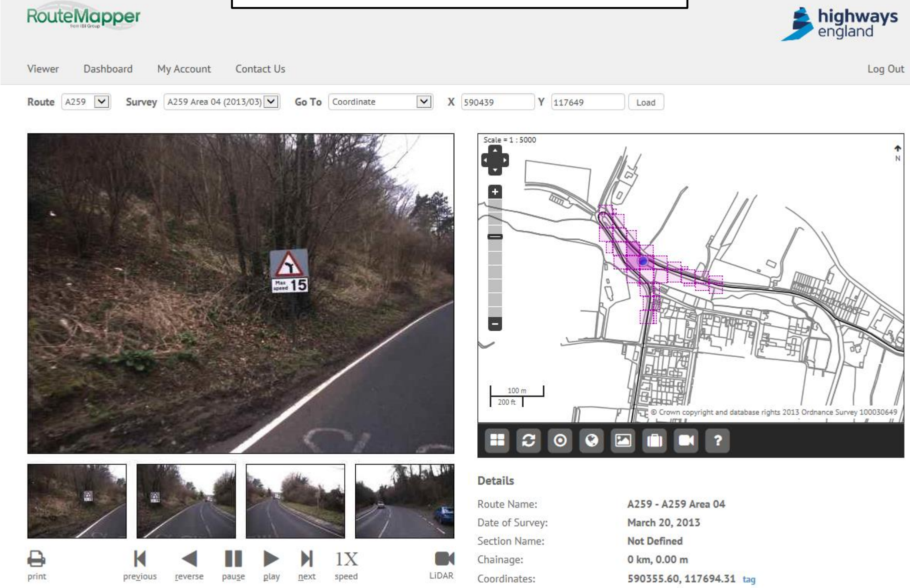
highways england

5.1 Data Processing & Analysis: AVIS (Mobile Mapper)

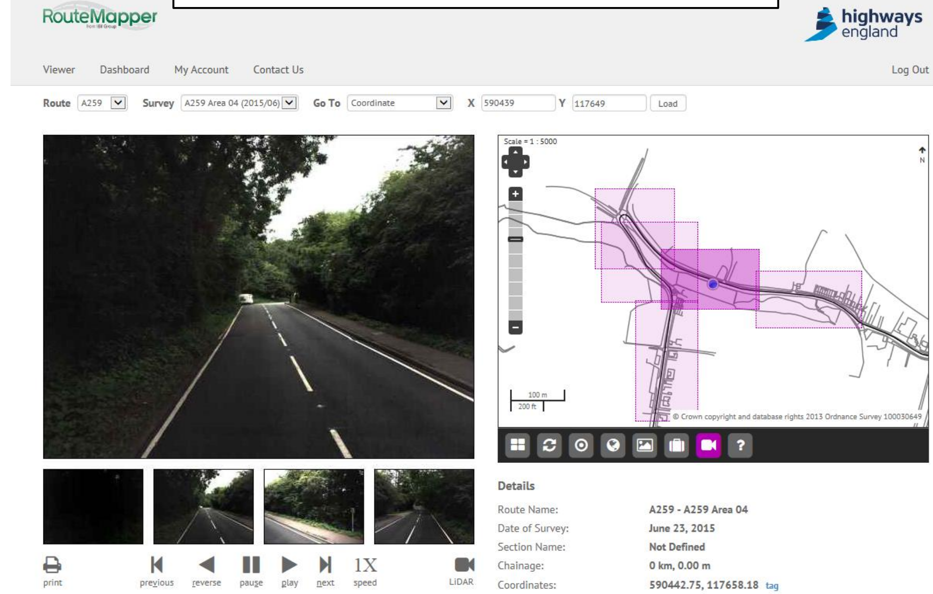
Tanyard Lane:

- 2013/03 Mobile Mapping System LiDAR data not available to view for this site
- 2015/06 Mobile Mapping System LiDAR data not available to view for this site
- Imagery – Difficult to see evidence of any slope failure between the start and end point of the site coordinates reported in the HAGDMS. This is due to vegetation, shadowing, and the comparison is made with a dataset where the remediation works have already been carried out.

2013: Less vegetation, winter

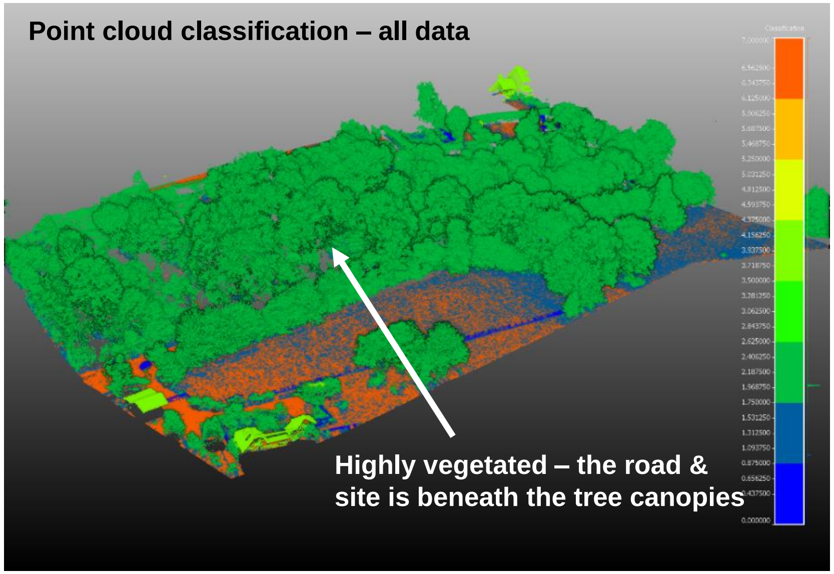


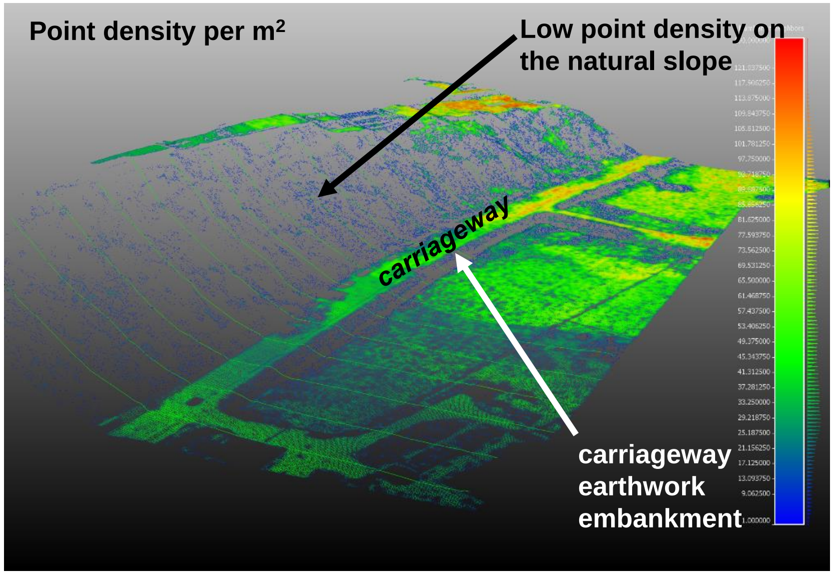
2015: shadows + dense vegetation, summer

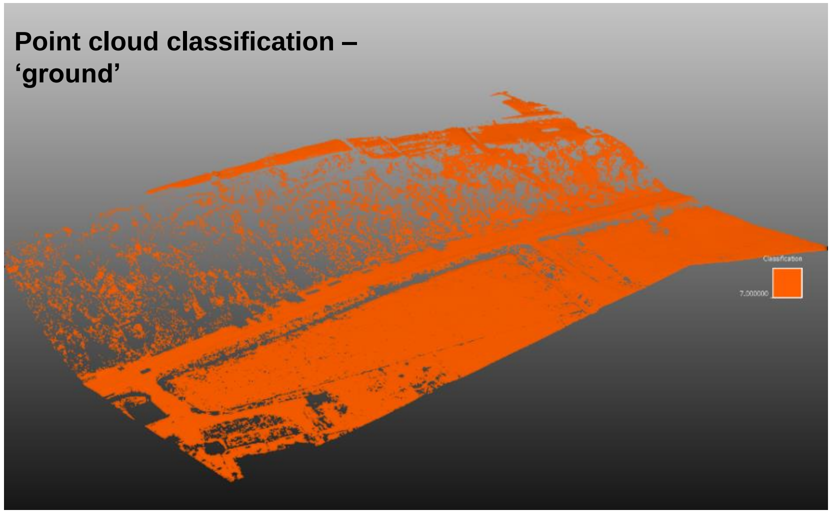


highways england

5.2 Data Processing & Analysis: 2016 Rotary-wing LiDAR







- Slope and surrounding point coverage is good/reasonable (1-15 and greater points per m^2) in spite of dense vegetation (which can be removed with filtering when data is well classified as shown in this example).

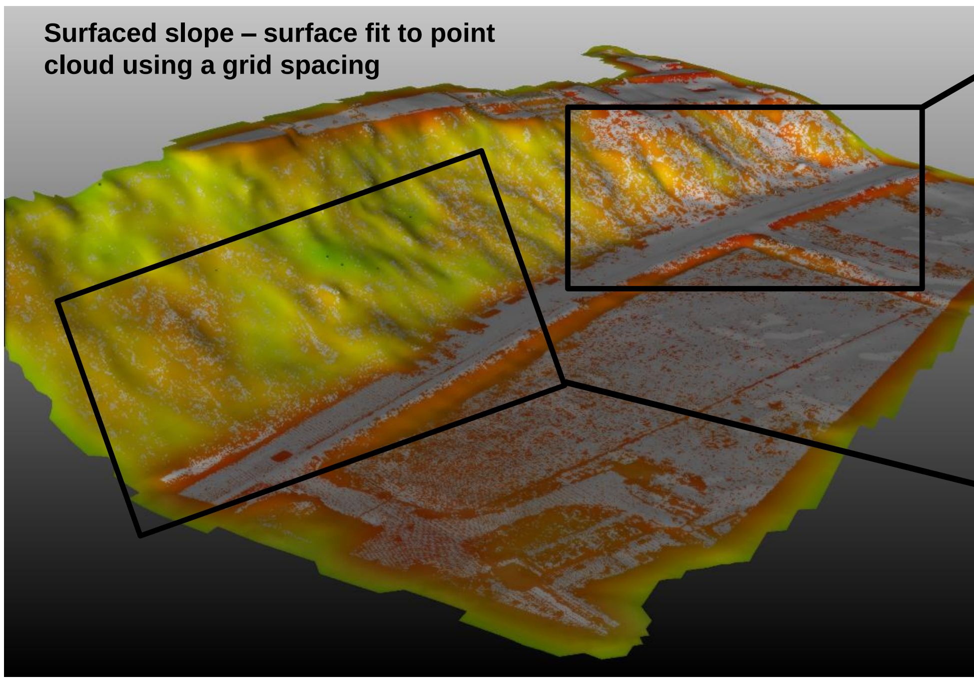
- The survey has captured the top and bottom of slope, which helps assess potential relationship of surrounding and slope-adjacent drainage with slope failure.

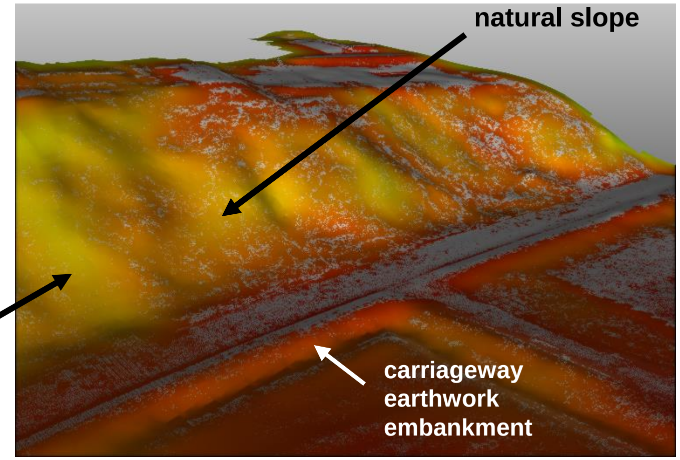
- In addition to the natural slope, the geometry of the earthwork upon which the carriageway has been constructed is well delineated. This provides geotechnical information that can be assessed over time.
- LiDAR dataset provides good 3D representation of site features and surrounding environment.

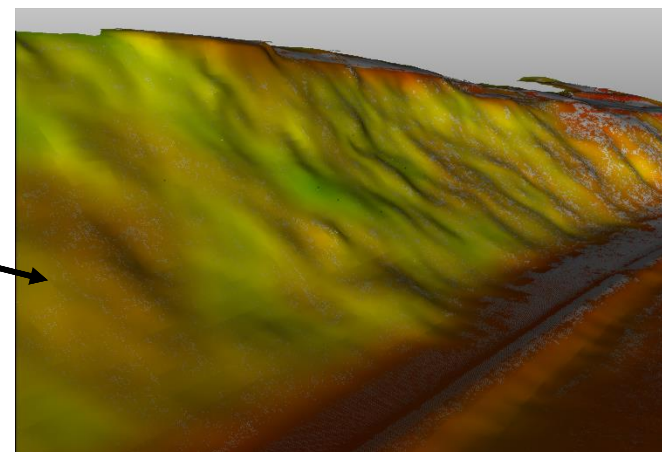
highways england

5.3 Data Processing & Analysis: 2016 Rotary-wing LiDAR

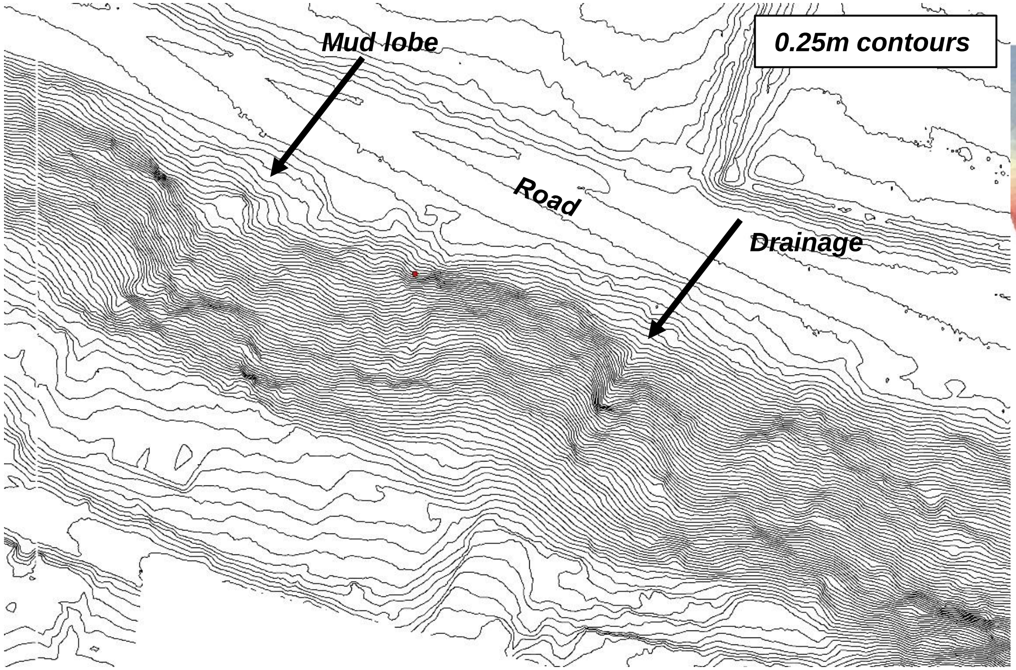
- 3D perspective views of surface models of the slope bare ground delineate slips and slope morphology well, in spite of relatively low point density (see previous slide).

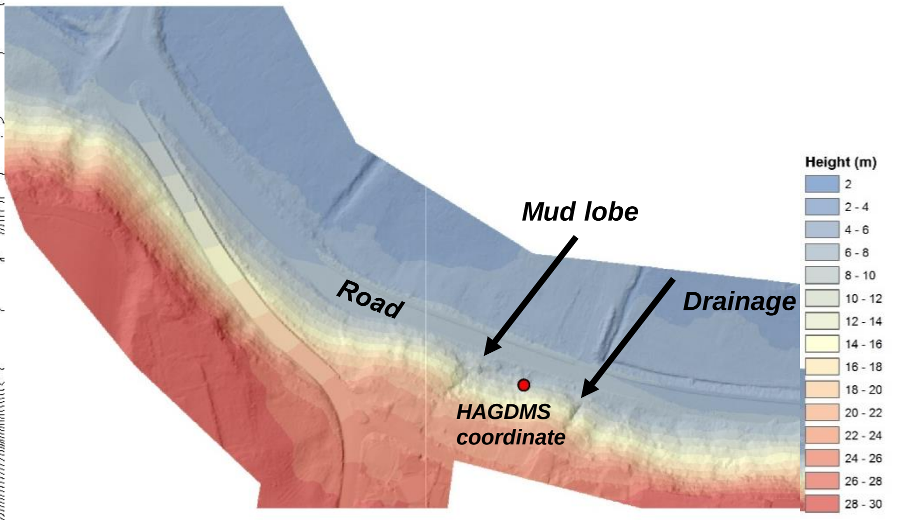


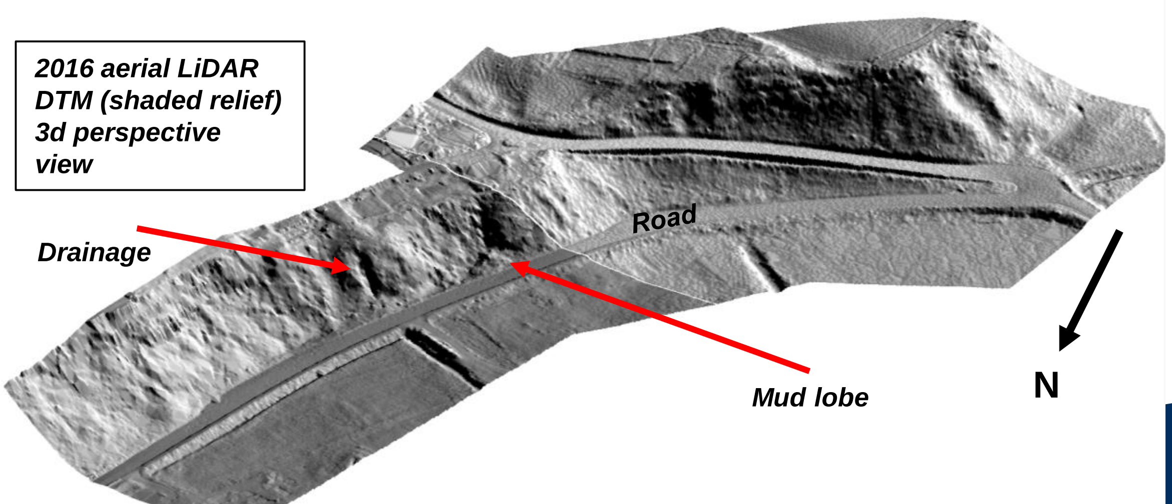




5.4 Data Processing & Analysis: 2016 Rotary-wing LiDAR





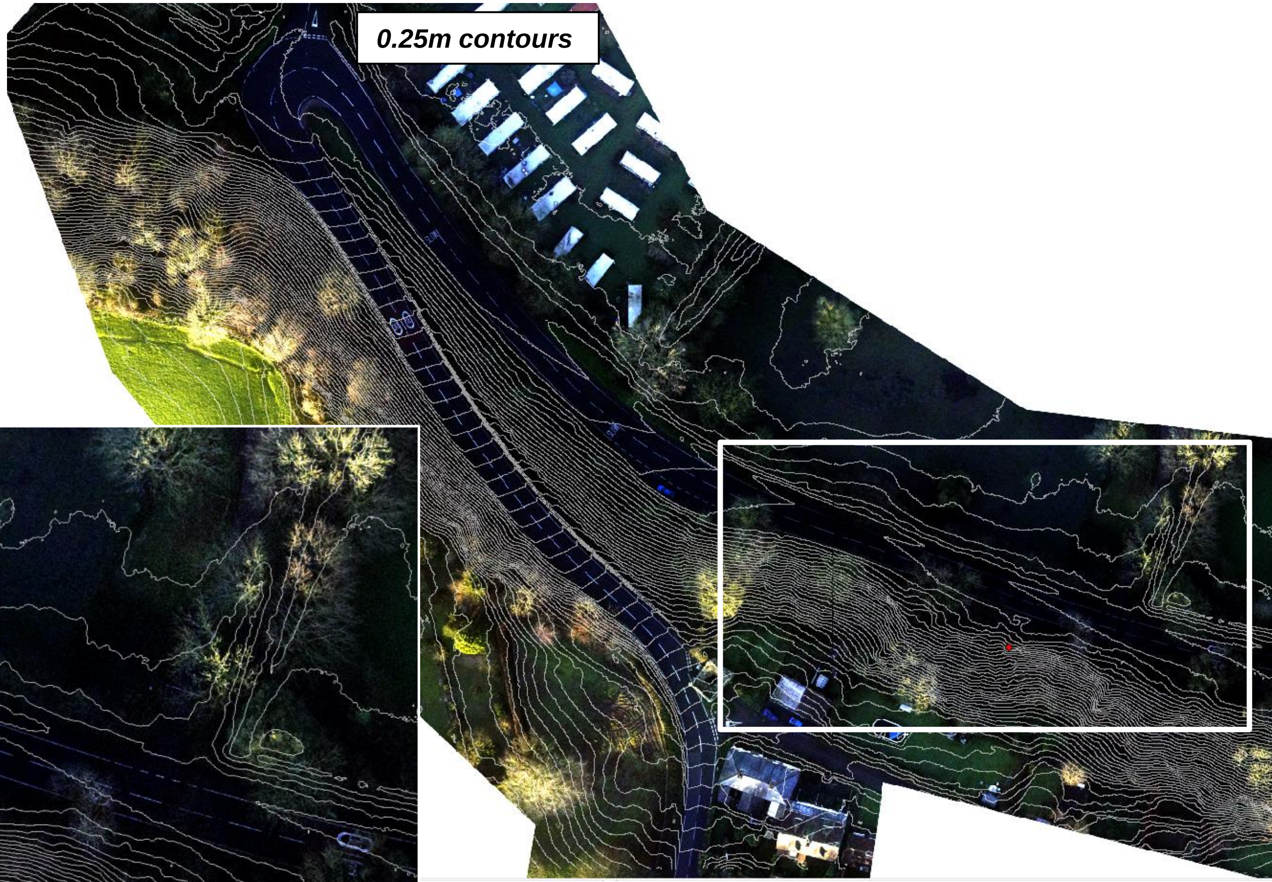


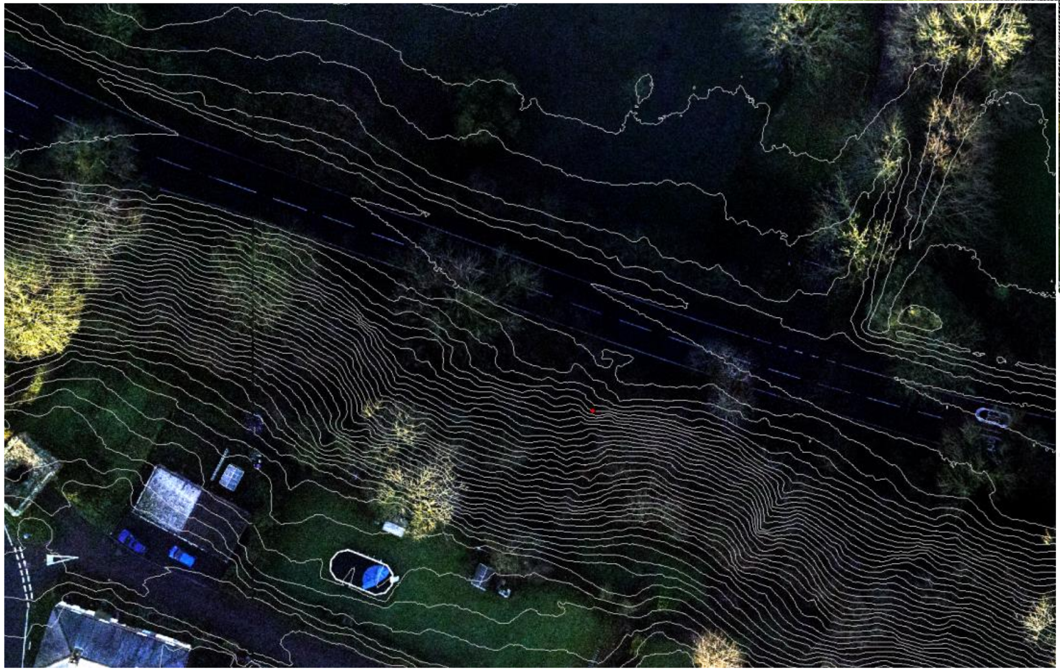
highways england

5.5 Data Processing & Analysis: 2016 Rotary-wing LiDAR

2016 Survey aerial orthoimagery

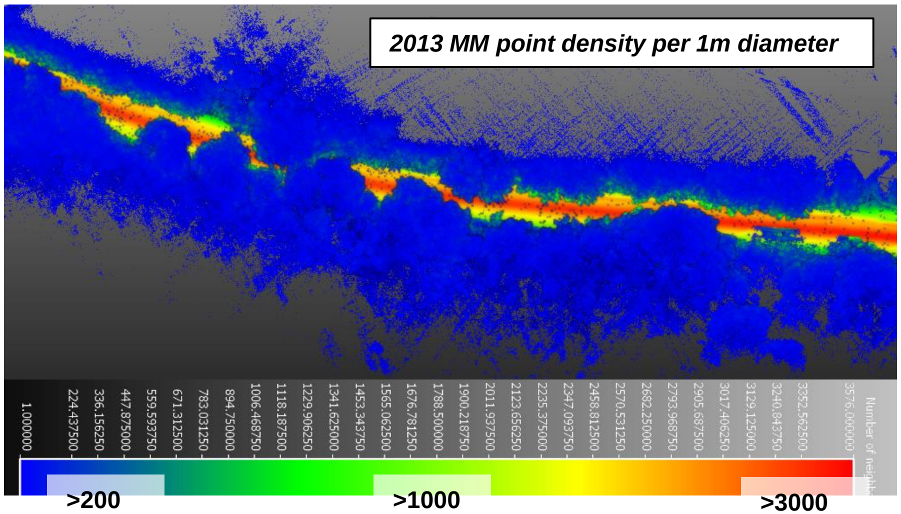
- Aerial orthoimagery suffer from shadowing due to tall, steep cutting and due to dense vegetation.
- The 25cm contours (derived from 2016 rotary-wing LiDAR) allow the cutting morphology and any potential slips to be observed in spite of the vegetation and shadowing.

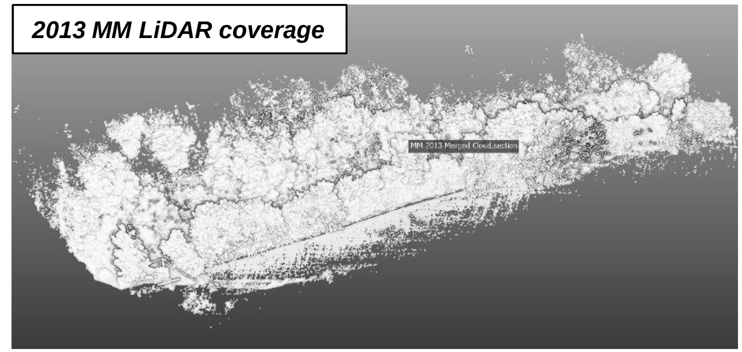


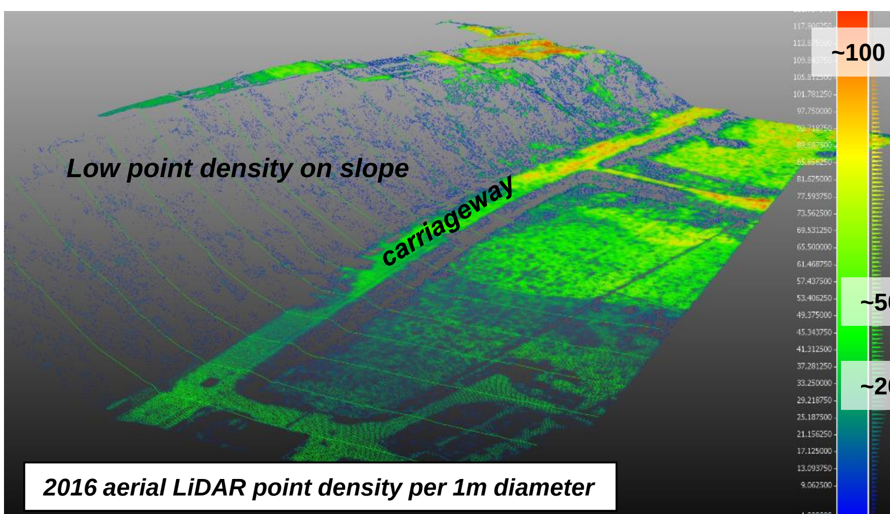


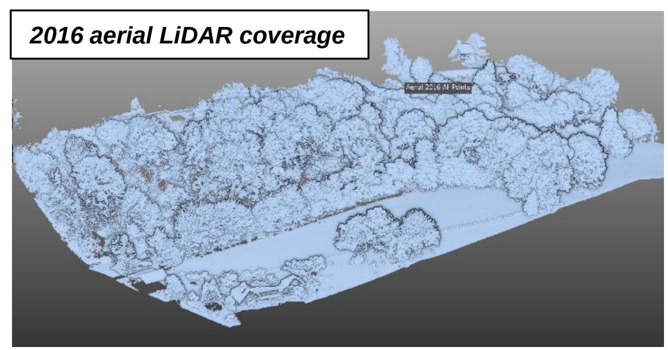
5.6 Data Processing & Analysis: 2013 Mobile Mapping System LiDAR

- The figures below show a comparison of the point density (left) and spatial coverage (right) between the 2016 aerial (top) and 2013 Mobile Mapping System (MM) (bottom) LiDAR data at the Tanyard Lane site
- The 2013 MM LiDAR has a much higher point density on the carriageway that 2016 aerial survey, however, the MM data has low point density on the slope due to limitations of the sensor line of sight and the dese vegetation.
- The MM has a more limited spatial coverage than the 2016 aerial LiDAR
- Change detection was not successful between the two datasets because the point cloud classifications of the 2013 and 2016 data were not equivalent and because of the limited spatial coverage and low point density of the MM data, particularly on the slope, relative to the 2016 data.







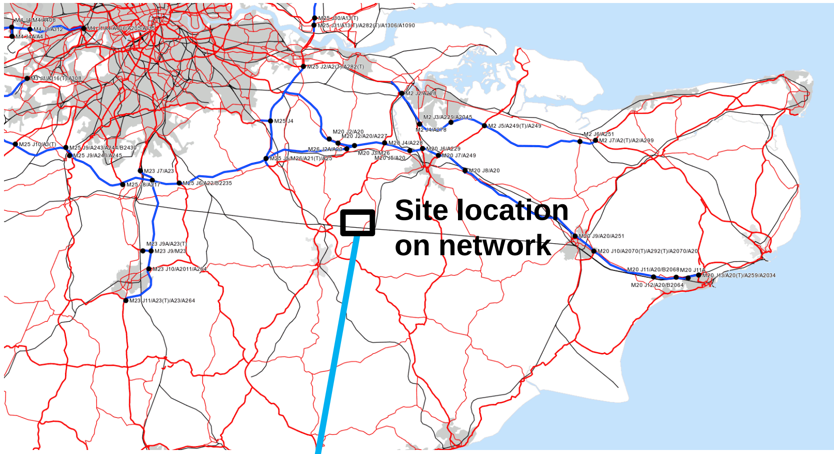


highways england

6. Site Location & Description

Lamberhurst, HAGDMS obs: 544255:

- This site is a high-risk slope earthwork on the south-side of the A21 carriageway close to Lamberhurst. The carriageway has been constructed on an earthwork that is itself located on a regional natural south-dipping slope. The geometry of the site is best shown in the aerial LiDAR 3D perspective view (see later slides). The site is surrounded by dense vegetation (trees and shrubs).



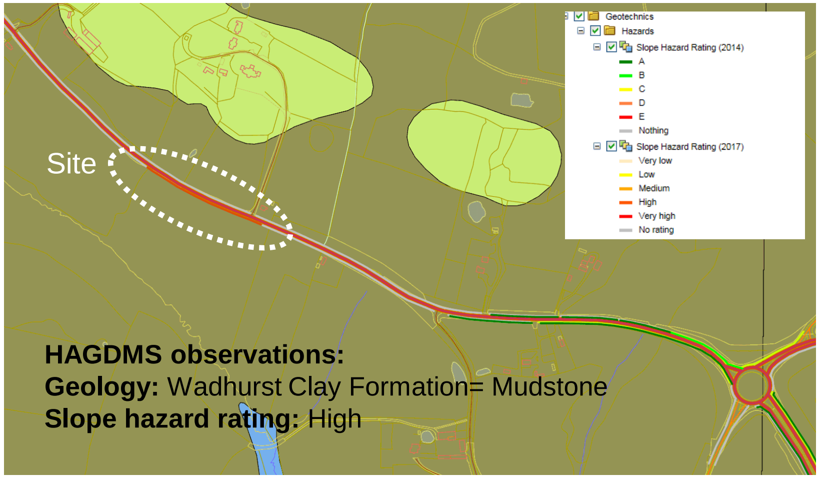


Table 1: HAGDMS slope survey details:

Location	GPS Easting	GPS Northing	Earthwork Chainage
Start	567248	137649	148
End	567248	137649	183

Table 2: Geotechnical Risk & Data Survey Timeline

Mobile Mapping System1	Failure (reported HAGDMS)	Remedial works	Mobile Mapping System2	Aerial LiDAR
2013	Winter 2014	Immediate	2015	2016

highways england

7. Geotechnical Risk

- HAGDMS (obs: 544255): “Granular replacement of the slope retained by 1 tonne sandbags at toe. Feb 2014 emergency works. Not a permanent repair, so risk of movement reoccurring.”
- GeoAMps Report (2016-2017): “Deep-seated earthwork failure due to prolonged rainfall, and poorly constructed older earthworks. Remedial works – gabion.”

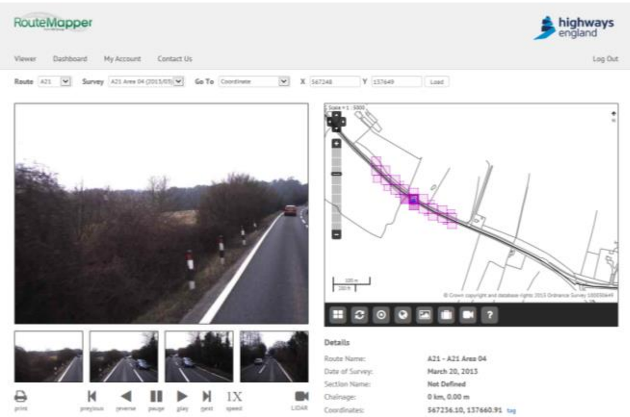
PRE-FAILURE winter 2014:

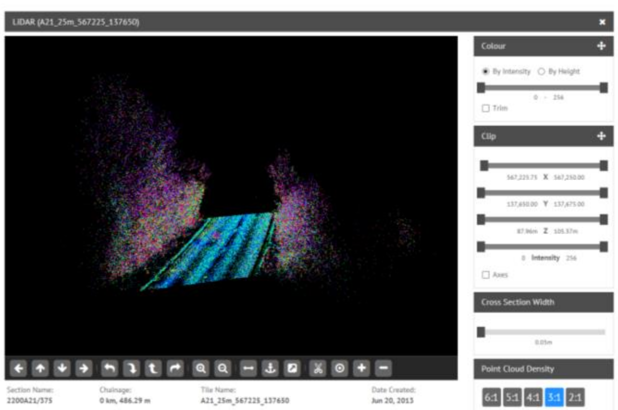
IMMEDIATE POST-FAILURE winter 2014:

8.1 Data Processing & Analysis: AVIS (Mobile Mapper)

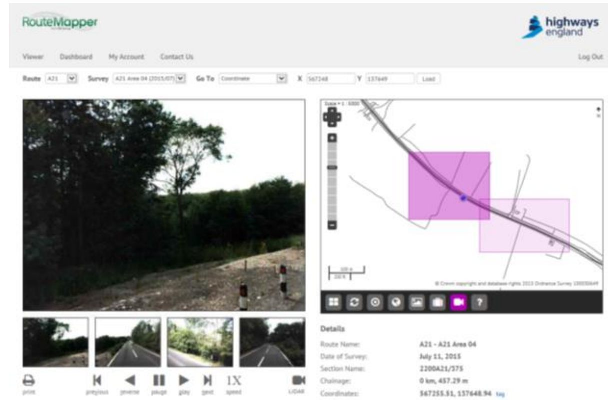
- Imagery is generally too shadowed to see the slope clearly at this site
- No evidence of pre-failure precursory features in the 2013 imagery
- LiDAR data has high point density on road carriageway, but less dense amongst the vegetation (and slope)
- LiDAR spatial coverage is relatively limited to an approximate 10m radius of the scan sensor location
- Slope direction means that the site is out of the sensor line of sight

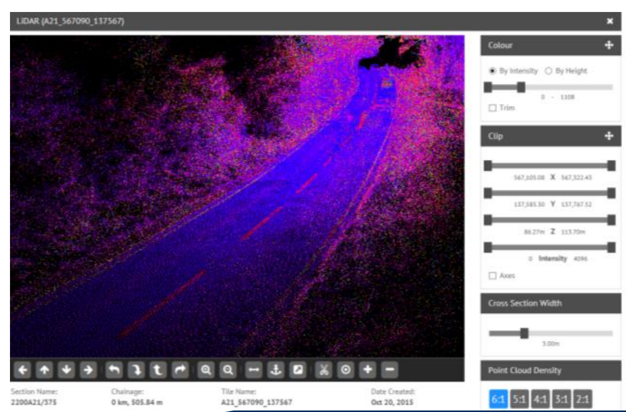
2013/03 (pre-slip)





2015/10 (post-slip – remedial slope regarding works concluded)

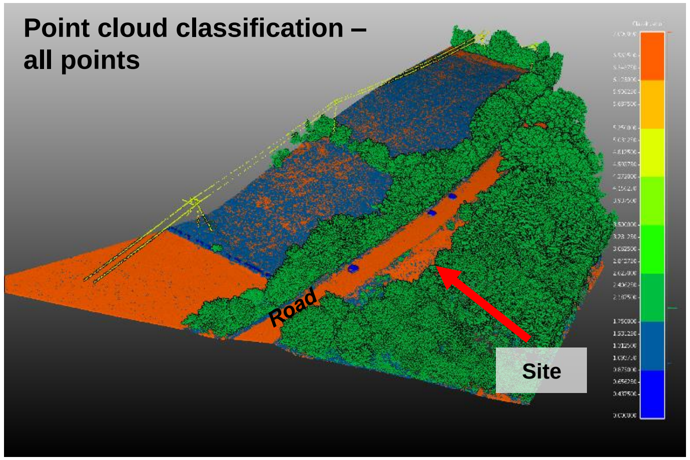


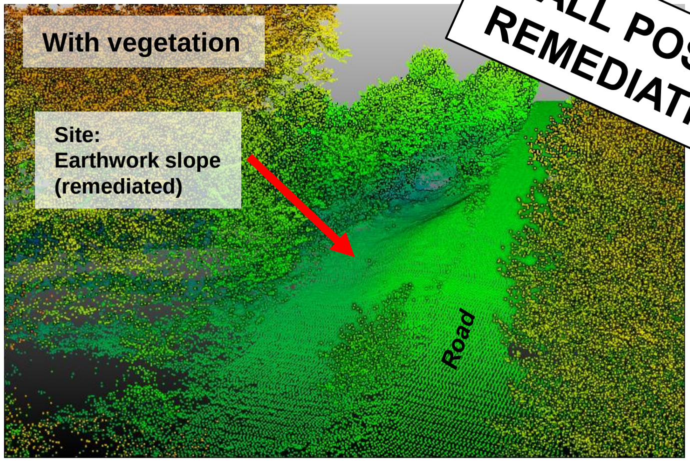


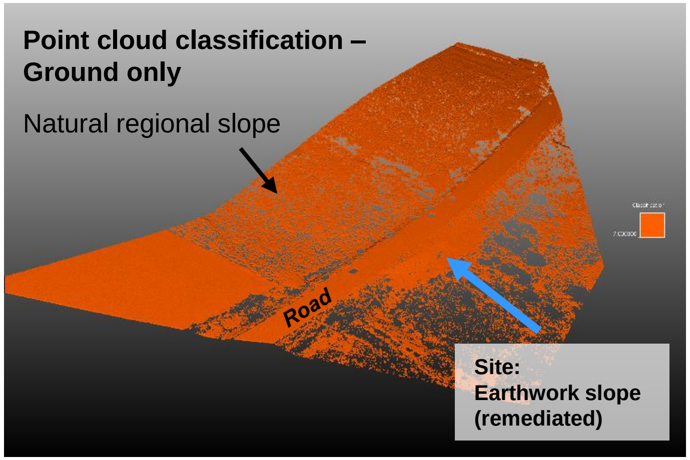
8.2 Data Processing & Analysis: 2016 Rotary-wing LiDAR

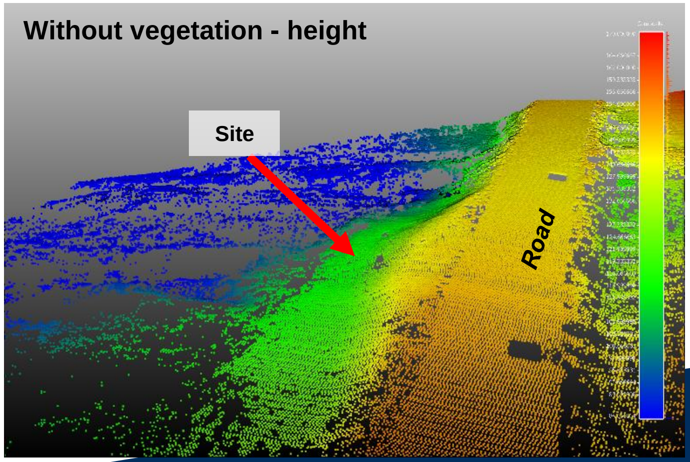
- By comparison to terrestrial Mobile Mapping System LiDAR:
- Point cloud classification is good
- High (~5->50 points/1m diameter) point density (see next slide)
- Broader spatial coverage – captures drainage network surrounding slope site, good for assessing relationship between drainage/soil moisture and slope failures

ALL POST-REMEDIATION





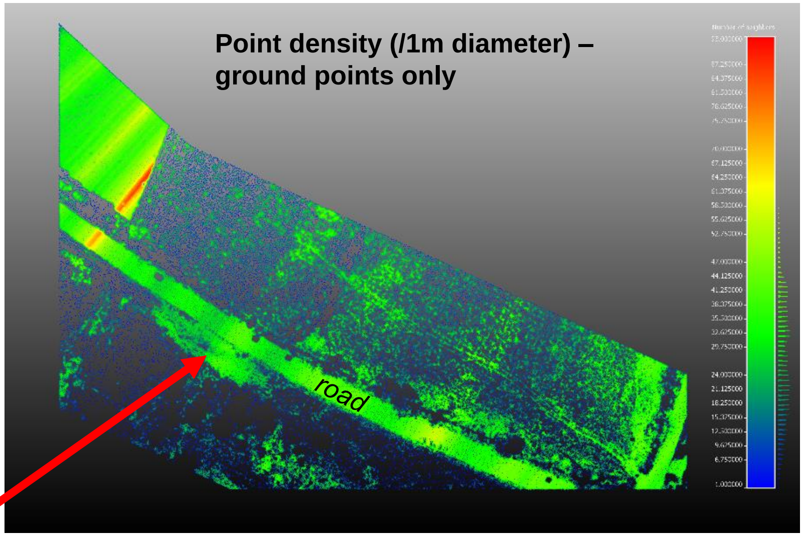




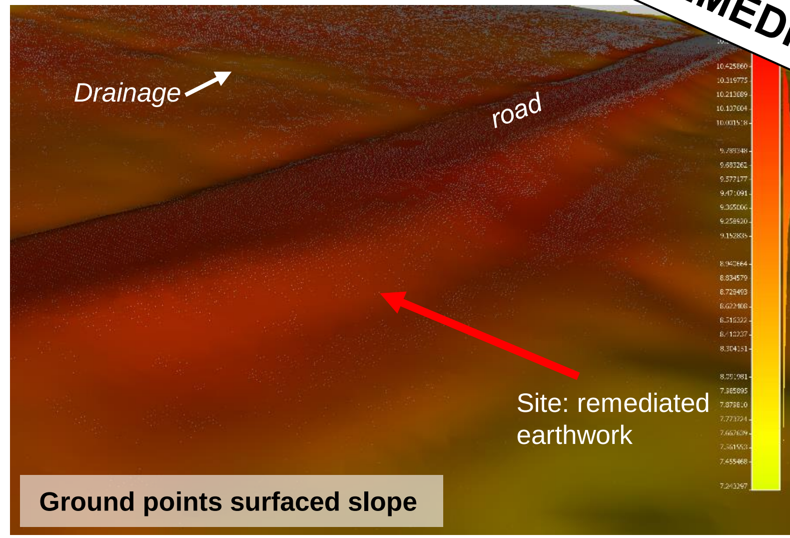
highways england

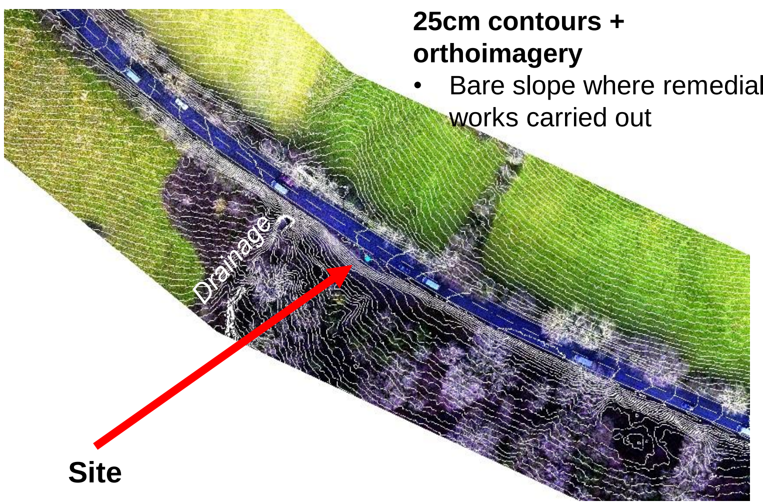
8.3 Data Processing & Analysis: 2016 Rotary-wing LiDAR

ALL POST-REMEDIATION



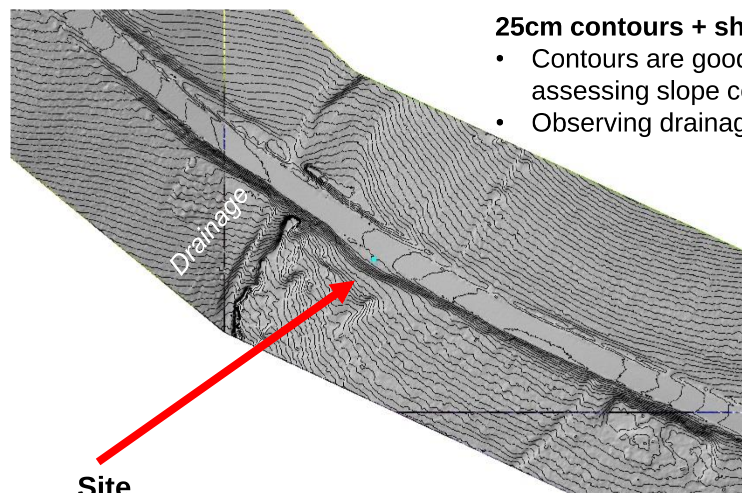
Site: remediated earthwork





25cm contours + orthoimagery
- Bare slope where remedial works carried out

Site



25cm contours + shaded relief
- Contours are good for assessing slope condition and,
- Observing drainage

Site

9. Overall Conclusions & Recommendations

Conclusions:

- The 2013 Mobile Mapping System imagery is often too shadowed to observe geotechnical issues along narrow densely-vegetated roads, particularly in the summer months when vegetation is densest.

- The 2016 rotary-wing aerial orthoimagery are also shadowed and geotechnical assets cannot be observed beneath the dense vegetation. Steep slopes are also difficult to observe from vertical aerial photography.

- Mobile Mapping System LiDAR data has high point density particularly on the carriageway, but the returns from the ground surface beneath dense vegetation are more limited/less dense, which is an issue if trying to observe slope failures as point cloud density is very limited on embankment slopes.

- The 2016 aerial LiDAR data:
  - has better spatial coverage (covering entire cutting ‘face’, top surface and bottom surface) than the Mobile Mapping System LiDAR
  - is better classified than the Mobile Mapping System LiDAR, therefore it is easy to filter vegetation and produce a bare ground or surface model, which is necessary for assessing slope failure potential.
  - has better point density on the slopes than the Mobile Mapping System LiDAR.
  - The 25cm LiDAR contours prove very useful for making slope assessments for slips, slumps, and drainage, in spite of dense vegetation and shadowing.

Recommendations:

- For the natural landslide hazard, and for the above listed reasons, the well-classified aerial rotary-wing LiDAR survey is recommended over the terrestrial Mobile Mapping System LiDAR survey data.

- LiDAR data needs to be collected using the same surveying platform and methodology (e.g. rotary wing, with consistent flight speed as this effects point sampling density) in order to compare survey data collected at different times

- LiDAR data needs to be well-classified in order to carry out height change detection and identify features that may relate to geotechnical changes.

- High-resolution aerial imagery has limited use for these types of sites, because of the steep slope and dense vegetation (particularly trees).

- High-resolution Mobile Mapping System imagery to be acquired when lighting is favourable is recommended in combination with the aerial LiDAR data for this type of site.

M2 Junctions 5-6 Dissolution feature

Phase 2 Pilot Study 2017

SPaTS 1-086 Application of remote survey data for Geotechnical asset condition and performance

1. Introduction

This document represents one of a series of pilot studies undertaken for SPaTS Task 1-086 '*Application of remote survey data for geotechnical asset condition and performance*'.

These studies present an evaluation of the use of remote survey data, utilising data currently procured by Highways England as well as emerging datasets that may be of additional benefit to the organisation in the management of their geotechnical assets.

This specific study focuses on the area of the M2 between Junctions 5 and 6. This study area has been identified as an area of either current high risk or having had a previous history of geotechnical problems during its lifecycle.

This document is structured as follows:

Please see other supporting documents for further information.

Click on the 'Home' button to get back to this slide

2. Site Location and Description

The section of the M2 between junctions 5 and 6 is located in Kent, between the towns of Sittingbourne and Faversham. The M2 is a dual lane motorway with hard shoulders that has a speed limit of 70mph. The carriageway links Canterbury with the M25 and London.

The geology of the area is ‘clay with flints’ over chalk.

This area has experienced a number of subsidence related problems over the last two decades. Events summarised by Balfour Beatty Mott MacDonald (2015) include:

- M2 Subsidence, 1994
- M2 Denehole, 2001
- M2 Solution feature, 2002

M2 Denehole, 2001 (Atkins)

M2 Solution feature, 2002 (Atkins)

3.1 Geotechnical Risk

On the 11th February 2014, 'a shoe box sized hole' was discovered in the central reservation, at marker post 74/2.

The hole further developed into a 4.6m hole, which affected the safety barrier and progressed under lane two in both directions.

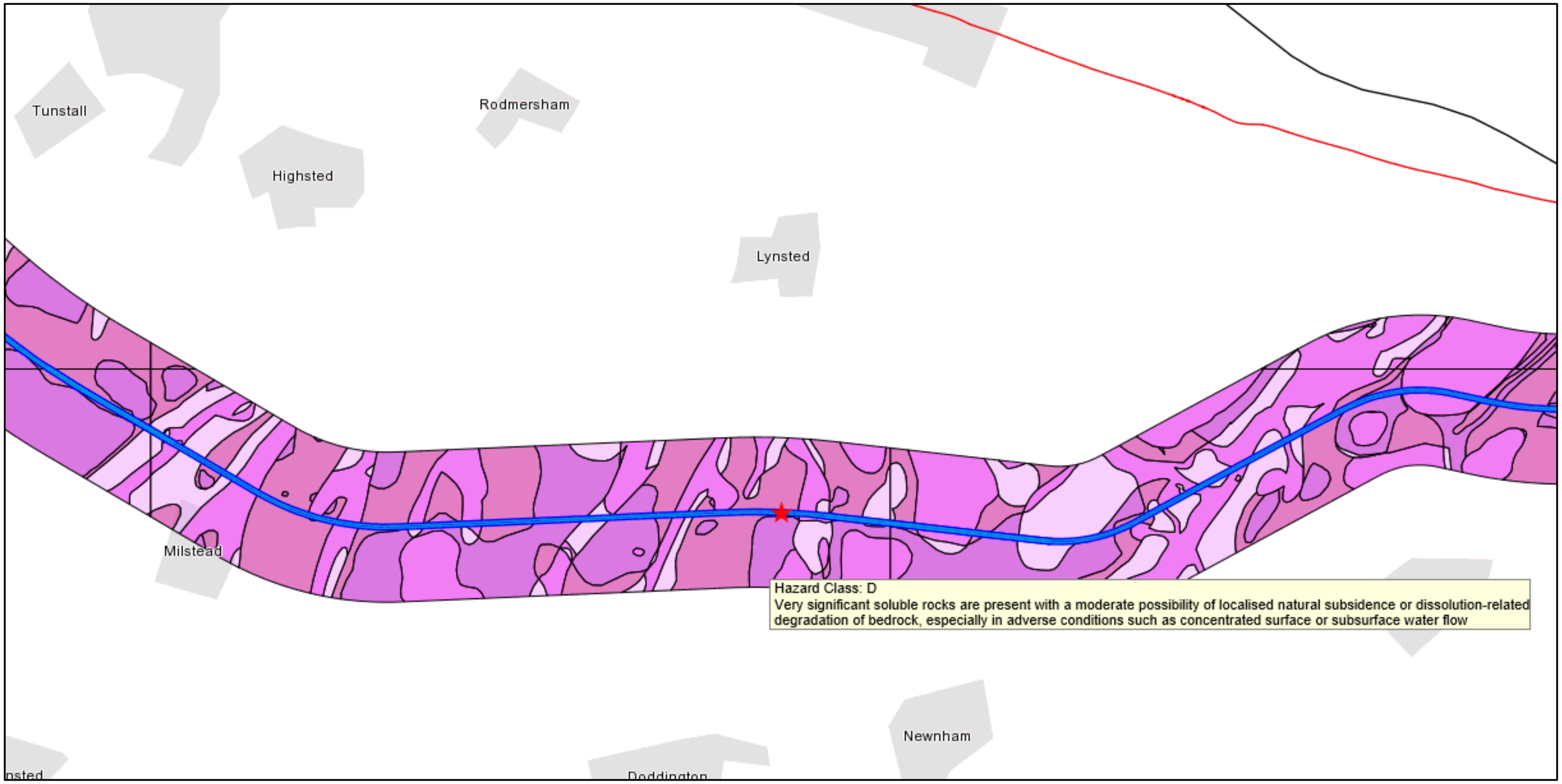
This resulted in a complete closure of the M2 whilst investigation and remediation were undertaken.

The pictures to the right show the location, in relation to the position in the central reservation of this particular dissolution feature.

It was later suggested that this incident occurred due to a failed drainage asset which led to increased water infiltration after a period of heavy rainfall, and which caused the washout of material forming the cavity.

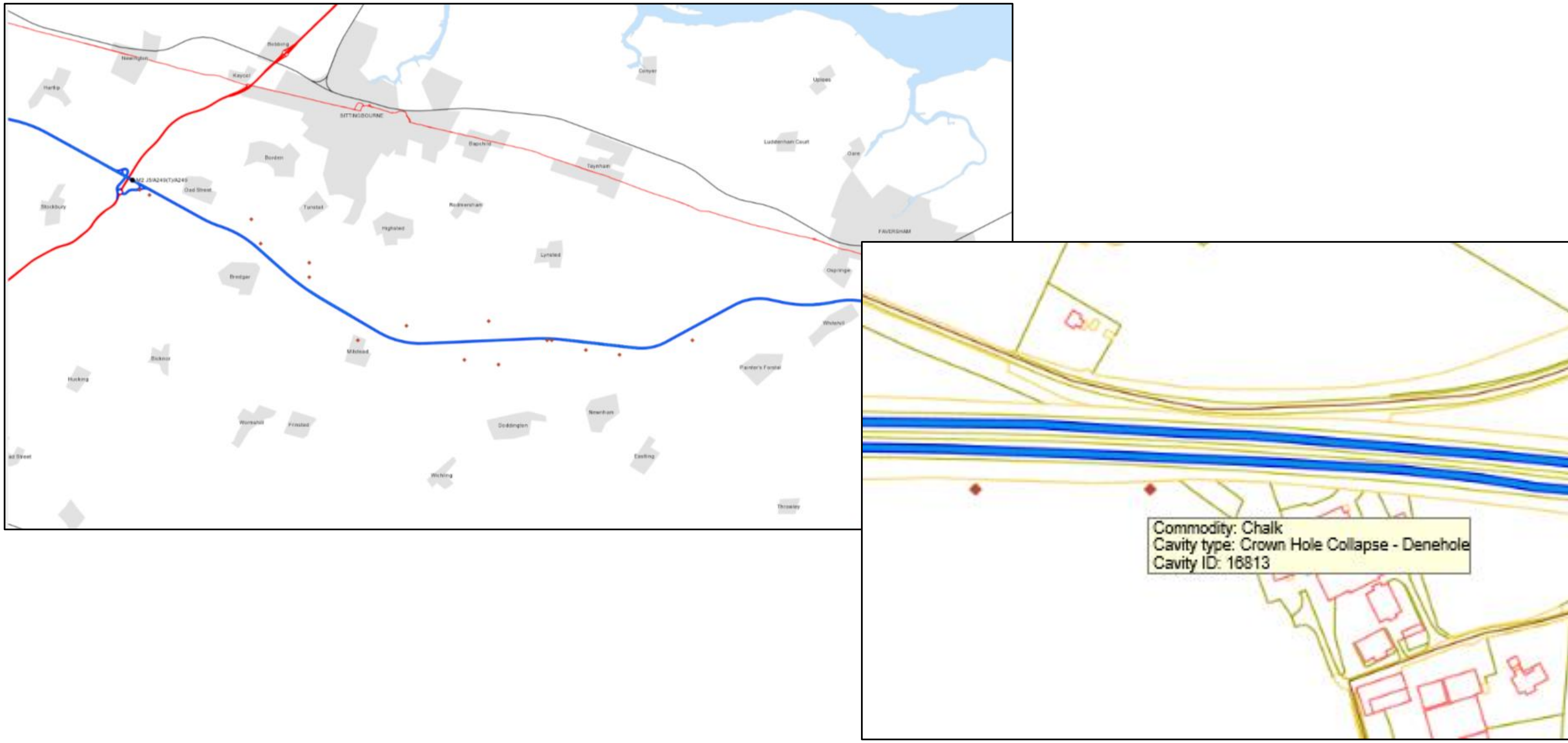
Source: Balfour Beatty Mott MacDonald

3.2 Geotechnical Risk



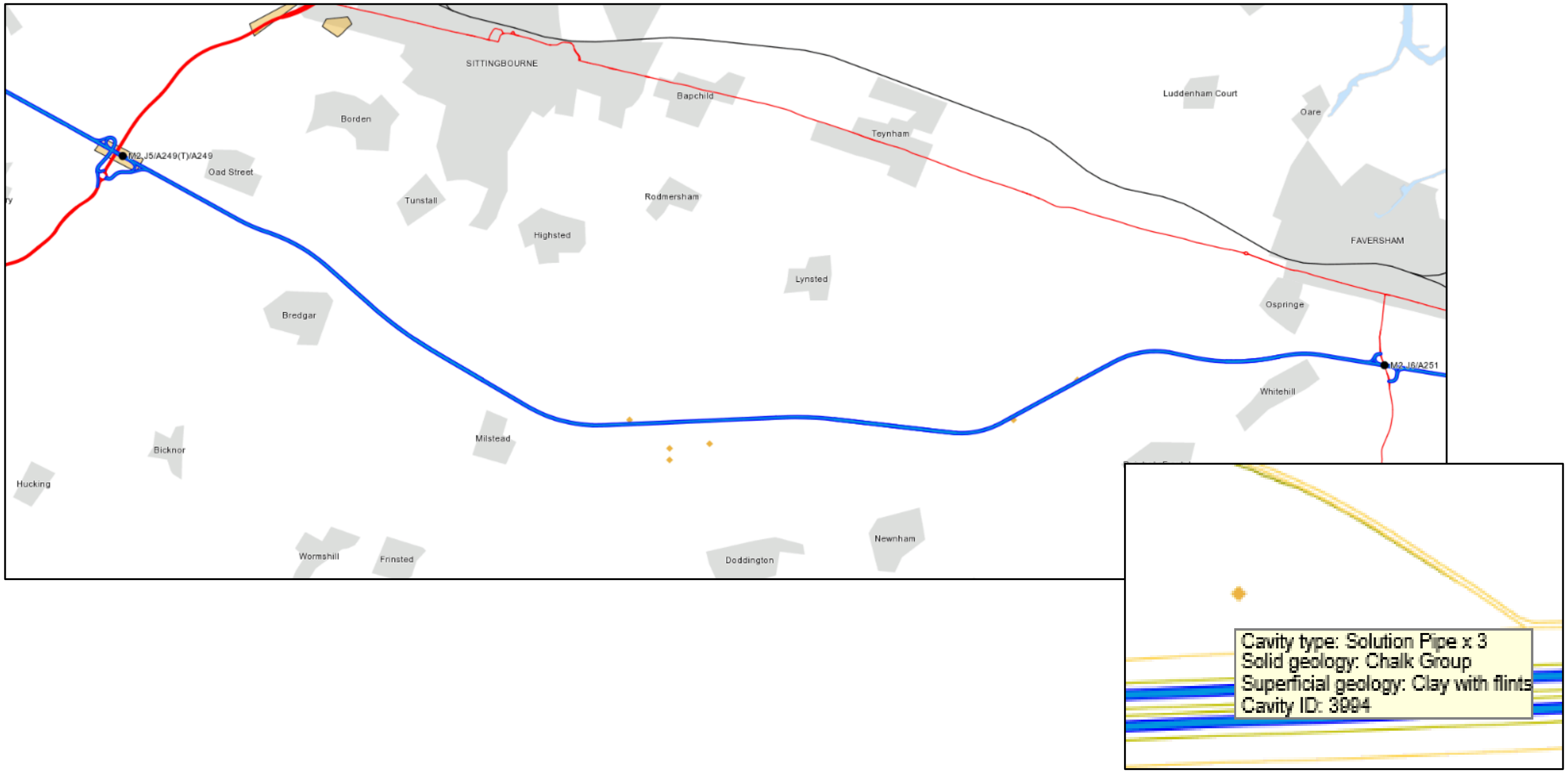
This image shows the British Geological Survey GeoSure layer for Soluble Rocks as seen on HAGDMS. The area of the event is labelled Hazard Class D i.e. "Very significant soluble rocks are present with a moderate possibility of localised natural subsidence or dissolution-related degradation of bedrock, especially in adverse conditions such as concentrated surface or subsurface flow".

3.3 Geotechnical Risk



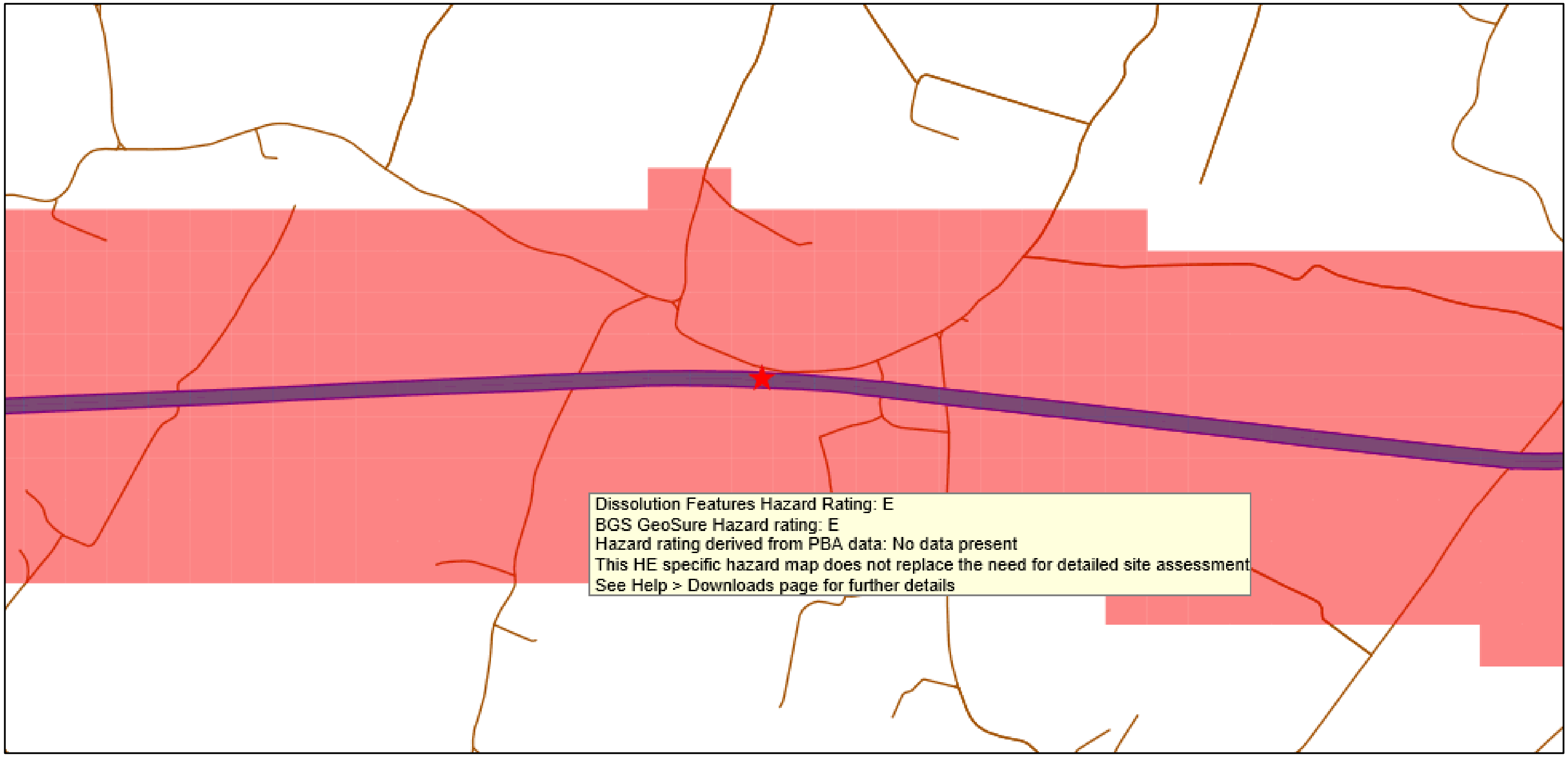
This image shows the man made mining cavities layer (Peter Brett Associates) as seen on HAGDMS. On the right are historic cavity collapses (presumed to be the same as those identified by Balfour Beatty Mott MacDonald).

3.4 Geotechnical Risk



This image shows the natural cavities layer (Peter Brett Associates) as seen on HAGDMS. On the right are historic natural cavity collapses (not exactly adjacent to the event).

3.5 Geotechnical Risk



Unsurprisingly, given the data shown on the previous two slides the Dissolution Features Hazard Rating Map gives the area the highest rating of E i.e. “Very significant soluble rocks are present with a high possibility of localised subsidence or dissolution-related degradation of bedrock occurring naturally, especially in adverse conditions such as concentrated surface or subsurface water flow.”

This is also available on HAGDMS.

highways england

4.1 Data Review

This section presents an overview of the remote survey data that can potentially be used to support Highways England in applying the use of remote sensing to improve the inspection regime and reduce primary (e.g. cavity collapse) and secondary (worker and customer exposure) On the M2 between junction 5 and 6.

This data assessment will also be used to provide an understanding of how these techniques can be applied to other geotechnical assets, and potentially other asset groups across the network, by identifying the advantages and disadvantages of each method.

For the purposes of this pilot study, four key datasets are being investigated, which include:

- Aerial imagery
- Light Detection and Ranging (LiDAR)
- Multispectral data

A more detailed description of these datasets and their properties are further detailed in the table on the following page. Further details on their application on the M2 is provided in the proceeding sections.

4.2 Data Review

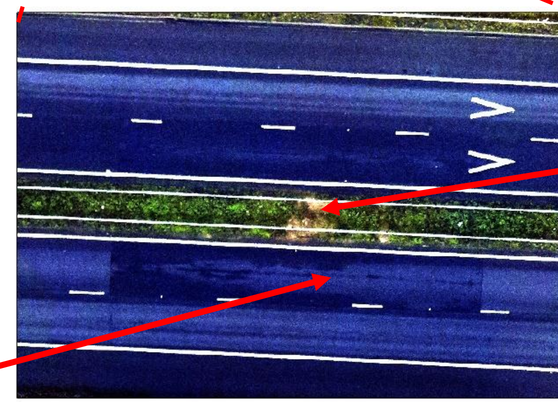
Data sources made available for this pilot study are summarised in the table below. With the exception of the multispectral data, all other datasets had previously been procured by Highways England; however, not for a specific geotechnical purpose.

Data Type	Instrument (if known)	Airborne/Terrestrial/S Pace	Spatial Resolution	Date(s) collected	Additional information
LiDAR		Terrestrial	Range	2015	Mobile Mapper/IBI Group
LiDAR		Airborne	Range	2016	Rotary Wing
Multispectral	Sentinel 2A	Space	30m	Various	European Space Agency
Aerial Imagery	Rotary Wing	Airborne	5cm	2015	

5.1 Data processing and analysis: Aerial imagery

The aerial data available is following the cavity collapse and the remedial measures carried out can be seen.

It is difficult to tell from this data if aerial imagery would be of use in identifying the signs leading up to a failure.



highways england

5.2 Data processing and analysis: LiDAR

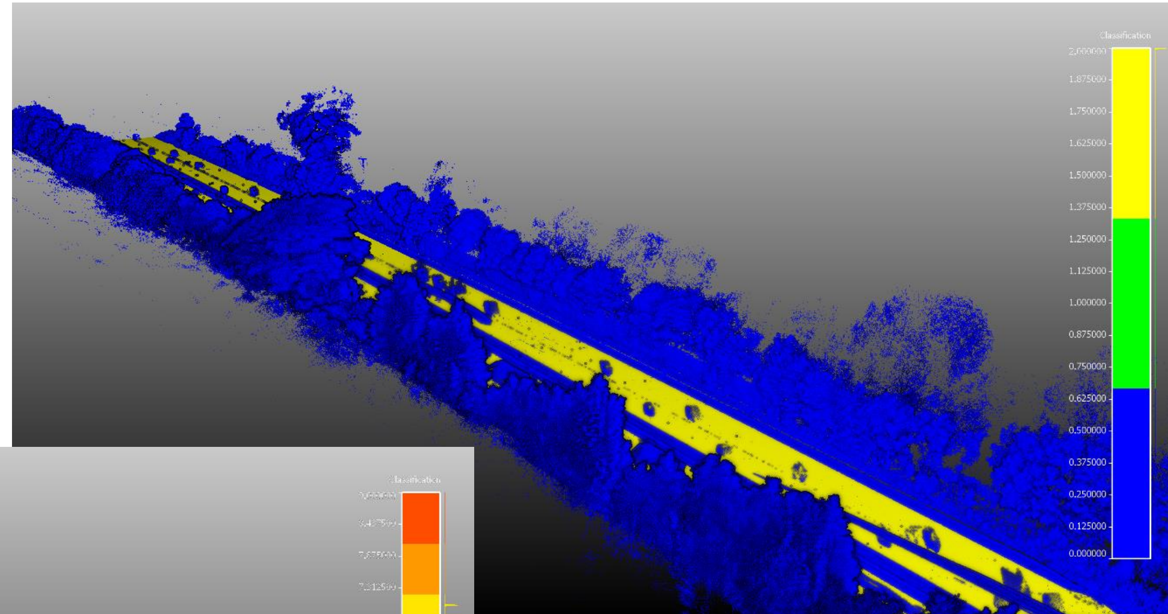
The analysis of the LiDAR data in this pilot study has considered the following aspects:

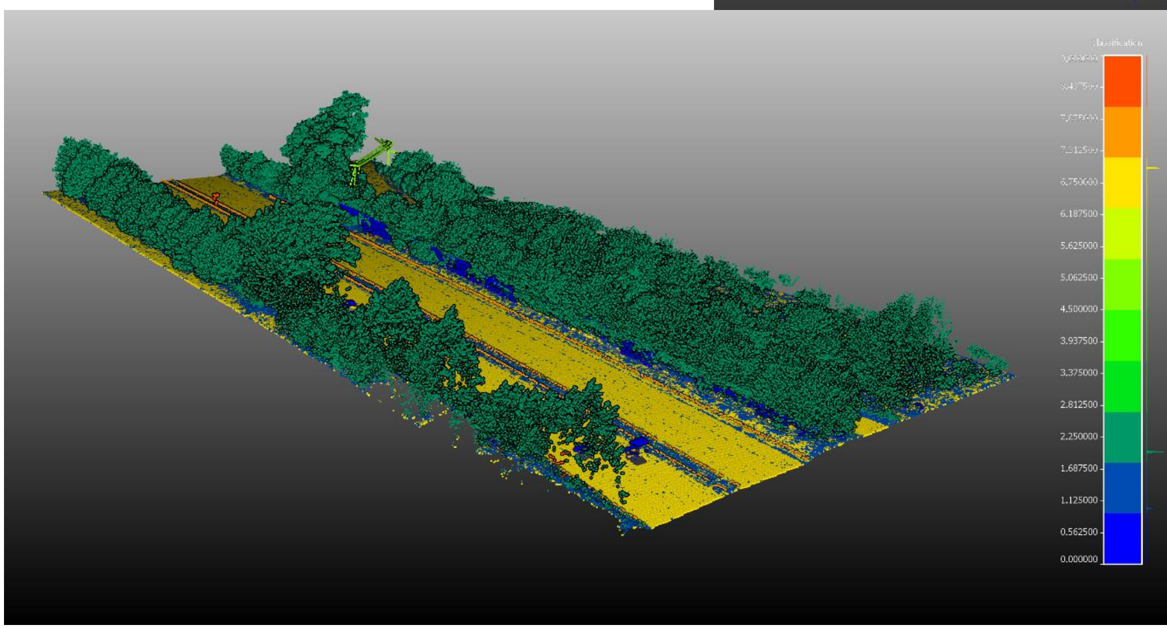
- Understanding of how LiDAR datasets are currently classified
- Understanding the data quality (with respect to geotechnical applications)
- Undertaking change detection between the different LiDAR surveys to understand potential changes in the asset morphology: specifically, being able to spot changes relating to dissolution features

Under the National ADC Surveying project mobile LiDAR has been undertaken along all the carriageways. The accuracy and point density of this LiDAR dataset are excellent for measurement and mapping but, as shown in other pilot studies, it is restricted to only the carriageway part (edge of carriageway to edge of carriageway). Rotary Wing LiDAR has the benefit of collecting LiDAR data of a 200m swathe in one pass. This can cover the highway area from 'fence to fence' and provide data for measurement and mapping.

5.3 Data processing and analysis: LiDAR

Mobile Mapping System LiDAR data is shown on the right. It has been classified as “ground“ with all other data classified as one layer. This limits the ability to look at data other than the pavement without significant additional processing.





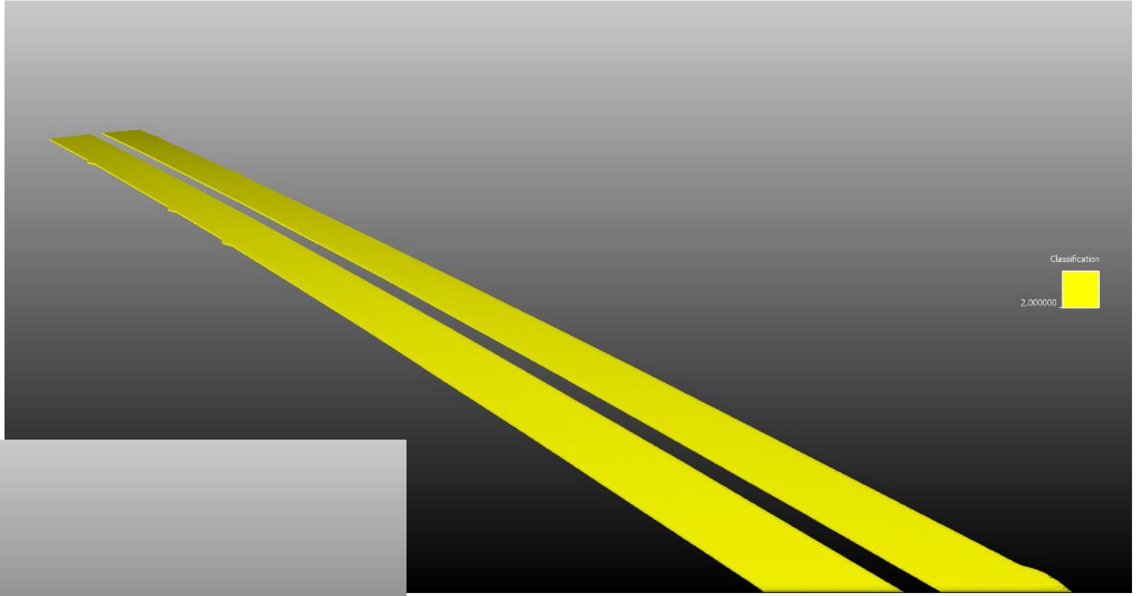
Aerial LiDAR data collected via Rotary Wing is shown on the left. The data has separate classification for ground, vegetation and other data.

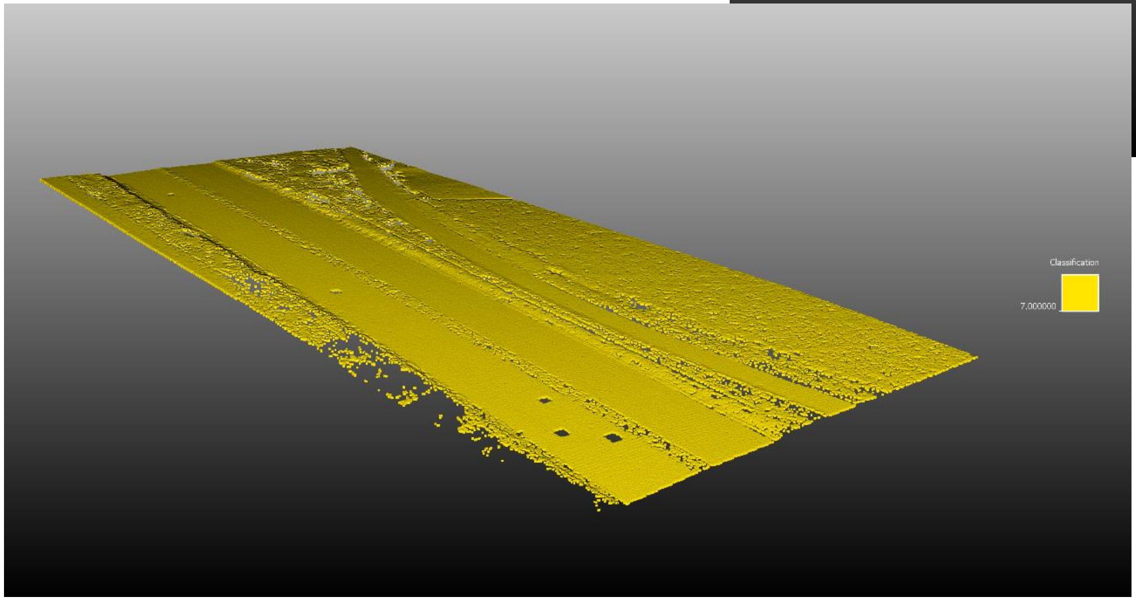
Conclusion: If Highways England is to use Mobile Mapping System LiDAR data for geotechnical applications, then a different classification would be required.

highways england

5.4 Data processing and analysis: LiDAR

Mobile Mapping System LiDAR data classified as ground is shown on the right.

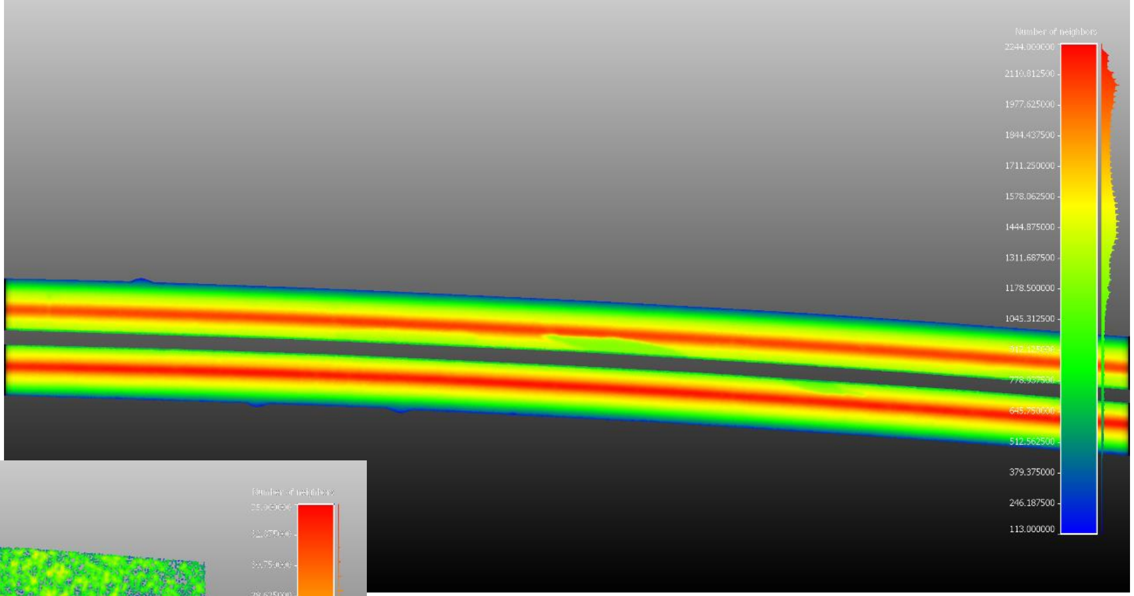


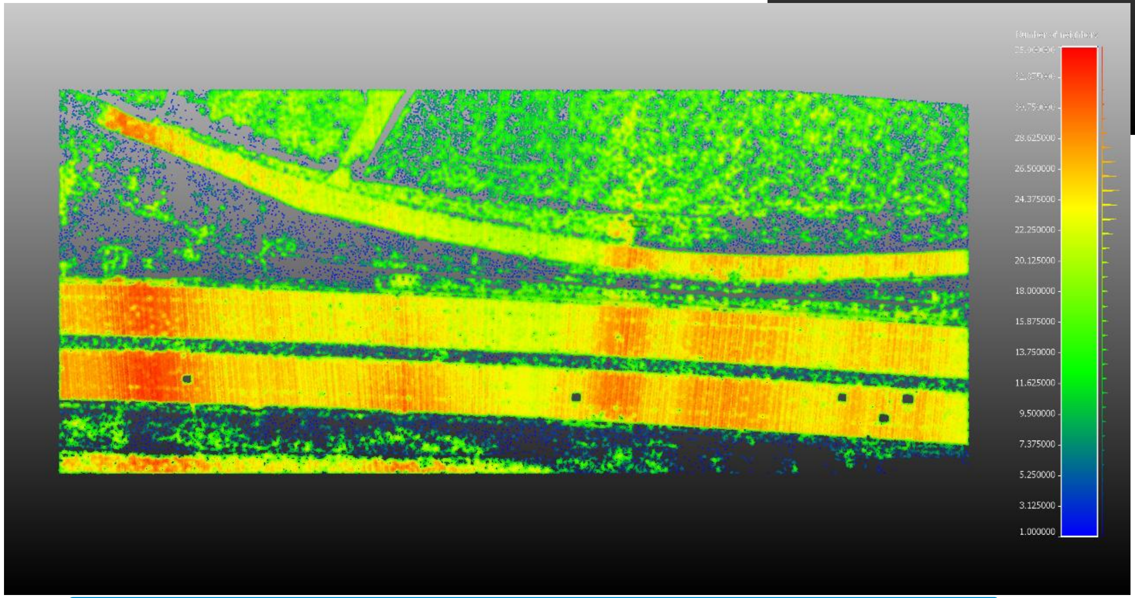


Aerial LiDAR data classified as ground is shown on the left. It can be seen that the data is much more patchy than the mobile mapper.

5.5 Data processing and analysis: LiDAR

Mobile Mapping System LiDAR data point density is represented on the right. The data shown is the number of neighbours within 1m diameter.





Aerial LiDAR data point density is represented on the left. Note that the scales are different in the images: the scale for aerial is a maximum of 35 whereas for the Mobile Mapping System it is a maximum of 2244.

Conclusion: Mobile Mapping System data has a much higher point density and therefore more details can be obtained from the data.

5.6 Data processing and analysis: LiDAR

Change detection was carried out between the LiDAR datasets. This compared the Mobile Mapping System data and the Aerial data. These were captured in 2015 and 2016, i.e. after the remedial works were carried out for the cavity that opened up on the central reservation. The image below shows the vertical height difference between the datasets. The location is marked by a red dashed line. No trend in the data is discernible. In order to use remote sensing for change detection the frequency of the data needs to be greater, and ideally the data needs to be from the same source in order to ensure accuracy.

Conclusion: More frequent data collection is required if change detection is to be carried out. The data should be from the same source in order to ensure accuracy.

5.7 Data processing and analysis: Multispectral imagery

Multispectral imagery was sourced from the European Space Agency's Sentinel 2A platform. This data is made freely available and was sourced from the UK Satellite Applications Catapult's SEDAS (Sentinel Data Access Service) portal.

For this study site, 21 Sentinel 2 images were available for the period 04/10/2016 to 01/06/2017. An image, dating from the 1st June 2017 was used for understanding the data's potential use.

The application of Sentinel 2 imagery in the UK can be problematic. This results from the often high percentage of cloud cover which inhibits the users ability to accurately assess conditions on the ground as you are unable to remove dense cloud. This differs from Sentinel 1 radar data (see M11 case study) which is able to pass through cloud.

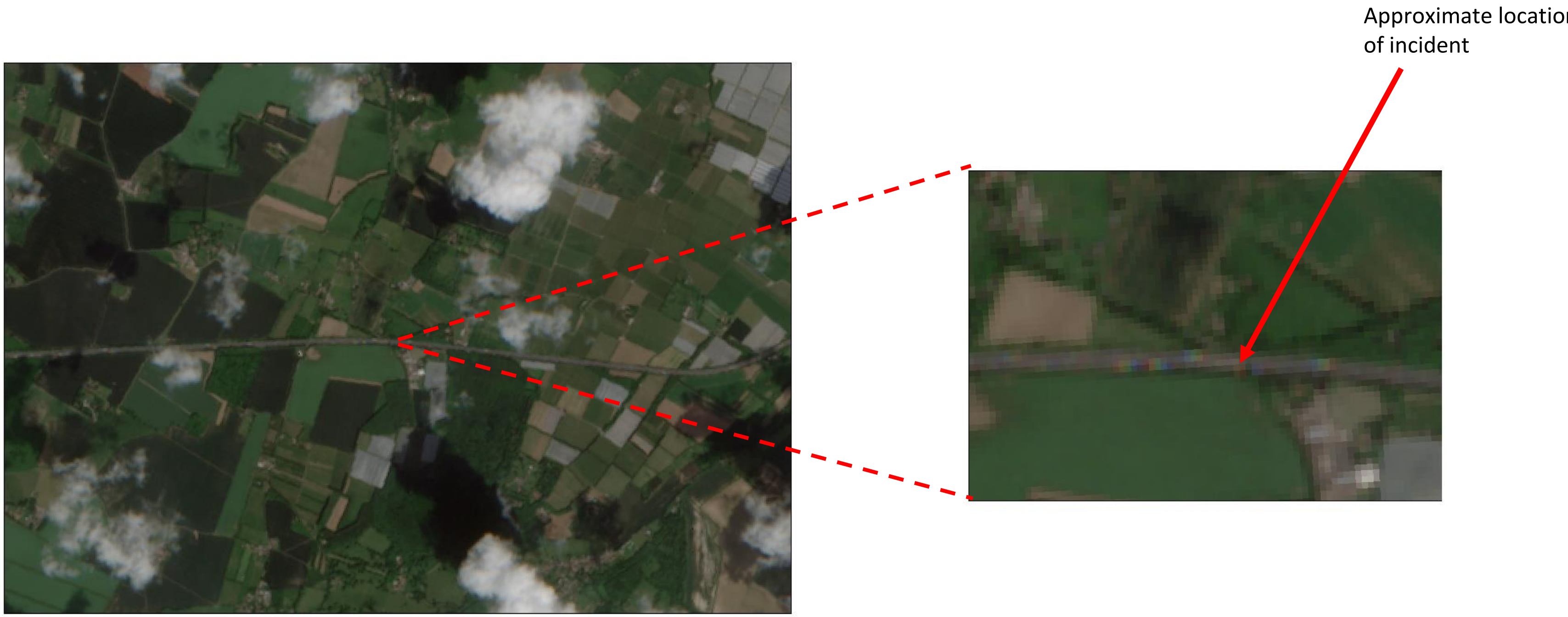
Sentinel 2 imagery is provided in a 10m spatial resolution (see image on following page). The imagery was analysed for its potential application for understanding further the condition of the geotechnical asset at Stokenchurch gap. The imagery can be presented in a number of ways, depending on the band combination used (see table to right). For the purposes of this initial analysis, only 'Natural Colour' has been represented.

Band Type	Combinations
Natural Colour	4 3 2
False Colour (Urban)	7 6 4
Color infrared (vegetation)	5 4 3
Healthy vegetation	5 6 2
Vegetation analysis	6 5 4

Conclusion: The spatial resolution of Sentinel 2 imagery is too coarse for the asset management of geotechnical assets. It is more appropriate for understanding regional changes. It is also highly limited by cloud cover and shadowing effects.

Sentinel 2 image acquired: GS2A_MSIL1C_20170601T110651_N0205, 01/06/2017, Cloud Cover 11%

5.8 Data processing and analysis: Multispectral imagery



As an example, the images below represent Natural Colour (Spectral Bands 4,3,2) of the area between M2 Junctions 5-6.

The right image shows a zoomed in view of the location of the February 2014 incident (arrowed).

Cloud cover for this image, whose overall extent was much greater than that represented, was 11%.

Sentinel 2 image acquired: GS2A_MSIL1C_20170601T110651_N0205, 01/06/2017, Cloud Cover 11%

6. Conclusions and Recommendations

The pilot found:

- Aerial Imagery is useful when interpreting other datasets
- Mobile Mapping System LiDAR has superior point cloud density to Aerial LiDAR
- For change detection to be carried out it needs to align in time with the known geotechnical issue
- Available multispectral data is too coarse for small scale geotechnical issues such as a cavity collapse.

The recommendations from this study are:

- Highways England should change the specification for Mobile Mapping System LiDAR to one in which at least pavement, bare ground, vegetation (high, medium and low vegetation) and structures are classified separately. Other additional classifications could include signage, vehicles, and buildings.

- Other surveys that Highways England carry out including TRACS and ground penetrating radar should be investigated with respect to detecting dissolution features. They could compliment the methods used in this pilot study. However, it should be noted that change detection with respect to dissolution features is difficult due rate of movements involved and, at times, the little warning that is associated with it.

- If Highways England are to use LiDAR data for change detection associated with condition monitoring, the data capture frequency should be increased. Mobile Mapping System appears to be a useful tool for this application and it is recommended that this is taken forward as the primary tool for change detection. A further pilot study should be carried out that compares Mobile Mapping System LiDAR data from two separate time points on an area that is known to have deteriorated. The initial study should be focussed on an area of more gradual ground movement than that associated with cavity collapse.

Use of AVIS for geotechnical applications

Phase 2 Pilot Study

SPaTS 1-086 Application of remote survey data for Geotechnical asset condition and performance

1. Introduction

This document represents one of a series of pilot studies undertaken for SPaTS Task 1-086 '*Application of remote survey data for geotechnical asset condition and performance*'.

These studies present an evaluation of the use of remote survey data, utilising data currently procured by Highways England as well as emerging datasets that may be of additional benefit to the organisation in the management of their geotechnical assets.

This specific study focuses on the use of the Asset Visualisation Information System (AVIS) tool to improve the knowledge of condition of Highways England's geotechnical assets. AVIS is currently utilised as a network asset inventory tool and remote survey data are not used for geotechnical applications.

The system has been reviewed to ascertain if it can be used to support geotechnical inspections as per Annex C of HD41/15.

This document is structured as follows:

Click on the 'Home' button to get back to this slide

2. Background on AVIS

Highways England's Asset Visualisation System (AVIS) is a national-level repository for Highways England's visual data and databased information about their assets.

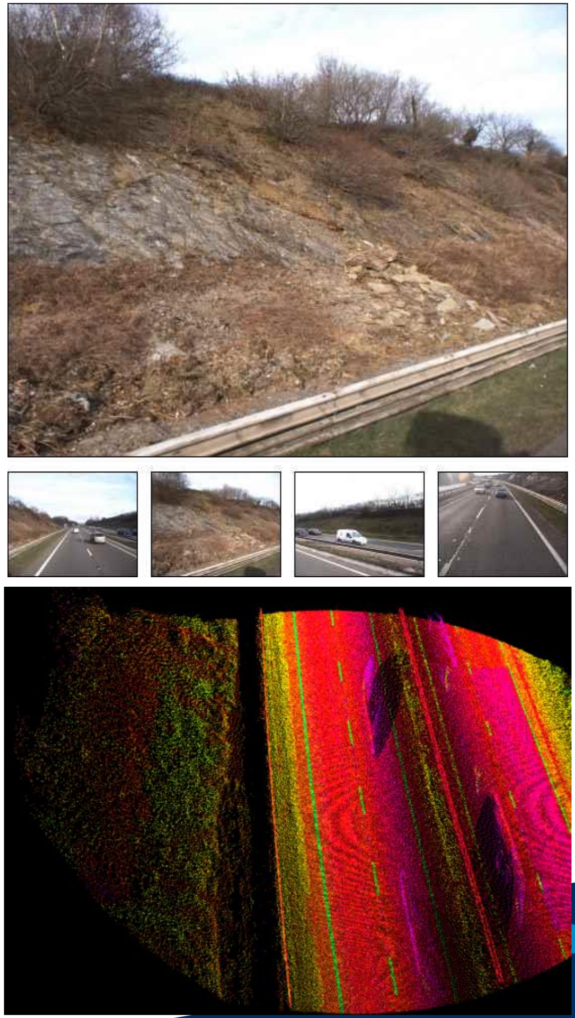
The AVIS system contains Mobile Mapping System imagery and LiDAR remote sensing data.

AVIS is currently utilised as a network asset inventory tool (primarily for highway furniture) and remote survey data are not used for geotechnical applications.

The system has been reviewed to ascertain if it can be used to undertake 'remote inspections' of geotechnical assets with the aim to:

- Complement and – potentially – reduce frequency of physical inspections;
- Identify defects that have yet to be discovered; and
- Optimise routine inspection schedule.

The pilot was carried out on version 1 of AVIS.



Ravelling of Rock Cutting on A38 Area 01, 1100A38/147, 0 km, 430.53 m, 258503.05, 55573.34.

3.1 'Remote inspections' as per HD41/15

Geotechnical assets have a long service life but have a loss of serviceability slowly over time. As assets deteriorate over time, they may develop physical characteristics that indicate a reduction in performance. For example, the development of tension cracks at the crest of a soil slope or subsidence.

Asset functionality is assessed by identifying variations in physical characteristics between repeat inspections, in particular, those characteristics that highlight deterioration in performance.

Asset inspections are performed in accordance with Highways England's Design Manual for Roads and Bridges, Vol. 4, Sect. 1, Part 3, HD 41/15: Maintenance of Highway Geotechnical Assets.

Annex C Sect.	Section Name	Recorded Information
C-1	Implementation	Description of how Annex C is to be implemented
C-2	Inspection Information	General inspection details including, inspection type, inspector, survey equipment used.
C-3	Geotechnical asset information	Inspection location, earthwork type and construction date, geology, earthwork geometry.
C-4	Observation information	Detailed observations related to vegetation, water features, direct and indirect earthwork features, reinforcement, drainage.
C-5	Geotechnical event information	Detailed observation after a geotechnical event has occurred.
C-6	Scheme information	Project reference number, contactor, client details, associated costs.

Structure of Geotechnical Asset Inspection Form (HD41/15 Annex C).

3.2 'Remote inspections' as per HD41/15

HD41/15 Annex C has the information requirements that must be captured in inspections. Therefore to assess the capability of AVIS as a tool for remote inspections it must be checked against the list contained in the annex.

Using Mobile Mapping System imagery and LiDAR point clouds the capability of AVIS was assessed for three asset types:

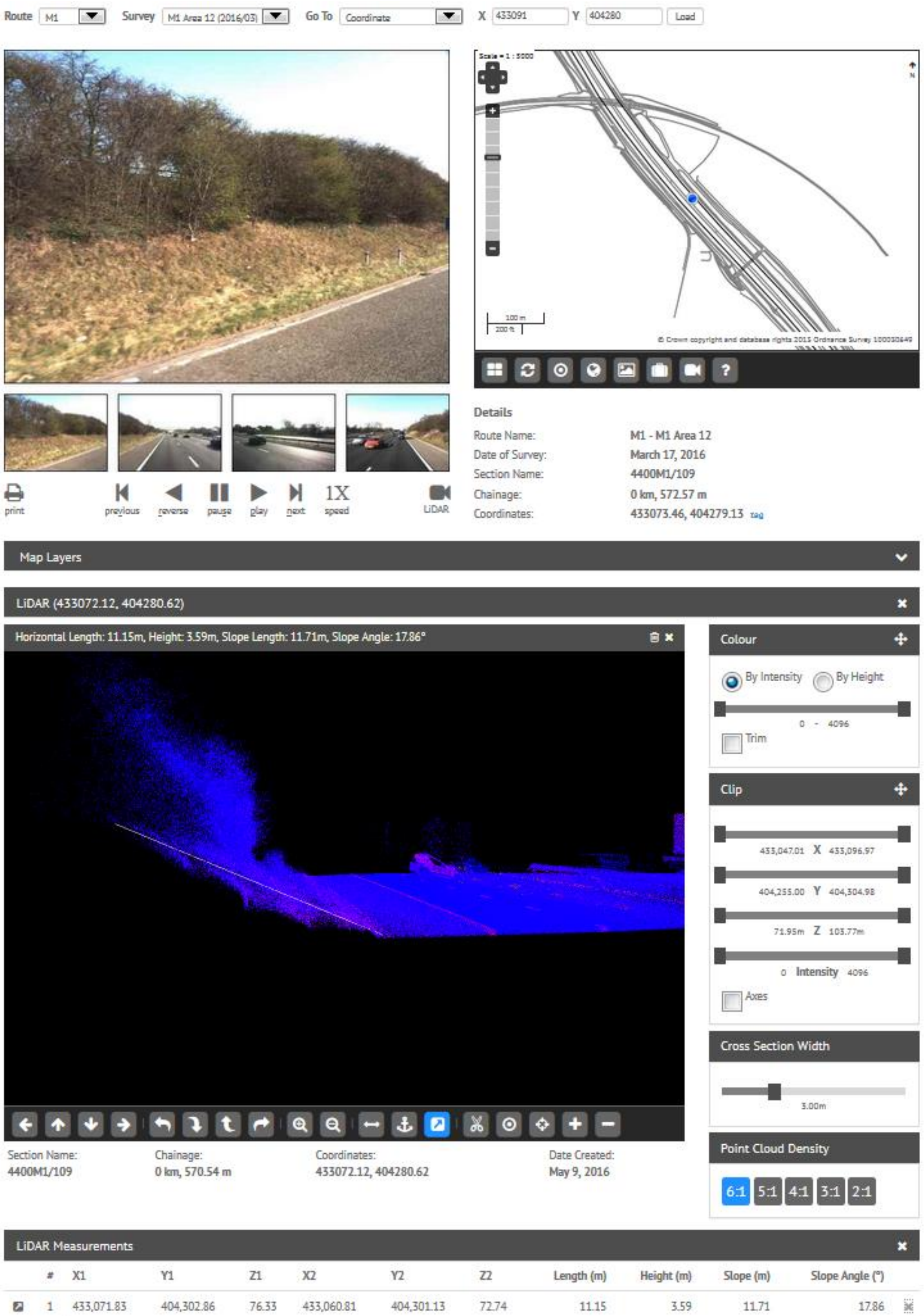
(1) a rock cutting,
(2) a soil cutting,
(3) an embankment.

Survey data from AVIS Viewer was analysed from a range of highway sites (see Photographic Log Summary). Where features were not observed, expert judgement was used to assess if likely to be visible.

Review results are shown in slides 3.3 to 3.17 (annotated HD41/15 Annex C) and 3.3 (Photographic Log).

Plate No.	Highway	Subject of Photograph (Geotechnical Inspection Field)
1	M1	Example of AVIS User Interface. Showing imagery (upper screen) and LiDAR (lower screen) and geometry measurement tool.
2	M1	Geological variation evident in cut slope
3	A1	Remediated rock slope using pattern rock bolting and double twist mesh.
4	M1	High quality image of Mobile Mapping System image of highway slope and retaining structure
5	A1(M)	Highway boundary fence
6	M1	Seepage and erosion of cut slope
7	M1	Concrete retaining wall
8	M1	Leaning trees overhanging hard shoulder
9	A45	Small shallow landslide within cut slope.
10	M1	Top of slope retaining wall and safety barrier
11	M1	Marshy ground and seepage
12	M40	Stokenchurch Rockslope and rockfall netting.
13	A38	Ravelling rock slope and debris.

Summary of Section 3.3 Photographic Log



3.3 Use of AVIS for ‘remote inspections’

Photographic Log

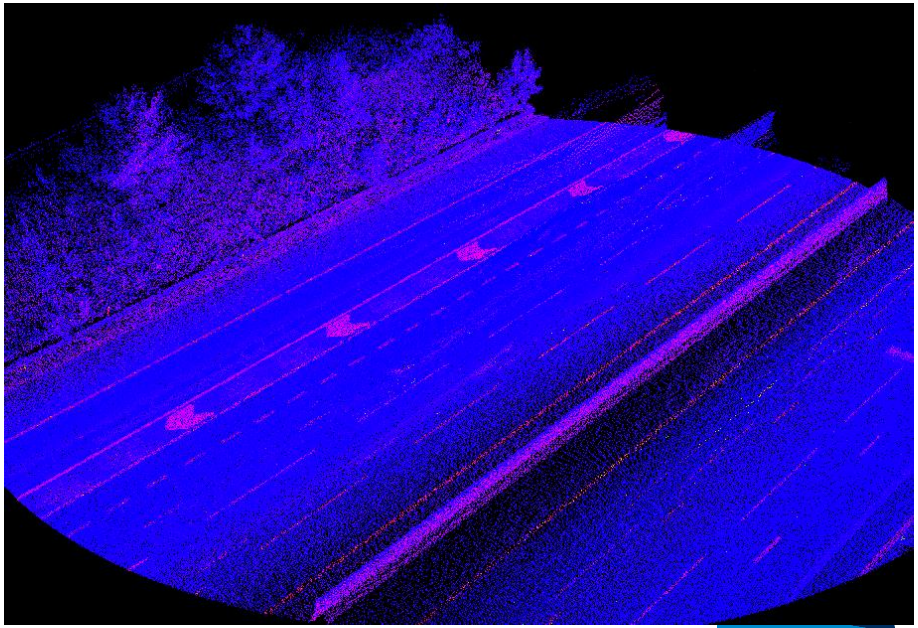
Plate 1. Example of AVIS User Interface. Showing imagery (upper screen) and LiDAR (Lower screen) and geometry measurement tool.

highways england

3.4 Use of AVIS for ‘remote inspections’

Photographic Log

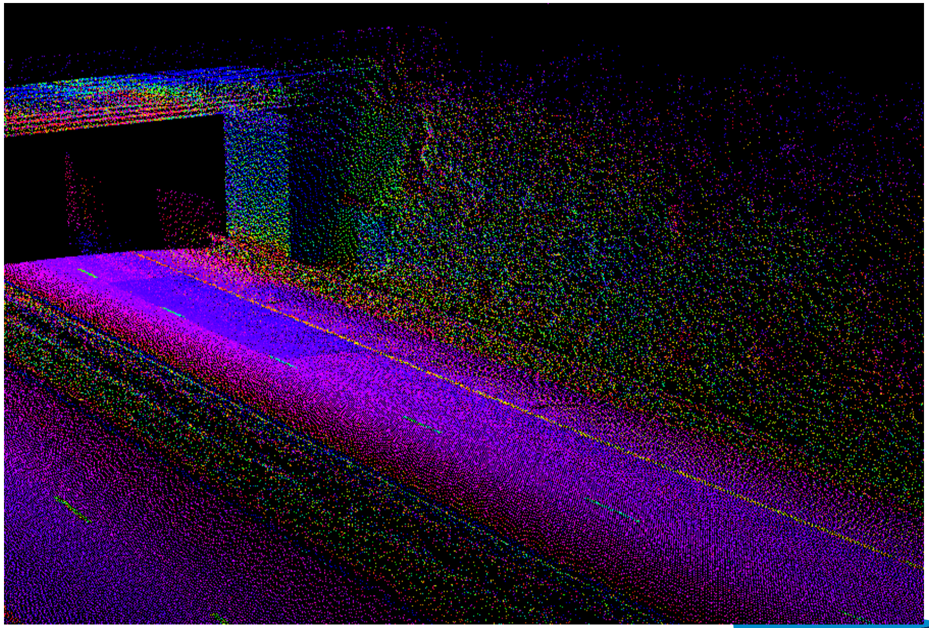
Plate 2. Geological variation evident in cut slope along M1.
M1 Area 12, March 17, 2016, 4400M1/192, 1 km, 672.15 m, 438841.41, 392538.35



3.5 Use of AVIS for ‘remote inspections’

Photographic Log

Plate 3. Remediated rock slope using pattern rock bolting and double twist mesh.
A1 Area 14, 1300A1M/332, 0 km, 988.25 m, 432301.48, 533789.36.



3.6 Use of AVIS for 'remote inspections'

Photographic Log

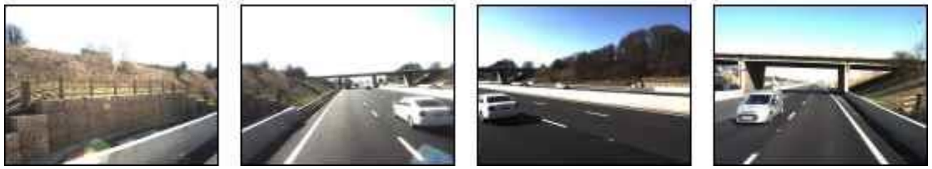
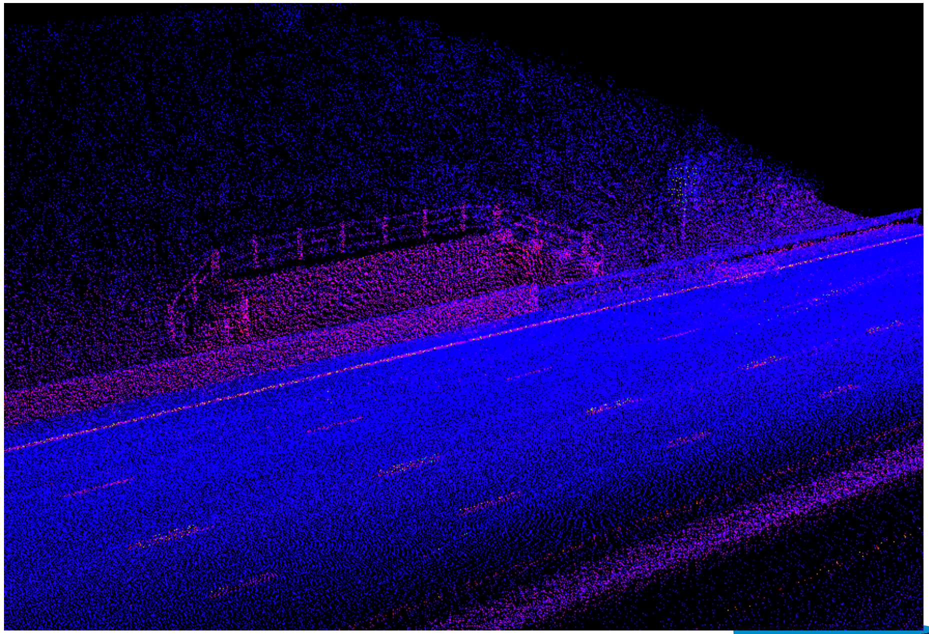


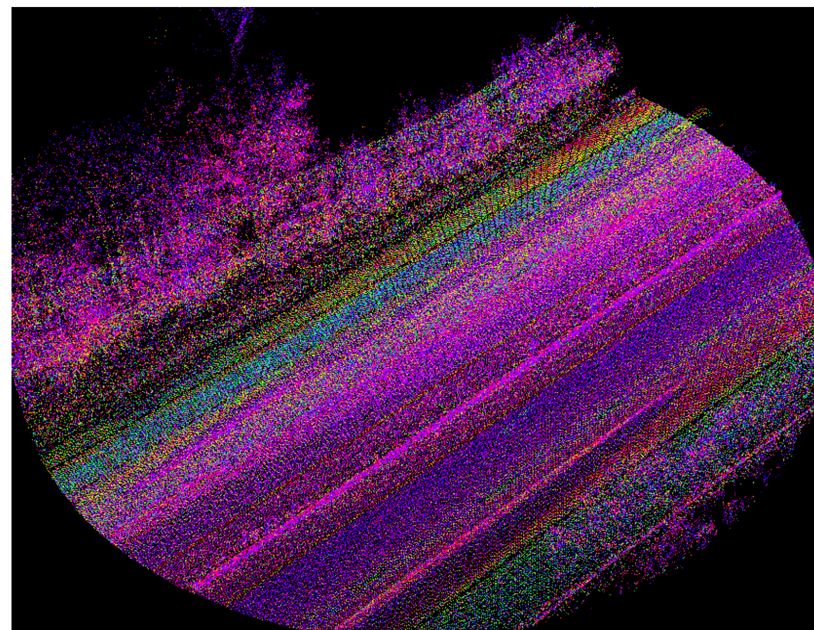
Plate 4. High quality image of Mobile Mapping System images of highway slope and retaining structure along the M1.
M1 - M1 Area 12, March 17, 2016, 4700M1/136, 0 km, 609.64 m, 430797.05, 424451.11



3.7 Use of AVIS for ‘remote inspections’

Photographic Log

Plate 5. Highway boundary fence along the A1(M).
A1M - A1M Area 08, March 28, 2014, 1900A1M/63, 0 km, 756.32 m,
523811.12, 217217.1

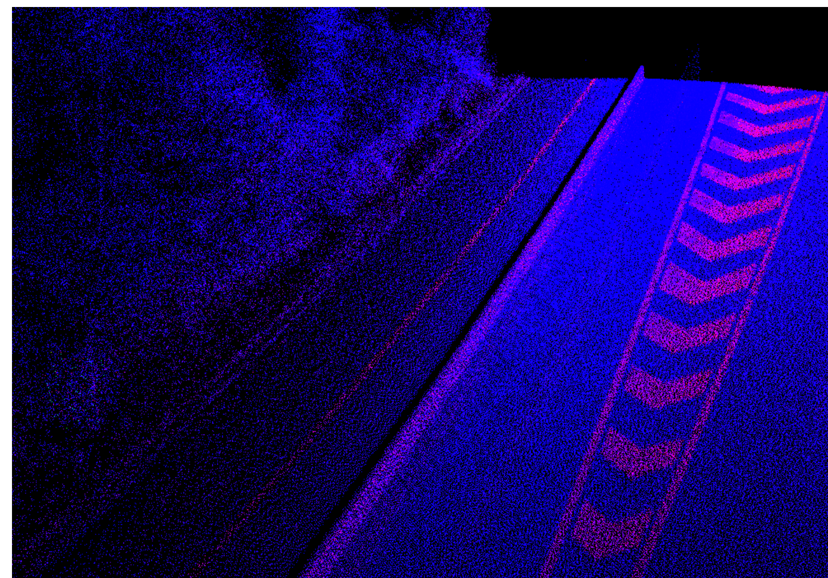


highways
england

3.8 Use of AVIS for 'remote inspections'

Photographic Log

Plate 6. Seepage and erosion of cut slope along M1 (near Junction 34, Meadowhall)
M1 - M1 Area 12, March 17, 2016, 4400M1/154, 0 km, 100.73 m, 438997.24, 392213.91

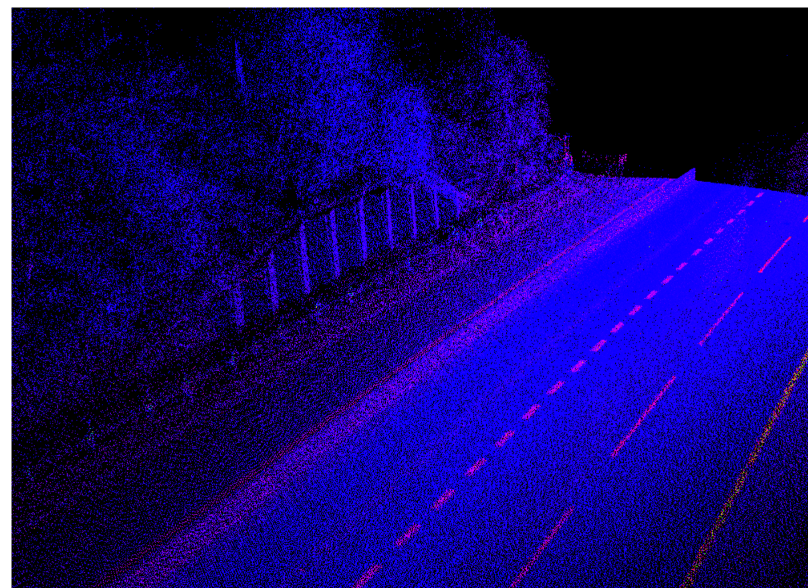


highways england

3.9 Use of AVIS for ‘remote inspections’

Photographic Log

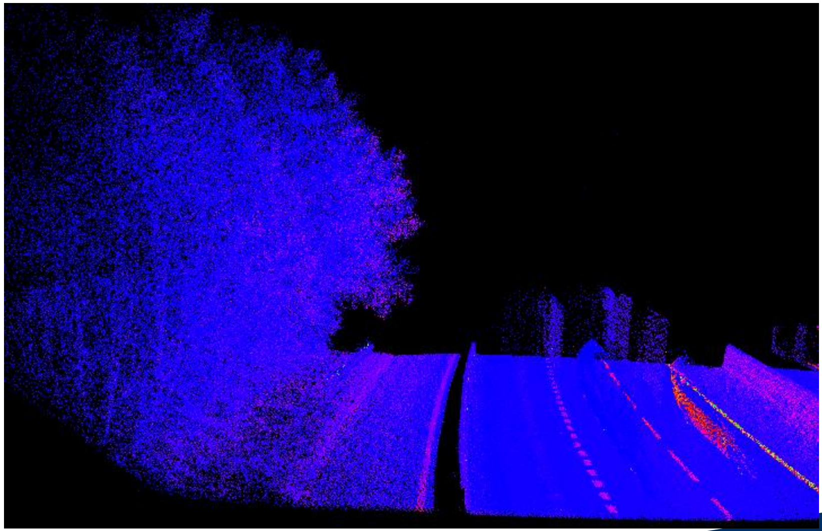
Plate 7. Concrete retaining wall along M1 (near Junction 34, Meadowhall)
M1 - M1 Area 12, March 17, 2016, 4400M1/154, 0 km, 100.73 m, 438997.24, 392213.91



3.10 Use of AVIS for ‘remote inspections’

Photographic Log

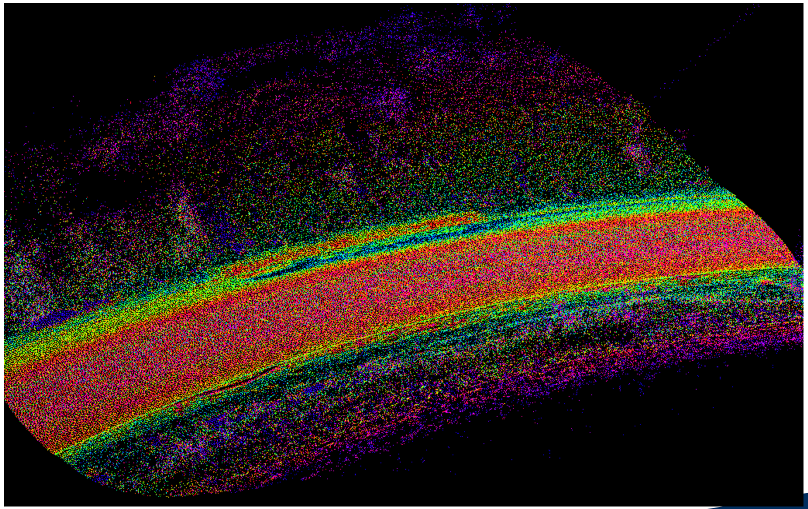
Plate 8. Leaning trees overhanging hard shoulder along M1.
M1 - M1 Area 12, March 17, 2016, 4400M1/192, 1 km, 672.15 m, 438841.41, 392538.35



3.11 Use of AVIS for 'remote inspections'

Photographic Log

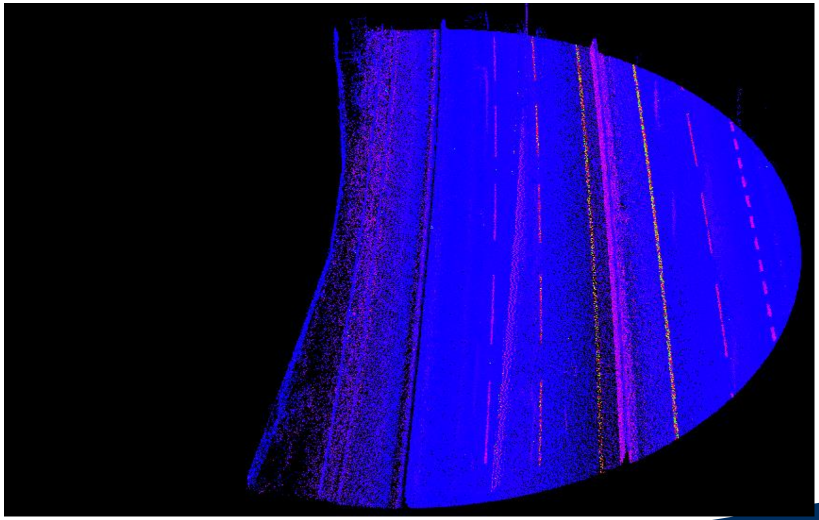
Plate 9. Small shallow landslide within cut slope.
A45 Area 07, 2800A45/487, 0 km, 113.05 m, 486685.29, 264021.65



3.12 Use of AVIS for 'remote inspections'

Photographic Log

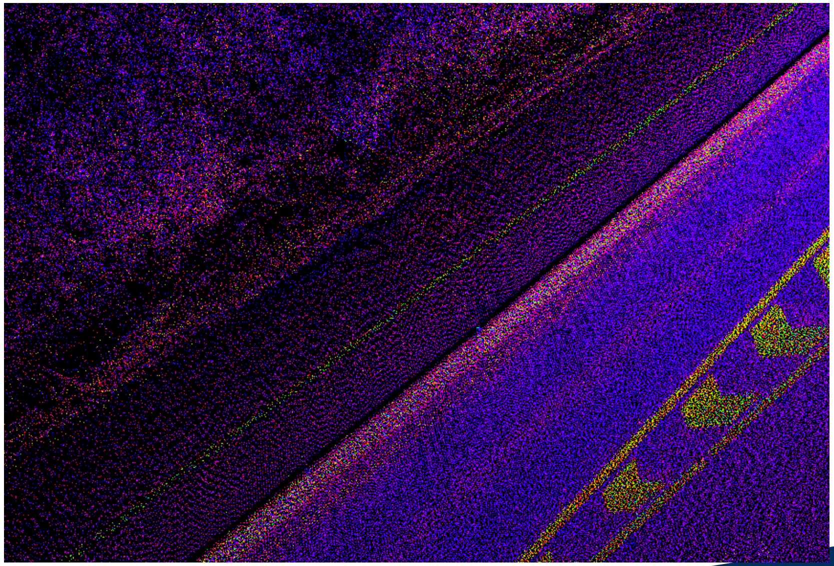
Plate 10. Top of slope retaining wall and safety barrier along M1.
M1 - M1 Area 12, March 17, 2016, 4400M1/291, 0 km, 297.21 m, 438696.36, 392712.56



3.13 Use of AVIS for 'remote inspections'

Photographic Log

Plate 11. Marshy ground and seepage present along M1.
M1 - M1 Area 12, March 17, 2016, 4400M1/154, 0 km, 86.69 m, 438989.64, 392225.74



3.14 Use of AVIS for ‘remote inspections’

Photographic Log

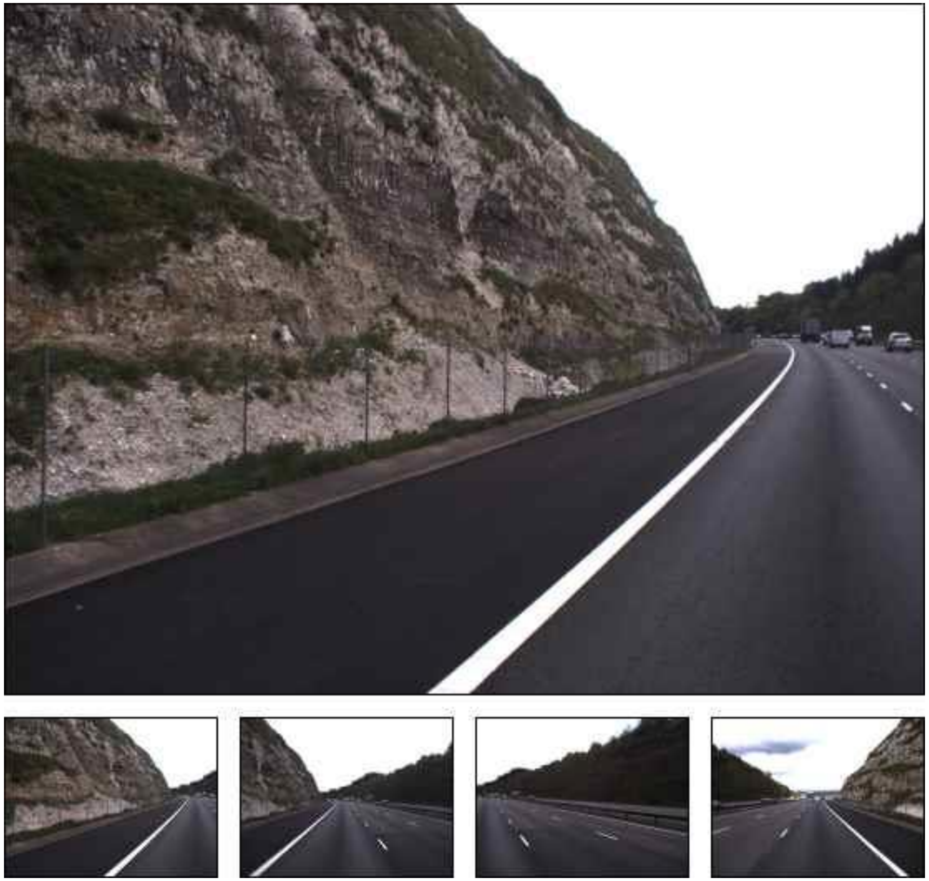
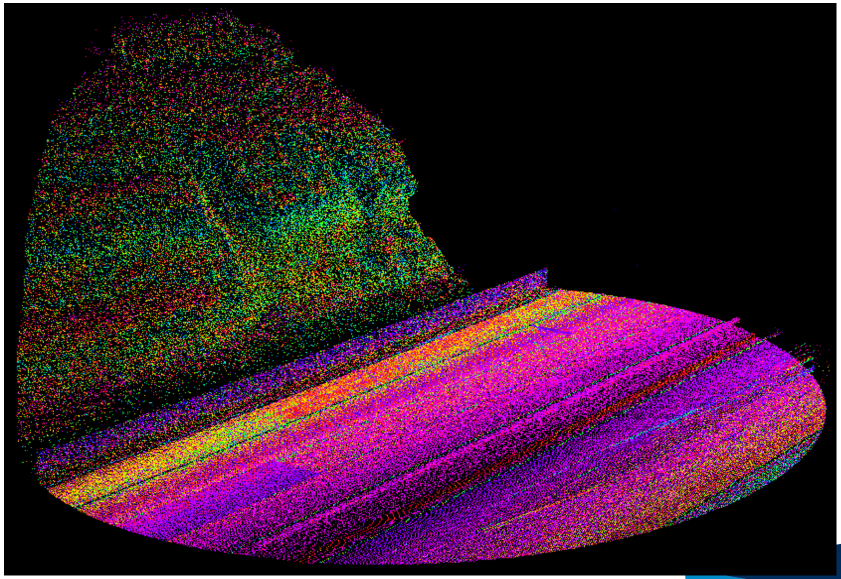


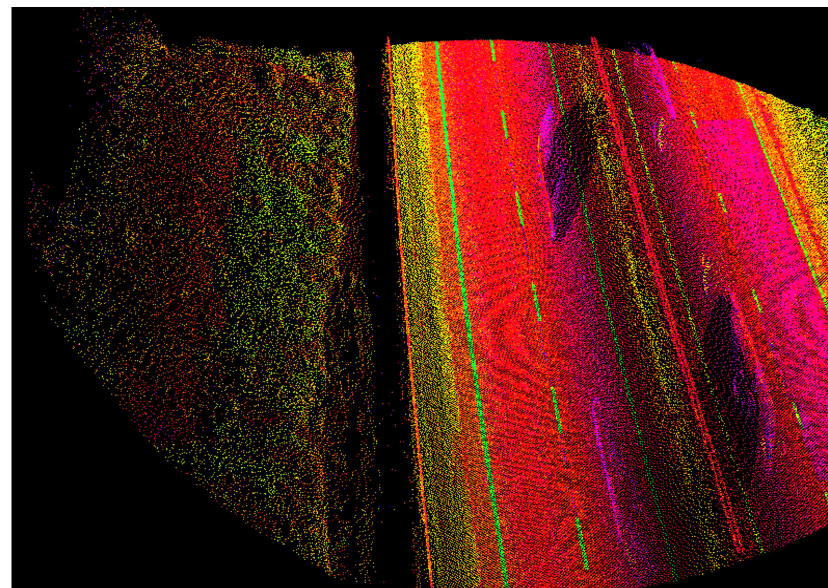
Plate 12. Stokenchurch Rockslope and rockfall netting.
M40 DBFO 2014, 3100M40/586, 0 km, 963.73 m, 473230.35, 196476.72



3.15 Use of AVIS for ‘remote inspections’

Photographic Log

Plate 13. Ravelling rock slope and debris.
A38 Area 01, 1100A38/147, 0 km, 430.53 m, 258503.05, 55573.34.



3.16 Conclusions - capabilities

A Pilot Study was performed to identify whether AVIS could be implemented as a tool to pre-populate geotechnical asset inspection forms (HD41/15: Annex C).

The following capabilities were identified:

1) Generally, AVIS can provide asset information relating to location, vegetation, direct and indirect features, drainage and reinforcement structures.

2) Water features such as marshy ground, ponding, erosion and hydrophilic vegetation *may* be observed.
   - Water seeping out of a slope is unlikely to be directly visible but may be visible if wet rock/soil material appears darker below the seepage than surrounding dry material.

3) AVIS is capable of recording information for many of C-2, C-3 and C-4 Sections. However this is dependent on the size of the feature of interest.

4) Direct and Indirect features (C-4) of asset instability include slips, slope bulges, distorted trees and terracing are visible at soil and rock cuttings, reinforcement structures, such as, geogrid, gabions and rock bolts *as long at they are surface visible features*.

5) In its current state, AVIS permits general observations about geotechnical assets. However, if detailed observations are to be made with high confidence the system requires additional and improved datasets.

3.17 Conclusions - limitations

The following limitations were identified:

1) Inspection fields pertaining to embankments are rarely visible due to the data acquisition system being line of sight.
   - Earthwork-Inventory (C-3) information, including slope angle and slope length and height cannot be ascertained, nor can Observation-Condition (C-4) information pertaining to vegetation, drainage, reinforcement, water features, direct (e.g. slip, slope bulge) and indirect (e.g. cracked pavement, toe debris) features, unless located at the embankment top, adjacent to the carriageway.
2) AVIS is unable to record information relating to Section C-3 *Earthwork-Inventory* as most of the fields require input from an external source, i.e. from BGS Geological Mapping.
3) Image quality of the Mobile Mapping System imagery is such that relatively large features (e.g. scree slopes) are visible. However, smaller features, such as individual blocks within the scree slope cannot be distinguished.
   - Similarly, at reinforced slopes, geotextile and soil nails are visible, however, the steel mesh (e.g. double-twist) between soil nails is not visible.
   - A geotechnical inspection using AVIS Viewer would require that the datasets be of sufficient uniformity, that the subtle, temporal evolution of the feature be evident.
   - Image quality of other, freely available, mobile imagery (e.g. Google StreetView) is better.
3) Many Mobile Mapping System images are either (1) shrouded in shadows or (2) over-exposed due to direct sunlight, thus, both scenarios create unusable images.
4) LiDAR point clouds can take up to twenty seconds to load.
   - Therefore, when assessing a long asset, considerable time would be spent waiting to visualise data.
5) Asset Query database inconsistencies, including: noise barriers and boundary fences described as retaining walls, and; gabion walls described as both concrete retaining walls and stone retaining walls.
   - It is not clear which carriageway highway structures are described within the Map Layer database.
   - Where repeat surveys are present within AVIS, for example the M1 Area 12 was surveyed in 2013 and 2016, there appears to be a lack of consistency in the descriptions of Asset Query database parameters between surveys.

3.18 Recommendations

The following recommendations are made to improve capability of the AVIS System for geotechnical applications:

- Standardise notation and expansion of Map Query inputted data;
- Imagery and LiDAR point cloud placed side-by-side.
- LiDAR data displayed as digital surface model (DSM).
- Mobile Mapping System camera surveys should be performed in more optimal conditions to reduce over-, or under-exposure of photographs.

Additional remote sensing methods are recommended to aid ‘remote inspections’ as per HD41/15.

It would be useful to be able to consult other remote sensing datasets in AVIS, these are:

1) High-resolution vertical aerial imagery and rotary-wing LiDAR dataset;
2) Airborne thermal-infrared (TIR) imaging or hyperspectral imaging.

Point (1) will improve the capacity to characterise embankments.
Point (2) will improve locating of seepage and high moisture content within earthworks.

4.1 Use of AVIS for SGMs

Some sections of the geotechnical asset have been designed and constructed using techniques that can help achieve a steeper angle, provide mitigation to geotechnical hazard or enable remediation of defects.

These techniques have been collectively termed as Special Geotechnical Measures (SGMs).

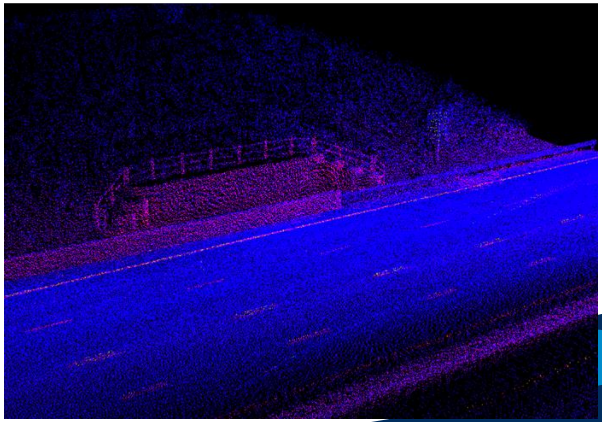
The ability to confirm existence, location - and potentially – condition of Highways England's SGMs using AVIS was assessed.

This pilot study makes use of geotechnical assets from across the highway network but focusses in detail on the M1 near Sheffield, South Yorkshire.

This section of the network was selected because :

(1) It presents a wide range of geotechnical assets and,

(2) It is currently being upgraded as part of widening and Smart Motorway Programmes (SMPs). Therefore, earthworks can be inspected at different stages of their lifecycles.



4.2 SGMs Recorded observations

A list of observations recording location of SGMs was provided by Atkins for the M1 Jct. 34 to 35, which was selected as study area for this Pilot Study. These observations were collated as part of Task 594 - Strengthened Earthworks. Each earthwork observation within the list adjacent was investigated within AVIS and any relevant observations recorded.

As shown in the table below, SGMs within the study area have been classified as Filter Drains (FILT) and Non Specified Retaining Walls (NSRW). The purpose of this pilot was to compare the observations here to information available in AVIS.

Observations recording location of SGMs within M1 J34 – 35 study area (Source: HA GDMS and Task 594 Strengthened Earthworks)

Earthwork ID	Observation ID	Road	Earthwork Type	Observation Start Easting	Observation Start Northing	Observation End Easting	Observation End Northing	Observation Description	SGMs
34372	488122	M1	Cutting	433091	404280	433091	404280	minor crack in over steepened cutting	FILT
34372	239222	M1	Cutting	433130	404217	433379	403953	Drainage	FILT
34372	239219	M1	Cutting	433026	404346	433049	404320	2m high retaining wall.	NSRW
42407	276918	M1	Cutting	432540	405165	432204	405836	vegetation	FILT
43931	285678	M1	Embankment	437803	393507	437803	393507	vertical gulley p991/2 - coudl be a vertical french drain possible seepage -moss/reeds p993	FILT
43931	285667	M1	Embankment	438750	392639	438429	392953	retaining wall p976/7	NSRW
43931	285668	M1	Embankment	438690	392708	438690	392708	geometry retaining wall approx 8m high	NSRW
43931	285669	M1	Embankment	438601	392799	438601	392799	geometry retaining wall 5m high	NSRW
43931	285670	M1	Embankment	438530	392863	438530	392863	geometry retaining wall 2m high	NSRW
44801	290393	M1	Cutting	438836	392566	439217	391973	vegetation	FILT
44801	290400	M1	Cutting	439009	392222	439009	392222	Seepage observed from lower bench - geometry given is for overall slope - hydrovegetation present and erosion of slope caused by seepage - landfill adjacent p204-207	FILT
44801	290401	M1	Cutting	439012	392208	439012	392208	seepage & dislocated trees and erosion p208-11 running water observed slope benched at 16m, seepage at 10m on 1st slope	FILT
44801	491652	M1	Cutting	439009	392222	439009	392222	Seepage observed from lower bench during 2009 inspection. Not seen during November 2011 inspection. Note that the geometry given is for overall slope.	FILT
44801	491653	M1	Cutting	439012	392208	439012	392208	Significant seepage recorded during 2009 inspection. Not seen during November / December 2011 inspection. Slope benched at 16m, seepage recorded at 10m on 1st slope	FILT
44801	290395	M1	Cutting	438862	392514	438872	392492	retaining wall	NSRW
44801	290398	M1	Cutting	438887	392456	438934	392336	retaining wall 10m high at max pt	NSRW
61853	518574	M1	Cutting	0	0	434915	431154	Retaining wall and comms cabinet	NSRW

4.3 SGM and other observations on AVIS

Earthwork ID 34272

Observation ID: 239219
Obs Desc: 2m high retaining wall

AVIS Obs: **Covered in graffiti. Upper coping stones are loose. Surface stonework colour is variable, potentially indicative of water flow along facing.**

Observation ID: 239222
Obs Desc: Drainage

AVIS Obs: **Manholes present every 8-10m.**

Earthwork ID 42407

Observation ID: 276918
Obs Desc: Vegetation

AVIS Obs: **Survey performed March 2016, therefore trees are without leaves. Many of the tree along this stretch are large, mature and frequently overlap onto the hard shoulder. Example of overgrown trees between 0 km, 849m and 0km, 955m, GR 432276, 405692 and 432228, 405787.**

Observation ID: 488122
Obs Desc: minor crack in over steepened cutting

AVIS Obs: **Not Visible**

highways england

4.4 SGM and other observations on AVIS

Earthwork ID 43931

Observation ID: 488122
Obs Desc: Vertical gully p991/2 – Could be vertical french drain possible seepage – moss/reeds

AVIS Obs: **Top of slope drain not visible due to line of sight nature of acquisition system. No reeds or moss visible possibly due to time of year. Top of slope drain potentially visible, as a light grey area, potentially loose gravel but insufficient to confirm.**

Observation ID: 285667, 285668, 285669, 285670
Obs Desc: Retaining wall p976/7, 8m, 5m, 2m high.

AVIS Obs: **Earthwork is present, however, as embankment the full extent is not visible.**

<u>Only partially visible in some areas:</u>

(1) top of safety barriers between 0km 220.91m, GR 438718, 392689;
(2) disused, damaged, small, roofed structure at 0km 266.60m, GR 438718, 392689 and;
(3) top of wall and safety fence at 0km 439m, GR 438597, 392813.

highways england

4.5 SGM and other observations on AVIS

Earthwork ID 44801

Observation ID: 290393
Obs Desc: Vegetation

AVIS Obs: Some large, mature trees. Much of the site is concrete retaining wall. Some trees towards the start of the feature could overhang the hard shoulder when in bloom.

Observation ID: 290400
Obs Desc: Seepage observed from lower bench - geometry given is for overall slope - hydrovegetation present and erosion of slope caused by seepage - landfill adjacent p204-207

AVIS Obs: *Large tree present at base of cutting, some are leaning towards carriageway. Seepage visible on carriageway hard shoulder.*
Top soil and grass has flowed over onto hard shoulder and is encroaching onto hard shoulder by ~0.2m. Evidence of reeds indicate hydrophilic vegetation present.

Observation ID: 290401
Obs Desc: seepage & dislocated trees and erosion p208-11. Running water observed. Slope benched at 16m, seepage at 10m on 1st slope.

AVIS Obs: *Seepage is not visible in slope due to vegetation.*
Verge appears to be wet top soil. Top soil and grass has flowed over onto hard shoulder and is encroaching onto hard shoulder by ~0.2m.

highways england

4.6 SGM and other observations on AVIS

Earthwork ID 44801

Observation ID: 290395
Obs Desc: Retaining Wall

AVIS Obs: **Appears to be in good condition. No clear defects present.**

Observation ID: 290398
Obs Desc: Retaining wall 10m high at max pt

AVIS Obs: **Appears to be in good condition. No clear defects present. Pedestrian foot bridge present at top of structure.**

highways england

4.7 Conclusions and Recommendations

A pilot study was carried out to identify whether Highways England's Asset Visualisation Information System (AVIS) is capable of informing about the location, existence and condition of Special Geotechnical Measures (SGMs).

It resulted in the following observations:

1. AVIS can be used to locate some SGMs (e.g. retaining walls, rock netting and bolts, visible drainage). Features and structures that infer the presence of SGMs are often visible. i.e. Safety fence at the top of concrete retaining walls.

2. Generally, AVIS is capable of identifying features that can give an indication of the SGM condition e.g. damaged brick work in retaining wall.

3. Observation of the full extent of SGMs located on embankments is not possible.

4. Other features of interest can be observed e.g.:
   - Vegetation type present on at grade and cut slopes;
   - Seepage from cut slopes, manifesting as wet soil or wet hard shoulder.

Recommendation:
AVIS should be used to crosscheck SGM locations and inventory with the output of Task 594. It should be used to create a layer in HAGDMS of all SGMs. Once this exists systematic repeat remote monitoring of SGMs will be possible, thus reducing the need for physical inspections.

M11 J5-J6

Phase 2 Pilot Study 2017

SPaTS 1-086 Application of remote survey data for Geotechnical asset condition and performance

1. Introduction

This document represents one of a series of Proof-of-Concept Pilot studies undertaken for Phase 2 of the SPaTS 1-086 project '*Application of remote survey data for geotechnical asset condition and performance*'.

These studies present an evaluation of the use of available selected remote-sensing survey data in both management and condition monitoring of Highways England geotechnical assets.

This specific study focuses on two high-risk soil slope earthworks on a section of the M11 between Junctions 5 and 6. This study area has been identified as an area of either current high risk or having had a previous history of geotechnical problems during its lifecycle.

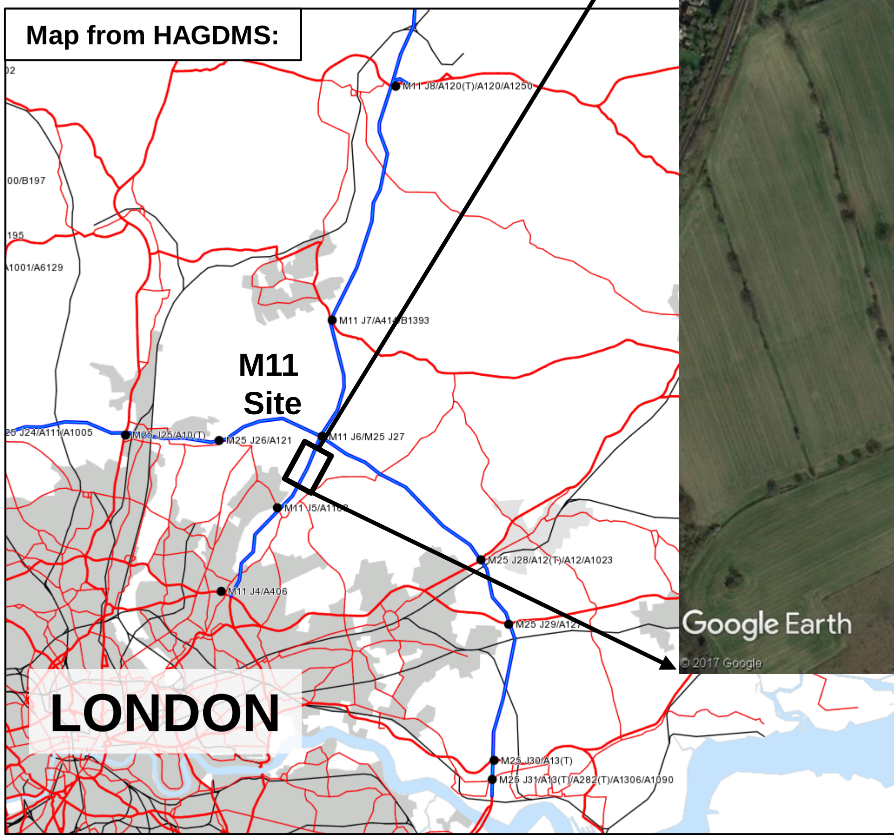
This document provides a review of the application of multiple different available remote sensing data but in particular provides a trial of Interferometric Synthetic Aperture Radar for remotely monitoring subsidence and uplift. The Pilot is structured as follows:

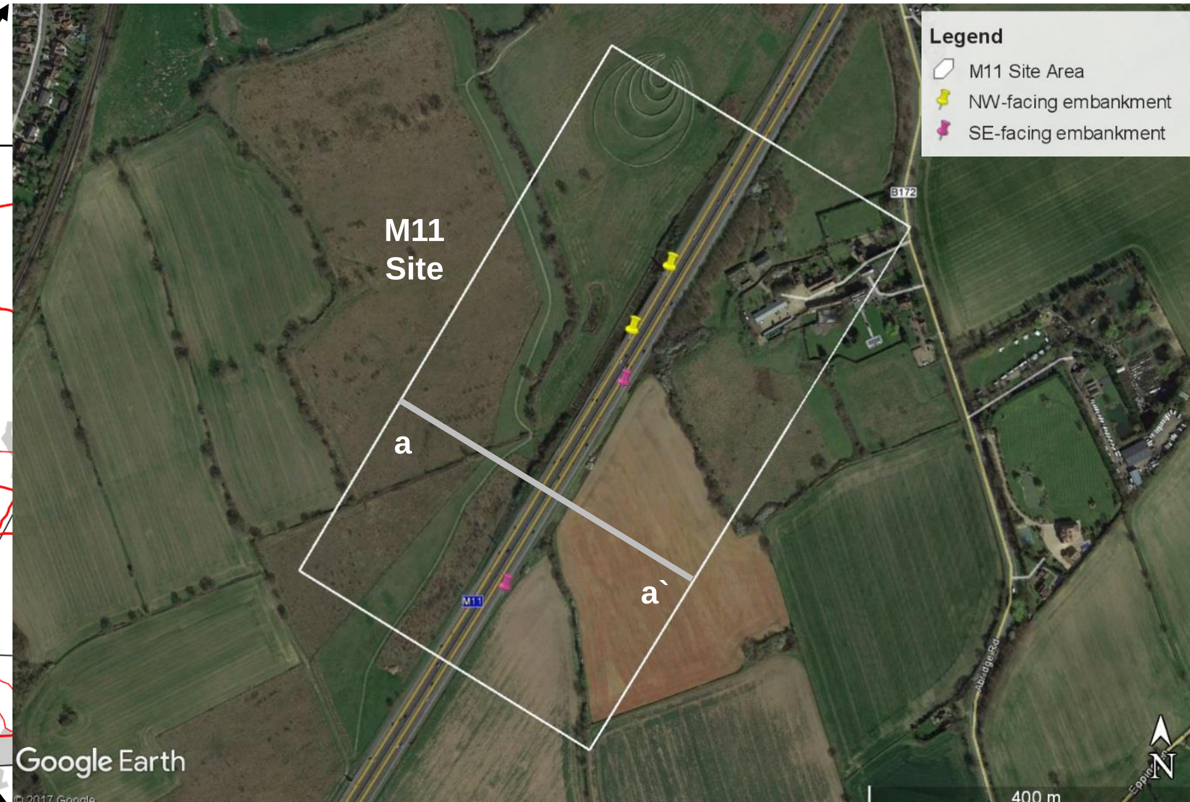
Click on the 'Home' button to get back to this slide

Please see other supporting documents for further information.

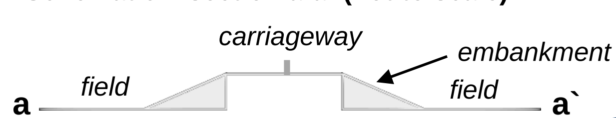
2. Site Location & Description

The M11 pilot site (shown in the figures below) includes two high-risk soil slope earthworks (one northwest-facing embankment slope, one southeast-facing embankment slope) adjacent to the M11 3-lane carriageway between junction 5 in the south and junction 6 in the north within Highways England Area 5.





Schematic x-section a-a` (not to scale):



3.1 Geotechnical Risk

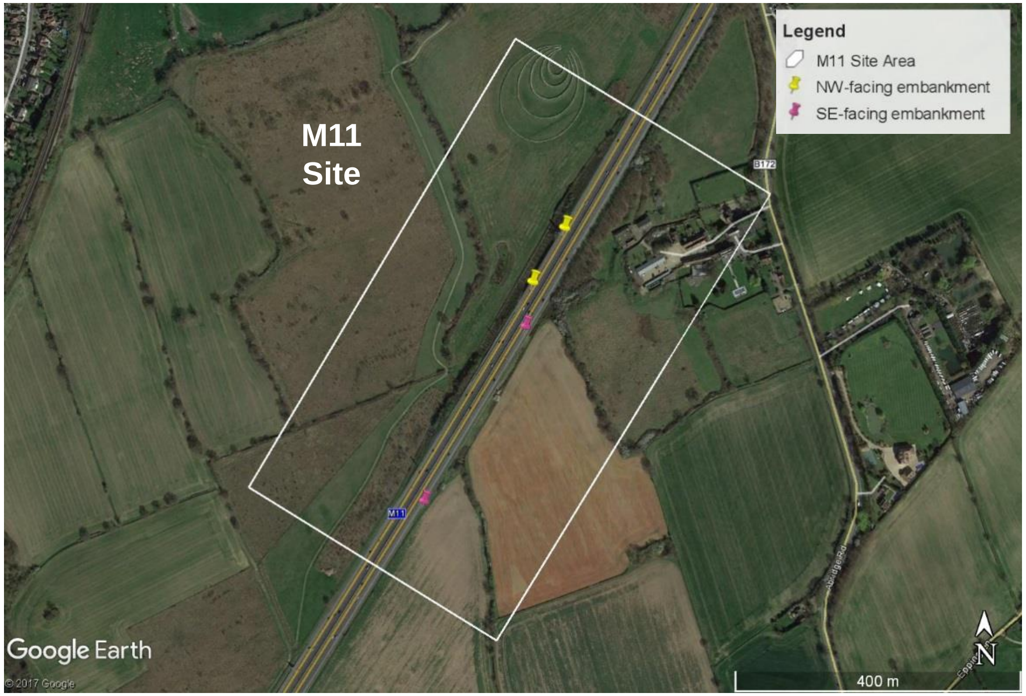
The site has multiple geotechnical failure observations on HAGDMS (see bullets below). On HAGDMS, both embankments are also categorised as 'high-risk' in terms of slope hazard rating. Geologically this area is located on the London Clay and so it is likely that the embankment is constructed from London Clay as well. As such the Geosure layer indicates a potential for shrink swell and also shows a potential for groundwater flooding.

Northwest-facing embankment (yellow pin markers):

- The first geotechnical observation documented on HAGDMS for this embankment was entered in 2012, described as 'tension cracking, slip, and dislocated fence/barrier/kerb'
- Sheet piles were implemented as a remedial measure in 2014, the available photos on HAGDMS indicate that counterfort drains were also implemented at this time.

Southeast-facing embankment (pink pin markers):

- The first observation of geotechnical failure(s) entered on HAGDMS are in 2003 and are reported as: 'soil slip, terracing, tension cracks, and distorted Structure'
- In 2010, the entry on HAGDMS records that the soil slip has been repaired 'full height and crest repair' i.e. soil regrading.

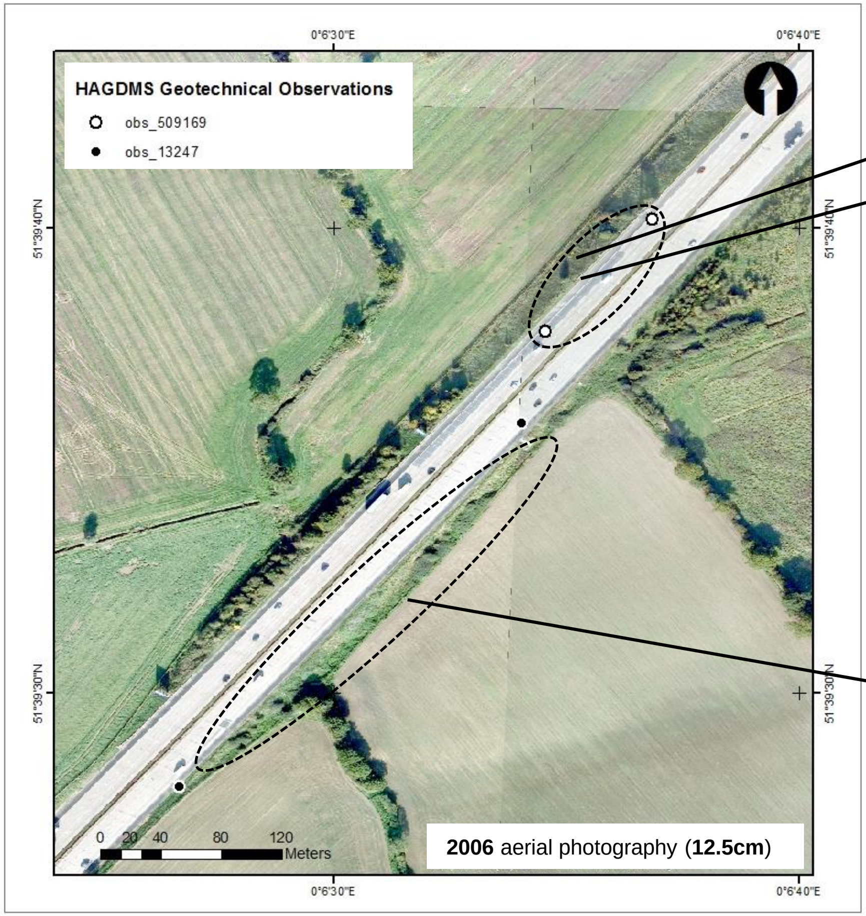


highways england

3.2 Geotechnical Risk

The aerial photo map shows the two approximate areas (shown in the black dashed ovals) in which the HAGDMS geotechnical observations have been reported. The white and black circle markers indicate chainage of observations, as reported on HAGDMS, along the northwest-facing embankment and southeast-facing embankment, respectively.

The 12.5 cm resolution aerial photo base map presented below is from a national survey that was carried out in 2006. This data has been procured by Highways England and is available on the Highways England Geostore. It has been downloaded on displayed in ESRI ArcGIS software below. Please note that the coordinate system used for the grid referencing in all following maps is geographic WGS84.



Photos of the geotechnical failures (left) and of the repaired NW-facing slope (above) from the HAGDMS website.

4.1 Data Review

The data sources made available for this pilot study are summarised in the table below. With the exception of the satellite multispectral data (which is feely available and open source from the European Space Agency, ESA), all other datasets had previously been procured by Highways England; however, not for a specific geotechnical purpose.

Data Type	Sensor/ Instrument	Platform	Spatial Resolution	Date(s) Collected	Additional Information
Aerial photographs (vertical)	Fixed Wing	Airborne	12.5 cm	2006	National Aerial Photography
Aerial photographs (vertical)	Fixed Wing	Airborne	25 cm	2014	National Aerial Photography
Aerial photographs (vertical)	Rotary Wing	Airborne	4 cm	June 2004	Blom
Multispectral Imagery	Sentinel-2A	Satellite	10 m*	May 2017	ESA
LiDAR	LiDAR scanner	Terrestrial	>500 to >1000 points/m^2	2013	Mobile Mapping System/IBI Group
LiDAR	LiDAR scanner	Airborne	~10 points/m^2	2004	Highways Agency LiDAR Framework
InSAR	Radar	Satellite	N/A***	Various* *	National Physics Laboratory (NPL)

*Multispectral sensor band imagery varies in pixel size depending on the wavelength of the reflected energy measured, therefore, the final composite scene (composed of at least three bands) used for interpretation e.g. true colour or false colour, see slide 12, depends on the combinations of bands used to generate final composite image.

**Depending on the InSAR radar scenes available for processing scenes are likely to have been collected from different satellites, and from different years and times of the year, month, day, hour.

***Point density varies depending on processing technique used, see later slides.

Note – the current version of data uploaded on the **AVIS Viewer (2017)** includes the: ‘M11 Area 08 (2014/03)’ and the ‘M11 Area 06 (2014/02)’. This pilot section of the M11 is located in Area 5, therefore it is not covered by the data currently uploaded on the AVIS Viewer.

4.2 Data Review

- The following section presents an analysis of how the remote sensing data, identified in the previous table, can be used to support Highways England to improve the inspection regime for the **high-risk soil slopes** at this section of the M11.

- This assessment will also provide an understanding of how these techniques can be applied to other geotechnical high-risk soil slopes, and other soil embankments in general, across the network.

- Four key datasets have been investigated, including:

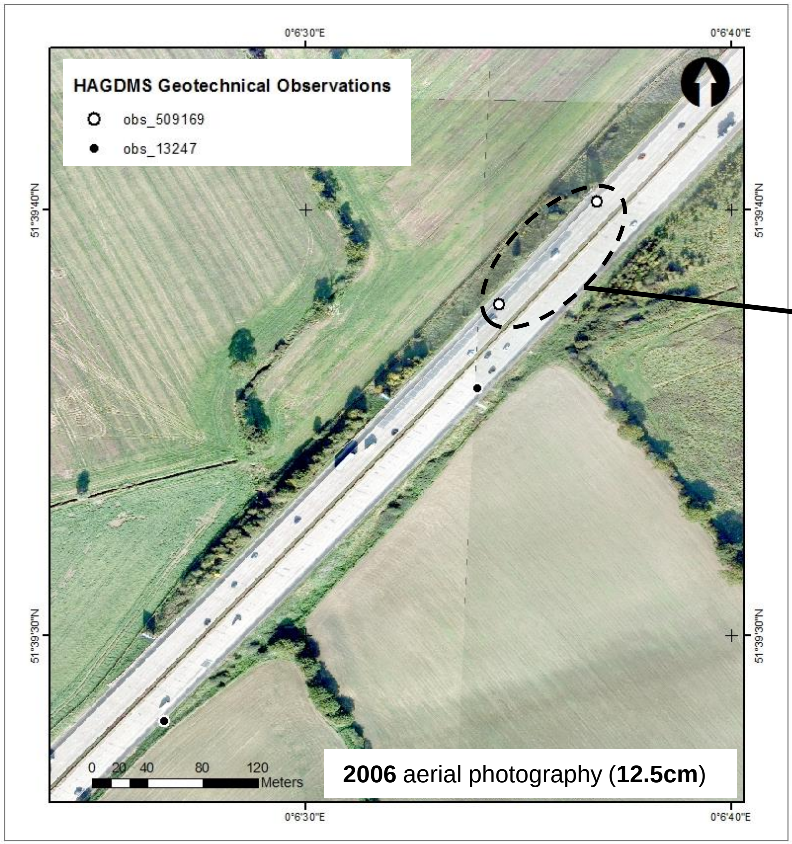
- Aerial imagery (colour vertical aerial photographs)
- Multispectral satellite imagery (ESA Sentinel-2)
- Light Detection and Ranging (LiDAR)
- Interferometric Synthetic Aperture Radar (InSAR)

5.1 Data Processing & Analysis: Aerial Imagery

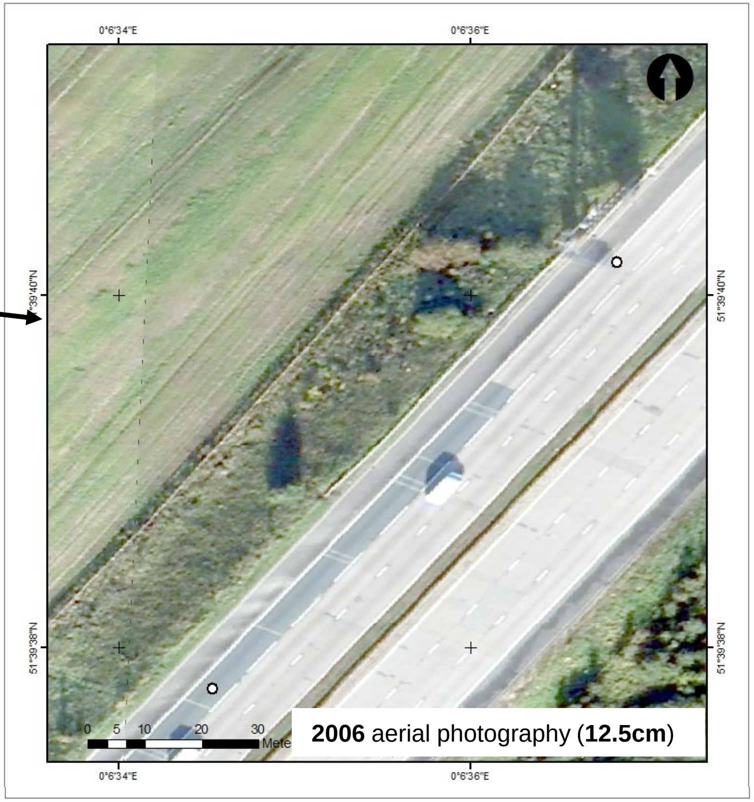
Colour vertical aerial photography has been considered in this pilot, however, other types of aerial photography exist, including: infrared, panchromatic, oblique, etc. and could be useful for the same/similar application as discussed in this pilot.
Vertical imagery is obtained using (typically) a digital camera mounted to point directly downward on the aircraft.

North-facing embankment:

- Tension cracking and slip observations were first reported on HAGDMS in 2012
- Sheet piles (and from the HAGDMS photographs, counterfort drains) were implemented as a remedial measures in 2014 (along the NW-facing slope)



2006 aerial photography (**12.5cm**)

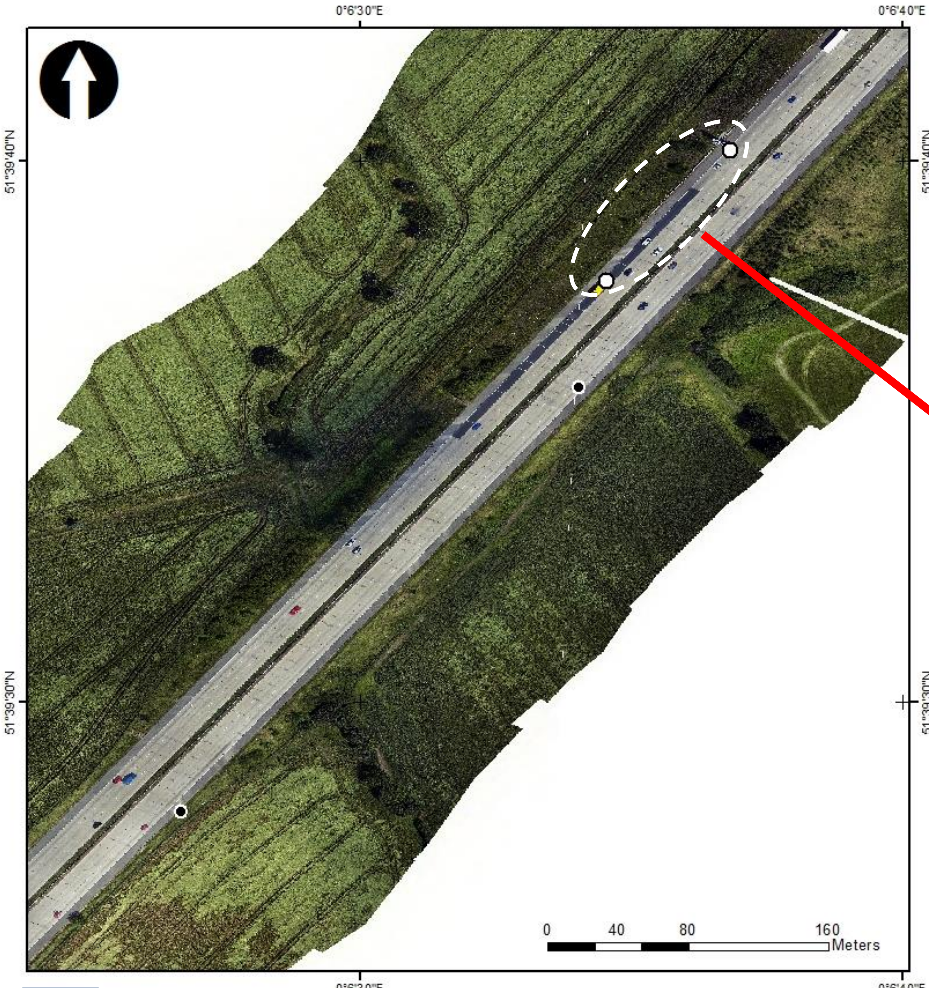


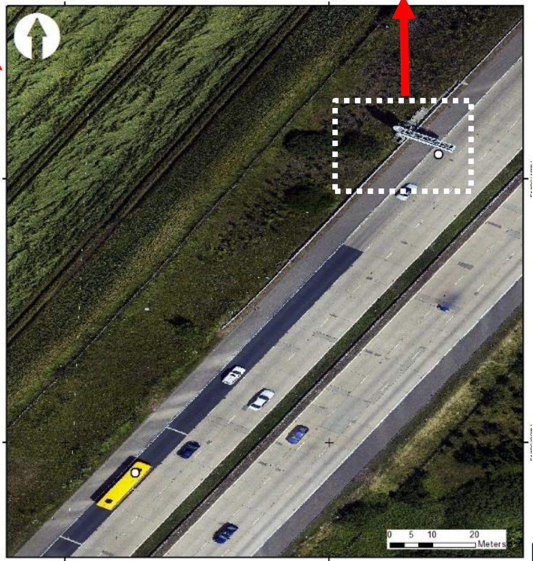
2006 aerial photography (**12.5cm**)

Conclusion:
No indication of slope instability is noted in this 12.5 cm imagery. This is either due to insufficient resolution or the instability not yet initiating – it was first recorded in 2012.

5.2 Data Processing & Analysis: Aerial Imagery

The available 4 cm high-resolution colour photography for the M11 site, collected by rotary-wing survey in 2004, is shown as an overview in the figure below. The white dashed oval indicate the zoomed view of the gantry area shown in bottom right figure.



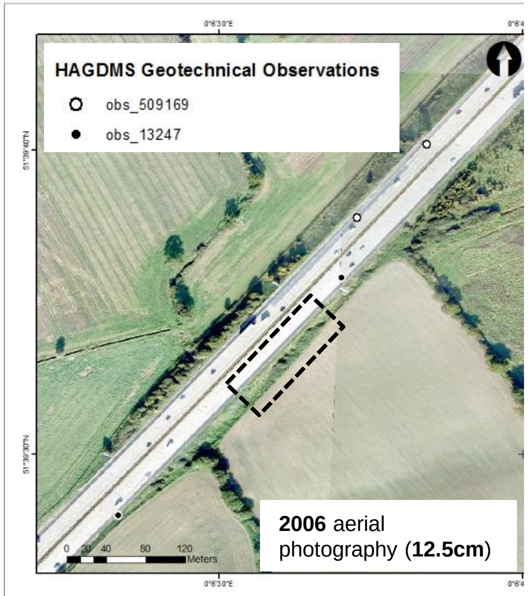


The area of the dashed white box is shown in above. Cracks (the black irregular line) in the pavement can be observed along the northwest boundary of the carriageway, as indicated by the white arrows.

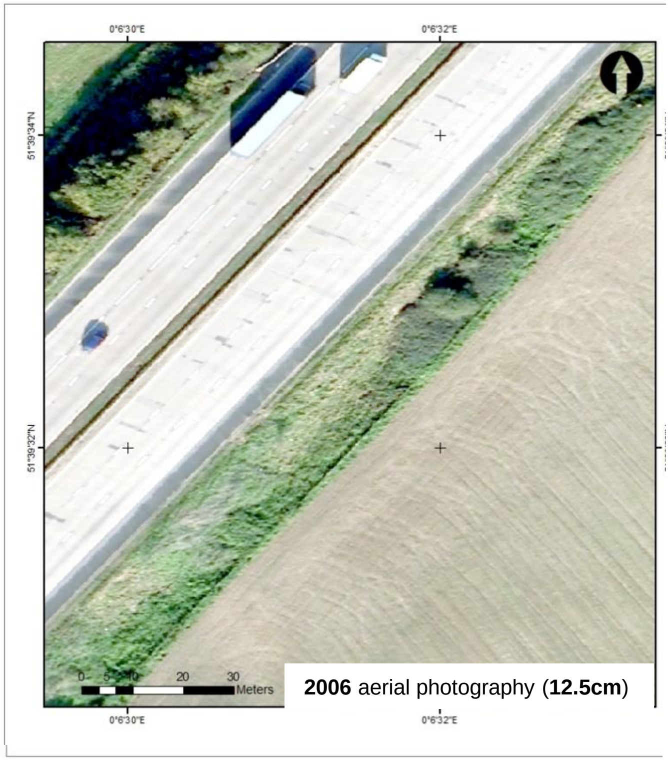
5.3 Data Processing & Analysis: Aerial Imagery

South-east facing embankment:

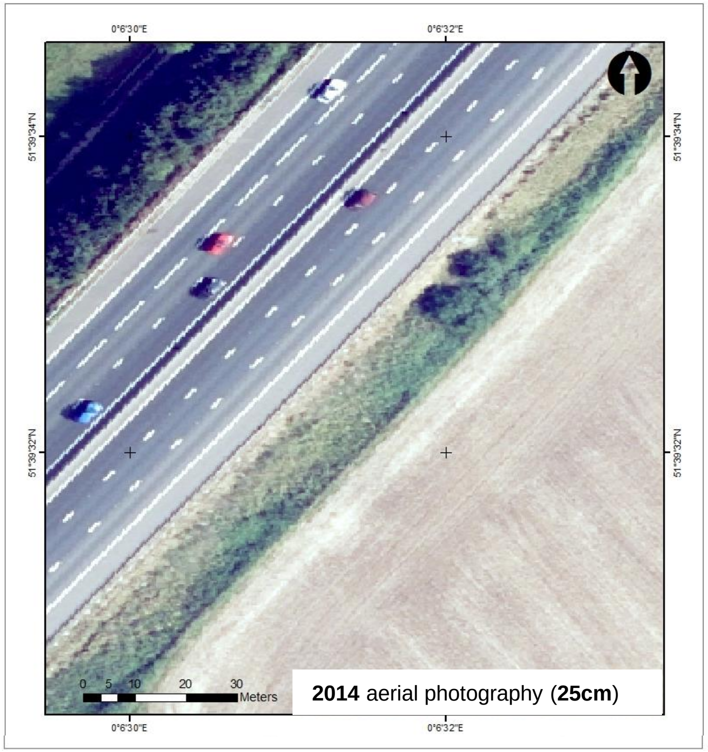
- Soil slip, terracing, tension cracks, and distorted structure were recorded on HAGDMS in 2003
- Regrading remedial works were carried out in 2010
- The approximate area shown in the black dashed box in the left-hand figure is shown in the centre and right-hand figures (different survey dates).



2006 aerial photography (**12.5cm**)



2006 aerial photography (**12.5cm**)



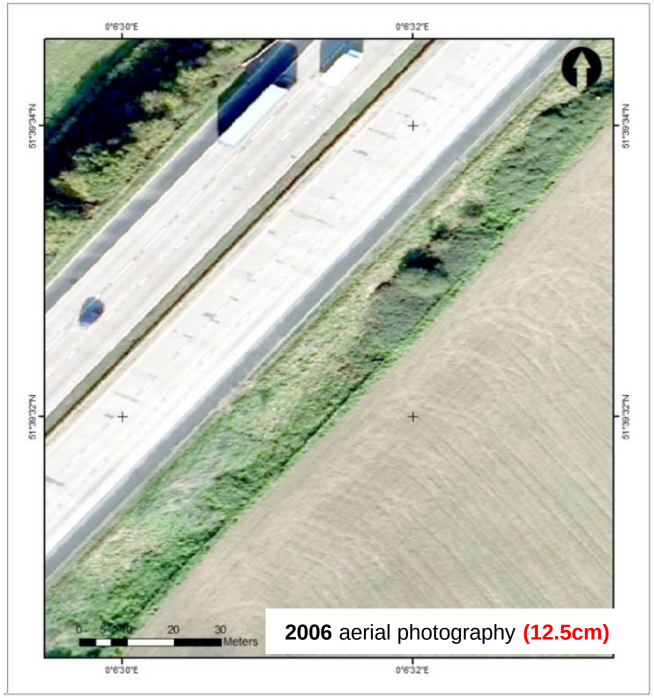
2014 aerial photography (**25cm**)

- Observations of the aerial imagery in 2006 indicate no clear evidence soil slip, terracing or tension-cracking. This is possibly because the resolution is not high enough.
- It is difficult to see any evidence of the soil regrading works carried out in 2010 in the 2014 photographs.

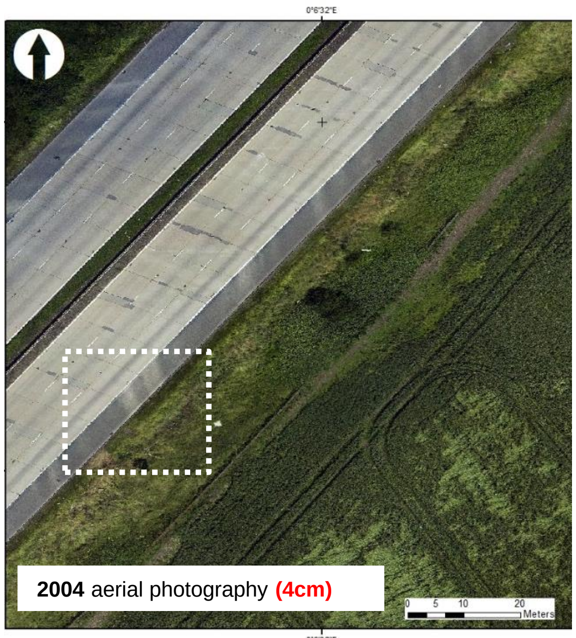
5.4 Data Processing & Analysis: Aerial Imagery

South-facing embankment:

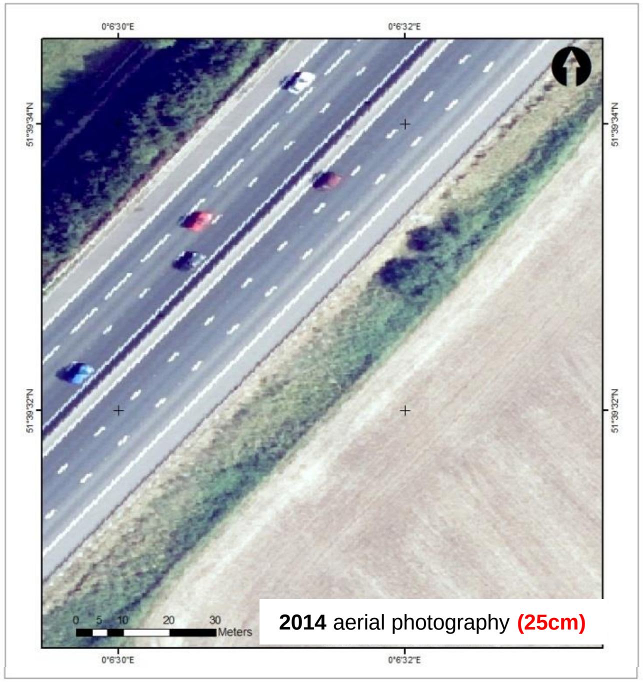
- The 2006 survey and 2014 survey figures below are the same as the previous slide. For comparison, the 4cm resolution 2006 photography survey of the same area shown in the figure in the centre.
- It is possible to observe evidence for terracing in the 2006 4cm resolution photography also.



2006 aerial photography **(12.5cm)**



2004 aerial photography **(4cm)**



2014 aerial photography **(25cm)**

- The area shown in the dashed white box above is shown in the bottom centre figure. The white arrows point to a region of possible terracing.

5.5 Conclusions: Aerial Imagery

Summary of the observations/ conclusions from the photography data reviewed:

- Vertical aerial colour photography shows potential for observing changes in known high-risk soil slope sites over time.

- The frequency of aerial surveys must be considered: how often is useful/in order to reveal change over time? Annual surveys are likely to be appropriate for high-risk earthworks (and less than this for lower risk)

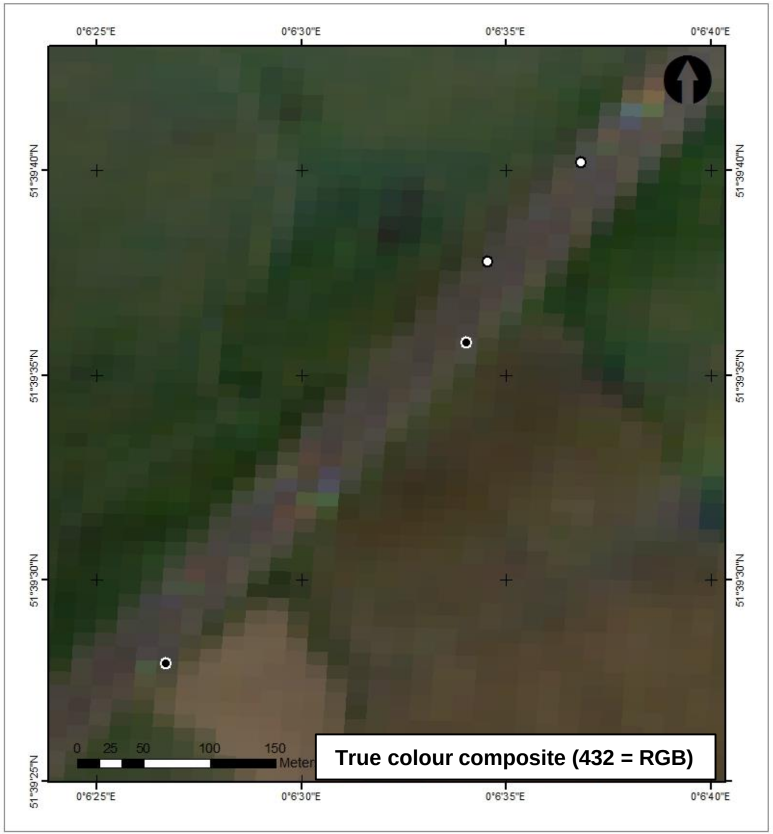
- Each survey needs to have the same or at least roughly equivalent high resolution (e.g. 4 cm) in order that data is comparable

- Along the same lines as the point above, in order that data is comparable the surveys should be flown during the same/very similar fair-weather conditions

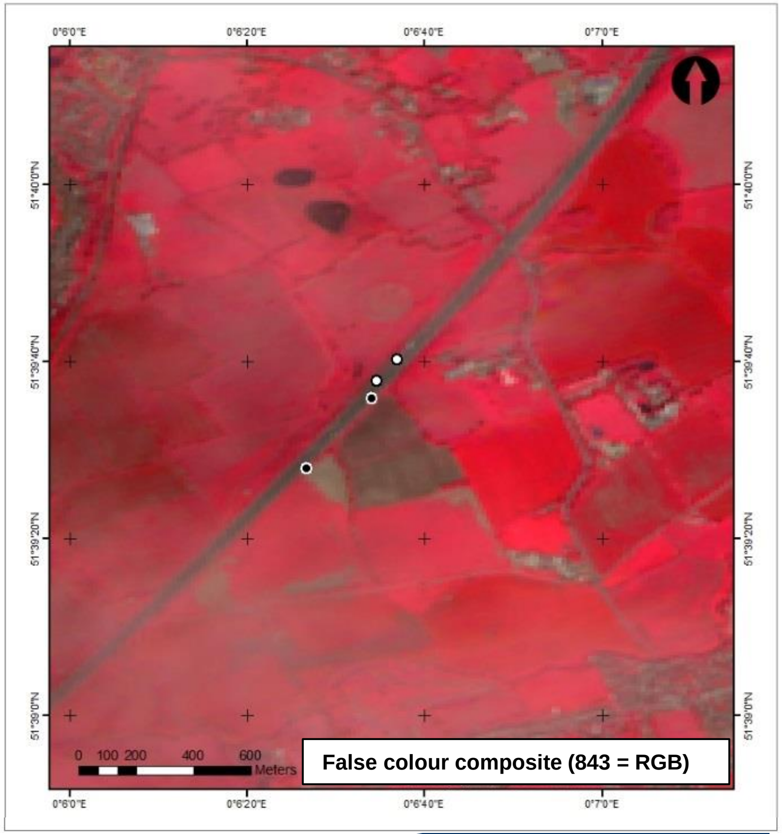
- It is likely that for the most effective interpretation results the aerial photography data is best viewed in combination with other remote-sensing datasets, such as LiDAR, to aid in correlating visible change (photographs) with physical change (measured topographic change).

5.6 Data processing & analysis: Sentinel-2 Multispectral Imagery

- The figures below present ESA Sentinel-2 multispectral satellite imagery (black and white circles indicate the extents of the two areas of interest).
- This Level1C data has been freely downloaded from the ESA Copernicus Open Access Hub (https://scihub.copernicus.eu/dhus/#/home).
- Multispectral bands have been combined in specific combinations in image processing software and displayed such that they show different information. Different bands can be displayed as a combination of three different colour channels (red, R; green, G; blue, B: RGB).
- The left-hand figure shows a 'true colour' scene, i.e. as the human eye sees the land.
- The right-hand figure shows a 'false colour' scene in which band 8 is in the red viewing channel, this band is sensitive to the health of vegetation, hence the grassed fields in the left-hand figure are displayed as very bright red in the right-hand figure. By contrast, the brown fields of the true colour image have very little red in the false colour image, representing the bare soil condition.
- Both scenes are medium (10 m) pixel resolution



True colour composite (432 = RGB)



False colour composite (843 = RGB)

Note the different scale of each image

highways england

5.7 Conclusions: Sentinel-2 Multispectral Imagery

Summary of the observations/ conclusions from the multispectral imagery data reviewed:

- The 10 m pixel resolution of the Sentinel-2 data is too coarse to resolve the high-risk soil slopes of interest.

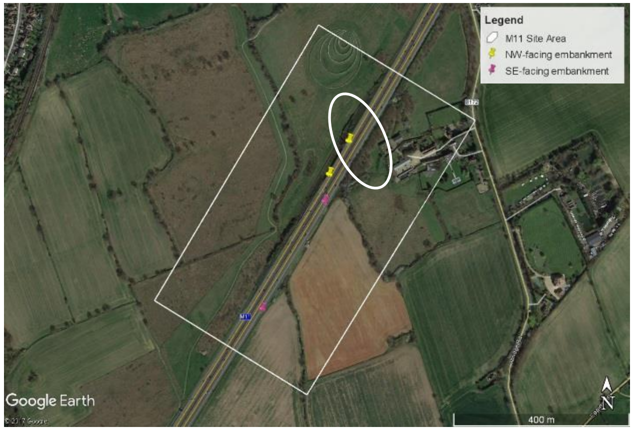
- It is possible that false colour scenes of the network could provide information about the health of the vegetation, which in turn could be used as a proxy for how the hydrological cycle or climatic seasonal change affect the network at a regional scale. However, such observations would be qualitative and regional, they might only complement targeted smaller scale data collection, and ground truth information.

5.8 Data Processing & Analysis: LiDAR

Two LiDAR datasets have been investigated as part of this pilot study:

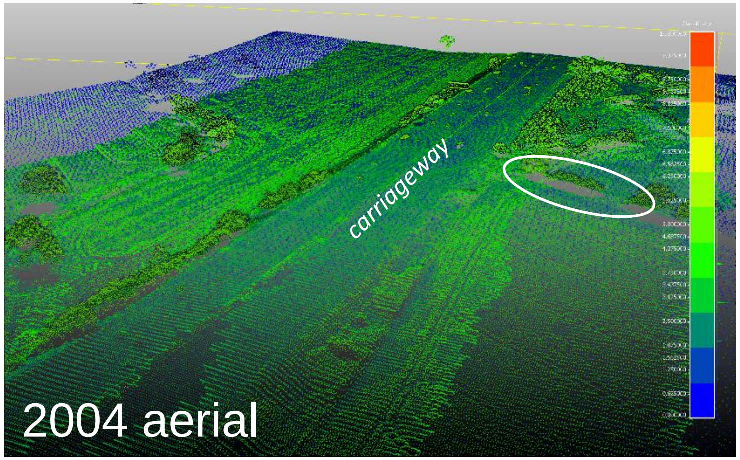
1) 2004 aerial survey (rotary wing)
2) 2013 terrestrial (vehicle) Mobile Mapping System survey

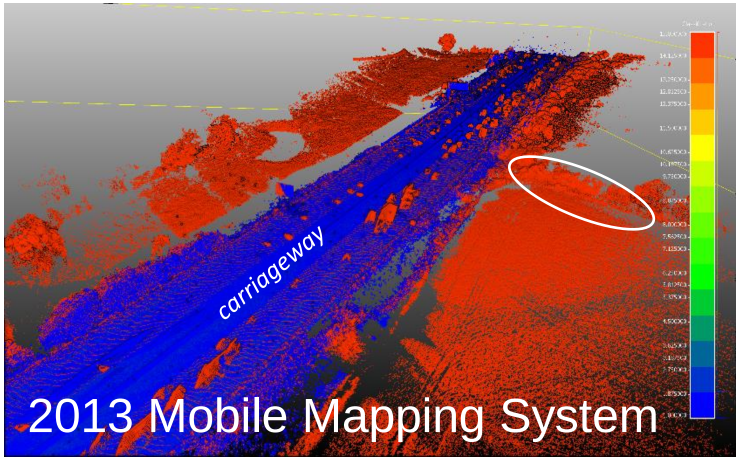
- The inset figure at the top right shows the M11 site overview for reference. The same hedgerow is circled in white in all of the figures on this slide.
- The left-hand figure below shows the 2004 aerial LiDAR survey coverage and data classification.
- The right-hand figure below shows the 2013 Mobile Mapping System survey coverage and data classification



Data Observations:

- The 2004 aerial survey data is well classified, has greater spatial coverage and a relatively low point density (see next slide)
- The 2013 Mobile Mapping System survey data only has the classification 'ground'. Otherwise the points are classed as 'undefined' or 'unclassified' (see the next slide). The data has less spatial coverage, and higher point density (see next slide).



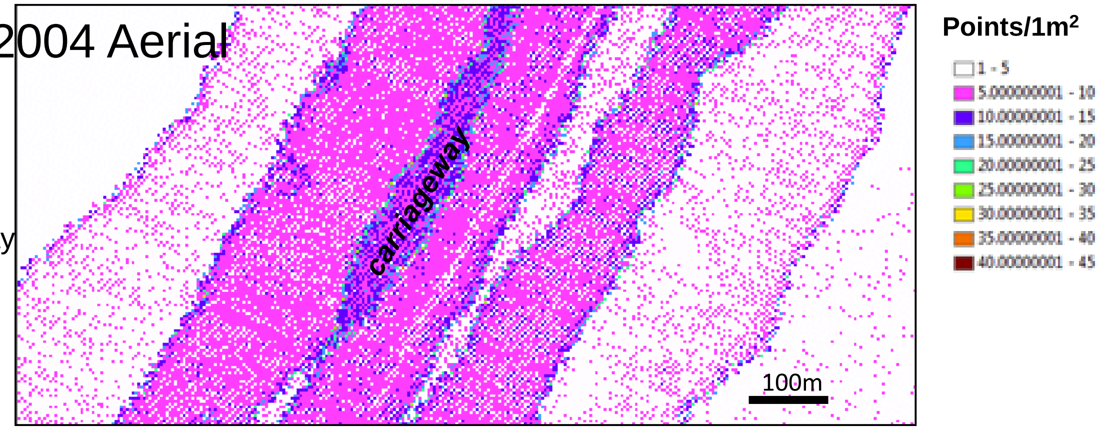


5.9 Data Processing & Analysis: LiDAR

Data Observations: Point Cloud Density

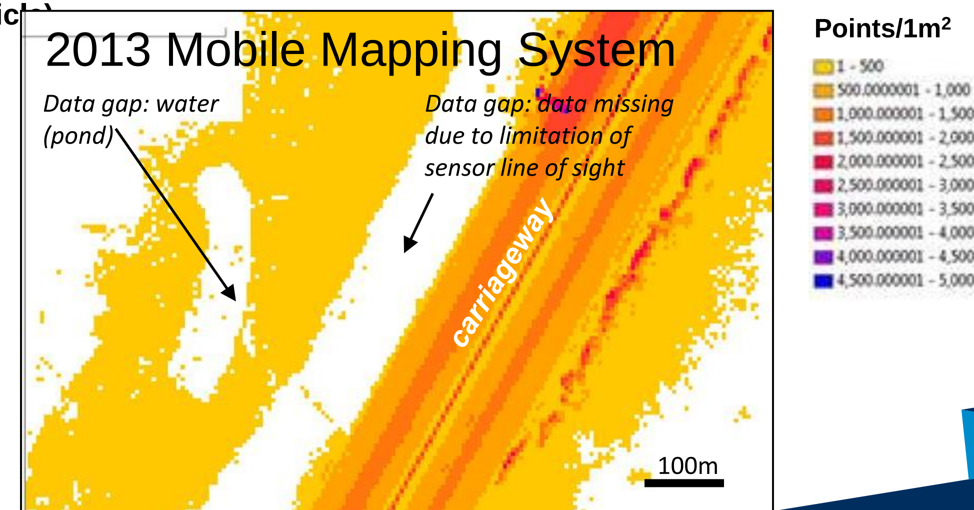
1) 2004 aerial survey (rotary wing)

- 5-15 points per $1m^2$ on the carriageway
- 1-5 points per $1m^2$ either side of the carriageway
- White areas indicate no data



2) 2013 Mobile Mapping System survey (vehicle)

- Figure shows image of Mobile Mapper point cloud gridded using 1m cell size. The colour scale indicates that There are point densities of:
- 1-500 points per $1m^2$ off carriageway
- 1000-2000 points per $1m^2$ on carriageway
- White areas indicate no data

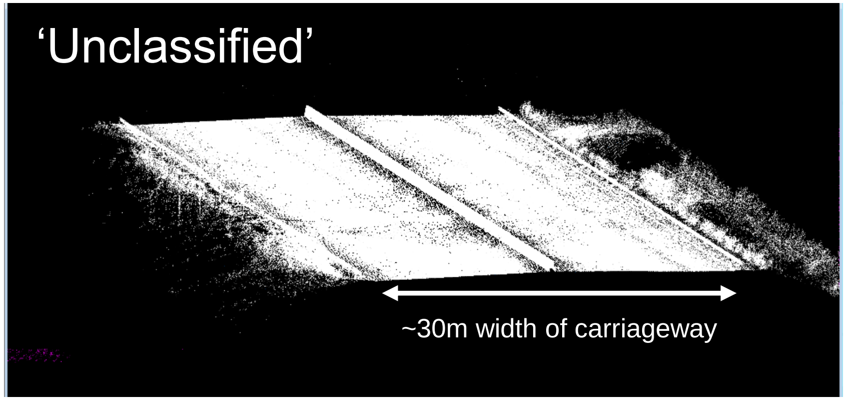


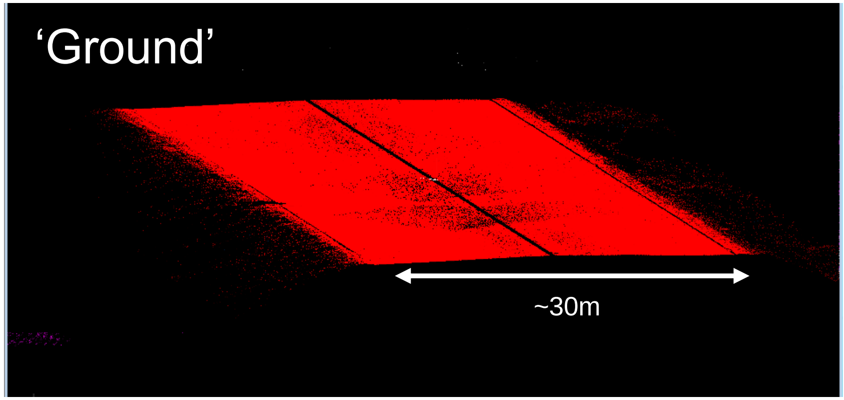
highways england

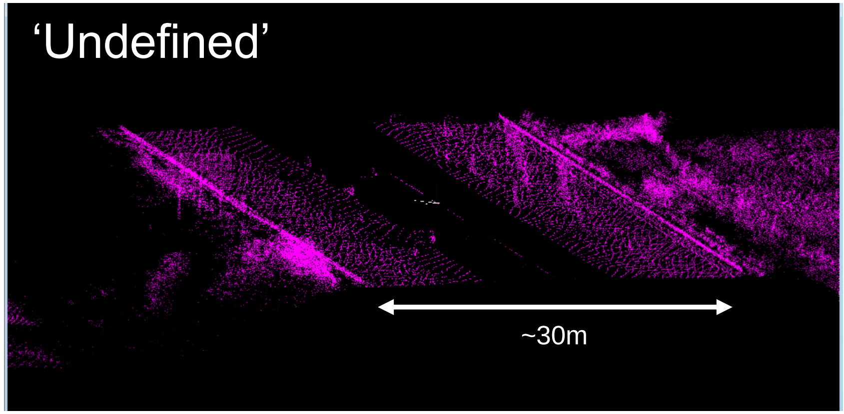
5.10 Data Processing & Analysis: LiDAR

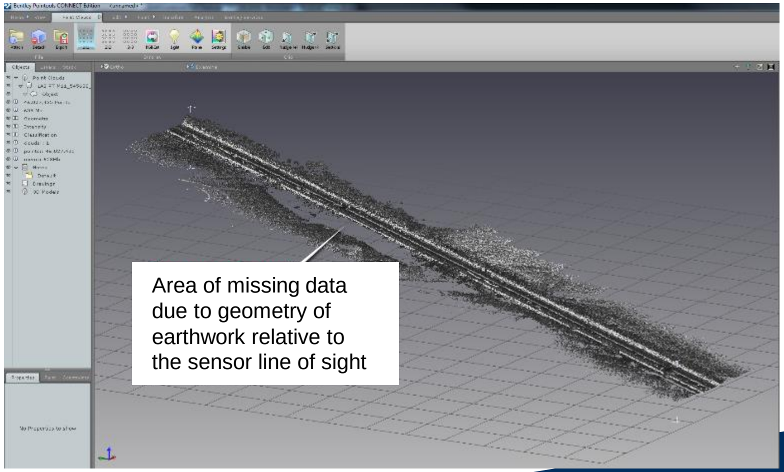
M11 – 2013 Mobile Mapping System data observations:

- The data was not well classified at the point of collection (immediate post-processing). Though data can be classified at a later stage through post-processing, this is not best practice. It should be agreed initially with, and carried out by, the contractor.
- There is a significant data shadow (missing data) on soil embankment of interest (see figure below)
- In each figure below, the original classification given to the data is stated in the top left-hand corner.





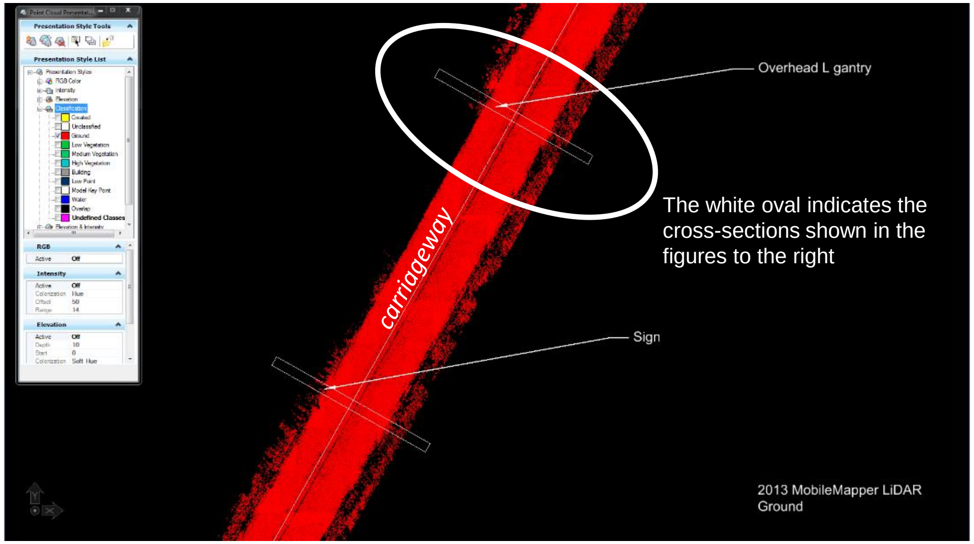


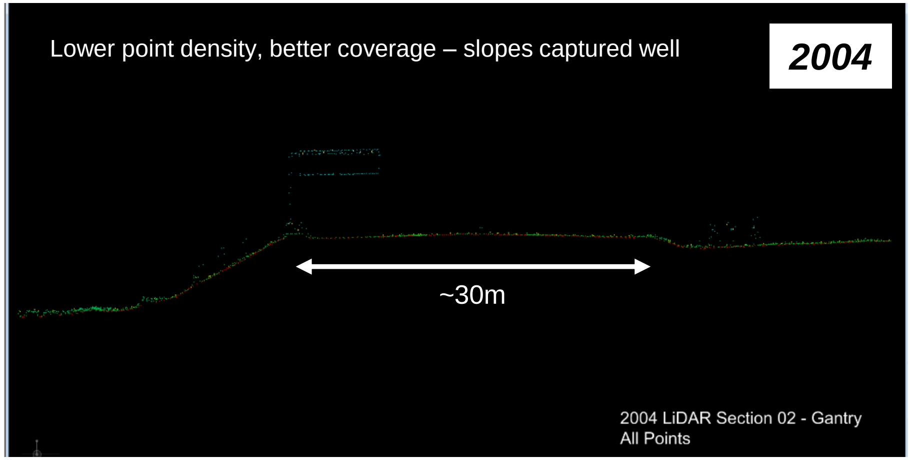


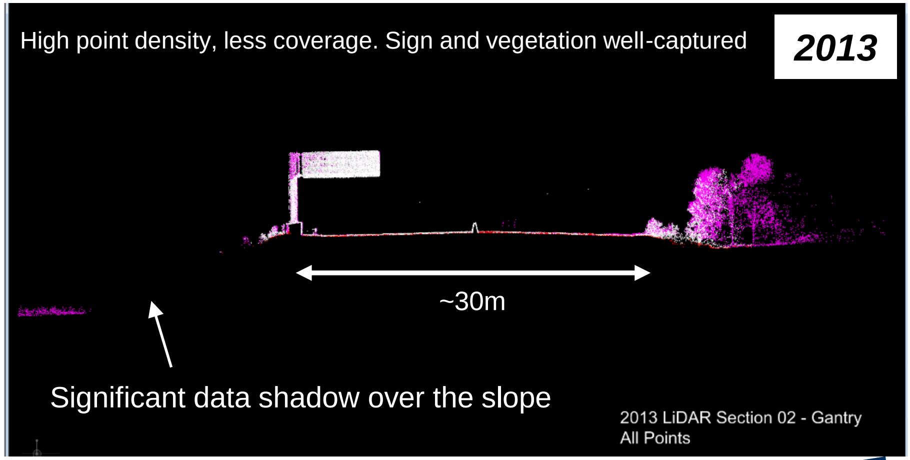
5.11 Data Processing & Analysis: LiDAR

This slide and the next slide show observations of both LiDAR datasets for two different cross-sections made perpendicular to the carriageway close to where the HAGDMS geotechnical observations were made.

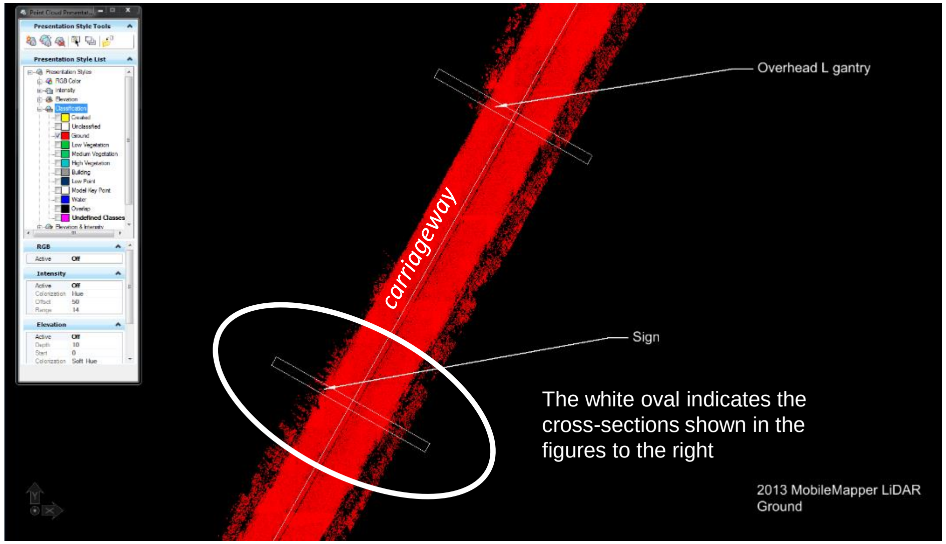
- On each slide the figure on the left provides an overview of the carriageway for reference (using the 2013 Mobile Mapping System data).
- The white oval highlights the sections shown in the right-hand figures for the 2004 (top) and 2013 (bottom) datasets.
- Observations are annotated with white text.

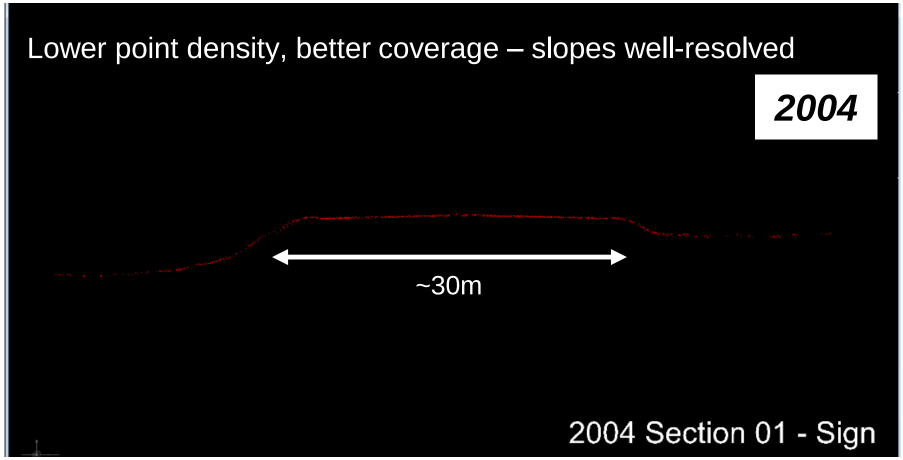


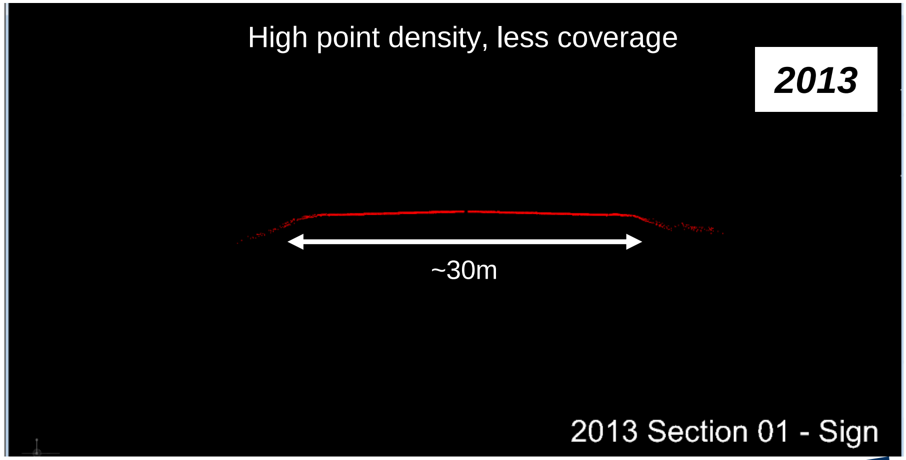




5.12 Data Processing & Analysis: LiDAR

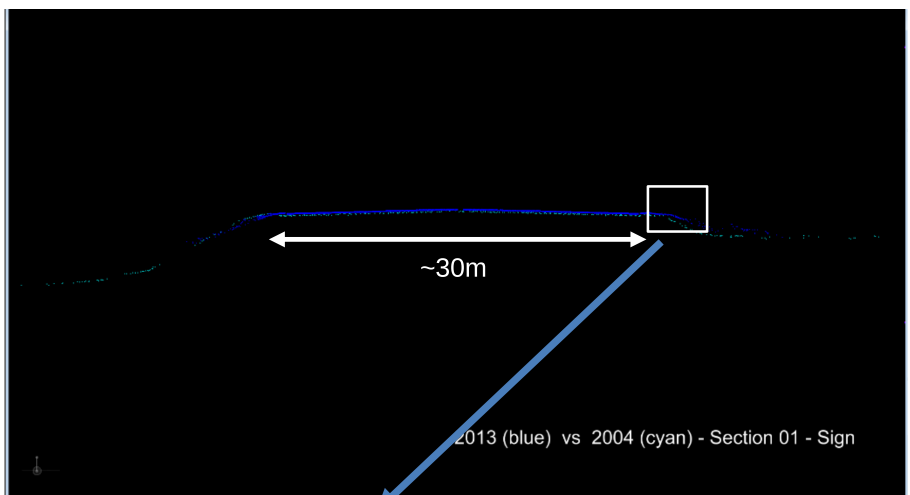


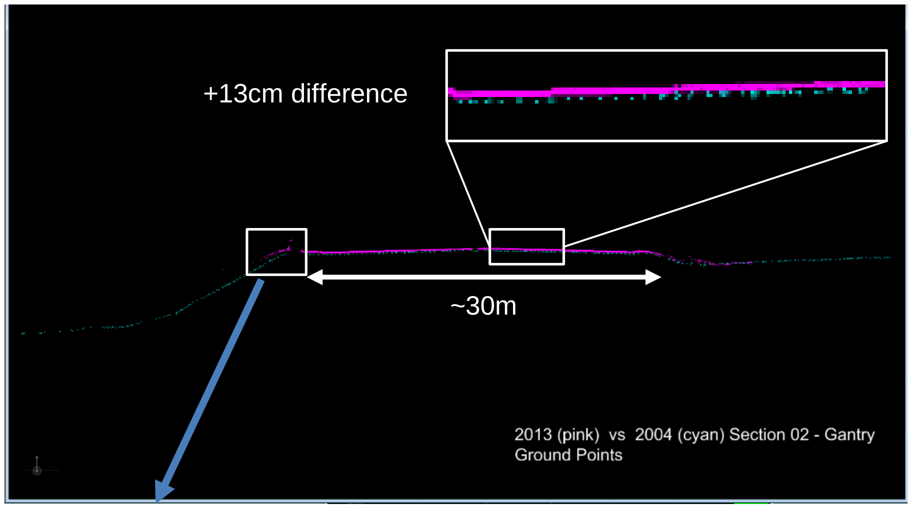


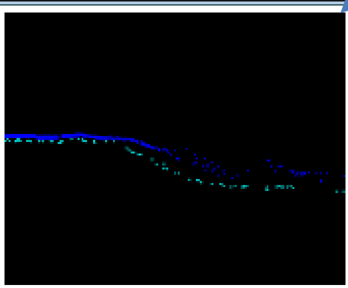


5.13 Data Processing & Analysis: LiDAR

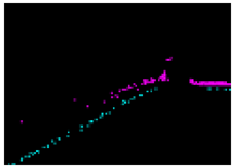
- The figures below show comparisons of the two different point clouds for the two different carriageway cross-sections ‘Sign’ and ‘Gantry’ (as shown previously).
- There is a consistent +13 cm vertical offset of the 2013 point cloud relative to the 2004 point cloud, along and across the carriageway.
- It is likely that this results from the different survey methods (aerial vs terrestrial) used to collect the data. Alternatively, this may have resulted from road resurfacing.







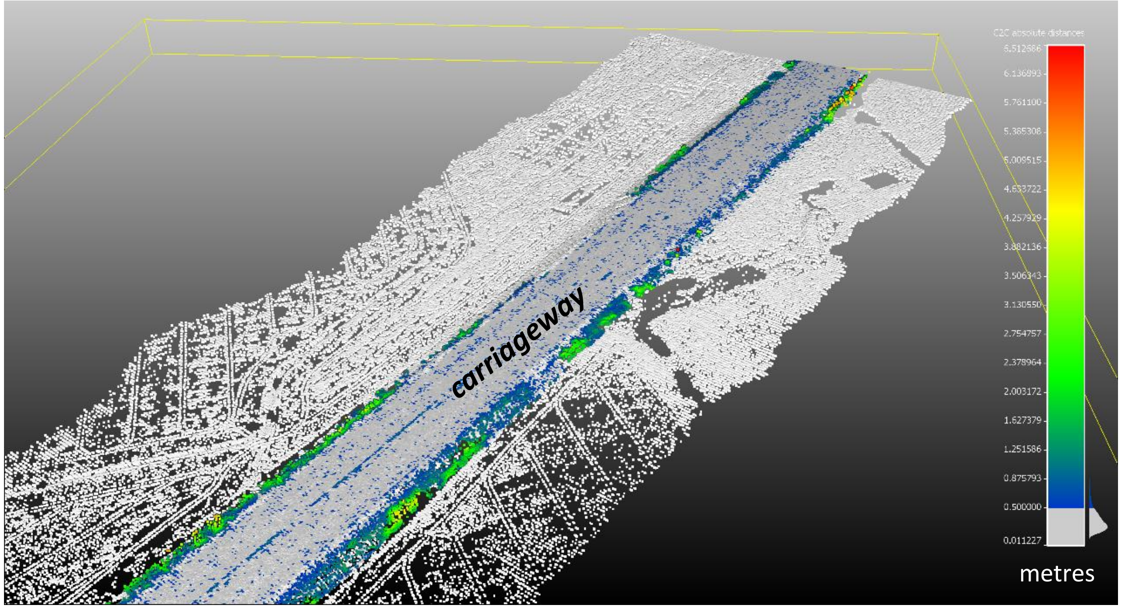
Difference in slope angle at embankment shoulder



Difference in slope angle at embankment shoulder

5.14 Data Processing & Analysis: LiDAR

- Offset or height change detection between the two datasets was attempted. This technique shows promise, i.e. a change in height can be detected between the two pointclouds as shown in the Figure below. However, to quantify this change and the uncertainties requires further study and more processing time.
- The left-hand figure below shows a 3D oblique view of the aerial and terrestrial LiDAR surveys covering a section of the carriageway.
- The coloured regions indicate the height change detected between the two different point clouds. The colour ramp therefore shows the amount of height difference. Grey points indicate where the change is less than 0.5 cm and where the two datasets do not overlap.



5.15 Data Processing & Analysis: LiDAR

Summary of the observations/ conclusions from the LiDAR data reviewed:

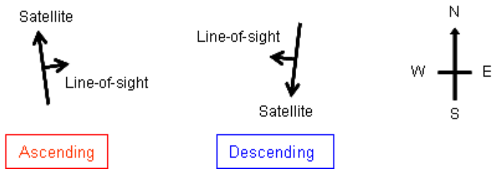
- As is well known, LiDAR surveys can capture the landscape in great detail and high spatial accuracy as has been observed with the two datasets investigated in this study.
- This pilot has shown that the platform used (aerial vs terrestrial) to collect the data makes a significant difference to the point density of the dataset (terrestrial datasets typically have higher density than aerial LiDAR).
- The survey platform also makes a difference to the spatial coverage – the aerial survey data has a broader, more complete coverage, particularly for embankments that slope away from and downwards from the carriageway.
- In particular, the Mobile Mapping System survey data at this site highlighted the latter point made above. A significant data gap existed on the earthwork embankment resulting from the unfavourable combination of sensor line of sight and earthwork geometry.
- The Mobile Mapping System point classification is limited to two classes, this means it cannot be easily compared and contrasted with the aerial LiDAR which has a greater number of classifications.
- The aerial LiDAR point classification is more complete and has greater classification of data.
- The classifications of interest (e.g. vegetation, earthwork ground surface, barrier, signage, pavement etc.) of the LiDAR point cloud should be identified before initial processing is undertaken.
- Elevation-change detection techniques show promise. However, the current study has highlighted that in order to do monitor change effectively using LiDAR surveys the same platform (either both terrestrial or both aerial) and data classifications should be used. Additionally, the point density and spatial coverage of different point clouds need to be similar if not the same. Furthermore, ideally the scanning geometry will be kept the same upon each new scan. With these survey requirements met, more work can be carried out to better understand if automated change detection using LiDAR point clouds can be used to detect the 'true' offset change associated with features such as small channels, slumps, bulges, and terracing.

5.16 Data Processing & Analysis: InSAR

InSAR data was made freely available and investigated in this pilot. The data was made available from the National Physics Laboratory (NPL) in the UK, and was processed by CGG, UK (www.cgg.com/npa). The data has been displayed and interpreted by Arup.

This pilot investigates the application potential of two InSAR data processing methods, including:

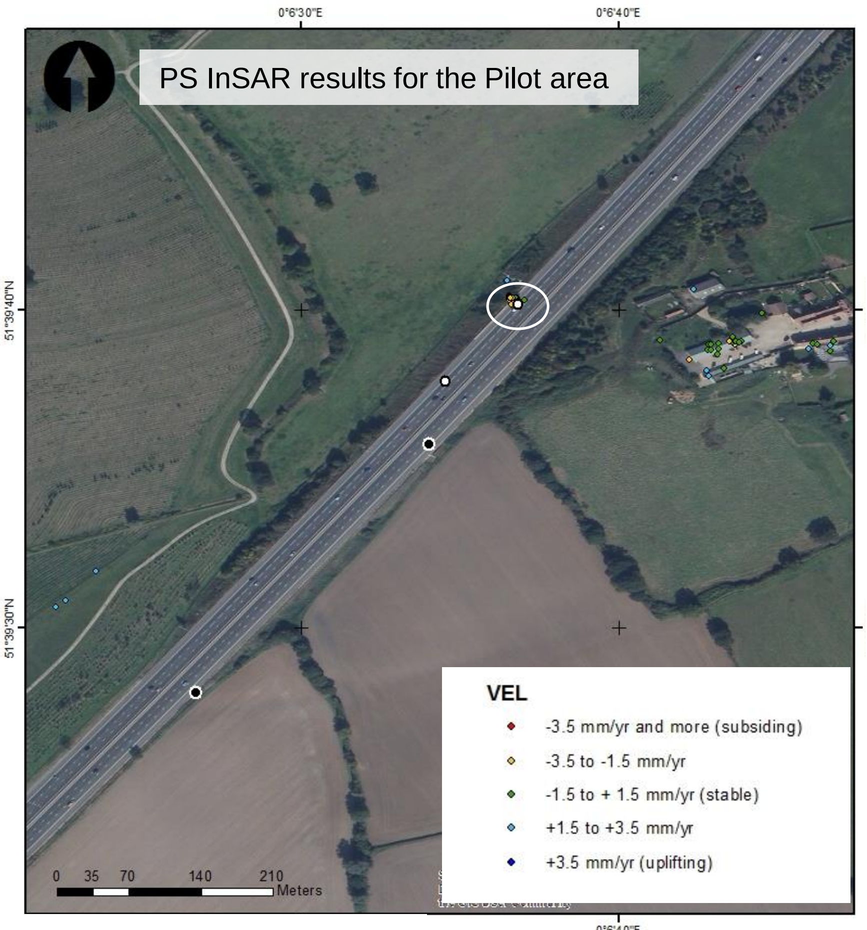
- **Persistent Scatterer (PS) data** – few number of highly reflective points. The measurement uncertainty on each point is low.
- **Temporary Distributed Scatterer (DS) data** – greater number of points, but the uncertainty on each point is higher.
  - *"Distributed"* because the whole pixels are being monitored rather than individual responses within pixels (as is monitored in PS InSAR). This adds a little more noise to the measurements but does allow us to increase the coverage.
  - *"Temporary"* because unlike traditional InSAR products the data has been processed to extract any valid measurement no matter what time period it covers – we could have anywhere from 0-100% of the time period covered.
- Movements measured are in the direction of the satellite line of sight (LOS), therefore, measurements are not providing purely horizontal or vertical measurement of motion, but a combination of both.
- The 'look' direction of the satellite and the orientation of the geotechnical feature (e.g. a N-S oriented soil slope vs an E-W oriented soil slope for example) can affect the number of favourable 'scatterers' available for data processing.
  - When satellite ascending orbit (travelling from south to north), then the line of sight is to the east
  - When the satellite is in descending orbit (travelling from north to south), the line of sight is to the west:



- Therefore, to understand/interpret the LOS measurement of offset, one must also know what the look direction of the satellite was and ideally the context of the offset (i.e. the expected sense of motion, magnitude of motion, etc.).

5.17 Data Processing & Analysis: InSAR

- **Persistent Scatterer (PS) results** (few number of highly reflective points. The spatial uncertainty on each point is low.)



VEL = average line of sight (LOS) displacement over a specific time period.

- The image on the left shows the M11 pilot site, with colour points representing the measurement 'VEL', which is the average LOS displacement over a specific time period.
- 19 points have been picked up on the carriageway, associated with 'high reflectivity' of the gantry (circled in image, zoom below).
- Most data points at the gantry record an average of -1.5 to -3.5 mm/yr subsidence in the LOS of the satellites, which were west-looking, so movement in this case was downward and/or from the east to the west.

5.18 Data Processing & Analysis: InSAR

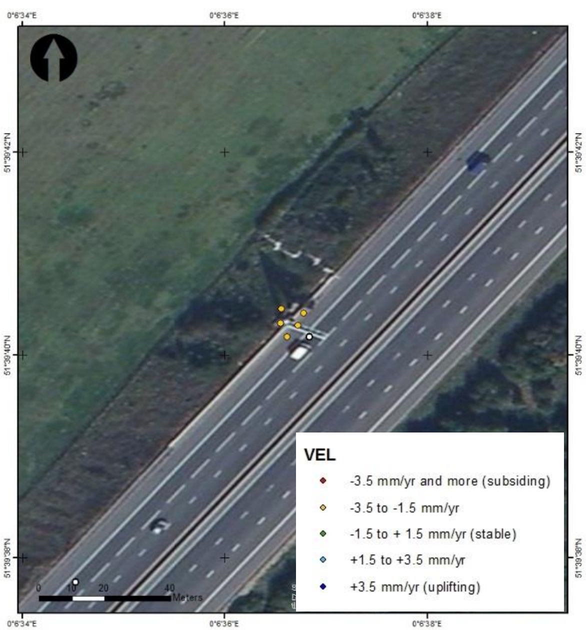
PS InSAR time-series data:

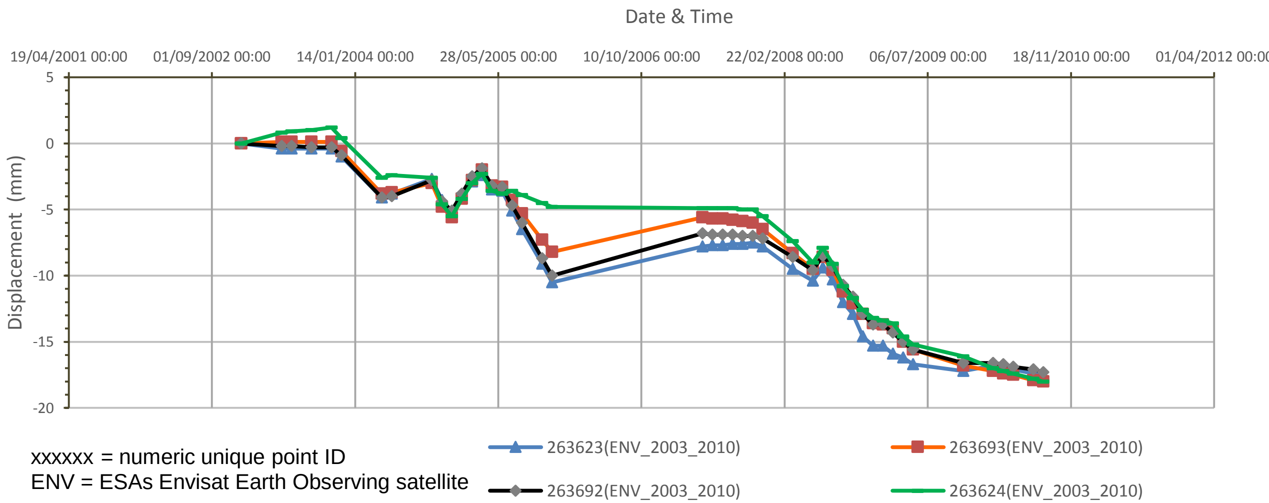
- The graph below shows how the different points at the carriageway gantry (shown in the map on the left) have moved over time (as opposed to an average of this movement, as is indicated by the colour of the point shown on the map).

- The points are spatially close and show similar time histories, this consistent behaviour adds certainty to the measurements.

- The time series indicates that apparent subsidence (of approximately 6-8 mm) occurred between 2008 and 2010.

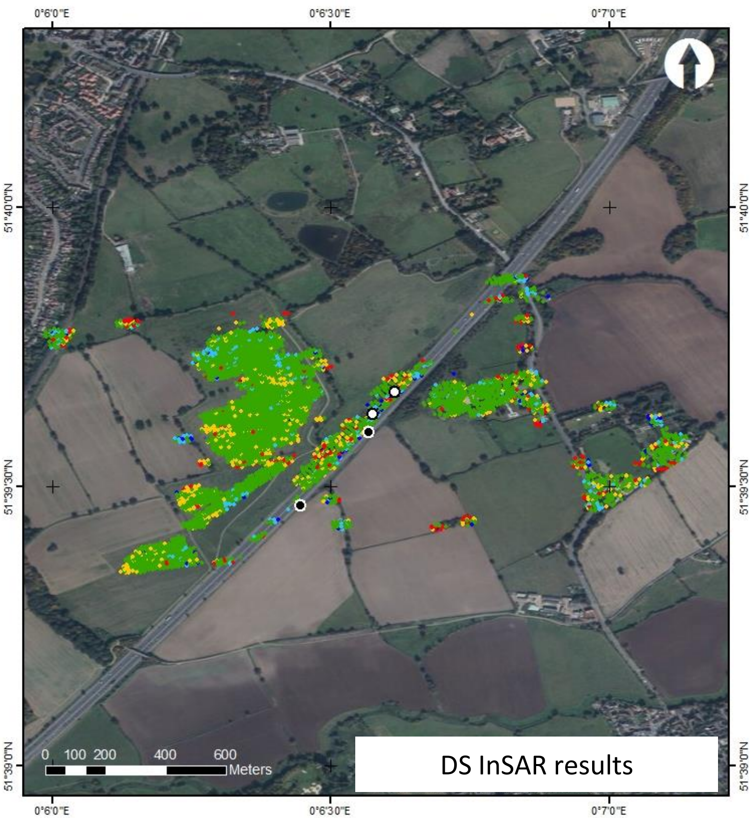
- This period of overall westward and downward motion could be consistent with ongoing slope failure of the NW-facing slope adjacent to the gantry. This observation is prior to the tension crack failure, which was first observed in the HAGDMS in 2012. However, is difficult to relate this subsidence to slope movement without ground measurements for the same time period to validate the remote-sensing measurement.





highways england

5.19 Data Processing & Analysis: InSAR



HAGDMS Geotechnical Observations

- obs_509169
- obs_13247

InSAR RS2 Time Series: 2010-Sep-2012 (pre-failure)

VEL

- -10 mm/yr and more (subsiding)
- -10 to -5 mm/yr
- -5 to +5 mm/yr
- +5 to +10 mm/yr
- +10 mm/yr and more (uplifting)

VEL = average line of sight (LOS) displacement over a specific time period.

DS InSAR results (Pre-failure)

The image on the left shows the M11 pilot site, with colour DS points representing the measurement 'VEL', which is the average satellite LOS displacement over a specific time period.

There is overall low point density and little/no data coverage on the southeast facing slope. Data spatial coverage is also limited. Relative to the PS results the point density is greater across the regional site area.

The lack of data can be related to:

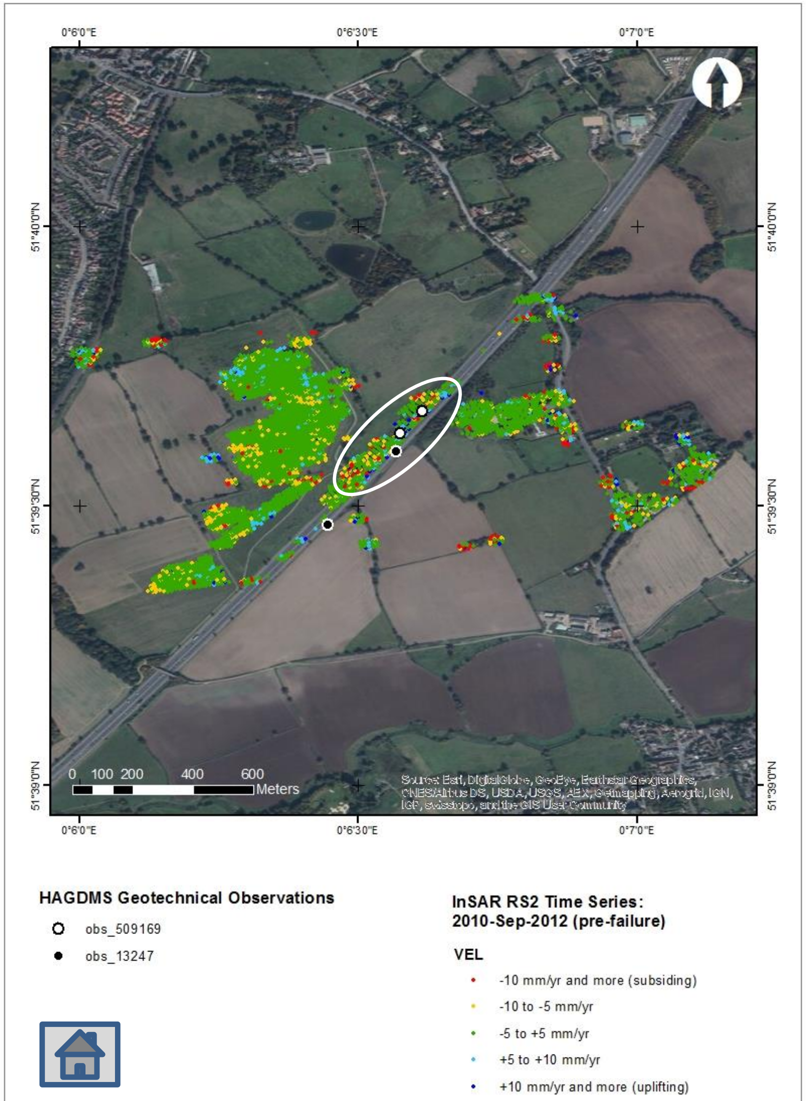
1) The satellite viewing geometry ('look direction') in general and relative to the orientation of the feature of interest.
2) Lack of good reflectors within the pixels.

highways england

5.20 Data Processing & Analysis: InSAR

DS InSAR (Pre-failure) general data observations:

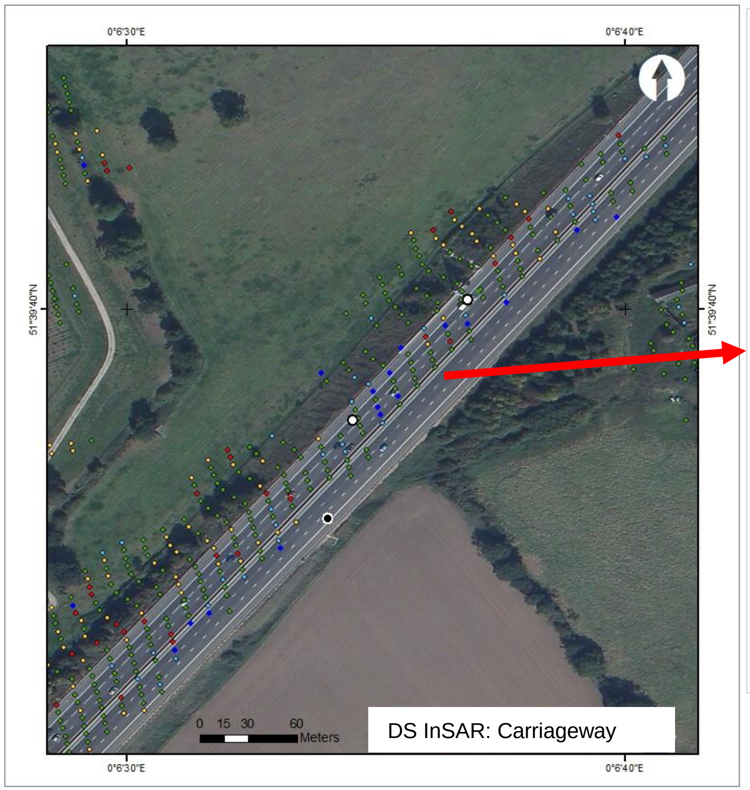
- Points covering the northwest-facing embankment show different amounts of average uplift and subsidence over the embankment:

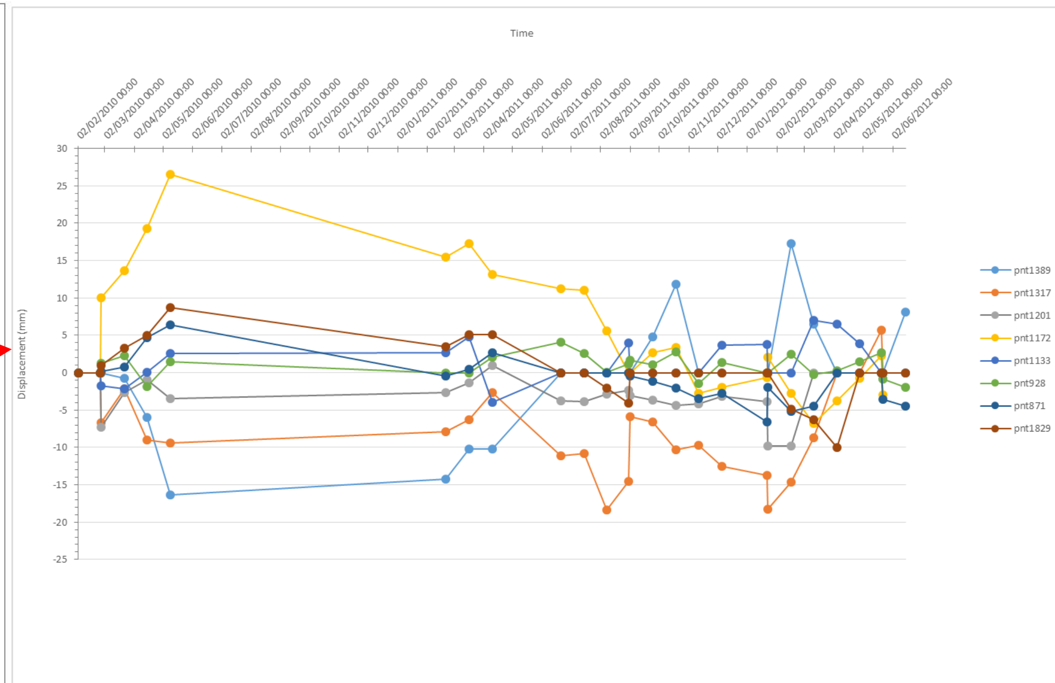


5.21 Data Processing & Analysis: InSAR

DS InSAR time-series data (Pre-failure) observations:

- Example of the time series data for a selection of average ‘stable’ (coloured green) DS points on the carriageway.
- Though the average motion is ‘stable’, variation in subsidence/uplift is observed for the different points over time.
- Hence, it is potentially misleading to report the average or ‘VEL’ for geotechnical/geological interests.

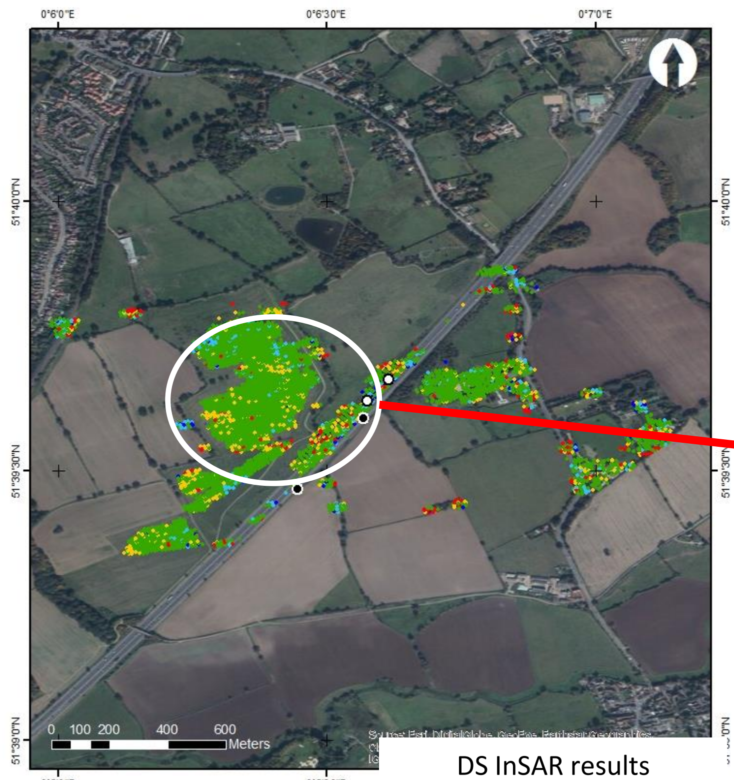




5.22 Data Processing & Analysis: InSAR

DS InSAR general data (Pre-failure) observations:

- Relatively high point density in the field
- Points also show different amounts of uplift/subsidence



DS InSAR results

HAGDMS Geotechnical Observations

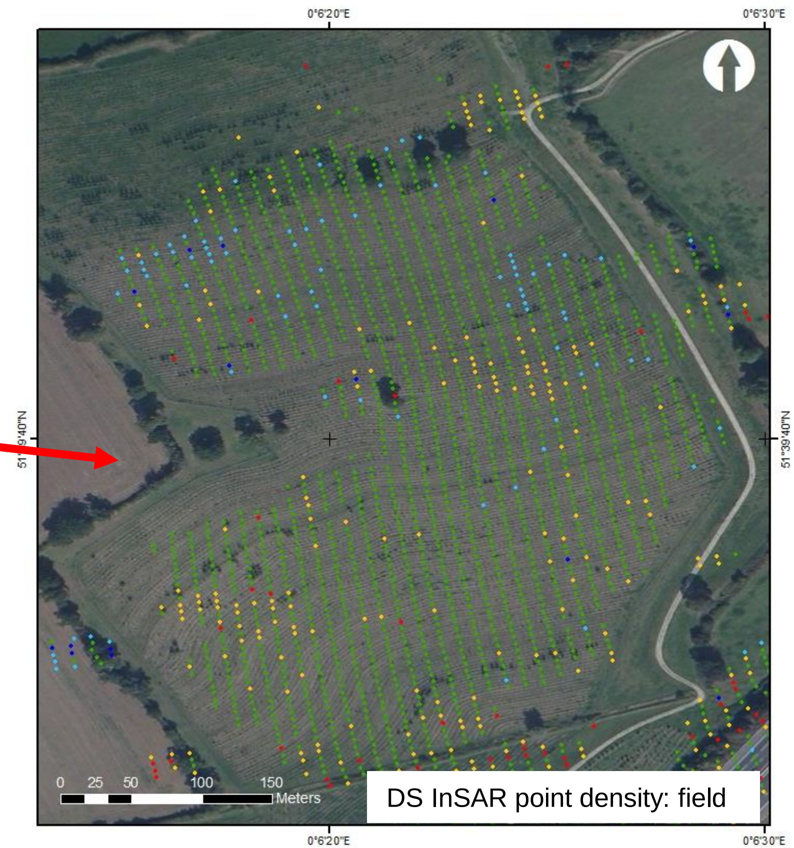
- obs_509169
- obs_13247

InSAR RS2 Time Series: 2010-Sep-2012 (pre-failure)

VEL

- -10 mm/yr and more (subsiding)
- -10 to -5 mm/yr
- -5 to +5 mm/yr
- +5 to +10 mm/yr
- +10 mm/yr and more (uplifting)

VEL = average line of sight (LOS) displacement over a specific time period.



DS InSAR point density: field

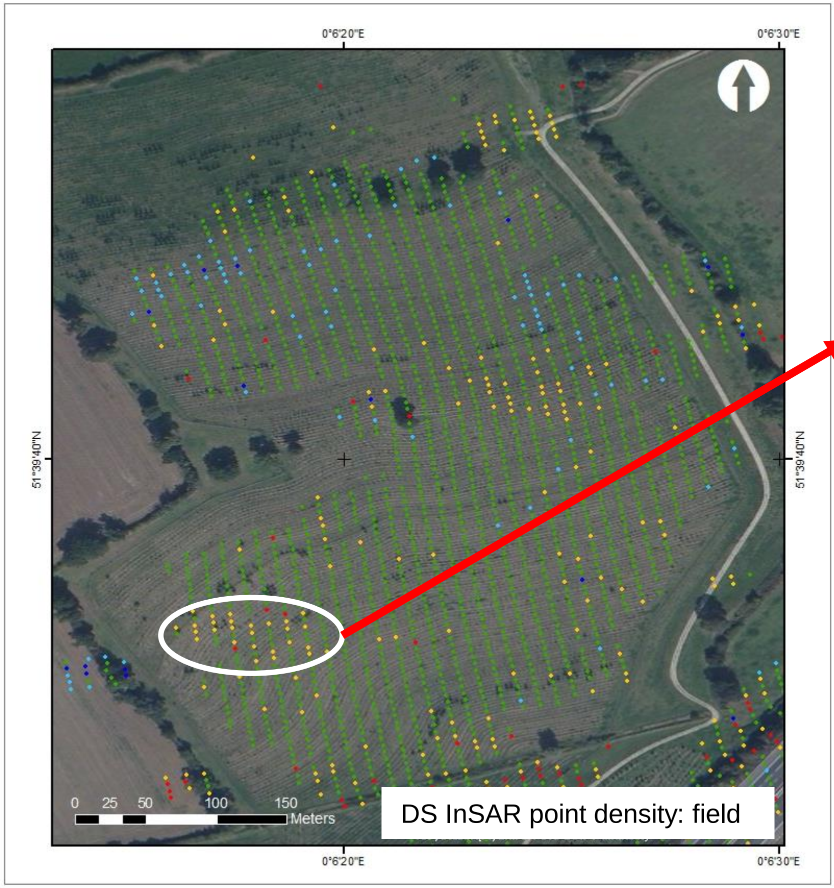
highways england

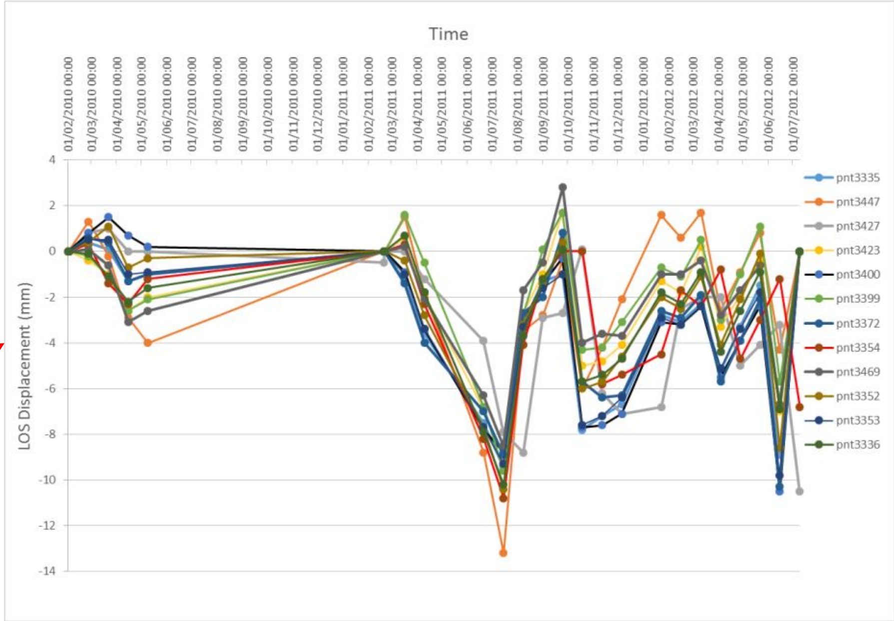
5.23 Data Processing & Analysis: InSAR

DS InSAR time series data (Pre-failure) observations:

- An example of time-series data for selection of average ‘subsiding’ points (coloured yellow) in SW of field. All points vary in terms of amount of uplift/subsidence over time, but with a largely similar pattern.

- This could indicate a possible seasonal effect associated with the increase/decrease of soil moisture content. But it is difficult to suggest this without more data over a longer time period, further analysis, and ground measurements to validate the remote sensing observation.





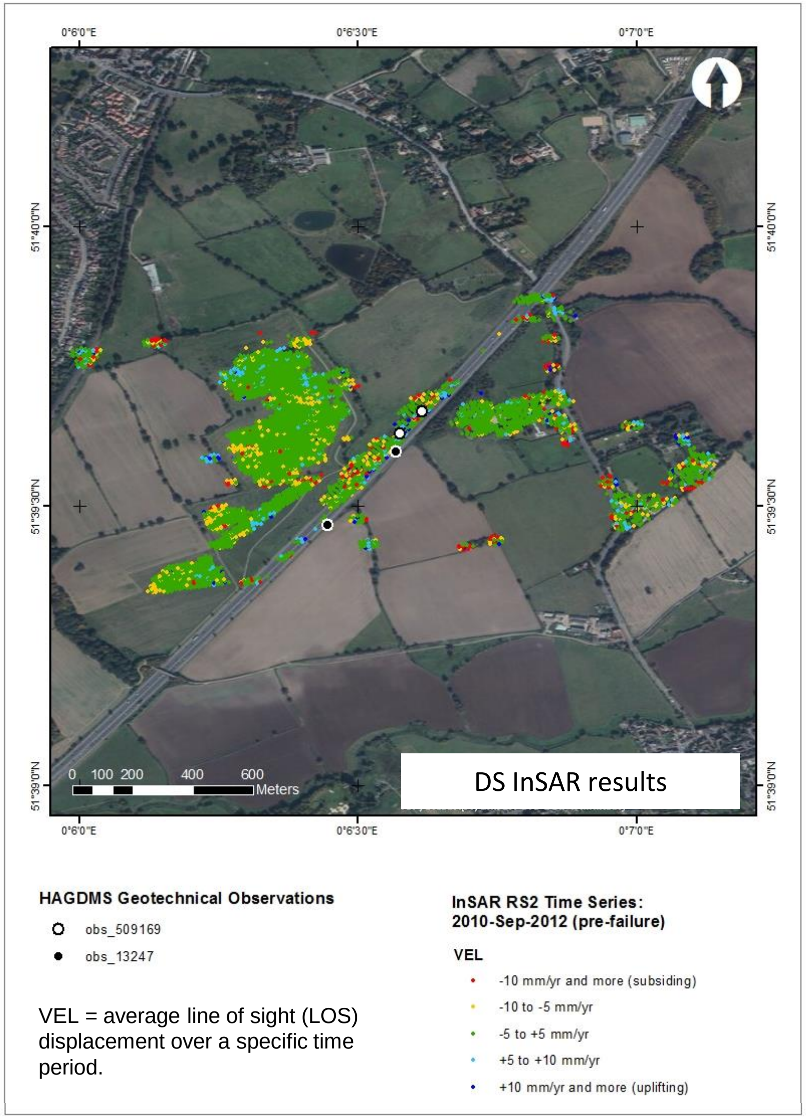
InSAR RS2 Time Series:
2010-Sep-2012 (pre-failure)

VEL

- -10 mm/yr and more (subsiding)
- -10 to -5 mm/yr
- -5 to +5 mm/yr
- +5 to +10 mm/yr
- +10 mm/yr and more (uplifting)

highways england

5.24 Data Processing & Analysis: InSAR



InSAR general data limitations:

- Though different amounts and senses (uplift/subsidence) of displacement have been detected in the PS and DS InSAR results for the study area, it is not possible to relate these observations with geotechnical observations/processes without having additional ‘ground truth’ data to confirm these offsets.

highways england

6.1 Overall Conclusions & Recommendations

Conclusions:

- Typically the 4cm resolution vertical colour aerial photography provided high enough resolution to resolve geotechnical features such as terracing on soil slopes and tension cracks in the pavement or carriageway.

- The 25cm and 12.5cm resolution national vertical colour aerial photography surveys, at least for this site, have too coarser resolution to resolve well the features as mentioned above.

- The freely available European Space Agency (ESA) Sentinel-2 multispectral satellite imagery has, at the highest, 10m pixel resolution, which is generally too coarse to resolve soil and rock slopes across the Network.

- Two different LiDAR datasets (the 2004 rotary-wing aerial 'LiDAR Framework' survey and the 2013 terrestrial Mobile Mapping System survey) were compared and assessed for evidence of height change related to geotechnical failures/ slope erosion/ degradation/ deposition over time:
    - In general, the aerial LiDAR survey has lower point density but better spatial coverage than the Mobile Mapping System survey
    - The sensor viewing geometry of the Mobile Mapping System can produce data gaps on embankments
    - The aerial LiDAR survey data is better classified than the Mobile Mapping System data. This has implications for what features can be interpreted within the data, such as vegetation, ground, signage, etc.
- Height change detection using the two LiDAR datasets shows promise but requires further work in order to quantify the 'real' height difference between the datasets, resulting from geotechnical processes, in addition to constraining the measurement errors, and data limitations relating to what types of features (soil slip, terracing, slope bulge, etc.) can be accurately resolved.

- InSAR data:
    - The Persistent Scatterer (PS) InSAR processing results had poor spatial coverage and low point density (typical for rural areas). Because of this it was not possible to associate the data with any type of geotechnical changes over time.
    - The Distributed Scatterer (DS) InSAR processing results have greater spatial coverage and point density relative to the PS data, but this is still considered limited and low, respectively. At this stage, it is not possible to relate the height changes recorded by the InSAR points to geotechnical feature changes.
    - Points coloured by **average subsidence/uplift** for a specific time period is not necessarily the best way to display the data for Highways England purposes (it can be misleading, as it is an average value).
    - Showing the point time series data is more informative, but displaying this data and analysing and interpreting it is more time consuming.
    - Overall, InSAR data requires specialist knowledge to process and requires both InSAR and geotechnical knowledge to
    - interpret.

6.2 Overall Conclusions & Recommendations

Recommendations:

- The InSAR data in this Pilot had relatively limited spatial coverage and point density, which is typical of rural areas that have few strong reflectors (such as building corners). It was therefore difficult to associate the remote sensing data with geotechnical features of interest. However, in other published research studies, InSAR has shown potential for monitoring regional subsidence/uplift in rural areas. At this stage, our recommendation is that further work needs to be done to refine the InSAR processing technique in rural areas such that more data is available for interpretation.

- The findings of this Pilot indicate that the best combination of remote sensing data to assess high-risk soil slopes over time would be a combination of aerial LiDAR survey data and high-resolution (4cm) vertical aerial photography.

- In this example, vertical aerial photography was successful, however, this may not be the case for more densely vegetated slopes.

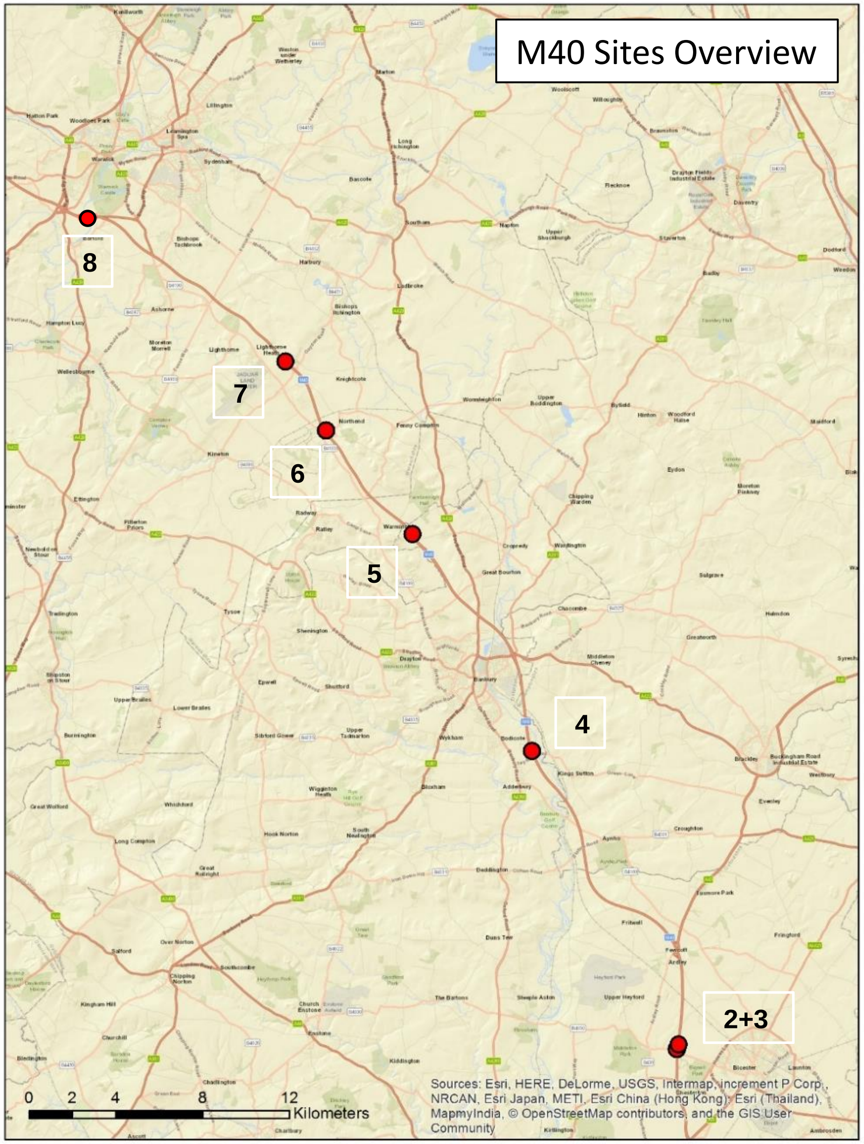
- The time of year for the aerial photography surveys should be planned for favourable light and vegetation conditions.

M40 Various Geotechnical Risk Sites – Hyperspectral Imagery

Phase 2 Pilot Study 2017

SPaTS 1-086 Application of remote survey data for Geotechnical asset condition and performance

1. Introduction



This document represents one of a series of pilot studies undertaken for Phase 2 of the SPaTS 1-086 project '*Application of remote survey data for geotechnical asset condition and performance*'.

These studies present an evaluation of the use of available selected remote-sensing survey data in both management and condition monitoring of Highways England geotechnical assets.

For this study potential geotechnical risk sites along the **M40** were shortlisted, the locations of which are shown in the figure. After a high-level review of the 2016 aerial imagery and 25 cm contour data (derived from the LiDAR point cloud) a number of the sites have been selected for further investigation in this pilot to assess the Mobile Mapping System and aerial LiDAR and the **hyperspectral data.**

Cyient carried out data processing of the hyperspectral imagery. For further information and background about the hyperspectral data, please refer to the Cyient presentation appended.

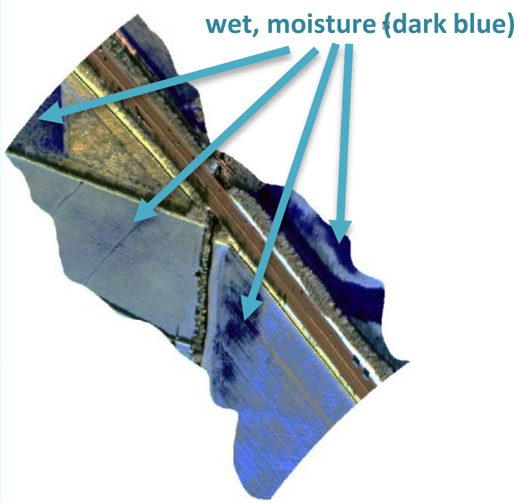
This document is structured as follows:

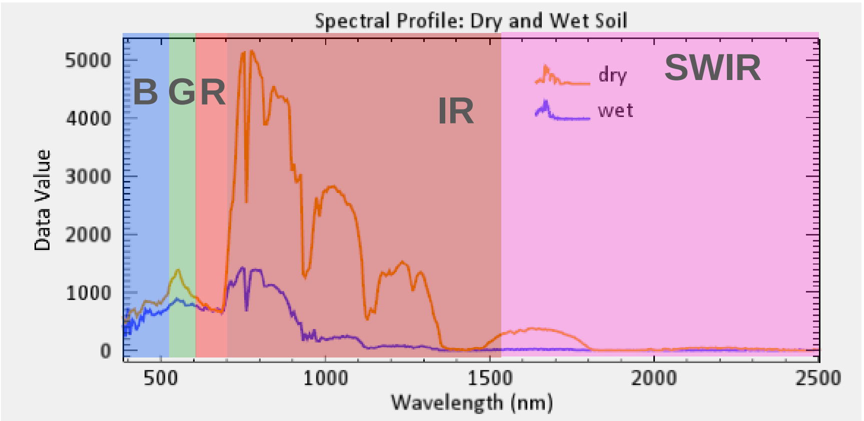
Click on the 'Home' button to get back to this slide

2. Using Hyperspectral Data to Characterise Soil Moisture and Vegetation

– **RGB Band Combination**

– **SWIR Band Combination**





– M40 Hyperspectral Data at 456625, 217714

- Bare soil; vegetation cover may obstruct soil analysis
- THEORY: As soil moisture increases, reflectance/data value of soil decreases at all wavelengths
- THEORY: The SWIR (Short Wavelength Infra Red) & IR (Infra Red) band combination used to find moisture characteristics of soil and vegetation

highways england

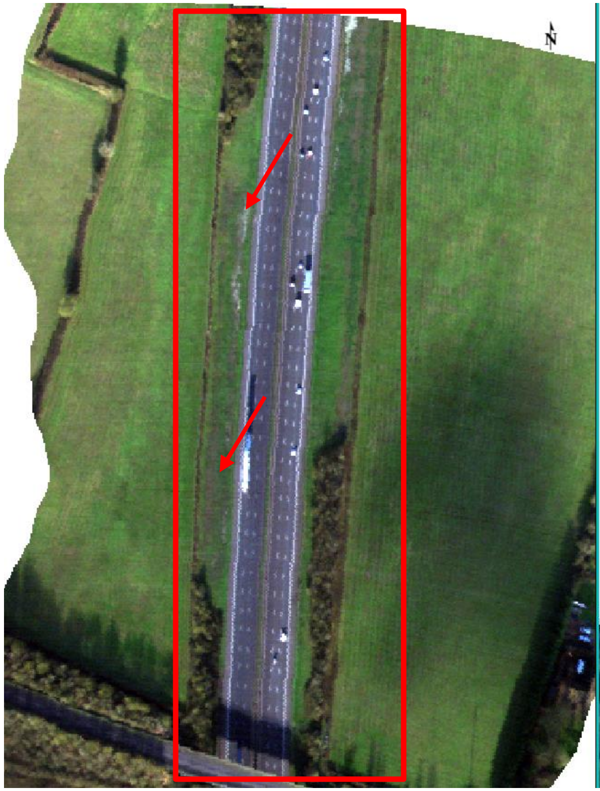
3. Data Review

The following datasets have been used for this pilot study:

Hyperspectral data	2016 rotary-wing survey data
• Date of capture was 15th January 2016 • Time of capture was between approximately 12.30 - 1.30pm • 363 Bands • Survey by Blom • 0.75-1m pixel resolution	including: • LiDAR pointcloud • Digital surface model (DSM) • Digital terrain model (DTM) • 25cm contours derived from LiDAR • Slope map • Orthophotos

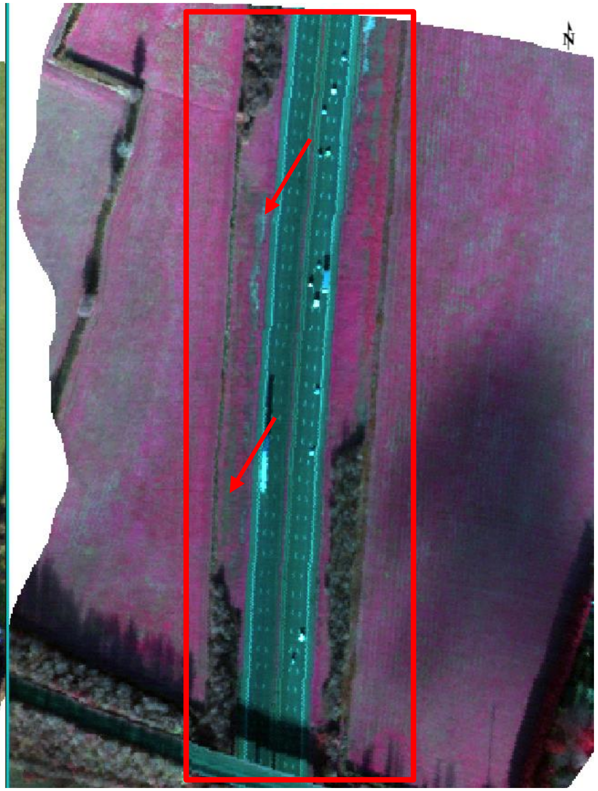
4.1 Site Description & Geotechnical Risk: M40 Site 2 + 3

Site 8: **Cutting slope Northbound side MP 101.7** **Grid ref: SP 54732 23618** **[UTM: 30U 623400mE 5750927mN]**



Band 38 (636.8100)
Band 25 (547.7700)
Band 14 (472.9500)

RGB Band Combination
Landscape in its natural colours



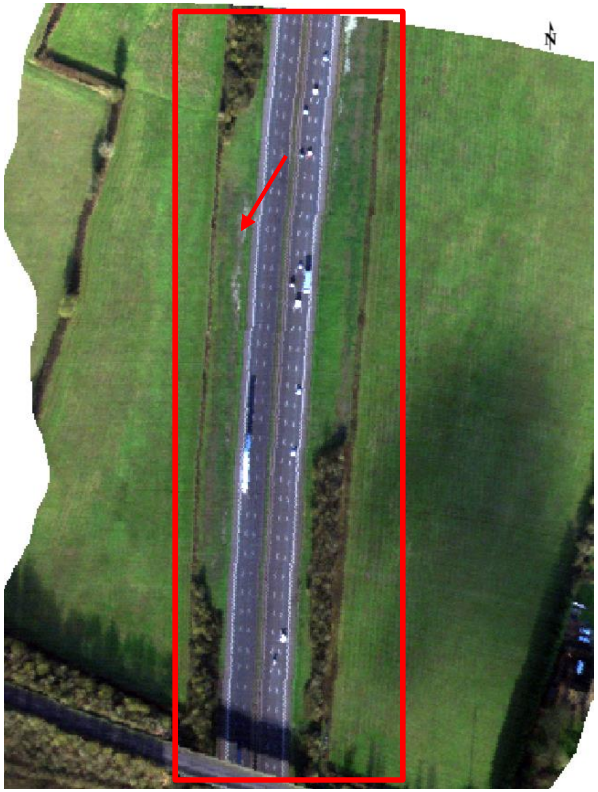
Band 70 (856.6400)
Band 40 (650.5400)
Band 25 (547.7700)

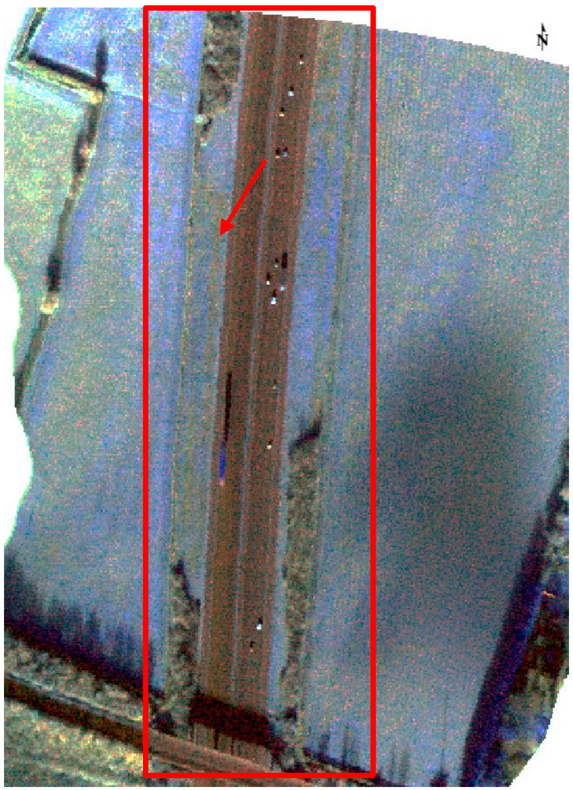
- **CIR (Colour Infra Red) Band Combination**
- Vegetation appears in shades of Red
- Useful band combination for vegetation studies and soil patterns

- Cutting slope. Bare or patchy ground cover / thinning grass.
- Imagery from 2009 – 2016, grass not re-establishing

highways england

4.2 Site Description & Geotechnical Risk: M40 Site 2 + 3





- **SWIR & IR (Short Wave Infra Red and Infra Red) Band Combination**
- SWIR & IR bands highlight different spectral signature between vegetated/ non-vegetated parts of the cutting.
- Possibly the hyperspectral can characterize between wet and dry (high moisture content/ low moisture content) soils.

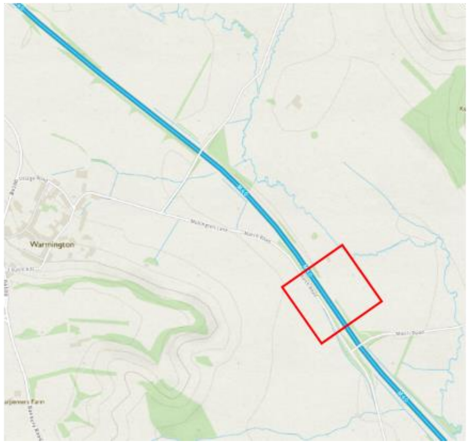
RGB Band Combination

Landscape in its natural colours

5. Site Description & Geotechnical Risk:
M40 Site 5

Site 5: Cutting slope Southbound side MP 130.4 Grid ref: SP 42512 47424 [UTM: 30U 610866mE 5776018mN]

- Possible cutting slope failure developing. Feature highlighted looks like a tension crack or small back scar with a slight dip in the slope just below this and a slight bulge lower down the slope

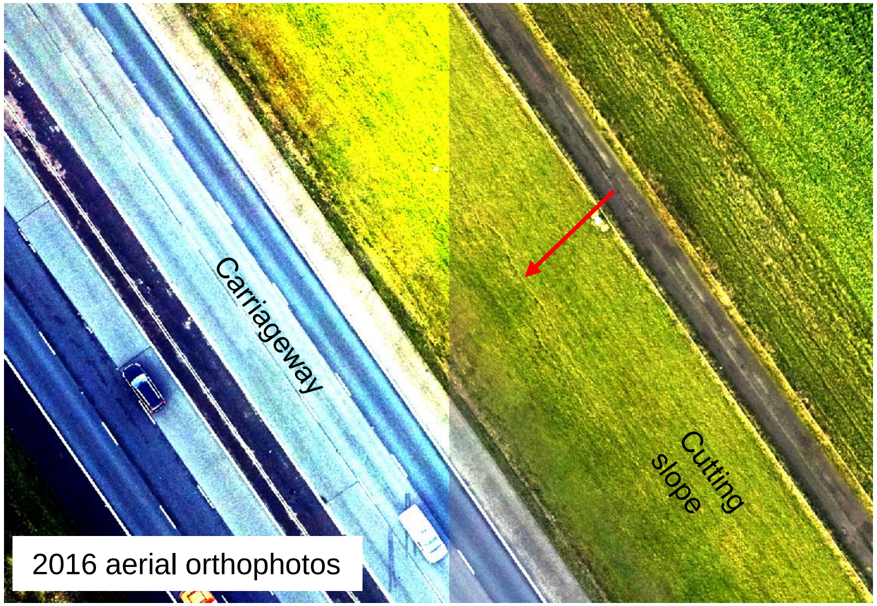


highways england

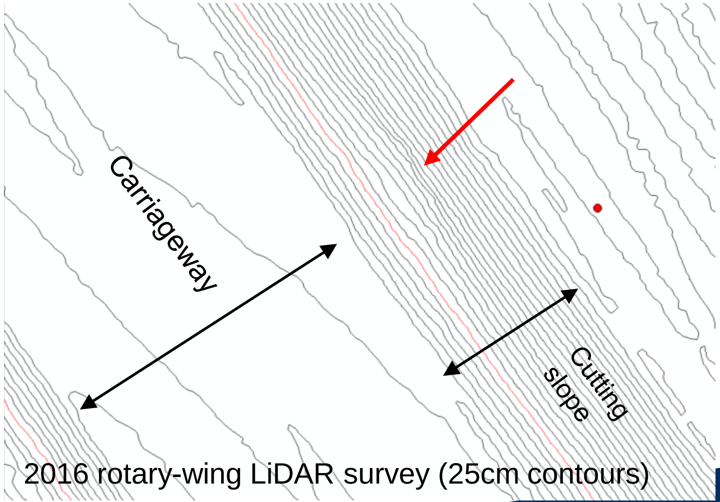
6.1 Data Analysis M40 Site 5: 2016 Rotary-wing LiDAR contours + orthophotos

Site 5: Cutting slope Southbound side MP 130.4 Grid ref: SP 42512 47424 [UTM: 30U 610866mE 5776018mN]

- Tension crack or small back scar with a slight dip in the slope just below this and a slight bulge lower down the slope
- Captured very clearly in the 25cm LiDAR contours and less well in the orthophotos.



2016 aerial orthophotos



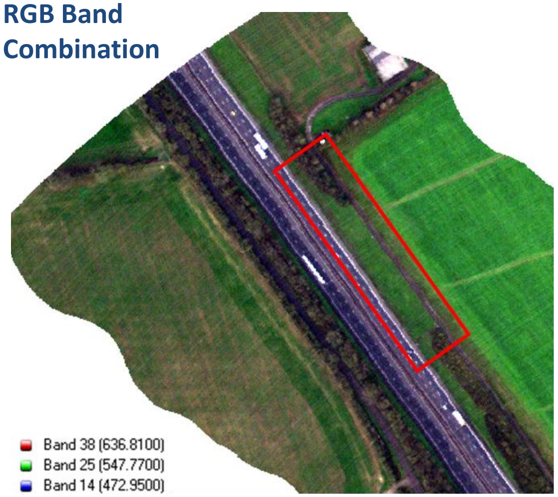
2016 rotary-wing LiDAR survey (25cm contours)

6.2 Data Analysis M40 Site 5: 2016 Rotary-wing Hyperspectral Imagery

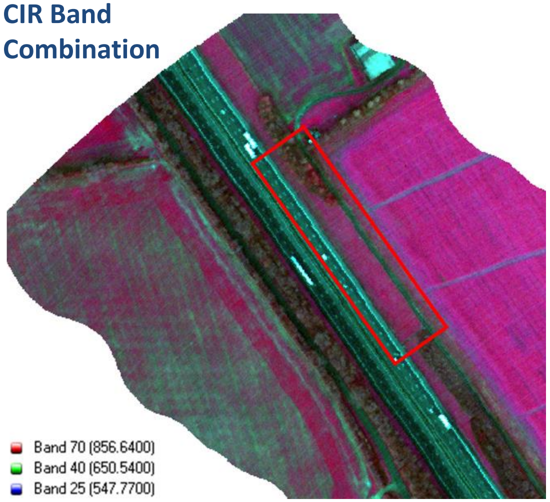
Site 5: Cutting slope Southbound side MP 130.4 Grid ref: SP 42512 47424 [UTM: 30U 610866mE 5776018mN]

- In the figures of the different hyperspectral band combinations shown below, the tension crack or small back scar with a slight dip in the slope just below this and a slight bulge lower down the slope is not visible.
- This is likely to be because the resolution of the imagery is too low.

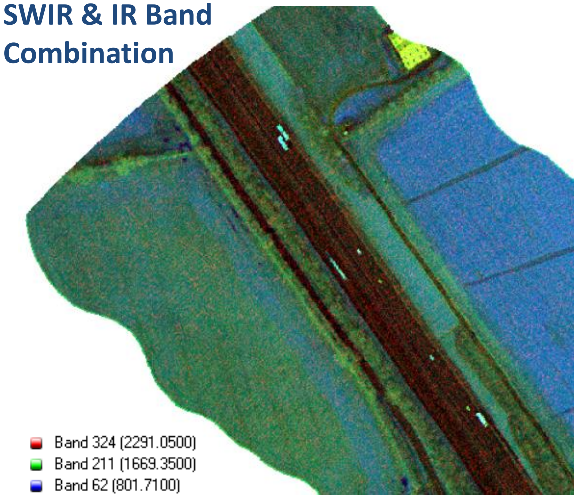
RGB Band Combination



CIR Band Combination



SWIR & IR Band Combination



7. Site Description & Geotechnical Risk: M40 Site 7

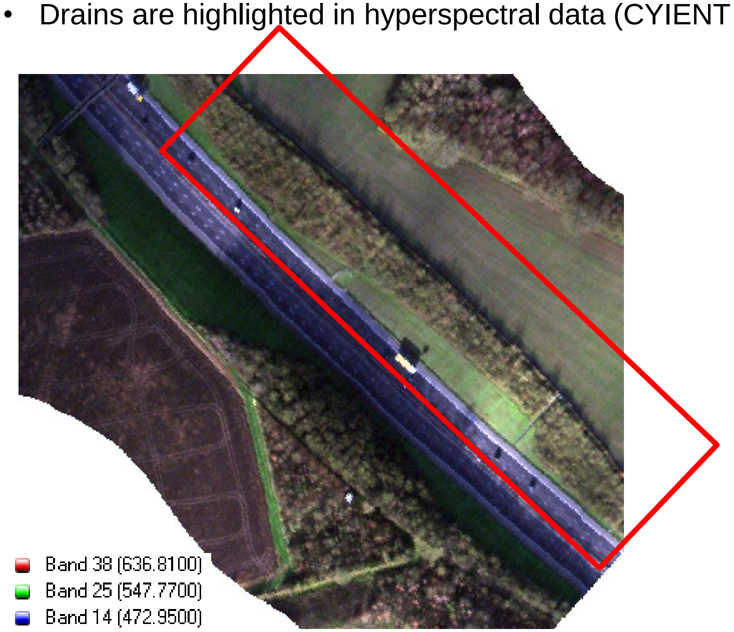
Site 7: Cutting slope Southbound side MP 140.4   Grid ref: SP 36660 55438   [UTM: 30U 604888 mE 5783958 mN]

- Assumed to be a set of parallel counterfort trench drains installed in cutting slope. Likely as a remedial measure due to poor slope drainage and / or slope instability.

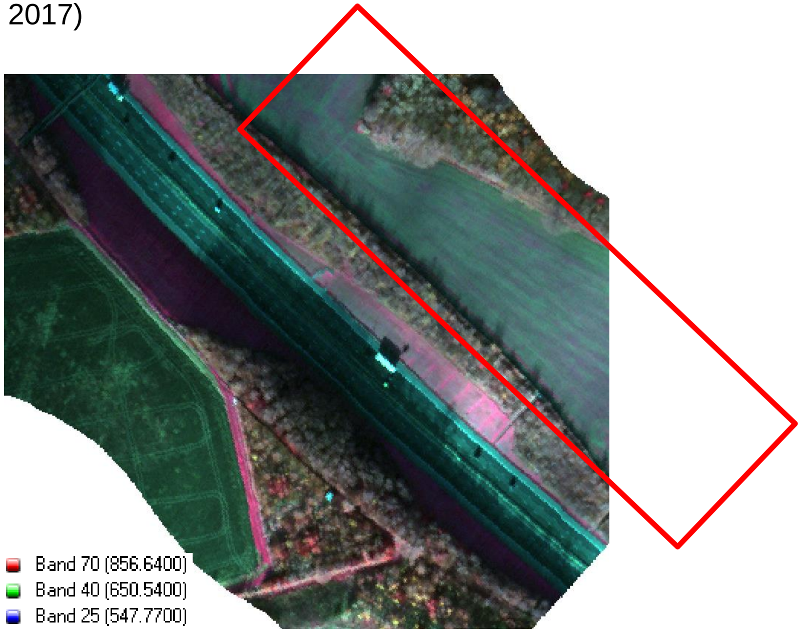
8.1 Data Processing & Analysis M40 Site 7: Hyperspectral Imagery

Site 7: Cutting slope Southbound side MP 140.4   Grid ref: SP 36660 55438   [UTM: 30U 604888 mE 5783958 mN]

- Assumed to be a set of parallel counterfort trench drains installed in cutting slope. Likely as a remedial measure due to poor slope drainage and / or slope instability.
- Drains are highlighted in hyperspectral data (CYIENT © 2017)



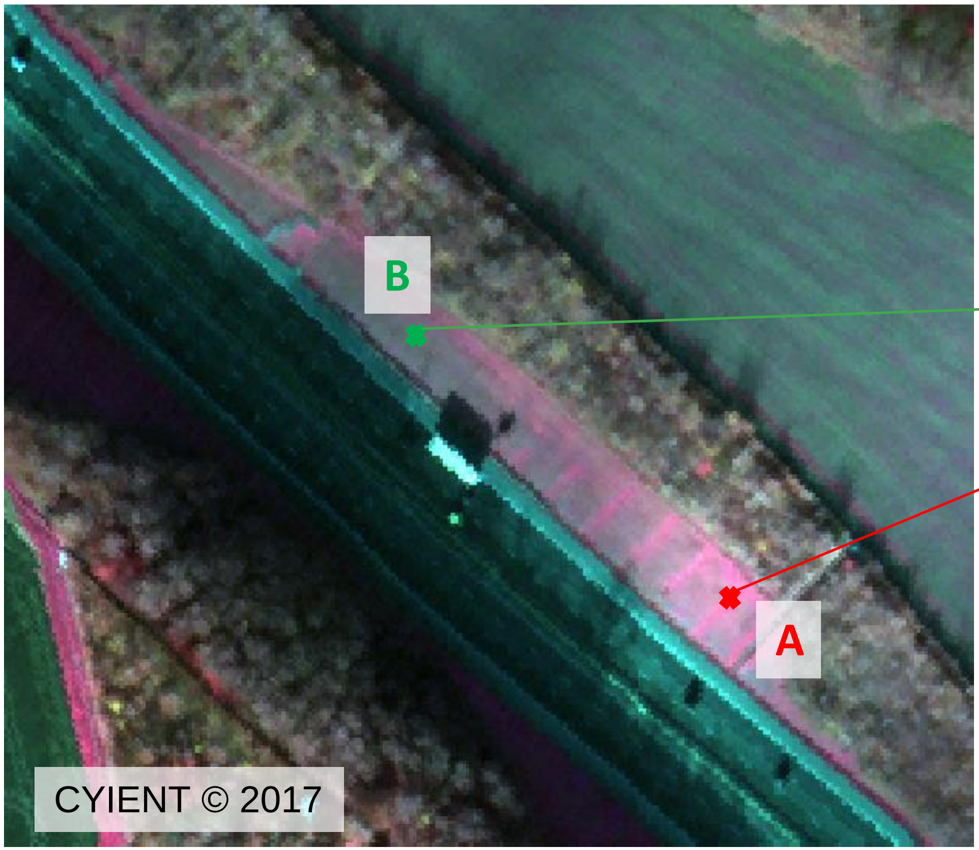
- **RGB Band Combination**
- Landscape in its natural colours

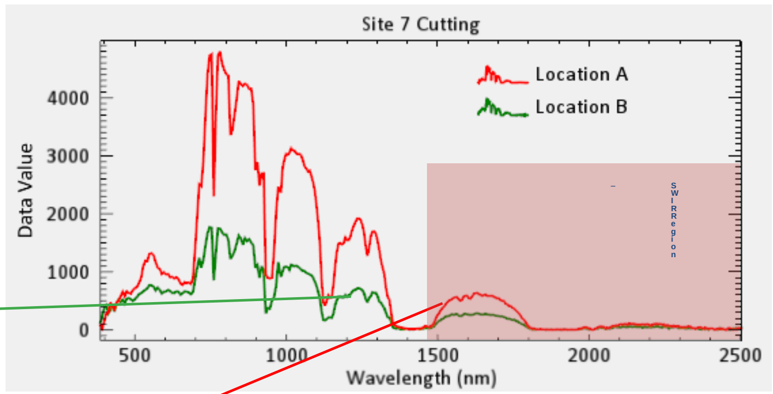


- **CIR (Colour Infra Red) Band Combination**
- Vegetation appears in shades of Red
- Useful band combination for vegetation studies, monitoring drainage and soil patterns

8.2 Data & Processing M40 Site 7: Hyperspectral Imagery

Site 7: Cutting slope Southbound side MP 140.4 Grid ref: SP 36660 55438 [UTM: 30U 604888 mE 5783958 mN]



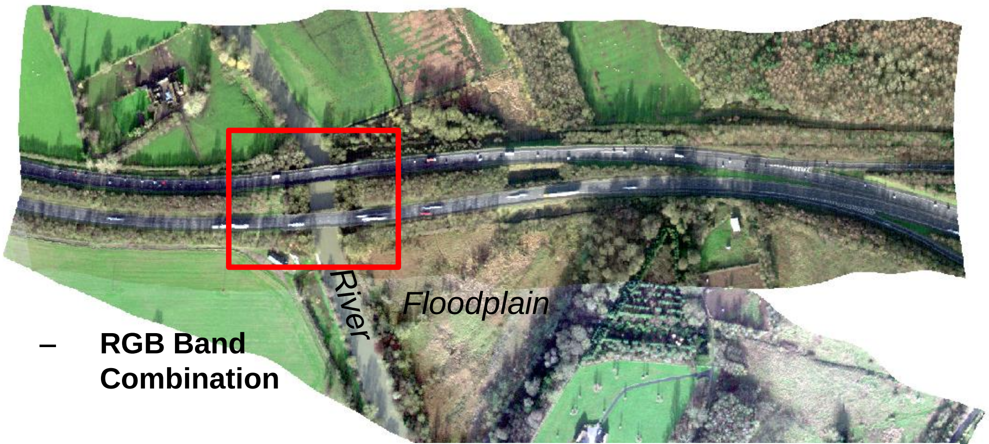


- **Location A** – appears as less moisture, i.e. drier, higher profile in SWIR region
- **Location B** – appears as more moisture, i.e. wetter, lower profile in SWIR region

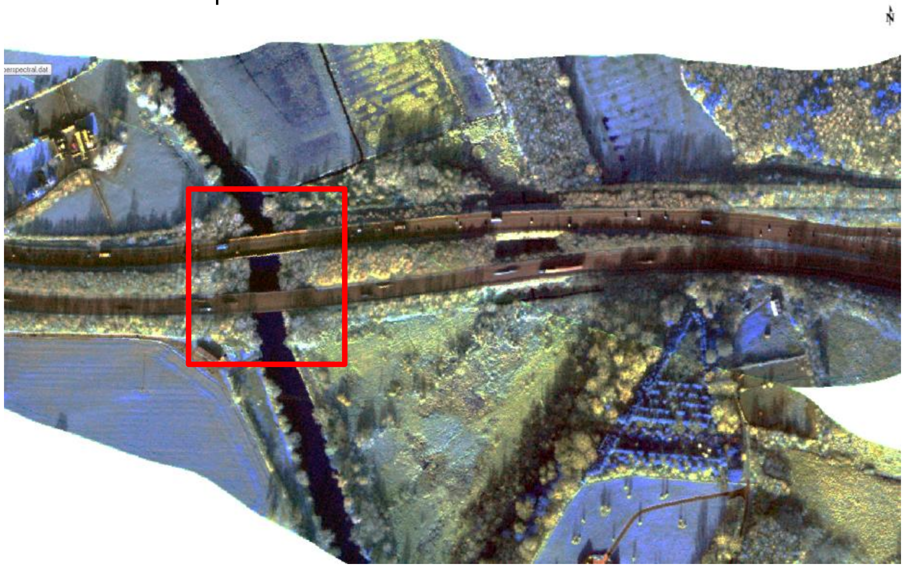
9. Site Description & Geotechnical Risk: M40 Site 8

Site 8: Embankment & floodplain interaction **Grid ref: SP 427508 262158** **[UTM: 30U 595664 mE 5790539 mN]**

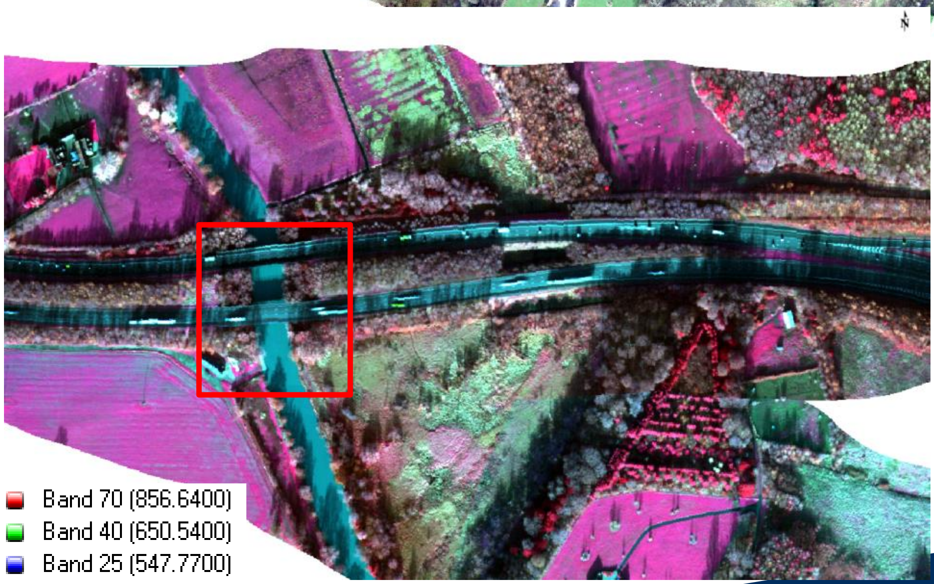
- This site is of interest because it shows an area where the carriageway intersects with a river and also crosses the river flood plain. High soil-moisture content is a key precursory signal for potential slope failure, therefore, the aim at this site was to assess whether the hyperspectral data could provide information on the variation of soil moisture content in different areas of the flood plain.



– **RGB Band Combination**



– **SWIR & IR Band Combination (Above)**
  - The flood plain soil-moisture signal is not obviously high (not dark or bright blue)
  - Suggests the soil of the flood plain is either not highly saturated or that the signal is masked by vegetation.



– **CIR Band Combination (Left)**
  - The health of the vegetation on the surrounding floodplain shown to vary significantly

10. Overall Conclusions and Recommendations

- The review has investigated the outputs from an airborne hyperspectral imaging survey carried out along the M40 motorway for Highways England. The survey was produced by the Asset Information Group together with rotary wing LiDAR and high resolution (4cm) orthophotos. The hyperspectral component was on a trial basis to allow potential benefits of this type of sensor to be investigated. It is thought that this review forms the first feedback received on the dataset.
- The survey was carried out in January 2016 – an ideal time for slope mapping with the LiDAR sensor and to collect photography (due to 'bare' tree canopy condition) but not for the hyperspectral sensor which operates better with the higher sun angles and clearer days when the illumination is increased and shadows are minimised. This provides a stronger reflectance from the surveyed area.
- The spatial resolution of the hyperspectral imagery is between 75 to 100 cm. This is generally too coarse for many targets of geotechnical asset inspections. Aerial hyperspectral systems with higher resolutions are not currently available but it is expected that this will develop in the future. A resolution of 50-25 cm may be more appropriate for monitoring many of the assets of interest with reasonable detail for change detection. The required resolution of the imagery depends on the scale of the assets of interest. This should be advised through discussion with the specialists carrying out the survey.
- However hyperspectral imagery shows some potential for identification of slope drainage features which may not otherwise be identified, or be more difficult to identify in the visible wavelength part of the spectrum. The site 7 example reviewed during this study showed that the (buried and grassed over) counterfort slope drains were highly visible in the CIR (colour infra red) wavelengths, and to a slightly lesser extent in the SWIR (short wave infra red) wavelengths.
- Another interesting observation is that the SWIR outputs appear to show the section of the slope with the drains was drier than the areas without drainage. Whether this facility would allow elevated slope moisture contents to be identified at a larger scale up to network wide scale would require much more investigation across a range of different sites potentially during different seasonal conditions together with ground-truthing.
- The site 5 example with the small cutting slope slip did not identify any differences in the hyperspectral imagery or in the spectral response curves across the slipped area. Whether this is due to no differences in moisture content inside and outside the slip is not known. There was no definition of the slip profile in any of the imagery.
- Using vegetation as a proxy for soil moisture content is not possible because there is not a straight forward relationship between these two variables (high soil moisture content does not necessarily equal denser or more healthy vegetation).
- The Site 8 example shows that vegetation health is more readily assessed in the CIR hyperspectral than with the simple visible RGB image.

M40 Stokenchurch Gap

Phase 2 Pilot Study 2017

SPaTS 1-086 Application of remote survey data for Geotechnical asset condition and performance

1. Introduction

This document represents one of a series of pilot studies undertaken for SPaTS Task 1-086 '*Application of remote survey data for geotechnical asset condition and performance*'.

These studies present an evaluation of the use of remote survey data, utilising data currently procured by Highways England as well as emerging datasets that may be of additional benefit to the organisation in the management of their geotechnical assets.

This specific study focuses on the area of the Stokenchurch Gap, M40, between mile markers 65/4 and 64/6. This study area has been identified as an area of either current high risk or having had a previous history of geotechnical problems during its life. Furthermore, this location and the M40 in general has been a trial site for the procurement of a number of remote survey activities. Therefore, it provides an ideal location to look at multiple datasets and changes over time.

This document is structured as follows:

Please see other supporting documents for further information.

Click on the 'Home' button to get back to this slide

2. Site Location and Description

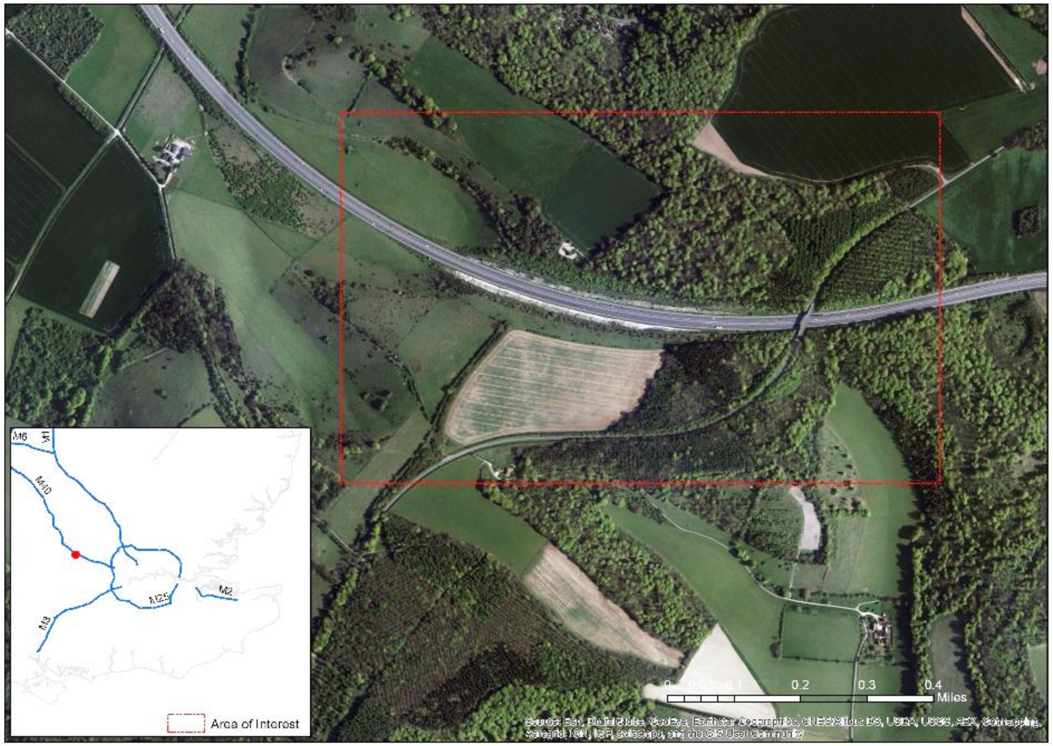
Stokenchurch Gap is a steep sided chalk cutting, constructed through the Chiltern Hills near to the village of Stokenchurch.

It was constructed during the building of the M40 motorway in the early 1970s and is situated between junctions 5 and 6.

The cutting is a Site of Special Scientific Interest (SSSI), due to it providing a stratigraphic view of the Upper Chalk Succession. The area is also within an Area of Outstanding Natural Beauty (AONB).

The cutting is approximately 1,200m long and 47m in depth at its deepest point.

A two by three lane carriageway passes through the cutting, which links the M42, Oxford and Warwick with the M25 and London.



3.1 Geotechnical Risk

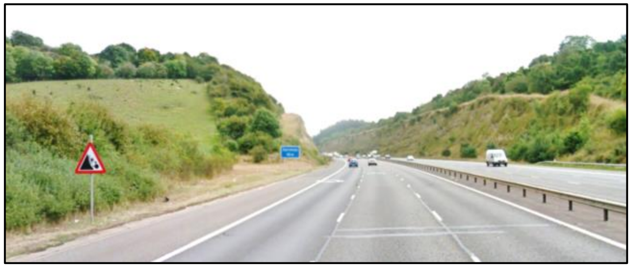
Geotechnical data was not available for this specific site on HA GDMS, due to the M40s DBFO status. Such information would have provided an understanding of prior geotechnical issues at Stokenchurch Gap.

However, from a review of imagery (i.e. Google Street View), it is evident that significant chalk weathering has led to the ravelling of the cutting face. Especially, when comparing a recent image to the time of or just after construction (approximately early 1970s) – see next page for images. Accumulation of chalk rock material at the toe of the cutting is indicative of this ravelling process.

The base of the cutting has seen the installation of a catch fence (a special geotechnical measure of unknown installation date) that has been installed (see top right image) and is situated on each side of the carriageway. Rockfall warning signs have also been placed at the location (see bottom right).

Collectively, this suggests that there a significant geotechnical risk at the location that could result in geotechnical asset performance issues, impede traffic flows or cause serious harm to road users if adequate geotechnical monitoring and investigation are not routinely undertaken.

Cutting view, M40 Southbound (Source: Google Maps, Sep 2016)



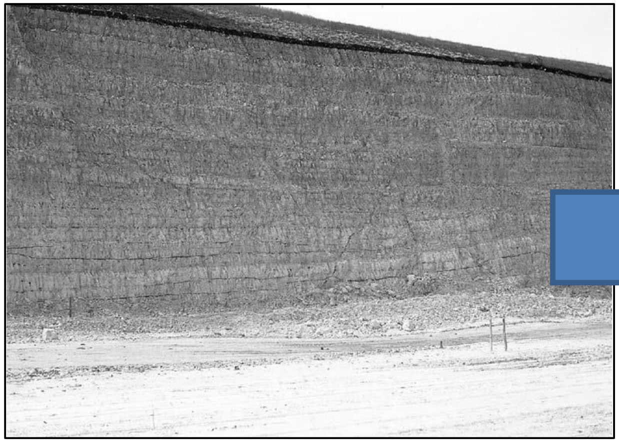
Rockfall hazard warning sign, M40 Southbound (Source: Google Maps, Sep 2016)

3.2 Geotechnical Risk: Then and Now

The images below present an idea of the deterioration that has taken place at Stokenchurch gap since its construction.

Cutting shortly after construction (Source: R Mortimore)

Google Streetview, Sep 2016 (Source: Google)



Cutting during construction (Source: CJ Wood)

Google Streetview, Sep 2016 (Source: Google)

Early photo source:
http://jncc.defra.gov.uk/pdf/gcrdb/GCRsiteaccount198.pdf

4.1 Data Review

This section presents an overview of the remote survey data that can potentially be used to support Highways England in applying the use of remote sensing to improve the inspection regime and reduce primary (e.g. rockfalls) and secondary (worker and customer exposure) risk at Stokenchurch Gap.

This data assessment will also be used to provide an understanding of how these techniques can be applied to other geotechnical 'cutting' assets across the network, by identifying the advantages and disadvantages of each method.

For the purposes of this pilot study, four key datasets are being investigated, which include:

- Aerial imagery
- AVIS viewer
- Light Detection and Ranging (LiDAR)
- Multispectral imagery
- Hyperspectral imagery

A more detailed description of these datasets and their properties are further detailed in the table on the following page. Further details on their application at Stokenchurch Gap is providing in the proceding sections.

4.2 Data Review

This section of the M40 was chosen as it has associated a number of remote survey datasets, which have been identified as having a particular use for geotechnical asset monitoring.

Data sources made available for this pilot study are summarised in the table below. With the exception of the multispectral data, all other datasets had previously been procured by Highways England; however, not for a specific geotechnical purpose.

Data Type	Instrument (if known)	Airborne/Terrestrial/Space	Spatial Resolution	Date(s) collected	Additional information
LiDAR	Mobile Mapping System	Terrestrial	Range	2015	Mobile Mapping System/IBI Group
LiDAR	Mobile Mapping System	Terrestrial	Range	2013	Mobile Mapping System/IBI Group
LiDAR	Rotary Wing	Airborne	Range	2015	Blom
Hyperspectral	Rotary Wing	Airborne	0.75m	2015	Blom
Multispectral	Sentinel 2A	Space	30m	2016, 2017	European Space Agency
Aerial Imagery	Rotary Wing	Airborne	5cm	2015	Blom

5.1.1 Data Processing and analysis: Aerial imagery

As part of the 2015 rotary wing survey of the M40, aerial imagery was captured at a 5cm resolution. An extract of this data for the area of Stokenchurch Gap is presented above.

An example of how this imagery can be used for geotechnical asset inspection and monitoring is described in the following pages.

5.1.2 Data processing and analysis: Aerial imagery

From a review of the aerial imagery available at Stokenchurch Gap, a number of features can be seen. This is due to the high spatial resolution (i.e. 5cm) of the imagery obtained.

In particular, the example in the picture (see right) is identified. This shows a likely rockfall that has caused several rock fragments to have fallen downslope from the crest of the cutting.

A zoomed in view of the area highlighted by the red dashed line circle is presented on the following page.

Potential rockfall – whiter material indicating fresh ‘unweathered’ chalk?

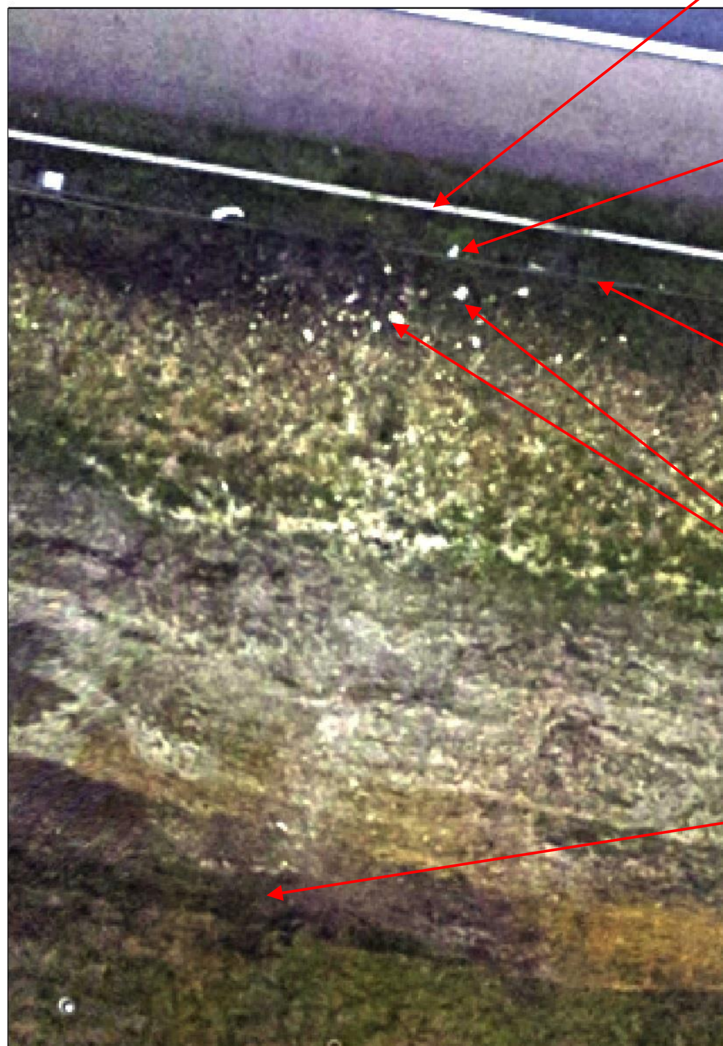
5.1.3 Data processing and analysis: Aerial imagery

The view presented on the right represents a zoomed in view of the rockfall identified in the previous image.

This image demonstrates the high spatial resolution of the aerial photography obtained during the rotary wing survey in 2015. The rockfall mitigation fencing and vehicle restraint barrier can be clearly seen despite their narrow profiles.

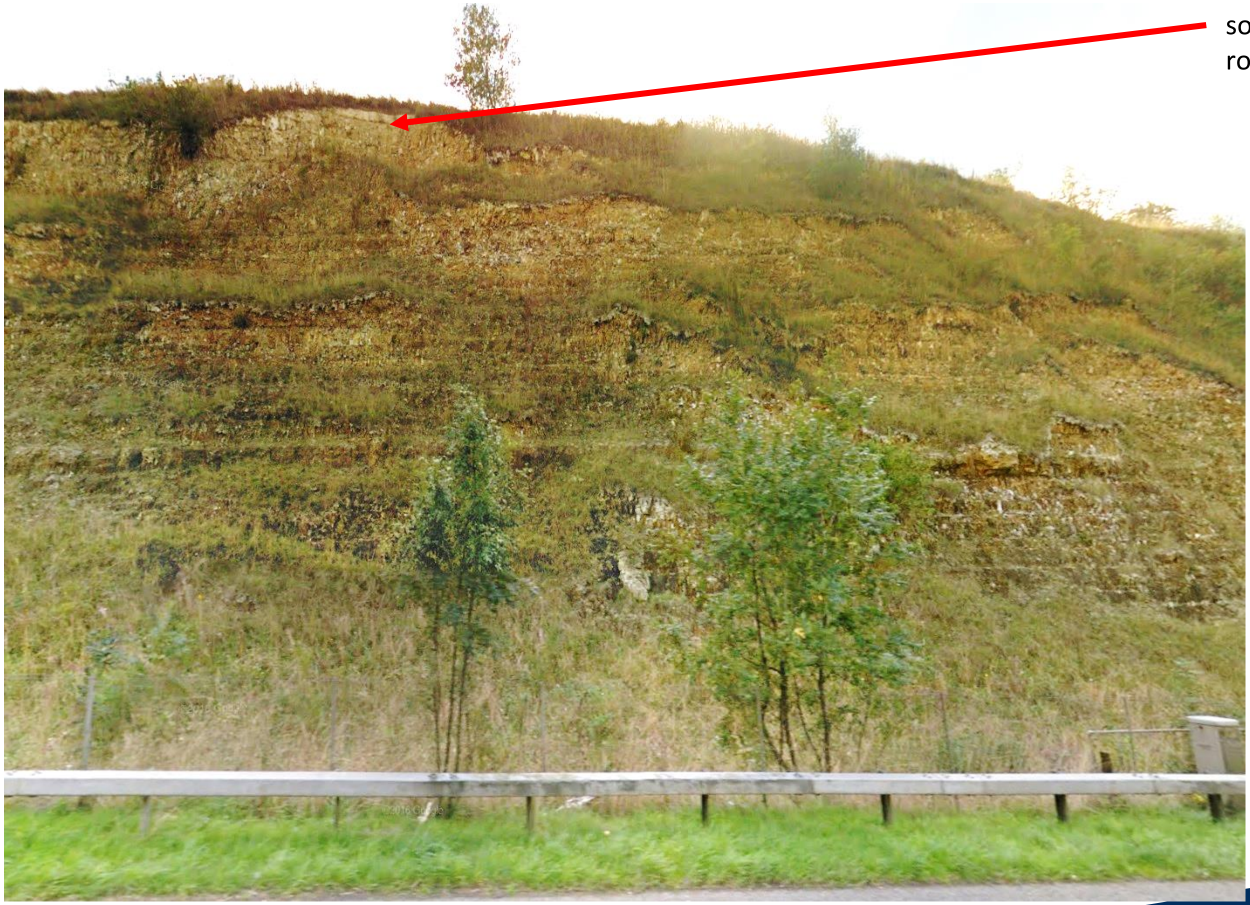
Moreover, the potential trajectory of the rockfall can be seen, with larger fragments at the base of the cutting with debris leading from the potential rockfall source.

Conclusion: High resolution aerial imagery (i.e. >5cm resolution) can be used to assess potential rockfalls on cuttings. Highways England should continue to collect such imagery.



5.1.4 Data processing and analysis: Aerial imagery

The Google Streetview image to the right shows the likely location for the rockfall identified in the aerial imagery.



Potential source of rockfall?

Source: Google, Sep 2016

5.2.1 Data processing and analysis: AVIS imagery

Imagery available from the Mobile Mapping System survey (2013 and 2014) was assessed for its application to assessing geotechnical asset condition.

An extraction from the AVIS viewer is presented on the right (Coordinates: 473042.63, 196530.53).

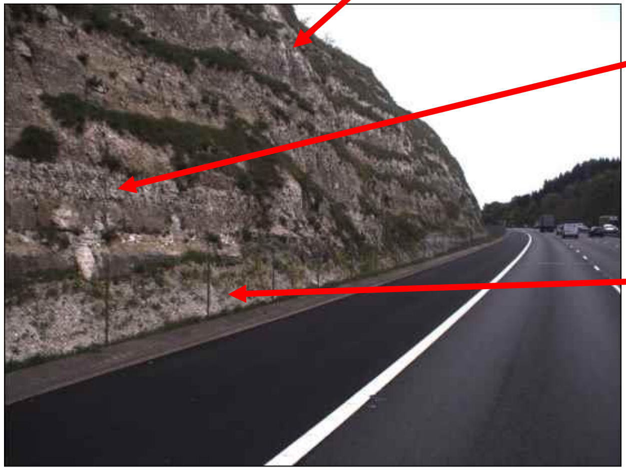
The imagery could be used to make a basic qualitative assessment of the cutting. For example, the image below shows a build up of chalk material, as a result of ravelling processes (Coordinate: 473113.49, 196507.38). The chalk bedding can also be seen, however, the imagery is likely not suitable for any detailed bedding/fracture analysis due to the relatively poor light quality.

The imagery is contained within a video file and not as a static image, and therefore is difficult to overlay on LiDAR data for further assessment.

It is fortunate for this cutting that it is in relative proximity to the running lanes and is fairly visible (i.e. not obscured by vegetation).

LiDAR is also available within AVIS and is discussed in more detail in later sections.

Conclusion: AVIS could be used for making a qualitative assessment of geotechnical asset condition. However, certain features may be obscured due to height, light conditions, or cutting orientation and therefore should not replace physical inspection or the use of other techniques (e.g. aerial imagery).



highways england

5.3.1 Data processing and analysis: LiDAR

The analysis of the LiDAR data in this pilot study has considered the following aspects:

- Understanding how Highways England's LiDAR datasets are currently classified
- LiDAR coverage and relative point densities
- Understanding of how change detection between the different LiDAR surveys can be used to monitor changes in morphology as an indication of asset deterioration.
- Application of change detection to understand condition of special geotechnical measures at location.

The aspects identified above have all been considered in respect of the rotary wing (2015) and Mobile Mapping System (2013 and 2014) LiDAR datasets that have previously been procured by Highways England. It should be noted that it is a rare occurrence to have three LiDAR datasets for a section of the Strategic Road Network.

The rotary wing LiDAR, on this section of the M40, was procured under the National ADC Surveying project. Mobile LiDAR (Mobile Mapping System) had previously been undertaken along all the carriageways. A statement from the business case for the rotary wing data collection stated that *"The accuracy and point density of this LiDAR dataset are excellent for measurement and mapping but is restricted to only the carriageway part (edge of carriageway to edge of carriageway)"*. A function of this pilot study will be to test this statement.

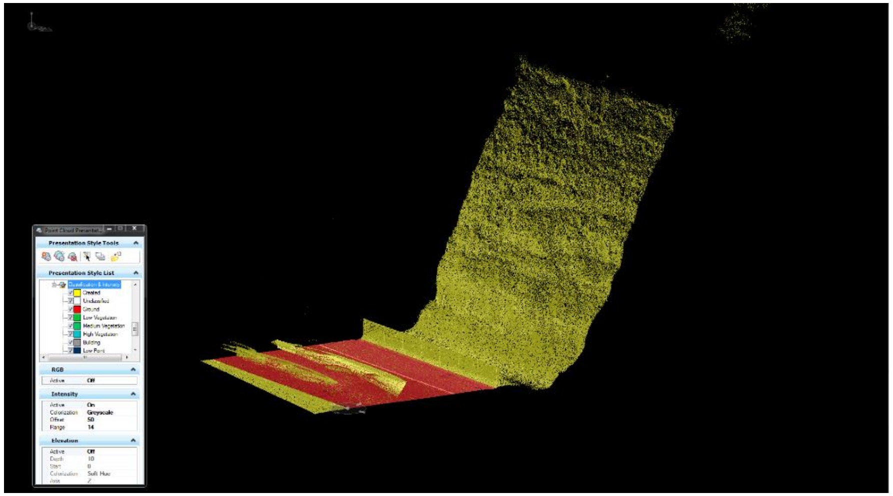
5.3.2 Data processing and analysis: LiDAR

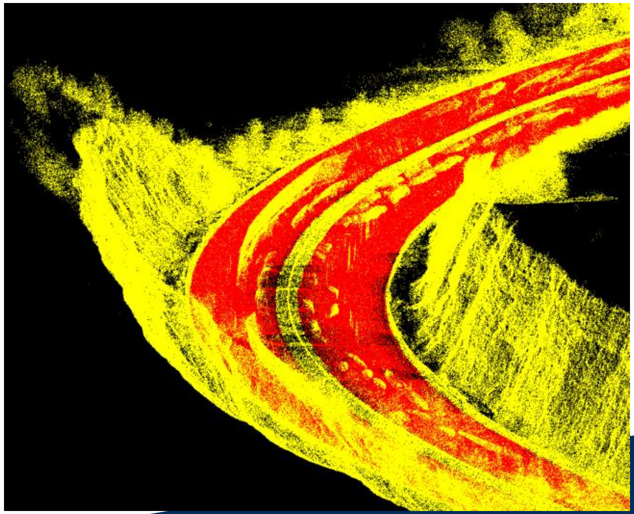
LiDAR classification issues

The LiDAR data provided for this study (procured by Highways England) has classified the ‘ground’ as being representative of the carriageway. This classification was informed by the terms of the original ADC collection contract. In the business case for the rotary wing survey (2015) it was stated that the Mobile Mapping System LiDAR data is not suitable for consideration beyond the carriageway asset.

As a result, all other ground (i.e. cutting, central reservation, vegetation, fences, signage etc.) are classified as one layer (see right). This limits the ability to create a model which shows purely the ground surface (i.e. the cutting sides as well as the carriageway) without undertaking significant additional processing.

Normally, such ground classification may be achieved by using the last return of LiDAR data. Ideally, Highways England would ask the supplier to reclassify the data before it was used for routine and/or automated change detection analyses.





Conclusion: If Highways England is to use Mobile Mapping System LiDAR data for geotechnical applications, then a different classification would be required.

5.3.3 Data processing and analysis: LiDAR

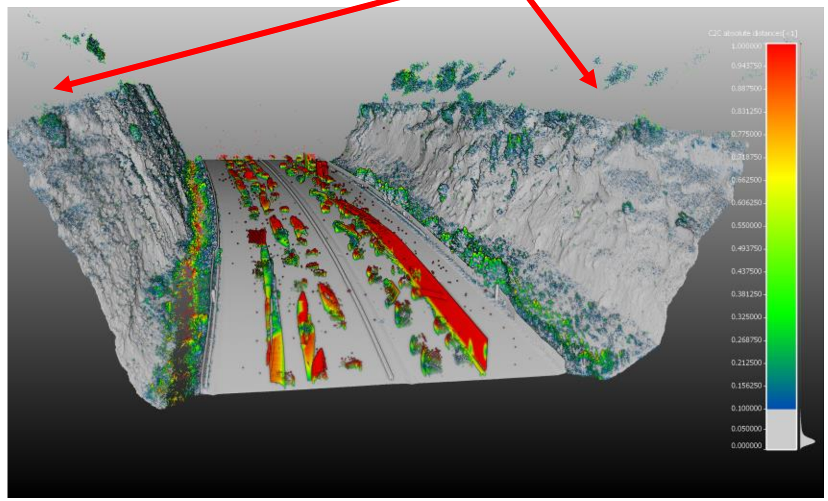
LiDAR coverage

The Mobile Mapping System LiDAR data (2013 and 2014) does not cover the entirety of the asset.

This will be a result of the orientation of the LiDAR scanner. Furthermore, there is a step at the top of the embankment, which will inhibit full coverage.

The rotary wing data will provide more data points for this missing section. However, there may be issues with aligning the data.

Top of cutting not captured by Mobile Mapping System survey



Top of cutting captured by rotary wing survey

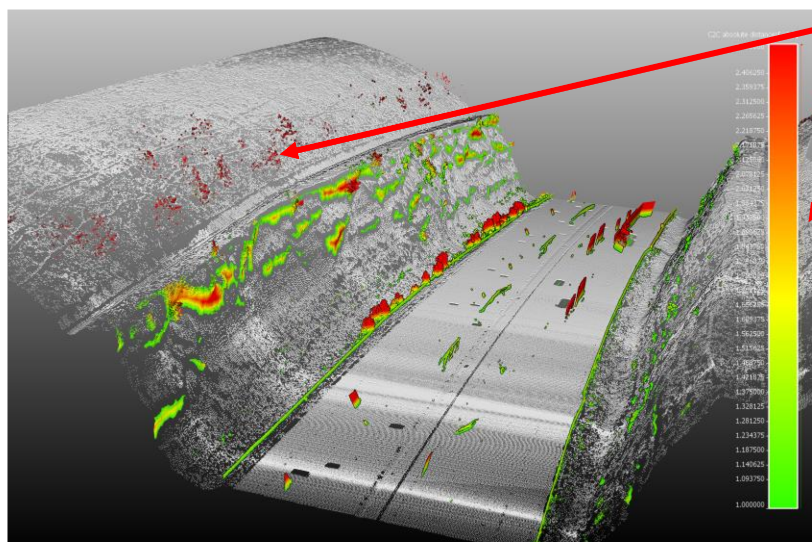
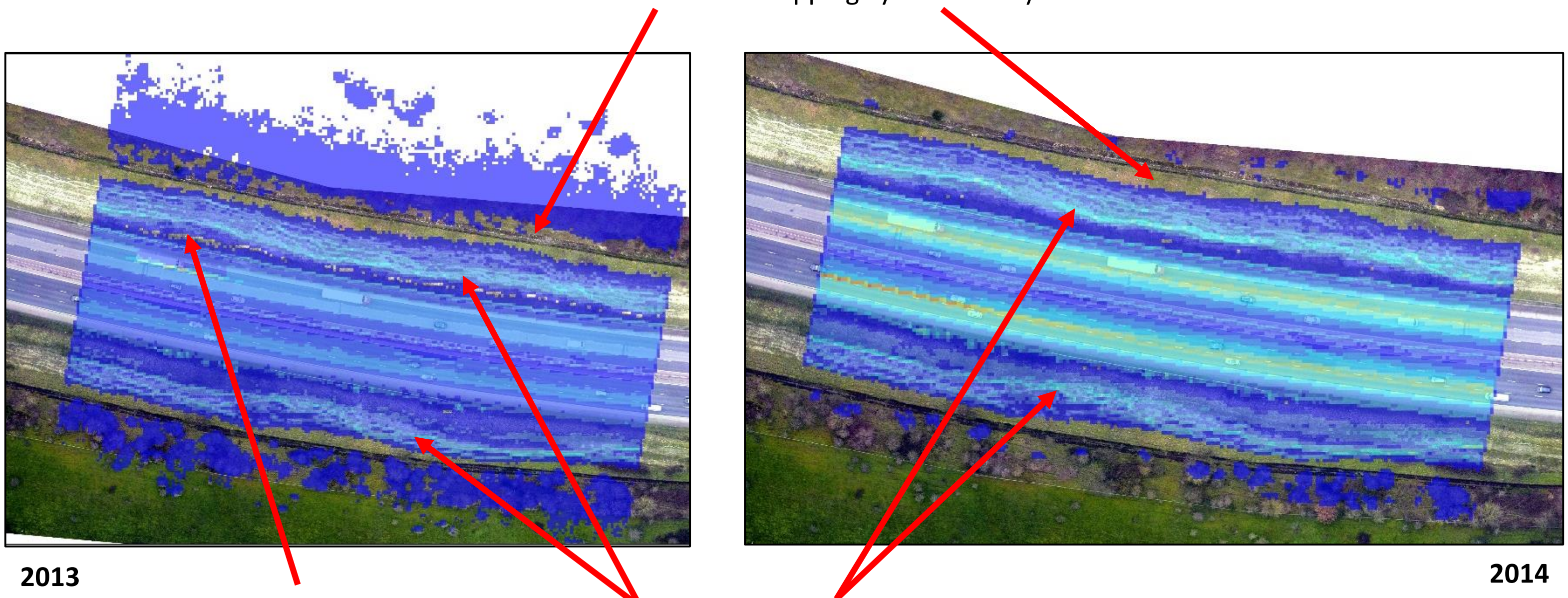


Image represents combination of Mobile Mapping System (top) and rotary wing LiDAR (bottom)

5.3.4 Data processing and analysis: LiDAR

Top of cutting not captured by Mobile Mapping System survey



2013

2014

low density or no coverage in drainage channel

Point density relatively high on cutting sides

LiDAR point density – Mobile Mapping System

The images above show the point density (points per m^2) for the 2013 (left) and 2014 (right) Mobile Mapping System LiDAR data collections, respectively. From this image, it can be clearly seen where the LiDAR scan has not been able to capture the very top of the cutting due to its relative orientation.

Although not originally intended for geotechnical asset inspection, the point density on the cutting sides is relatively high (3,000-4,000 points per m^2).

Lidar Point Density

- 1 - 500
- 500-1000
- 1000-2000
- 2000-3000
- 3000-4000
- 4000-5000
- 5000-6000
- 6000-7000
- 7000-8000
- 8000-9000
- 9000-10000

highways england

5.3.5 Data processing and analysis: LiDAR

Change detection: Aerial vs Mobile Mapping System

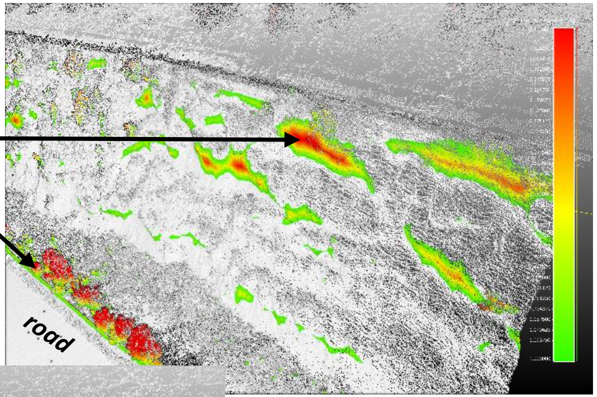
LiDAR data was compared between the aerial (rotary wing) survey commissioned in 2015 and the ground-based Mobile Mapping System survey commissioned in 2013.

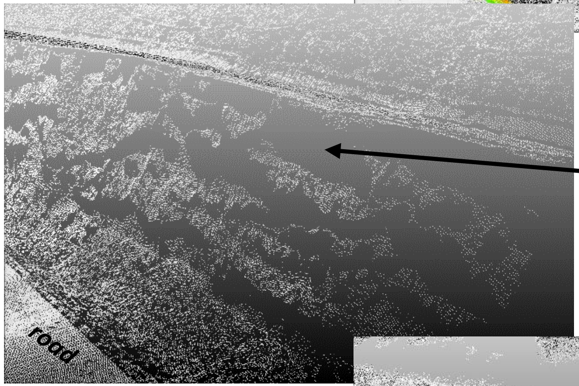
The analysis shows apparent significant changes in ground levels between the two datasets (lower left of the top right image), which at first seems promising. However, when we look at the point cloud for the rotary wing LiDAR (middle right), it is evident that there are areas where no data is returned. Through further inspection, this is a factor of differential weathering of the chalk beds, leading to overhanging and the orientation of the laser not being able to capture the underneath of the overhang. An illustrative diagram is provided for clarity.

When compared to the Mobile Mapping System LiDAR (bottom right), it is evident that data collection is much more dense across the cutting face.

Conclusion: In this context, on a steep sided cutting, aerial and terrestrial LiDAR cannot be compared to a high degree of accuracy. This is due to the different sensor viewing geometries and resulting point cloud point densities and differing spatial coverage.

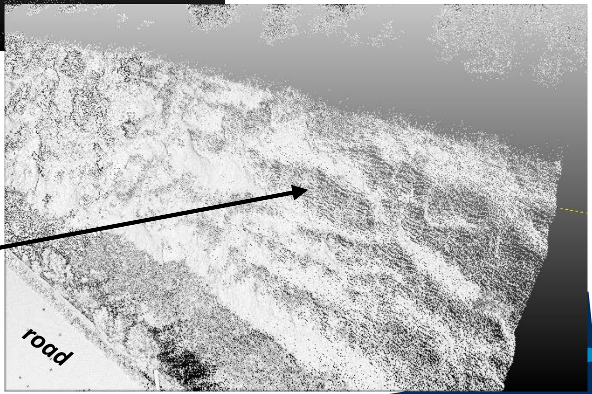
Figure shows a comparison between 2013 and 2015 LiDAR point clouds – initially shows large changes but this is due to the limited line of sight of the sensor causing data gaps in the 2015 rotary wing dataset





2015 rotary wing – missing data from overhanging chalk

2013 Mobile Mapping System data has more dense coverage of cutting face due to sensor orientation

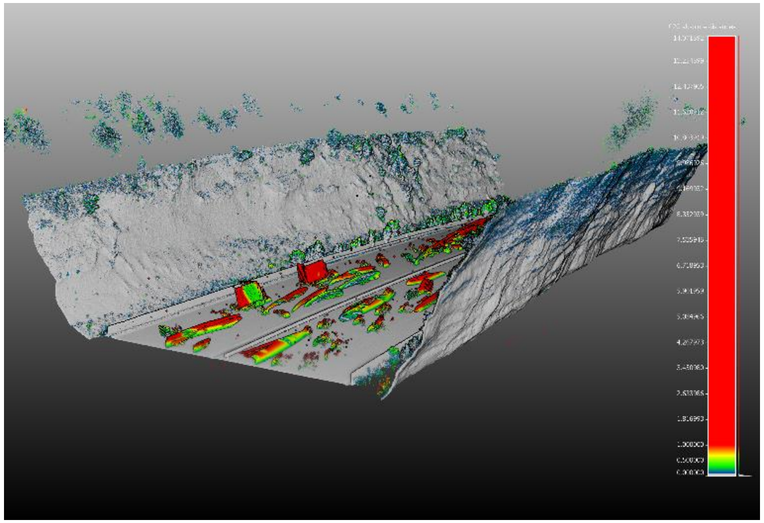


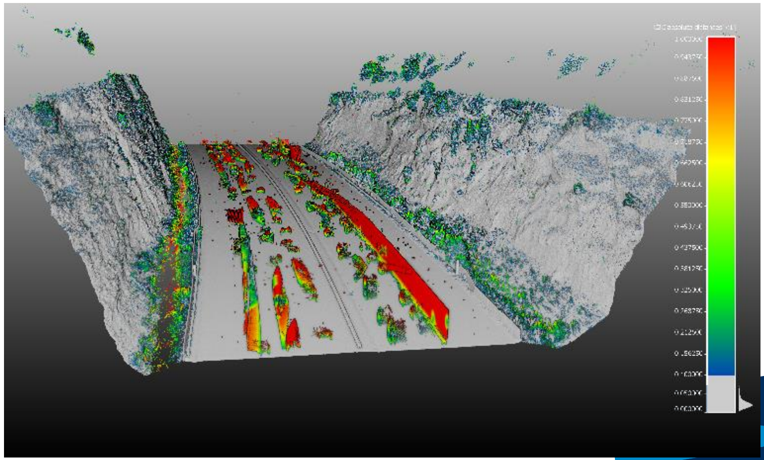
5.3.6 Data processing and analysis: LiDAR

Change detection: comparison of two Mobile Mapping System LiDAR datasets

The two terrestrial Mobile Mapping System LiDAR surveys commissioned in 2013 and 2014 were compared to assess the potential of detecting change in the chalk cutting face using two datasets collected from the same platform and same sensor viewing geometry. The analysis was undertaken using the open-source ‘Cloud Compare’ software.

Aerial imagery and Google Street View shows that there is potentially ongoing weathering of material which is leading to chalk ravelling. However, the results of the LiDAR comparison, shown in the right hand images, do not appear to show any significant changes in the chalk cutting face. Significant changes were detected in the vegetation at the base of the cutting and on the cutting sides. Therefore, as well understanding changing asset condition, this assessment could be used to understand the potential impact of vegetation on the geotechnical asset. As there are no static images available from the survey, it is not possible to overlay imagery onto the change detection maps to understand what is causing the apparent change.



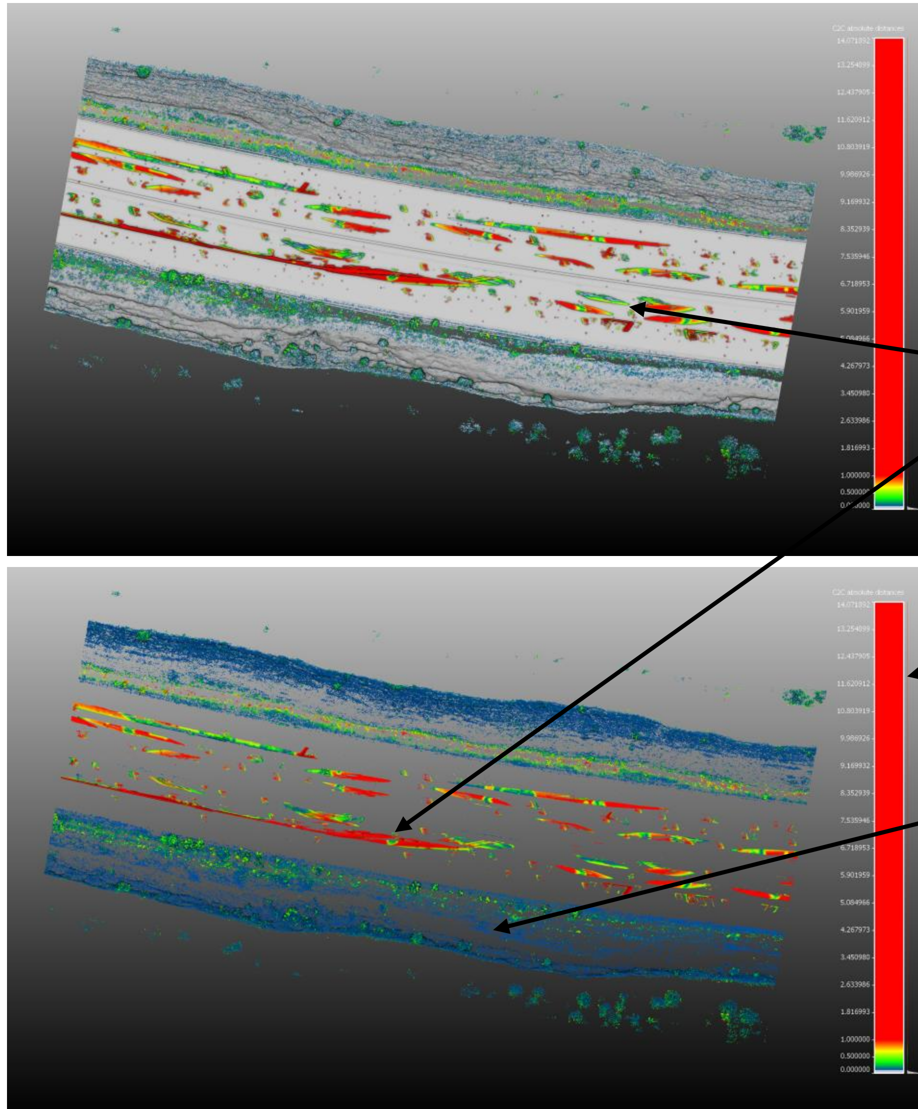


Conclusion: LiDAR change detection has the potential to allow semi-automation to assess potential changes in the cutting face. For this example, the surveys only being a year apart may have not witnessed any changes. Therefore, it is recommended that Highways England undertake repeat LiDAR surveys going forwards and that static imagery is taken at the time of data collection.

5.3.7 Data processing and analysis: LiDAR

The figures to the right show the LiDAR change detection between Mobile Mapping System between 2013 and 2014 surveys.

The majority of the change is a result of vegetation changes. However, there are some areas (mainly in blue) that could be a result of chalk ravelling processes. However, to validate this would require further investigation.



5.3.8 Data processing and analysis: LiDAR

Assessment of Special Geotechnical Measures (SGMs)

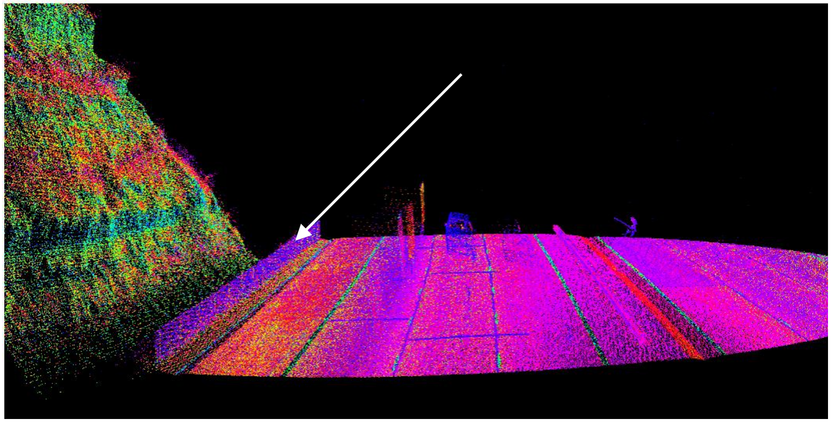
As well as assessment of the geotechnical asset itself, Highways England also have the requirement to assess the condition of SGMs which are installed on higher risk assets to protect road users.

Stokenchurch Gap has had rockfall mitigation fencing installed at the base of the cutting (see images to right), which falls under Highways England's classification of an SGM.

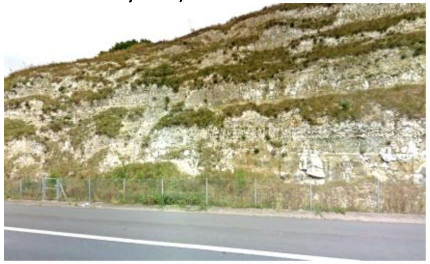
The top right image is an extract from Highways England's AVIS Viewer system that allows users to view LiDAR point clouds. For Stokenchurch Gap, two LiDAR point clouds are available (collected in 2013 and 2014), which can be visualised by intensity (shown) or height. The location of the rockfall fencing is represented by the white arrow.

This point cloud, alongside imagery (terrestrial and airborne) will provide Highways England with an indication of the condition of the special geotechnical measure (e.g. whether it has been compromised by a rockfall or third-party activity). From assessing Google Streetview imagery (Sep, 2016) it can be seen that the fencing has been damaged on the northbound side of the carriageway.

The following page shows how semi-automated LiDAR change detection could potentially be used to locate defects along the catch fencing.



LiDAR extract from AVIS Viewer (Coords: 473036.91, 196532.50 S/Bound, PC density 2:1)



(Google, Sep 2016)

Damaged fencing. (Google, Sep 2016)

Conclusion: The use of AVIS would currently require a manual process of viewing known sites where such measures are known to be located for any defects to be recognised. However, AVIS allows, in this case, for the viewer to see and locate the SGM.

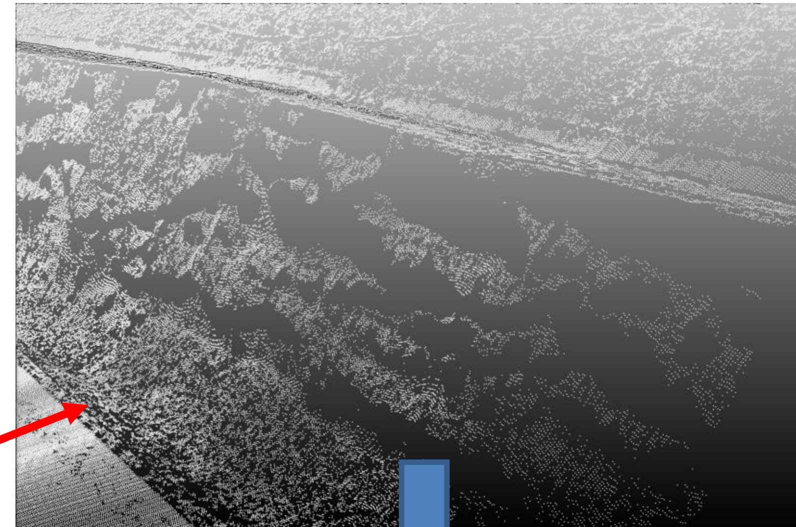
highways england

5.3.9 Data processing and analysis: LiDAR

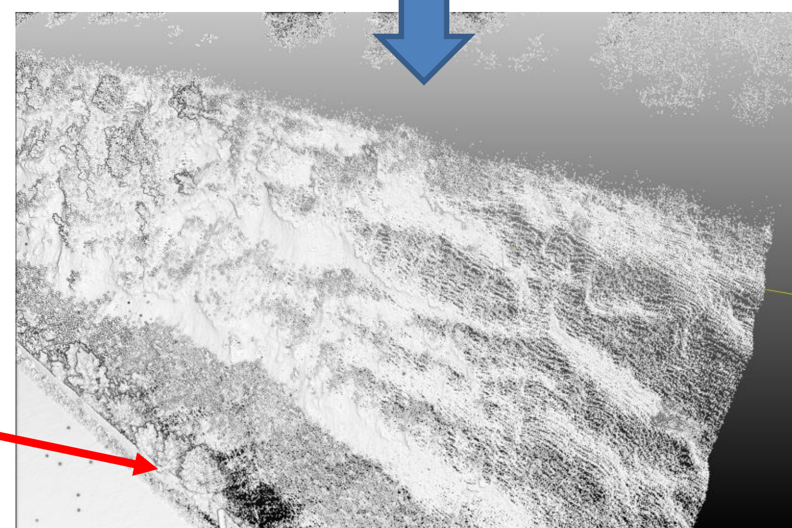
Assessment of special geotechnical measures (SGMs)

Change detection analysis between the 2013 Mobile Mapping System and the 2015 Rotary Wing survey appears to show a significant change in the entire length of the rockfall mitigation fencing.

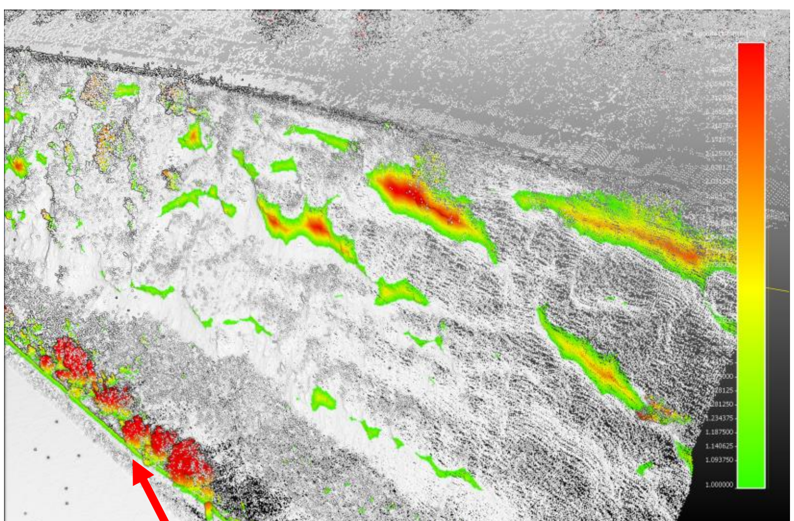
However, on closer inspection, this seems to result from the rotary wing survey having not picked up the rockfall mitigation fencing. This may be due to the plan profile being very narrow and the orientation of the LiDAR instrument. Please see figures for more annotated information.



Rockfall fence not present in aerial LiDAR



Rockfall fence present in Mobile Mapping System (2013) LiDAR



Change therefore detected between Mobile Mapping System and rotary wing LiDAR datasets

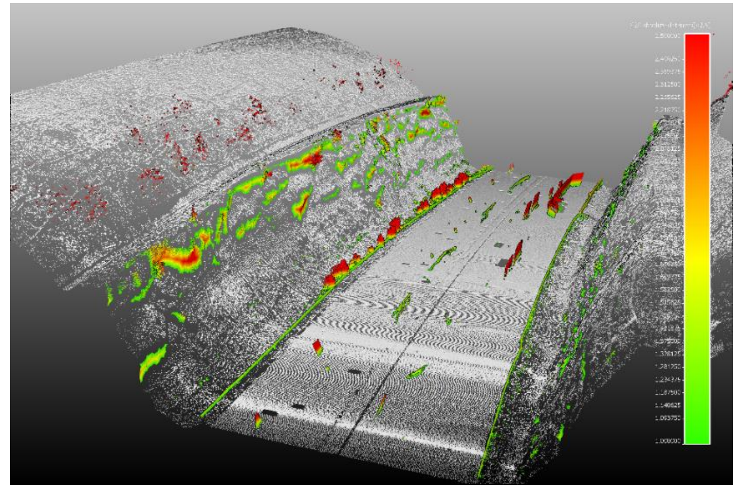
5.3.10 Data processing and analysis: LiDAR

Assessment of Special Geotechnical Measures

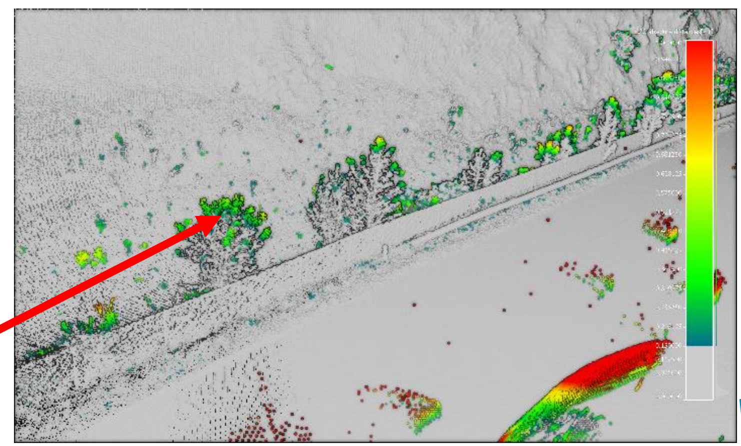
Unfortunately, no further examples can be provided as to changes detected in the catch fencing between the 2013 and 2014 Mobile Mapping System datasets; therefore the damage shown in the previous Google Streetview image is likely to have occurred post 2014/15.

However, the application of the potential for change detection analysis is exemplified in the vegetation changes which are clearly evident in the bottom, right image. Details such as leaf and branch growth can be seen from this image.

Conclusion: LiDAR change detection shows suitability for potentially understanding changes (i.e. defects) in special geotechnical measures. However, further analysis would be required and issues between comparing change in aerial and terrestrial LiDAR datasets have been identified.



Change detection between 2015 Rotary Wing and 2013 Mobile Mapping System LiDAR



Change detected in vegetation growth

Change detection between 2013 and 2014 Mobile Mapping System LiDAR

highways england

5.4.1 Data processing and analysis: Multispectral imagery

Multispectral satellite imagery was downloaded from the European Space Agency's Sentinel-2A platform. This data is freely available and was sourced from the UK Satellite Applications Catapult's SEDAS (Sentinel Data Access Service) portal.

For this study site, 21 Sentinel-2 images were available for the period 04/10/2016 to 01/06/2017. An image, dating from the 13th March 2017 was used for understanding the data's potential use.

The application of Sentinel-2 imagery in the UK can be problematic. This results from the often high percentage of cloud cover which inhibits the users ability to accurately assess conditions on the ground as you are unable to remove dense cloud. This differs from Sentinel 1 radar data (see M11 case study) which is able to pass through cloud.

Sentinel-2 imagery is provided in a 10m spatial resolution (see image on following page). The imagery was analysed for its potential application for understanding further the condition of the geotechnical asset at Stokenchurch gap. The imagery can be presented in a number of ways, depending on the band combination used (see table to right). For the purposes of this initial analysis, only 'Natural Colour' has been represented.

Band Type	Combinations in red green blue (RGB) visible viewing channels
Natural Colour	4 3 2
False Colour (Urban)	7 6 4
Colour infrared (vegetation)	5 4 3
Healthy vegetation	5 6 2
Vegetation analysis	6 5 4

Conclusion: Sentinel-2 imagery has too coarse spatial resolution for geotechnical asset management. It is more appropriate for understanding regional changes in vegetation coverage for example. It is also highly limited by cloud cover and shadowing effects.

Sentinel 2 image acquired: GS2A_20170313T110831_009000_N02.04, 13/03/2017, Cloud Cover 84%

5.4.2 Data processing and analysis: Multispectral imagery

As an example, the images below represent Natural Colour (Spectral Bands 4,3,2 in RGB respectively) of the Stokenchurch Gap area (10m pixel resolution).

The right image shows a zoomed in view of the cutting, with the white chalk face on the northern side visible. Whereas, the southern cutting face is masked by shadow.

Cloud cover for this image, whose overall extent was much greater than that represented, was 84%, which represented the lowest value available within the period considered.

Natural colour image, Sentinel 2A L1C Product, capture date 13/03/2017

5.5.1 Data processing and analysis: Hyperspectral imagery

Hyperspectral imagery was produced during the rotary wing survey undertaken in 2015, alongside aerial imagery and LiDAR. The imagery was captured at a spatial resolution of 0.75 m.

Cyient (previously Blom) who undertook the data collection, provided assistance with data interpretation for a number of sites along the M40 including Stokenchurch Gap.

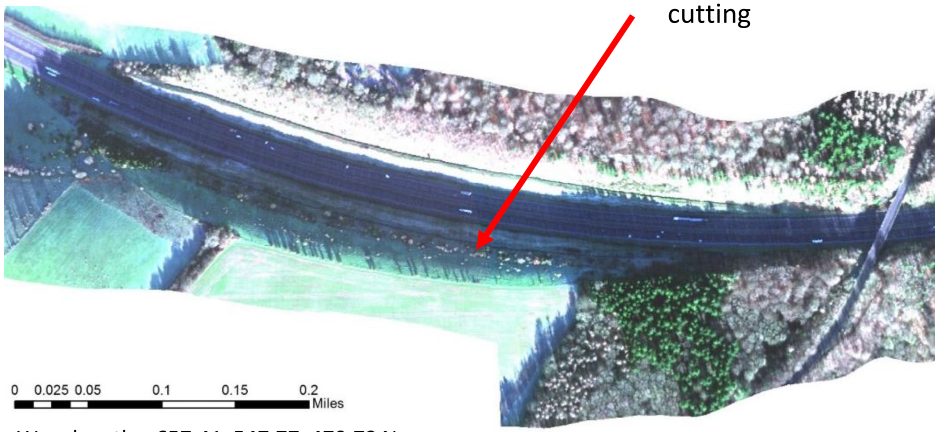
Overall, it was considered that the time of data collection (January) had insufficient natural light for the data to be used. Furthermore, the low sun angle also resulted in shadowing of the cutting, especially on the southern side, which limited the use of the data for any detailed analysis.

Results of analysis undertaken internally show some of the issues with the current hyperspectral dataset.

Conclusion: Highways England would need to undertake further investigation into the use of hyperspectral imagery by capturing data at different times of year when the environmental settings are more suitable for analysis. However, there may be issues with undertaking hyperspectral imaging in summer when there is a greater presence of vegetation and ground is likely to be drier.

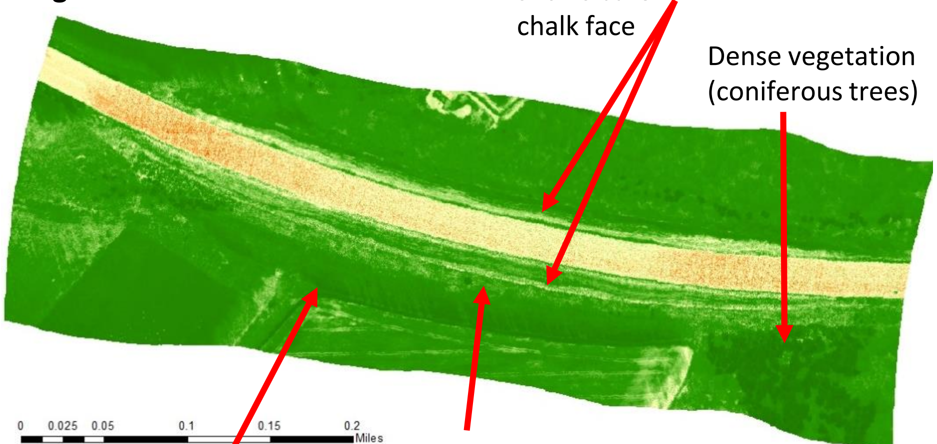
5.5.2 Data processing and analysis: Hyperspectral imagery

Image A



Wavelengths: 657.41, 547.77, 479.73 Nm
Contrast and brightness altered.

Image B



These images are produced from the obtained hyperspectral rotary wing survey (2015) of Stokenchurch Gap. Both images contain shadowing effects as a result of the low sun angle.

- **Image A –** Natural Colour Image

Coniferous vegetation is indicated as the dark green patches to the right of the image. It is difficult to make out any particular features evident on the cutting.

- **Image B –** Normalised Difference Vegetation Index (NDVI)

NDVI = (NIR — VIS)/(NIR + VIS), where NIR (Near Infrared) and VIS (visible)

This image more readily demonstrates the use of the data in assessing the cutting sides. Greener areas represent higher levels of healthy vegetation, whereas white and red areas represent either bare ground or man-made surfaces (i.e. carriageway).

Coniferous vegetation is clearly seen as the dark green patches to the right of the image.

6.1 Conclusions

This pilot study has shown that :

- Typically, the 5cm resolution rotary wing aerial photography provided high enough resolution to delineate geotechnical features such as rock falls. But because of the vertical viewing geometry it was more challenging to make useful observations of the steep rock cutting face.

- LiDAR point clouds showed:
  - Information on the condition of the chalk cutting
  - Location and condition of special geotechnical measures (i.e. catch fencing in this example)

- Three different LiDAR datasets (2013 and 2014 Mobile Mapping System and 2015 Rotary Wing) were analysed and change detection algorithms applied to try to understand if the condition of geotechnical assets could be monitored over time. Findings included:
  - The LiDAR pointcloud classification categories were limited to the carriageway and 'everything else'. This was because the original driver for data collection was for better understanding the carriageway condition. Reclassification of the point cloud would be required to enable more effective comparison of the entire pointcloud and to facilitate a more automated analysis.
  - Change detection was not successful when comparing the Mobile Mapping System and rotary wing LiDAR, this was due to the fact that the sensor viewing geometries were different and the point densities and spatial coverage of each dataset was significantly different.
  - Change detection between the two Mobile Mapping System datasets showed promise in terms of understanding small-scale condition changes (e.g. vegetation growth).
  - Mobile Mapping System LiDAR could be used to observe the condition of special geotechnical measures at the location (i.e. catch fencing). No deterioration was detected across the years 2013-2014.

- Sentinel-2A multispectral satellite imagery with 10m spatial resolution is too coarse to resolve various geotechnical features including the Stokenchurch Gap rock cutting.

- Hyperspectral imagery, due to the time of data collection (hour and season),

was not optimal for analysis.

6.2 Conclusions

When used in combination, the techniques investigated present a number of potential advantages for assessing the condition of Stokenchurch Gap by:

- Reduced requirement for workers to be exposed to traffic, a tall steep high-risk rock slope or to working from height
- Subsequently, less requirement for traffic management, reducing delays to customers
- Detect change without potential ambiguities and in a semi-automated process
- However the collection and processing of LiDAR data and subsequent change detection requires skills in geographical information systems (GIS) software and the relevant LiDAR processing software. It offers a relatively rapid way of assessing geotechnical asset condition at high levels of detail and if comparable surveys are undertaken on a relatively regular basis (to be defined), then appropriate change detection algorithms can be implemented. Imagery, captured at the same time as the LiDAR surveys are fundamental to understanding what changes are occurring.

7. Recommendations

- High resolution (i.e. >5cm) aerial imagery is useful to complement the terrestrial remote surveys
- AVIS is useful for fast remote qualitative analysis, however, the imagery available is limited for geotechnical asset assessment. Specifically, certain geotechnical features may be obscured due to height, light conditions, or cutting orientation
- For future LiDAR data procurements, Highways England should ask for data to be classified to define ground surface, structures, and vegetation, for example, rather than purely carriageway and all other features grouped together as a second single class.
- In terms of the Mobile Mapping System data, static imagery should be captured in order to understand change detection results.
- A combination of terrestrial and aerial LiDAR data appears to be most suitable for analysis of the geotechnical asset at the Stokenchurch Gap cutting.
- The hyperspectral dataset could be useful for asset condition surveys. However, for optimal data, the survey should be carried out when there is minimal cloud cover, and when there is minimal shadowing, corresponding at noon-time of day when the sun is high overhead. Vegetation can potentially mask other assets, therefore, the season of collection is important. A good day for data collection could be noon-time on a clear, sunny winter day.
- The airborne vertical hyperspectral surveying method provided good network coverage, however, higher resolution (e.g. 0.25-0.5 m resolution) would allow delineation of smaller geotechnical features than the trial 0.75 m resolution imagery facilitates.
- The asset geometry should be considered in survey method selection, for example, if monitoring tall, steep, laterally extensive soil or rock cuttings, an oblique viewing geometry may be more suitable than a vertical viewing geometry.

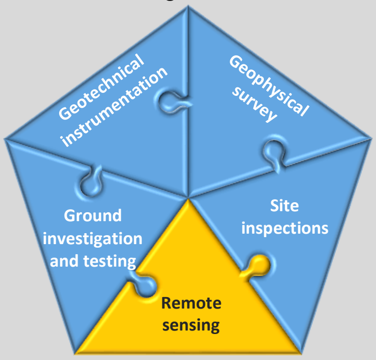
Appendix B – Technical Guidance Notes

USE OF REMOTE SENSING TECHNIQUES FOR INSPECTION AND ASSESSMENT OF HIGH RISK SOIL EARTHWORKS AND ROCK SLOPES

This Technical Guidance Note (TGN) is part of a series of TGNs intended to raise awareness and provide guidance on the use of various remote sensing techniques for geotechnical asset management across the Strategic Road Network (SRN). Remote sensing techniques can be used to complement and improve upon other methods to enhance the information Highways England's needs to manage the resilience of the SRN.

This TGN is aimed at engineers and managers without specialist knowledge of remote assessment. It focuses on the use of those techniques that have potential for remote inspection and assessment of **high risk soil earthworks and rock slopes**.

Geotechnical resilience: knowledge resources



This document is based on the findings of extensive research previously undertaken on this topic (2000-05) and a more recent research project (2017) that has reviewed advances and applicability of selected remote sensing techniques. As part of this study, proof-of-concept pilot studies were carried out at a number of sites across the network and the findings have informed the content of this guidance note.

This technical note may need to be updated or developed further if techniques are reviewed against a wider range of sites, geotechnical features and ground hazards.

1.0 Background

Following earlier research work on remote assessment by Highways England from 2000-05 a framework contract was set up for the capture of selected remote sensing data by Major Projects in 2004. The main driver for this was the need to procure 1:500 scale topographic mapping for improvement schemes, but many other applications were identified including geotechnical asset management. The LiDAR Framework was replaced by the SPS Framework from 2011-15 and subsequently the current SPaTS Framework. The focus of data collection during these later frameworks changed, with AIG as the sponsor collecting data for wider asset inventory surveys used for letting term maintenance contracts.

The recent research in 2017 reviewed the potential capabilities of those techniques currently procured through the SPaTS Framework, in order to establish whether there are geotechnical applications for the data. In addition, a more limited review of other developing techniques was also undertaken where it was possible to obtain suitable data.

Remote sensing survey: hereby defined as gathering of data *at a distance* e.g. collected via satellite, plane, vehicle, drone etc. It does not include data collected via on-slope instrumentation such as inclinometers, piezometers or sensors that can be connected wirelessly.

A summary of the techniques currently procured by Highways England and other datasets held in storage (GeoStore) or on HAGDMS is provided in **Table 1**:

Table 1 Remote sensing techniques and data sources

	Techniques (single or complementary)	Description	Data source
Available data	Mobile Mapping System	Network wide van-mounted LiDAR and imagery collected every 1-3 years. Imagery and point cloud data can be viewed through on-line AVIS interface.	AIG, contact: AIG_Surveying@highwaysengland.co.uk
	Rotary wing LiDAR and high-resolution orthoimagery (SPaTS)	Helicopter mounted surveys carried out along selected sections of the network, but planned for future network wide rollout. Frequency depends on available budgets. Outputs include point clouds, terrain models, contour data and 4cm resolution imagery.	AIG, contact: AIG_Surveying@highwaysengland.co.uk
	Rotary wing hyperspectral imaging	Helicopter mounted hyperspectral imaging with over 300 spectral bands. Collected in combination with LiDAR and orthoimagery, to date only on a trial basis along the M40.	Contact relevant specialist supplier
	National aerial photography	Network-wide national coverage purchased 'off-the-shelf' and provided as a layer within HAGDMS (12.5 to 25 cm resolution).	Geostore (registration and login required): http://www.geostore.com/highwaysengland/
	LiDAR Framework rotary and fixed wing LiDAR	Archive datasets captured for now completed improvement schemes along sections of the network and available through GeoStore. Narrow and wide corridor LiDAR datasets at various point densities. Limited use for current condition assessment but potential application for change monitoring.	Geostore (registration and login required): http://www.geostore.com/highwaysengland/
From suppliers	Bespoke aerial photography (fixed wing)	More conventional stand-alone aerial photography collected from fixed wing aircraft rather than synchronously with rotary wing LiDAR. Range of resolutions available, typically from 25 cm to as high as 2 cm. Limited current availability through HE databases and would have to be procured specifically.	Contact relevant specialist supplier
	Radar satellite InSAR datasets	Differential InSAR, PSInSAR and DSInSAR outputs processed from radar satellite data have been reviewed during the research work but there is currently very limited data available through HE sources. Future inSAR data would have be procured through specialist suppliers.	Contact relevant specialist supplier

2.0 Application context

This TGN provides feedback on the use of remotely sensed data for the inspection and condition assessment of high risk earthworks across the network. The location of high risk earthworks are shown in HAGDMS. The requirement for remote surveys to complement or partly replace physical inspections may be due to one or more of the following reasons:

- **Access** to the earthworks is restricted or not possible on a temporary basis due to:
    - Lane closure (e.g. long-running road works)
    - Other uses occupy the hard shoulder (e.g. SMART motorways)
    - Dense vegetation
    - Flooding
    - Earthwork extent away from the carriageway is significant or the earthwork crosses a natural slope, the stability of which is impacting on the earthwork
- **Safety** is an issue, for example accessing large, steep rock slopes.

- **Frequency of inspection** where additional or more frequent inspections than the typical inspection regime are required to monitor on-going movements
- Remote sensing can provide **additional information** not readily available from physical inspections such as quantitative data on slip morphology or changes between inspections.
- **Available remote sensing techniques** can provide the necessary information faster or at lower cost than physical inspections.

The TGNs have been developed to align with the *Maintenance of Highway Geotechnical Assets* (**HD41/15**) standard, which provides guidance on the inspection regime etc. and with the risk-based inspection regime process set out in the Geotechnical Asset Management Plan (GeoAMP).

3.0 Aims of remote sensing surveys

Different sensors provide different information about earthworks and usually a combination of techniques (the data of which can be collected simultaneously from a single platform) provides the most useful data. This multi-data approach to network asset inventorying and condition monitoring is most appropriate because earthworks vary with scale, geology, slope morphology and age and deterioration rates and timescales can vary considerably; and, depending on the location in relation to the carriageway, the resulting level of risk posed.

As for all earthworks inspections, after collection of inventory data the aim is to assess condition and then monitor the deterioration to identify when timely intervention is required. The 2017 research sought to identify whether remote sensing techniques can monitor gradual change over time and provide an early warning of major change. The suitability of each dataset for change detection over time was also assessed (particularly for the LiDAR data).

4.0 Techniques and suitability for providing inspection data

1) Mobile Mapping System

Frequent (every 1 to 3 years) and recent surveys across the whole network providing high point density LiDAR and imagery captured from a van travelling at road speed. Earthwork data is limited to cuttings only, and within 30 m range of the sensor on the carriageway. Embankment slopes are mostly beyond the line of sight, although some information on the surrounding land can be captured where the earthwork geometry and line-of-sight permits this. However the LiDAR point cloud classification requires changes to the current specification to provide classifications suitable for slope feature detection. At the moment slope contours are not always provided by the suppliers but can be generated from the derived 3D surfaces.

Bare rock slopes on smaller cuttings or slopes scan well with medium resolution of slope morphology, bedding dip, gulleys, overhangs and toe debris. Comprehensive discontinuity observations are not possible.

Imagery is good from kerb to kerb but of mixed quality for the cutting slopes. Frequently too dark or in shadow but feature detection including slips, bare ground, vegetation, barriers, fences and remedial works is possible where captured in good light. Limited to line of sight and slopes obscured by vegetation are not visible.

Accessed through on-line AVIS platform with minimal training required, and is a good interface for the imagery, point clouds and positional reference data. Further development of AVIS to display additional datasets (e.g. LiDAR slope contours and aerial photography) would increase its potential application.

Application for high risk earthworks and slopes: The Mobile Mapping System offers a useful 'first-pass' survey from which inspection pro-forma could be partly populated to reduce time during subsequent physical inspections. The surveys are frequent enough to allow additional intermediate inspections of particular sections to be carried out where the risk may be increasing due to earthwork deterioration.

The repeat LiDAR data offers potential for change detection to be undertaken but much depends on the orientation of features in relation to the sensor.

2) Rotary wing LiDAR and 4cm orthoimagery

Suitable for detecting slope features on cuttings, embankments and outside the highway corridor across natural slopes. Corridor usually fence to fence, but this can be extended with additional flight lines. Where the survey corridor needs to be much wider, then fixed wing LiDAR should be considered but Highways England are not using this system routinely. However specifications for this from the LiDAR Framework.

Good penetration of LiDAR pulses through vegetation cover to map slopes below the canopy - although point density drops to around 1 - 5 / m^2 this is sufficient to detect even small slope deformations. Good definition of earthwork or natural slope geometry and detection of small and large slips, including those with subtle surface expressions such as relic mudslides. Low, medium and high vegetation can be classified. Some useful information provided for steeper rock slopes but suitability decreases with slope angle. The 4 cm imagery can be variable in quality but with optimum flying conditions will allow many smaller features to around 12 cm in size to be identified, except where vegetation obscures the slope. Better quality imagery is obtained from a fixed wing aircraft but cannot be flown simultaneously with the LiDAR.

Change detection between repeat surveys can be undertaken but requires some expertise in data handling and appropriate software. This would be useful for monitoring any changes to high risk earthworks or detecting where recent rock slides have occurred. The amount of change it is possible to detect has not been fully researched and requires further datasets and suitable sites, but initial observations suggest that this could be in the order of around 10 to 25 cm vertical change.

Application for high risk earthworks and slopes: This system combines vertical LiDAR data and high resolution aerial imagery and is considered to be the most appropriate remote technique for high risk earthworks inspections, as well as areas outside the highway boundary that may be affecting earthwork stability. Selection of fixed wing or rotary wing platforms depends on the site scale but for highest risk earthworks the rotary wing system is suitable.

The data collected is suitable for providing inspection data in most of the HD41 observation fields and considerably reducing time spent on physical inspections. The LiDAR data can be processed into multiple outputs including shaded relief 3D surfaces and contour data. LiDAR point clouds can be used to identify different vegetation types and their geometry. Smaller features such as desiccation crack and animal burrows may be more difficult to identify, particularly below vegetation cover.

3) Vertical aerial photography

Vertical aerial photography captured from a fixed wing aircraft can be provided at lower cost than comparable imagery taken from a rotary wing LiDAR platform, due mainly to the different type of camera used. Resolution of widely available 'off-the-shelf' imagery typically ranges from 25 cm up to 10 cm and this is available through HAGDMS and Geostore, although the most recent national dataset is from 2013. For bespoke surveys the highest resolution possible with modern cameras is now 2 cm, which would allow features of around 6-10 cm in size to be detected. However, this type of photography is not being routinely procured by Highways England and is mainly suitable for discontinuous sections of the network where particular issues are present.

For earthworks inspections the lowest suitable resolution would be around 10cm, but 2 to 4cm imagery provides much more detail, particularly for smaller features. The higher resolution imagery captured by rotary wing is the optimum technique for identifying surface visible features with no topographic expression, such as slope drainage, bare slopes and seepages as well as areas of darker hydrophilic vegetation which may be related to softer, wetter ground.

Application for high risk earthworks and slopes: Vertical aerial photography captured from a fixed wing aircraft can be used to detect some slope features of geotechnical interest as well as roadside features such as leaning fences, distorted barriers and pavement cracking, providing they are not obscured by vegetation. Dislocated trees are more difficult to detect, unless extreme. However, high resolution aerial photography captured from a rotary wing platform is the optimum image dataset available. This data is best used in combination with high resolution LiDAR point cloud data. The combination allows for monitoring visible and morphological changes.

4) Terrestrial LiDAR (static/tripod)

Limited research has been carried out on this type of sensor by Highways England but work by others has shown that detailed rock slope assessments can be undertaken. A high density LiDAR point cloud is generated from this sort of survey and is able to determine even small features. Previous applications have mainly been for quarry faces and coastal cliffs but high definition of discontinuities is possible and automated routines can provide stereonet plotting of this data. Features such as gulleying, toe debris and slumping are detectable and change detection can be carried out with repeat surveys. Openness of discontinuities may be challenging to determine exactly.

Application for high risk earthworks and slopes: This technique would be suitable for high risk, tall and steep rock cuttings of limited linear extent that would be difficult to inspect from the carriageway, providing a suitable scanning point opposite the slope can be found. Repeat surveys should be taken from the same points opposite the slope in order to monitor slope degradation over time.

4) Hyperspectral scanning

Imagery is collected across 300+ spectral bands at 0.75-1 m spatial resolution. This is too coarse for detailed slope inspections and small feature detection. However selected bands in the colour and short-wave infra-red spectrum have shown good initial results for detection of drainage features such as counterfort drains and areas of wet ground or ponding (as shown in **Figure 1**). In addition, it may be possible to identify wetter and drier areas of grassed slopes through the spectral wavelength responses. However only limited research has been undertaken to date and further investigation of this is required before any firm recommendations can be made.

Application for high risk earthworks and slopes: This dataset has shown promise for identifying changes in soil moisture and highlighting slope drainage but slope features below vegetation cover are not visible in the hyperspectral image. Some technical expertise is required for data analysis and the dataset would require significant storage capacity if collected network-wide.

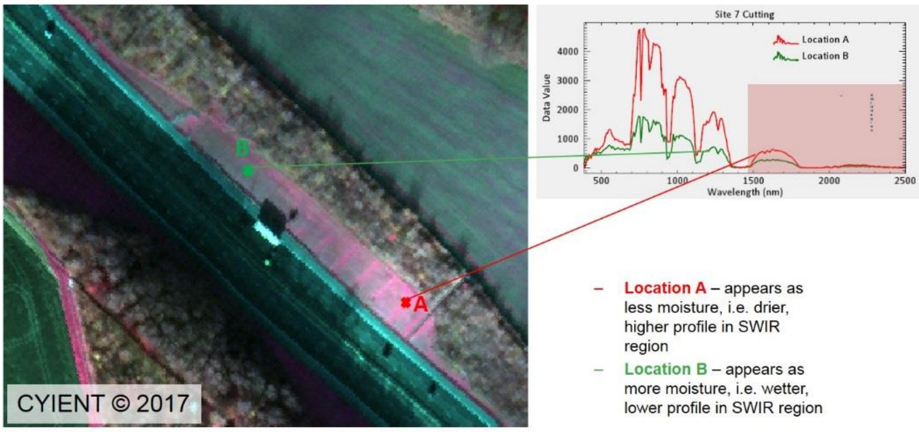


Figure 1 Hyperspectral imagery highlighting counterfort drains installed along a soil cutting on the M40. The spectral wavelength profile on the right suggests that the ground around the slope drains (A) is drier than the rest of the slope (B)

5) InSAR

Based on trials of PSInSAR and DSInSAR undertaken for high risk embankments along the M1, M6 and M11 it is concluded that these techniques are not suitable for earthwork scale assessments as there are usually insufficient persistent scatterers along the carriageway and on the slopes to allow any reliable detection of movement.

Although the technique may be suitable for wider area deformation assessments it is not yet recommended for earthworks assessments. There are newer radar satellites collecting more frequent and potentially useful datasets, such as Terrasar-X, but these have not been evaluated as the data was not freely available during the research.

Application for high risk earthworks and slopes: not recommended for use.

6) Multispectral imaging (Sentinel-2 satellite)

This data is freely available by download from the ESA website (Sci-hub) and provides imagery of the visible and near infra-red parts of the spectrum.

Application for high risk earthworks and slopes: Usually used for vegetation health studies across wider areas or corridors and the spatial resolution of ~10 m is too coarse for earthworks inspections.

5.0 Technical Guidance Summary Matrix

A Guidance Summary Matrix (**Figure 2** & **Figure 3**) is included for quick reference to help inform the choice of most appropriate remote sensing techniques for particular applications.

Figure 2 Technical Guidance Summary Matrix Key

Matrix Parameter	Rating
Data coverage:	High = national or full network Medium = sections of the network Low = limited
Data availability:	High = readily available / easy to access Medium = delivery on request Low = capture or processing required
Data quality (with respect to ground hazard detection and monitoring)	High = high resolution, accuracy, detection Medium = some limitations Low = not suitable
Ease of analysis (includes processing)	High = No specialist manipulation or processing required Medium = some processing / data manipulation required Low = specialist processing or interpretation skills needed
Frequency (current)	High = < 1 year Medium = 1-5 years Low = > 5 years or not yet widely available
Cost	High Medium Low
Suitability for ground hazard detection and monitoring	High = useful for multiple hazard detection Medium = some inspection / monitoring possible Low = limited capability

	Data coverage	**Data availability**	**Data quality**	**Ease of analysis**	**Frequency of survey**	**Cost**	**Geo-hazard detection / monitoring**
Mobile Mapping System imagery	H	H	L	H	H	M	L
Mobile Mapping System LiDAR	H	H	L	L-M	H	M	L
Rotary wing vertical aerial photography (4cm)	H	H	M-H	H	M	H	H
Rotary wing LiDAR	H	H	H	L - H	M	H	H
Fixed wing aerial photography (2 to 4cm)	L	L	H	H	L	M	H
Fixed wing vertical aerial photography (10 to 25cm)	H	H	M	H	M	L-M	M
Hyperspectral imaging	L	L	M	L-M	L	H	M
InSAR	L	L	L	L	H	M	L-M
Aerial thermal imaging	L	L	L	M	L	M	L-M

* All aerial photography is vertical colour. H-M-L = High – Medium – Low

Figure 3 Technical Guidance Summary Matrix

6.0 Key references and further information

Reference should be made to the Phase 1 Report and Phase 1 Research Summary Sheets for further detail and complementary information.

The following hazard guidance notes are available on Highways England's Geotechnical Data Management System / Geographical Information System (HAGDMS / HAGIS):

- Engineered Soil Slopes Hazard on the Strategic Road Network of England
- Engineered Rock Slopes Hazard on the Strategic Road Network of England

Acknowledgement and contact details

This work has been informed by the current task being undertaken as part of Highways England's Innovation Programme: SPaTS Task 1-086 *Application of Remote Survey Data for Geotechnical Asset Condition and Performance*.

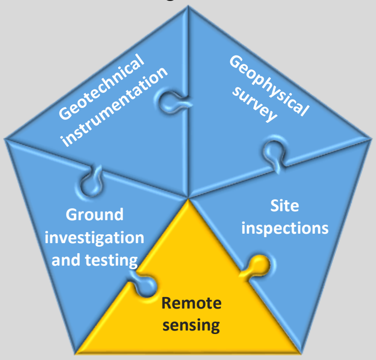
For further information, queries or comment please contact James Codd
james.codd@highwaysengland.co.uk

REMOTE ASSESSMENT FOR DETECTION AND MONITORING OF SPECIAL GEOTECHNICAL MEASURES

This Technical Guidance Note (TGN) is part of a series intended to raise awareness and provide guidance on the use of various remote sensing techniques for geotechnical asset management across the Strategic Road Network (SRN). Remote sensing techniques can be used to complement and improve upon other methods to enhance the information Highways England's needs to manage the resilience of the SRN.

This TGN is aimed at engineers and managers without specialist knowledge of remote assessment. It focuses on the use of those techniques which have potential for **detecting and monitoring Special Geotechnical Measures (SGMs)** which have been installed either during highway construction or at a later date as part of remedial or improvement works.

Geotechnical resilience: knowledge resources



This document is based on the findings of extensive research previously undertaken on this topic (2000-05) and a more recent research project (2017) that has reviewed advances and applicability of selected remote sensing techniques. As part of this study, proof-of-Concept pilot studies were carried out at a number of sites across the network and the findings have informed the content of this guidance note.

This technical note may need to be updated or developed further if techniques are reviewed against a wider range of sites, geotechnical features and ground hazards.

1.0 Background

Following earlier research work on remote assessment by Highways England from 2000-05 a framework contract was set up for the capture of selected remote sensing data by Major Projects in 2004. The main driver for this was the need to procure 1:500 scale topographic mapping for improvement schemes, but many other applications were identified including geotechnical asset management. The LiDAR Framework was replaced by the SPS Framework from 2011-15 and subsequently the current SPaTS Framework. The focus of data collection during these later frameworks changed, with AIG as the sponsor collecting data for wider asset inventory surveys used for letting term maintenance contracts.

The recent research in 2017 reviewed the potential capabilities of those techniques currently procured through the SPaTS Framework, in order to establish whether there are geotechnical applications for the data. In addition, a more limited review of other techniques was also undertaken where it was possible to obtain suitable data.

Remote sensing survey: hereby defined as gathering of data *at a distance* e.g. collected via satellite, plane, vehicle, drone etc. It does not include data collected via on-slope instrumentation such as inclinometers, piezometers or sensors that can be connected wirelessly.

A summary of the techniques currently procured by Highways England and other datasets held in storage (GeoStore) or on HAGDMS is provided in **Table 1**:

Table 1 Remote sensing techniques and data sources

	Techniques (single or complementary)	Description	Data source
Available data	Mobile Mapping System	Network wide van-mounted LiDAR and imagery collected every 1-3 years. Imagery and point cloud data can be viewed through on-line AVIS interface.	AIG, contact: AIG_Surveying@highwaysengland.co.uk
	Rotary wing LiDAR and high-resolution orthoimagery (SPaTS)	Helicopter mounted surveys carried out along selected sections of the network, but planned for future network wide rollout. Frequency depends on available budgets. Outputs include point clouds, terrain models, contour data and 4 cm resolution imagery.	AIG, contact: AIG_Surveying@highwaysengland.co.uk
	Rotary wing hyperspectral imaging	Helicopter mounted hyperspectral imaging with over 300 spectral bands. Collected in combination with LiDAR and orthoimagery, to date only on a trial basis along the M40.	Contact relevant specialist supplier
	National aerial photography	Network-wide national coverage purchased 'off-the-shelf' and provided as a layer within HAGDMS (12.5 to 25 cm resolution).	Geostore (registration and login required): http://www.geostore.com/highwaysengland/
	LiDAR Framework rotary and fixed wing LiDAR	Archive datasets captured for now completed improvement schemes along sections of the network and available through GeoStore. Narrow and wide corridor LiDAR datasets at various point densities. Limited use for current condition assessment but potential application for change monitoring.	Geostore (registration and login required): http://www.geostore.com/highwaysengland/
From suppliers	Bespoke aerial photography (fixed wing)	More conventional stand-alone aerial photography collected from fixed wing aircraft rather than synchronously with rotary wing LiDAR. Range of resolutions available, typically from 25 cm to as high as 2 cm. Limited current availability through HE databases and would have to be procured specifically.	Contact relevant specialist supplier
	Radar satellite InSAR datasets	Differential InSAR, PSInSAR and DSInSAR outputs processed from radar satellite data have been reviewed during the research work but there is currently very limited data available through HE sources. Future inSAR data would have be procured through specialist suppliers.	Contact relevant specialist supplier

2.0 Application Context

This TGN provides feedback on the recent assessment of the potential for selected remote sensing techniques to support the detection, assessment and monitoring of Special Geotechnical Measures (SGMs). Atkins have recently undertaken Task 594 for Highways England - reviewing data currently held for SGMs, and have provided a comprehensive list of 96 known SGM types. For the purposes of this TGN on remote inspection these have been divided into three groups, as shown below. This division does not follow the classification or hierarchy developed for Task 594 as it is not necessary to break down the SGMs into functional categories for the purpose of remote sensing.

- **Surface visible**: includes a wide range of retaining walls, buttressing, toe berms, dentition, catch fences or ditches, regrading and rock netting.
- **Buried but some surface trace visible**: includes some slope drainage (counterfort, herringbone, toe, etc.), soil nails, rock bolts, pile walls (capping beam), recent excavate and replace works.

- **Buried with no surface trace visible**: includes measures such as fully rehabilitated or overgrown excavate and replace works, slabs and rafts, cement and lime stabilisation, shear keys and trenches, stone columns, dynamic compaction, grout injection, fibre reinforcement and geotextiles

Remote assessment – as for physical inspections – will not provide any direct information on the location or performance of the last group, although indirect observations of the earthwork condition where buried SGMs are not performing may be possible. This TGN focuses on the first two groups, where there is some surface exposure of the SGM.

The TGNs have been prepared to align with the *Maintenance of Highway Geotechnical Assets* standard (**HD41/15**), which provides guidance on the inspection regime and the data fields to populate, as well as the risk-based inspection process set out in the Geotechnical Asset Management Plan (GeoAMP).

3.0 Aims of remote sensing surveys

The information required or the importance of different data fields for earthworks inspections can vary depending on site scale, geology, slope morphology, vegetation cover and age. Deterioration rates and timescales can also vary considerably. The location in relation to the carriageway, will determine the resulting level of risk posed. Different sensors provide different information about earthworks and usually a combination of techniques (often captured together from a single platform) provides the most useful datasets. The aim of remote sensing surveys will be to supplement physical inspections carried out on-foot and to provide information that would otherwise be difficult to assess from ground level on the earthwork. This is particularly relevant to the detection of geo-hazards, which can be external to the highways corridor.

As for all earthworks inspections, after collection of inventory data the aim is to assess condition and then monitor the deterioration to identify when or if timely intervention is required. The 2017 research sought to identify whether remote sensing techniques, particularly LiDAR, can monitor gradual change over time and provide an early warning of major change.

4.0 Techniques and suitability for providing inspection data on SGMs

1) Mobile Mapping System

Frequent (every 1 to 3 years) and recent surveys across the whole network providing high point density LiDAR data and multiple imagery captured from a van travelling at road speeds (as shown in **Figure 1**). Data extent is limited to line of sight and within 30 m of the laser sensor which means that embankment slopes and the crests of deeper cuttings are not fully covered. The ability of the imagery and laser points to delineate features beyond the kerb is affected by vegetation and other obstructions such as signs and fences.

Currently the survey specification for Mobile Mapping System does not require detailed classification of the laser point cloud and the classes are limited to 'the carriageway' and 'all other features'. Although this still allows roadside furniture and other structures, including SGMs like retaining walls, to be identified in the point cloud this could be improved considerably by more detailed point classification. Various derived outputs from the point cloud are possible including 3D surfacing and slope contour data. Hard surfaces like concrete walls will provide good reflectance of the laser pulses and allow accurate spatial referencing of the surface. More discontinuous surfaces like gabion baskets and crib walls will provide a more diffuse surface and if laser systems are to be used for monitoring these types of SGM then it is recommended that multiple target plates are fixed to the faces for improved change detection. Due to the high point density provided by the laser sensors sufficient reflectance is obtained from the wire mesh sheets forming catch fences and rock netting to allow detection.

Bare rock slopes scan well with medium resolution of slope morphology and SGMs like dentition works can be observed (they will also be detected in the imagery).

The imagery provided by the system is good from kerb to kerb but currently of mixed quality for the areas outside where most geotechnical assets are located, and SGMs. The imagery is often too dark or in shadow but detection of surface visible SGMs from retaining walls to rock bolt heads is possible when natural lighting conditions are suitable. The capability to detect buried SGMs with some surface trace depends on a suitable line of sight, vegetation and other obstruction and lighting conditions but where this is suitable then SGMs like pile wall capping beams, counterfort / trench drains and recent excavate and replace works can be detected.

The Mobile Mapping System data is accessed through the on-line AVIS platform for which minimal training is required, and this is very useful interface through which to view the multi-aspect imagery, point clouds and positional reference data. Examples from AVIS are shown in **Figure 1** below. Further development of AVIS to display additional datasets like LiDAR slope contours and high resolution aerial photography would help develop its future potential for SGM inspections.

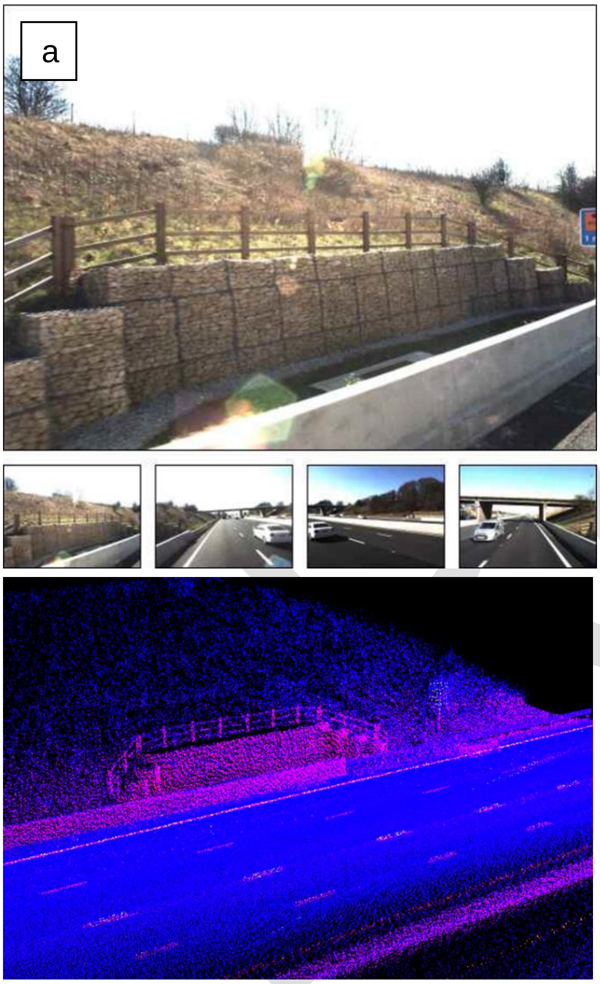


Figure 1a: Mobile Mapping System imagery and laser data showing gabion basket wall retaining cutting slope (M1).

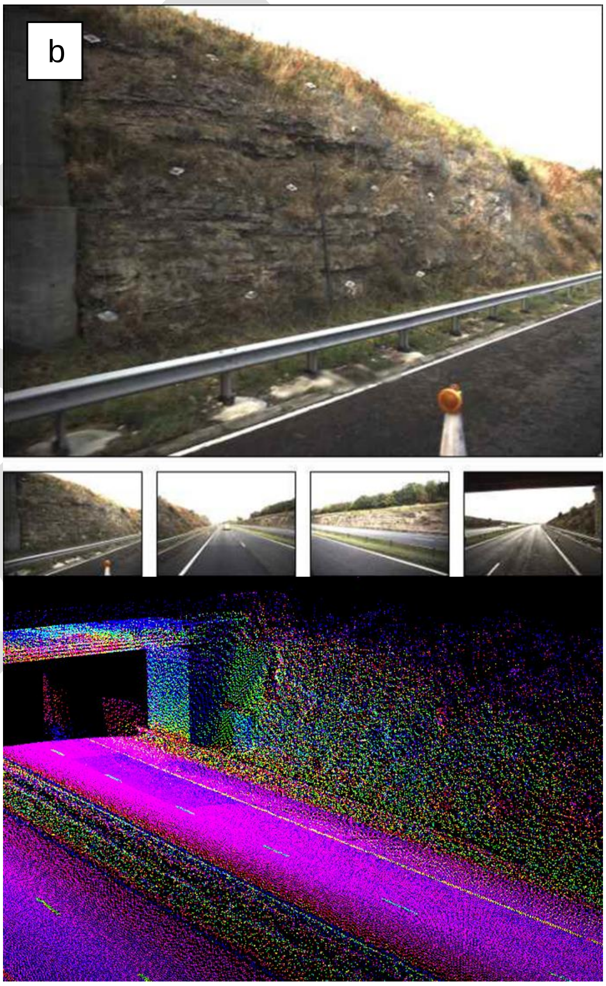


Figure 1b: Rock bolting and mesh installed in rock cutting (A1).

Application for SGMs: Data collected by the Mobile Mapping System is available for the whole network. It is easily accessible on-line through the AVIS interface which requires minimal training to use. All the imagery and data is geo-referenced, and to highway mileposts. Improvements to the LiDAR processing specification and the imagery quality would be beneficial for SGM inspections but the system currently provides a good resource for initial first pass inspections and SGM inventory where these are surface visible. Where specific SGMs require monitoring, for example where it is noted that a gabion wall has started to deform, then it would be possible to provide quantitative data for change detection with the LiDAR point data for repeat surveys.

2) Rotary wing LiDAR and 4 cm orthoimagery

This airborne survey system provides both LiDAR data and high resolution orthoimagery of the highway corridor (e.g. **Figure 2**). The corridor is usually fence to fence, but this can be extended with additional flight lines. Where the survey corridor needs to be much wider, then fixed wing LiDAR can be considered but Highways England are not using this system routinely and it is unlikely to be required for SGM monitoring. The LiDAR point density provided is lower than that from the Mobile Mapping System but the vertical azimuth provides a different perspective to the roadside view. All earthworks can be properly covered and there are no data shadows except under bridges or overhangs on rock faces.

Penetration of LiDAR pulses through vegetation cover allows above ground SGMs like toe berms and gabion baskets to be detected even under the tree canopy. If the SGM is vertical – like a sheet pile wall – then there is less surface available to reflect the laser pulses and, while the feature location and extent can usually be detected the potential for change detection decreases. This is also a restriction for monitoring of any SGMs installed on steep rock cutting faces, such as dentition, rock bolts and rock netting. 3D surface models, including contours, generated from the LiDAR data will allow good definition of earthwork morphology including the alignment and depth of toe or crest drainage ditches.

The 4 cm imagery captured from the helicopter synchronously with the LiDAR data can be variable in quality but with optimum flying conditions will allow many smaller features to around 12 cm in size to be identified, except where vegetation obscures the slope. Better quality imagery is obtained from a fixed wing aircraft but cannot be flown simultaneously with the LiDAR. The imagery is suitable for detecting many features including slope drainage - counterforts, herringbone, toe etc. - as well as recent excavate and replace works, soil nail heads, various retaining walls and pile walls with capping beams.

The LiDAR outputs and imagery can be viewed in GIS but simpler viewer packages are also available – the imagery is compressed and 3D surfaces or contour data can be provided in .shp file format. The data can also be used in CAD. More experienced users can view and manipulate the laser point data using point cloud software. Both the laser data and the imagery are fully geo-referenced to a high degree of vertical and horizontal accuracy.

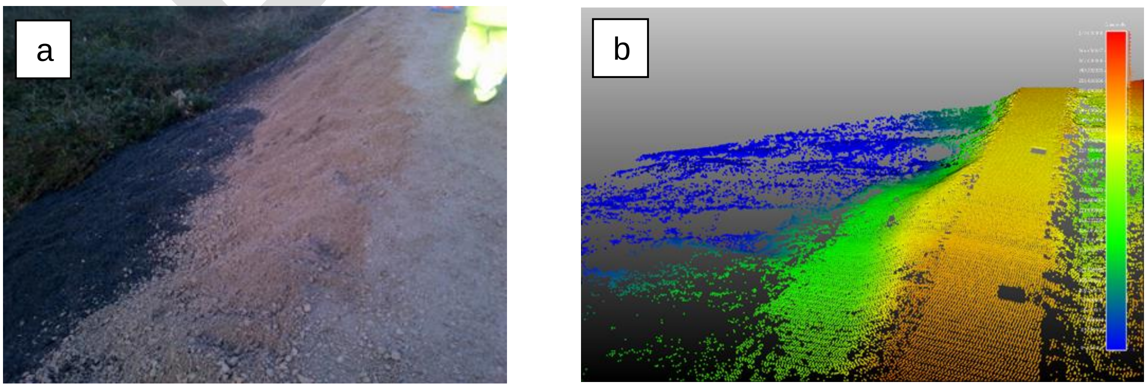


Figure 2a: Photo of emergency slope support remedial works placed following failure (A21); Figure 2b: LiDAR point cloud data (bare earth) showing the same site after remediation

Application for SGMs: This system combines vertical LiDAR data and high resolution aerial imagery and is considered to be the most appropriate remote technique for inspections across all earthwork types, as well as allowing detection of visible and above surface SGMs. However there are imitations to the information that can be provided for more vertical retaining structures and this would be better assessed through oblique or roadside systems in conjunction with this vertical sensor.

3) Vertical aerial photography

Vertical aerial photography captured from a fixed wing aircraft can be provided at lower cost than comparable imagery taken from a rotary wing LiDAR platform, due mainly to the different type of camera used. Resolution of widely available 'off-the-shelf' imagery typically ranges from 25 cm up to 10 cm and this is available through HAGDMS and Geostore, although the most recent national dataset is from 2013. For bespoke surveys the highest resolution possible with modern cameras is now 2 cm, which would allow features of around 6 -10 cm in size to be detected. However, this type of photography is not being routinely procured by Highways England and is mainly suitable for discontinuous sections of the network where particular issues are present.

For surface visible SGMs the higher resolution data (better than 10cm) captured from rotary wing aircraft is the optimum imagery product, although some SGMs can be detected with lower resolution imagery (see **Figure 3**).

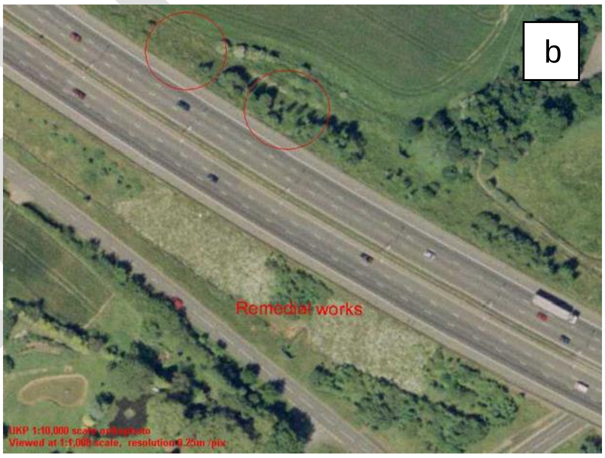


Figure 3a: 10 cm resolution photography showing buried but surface visible slope drainage (M25)

Figure 3b: 25 cm resolution photography showing recent excavate and replace remediation (M25)

Figure 3c: 10 cm imagery showing bridge abutment walls – but limited slope view due to tree cover (M25)

Application for SGMs: High-resolution (2 to 4 cm) vertical aerial photography captured from a rotary wing platform is the optimum image dataset available for visible detection and visual monitoring of geo-hazards, providing they are not obscured by trees or other low lying vegetation. Open tension cracks can be detected when they are around 10 cm wide, or possibly narrower if they are sufficiently elongate.

6) Hyperspectral scanning

Hyperspectral imagery is collected across more than 300 spectral bands at 0.75 - 1 m spatial resolution. This is too coarse for detailed slope inspections or detection of many SGMs but the research has shown some promising initial results for detecting slope drainage features (as shown in **Figure 4**). In addition it may be possible to identify wetter and drier areas of grassed slopes through the spectral wavelength responses. This would help to understand how the slope drains are performing. However only limited research has been undertaken to date and further investigation of this is required before any firm recommendations can be made.

Application for SGMs: Some initial promising results from the research suggest that hyperspectral imaging could have an application for the detection and assessment of slope drainage, where this is surface visible.

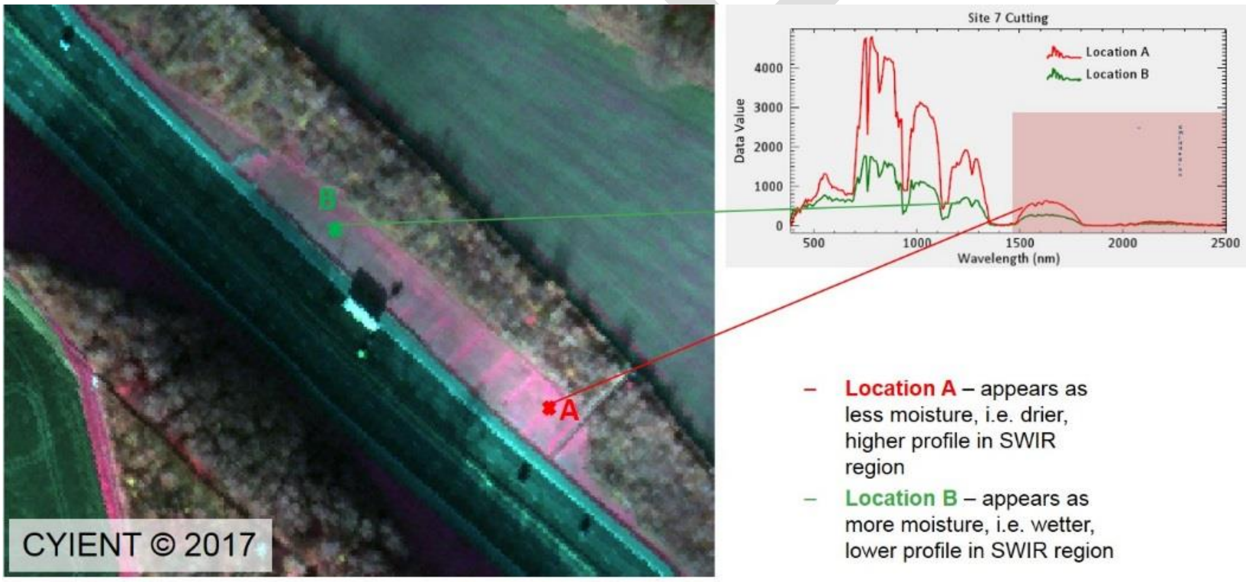


Figure 4: Hyperspectral imagery highlighting counterfort drains installed along a soil cutting on the M40. The spectral wavelength profile on the right suggests that the ground around the slope drains (A) is drier than the rest of the slope (B).

6) InSAR

There are various forms of inSAR outputs available following processing of raw data from radar satellites. The processing relies on skilled analysts but the qualitative and quantitative outputs can be interpreted by engineers. The technique which is most likely to be suitable for monitoring the deformation of retaining walls is PSinSAR. This would require the wall to have the correct geometry for it to behave as a persistent and reliable reflector in the radar scene, over the time series required for monitoring. It may also be possible to form or place a suitable artificial reflector on to the wall to allow monitoring to be carried out. If these conditions can be met then it is possible that wall deformations in the look direction of the satellite can be resolved down to mm accuracy but this has not been widely used for highway applications and some form of trial would be needed before the technique can be adopted for network wide use. This would likely be used only for a small number of retaining walls where on-going deformations are experienced and the consequences resulting from wall failure are severe.

No other applications have been identified for SGM detection and monitoring with inSAR.

Application for SGMs: The PSinSAR technique may have some application for the monitoring of selected high risk retaining structures, where these form reliable and persistent scatterers in the satellite radar scene. Trials are recommended before adoption.

5.0 Technical Guidance Summary Matrix

A Guidance Summary Matrix (**Figure 5** and **Figure 6**) is included for quick reference to help inform the choice of most appropriate remote sensing techniques for particular applications.

Figure 5 Technical Guidance Summary Matrix Key

Matrix Parameter	Rating
Data coverage:	High = national or full network Medium = sections of the network Low = limited
Data availability:	High = readily available / easy to access Medium = delivery on request Low = capture or processing required
Data quality (with respect to geohazard detection and monitoring)	High = high resolution, accuracy, detection Medium = some limitations Low = not suitable
Ease of analysis (includes processing)	High = No specialist manipulation or processing required Medium = some processing / data manipulation required Low = specialist processing or interpretation skills needed
Frequency (current)	High = < 1 year Medium = 1-5 years Low = > 5 years or not yet widely available
Cost	High Medium Low
Suitability for geohazard detection and monitoring	High = useful for multiple hazard detection Medium = some inspection / monitoring possible Low = limited capability

	Data coverage	Data availability	Data quality	Ease of analysis	Frequency of survey	Cost	Geo-hazard detection / monitoring
Mobile Mapping System imagery	H	H	L	H	H	M	L
Mobile Mapping System LiDAR	H	H	L	L-M	H	M	L
Rotary wing vertical aerial photography (4cm)	H	H	M-H	H	M	H	H
Rotary wing LiDAR	H	H	H	L - H	M	H	H
Fixed wing aerial photography (2 to 4cm)	L	L	H	H	L	M	H
Fixed wing vertical aerial photography (10 to 25cm)	H	H	M	H	M	L-M	M
Tripod LiDAR	L	L	H	M	L	L-M	M
Hyperspectral imaging	L	L	M	L-M	L	H	M
InSAR	L	L	L	L	H	M	L-M
Aerial thermal imaging	L	L	L	M	L	M	L-M

* All aerial photography is vertical colour. H-M-L = High – Medium – Low

Figure 6 Technical Guidance Summary Matrix

6.0 Key references and further information

Reference should be made to other deliverables from this project (Phase 1 Report and Phase 1 Research Summary Sheets) for further detail and complementary information.

For more details on the SGMs, please refer to T-TEAR Task 594 'Strengthened Earthworks Report'.

Acknowledgement and contact details

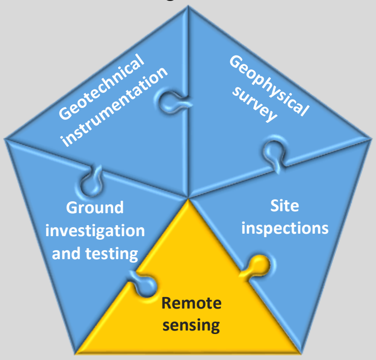
This work has been informed by the current task being undertaken as part of Highways England's Innovation Programme: SPaTS Task 1-086 *Application of Remote Survey Data for Geotechnical Asset Condition and Performance*.

For further information, queries or comment please contact James Codd
james.codd@highwaysengland.co.uk

REMOTE ASSESSMENT FOR DETECTION AND MONITORING OF GEO-HAZARDS AFFECTING HIGHWAYS ENGLAND'S NETWORK

This Technical Guidance Note (TGN) is part of a series intended to raise awareness and provide guidance on the use of various remote sensing techniques for geotechnical asset management across the Strategic Road Network (SRN). Remote sensing techniques can be used to complement and improve upon other methods to enhance the information Highways England's needs to manage the resilience of the SRN.

Geotechnical resilience: knowledge resources



This TGN is aimed at engineers and managers without specialist knowledge of remote assessment. It focuses on the use of those techniques which have potential for **detecting and monitoring geo-hazards** which may pose a risk to the safe running and performance of the highway.

This document is based on the findings of extensive research previously undertaken on this topic (2000-05) and a more recent research project (2017) that has reviewed advances and applicability of selected remote sensing techniques. As part of this study, proof-of-concept pilot studies were carried out at a number of sites across the network and the findings have informed the content of this guidance note.

This technical note may need to be updated or developed further if techniques are reviewed against a wider range of sites, geotechnical features and ground hazards.

1.0 Background

Following earlier research work on remote assessment by Highways England from 2000-05 a framework contract was set up for the capture of selected remote sensing data by Major Projects in 2004. The main driver for this was the need to procure 1:500 scale topographic mapping for improvement schemes, but many other applications were identified including geotechnical asset management. The LiDAR Framework was replaced by the SPS Framework from 2011-15 and subsequently the current SPaTS Framework. The focus of data collection during these later frameworks changed, with AIG as the sponsor collecting data for wider asset inventory surveys used for letting term maintenance contracts.

The recent research in 2017 reviewed the potential capabilities of those techniques currently procured by the Asset Information Group (AIG), in order to establish whether there are geotechnical applications for the data. In addition, a more limited review of other techniques was also undertaken where it was possible to obtain suitable data.

Remote sensing survey: hereby defined as gathering of data *at a distance* e.g. collected via satellite, plane, vehicle, drone etc. It does not include data collected via on-slope instrumentation such as inclinometers, piezometers or sensors that can be connected wirelessly.

A summary of the techniques currently procured by Highways England and other datasets held in storage (GeoStore) or on HAGDMS is provided in **Table 1**:

Table 1 Remote sensing techniques and data sources

	Techniques (single or complementary)	Description	Data source
Available data	Mobile Mapper	Network wide van-mounted LiDAR and imagery collected every 1-3 years. Imagery and point cloud data can be viewed through on-line AVIS interface.	AIG, contact: AIG_Surveying@highwaysengland.co.uk
	Rotary wing LiDAR and high-resolution orthophotos	Helicopter mounted surveys carried out along selected sections of the network, but planned for future network wide rollout. Frequency depends on available budgets. Outputs include point clouds, terrain models, contour data and 4cm resolution imagery.	AIG, contact: AIG_Surveying@highwaysengland.co.uk
	Rotary wing hyperspectral imaging	Helicopter mounted hyperspectral imaging with over 300 spectral bands. Collected in combination with LiDAR and ortho-photos, to date on a trial basis only along the M40.	Contact relevant specialist supplier
	National aerial photography	Network-wide national coverage purchased 'off-the-shelf' and provided as a layer within HAGDMS (12.5 to 25 cm resolution).	Geostore (registration and login required): http://www.geostore.com/highwaysengland/
	Rotary and fixed wing LiDAR	Archive datasets captured for now completed improvement schemes along sections of the network and available through GeoStore. Narrow and wide corridor LiDAR datasets at various point densities. Limited use for current condition assessment but potential application for change monitoring.	Geostore (registration and login required): http://www.geostore.com/highwaysengland/
From suppliers	Bespoke aerial photography (fixed wing)	More conventional stand-alone aerial photography collected from fixed wing aircraft rather than synchronously with rotary wing LiDAR. Range of resolutions available, typically from 25 cm to as high as 2 cm. Limited current availability through HE databases and would have to be procured specifically.	Contact relevant specialist supplier
	Radar satellite InSAR	Differential inSAR, PSinSAR and DSinSAR outputs processed from radar satellite data have been reviewed during the research work but there is currently very limited data available through HE sources. Future inSAR data would have be procured through specialist suppliers.	Contact relevant specialist supplier

2.0 Application Context

This TGN provides feedback on the application of remotely sensed data to earthworks inspections across the network, specifically where there is the potential for or actual presence of geo-hazards, either along or adjacent to the highway corridor. These geo-hazards can include:

- **Coal mining / non-coal mining** –a range of hazards from collapses into shallow hand-dug deneholes or bell pits, to settlements across discrete backfilled open cast pits and more widespread subsidence over deeper sub-surface mines, partly due to groundwater rises following mine closures as well as general subsidence due to extraction.
- **Dissolution features** – Areas underlain by soluble rocks including limestone, chalk, gypsum and rock salt where there is the potential for sudden or gradual collapse of overburden into pre-existing **sinkholes** below or adjacent to the highway.

- **Groundwater flooding** – where the water level within the ground rises to inundate assets or cause surface flooding. Events are becoming more common with climate change and development across flood plains.
- **Landslides and rockfalls** – large natural slopes or engineers soil and rock slopes where relic or active slope instability features exist and the highway either traverses or runs adjacent to the slope.
- **Compressive / Collapsible ground** – naturally occurring soft materials the susceptible to large progressive settlement, or structured deposits that undergo large volume change (collapse) when under load and saturated.

For further information relating to ground-related hazards, see the Tier 0 Hazard Guidance Notes available on Highways England's Geotechnical Data Management System (HAGDMS) and Highways England's Geographic Information System (HAGIS).

The TGNs have been prepared to align with the *Maintenance of Highway Geotechnical Assets* standard (**HD41/15**) that provides guidance on the inspection regime and the data fields to populate, as well as the risk-based inspection process set out in the Geotechnical Asset Management Plan (GeoAMP).

3.0 Aims of remote sensing surveys

The information required or the importance of different data fields for earthworks inspections can vary depending on site scale, geology, slope morphology, vegetation cover and age. Deterioration rates and timescales can also vary considerably. The location in relation to the carriageway, will determine the resulting level of risk posed. Different sensors provide different information about earthworks and usually a combination of techniques (often captured together from a single platform) provides the most useful datasets. The aim of remote sensing surveys will be to supplement physical inspections carried out on-foot and to provide information that would otherwise be difficult to assess from ground level on the earthwork. This is particularly relevant to the detection of geo-hazards, which can be external to the highways corridor.

As for all earthworks inspections, after collection of inventory data the aim is to assess condition and then monitor the deterioration to identify when or if timely intervention is required. The 2017 research sought to identify whether remote sensing techniques, particularly LiDAR, can monitor gradual change over time and provide an early warning of major change.

4.0 Techniques and suitability for providing data on geo-hazards

1) Mobile Mapper

Frequent (every 1 to 3 years) and recent surveys across the whole network providing high point density LiDAR and imagery captured from a van travelling at road speed. Earthwork data is limited to cuttings only, and within 30 m range of the sensor on the carriageway. Embankment slopes are mostly beyond the line of sight, although some information on the surrounding land can be captured where the earthwork geometry and line-of-sight permits this. However, the LiDAR point cloud classification requires changes to the current specification to provide classifications suitable for slope feature detection. At the moment slope contours are not always provided by the suppliers but can be generated from the derived 3D surfaces.

Bare rock slopes scan well with medium resolution of slope morphology, bedding dip, gulleys, overhangs and toe debris. Comprehensive discontinuity observations are not possible.

Imagery is good from kerb to kerb but of mixed quality for the cutting slopes. Frequently too dark or in shadow but feature detection including slips, bare ground, vegetation, barriers, fences and remedial works is possible where captured in good light. Limited to line of sight and slopes obscured by vegetation are not visible.

Accessed through on-line AVIS platform with minimal training required, and is a good interface for the imagery, point clouds and positional reference data. Further development of AVIS to display additional datasets (e.g. LiDAR slope contours and aerial photography) would increase its potential application.

Application for geo-hazard detection: The Mobile Mapper system is limited with respect to geo-hazard detection particularly for larger natural slopes and river channels as the field of view is restricted mainly to the highway corridor. It is possible to get views across surrounding areas from low height embankments unless vegetation is present. Sinkholes opening up within the verge or in the central reservation would be detectable through the imagery but are likely to be immediately reported by road users. Gradual settlement of overburden capping a sinkhole may be possible through change detection using the LiDAR. This would have to be through repeat Mobile Mapper LiDAR surveys and not a mixture of van-mounted and aerial LiDAR. Settlements caused by mining subsidences are unlikely to be determined in a quantitative way, even with the LiDAR data, but where subsidence affects the pavement through tension cracking or distortion of structures then the Mobile Mapper will be suitable for this. Viewing a series of repeat surveys will help establish changes over time.

2) Rotary wing LiDAR and 4 cm ortho-photography

Suitable for detecting features on cuttings, embankments and outside the highway corridor on natural slopes and river valleys (e.g. **Figure 1**). Corridor usually fence to fence, but this can be extended with additional flight lines. Where the survey corridor needs to be much wider, then fixed wing LiDAR should be considered but Highways England are not using this system routinely. However, specifications for this exist within the LiDAR Framework.

Good penetration of LiDAR pulses through vegetation cover to map slopes below the canopy - although point density drops to around 1 – 5 / m^2 this is sufficient to detect even small slope deformations. Good definition of earthwork or natural slope geometry, including gulley heads, and detection of small and large slips, including those with subtle surface expressions such as relic mudslides. Low, medium and high vegetation can be classified. Some useful information provided for steeper rock slopes but suitability decreases with slope angle. The 4 cm imagery can be variable in quality but with optimum flying conditions will allow many smaller features to around 12 cm in size to be identified, except where vegetation obscures the slope. Better quality imagery is obtained from a fixed wing aircraft but cannot be flown simultaneously with the LiDAR.

Change detection between repeat surveys can be undertaken but requires some expertise in data handling and appropriate software. This would be useful for monitoring any changes to larger natural slope and river bank morphology. The amount of change detectable has not been fully researched and requires further datasets and suitable sites, but initial observations suggest that this could be in the order of around 25 cm vertical change.

Application for geo-hazard detection: This system combines vertical LiDAR data and high resolution aerial imagery and is considered to be the most appropriate remote technique for both earthworks inspections and detection of most geo-hazards inside and outside the highway boundary. Detection of sinkholes prior to collapse is difficult unless there is some prior surface deformation or the infill material is visibly different at the ground surface. Open tension cracks can be detected when they are around 10 cm wide, or possibly narrower if they are sufficiently elongate.

Selection of fixed wing or rotary wing platforms depends on the site and geo-hazard scale.

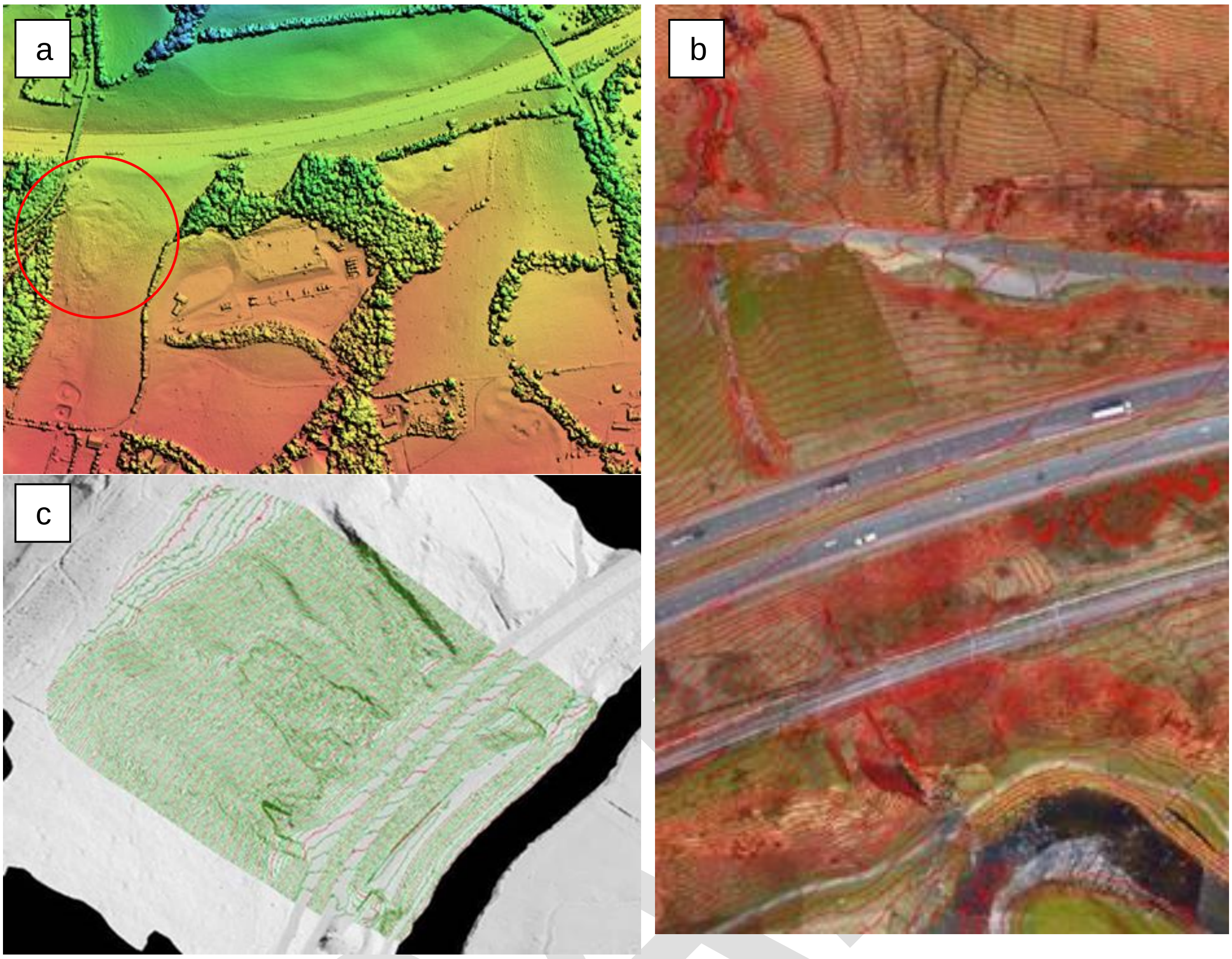


Figure 1a: LiDAR data 3D surface highlighting relic mudslide adjacent to the M25

Figure 1b: LiDAR contours and imagery at M6 Lune Gorge delineating slope morphology, gulleys and river channel

Figure 1c: LiDAR contours and 3D surface showing natural slope instability below dense tree canopy – M40 Leys Bend

3) Vertical aerial photography

Vertical aerial photography captured from a fixed wing aircraft can be provided at lower cost than comparable imagery taken from a rotary wing LiDAR platform, due mainly to the different type of camera used. Resolution of widely available 'off-the-shelf' imagery typically ranges from 25 cm up to 10 cm and this is available through HAGDMS and Geostore, although the most recent national dataset is from 2013. Some examples of the different available photo resolutions are shown in **Figure 2.** For bespoke surveys the highest resolution possible with modern cameras is now 2 cm, which would allow features of around 6-10 cm in size to be detected. However, this type of photography is not being routinely procured by Highways England and is mainly suitable for discontinuous sections of the network where particular issues are present.

For geo-hazard features requiring visible detection rather than morphology detection then aerial photography captured by rotary wing is the optimum system due to the better resolution. This could be appropriate for sinkhole detection where there is limited deformation prior to collapse but vegetation differences or ponding water may provide an indication of their presence. Existing open or depression sinkholes could be detected providing they are not obscured by vegetation. This would be a useful technique for assessments of large natural slopes and river bank erosion.

Application for geo-hazard detection: Vertical aerial photography captured from a fixed wing platform can be used for visible detection and visual monitoring of geo-hazards, providing they are not obscured by trees or other low lying vegetation. However, high resolution aerial photography captured from a rotary wing platform is the optimum image dataset available.

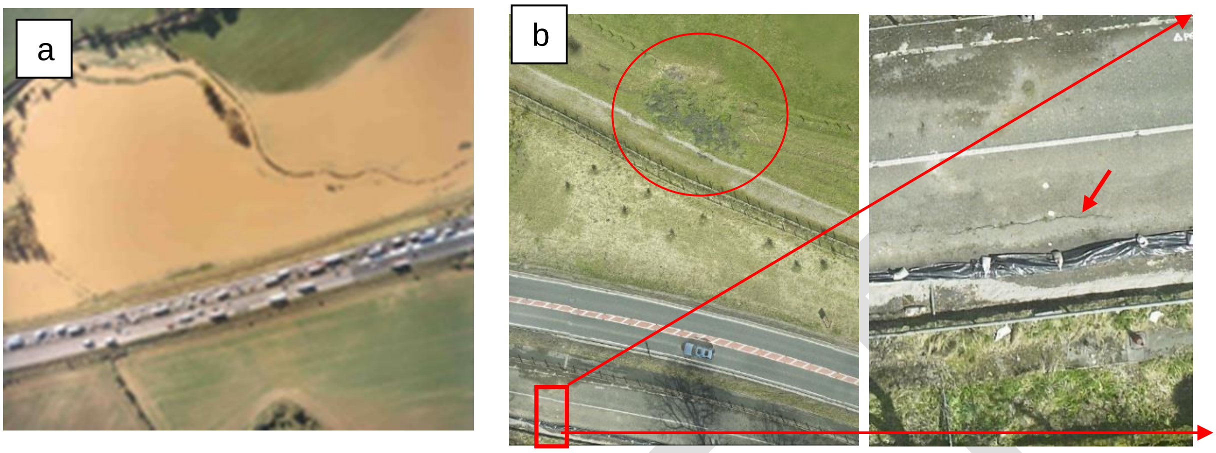


Figure 2a: 25 cm photography showing extent of flooding adjacent to highway

Figure 2b: 5 cm imagery showing a land slip (circled in red) and a zoomed in section of the image showing cracking (indicated by the red arrow) on the highway, related to natural slope failure further to the south (bottom of the image)

4) Terrestrial LiDAR (static/tripod)

Limited research has been carried out on this type of sensor by Highways England but work by others has shown that detailed rock slope assessments can be carried out. Application has mainly been for quarry faces and coastal cliffs but high definition of discontinuities is possible and automated routines can provide stereonet plotting of discontinuity data. Features such as gulleying, toe debris and slumping are detectable and change detection can be carried out with repeat surveys.

Application for geo-hazard detection: This technique would be suitable for assessing geo-hazards associated with high risk, large and steep rock cuttings of limited linear extent that would be difficult to inspect from the carriageway, providing a suitable scanning point opposite the slope can be found. Repeat surveys should be taken from the same points opposite the slope in order to monitor slope degradation over time.

5) Hyperspectral scanning

Imagery is collected across 300+ spectral bands at 0.75-1 m spatial resolution. This is too coarse for detailed slope inspections and small feature detection. However, selected bands in the colour and short-wave infra-red spectrum have shown good initial results for detection of drainage features such as counterfort drains and areas of wet ground or ponding (e.g. **Figure 3**). In addition, it may be possible to identify wetter and drier areas of grassed slopes through the spectral wavelength responses. However, only limited research has been undertaken to date and further investigation of this is required before any firm recommendations can be made.

Application for geo-hazard detection: No current applications in relation to geo-hazards have been identified, but research by Highways England has been limited to date and use of this technique is likely to develop further in future. In particular, for the detection of sinkholes where infill materials may have a different spectral response to the surrounding ground.

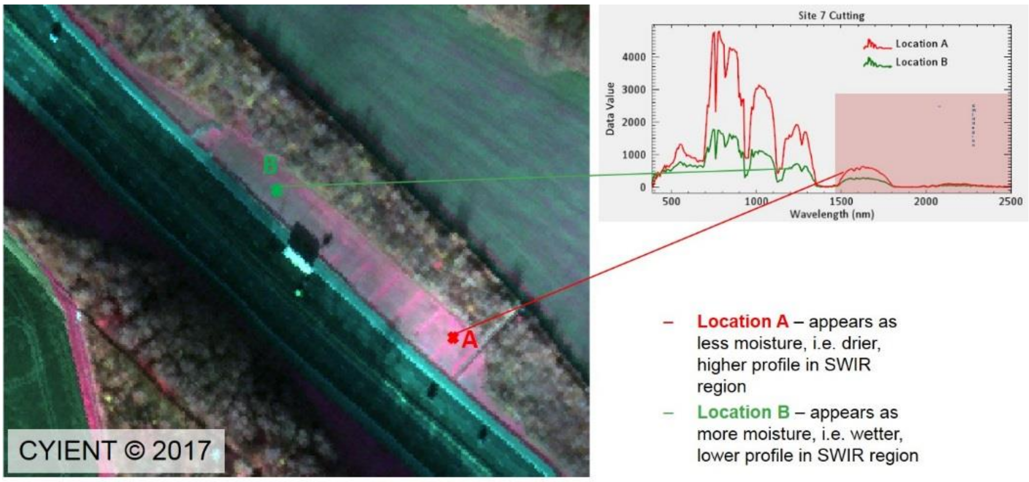


Figure 3: Example of the hyperspectral imagery highlighting counterfort drains on a soil cutting along the M40. The drains are highlighted in the short wavelength infrared (SWIR) which detects the signal for high/low soil moisture

6) InSAR

There are various forms of inSAR datasets available from the processing of radar satellite raw data. The processing relies on skilled analysts but the qualitative and quantitative outputs can be interpreted by engineers. Differential inSAR can provide DTM data and highlight ground surface deformations over a time series, but not on the typical highways earthwork scale. However, it may be possible for this technique to be used for detecting and monitoring wider area movements due to coal mining, brine pumping or groundwater extraction. To date this has not been researched by Highways England and no recommendations can be made yet, but this is likely to be an area of future interest.

PSinSAR (persistent scatterer) can detect and measure mm scale movements to discrete radar reflectors on the ground but there are usually insufficient of these along earthworks, particularly in rural areas, for the technique to currently be of any benefit for earthworks inspections. Where sufficient persistent scatterers such as buildings and structures exist across areas suffering from subsidence then there may be potential for monitoring general area deformations through analysis of a time series. This would help to identify the extent of the depression and areas of accelerating movement which may be affecting earthwork condition. The DSinSAR (Distributed Scatterer) technique was similarly found to be of limited application to earthworks assessments. This is also likely to be true for larger instability features on natural slopes but for wide area subsidence monitoring if there are sufficient persistent scatterers such as buildings and other structures across the depression.

Application for geo-hazard detection: The use of various InSAR techniques for geo-hazard detection and monitoring has to date not been researched in detail by Highways England. While inSAR currently has little application for earthworks inspections it may be possible to use differential or persistent scatterer inSAR to monitor wider areas of ground subsidence, which may be affecting the earthworks crossing the area.

7) Airborne thermal imaging

Thermal infra-red imagery can be used to map variations in ground moisture content (damp – dry) through differences in thermal response. However, the 1 m spatial resolution currently available is mostly too coarse for detection of these variations on an earthwork scale and previous research has shown that even large slope failures cannot be delineated by their thermal response. This may be due to insufficient moisture content differences within and without the slipped mass.

Aerial thermal imaging has been used by others for detecting mine shafts and may therefore also prove useful for sinkhole detection. This has not yet been subject to research by Highways England.

Application for geo-hazard detection: Limited application currently identified for geo-hazard detection but may have some potential for sinkhole detection or backfilled depressions and infilled open cast pits.

5.0 Technical Guidance Summary Matrix

A Guidance Summary Matrix (**Figure 4** and **Figure 5**) is included for quick reference to help inform the choice of most appropriate remote sensing techniques for particular applications.

Figure 4 Technical Guidance Summary Matrix Key

Matrix Parameter	Rating
Data coverage:	High = national or full network Medium = sections of the network Low = limited
Data availability:	High = readily available / easy to access Medium = delivery on request Low = capture or processing required
Data quality (with respect to geohazard detection and monitoring)	High = high resolution, accuracy, detection Medium = some limitations Low = not suitable
Ease of analysis (includes processing)	High = No specialist manipulation or processing required Medium = some processing / data manipulation required Low = specialist processing or interpretation skills needed
Frequency (current)	High = < 1 year Medium = 1-5 years Low = > 5 years or not yet widely available
Cost	High Medium Low
Suitability for geohazard detection and monitoring	High = useful for multiple hazard detection Medium = some inspection / monitoring possible Low = limited capability

	Data coverage	Data availability	Data quality	Ease of analysis	Frequency of survey	Cost	Geo-hazard detection / monitoring
Mobile Mapper imagery	H	H	L	H	H	M	L
Mobile Mapper LiDAR	H	H	L	L-M	H	M	L
Rotary wing vertical aerial photography (4cm)	H	H	M-H	H	M	H	H
Rotary wing LiDAR	H	H	H	L - H	M	H	H
Fixed wing aerial photography (2 to 4cm)	L	L	H	H	L	M	H
Fixed wing vertical aerial photography (10 to 25cm)	H	H	M	H	M	L-M	M
Tripod LiDAR	L	L	H	M	L	L-M	M
Hyperspectral imaging	L	L	M	L-M	L	H	M
InSAR	L	L	L	L	H	M	L-M
Aerial thermal imaging	L	L	L	M	L	M	L-M

* All aerial photography is vertical colour. H-M-L = High – Medium – Low

Figure 5 Technical Guidance Summary Matrix

6.0 Key references and further information

Reference should be made to the Phase 1 Report and Phase 1 Research Summary Sheets for further detail and complementary information.

The following hazard guidance notes are available on Highways England's Geotechnical Data Management System / Geographical Information System (HAGDMS / HAGIS):

- Coal Mining Hazard on the Strategic Road Network of England
- Non-Coal Mining Hazard on the Strategic Road Network of England
- Dissolution Features Hazard on the Strategic Road Network of England
- Brine Extraction Hazard on the Strategic Road Network of England
- Groundwater Flooding Hazard on the Strategic Road Network of England
- Landfill Sites Hazard on the Strategic Road Network of England
- Natural Landslides Hazard on the Strategic Road Network of England
- Aggressive / Corrosive Soil and Groundwater Hazard on the Strategic Road Network of England
- Compressible / Collapsible Ground Hazard on the Strategic Road Network of England
- Shrink/Swell Susceptible Soils Hazard on the Strategic Road Network of England

Acknowledgement and contact details

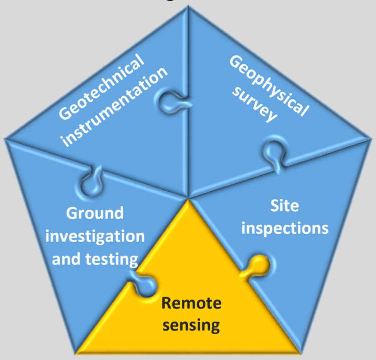
This work has been informed by the current task being undertaken as part of Highways England's Innovation Programme: SPaTS Task 1-086 *Application of Remote Survey Data for Geotechnical Asset Condition and Performance*

For further information, queries or comment please contact James Codd
james.codd@highwaysengland.co.uk

USE OF REMOTE SENSING TECHNIQUES TO REDUCE THE NEED FOR PHYSICAL INSPECTIONS

This Technical Guidance Note (TGN) is part of a series intended to raise awareness and provide guidance on the use of various remote sensing techniques for geotechnical asset management across the Strategic Road Network (SRN). Remote sensing techniques can be used to complement and improve upon other methods to enhance the information Highways England's needs to manage the resilience of the SRN.

Geotechnical resilience: knowledge resources



This TGN is aimed at engineers and managers without specialist knowledge of remote assessment. It focuses on the use of those techniques that have potential to **reduce the need for physical inspections**.

This document is based on the findings of extensive research previously undertaken on this topic (2000-05) and a more recent research project (2017) that has reviewed advances and applicability of selected remote sensing techniques. As part of this study, proof-of-Concept pilot studies were carried out at a number of sites across the network and the findings have informed the content of this guidance note.

This technical note may need to be updated or developed further if techniques are reviewed against a wider range of sites, geotechnical features and ground hazards.

1.0 Background

Following earlier research work on remote assessment by Highways England from 2000-05 a framework contract was set up for the capture of selected remote sensing data by Major Projects in 2004. The main driver for this was the need to procure 1:500 scale topographic mapping for improvement schemes, but many other applications were identified including geotechnical asset management. The LiDAR Framework was replaced by the SPS Framework from 2011-15 and subsequently the current SPaTS Framework. The focus of data collection during these later frameworks changed, with AIG as the sponsor collecting data for wider asset inventory surveys used for letting term maintenance contracts.

The recent research in 2017 reviewed the potential capabilities of those techniques currently procured through the SPaTS Framework, in order to establish whether there are geotechnical applications for the data. In addition, a more limited review of other developing techniques was also undertaken where it was possible to obtain suitable data.

Remote sensing survey: hereby defined as gathering of data *at a distance* e.g. collected via satellite, plane, vehicle, drone etc. It does not include data collected via on-slope instrumentation such as inclinometers, piezometers or sensors that can be connected wirelessly.

A summary of the techniques currently procured by Highways England and other datasets held in storage (GeoStore) or on HAGDMS is provided in **Table 1**:

Table 1 Remote sensing techniques reviewed

	Technique (single or complementary)	Description	
Available data	Mobile Mapper	Network-wide van-mounted LiDAR and imagery collected every 1-3 years. Imagery and point cloud data can be viewed through on-line AVIS interface.	AIG, contact: AIG_Surveying@highwaysengland.co.uk
	Rotary wing LiDAR and high-resolution orthoimagery	Helicopter mounted surveys carried out along selected sections of the network, but planned for future network wide rollout. Frequency depends on available budgets. Outputs include point clouds, terrain models, contour data and 4cm resolution imagery.	AIG, contact: AIG_Surveying@highwaysengland.co.uk
	Rotary wing hyperspectral imaging	Helicopter mounted hyperspectral imaging with over 300 spectral bands. Collected in combination with LiDAR and orthoimagery, to date on a trial basis only along the M40.	Contact relevant specialist supplier
	National aerial photography	Network-wide national coverage purchased 'off-the-shelf' and provided as a layer within HAGDMS (12.5 and 25 cm resolution).	Geostore (registration and login required): http://www.geostore.com/highwaysengland/
	LiDAR Framework rotary and fixed wing surveys	Archive datasets captured for now completed improvement schemes along sections of the network and available through GeoStore. Narrow and wide corridor LiDAR datasets at various point densities. Limited use for current condition assessment but potential application for change monitoring.	Geostore (registration and login required): http://www.geostore.com/highwaysengland/
From suppliers	Bespoke aerial photography (fixed wing)	More conventional stand-alone aerial photography collected from fixed wing aircraft rather than synchronously with rotary wing LiDAR. Range of resolutions available, typically from 25 cm to as high as 2 cm. Limited current availability through HE databases and would have to be procured specifically.	Contact relevant specialist supplier
	Radar satellite InSAR datasets	Differential InSAR, PSInSAR and DSInSAR outputs processed from radar satellite data have been reviewed during the research work but there is currently very limited data available through HE sources. Future InSAR data would have be procured through specialist suppliers.	Contact relevant specialist supplier

2.0 Application context

This TGN provides feedback on the application of remotely sensed data to earthworks inspection across the network, specifically where there is a need to reduce the frequency of physical inspections. This could be where:

- **Access** to the earthworks is restricted or not possible on a temporary basis due to:
    - Lane closure (e.g. long-running road works)
    - Other uses occupy the hard shoulder (e.g. SMART motorways)
    - Dense vegetation
    - Earthwork extent/distance from the carriageway (access point) is too great, such as can be the case with natural soil slopes or sidelong ground – problems with line of sight and possibly location referencing
    - Geo-hazards originating outside the highways corridor, such as unstable ground associated with former mining cavity or dissolution feature subsidence or boggy ground, etc.
- **Safety** (and access) is an issue, such as is the case for tall, steep and benched rock slopes.

- **Long lengths of lower-risk earthworks** can be inspected at lower frequencies and the level of detail provided by physical inspections is not required so often.
- **Available remote sensing techniques** can provide the necessary information faster and cheaper.

The TGNs have been prepared to align with the *Maintenance of Highway Geotechnical Assets* standard (**HD41/15**), which provides guidance on the inspection regime and the data fields to populate, as well as the risk-based inspection process set out in the Geotechnical Asset Management Plan (GeoAMP).

3.0 Aims of remote sensing surveys

The information required or the importance of different data fields for earthworks inspections can vary depending on site scale, geology, slope morphology, vegetation cover and age. Deterioration rates and timescales can also vary considerably. The location in relation to the carriageway, will determine the resulting level of risk posed. Different sensors provide different information about earthworks and usually a combination of techniques (often captured together from a single platform) provides the most useful datasets. The aim of remote sensing surveys will be to supplement physical inspections carried out on-foot and to provide information that would otherwise be difficult to assess from ground level on the earthwork.

As for all earthworks inspections, after collection of inventory data the aim is to assess condition and then monitor the deterioration to identify when or if timely intervention is required. The 2017 research sought to identify whether remote sensing techniques, particularly LiDAR, can monitor gradual change over time and provide an early warning of major change.

4.0 Techniques and suitability for providing inspection data

1) Mobile Mapper

Frequent (every 1-3 years) and recent surveys across the whole network providing high point density LiDAR and imagery captured at road speeds (**Figure 1** shows several examples of Mobile Mapper data). Earthwork data limited to cuttings only and within 30 m of the carriageway. The LiDAR point cloud classification requires changes to the specification for vegetated slopes. Bare rock slopes scan well with medium resolution of slope morphology, bedding dip, gulleys, overhangs and toe debris. Comprehensive discontinuity observations (orientation, openness etc.) are not possible.

Imagery is of mixed quality for the cutting slopes but good from kerb to kerb. Frequently too dark / shaded but feature detection including slips, bare ground, vegetation, barriers, fences and remedial works possible where captured in good light. Limited to line of sight and slopes obscured by vegetation are not visible. Detection of seepages, soft ground and burrowing limited unless highly visible.

Accessed through on-line AVIS platform with limited training required, and a good interface for the imagery, LiDAR point clouds and positional reference data. Further development of AVIS to display additional datasets (LiDAR slope contours, hyperspectral data etc.) would increase its potential application.

Application for reducing physical inspections: The Mobile Mapper system offers a useful ‘first-pass’ survey from which inspection pro-forma could be partly populated to reduce time during physical inspections. The surveys are frequent enough to allow intermediate part inspections of particular sections or particular features to be monitored. The repeat LiDAR data offers potential for change detection to be undertaken but much depends on the orientation of features in relation to the sensor.

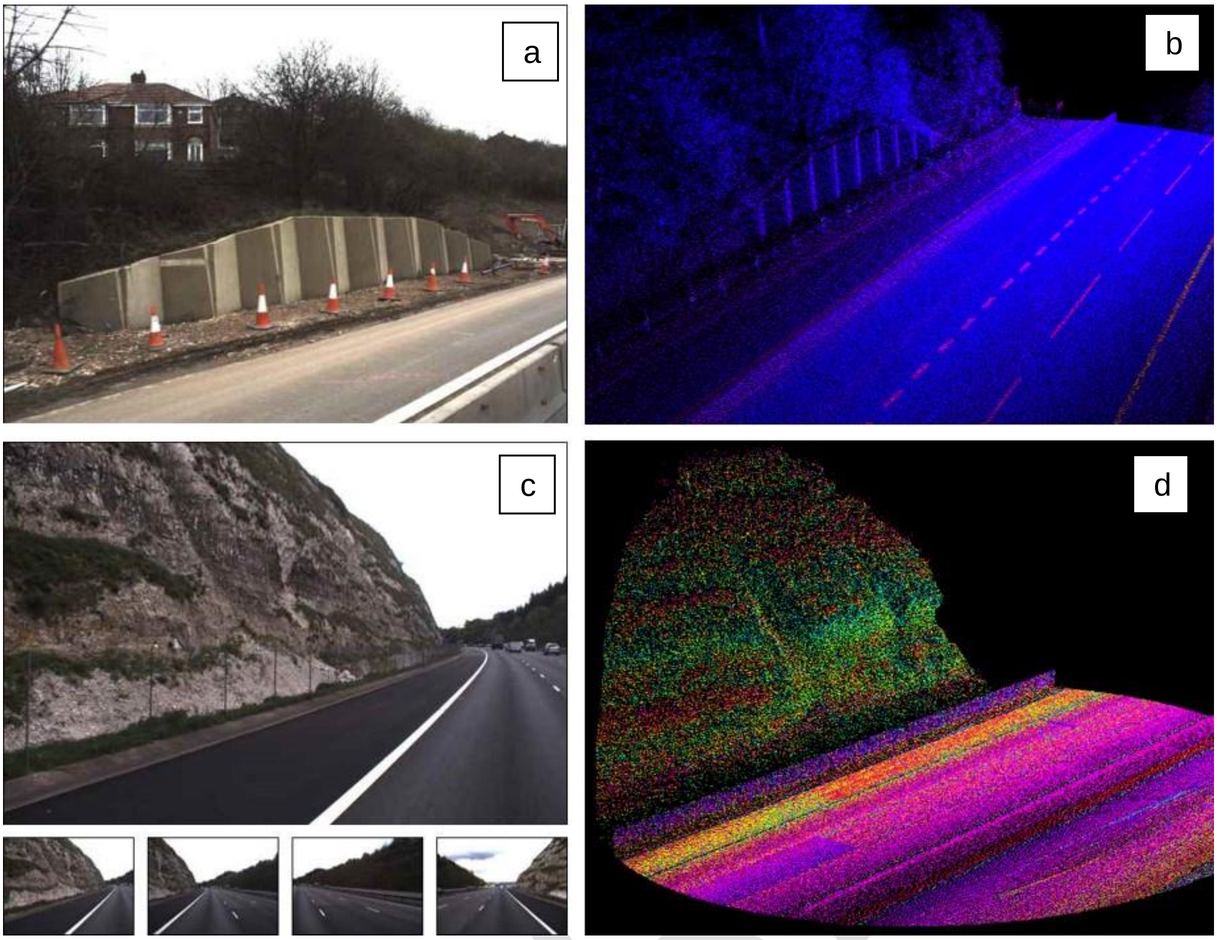


Figure 1 Examples of Mobile Mapper vehicle imagery and LiDAR point cloud from the AVIS viewer: (a) & (b) show a concrete retaining wall (M1); (c) & (d) show the M40 Stokenchurch rock cutting

2) Rotary wing LiDAR and 4 cm orthoimagery

Suitable for cuttings, embankments and natural slopes, as shown in **Figure 2**. Corridor usually fence to fence, but can be extended with additional flight lines. Good penetration through vegetation to map ground below although point density drops to ~1-5 / m^2. Good definition of earthwork geometry and detection of small slips. Low, medium and high vegetation can be classified. Some useful information for provided for steeper rock slopes but suitability decreases with slope angle. The 4 cm imagery can be variable in quality but with optimum flying conditions will allow many smaller features to around 12 cm in size to be identified, except where vegetation obscures the slope.

Application for reducing physical inspections: This system is suitable for providing inspection data in most of the HD41 observation fields and considerably reducing time spent physical. This has most application for longer stretches of low risk earthworks as well as for large natural slopes with vegetation cover and access issues. As an aerial system it can provide good views of the local setting (e.g. watercourses) adjacent to the highway boundary.

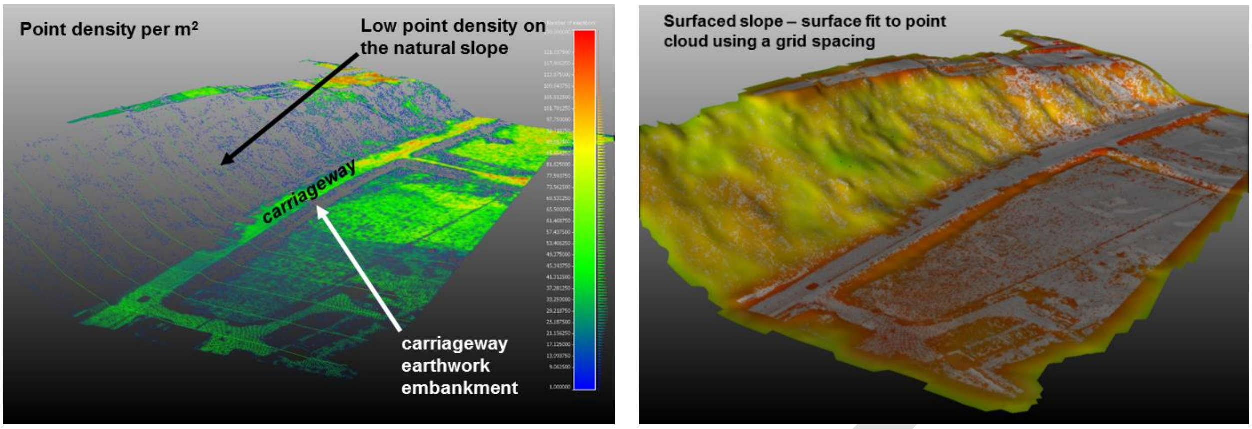


Figure 2 Rotary-wing aerial LiDAR point density (left) and surfaced slope (right) for the A259 Tanyard Lane high-risk site. Road carried on an embankment at the base of a natural slope. Vegetation has been filtered.

3) Vertical aerial photography

Vertical aerial photography captured from a fixed wing aircraft can be provided at lower cost than comparable imagery taken from a rotary wing LiDAR platform, due mainly to the different type of camera used. Resolution of widely available 'off-the-shelf' imagery typically ranges from 25 cm up to 10 cm and this is available through HAGDMS and Geostore, although the most recent national dataset is from 2013. For bespoke surveys the highest resolution possible with modern cameras is now 2 cm, which would allow features of around 6 -10 cm in size to be detected. However, this type of photography is not being routinely procured by Highways England and is mainly suitable for discontinuous sections of the network where particular issues are present.

Application for reducing physical inspections: Vertical aerial photography captured from a fixed wing platform can be used to resolve some features of geotechnical interest such as burrowing, terracing on soil slopes, and tension cracks in the paving and soil slopes. However, high resolution aerial photography captured from a rotary wing platform is the optimum image dataset available. This data is best used in combination with high resolution LiDAR point cloud data. The combination allows for monitoring visible and physical changes.

4) Terrestrial LiDAR (static/tripod)

Limited research has been carried out on this type of sensor by Highways England but work by others has shown that detailed rock slope assessments can be carried out. Application has mainly been for quarry faces and coastal cliffs but high definition of discontinuities is possible and automated routines can provide stereonet plotting of discontinuity data. Features such as gulleying, toe debris and slumping are detectable and change detection can be carried out with repeat surveys.

Application for reducing physical inspections: This technique would be suitable for high-risk, tall and steep rock cuttings of limited linear extent that would be difficult to inspect from the carriageway, providing a suitable scanning point opposite the slope can be found. Repeat surveys should be taken from the same points opposite the slope in order to monitor slope degradation over time.

5) Hyperspectral scanning

Imagery is collected across 300+ spectral bands at 0.75-1 m spatial resolution. This is too coarse for detailed slope inspections and small feature detection. However, selected bands in the colour infrared (CIR) and short-wave infra-red (SWIR) spectrum have shown good initial results for detection of drainage features such as counterfort drains and areas of wet ground or ponding (as shown in **Figure 3**). In addition it may be possible to identify wetter and drier areas of grassed slopes through the spectral wavelength responses. However, only limited research has been undertaken to date and further investigation of this is required before any firm recommendations can be made.

Application for reducing physical inspections: This dataset has shown promise for highlighting large and small scale regions of varying soil moisture. The available dataset has a resolution which is too coarse for delineating small features of potential interest, but has shown capability in detecting previously unmapped counterfort drains and shows potential to assess the efficacy of these features. Technical expertise required for data analysis, dataset would require significant storage capacity if collected network-wide.

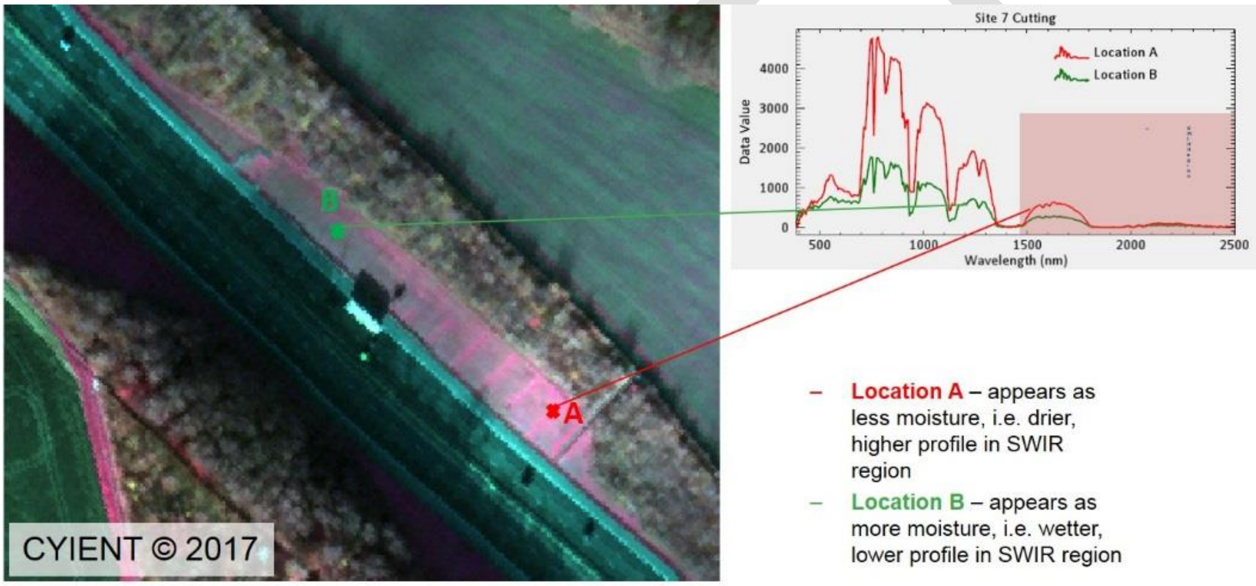


Figure 3 Hyperspectral imagery highlighting counterfort drains installed along a soil cutting on the M40. The spectral wavelength profile on the right suggests that the ground around the slope drains (A) is drier than the rest of the slope (B).

6) InSAR

There are various forms of radar satellite InSAR data and processing methods for different outputs. The processing relies on skilled analysts but the qualitative and quantitative outputs can be interpreted by engineers. Differential InSAR can provide DTM data and highlight ground surface deformations, but not on the typical highways earthwork scale. There may be some potential for detecting wider area movements due to coal mining or brine extraction but this has not been investigated to date. PSInSAR (permanent scatterer) can determine mm scale movements over time to certain reflectors but there are insufficient of these along earthworks, particularly in rural areas for the technique to currently be much benefit. The DSInSAR (Distributed Scatterer) technique was similarly found to be of limited application to earthworks assessments.

Application for reducing physical inspections: the DSInSAR result shows potential for monitoring millimetre-scale regional subsidence/uplift in rural areas, which can be related to seasonal change or ground hazard issues such as subsidence related to former mining cavities. The time series data is particularly informative for revealing potential trends in subsidence/uplift over time. However, the usability of the data is limited depending on satellite LOS, and strength of 'reflectors' within different radar scenes.

7) Multispectral imaging (Sentinel-2 satellite)

This data is freely available by download from the Sentinel website and provides imagery across the visible and near infra-red parts of the spectrum.

Application for reducing physical inspections: Usually used for vegetation health studies across wider areas or corridors and the spatial resolution of ~10 m is much too coarse for earthworks inspections.

8) Airborne thermal imaging

Thermal infra-red imagery can be used to map variations in ground moisture content (damp – dry) from the changes in thermal response. However, the 1 m spatial resolution currently available is mostly too coarse for detection of these variations on an earthwork scale and previous research has shown that even large slope failures cannot be delineated by their thermal response. This may be due to insufficient moisture content differences within and without the slipped mass.

5.0 Technical Guidance Summary Matrix

A Guidance Summary Matrix (**Figure 4** & **Figure 5**) is included for quick reference to help inform the choice of most appropriate remote sensing techniques for particular applications.

Figure 4 Technical Guidance Summary Matrix Key

Matrix Parameter	Rating
Data coverage:	High = national or full network Medium = sections of the network Low = limited
Data availability:	High = readily available / easy to access Medium = delivery on request Low = capture or processing required
Data quality (with respect to geohazard detection and monitoring)	High = high resolution, accuracy, detection Medium = some limitations Low = not suitable
Ease of analysis (includes processing)	High = No specialist manipulation or processing required Medium = some processing / data manipulation required Low = specialist processing or interpretation skills needed
Frequency (current)	High = < 1 year Medium = 1-5 years Low = > 5 years or not yet widely available
Cost	High Medium Low
Suitability for geohazard detection and monitoring	High = useful for multiple hazard detection Medium = some inspection / monitoring possible Low = limited capability

	Data coverage	Data availability	Data quality	Ease of analysis	Frequency of survey	Cost	Geo-hazard detection / monitoring
Mobile Mapper imagery	H	H	L	H	H	M	L
Mobile Mapper LiDAR	H	H	L	L-M	H	M	L
Rotary wing vertical aerial photography (4cm)	H	H	M-H	H	M	H	H
Rotary wing LiDAR	H	H	H	L - H	M	H	H
Fixed wing aerial photography (2 to 4cm)	L	L	H	H	L	M	H
Fixed wing vertical aerial photography (10 to 25cm)	H	H	M	H	M	L-M	M
Tripod LiDAR	L	L	H	M	L	L-M	M
Hyperspectral imaging	L	L	M	L-M	L	H	M
InSAR	L	L	L	L	H	M	L-M
Aerial thermal imaging	L	L	L	M	L	M	L-M

* All aerial photography is vertical colour. H-M-L = High – Medium – Low.

Figure 5 Technical Guidance Summary Matrix

6.0 Key references and further information

Reference should be made to the Phase 1 Report and Phase 1 Research Summary Sheets for further detail and complementary information.

The following hazard guidance notes are available on Highways England's Geotechnical Data Management System / Geographical Information System (HAGDMS / HAGIS):

- Engineered Soil Slopes Hazard on the Strategic Road Network of England
- Engineered Rock Slopes Hazard on the Strategic Road Network of England

Acknowledgement and contact details

This work has been informed by the current task being undertaken as part of Highways England's Innovation Programme: SPaTS Task 1-086 *Application of Remote Survey Data for Geotechnical Asset Condition and Performance*.

For further information, queries or comment please contact James Codd
james.codd@highwaysengland.co.uk