ATKINS
AECOM

Transport related Technical & Engineering Advice and Research – Lot 2 Roads

STRENGTHENED EARTHWORKS

Task: 594 (4/45/12) ATKS

Project Sponsor: Mark Shaw

TASK 594 FINDINGS REPORT

Plan Design Enable

Highways England/DfT Framework for Transport Related Technical and Engineering Advice and Research Lot 2

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Task Findings Report

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1 Acronyms and Abbreviations

CMR	Contractors Monthly Report
ECR	Extent Confidence Rating
GAD	Geotechnical Asset Data
HAGDMS	Geotechnical Asset Information System for Highways England
KPI	Key Performance Indicators
MST	Managing Success Toolkit (template for recording KPIs)
OCR	Optical Character Recognition
PID	Project Initiation Document
PD	Project Director (Atkins)
PM	Project Manager (Atkins)
PS	Project Sponsor (Highways England)
SGM	Special Geotechnical Measure
TTEAR	Transport related Technical & Engineering Advice and Research

2 Definitions

2.1 Project-Specific Definitions

Special Geotechnical Measure (SGM) - Measures over and above traditional earthworks construction required to mitigate geotechnical risk associated with ground related hazards or remediate geotechnical defects that may have resulted from the presence of geohazards. Similar techniques implemented to facilitate widening or improvements are also classified as Special Geotechnical Measures for the purposes of this task.

HAGDMS –The Highways England geotechnical asset information system is a Geographical Information System (GIS), developed for the purpose of managing Highway England geotechnical asset information. The system is based on a mapping interface, providing an interactive map that shows various mapping layers, as well as mapping (geospatial) objects representing the geotechnical asset inventory and condition.

Structured data - Structured data refers to information held within fields within a defined database hierarchy. For the purposes of this task, this term relates to the Geotechnical Asset Data (GAD) held in HAGDMS.

Geotechnical asset data (GAD) – GAD Observation Data is considered for the purposes of this task as “Structured Data”. It is gathered generally during onsite Principal Geotechnical Inspections, which are carried out by managing agents in accordance with HD41/15. Geotechnical features observed are recorded using a series of specified data entry fields, tick boxes and/or as free text in the observation description. Condition-related information is also obtained and recorded as defects, including classification in accordance with Standards where required. The GAD data utilised in this task is a snapshot from 22/05/2015 as is based on the preceding HD41/03.

Unstructured data - Unstructured data refers to information held without a pre-defined data model, typically not in a database format. For the purposes of this task, this term relates to the information contained within PDF reports.

HAGDMS reports – Approximately 13,500 geotechnical related reports are held digitally by Highways England. These reports date back to the 1950s and the early construction of the road network. As such they contain a significant information regarding the construction of the networks geotechnical assets. For the purposes of this task, these reports are referred to as “unstructured data”.

Enhanced data – This is information that has been generated through the combination of the outputs of both the structured and unstructured data processing.

Quad code - This refers to the four-letter reference codes which have been generated as part of the project to represent each SGM type (e.g. SNAL = Soil Nail). Where possible, this was aligned with the existing four-character referencing within the existing structured database.

Extents Confidence Rating (ECR) – This is project derived terminology that indicates the reliability and confidence of the extents and characteristics of the SGM identified. It also indicates the source from which the SGM has been derived.

DtSearch – DtSearch is a text retrieval / full text search engine software, with the ability to search large amounts of text in a matter of seconds through a process of building an index that stores the locations of words within files. DtSearch can then be used to apply complex filters and rules to word searches to refine the results.

Data mining – For the purposes of this task data mining refers to the process of identifying information within targeted data sets. Data mining methodologies developed during this task have used text retrieval software to identify the location of SGM and context search terms within geotechnical asset records and pdf reports.

Positive context – This is context surrounding the use of an SGM search term that implies that the SGM was likely to have been installed. For example: “soil nails ***were installed***”, “lime stabilisation ***was utilised***”, and “grouting ***has been carried out***”.

Negative context – This is context surrounding an SGM that does not confirm the presence of an SGM. For example: "soil nailing ***was considered***", "***option*** 3: lime stabilisation", "grouting was ***not necessary***".

Coincident observations – This refers to observations that are geospatially coincident on the same geotechnical asset. These may be either entirely within the same extents of each other, or with any overlapping extents.

2.2 Highways England Terminology

HD41/15 – Standard for "Maintenance of Highway Geotechnical Assets" (supersedes HD41/03).

Observation – Characteristic (or group of characteristics) located on a geotechnical asset.

Feature – An observation that is assessed as requiring a feature grade (a grading based on whether the observation is of a defect, at risk or area of repair, and the size and location of the observation)

Defect – A feature observed within a geotechnical asset that is assigned a Class 1 in accordance with HD41/15.

HD41/03 – Superseded by HD41/15 Standard, providing best practice for the inspection and maintenance management of the highway Geotechnical Asset. The structured data utilised in this task was provided with formatting required by this Standard.

Form A - Geotechnical Maintenance Form (GMF) (HD41/03) Part A (Initial Proposals) was used to notify Class 1 defects requiring investigation and/or remedial works or for which emergency remedial works have been carried out. This information is held as free text within structured data in HAGDMS.

Form B - GMF Part B (Defect Remedial Works Proposal) (HD41/03) provides feedback on investigations carried out as outlined on the GMF Part A, and describes proposed remedial/preventative works or monitoring measures. This information is held as free text within structured data in HAGDMS.

Form C - GMF Part C (Remedial or Preventative Works Feedback and Monitoring Proposals) (HD41/03) provides feedback on remedial or preventative works carried out as outlined on GMF Part B. This information is held as free text within structured data in HAGDMS.

2.3 Associated Highways England Tasks

Task 416 Review of Geotechnical Asset Data – Completed Highways England sponsored task that aimed to identify the locations and condition of Special Geotechnical Measures across the Highways England network, utilising structured and unstructured data as it is held within HAGDMS. The recommendations and output from this task are the basis of the aims for Task 594.

Task 408 As-Built Geotechnical Asset Data - Completed Highways England sponsored task utilising data mining of existing data sources to identify areas on the network where certain ground related hazards can occur. This information will ultimately support service providers to manage the network risks from natural and ground related hazards by highlighting potential useful information sources. Arup - Mott MacDonald.

Task 197 National Geotechnical Hazard Review – Completed Highways England sponsored task which aimed to identify ground related hazard information that would: be useful, could be collated, and then provided to network managers in a suitable format to support better hazard assessment and risk management of the network. Arup - Mott MacDonald.

Task 1-105 Handover of Geotechnical Information – Ongoing Highways England sponsored task which aims to provide guidance, setting out the means by which, the current inventory and condition data regarding the geotechnical asset, should be updated with the as-built information following scheme completion. This includes, guidance related to the addition of new assets and modification of existing assets, as well as, creating and updating records of the project and report information associated with the scheme.

3 Executive Summary

Highways England recognise that many of their geotechnical assets have been built on and through areas of ground related hazards, and that the Special Geotechnical Measures (SGMs) designed to mitigate these hazards are aging, whilst simultaneously the road network is becoming more critical to the country's infrastructure. It has become apparent that understanding these assets in detail and being able to accurately predict, model and proactively manage the geotechnical asset will become increasingly important to the future sustainability of the network.

Only relatively recently has Highway England began to capture and hold all of its geotechnical asset data electronically, in the form of pdf reports and digital inspection records. At the time that the majority of the road network was constructed digital technology did not exist, and the inventory and condition information that was routinely captured, until relatively recently was not sufficiently detailed to allow useful analyses. Highways England has conducted a significant project to collate and digitise the large historical archive of paper geotechnical reports. The introduction of electronic data capture for the routine principal geotechnical inspections has also significantly improved the digital record that Highways England holds for its assets. The hosting of such data in one accessible database has proven invaluable to Highways England and its suppliers.

These sets of data are the best sources of information available regarding the construction history and current condition of the network. As part of the ambition to better understand their networks assets, Highways England is investing in a number of research projects aimed at identifying useful information within this substantial collection of reports and inspection records, to inform future risk management of the roads network.

This project followed on from the work carried out as part of Task 416 - Review of Geotechnical Asset Data, which undertook a review of these data sets, and began to consider and develop methodologies for identifying SGM extents and critical construction information. This task intends to build upon the recommendations and conclusions of Task 416, developing and applying improved data mining methodologies to the national database of reports and inspection records, to determine the extents and details of SGMs installed across the network in a more automated and repeatable manner

This research has successfully developed data mining methodologies that have addressed and overcome a number of the limitations encountered during Task 416. Although the task has experienced a number of limitations of its own, the project has been successful in generating a summary of design and construction reports, verified to likely contain information concerning the construction of SGMs across the network. A geospatial data set of SGMs identified from within the existing structured inspection data has also been produced. Together these two data sets will dramatically improve Highway England's knowledge of where SGMs exist within the geotechnical assets that they own and will support a proactive approach to their management and maintenance in future.

The methodologies have effectively identified 93 different types of SGM within 3,169 pdf Reports, and 72 SGM types, representing 9,833 unique SGM extents, covering approximately 1,300 km of earthworks, from within the existing electronic asset information.

This task has gone on to interrogate the outputs of these data mining methodologies, to further enhance the quality of the data sets, search for patterns in performance and understand potential network risk.

A substantial element of this work, beyond the production of an enhanced digital data set, has been a critical review of how geotechnical asset information is currently captured and managed by Highways England. Recommendations have subsequently been presented to address how these systems could be improved to enhance the collection and management of SGM information and analyse asset lifecycle performance in relation to network risk.

4 Introduction

The Task Findings Report defines project outcomes and recommendations under Contract Transport Related Technical & Engineering Advice and Research (TTEAR) – Lot 2 Roads. This report and the datasets produced form the deliverables outlined in the Project Initiation Document (PID).

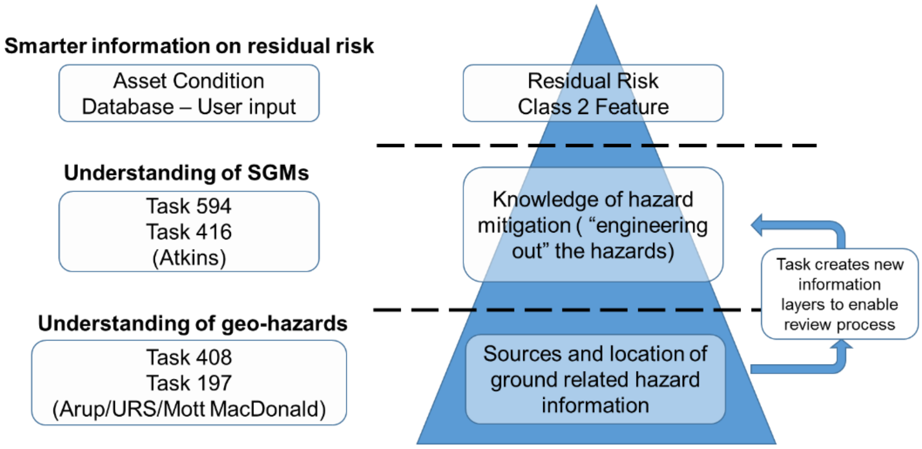
Highways England recognise that many of their geotechnical assets have been built on and through areas of ground related hazards, and that the Special Geotechnical Measures (SGMs) designed to mitigate these hazards are aging, whilst at the same time the performance of the road network is becoming more critical to the country's infrastructure. It has become apparent that understanding these assets in detail and being able to accurately predict, model and proactively manage the geotechnical asset will become increasingly important to the sustainability and resilience of the network.

The strategic road network is relatively recent, having been developed considerably over the last 60 years. When the strategic road network was constructed, the technology was not available to capture, collate and store the associated reporting and records digitally. This type of information is invaluable to understanding and predicting the performance of the geotechnical asset today and going forward. Highways England has been in the process of collating and digitising the large historical archives of reports dating back to the networks design and construction. The introduction of electronic data capture for the routine principal inspections has also significantly improved the digital record that Highways England holds for its assets.

These sets of data are the best sources of information available regarding the construction history and current condition of the network. Highways England is investing in a number of research projects aimed at extracting information from the significant archive of data to help inform the successful management of the network and shape future operating policy.

This research project aims to expand and develop the work undertaken during Task 416, which carried out a review of the available geotechnical asset data, and began creating data mining methodologies to extract the extents and details of SGMs across the network from reports and inspection records. This task intends to refine those methodologies to better identify where SGMs exist on the network from existing data. This research is being carried out as part of a wider portfolio of research projects sponsored by Highways England aimed at understanding where geotechnical hazards exist across the network and developing resilience strategies for managing potential "at risk" areas. The conceptual relationship between these tasks is presented in Figure 4-1.

Figure 4-1: Highways England Risk Management Aims



The combination of these research outputs aims to significantly improve Highway England's ability to proactively identify and manage geohazard risk across the network.

5 Project Assumptions

5.1 General

This research project has encountered a number of issues that have influenced the final output and are important to understand in context. Where possible, methodologies have been designed to address these, but in some cases the limitations have had to be accepted in order to proceed with the research. This section outlines the limitations and assumptions that have applied to this research task as a whole. Problems that have been encountered with specific areas of this research are covered in later sections of this report.

5.2 Summary

Data quality

This project has largely focused on the extraction of useful information from large volumes of both structured and unstructured data. These datasets are naturally subject to language variation and some minor human error due to the number of people involved in the data collection and in the production of the associated reporting. A great deal of work has been carried out to identify and address these inconsistencies and variation where possible. However, it is inevitable that there will be some limited impact on the accuracy of the findings of this Task due to residual variability in terminology and context. It is estimated that this influence is near negligible on the overall results and cannot reasonably be negated within the project programme.

Data sources

The Geotechnical Asset Data and PDF Reports data sets utilised by this task were provided by Highways England. All findings and results are based on snapshots of the databases, from the 22nd of May 2015, and the 28th of September 2015 respectively. The results of this project are therefore representative of the data available up to these dates. Any information added to the databases after this date does not form part of the output. It should also be noted that the introduction of HD41/15 postdates the data extract. However, this has negligible impact on the output due to post extraction processing, replicating data migration from 41/03 format.

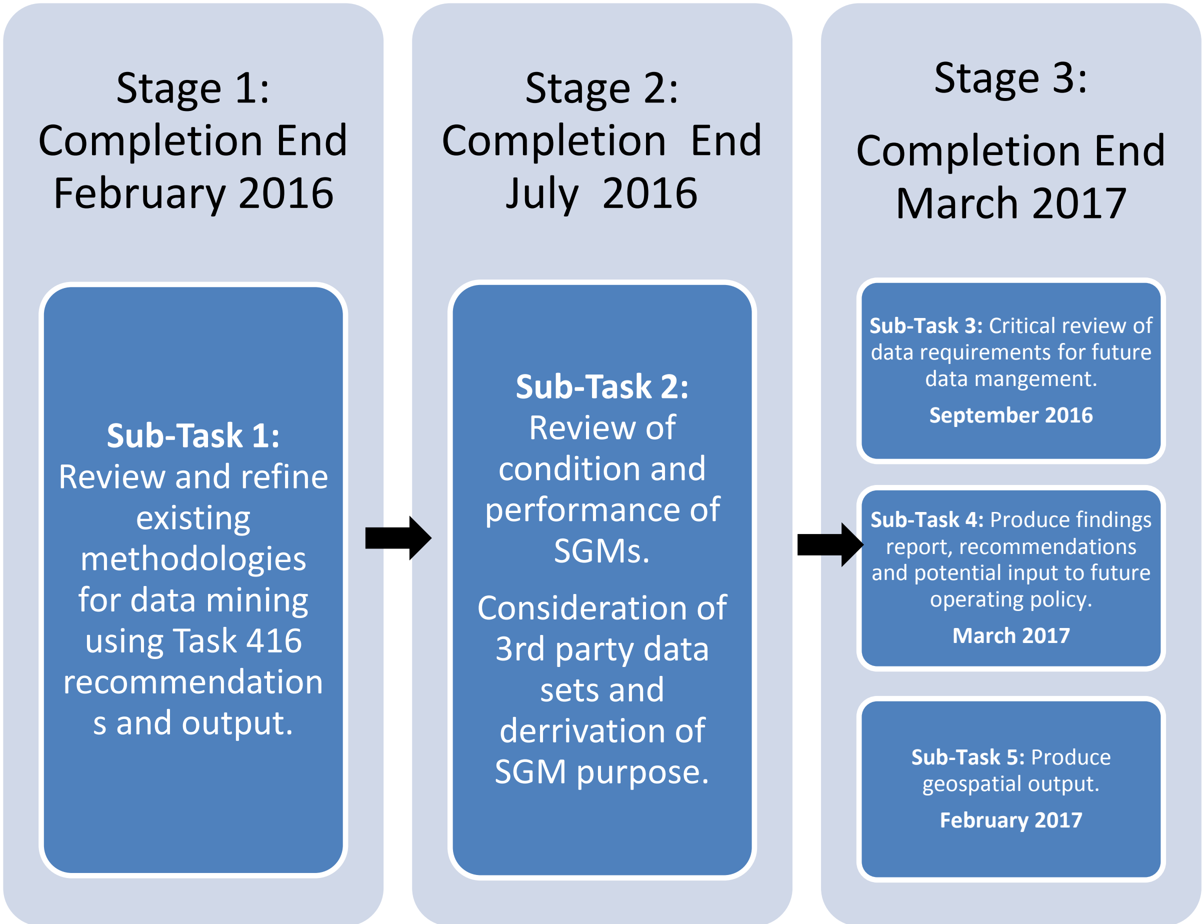
Data mining and text retrieval

Data mining methodologies developed during this task have used text retrieval and recognition software to identify the location of SGM and context search terms within the source data sets. These techniques are dependent on the completeness of the search term library/corpus developed and the extents to which search terms can be developed to deal with optical character recognition issues and common spelling mistakes. The project has strived to achieve a high level of accuracy by mitigating limitations within the data as far as practicable. The search terms generated have been based on industrial experience and have undergone peer review so should represent a comprehensive list of SGM types, together with synonyms and common spelling variations. There is however, still the potential for some more atypical SGM types or search terms to have been omitted and this may have led to uncommon SGMs not being identified by the task. These are expected to represent a negligible number of SGMs across the network. Although complex, the mining methodologies developed have been documented and designed to be a repeatable process, to enable additional searches to be carried out should further SGM types be recognised in the future.

6 Project Stages and Deliverables

This task has been completed in 3 No. stages between September 2015 and March 2017, comprising 18. No individual work activities, within 5 No. sub-tasks. These stages and sub-tasks are depicted in Figure 6-1 and are briefly described in this section to give an overview of the work that has been undertaken. A more detailed breakdown of deliverables and activities within each sub-task is presented in Section 7 of this report.

Figure 6-1: Project stages



6.1 Stage 1

Stage 1 of this task aimed to review and further develop the work undertaken as part of Task 416, which carried out a review of the available geotechnical asset data, and developed methodologies for identifying and extracting SGM information from the structured and unstructured data sets. In this task, the methodologies have been developed further, to build on what was learnt throughout the previous task, improving the efficiency of the methodologies by increasing automation, and mitigating identified limitations where possible. Stage 1 consists of 8 No. activities, which comprise a considerable proportion of the work undertaken in this project, in determining where SGMs are located across the network based on the existing data sets.

6.2 Stage 2

Stage 2 aimed to further refine and enhance the outputs of Stage 1. A key deliverable at this stage was to develop a more automated methodology for determining the presence of coincident observations from the structured data set, particularly the existence of defects within the extents of SGMs. This information has then been analysed to help appreciate the potential condition and performance characteristics of SGMs across the network. Stage 2 also investigated the potential for use of additional third party data sets to enhance the existing data.

6.3 Stage 3

Stage 3 of this project had the objective of undertaking a critical review of the current system in place for capturing and managing geotechnical data and asset information, and also how best to visualise and utilise the outputs of this task. This stage also includes the production of this report summarising the task's findings, which will be followed by a presentation / workshop to discuss the outputs this research and to consider future research opportunities. The workshop shall also advise on the practical use of the outputs for the management of risk on the network.

6.4 Key Deliverables

Table 6-1 outlines the key deliverables defined in the Project Initiation Document (PID) for Task 594. This report represents deliverable 7 of this research task, and intends to detail the development activities that have been undertaken in order to meet deliverables 1 through 6. Subsequent deliverables 8 and 9 will come in the form of a task findings presentation and handover of the final data sets.

Table 6-1: Key Deliverables

Deliverable	Description
1	Two-page briefing note, outlining task and project aims.
2	Sub-task briefing note/findings summary report - SGM hierarchy and search terms briefing note for Managing Agent consultation. Request for SGM network knowledge.
3	Sub-task briefing note/findings summary report - Methodology derived for identification of useful unstructured reports. Proposals for next steps.
4	Sub-task briefing note/findings summary report - Summarised SGMs by area for consultation with Managing Agents.
5	Sub-task briefing note/findings summary report – Output from review of potential 3rd party data sets. Proposals for next steps.
6	Sub-task briefing note/findings summary report - Recommendations for future data capture.
7	Final report on task findings and recommendations for future work.
8	Presentation of final task findings and recommendations to HE
9	Final geospatial representation of location of SGMs (format to be agreed). Including system functional specification.

6.5 Report outline

The following sections of this report discuss:

- The progress of the development activities. An overview of each sub-task is presented along with its deliverables as defined in the PID. The sub-tasks have been broken down in regards to their development and individually discussed.
- The results and findings of the sub-tasks are then discussed with regards to the structured and unstructured data mining methodology outputs and the use of these outputs to analyse patterns in SGM performance.
- The recommendations formulated throughout this work are summarised to illustrate how the outputs of this tasks can be applied and what could be done in future to improve Highways England's ability to capture SGM and manage information.

7 Development Activities

7.1 Sub-Task 1 – Review and refine data mining methodologies

The aim of sub-task 1 was to review and update the SGM hierarchy whilst refining the structured and unstructured data mining methodologies developed in Task 416. Applying the recommendations and lessons learned to refine and enhance the accuracy of the outputs, whilst reducing the requirement for manual interrogation and improving repeatability. These methodologies, once fully developed on a confined data set, were applied at a national level to the structured and unstructured data sets, to locate SGM information within the two data sets. The derived information has then been produced in a format that can be displayed, analysed and processed in a GIS format, to support Highways England in their knowledge and management their aging geotechnical assets. Following the national application and generation of SGM data sets, where possible the information has been combined and a methodology to identify potential purpose of construction also applied.

The sub-task methodology was broken down in to 8 activities and associated deliverables as summarised in Table 7.1.

Table 7-1: Summary of sub-task 1 planned activities and deliverables

Item	Activities	Deliverables
1.1	Obtain latest structured data set from Highways England	GAD data set (Highways England) – HD41/03 version
1.2	Obtain latest unstructured data set from Highways England	Reports database (Highways England)
1.3	Procurement and packaging of DtSearch software	DtSearch available for task
1.4	Review and define, through experience and HE supply chain input, SGM search terms from Task 416.	Sub-task briefing note – Revised SGM hierarchy and search terms
1.5	Review and refine Task 416 methodology for data mining of structured data. Application of methodology.	Revised methodology. Improved SGM data set
1.6	Review and refine Task 416 methodology for data mining of unstructured data. Consultation with PS for next steps. Decision on extent of data that can/will be extracted.	Sub-task briefing note – revised methodology
1.7	Compile and combine SGMs identified from application of structured and potentially unstructured data to form a comprehensive SGM data set.	Sub-task briefing note - SGMs summarised by route
1.8	Investigate potential to identify purpose of SGM construction. Apply methodology if successful.	Revised methodology. Improved SGM data set

The following sections discuss the development of these activities, limitations encountered and the subsequent assumptions that applied where necessary. Sub-tasks 1.1, 1.2 and 1.3 cover the acquisition of the structured and unstructured data sets and the procurement and packaging of the DtSearch software implemented in sub-task 1.6. These details shall be discussed briefly in the context of where they have been implemented in their respective activities.

The findings and discussion of the results from this sub-task can be found in Section 8 of this report.

7.1.1 Sub-Task 1.4 - Review of SGM hierarchy

The SGM hierarchy developed during Task 416 was a critical element of the project to confirm at an early stage. This was to ensure a complete and comprehensive list of SGMs was available to be utilised throughout the project and could be established prior to the application of the data mining methodologies. This collection of 99 No. different SGM types was initially developed through an appreciation of the geotechnical hazards investigated during Task 197 and design mitigations provided in CIRIA guidance. This was substantially supplemented by additional knowledge from industry experience and peer consultation.

7.1.1.1 Aims and objectives

The aim of sub-task 1.4 was to review and further develop the catalogue of SGMs, to ensure that it was as comprehensive as possible and also considered synonyms to be associated with SGMs when performing searches. The objective was to produce an updated catalogue and an appropriate hierarchy that could be implemented during the data mining programme, and to structure future capture and reporting of SGM data across the network.

7.1.1.2 Limitations and assumptions

Naming conventions

Given the wide variety in naming conventions that exist and have existed for many SGMs over the construction history of the road network, it is possible that some more obscure or uncommon naming conventions may not have been identified and included in the SGM hierarchy and search terms due to their rarity. Due to the significant consultation and peer review in generating the search terms it is considered any omissions will be negligible and will not significantly impact on the completeness and quality of the results. Should additional SGM types be identified or developed following this work, the data mining methodologies have been developed to be repeatable so that searches for new SGM types may be applied to the dataset.

Non-specific SGM types

As part of Task 416, search terms were included for non-specific SGM types e.g. Non-Specific Reinforced Earth. These terms were included in order to identify where the use of these terms may indicate the presence of an SGM even though the specific type was not confirmed. Further work during this task has suggested that the instances of some non-specific terms are less likely to represent useful information on the presence of an SGM, and these terms have consequently been removed from the list of search terms.

Development of the SGM hierarchy

The development of the SGM hierarchy throughout this task has been an iterative process with continual improvements and adjustments to the catalogue as additional SGMs have been identified during manual checks. Through the process, some limitations have also become apparent as the sub-tasks have developed and the methodologies applied. Table 7-2 provides a summary of the SGM hierarchy, including categories, number of types and associated synonyms generated. The complete SGM hierarchy including the types and full set of synonyms is included in Appendix A.

Table 7-2: Summary of SGM hierarchy

SGM Category	SGM Sub-Category	Number of SGM Types	Number of Synonyms
Drainage	Drainage	16	42
Earthworks	Ground Improvement	9	24
	Material Modification (Soil Mixing)	4	18
	Material Replacement	3	16
	Non- Specific Earthworks Intervention	1	1
	Reprofiling	2	12
	Rock Cut Management	10	51
	Slope Facing	9	30
	Special Foundation Measures	8	15
	Strengthened Earthwork	10	34
Structures	Piles	17	42
	Retaining Walls	10	58
	TOTAL	**99**	**344**

7.1.2 Sub-Task 1.5 - Review and refine the structured data methodology

Task 416 previously developed a data mining methodology to identify and derive the locations of SGMs and defects recorded within the structured data set. The methodology made use of a number of complex data queries that required a set sequence of manual inputs. The methodology was successful in identifying SGM data, however a number of limitations with the method were recognised. A process of refinement to improve the quality and repeatability of the methodology was an integral part of this Task.

Data Source

As part of sub-task 1.1, a snapshot of the Geotechnical Asset Database from 22nd of May 2015 was provided by Highways England. This flattened database consisted of over 420,000 No. rows of data comprising up to 233 No. data entry fields, each row representing a time specific observation made during earthwork inspections.

7.1.2.1 Aims and objectives

Sub-task 1.5 aimed to revisit and re-work the methodology derived during Task 416, to enable the process to be more repeatable, transferable and more effective in identifying the locations of likely SGMs from the structured data. A key objective of revisiting the methodology was to reduce the requirement for manual interrogation as far as reasonably possible, to moderate the probability for human error and to keep the process as automated as possible, ensuring it is readily repeatable in the future.

7.1.2.2 Limitations and assumptions

Data quality

The quality and consistency of inspection data by its nature is influenced by: subjectivity, terminology referencing and manual input error. The observations that are made on site are currently captured through free text fields and tick box selection using a hand-held device, which can be subject to input errors and inconsistencies between inspectors. A number of data quality issues have been encountered throughout this task, with regards to incorrect data input and errors in SGM identification. Due to the character count restrictions that currently exist for free text data capture, inspectors will occasionally abbreviate words, leading to a greater variability and unpredictable ways in which SGMs may be recorded, this is in addition to potential spelling errors. Although efforts have been made to mitigate these issues through the development of the search methodology, there are likely to be some discrepancies that have been missed.

There are also known errors in the structured data capture fields, due to incorrect tick box selection (manual and misinterpretation) and superseded information being carried forward in error. A system issue is known to have occurred which caused the Sheet Pile Wall and Soil Nail tick box data to be swapped when the observation was edited online post inspection. The scale of this error is unknown however for the purpose of summarising locations and analysing the project outputs these errors are accepted recognised quality issue, which will be rectified and improved by inspectors over time as the errors become apparent during routine inspections. Recommendations have been made to address these issues and proposals to reduce the occurrence of these in future are included in Section 9.

Superseded Standards

It should be noted that the data used as the basis of this task was extracted on 22nd of May 2015, and was therefore collected in accordance with the now superseded HD41/03 standard. The methodology has been developed and output compiled with an appreciation of the changes from the introduction of HD41/15. Where field names have changed, i.e. due to the consolidation of Class 3A, 3B and 3C to a singular Class 3, this has been manually edited in the data outputs. HD41/15 definitions have been utilised for the data outputs.

SGM Context

Analysis of the structured data shows that, SGMs may occasionally be referred to in a negative context, for example, “soil nails have been removed”. It is possible to flag and remove observations with this negative context. However, it was considered appropriate to confirm these observations manually during the next inspection. This decision was made because negative context does not always confirm that the SGM is no longer present on site, particularly in the case of non-visible SGMs or SGMs that may have become hidden on site by structures or vegetation. Negative context may also refer to a defect rather than the SGM itself, for example “cracking on retaining wall not observed – delete”, in this instance the SGM is still present and visible.

SGM Consistency

Occasionally multiple observations recording the same SGM feature can reference the SGM differently, this is most common for retaining walls, which are often described both specifically e.g. “gabion wall” or “sheet pile wall” etc. and more generically e.g. “retaining wall”. Work has been undertaken to address and reduce these issues and to improve the quality of the results, however it is possible there are still duplicate observations of different SGM types in the GAD data that in reality refer to the same SGM on site. The recommendations identified from this work aim to address these issues in the future capture of SGM information.

7.1.2.3 Development

This section presents an overview of the key stages in development and the decisions made in developing the data mining methodology to locate and then derive the overall locations of SGMs within the structured data set as a representation of what is on the network.

SGM fields and output format

One of the first decisions made in the development of this methodology was which fields should be investigated for potential SGM information, and how this information should be output against the structured data. A four-letter reference code (“QUAD” code) had been derived for each SGM type as part of Task 416 and sub-task 1.4 of this task, to enable a more consistent output when reporting SGM information. It was also considered useful to know where in the raw data the information had been sourced from. For this, the same system implemented in Task 416 was adopted. This consisted of a numbering system to attach to the reference code as shown in Table 7-3. These source and identifier codes are output against their respective observation in a new data entry field, to be later used in the format and analysis of the structured data (see Table 7-4). The identification code 2 has been modified since the previous task to include the drainage field that can also identify potential SGMs.

Table 7-3: SGM information field identifier

QUAD#	Description
1	SGM tick box
2	Observation description / Drainage
3	Form C description

Example: “SNAL1, SNAL2” would indicate that the SGM tick box for soil nails was ticked and that reference to soil nails has been made in the observation description.

Software - Microsoft Access

It was decided in this task to continue working with Microsoft Access to process the initial raw GAD data due to its substantial file size (>800MB). This allowed the creation of a relational database and the use of Structured Query Language (SQL) to build bespoke queries and interrogate the information. This also allowed the generation of the reference and source code automatically through the use of inbuilt functionality.

Reduced data set

The raw GAD data includes a considerable amount of data that is not relevant in the identification of network SGMs including duplication of history and other information. To reduce the initial data set and improve processing time, a query was designed to extract only the fields and information relevant to this task, removing duplicates and unrelated information. This process reduced the initial data set by approximately 36% to 270,000 No. data entry records.

SGM searches

The identification of SGMs was made possible with the combination of numerous separate queries. These searches identified the observations and specific fields where SGMs are most likely to be referenced in accordance with Table 7-3. Multiple queries were required due to query limitations within the software, and the large number of SGMs being searched for within the multiple data entry fields. Queries were run sequentially to ultimately generate a comma separated list of the SGMs contained in each observation, an example of this data output is shown in Table 7-4.

Table 7-4: Structured data methodology - SGM identification

dbf_GAD | FINAL_RESULTS

SGMs	OB_REF	EW_ID	EW_AREA	MaxOfIN_D.	EW_ROAD	EW_TYPE	OB_STATUS	OB_DESCRIP
GABN1, GABN2,	12_A616_63743_557640	63743	12	15/05/2015	A616	Cutting	Approved	Gabion wall constructed in 2014 to acc
GABN2,	12_A616_63743_557641	63743	12	15/05/2015	A616	Cutting	Approved	geometry - above gabion wall
GABN1, GABN2,	8_M11_63706_553571	63706	8	07/01/2015	M11	Embankment	Approved	Gabions in generally good condition u
GABN1, GABN2,	8_M11_63705_553452	63705	8	07/01/2015	M11	Embankment	Approved	Gabions at toe of slope generally in g
GABN1, GABN2,	8_M11_63704_553445	63704	8	07/01/2015	M11	Embankment	Approved	Gabions up to 3.5 cages high (3.5m) in
GABN1, GABN2,	8_M11_63703_553440	63703	8	07/01/2015	M11	Embankment	Approved	Gabions at toe of slope in generally g
NSRW2,	12_M62_63702_553283	63702	12	04/03/2015	M62	Embankment	Approved	retaining wall behid pylon base
CNCW1, NSRW2,	12_M62_63701_552767	63701	12	06/03/2015	M62	Embankment	Approved	RetAINING WALL FOR TECHNOLOGY U
SNAL2, SHPL1, REGD2,	12_M62_63701_552763	63701	12	06/03/2015	M62	Embankment	Approved	SOIL NAILS, HEXMESH & REGRADE for
BLCW1, NSRW2,	4_A27_63698_552152	63698	4	25/02/2015	A27	At Grade	Approved	Vegetation and retaining wall. Site is
SNAL1, SMEH1,	12_M62_63697_551929	63697	12	02/03/2015	M62	Embankment	Approved	reinforced
SMEH2,	12_A63_63664_546870	63664	12	20/01/2015	A63	Embankment	Approved	Reinforced slope - Welded steel mesl
SMEH1, NSRW2,	12_A63_63663_546864	63663	12	19/01/2015	A63	Embankment	Approved	Reinforced retaining structure at base
STNW2,	4_A21_63646_545043	63646	4	21/05/2014	A21	At Grade	Approved	A21 Pillory Corner: A collapsed sectio
FILT2, TODR2,	10_A494_63594_544168	63594	10	11/06/2014	A494	At Grade	Approved	Toe filter drain
ROCB1, ROCB2, SMEH1, SMEH2,	14_A1M_63396_553743	63396	14	26/02/2015	A1M	Cutting	Approved	Tecco Mesh and Dywiddag Rock Bolts
ROCB2, SHOT2,	27_M1_63387_543452	63387	27	30/05/2014	M1	Cutting	Preliminary	Shotcreted, meshing, rock bolts
ROCB1, ROCB2, SMEH1, SHOT2,	27_M62_63386_543449	63386	27	30/05/2014	M62	Cutting	Preliminary	Shotcreted, meshing, rock bolts
CRIB1, CRIB2,	4_A21_63262_543141	63262	4	21/05/2014	A21	Cutting	Approved	Crib Wall 3.5m high

The process of correctly identifying SGMs was iterative and required review of the data output, correcting any issues and recognising where search queries required amendment to more accurately identify SGM types within the data. One example of improvement is the identification of “non-specific anchors” which was originally returned results relating to the more specific ground anchors and rock anchors, due to the use of a common search term. To remove this duplication, an exclusion query was developed to enable the accurate identification of where “anchor” was used, without reference to a specific type, such as “rock” or “ground”. Similar search queries were required for a number of the SGM types, improving the quality of the final data output and addressing the nesting limitations experienced during Task 416.

SGM and defect observation compilation

Following the searches for SGM types within the structured data set, a final query was designed to compile only observations that either contained an SGM or a feature (classified observation), this was for use in the later analysis of the structured data output. This final query output a total of 70,000 No. rows of data, an 85% reduction in the initial data set, approximately half (36,000 No.) of those observations containing a reference to at least one SGM.

Data refinement

Following the production of the reduced data set, it was determined that the most efficient way to analyse and manipulate the data would be though the use of Excel functionality. A number of macros have been developed for the analysis and processing of the structured data. This enables the process to be repeatable whilst aiming to improve efficiency and reduce calculation time, which can become significant when dealing with such a large data set. As a progression from Task 416, these macros have been designed to be easy to use and automates those which run sequentially. The following summary provides a brief overview of the process stages utilised within Excel to further enhance the structured data following the identification of SGMs within Access.

- **Earthworks with SGMs and potential coincident classified features**
  The first step in the process was to identify earthwork relationship with SGMs and classified features. Removing all data rows where there was a feature but no SGM on the same asset. This reduced the working data set to around 53,000 No. results representing all of the SGMs and any classified features on the same earthworks.

- **Creating unique data per SGM**
  The initial output provides a comma separated list of SGMs identified within a single observation. This format is useful for appreciating the SGMs contained within an observation and the source of this information, however for analysis purposes and to allow analysis and reporting of the data for each SGM type, a process was developed to separate this data into a unique row per SGM.

- **Data cleansing**
  Through critical review of the data a number of improvements were identified. This included the removal of SGM records that were uniquely identified as Filter Drains. In practice these, on their own, are not likely to have been installed to perform as per the definition of an SGM. These records have been maintained where they are coincident with another SGM type as they are potential influencers in the long-term performance of the asset at these locations. The removal of unique filter drains significantly reduced the size of the database, which allowed more efficient data analysis.

  An additional element of refinement required was the removal of duplication caused by the initial process not recognising multiple references to the same SGM within one observation. Duplication would be caused where an SGM was identified by a tick box and in the free text description generating two codes, e.g. "GABN1, GABN2".

Another limitation identified in Task 416 was significant duplication from the use of specific and non-specific reference to the same SGM in the same observation record. As part of Task 594 a hierarchy was applied which removes the non-specific SGM where more specific information has been captured e.g. Retaining Wall description and Gabion Wall tick box, only the Gabion record will be taken forward. This also allowed additional detail to be taken forward where limitations existed with the available tick boxes e.g. where PVC piled wall was recorded in the description and sheet pile tick box selected, the PVC sheet pile record was taken forward. This has significantly improved the reported lengths and detail of the SGMs on the network.

7.1.3 Sub-Task 1.6 - Review and refine the unstructured data methodology

As part of Task 416, a sub-task to investigate the potential to extract useful information from the unstructured data set was completed. The task utilised pdf reports associated to the M11, as a sub-set of data. The task encountered a number of limitations, most significant of which was that the project team were reliant on searches being ran as part of a separate Highways England task. In addition, the process was based on limited SGM search terms, a limited number of SGM types, and using set search process parameters. On completion of Task 416, it was evident that significant additional value could be obtained from information held within the unstructured data though modification and improvements to the use if the search process and software.

Data Source
A snapshot of the national unstructured reports data set from the 28th of September 2015 was provided by Highways England. This data set consisted of 13,819 No. pdf reports that represented the archive of geotechnical report data available electronically within HAGDMS at that time.

7.1.3.1 Aims and objectives

This sub-task aimed to develop and refine the data mining methodology for the unstructured database and apply it to the national reports database. The task set out to do this by reviewing and applying the recommendations from Task 416, and aiming to rectify and mitigate some of the previous limitations, most significantly to reduce the requirement for manual interrogation and to utilise context to better identify relevant data.

7.1.3.2 Limitations and Assumptions

Accuracy of results

The methodology was built based on logical reasoning and a cycle of improvement through iterative testing. Due to inevitable variation in engineering terminology, optical character recognition issues and human errors that exist within reports, it was not possible to build a single methodology that would suit every report and SGM type with complete accuracy. Testing has therefore been carried out as far as reasonably practicable in the project timeframe, to develop this methodology to be as efficient and accurate as possible (before manual input) in identifying the relevant occurrences of existing SGMs in the reports. The software used has the functionality to apply levels of fuzziness and stemming to search terms to allow for slight variations in spelling. Some OCR issues have also been found to be fairly common such as the letters "i and l" becoming the number 1 (e.g. "so1l na1l"). These type of OCR issues have been addressed by the methodology, however there will likely be some unforeseen less common OCR issues that may have been omitted.

Developing a bespoke methodology for each of the individual 99 No. SGM types would be impractical and inefficient. Although every attempt has been made within the project programme to reduce inaccuracies in the results through the use of specific context strings and SGM specific testing, there will inevitably be a small number of results that are omitted by the methodology.

Incomplete data set

The research recognises that the unstructured reports data set provided by Highways England does not represent a complete data set. A number of reports are potentially missing or have been lost and therefore are not part of the archive maintained by Highways England. It is possible that SGMs exist within the extents of areas not covered by the available dataset, although this has been assumed to be negligible. It is also recognised that those reports produced and issued to Highways England since September 2015 will not form part of the data set interrogated.

Report Types

Schemes involving the design and construction of geotechnical assets, which could therefore include SGMs will typically generate a sequence of reports, progressing from project initiation documents and desk study through to the geotechnical design and feedback reports, in line with the Certification procedure for managing geotechnical risk. Of the 13,819 No. reports provided by Highways England, a large number of these reports were considered unlikely to contain specific SGM information or would contain information that is likely to be less detailed or certain than that included in other report types (such as geotechnical feedback reports). It was therefore decided to apply an initial filter on the reports database, to only include report types considered most likely to contain specific SGM construction details. This decision (documented in Appendix B) reduced the initial data set by 54%, to 6,396 "relevant" reports, significantly increased the efficiency of the searches, and reduced the occurrence of duplicate SGM identification. This approach could also be considered a limitation in the cases where the only reference to an SGM is in an earlier report type, perhaps due to later reports being unavailable. However, due to the significant increase in accuracy and efficiency provided by this approach, this minimal impact was considered acceptable.

Software Limitations

There are some known limitations of the software used that have influenced the accuracy of the output. One of the more significant of these is the inability of the software to recognise more complex formatting and grammar within reports. For instance, the software cannot recognise where text is within a table. It may identify positive context of an SGM within a table, however it is not possible to reliably determine if this content is correct for text contained in a table. Similarly, the software does not recognise grammar such as full stop and paragraphs, for this reason an incorrect context may be applied to the SGM. Work has been undertaken to minimise these effects through adjustment of algorithms and creating SGM-specific search strings where necessary. An example of a correct and incorrect identification of soil nailing is demonstrated in Figures 7-1 & 7-2. The subsequent manual verification undertaken as part of the overall methodology would remove the latter example here.

Figure 7-1: DtSearch correct identification example

PROPOSED STRENGTHENED EARTHWORK

Description of Strengthened Earthwork

The strengthened earthwork comprises a 1 in 1 slope reinforced by the inclusion of drilled and grouted soil nails installed at an angle of 10 degrees below horizontal. It is expected that the reinforced slope will be constructed top down, by the sequential excavation and installation of soil nails. The spacing of soil nails is expected to be in the range 1.2 to 1.5 metres. The length of soil nails is expected to be in the range 8 to 10 metres. A geogrid will be placed over the excavated 1V in 1H surface and held in place by the soil nail plates. The soil nail plates will be nominally tensioned to remove any slack between the plate and excavation. On completion of the installation of the soil nails a geotextile topsoil retention system (such as Armater) will

Figure 7-2: DtSearch incorrect identification example

Table 1.1 - Rejected Remedial Options

Option	Reason Rejected
Reduction in slope gradient	In order to reduce the slope gradient additional land take would be required
Soil nailing	Excavation and treatment or replacement of the slipped materials would be required prior to the installation of soil nails. Installation costs are considered likely to be high

Relevancy score

The search tool provides a relevancy score, based on an in-built algorithm, which takes into account the density and number of times search terms are found within a report. This is output as a percentage with the top score being allocated a relevancy score of 100%, with all other results being scored against this. The relevancy score was not found to aid in the identification of correct SGM results, with a number of results given a relevancy score of 1%, often still containing useful SGM information. The relevancy score therefore was not used as part of this task.

Data Extraction

One of the limitations encountered in this sub-task was the time required to extract the desired geospatial, condition and historical information from the unstructured data. An exercise was carried out to trial the extraction of SGM relevant information however, due to the nature of the reports, this data was often complex and time-intensive to identify and extract, requiring the additional manual interrogation of maps, drawings and HAGDMS to determine the exact extents, purpose and condition of the SGMs installed.

Based on the trial, four hours per report was required on average to extract the relevant SGM information it contained. Based on the number of reports identified to contain SGMs it would take around six person years to extract all of the relevant data. This was evidently unfeasible within the project programme. Following discussions with Highways England it was agreed that this task would focus on the manual validation of relevant SGM content in each of the reports identified by the methodology.

7.1.3.3 Development

This section presents an overview of the key stages in development and key decisions in deriving the data mining methodology to locate SGMs that are likely to have been constructed based on information contained within the unstructured data set.

M11 Control data set

In developing the original methodology used for Task 416, 125 No. reports relating to the M11 were identified as potentially containing information identifying the extents and details of SGMs. Each of these reports was later manually reviewed to verify the content. A significant number of the initial results output were found to be referring to SGMs in a negative context. The output provided a valuable validated data set against which a refined methodology could be baselined.

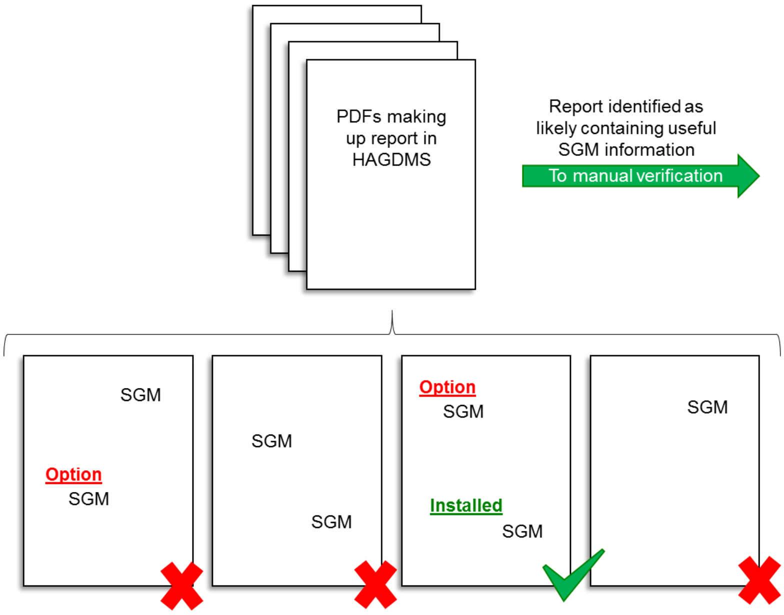
Of the initial 125 No. reports identified in Task 416, 78 No. were of the "relevant" report types defined in this task. 40 No. of these were found to contain useful information regarding the extents and details of SGMs. This verified control data set was used to develop the unstructured data mining methodology as part of this task.

Context search terms

A significant step taken in this task has been to introduce the use of context to improve the accuracy of the first stage data mining outputs. One of the first requirements in this approach was to develop a comprehensive list of context search terms to apply alongside SGM search terms. This list of context search terms was initially developed through industrial experience and a review of the context terms contained within the validated M11dataset. The final context list was established following a refinement process as searches and testing were undertaken and results reviewed. It was originally considered that the use of positive context search terms would be utilised to identify instances of SGMs. After the first round of testing it was apparent that using positive context alone generated too many false positives. Terms for negative context were therefore introduced to improve the methodology's accuracy.

The final methodology firstly filters results by identifying where an SGM is referred to in a report with positive context. It then searches around this instance of positive context for any negative context search terms. This methodology was a more conservative approach than in Task 416, bringing in a smaller number of reports to be reviewed, as it required there to be at least one instance of a positive context and SGM term within a report to identify it as likely to contain useful information, as demonstrated in Figure 7-3.

Figure 7-3: Identification of SGM and context within a report comprising multiple PDFs



Application to the national data set

Following the development and testing on the M11 dataset, work commenced to apply the methodology on the 6,396 No. relevant reports for each of the 99 No. SGM types. At commencement of the application, each search undertaken included a manual review process, during which significant proportion of the reports were checked following each search. This allowed identification of any significant issues with accuracy that could be improved through bespoke edits to the search terms. This process identified a number of SGM specific problems that required subsequent updates to the search algorithm and search terms used within the process. The result of this process was a total of 4,215 No. reports identified as containing 17,223 No. SGM references, representing 96 No. of the 99 No. SGM types searched for. The output was captured in Excel with a single record per report and columns representing each SGM. Table 7-5 gives a simplified version of how the unstructured data results were reported at this stage.

Table 7-5: Example of unstructured methodology output format

Report number	Report Details	SGM1	SGM2	SGM3	SGM4	SGM5	SGMs identified in report
1	-	x					SGM1
2	-		x				SGM2
3	-				x		SGM4
4	-	x			x		SGM1, SGM4
5	-			x		x	SGM3, SGM5

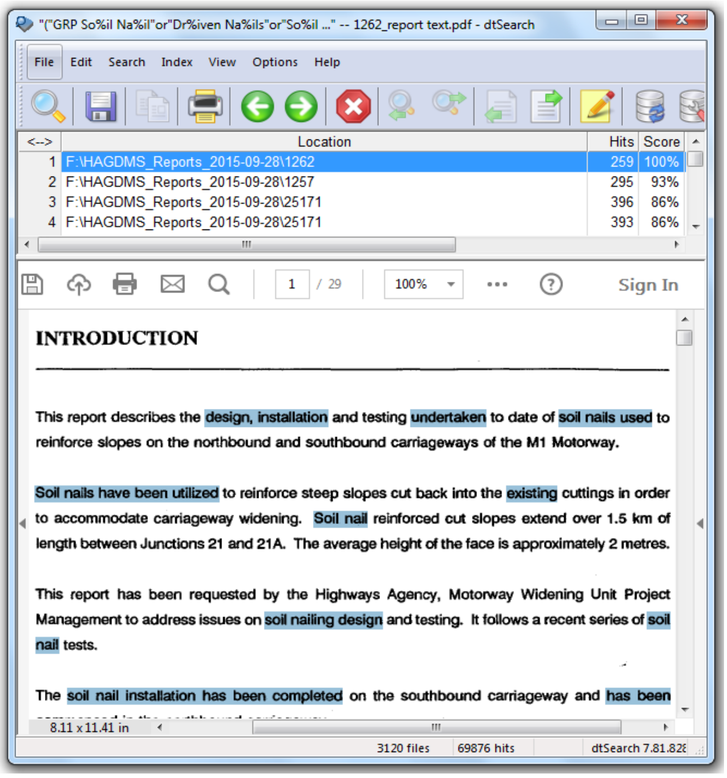
Road extents

To further refine these results and improve the efficiency of future data extraction, an additional process of identifying which reports were within the extents of Highway England and DBFO management areas was carried out using a geospatial query. This reduced the data set of reports likely to contain SGM information to 3,904 No. reports. The presence of reports relating to road sections outside the management of Highways England had not been anticipated to have been included in the data set and had therefore not been removed in the process earlier.

Manual verification

As stated earlier in this report, it was agreed that manual verification of each SGM instance would be undertaken as part of this task. However, associated attributes would not be extracted due to the time required to achieve this. It was decided that the best approach was to verify the search output by manually using the text retrieval software functionality to rapidly review SGM terms in context in the report. An example showing the typical information available during the validation process is given in Figure 7-4, and demonstrates how the software highlights the SGM term and the context within the report, allowing the user to very quickly confirm the validity of the result.

Figure 7-4: Example of SGM context validation review



Using this technique, SGMs references could be reviewed at an average rate of 50 No. results per hour. This is significantly more efficient than other options, such as using a pdf viewer or through Highway

England's online reports viewer. Manually verifying the initial data set at this rate of review was considered achievable and appropriate to ensure the task delivered an accurate set of reports, likely to contain useful SGM installation information. This process was tracked and recorded resulting in a compiled list of verified SGMs per report, as illustrated in Table 7-6.

Table 7-6: Example of unstructured data verification format

Report number	Report Details	SGM1	SGM2	SGM3	SGM4	SGM5	Verified SGMs in report
1	-	x ✓					SGM1
2	-		x ✓				SGM2
3	-				x ✖		-
4	-	x ✖			x ✓		SGM4
5	-			x ✓		x ✓	SGM3, SGM5

The manual verification process significantly increased the accuracy of the data set and eliminated a further 735 No. reports as not containing useful information regarding the location of an SGM. This also reduced the ultimate number of SGM types verified in the data set to 93 No. of the 99 No. types originally searched for.

A summary of the output of the unstructured data mining methodology can be found in Section 9 of this report.

7.1.4 Sub-Task 1.7 - Enhanced data set

Geotechnical inspections have been carried out using digital data capture methods across the network managed by Highways England for just over 10 years. Although not explicitly required, these have successfully recorded the geospatial location of SGMs which are either visible or known to have been installed. Primarily these SGM locations have been identified by the structured data methodology developed in sub-task 1.5. Highways England are interested in better utilising their archive of digital information and supplementing it with the significant amount of SGM data recorded solely in pdf reports. Understanding and capturing a more complete digital and geospatial catalogue of the location of all SGMs is important to allow recognition of correlations with defects and performance issues over time, or where potential geohazards have not been mitigated and a residual risk to the network is therefore present.

7.1.4.1 Aims and objectives

This task aimed to combine the datasets output by the structured and unstructured data mining methodologies with the objective of producing an "enhanced" SGM data set.

7.1.4.2 Limitations and Assumptions

Data Extraction

It was originally proposed that the extraction of detailed SGM attributes, including the SGM purpose, installation details and extents could be extracted and utilised to generate a digital record of the SGM to then incorporate into an enhanced data set. Due to the large number of SGMs identified and the data extraction limitations experienced in sub-task 1.6 this was found to be un-achievable within the time frame of this task. A sample of extracted attribute information was generated for Lime Stabilised SGMs from the unstructured dataset in order to illustrate the concept and demonstrate the value that could be realised through wider application of this process. It is anticipated that the continued development of data mining technology will allow this process to be completed far more efficiently in future.

7.1.4.3 Development

This section presents an overview of the stages and key decisions in the development of the enhanced data set. Recognising the limitations, and defining a categorisation tool that provides the confidence in the derived SGM locations. A strategy for continual improvement of the enhanced data set over time has been developed as part of this sub-task.

SGM attributes extraction process

Following the creation of the unstructured SGM data summary, work was undertaken to begin extracting information from the reports identified as being relevant. Using the search software, it was possible to rapidly identify where SGMs are referred to within a report and review the surrounding report text for attribute information. It was found that typically the context in close proximity to where the SGM search term had been identified was insufficient to identify all of the relevant information. Often information from numerous sections of the report had to be combined to generate the required information.

There is naturally substantial variation in how reports have been structured, depending on the report type, changes in standards and different styles of writing. Consequently, the locations of useful information within a report are not predictable. It was found that, often, manual correlation with online structured inspection data was required to locate the corresponding earthwork and chainage at which the location is anticipated. This is a labour-intensive process and required approximately 4 hours per report to extract all SGM information. Due to the available programme, it was agreed with Highways England that one SGM type (Lime Stabilised) would be focused on to illustrate of the value of data extraction. The benefit of selecting this SGM was its generally non-visible nature, therefore unlikely to be captured through inspection, together with and its known performance problems within some network areas. Due to the size of the cohort, the time predicted to complete the data extraction was also reasonable. The extracted information has been incorporated into the geospatially reference output of this task.

To aid understanding of the source data and confidence in the each of the identified SGMs, the concept of an Extents Confidence Rating (ECR) was developed. This has been revisited and significantly developed in relation to the recorded location of the SGM, and also provides a link to more detailed information that may be available and included within supporting pdf reports. Table 7-7 summarises the ECR developed during this task. The data process flow and assignment of ECR is discussed in Section 9 of this report.

Table 7-7: ECR definitions

Extent Confidence Rating (ECR)	ECR Definition	Example	Process
1	Report confirms extent of SGM, any length of which is visible on site. Observation length will be derived by report data extraction, utilising existing ECR 2 or 3 SGM observation.	Full extents of reinforced soil have been confirmed by Report. Exposed reinforcement has been observed during site inspection.	Any existing ECR 2 or 3 observations where the extents are confirmed by a report..
	Report confirms extent of SGM, which has not been observed on site due to either lack of information or its buried nature.	Detailed as-built drawings in GFR confirm the installation and extent of ground anchors behind shotcrete facing.	Generated new from report data extraction.
2	**Full** extent of SGM is confirmed though visual inspection. Judgement required into visual evidence that the full extent of SGM are visible. No detailed report information.	Observation extends over full length of sheet pile wall. Definite extents are fully visible.	New observation capturing full extents or upgrade of ECR 3 on initial inspection confirming that the observation covers the full extent of SGM.
3	SGM extents are based on existing GAD observations, full extents unconfirmed or not possible through visible inspection. No detailed report information.	Section of geogrid recorded due to localised defect. Unconfirmed if existing observation covers entire extents of reinforced soil.	All existing SGM observations until they have been “initially inspected”. On judgement that observation covers full extents, observation will become ECR 2 or ECR1 if sourced from a report. If unsure of full extents, observation shall remain ECR 3.
4	Report references SGM but accurate location is not available. No existing observation.	Report discussed Lime stabilised repair at Franks Farm, no plans or earthwork ID available.	To be generated with specific location as additional information becomes available. Location will not be georeferenced as a viewable observation but will be included in the reports database summary for easier reference.
5	Anecdotal evidence suggests presence of SGM. No recorded observation or report available.	Rock backfill placed as a result of failure occurring during historic scheme. Anecdotal from network service provider (unrecorded but often reliable network knowledge).	Location generated new from anecdotal information. To be upgraded appropriately if any additional information becomes available.

7.1.5 Sub-Task 1.8 - Potential SGM purpose

Highways England and other network stakeholders would benefit from understanding why particular SGMs have been installed on the network. This knowledge would support the assessment and understanding of performance of specific SGMs and their ability to fulfil the intended purpose. It may also highlight areas or locations of potential underlying geohazards and areas of susceptibility to geotechnical problems.

7.1.5.1 Aims and objectives

This sub-task aimed to investigate the potential to identify SGM purpose from the unstructured and structured data sets. With the objective of supplementing the SGM data in a structured format where it could be easily identified or derived.

7.1.5.2 Limitations and assumptions

Data extraction

The data extraction limitations discussed in the previous sections controlled the extent to which purpose information could be determined, particularly from the unstructured data set. It was originally perceived that this information would primarily originate from the unstructured data set, during the extraction and enhancement of the structured data. Due to the limited SGM attribute extraction undertaken as part of this project, potential alternative sources of purpose were investigated to ascertain whether this information could be readily determined.

7.1.5.3 Development

The initial objective associated with identifying the potential purpose of different SGM types was to generate a list of likely purposes that could form a standard list for selection as part of future data capture. This list was generated through engineering experience and considered during the process of validating the unstructured data output.

Structured data

The approach taken to identify purpose was to adopt a similar methodology to that used in the structured data mining for identification of SGM types. A catalogue of potential SGM purpose and associated search terms was generated based on a review of the terminology referenced in the structured data set and engineering experience.

The following high level categories were derived based on a review of the structured data set and the definition of SGMs:

- **Improvement** – This includes network enhancements, such as: widening schemes, installation of communication infrastructure (e.g. Gantries) and smart motorways related activities.
- **Repairs** – These are where SGMs have been utilised to remediate defects on the network, this information can be located in the observation description, Form C free text fields, and from the observations classification (Class 3 Repairs).
- **Hazard mitigation** – This is specific to where an SGM has been installed during construction of the earthwork to mitigate a known geotechnical hazard. Or where an SGM has been installed proactively to manage the risk from a known hazard.
- **Report** – This indicates that a report has been referred to within the free text fields, these report references have subsequently been manually extracted and output into a “relevant reports” field within the structured data output. The report is likely to indicate the SGM purpose although this detail has not subsequently been extracted.

Application of the method has output the determined purpose into a unique purpose field created in the enhanced data. An example of how this output is derived and displayed is demonstrated in Table 7-8, the bold text represents the search term that has been identified and used to determine the potential purpose.

The purpose of each SGM derived is to be considered as “potential purpose” as without reviewing each design report it cannot be possible to say with certainty why an SGM has been installed.

Table 7-8: Potential purpose identification within structured data

SGM	Observation ID	Road	Observation Description	Class (HD41/03)	SGM Potential Purpose
Sheet Pile Wall	470613	A2	sheet pile retaining wall due to **widening** works approx. 5m high	-	Improvement (Widening)
Gabion Wall	544220	A49	safety fence foundation subsidence; embankment slope **widened** with gabion wall at toe and culvert headwall **reconstructed**	**3C**	Repair and/or Improvement (Widening)
Soil Nails	512712	M4	40m wide **repair** comprising 113 No. soil nails over 5 rows. Refer to **GFR HAGDMS Report 21927**.	**3A**	Repair and/or Report

SGM	Observation ID	Road	Form C Description	Class	SGM Potential Purpose
Geogrid	514737	M4	Reinforcement - 280m long section of embankment crest **repaired** using geogrid reinforced granular fill.	**3A**	Repair

Unstructured Data

Due to the limitations faced with the extraction of a comprehensive set of attributes from the unstructured data, an alternative approach was taken to identify potential purpose within the reports, making use of the report title and scheme name to indicate a "potential purpose" for the SGMs contained within it. Table 7-9 the bold text represents the search term that has been identified and used to determine the potential purpose from the unstructured reports titles.

Table 7-9: Potential purpose identification within unstructured data

Report No.	Date	Road	Area	Scheme Title	SGMs
1249	1991	M1	7	M1 **Widening** Junction 19 TO 23A	Concrete Wall
1439	1993	M25	5	M25 **Widening** Junction 23	Anchored Sheet Pile Wall, Shear Key, Non-Specific Bored Pile Wall, Sheet Pile Wall, Regrade, Non-Specific Anchor

The use of the text retrieval software to locate specific purpose search terms within the unstructured data was considered, however upon initial review it was found that the typical purpose search terms were too ambiguous and were returning significant amounts of irrelevant information due to the common use of search terms such as "widen" or "repair". This methodology was not therefore taken forward as part of this project.

7.2 Sub-Task 2 – Review of condition and performance of SGMs

For Highways England to most effectively manage the geotechnical assets throughout their lifecycle it is becoming increasingly important to be able to understand in more detail the current condition and the ongoing and predicted performance of special geotechnical measures installed. Developing a comprehensive structured data record to support this will support effective modelling of the network and proactive identification of geotechnical risk. Currently there is no direct data relationship between observations recording the location of an SGM and observations recording condition or performance issues within the extents, unless the two are recorded on the same observation. The ability to accurately associate condition with the SGM data would significantly improve Highway England's ability to analyse the current performance of its SGMs and allow identification of areas potentially at risk in the future.

Understanding geotechnical asset performance and deterioration is a developing area and of interest to most geotechnical asset owners. Lessons learnt and knowledge gained from research in other sectors and countries would therefore be beneficial to Highways England's ongoing programme of projects. Understanding what work has been carried out and may be available in the public domain was an important as part of this task.

A summary of this sub-tasks deliverables is presented in Table 7-10.

Table 7-10: Summary of sub-task 2 activities and deliverables

Item	Activities	Deliverables
2.1	Review and refine methodology from task 416 to define extents of SGMs and condition.	Revised methodology – identification of coincident observations / defects
2.2	Review of performance of SGMs following on from findings of task 416.	Revised SGM data set with condition indicators
2.3	Review of potential for consideration of 3rd party datasets.	Briefing note – recommendations for potentially useful data sets

The following sections give an overview of the progress made with each sub-task. The findings and concluding recommendations are found in the relevant sections within this report.

7.2.1 Sub-Task 2.1 - Review methodology to define extents and condition of SGM

Understanding the condition of SGMs and potential patterns in performance across the network is an important part of this research and was initially investigated as part of the previous task. The methodology developed as part of Task 416 was able to identify geospatially coincident observations. However, a manual process was required to identify and remove duplicates and calculate the total lengths of SGMs on the network. This process was complex, with limitations on the accuracy of the total length and numbers that could be calculated. The ability to remove duplication and ambiguous results in a more automated process, thus identifying a much more accurate total extent of SGMs across the network and assess where these are coincident with recorded defects, was therefore required.

7.2.1.1 Aims and objectives

A key lesson learnt from Task 416 was to improve automation of data manipulation. The aim of this sub-task was to develop a repeatable methodology to determine a more accurate assessment of total SGM extents, and potential condition, from the structured asset data with minimal manual input.

7.2.1.2 Limitations and assumptions

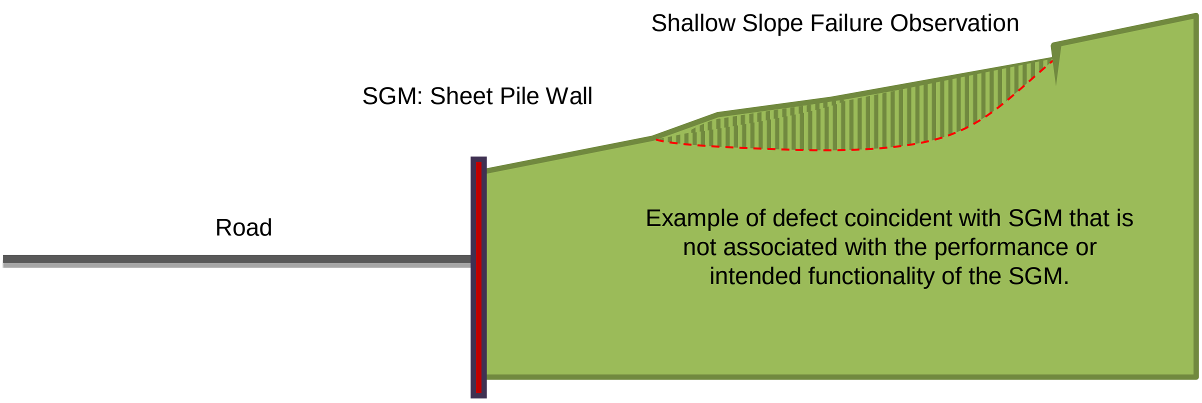
SGM extents recorded against reality

The total length and location of SGMs identified by this task have been generated through the application of the structured data mining methodology developed as part of sub-task 1.5. It is anticipated that in some cases the recorded length of observation will not match the true extent of the SGM. This is either because the observation only records a shorter length where there may be a localised defect (for example, damage recorded for a short section of a retaining wall, but the wall is actually longer), or because the SGM is only visible over a short length. For example, reinforced earth, where a buried reinforcement becomes exposed due to burrowing. In both these cases, the actual extents of the entire SGM may not have been recorded.

Associated observations

Although this task has been successful in identifying SGM observations coincident with classified defect observations, there is currently no existing approach to associate separate observations on an earthwork. Recommendations have been made later in this report describing how this could be achieved and incorporated into future inspection methodologies. For the purposes of this task, "coincident observations" have been used to assess performance, as comparing the geospatial location of an SGM and a classified observation is the only tool available to assess current condition. How this has been derived is shown in Figure 7-5. The accepted limitation with this methodology is that the occurrence of a coincident defect does not always mean that the SGM is defective, or that it is no longer effective in its intended design purpose.

Figure 7-5: Example of coincident observations but not associated with SGM performance



7.2.1.3 Development

This task continued to develop and improve the output of the structured data mining methodology derived during earlier sub-tasks. During the development of the data processing methodology, this task developed an automated procedure to recognise where SGM extents overlapped on an earthwork. The methodology was able to generate overall SGM extents based on the recorded chainages of observations with SGMs in the structured data.

The method developed identified where similar SGM types within the same earthwork have extents that either overlap or are encompassed within one another other. The methodology then evaluates the extents by chainage and calculates consolidated lengths of the SGM as new fields related to the original SGM observation IDs. Figure 7-6 and Table 7-11 demonstrate how this methodology generates SGM extents based on existing observations. The figure also illustrates how 5 No. separate observations of the same SGM type can be effectively summarised and more accurately reported, producing a more realistic representation of the total extents of SGM on an asset. The table gives a real example of how this methodology has automatically refined the data. The original 5 No. observations have been converted to one consolidated record and the total length automatically calculated.

Figure 7-6: Identification if coincident SGM observations and generation of total extents

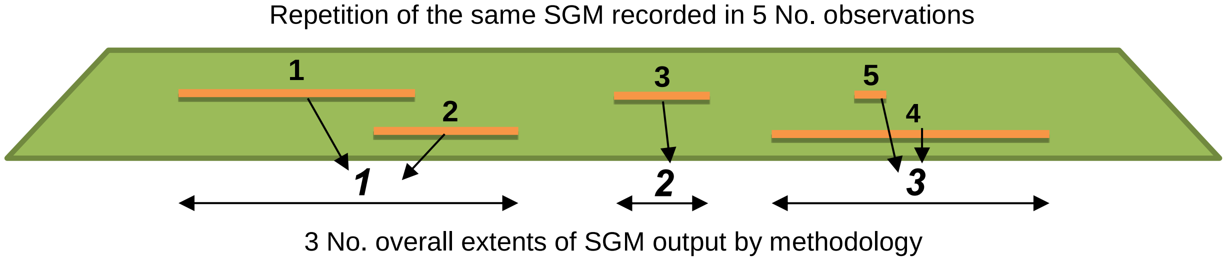


Table 7-11: Example of SGM data refinement

SGMs	Earthwork ID	Observation ID	Road	Observation Start Chainage	Observation End Chainage	Length (m)
Geogrid	591	257355	A14	538	758	220
Geogrid	591	230496	A14	557	570	13
Geogrid	591	230497	A14	569	623	54
Geogrid	591	230498	A14	648	715	67
Geogrid	591	230499	A14	716	738	22

SGMs	Earthwork ID	Road	SGM Start Chainage	SGM End Chainage	SGM Length
Geogrid	591	A14	538	758	220

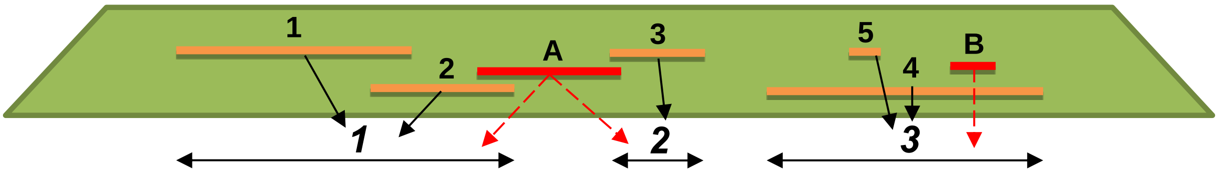
Condition Indicator - Coincident defect observations

Following the development of the method to identify and refine the extents of coincident SGM types across an earthwork, it was recognised that the same process could be applied to identify where classified defect observations were coincident with these extents, which could potentially indicate the SGM's current condition.

Applying this logic enabled the output of all IDs for observations coincident with the SGM extents into a new data field that could be reviewed by approval status and classification to understand what information was available for observations coincident with the SGM. Figure 7-7 demonstrates how this automatic procedure works to link defect observations to the calculated SGM extents.

Figure 7-7: Coincident defects

Ranges of same SGM Observations (1-5) and Defect Observations (A & B).



Total extents of SGM output by methodology with linked observations

The coincident observation procedure was developed by trialling and testing a number of different method variations. It was possible to develop and apply the method in a number of ways to enhance the information available for interpretation. Data were collated and enhanced through the application of the following:

- **SGM solutions** – A data query process, comparing earthwork ID and chainage, was developed to identify where any SGM types are geospatially coincident with each other. This was output as a list of coincident SGM types and corresponding observation IDs. This allows the identification of potential SGM solutions within the structured data set, where their coincident construction was to collectively mitigate a problem.

- **Coincident tick boxes** – It was possible to identify the tick boxes that had been selected for defect observations coincident to an SGM, through the return of fixed fields based on a comparison of earthwork ID and chainage. This summary of defect characteristics was reviewed in relation to the SGM types.

- **Data clean up** – It was possible using this identification of coincident observations to reduce the number of “non-specific” SGM types identified within the data. Occasionally records use different terminology when referring to the same SGM (for example referring to a sheet pile wall as a retaining wall). A hierarchical data selection process was developed and applied to recognise these occurrences and where possible remove the generic SGM type, whilst retaining all original information in a different field so that no information was lost.

- **Date first recorded** – This identified the date of the earliest observation that had recorded the SGM within the identified extents on the earthwork. This was to help identify potential approximate construction dates for subsequent analysis.

7.2.2 Sub-Task 2.2 - Review of performance of SGMs

Highways England want to better use their existing data to help develop a network model to identify potential patterns in performance and ultimately manage network risk through performance predictions and, potentially, planned pro-active maintenance.

Sub-task 2.1 successfully generated a number of new data fields to help assess the current condition of SGMs across the network. One of the key fields generated in this task for assessing condition was the "current coincident defects" which identified where approved or preliminary classified defect observations were currently located within the extents of SGMs.

7.2.2.1 Aims and objectives

This sub-task aimed to utilise the new condition related fields generated, and the existing knowledge of SGMs to investigate potential patterns in performance. Understanding these patterns in performance will aim to support the long-term risk management and inform intervention selection processes for Highways England.

7.2.2.2 Limitations and assumptions

Sample size

A number of the SGMs, principally those that are not visible during inspections, have a relatively small cohort to inform analysis and identification of patterns in performance. Also, several engineering characteristic fields that are likely to drive performance have a large number of data entry options that result in a significant range of test parameters. For example, HAGDMS recognises over 9,800 No. different geology codes, over 200 No. of which are represented in the final data set. Such large ranges impact on the ability to identify patterns. This was true for a number of the potential performance-driving parameters investigated, such as slope angle. In these cases, data groupings or ranges were applied. For example, the geology codes have been grouped into 11 No. engineering based categories, improving the ability to recognise patterns within the related data.

Relevance of coincident defects

It is considered likely that the percentage of SGMs with coincident defects identified represents an overestimate of the proportion that are actually defective. This is mainly as a result of cases where an SGM has only been observed due to the presence of a defect. There may be many more instances where the SGM exists without a defect but these locations will not have been recorded and are therefore omitted from the cohort for analysis.

Data quality issues

General data quality issues are known to exist within the structured data that may affect some of the results. This may occur where the record of a pre-existing defect may not have been updated following the installation of a remedial SGM. For example, Observation 175652 has been identified as a location of Electrokinetic stabilisation (from its attached Form C), however the observation is still classified in accordance with the original 1A defect. Based on the methodology this incorrectly identifies the SGM coincident with a defect. This example is not anticipated to be a unique occurrence, the overall impact is likely to be negligible in relation to other limitations.

The assessment of coincident defects by embankment geology highlighted an additional data quality issue. The embankments classed as "Made Ground" in the geotechnical data management system should be given a more specific geology coding, to improve such parametric analyses in future. This was investigated further, to determine where this data quality issue was arising. 4,215 No. embankments are currently identified on the system as "Made Ground", with over 40% of these being associated to one managing area.

Situational Consideration

When analysing potential patterns in SGM performance it is important to consider the results relative to the engineering scenario that the technique would most commonly be implemented. For example; when analysing Soil Nails by earthwork type, it should be considered that soil nails are more frequently installed in cuttings rather than on embankment, and are therefore likely to have a greater total number with coincident defects.

This is particularly important when analysing patters by geology, as some SGMs will be more suited and more applicable in certain geologies. It also aids identification of quality issues, where an SGM has been identified in an unlikely engineering scenario e.g. Rock Bolts on Embankment.

For this task, percentage of SGMs with coincident defects to those without is used for analysis, whilst also considering the size of the cohort.

SGM geometry

Due to the nature of the data collection process there is commonly a lack of information available regarding the geometry of the slope at the specific location of the SGMs. Approximately 30% of the SGMs have slope dimensions recorded. A logical methodology has therefore been derived through extrapolation of nearby information, to estimate the slope angle at the location of the SGM. A small number of SGMs (around 2%) did not have any coincident dimension information available within the GAD data with which to estimate an angle, however over half of these where retaining walls and so were considered to have a negligible impact on the assessment of the results.

Granularity and availability of relevant data

The performance of an SGM is influenced by a number of engineering parameters. Identifying performance trends is complex due to the significant number of variables for each of these parameters and for some SGM types, the relatively small size of the cohort. It is further complicated by the availability of key attribute data including, year of construction (deriving age) and design life, as well as other influencing factors such as, adverse weather and accidental/intentional damage.

7.2.2.3 Development

This sub-task initially had to decide on which parameters would be suited to analyse in order to identify potential patterns in performance. The parameters were selected largely based on engineering judgement and network knowledge. A parametric study was then undertaken, comparing different parameters to determine which combinations gave an indication of performance issues through the larger percentage of coincident defects. The parameters utilised have been defined in Table 7-12.

Table 7-12: Parameters investigated

Parameter	Description
Earthwork Type	It is anticipated that the behaviour of SGMs will be influenced by the type of earthwork they are constructed on. The geotechnical properties and behaviours between embankments and cuttings vary considerably, particularly in more cohesive materials, where the long-term strength parameters are likely to change over time. The data for each of the subsequent parametric tests has been summarised by earthwork type.
Geology	The geology of an earthwork will have a significant influence on the way particular SGMs behave and their lifecycle performance. 11 No. higher level geology groupings based on previous Highways England research have been utilised to simplify the data set to aid in pattern recognition. A summary of the statistics generated in this investigation can be found in Appendix E.
Geometry	The geometry of the slope is anticipated to influence the performance of SGM types differently. An investigation into how the numbers of coincident defects vary with earthwork height and slope angle for the SGM types has been undertaken. A summary of the statistics generated in this investigation can be found in Appendix F and Appendix G.
SGM Type	72 No. of the 99 No. SGM types searched for in sub-task 1.5 have been identified in the structured (inspection) data set and therefore form part of cohort of data to be analysed. It is these identified SGM locations that shall be investigated to see how they are influenced by various situation conditions.
Coincident tick boxes	16 No. defect tick boxes have been utilised to review what types/nature of defect appear most commonly coincident with the SGMs of different types.
Coincident defects	This project generated field has formed the basis of the investigations into potential performance patterns for each SGM type.
Earthwork construction date	The number of defects coincident with SGMs relative to when the earthwork was constructed, to investigate any potential correlations that may exist. It would be expected that older earthworks may contain the most degraded SGMs.
Road name	SGMs and number of coincident defect was also considered with regards to the road name, to identify which roads might have a higher incidence of problems than others. This could also provide insight to the reason for the number of coincident features (age, geology etc.).

The summarised results and a discussion on the findings are presented in Section 8 of this report. A number of recommendation have also been proposed to address the limitations identified during the analysis, mainly through improvements in data collection and management.

7.2.3 Sub-Task 2.3 - Review of third party datasets

Highways England holds a significant archive of information concerning the construction and maintenance history of the road network, in the form of the unstructured and structured datasets that have been utilised in this research project. There are, however, other potential sources of information held by third parties, which could supplement this information, or provide a wider context against which to assess the typical performance of SGMs in future, such as: Motorway Archive, International Research Institutes and published Standards. Cross reference to other sectors, such as Rail, is also important to understanding the long-term performance and potential future behaviour of geotechnical assets.

7.2.3.1 Aims and objectives

Sub-task 2.3 aimed to identify and investigate the potential for third party data to enhance the outputs generated in this research project. The objective of this sub-task was to provide a review of these potential data sets and how they could improve network performance knowledge. A more detailed technical note summarising the potential usefulness of third party data can be found in Appendix H.

7.2.3.2 Limitations and assumptions

Unidentified data sources

Due to the large amount of information that exists in the public domain there are potentially additional sources of SGM related information that may not have been identified. However, given the technical and specialist nature of such data it is considered that a significant proportion of potentially useful information has been identified and investigated as part of this sub-task.

Availability of data

Not all data, identified as potentially useful, was readily available via public access during the task programme. The conclusions from the review has been made, in some cases, on limited information and may therefore overestimate the potential value of these data sources. Although anticipated to be negligible, there could also be potential for useful information to have been dismissed.

Data extraction

No extraction of data from third party data sets was carried out as part of the programme. Recommendations for further investigation and extraction of information to supplement the understanding and knowledge developed as part of this research are included in Section 9 of this report.

7.2.3.3 Development

The search for additional SGM information has been undertaken using web searches and industry knowledge of where this information may be held online. This task initially sought to investigate known website based archives for information concerning the presence of SGM information. A summary of this tasks findings can be found in Appendix H.

Adaptation of Text Retrieval and Search Software

To ensure that the web sites being reviewed were thoroughly interrogated, a feature of the software used during earlier sub-tasks was utilised. The software has the functionality to index websites, which then enabled the SGM search terms to be used to search an entire website's contents for SGM information. This was considered the most efficient and effective way of locating potentially relevant information. The manual reviewing methodology used in sub-task 1.6 was again utilised to review the results.

Sources of information

While undertaking this task a number of sources of information were identified, as summarised in Table 7-13.

Table 7-13: Potential sources of third party information

Source	Description
Websites	A number of websites exist focused on archiving and capturing the development of the British road network; typically, these websites are run and populated by road enthusiasts and professionals who take an interest in the network construction.
Published Research (Papers)	A large amount of research and papers have been produced, looking into the effectiveness of specific SGM types. These sources of information were not thought likely to contain a significant amount of additional information regarding the location of SGMs on the network. They were however, considered potentially useful in providing performance and long term behavioural related information for certain SGM types, which may aid in identifying trends in performance and areas of future risk.
Books and Standards	A large number of reference books and engineering standards are available relating to earthwork construction, detailing both specific SGMs and generic ground treatment methods. These may contain information relevant to the performance of SGMs and were considered worth investigating for their usefulness in enhancing the data outputs and SGM performance knowledge
Wider industry (Rail)	An important aspect to consider when identifying potential 3rd party sources of information was where this information may exist for other asset owners, in the UK and internationally. The rail industry has implemented SGMs for a number of years and therefore potentially has resources and performance history that may be applicable to highways SGMs construction and performance. However, it is recognised that, at least in the UK, the differences in age and construction techniques for these assets may make direct performance comparisons complex.
SGM specific	Research and testing to assess long-term performance of some SGMs, is carried out and published by product manufacturers (e.g. Tensar) and research groups. SGMs which are more difficult to visually assess their condition would benefit most significantly from the supplement of this type of information. There are also ongoing tasks lead by asset owners to evaluate performance of more innovative SGMs installed on their networks, which could be of value to future elements of this task.

7.3 Sub-Task 3 – Recommendations for future data capture and storage

Highways England want to understand how their existing management of geotechnical data could be improved. Throughout this research project, a great deal of work has been undertaken utilising the existing systems and data that is currently in place. An important part of the task has been to challenge the data and the way in which it is captured and managed to allow the production of recommendations for future consideration. These recommendations aim to improve data capture and management requirements whilst considering digital and technological advances.

This sub-task contained one item as outlined in the PID, presented in Table 7-14.

Table 7-14: Summary of sub-task 3 activities and deliverables

Item	Activities	Deliverables
3.1	Critical review of information held in HAGDMS.	Briefing note/summary report - Data capture recommendations

7.3.1 Sub-Task 3.1 - Recommendations for data capture

7.3.1.1 Aims and objectives

The aim of this sub-task was to provide recommendations following a critical review of the way information is currently captured and stored within the existing geotechnical data management system. The output of this sub-task was a briefing note summarising these recommendations, which shall form part of the recommendations included in Section 9 of this report.

7.3.1.2 Limitations and assumptions

These recommendations are based on activities that are considered achievable and that would significantly benefit the acquisition and management of information regarding SGMs in the future. These recommendations could be built into any system for managing Highways England's Geotechnical data. Recommendations have not been bounded by the capability of existing systems and data capture process. The recommendations have been developed continually throughout the Task, based on limitations with existing data (availability and format) as they have been encountered. The continual review process has identified a number of areas that would benefit from improvements. These recommendations would ultimately reduce ambiguity within the data moving forward, and strive to make the existing and new information more structured and manageable, benefiting Highways England and the other stakeholders.

The findings of this sub-task are presented in Section 9 of this report.

7.4 Sub-Task 4 - Final report, recommendations and presentation of task findings

Sub-task 4 includes the production of this report, which comprises a review and discussion of the sub-tasks outputs and findings. The sub-task also includes the delivery of a presentation/workshop with Highways England and the key stakeholders to discuss the findings of this report.

Table 7-15: Summary of sub-task 4 activities and deliverables

Item	Activities	Deliverables
4.1	Review sub-task findings assessment of reliability and accuracy	Task Findings Report
4.2	Future data collection / storage recommendations for condition assessment	Task Findings Report
4.3	Recommendations for future asset management activities	Task Findings Report
4.4	Write task findings report	Task Findings Report
4.5	Prepare and present findings of Task to HE and key stake holders	Presentation / Workshop

Sub-task 4.1 is presented in Section 8 of this report and discusses the results from the data mining and development activities.

Sub-task 4.2 and 4.3 are captured in Section 9 of this report, comprising the subsequent recommendations that have resulted as a part of this research project.

7.4.1 Sub-Task 4.1 to 4.4 – Final Report

7.4.1.1 Aims and objectives

This task aimed to summarise the key activities that have been undertaken in completing this research task and to clearly set out the limitations and assumptions taken to achieve each step. A key element of the report was not only to provide a catalogue of the network SGMs but also to provide recommendations regarding the future capture, management and use SGM of data, and where future research should be considered to improve SGM performance knowledge.

7.4.1.2 Limitations and assumptions

This report and associated outputs are bounded by the limitations experienced throughout each sub-task. Where limitations have been significant, the original scope has been adapted following agreement with Highways England.

7.4.1.3 Development

This report is the deliverable of this sub-task and was prepared following the completion of the activities defined in all previous sub-tasks.

7.5 Sub-Task 5 – Production of geospatial representation of SGMs

A key deliverable of this research project is a geospatial data set of the SGM information derived from existing data sets. The structured data mining methodology developed throughout this research has been designed to output start and end coordinates and earthwork chainage relating to the overall SGM extents identified across the network. The locations have, where possible, been associated to source observation references.

Table 7-16: Summary of sub-task 5 activities and deliverables

Item	Activities	Deliverables
5.1	Compile geospatial information for all SGM locations derived, including associated data fields.	Data set of SGM data

7.5.1 Sub-Task 5.1 – Compile geospatial information

7.5.1.1 Aims and objectives

The aim of this sub-task was to compile the geospatial information identified by the structured data mining methodology. This data set is to be provided to Highways England for incorporation into the current or future geospatial information system.

7.5.1.2 Limitations and assumptions

The geospatial data sets output by this task are subject to data quality limitations as discussed throughout this report. The accuracy of the start and end coordinates of SGMs are dependent on the accuracy of the data collected on site, no processing of the co-ordinates other than selecting maximum and minimum to derive extents has taken place. Recommendations addressing limitations have been discussed in the data capture recommendations, in Section 9 of this report.

It was established early on the in programme that the extraction of SGMs exclusively detailed in pdf reports for incorporation into an enhanced geospatial data set would not be achievable within the programme. The geospatial information produced is therefore only representative of data captured through the inspection process and supplemented by minimal reports data extraction as summarised as part of sub-task 1.6. It was agreed that a summary of pdf reports and the likely SGMs contained within them, generated as part of sub-task 1.7 will be provided as an additional deliverable to the project.

7.5.1.3 Development

Following the identification and refinement of SGM extents, it was important to establish and summarise the key attributes to be associated to each SGM, including geospatial specific data.

The key attributes were developed through the continual review of information and analysis, and importantly considering future use/need for information. Where possible geospatial information has been generated by extraction and interrogation of the existing observation source data. E.g. co-ordinates and earthwork start and end chainage of observations recording presence of an SGM. Data been combined, not losing any history, therefore each SGM includes all related observation IDs and therefore traceable origins of information.

8 Summary of Findings and Discussion

This section presents the summaries of the output from the project typically sorted by Highways England Area. The results have been separated according to those determined from the structured and unstructured source data. Data recorded and available for several DFBO's are also included for comparison.

8.1 Structured data summary

The result of the work undertaken as part of this project programme was a revised and more efficient methodology for the identification of SGMs within the existing structured data held by Highways England. The limited data which was extracted from the reports has been incorporated and included in the below summary.

This methodology was able to identify and then refine the recorded extents of 74 No. different types of SGMs located on the network. Calculating the total number and length of extents of SGMs as well as identifying a number of attributes and data linkages. The output of the project shall be provided to Highways England in digital format along with this report submission.

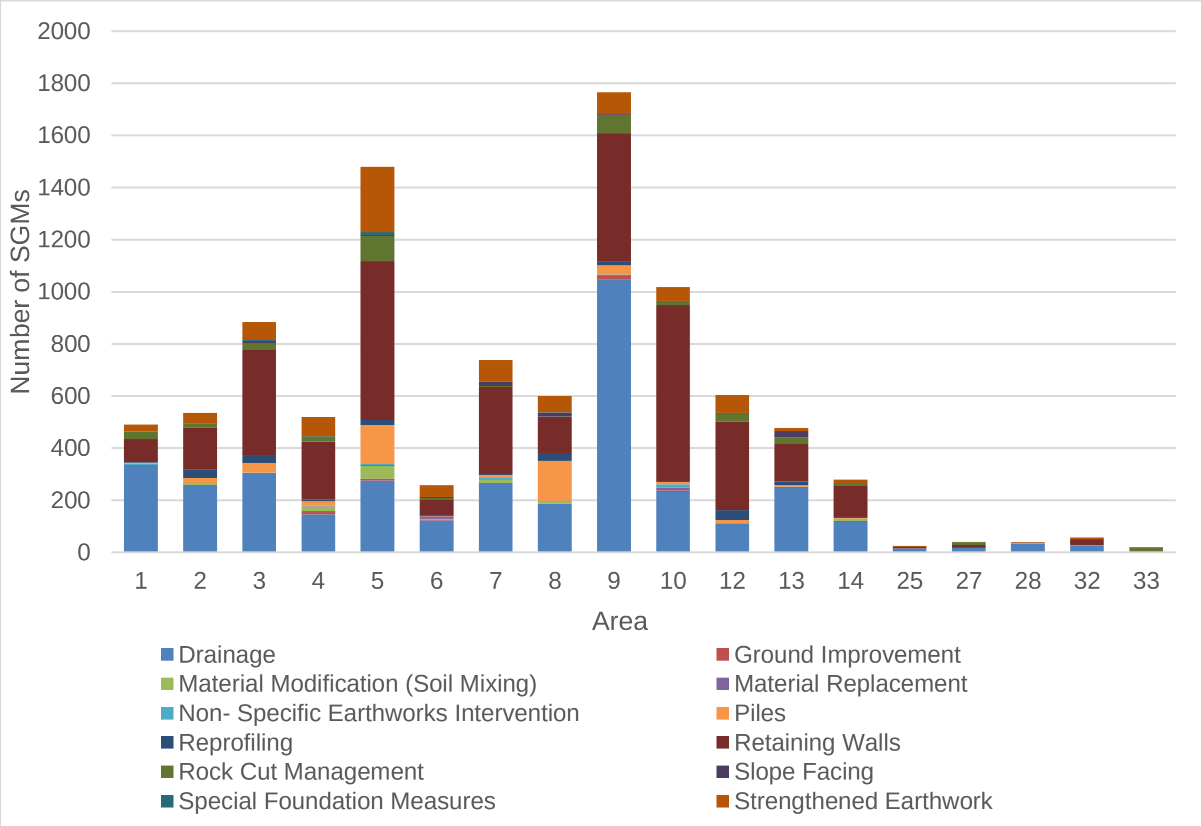
A summary of the total number of SGMs by area is presented in Table 8-1 and by higher level SGM category in Figure 8-1.

Table 8-1: Summary of SGMs from structured data by area

	AREA / DBFO's																		
SGM Type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**12**	**13**	**14**	**25**	**27**	**28**	**32**	**33**	**Total**
Anchored Sheet Pile Wall (ASHP)					9														9
Basal Drainage (BSDR)			2		2	3		1	4										12
Block Wall (BLCW)	6	37	135	23	19	4	35	13	115	76	53	8	35			1	4		564
Buttress (BTTR)	4						1	1	2		8								16
Cobbled Facing (COBB)									2										2
Concrete Cladding (CLAD)		1																	1
Concrete Driven Piles (CNPL)		1			1														2
Concrete Facing (CONF)				1	4														5
Concrete Rubble Facing (CNRF)												1							1
Concrete Sandbag Wall (CNSB)		2		4			1	1	4		2								14
Contiguous Bored Pile Wall (CBPW)			1	1					1			1							4
Counterfort Drain (CFDR)	132	83	12	9	15	1		6	25		3	2	16	4					308
Crest Drain (CSDR)		1	9	1		1		2	78		1	4	2		6				105
Crib Wall (CRIB)	8	7	7	3	2	8		2		5	3	2							47
Cut off Drain (CODR)		5			3				10										18
Dentition (DNTT)	4	1							2									5	12
Electrokinetic (ELEC)				1					1										2
Erosion Mat (ERSN)			9	1	3	3	16	15	2		1	3	1				2		56
Fibre Reinforcement (FBRN)				2	1														3
Filter Drain (FILT)	148	136	219	98	205	82	154	92	492	227	101	127	77	8	8	14	13	2	2203
Frost Blanket (FRBL)			1	8															9
Gabion Wall (GABN)	31	48	60	101	47	2	64	28	80	50	101	28	24	3	2	1	5	2	677
Geogrid (GEGD)	17	15	17	33	132	20	40	27	17	32	15	7	3	3			1		379
Geomembrane (GMEM)			1					1											2
Geotextile (GETX)	1	6	16	7	23	10	4	22	15	7	24	6	3		1		2		147
Ground Anchor (GANC)	2							1	1	1									5
Ground Beam (GBEM)		2	1	1															4
Grout Injection (GROT)		1	1	2	2	1			13										20
Herringbone Drainage (HBDR)		7	2	1	11	5	49	20	24	3	2	17	16	1		11	1		170
Inclined Piles (INCP)				1															1
Internal Drainage (INTD)									1										1
King Post Wall (KPWL)						2													2
King Sheet Pile Wall	1																		1
Lightweight Fill (LGHT)		1		1	2	1													5
Lime Stabilisation (LMST)		6	1	16	48	6	13	9					9						108
Masonry Facing (MSNF)						1						2							3

	AREA / DBFO's																		
SGM Type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**12**	**13**	**14**	**25**	**27**	**28**	**32**	**33**	**Total**
Masonry Wall (BKRW)		13	3	13	19	4	16	11	77	26	4	2	5		2		6		201
Mass Concrete Wall (CNCW)	7	13	38	35	123	8	22	25	96	66	50	7	31		6	1	1		529
Micro Piles (MCRP)											2								2
Natural Material Poles (POLE)		1		1				2		1									5
Metallic Reinforcement (MTLK)		8	4	2	37	3	14	2	10	5	6								91
Non-Specific Anchor (NANC)	5	1		3	5		5		3	12		1		1	1		1		38
Non-Specific Bored Pile Wall (NSBP)		6		1	1							1							9
Non-Specific Pile Wall (NSPW)	1	4	3									1							9
Non-Specific Retaining Wall (NSRW)	12	25	163	39	400	30	195	59	115	446	106	75	22	1	1		2		1691
PVC Pile Wall (PVCS)								107											107
Raft (Mining) (MRAF)					1														1
Regrade (REGD)	3	32	19	5	15	3	3	28	14	3	38	11	4				1	1	180
Rock Armour (ROCA)												18							18
Rock Bolts (ROCB)	8	4		4	6		2		20	6	12	6	5		3			2	78
Rock Catch Fence (DBFN)	1	5	10		33				2	3		2	1					1	58
Rock Fill (ROCF)	1				1	8	1	2	2	11	1	5	1	2					35
Rock Mattress (ROCM)				1							2								3
Rock Netting / Mesh (SMEH)	9	4	11	15	47	6	2		32	8	11	10	5	1	4			3	168
Rock Ribs (RIBS)								1											1
Rock Trap / Catch Ditch (DITC)	1		2		1							5					1		10
Scaling (SCAL)	1								3										4
Shear Dowel (SRDW)	4																		4
Shear Key (SRKY)			1		9														10
Sheet Pile Wall (SHPL)	1	8	33	13	137	1	10	47	35	9	10	2	2			1	1		310
Shotcrete (SHOT)	1				6				7			1			3				18
Slope Drain (SLDR)	48	10	25	24	22	16	48	46	58	1	1	38	7			9	8		361
Soakaway (SOAK)			7		1	1	6	6	2	1							1		25
Soil Nails (SNAL)	4	8	30	21	59	11	25	9	37	6	20		7			1	2		240
Soil Nail Mesh (SNMS)		2	4	6		1			3	1	3						1		21
Spaced Bored Pile Wall (SBPW)					1												1		2
Stone Columns (STCL)					1														1
Stone Pitching (PITC)											1							2	3
Stone Wall (STNW)	23	15		3		1	1		6	5	21	23	2	1			2	1	104
Syphon Well (SYWL)					1														1
Timber Boards (TIMB)				1															1
Toe Berm (TOBR)		1	11	2	4	1	1	1		1		4							26
Toe Drain (TODR)	7	16	27	5	16	13	9	12	353	1	2	58			3		1		523
Vertical Drains (VERT)				10	4		1	1	1	5			2						24
Grand Total	**491**	**536**	**885**	**519**	**1480**	**257**	**738**	**600**	**1765**	**1018**	**604**	**478**	**280**	**25**	**40**	**39**	**57**	**19**	**9830**

Figure 8-1: Number of SGM Categories by area



Length of SGM by Highways England Maintenance Area

Table 8-2 presents a summary of the lengths of SGM (by higher level SGM Category) derived through application of the structured data mining methodology and limited report data extraction through Areas 1 to 14. This methodology has identified 1,337km of SGM across the network. A full summary of the lengths of SGM by all (including DBFO Areas 25 to 33) areas can be found in Appendix C.

Table 8-2: Summary of SGM category length (km) by area from the structured data

	Area												
SGM Category	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**12**	**13**	**14**
Drainage	49.52	52.78	83.77	36.55	68.98	23.05	67.86	28.03	211.56	50.74	40.37	53.59	22.16
Ground Improvement		0.14	0.00	2.68	0.08	0.09	0.13	0.09	3.16	0.19			0.00
Material Modification (Soil Mixing)		0.41	0.00	3.30	2.61	0.16	1.51	0.30					3.51
Material Replacement	0.00	0.08		0.02	0.11	0.25	0.07	0.22	0.01	0.42	0.02	0.47	0.01
Non- Specific Earthworks Intervention	2.68	1.22		0.47	0.89		0.64		0.15	2.66		0.07	
Piles	0.70	2.24	5.40	1.24	9.36	0.63	1.29	7.76	2.05	0.73	0.83	0.67	0.43
Reprofiling	0.19	2.36	4.38	0.62	1.50	0.23	0.64	2.30	1.22	0.29	3.12	1.07	0.06
Retaining Walls	6.88	14.91	18.89	9.75	77.97	3.04	18.84	6.03	34.66	33.38	25.47	12.77	6.18
Rock Cut Management	3.41	5.72	4.79	4.04	15.80	1.81	1.37	0.06	6.74	2.78	5.11	4.75	1.56
Slope Facing		0.26	0.42	0.06	0.78	0.45	3.03	0.68	0.46		0.29	1.52	0.04
Special Foundation Measures		0.10	0.09	0.15	0.36			0.21					
Strengthened Earthwork	3.67	3.99	9.80	10.30	48.21	5.27	11.60	4.79	5.87	5.16	8.85	1.35	1.19
Grand Total (km)	**66.33**	**83.22**	**126.72**	**68.34**	**217.92**	**34.33**	**105.67**	**50.40**	**265.13**	**95.74**	**82.89**	**76.25**	**35.13**

Discussion

The following general commentary can be applied on review of this information:

- Area 9 records the greatest total length of SGM on the network. However, approximately 80% of this is attributed to drainage SGMs.
- Area 5 stands out as having the most significant length of strengthened earthwork, retaining walls and rock cut management. This is most likely due to the installation of measures during several significant phases of widening works around the Area.
- Area 9 and Area 4 are suggested to have the most ground improvement SGMs accounting for approximately 88% of these SGM types between them. Ground Improvement methods are not commonly SGMs which are recorded during inspection, therefore these are either likely to have been identified from the limited reports review carried out during this project or inspection records have captured this type of data. GAD records would be more likely to capture this information from either the occurrence of defects that have exposed these SGMs or from network knowledge of these locations.
- Area 8 contains all of the recorded PVC sheet pile walls. These are known to have been the preferred method for low height retaining structures for a specific project. The locations and condition are likely to have been a focus during inspections due to their uncommon and innovative use.
- The number of SGMs for some solutions is surprisingly low.

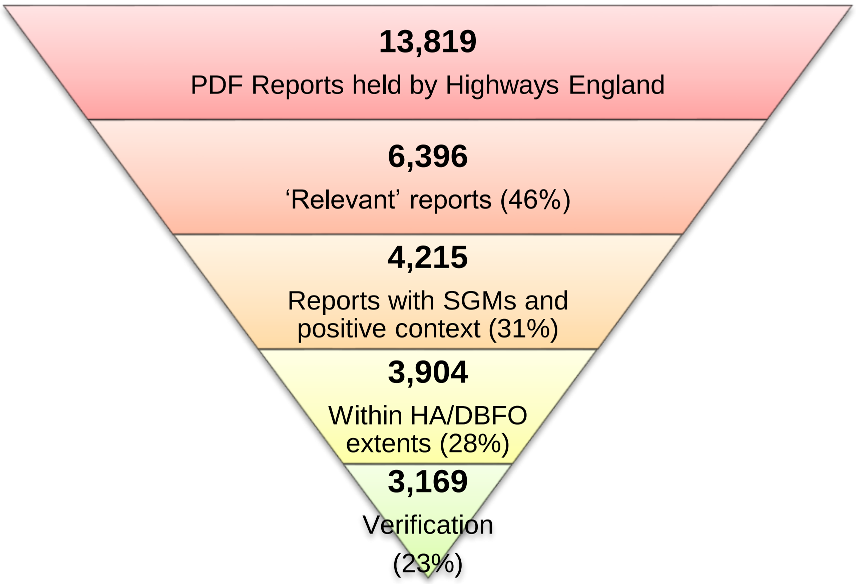
Trends and patterns in the data will be influenced by the quality and preferred methods by which inspections are carried out. Many SGM types are not specifically required to be captured as part of the routine inspections in accordance with HD41 and therefore no record in the data does not mean that these SGMs do not exist on the network in reality. Specific schemes where certain techniques feature heavily are evident in the data. The lack of consistency in SGM recording is highlighted as a significant limitation of the project and is a fundamental recommendation for improvements in data capture going forward. The information identified and summarised shall form a good baseline from which to refine and complete a detailed and accurate SGM data set.

8.2 Unstructured data mining methodology

Application of the developed methodology to the national data set of pdf reports has identified 3,169 No. reports likely to contain useful information regarding the installation of 93No. types of SGMs across the Highways England network. The culmination of this work has resulted in a methodology able to identify with acceptable verified accuracy, where useful SGM information is likely to be located within Highways England held reports.

Figure 8-2 demonstrates the progress this methodology has made in refining the initial data set to a final data set of reports containing information regarding the extents of SGMs across the network.

Figure 8-2: Summary of unstructured data methodology refinement



Data format

The final output of this data mining methodology is provided to Highways England in an agreed digital format attached to this report submission. The summary comprises a catalogue of report ID's and the type of SGMs associated with each of them. It is anticipated that this information will be appended to the attributes for each report to supplement the existing data available to users in the reports summary.

Reports have been associated with Areas based on the existing report extents (where available) and Area boundaries. The summary below, when compared to the structured data summary, highlights the types of SGMs not currently digitally recorded on the network. It also provides an indication of where there may be little report information available to support the presence of SGMs that have been recorded during inspection. This summary is presented in Table 8-3. It should be noted that due to technical complexities, where a linear DBFO Area falls within the geographic extents of a Highways England Area, all reports will have been associated to the wider Highways England Maintenance Area.

Table 8-3: Summary of SGMs identified in the unstructured data set by Area.

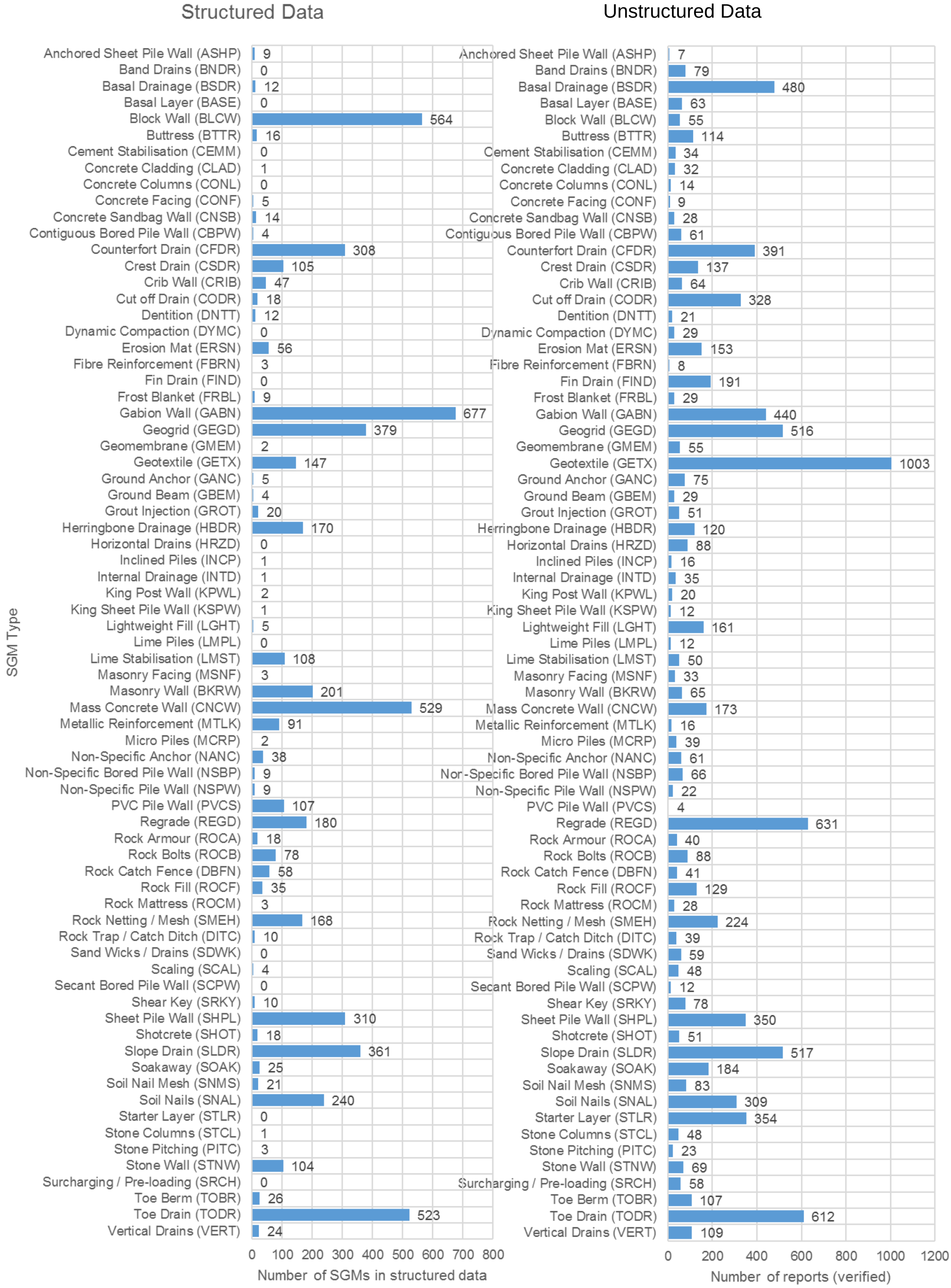
	Area													
SGM Type	1	2	3	4	5	6	7	8	9	10	12	13	14	Total
Anchor Piles (ANPL)		1	2	2	1	2			2		1			11
Anchored Bored Pile Wall (ABPW)		2	1	1	1							1		6
Anchored Sheet Pile Wall (ASHP)				2	3	1	1				1			8
Band Drains (BNDR)	1	13		3	1	12	6	3	4	15	9	5	8	80
Basal Drainage (BSDR)	15	56	41	62	65	52	43	22	45	64	39	15	37	556
Basal Layer (BASE)	4	12	1	4	3	2	13		7	5	6	7	4	68
Block Wall (BLCW)	1	15	6	4	6	1	6		7	4	5	4	1	60
Buttress (BTTR)	11	8	5	6	14	7	4	1	7	39	14	6	4	126
Cement Stabilisation (CEMM)		5	8	3	5	9	2	2	3		1		3	41
Cobbled Facing (COBB)		1	1	1	1			1						5
Concrete Cladding (CLAD)	1	6	10	3	3		1	1	3	2	1	2	4	37
Concrete Columns (CONL)		1	1					3	3	2		2		12
Concrete Driven Piles (CNPL)				1						3			2	6
Concrete Facing (CONF)		1					2		1		3		1	8
Concrete Sandbag Wall (CNSB)		9	2	5	1	1	1	2	8			1		30
Concrete Slab (Non-mining) (RAFT)		1			1					2	1			5
Contiguous Bored Pile Wall (CBPW)		5	1	10	3	4	5	3	3	14	6	10	1	65
Counterfort Drain (CFDR)	33	88	54	42	65	23	41	29	34	37	15	10	11	482
Crest Drain (CSDR)	6	8	19	9	5	11	14	4	27	26	8	6	11	154
Crib Wall (CRIB)	1	7	2	19	7	14	1	3	4	6	4	1	1	70
Cut off Drain (CODR)	20	30	30	50	36	16	29	19	47	30	16	26	18	367
Dentition (DNTT)	2	3					1		3	1	6	4	2	22
Dowel Piles (DOWP)		1												1
Dynamic Compaction (DYMC)	1	3			17	1		5		2	2			31
Electrokinetic (ELEC)		2		1					1	1			1	6
Erosion Mat (ERSN)	8	25	27	20	10	14	7	2	20	7	10	10	9	169
Fibre Reinforcement (FBRN)	1			4	2									7
Filter Drain (FILT)	37	123	130	102	98	107	101	52	110	123	78	67	39	1167
Fin Drain (FIND)	6	19	17	25	27	26	13	22	19	18	11	7	8	218
Frost Blanket (FRBL)		2	6	11	3		5	1	1		1	1		31
Gabion Facing (GABF)			1		1	1	2		2			2		9
Gabion Wall (GABN)	33	47	54	55	47	7	44	26	53	36	40	38	30	510
Geogrid (GEGD)	12	70	49	67	68	31	59	45	71	36	25	32	19	584
Geomembrane (GMEM)		1	8	9	9	5	5	2	5	3	3	4	5	59
Geotextile (GETX)	25	111	122	125	78	77	104	62	121	82	52	63	62	1084
Ground Anchor (GANC)	9	5	7	10	14	5	10		6	10	9	6		91
Ground Beam (GBEM)		6	1	2	3	1		1	7	3	1	5		30
Grout Injection (GROT)	2		1	11	4	5	5		10	4	5	6	3	56
Helical Piles (HELI)							4		1	1				6
Herringbone Drainage (HBDR)	4	13	11	8	14	9	10	9	19	22	11	5	5	140
Horizontal Drains (HRZD)	20	9	3	12	5	3	8	4	8	17	2	2	1	94
Inclined Piles (INCP)		3		3	2	1	4		1	2		2		18
Internal Drainage (INTD)	1	5	1	4	3	1	4	1	5	5	4	1	1	36
King Post Wall (KPWL)	3	5	4	4	3	2		2	3	1	1			28
King Sheet Pile Wall (KSPW)	1		6	2	9	1	1		1					21
Lightweight Fill (LGHT)	3	19	4	7	9	17	27	11	16	28	15	6	15	177
Lime Nails (LMNL)														
Lime Piles (LMPL)		1		1	7	1		1	1					12
Lime Stabilisation (LMST)		1	3	19	15	10	13	6	4	1		2	3	77
Masonry Facing (MSNF)	2	2	2	4	2				8	6	8	3	2	39
Masonry Wall (BKRW)	1	11	1	3	1	1	7	1	7	10	13	8	4	68
Mass Concrete Wall (CNCW)		27	24	22	19	8	13	1	19	23	15	14	8	193
Metallic Reinforcement (MTLK)			1	4	2				9	1			1	18
Micro Piles (MCRP)	1	8	3	3	6		5		2	3	5	1		37

	Area													
SGM Type	1	2	3	4	5	6	7	8	9	10	12	13	14	Total
Natural Material Poles (POLE)		1		3	2							1		7
Non-Specific Anchor (NANC)	4	9	4	12	5	1	7		7	3	6	1	4	63
Non-Specific Bored Pile Wall (NSBP)	4	27	15	15	14	1	3	3	5	2	1	1	1	92
Non-Specific Pile Wall (NSPW)	1	7	3	5	5	1		1	1			2	2	28
Non-Specific Retaining Wall (NSRW)	11	42	45	54	60	28	54	27	62	64	47	20	25	539
PVC Pile Wall (PVCS)			1		1			1	1					4
Raft (Mining) (MRAF)	1						2		2			2	1	8
Regrade (REGD)	16	80	95	78	82	32	54	17	78	59	45	52	32	720
Rock Armour (ROCA)	1	2	4	3	3	1	7	4	3	5		9	3	45
Rock Bolts (ROCB)	17	9	1	2			4		12	3	17	21	2	88
Rock Catch Fence (DBFN)	5	6	6	4	5		4		5	2	6	6		49
Rock Fill (ROCF)	7	10	7	1	6	4	16	3	22	28	9	15	5	133
Rock Mattress (ROCM)		2	5	1	3	3		4	6	1	2	4	2	33
Rock Netting / Mesh (SMEH)	18	25	22	32	13	9	16	6	34	6	29	23	10	243
Rock Ribs (RIBS)			3					1	4		1			9
Rock Trap / Catch Ditch (DITC)	5	6	4	3	1		5	2		4	7	3		40
Sand Wicks / Drains (SDWK)	1	14	1	5	11	11	1	1	5	7	3	2	2	64
Scaling (SCAL)	7	6	1				3		13		8	9	1	48
Sealed Drainage (SEAL)		1	1	1	1	1		1			1			7
Secant Bored Pile Wall (SCPW)		2		1	4	1			2	1		1	1	13
Shear Dowel (SRDW)	3										1			4
Shear Key (SRKY)	1	14	12	6	14	5	10	5	3	8	5	2	5	90
Shear Trench (SRTR)														
Sheet Pile Wall (SHPL)	3	29	61	42	56	34	24	21	51	48	16	11	12	408
Shotcrete (SHOT)	6	2	10	5			1		12	2	10	3	2	53
Slope Drain (SLDR)	21	61	94	50	62	47	65	35	59	59	21	17	16	607
Soakaway (SOAK)	1	21	37	49	39	21	15	7	7	4	8	1	8	218
Soil Nail Mesh (SNMS)	7	9	16	14	9	9	6	3	7	1	8	3	3	95
Soil Nails (SNAL)	16	38	50	49	43	30	25	19	25	9	29	9	17	359
Spaced Bored Pile Wall (SBPW)				1		1						1		3
Starter Layer (STLR)	17	38	22	20	24	29	53	29	69	34	12	16	28	391
Stone Columns (STCL)	1	2	6	2	6	4	8	10	13	2	5	2		61
Stone Pitching (PITC)			3				3		6	6	9			27
Stone Wall (STNW)	14	21	1	1		1	2		2	6	6	18	2	74
Surcharging / Pre-loading (SRCH)		12	4	4	4	7	7	1	7	4	7	2	4	63
Syphon Well (SYWL)				1	3									4
Tied Wall (TDWL)														
Timber Boards (TIMB)				3										3
Toe Berm (TOBR)	1	9	28	30	20	6	6	5	19	8	4		2	138
Toe Drain (TODR)	16	77	89	58	62	45	66	39	71	80	37	25	28	693
Tyre Bales (TYRB)		1	1					3						5
Vertical Drain (VERT)	1	11	4	12	4	15	2	2	6	21	9	6	8	101

Data comparison

Figure 8-3 provides a visual comparison, and demonstrates the difference in the quantity of SGM data between the two data sets. In particular, it reveals the benefit of mining the unstructured data set, as 21 No. SGM types are exclusively recorded within the reports data. There is also a clear, and although anticipated, distinction between the SGMs that would typically be visible on site and therefore recorded during inspection, and the SGMs that would more typically be buried. SGMs such as geotextiles, geomembranes and basal drainage, all indicate a larger volume of information in the unstructured data. Similarly, unsurprisingly, the more visible SGM types such as the retaining walls and drainage SGMs are typically better represented in the structured data.

Figure 8-3: Structured and Unstructured output comparison

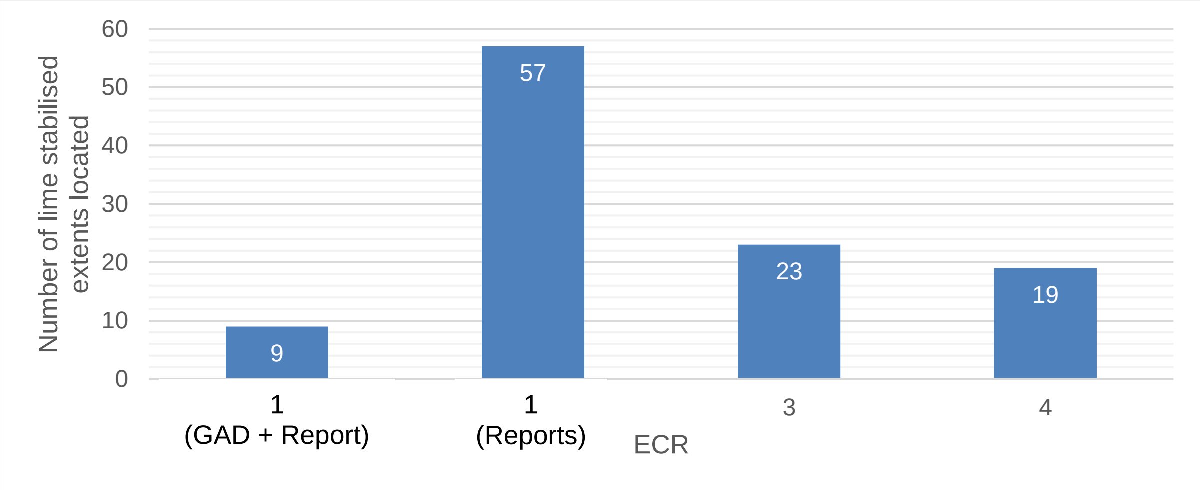


8.2.1 Unstructured data extraction

As part of the project, data associated with the use of lime stabilisation has been extracted to support a review of the benefits and value of the manual data extraction process. This process proved useful in generating geospatial information for the largely unrecorded locations of the utilisation of this non-visible SGM. Figure 8-4 illustrates the benefits of this data extraction. The extraction identified 76 No. additional locations of lime stabilisation that were not recorded in the structured data (ECR 1 (Reports) & 4). The extraction process has also confirmed the full extents of 9 No. locations already held in the structured data and highlighted 19 No. cases where the report suggests the presence of lime stabilisation across an earthwork without presenting specific extents. The structured data has subsequently been supplemented and updated with this additional extracted information.

A small number of SGMs in addition to lime stabilisation were also extracted from a limited number of reports during the testing phase. Information from which although not extensive has also been added to the structured data set.

Figure 8-4: ECR rating of lime stabilised locations identified from structured and unstructured data



Future data extraction

It was not possible to fully extract information for all SGM types due to the signifcant quantity of information available and time required to complete manual intensive process. This exercise has demonstrated the benefits and difficulties that currently exist with reviewing the historical reports and locating the relevent information within them. This process has resulted in a number of recommendations for how best to capture this information moving forward, including proposed studies to enhance the method for data extraction. With continued technological developments in natural lanugage processing and the speed in which advances in this area are being made, it is possible that data identification and potential extraction could be futher automated in the near future. However, complications such as locations being reported using project chainage, or local grid co-ordinates, are likely to mean that manual input would still be required to ensure appropriate data accuracy.

8.3 Review of performance

The methodology developed in sub-task 2.1 was able to successfully identify classified defect observations that were coincident with located SGMs across the network. Table 8-4 presents the results of the process. The values represent the number of SGMs identified and the percentage of those that are coincident with a preliminary/approved classified defect. A full list of SGMs with conincident defects by area is included in Appendix D.

Table 8-4: Number of SGMs (% with coincident defects) by Area

	AREAS / DBFO's																		
SGM Type	1	2	3	4	5	6	7	8	9	10	12	13	14	25	27	28	32	33	Total
Anchored Sheet Pile Wall					9 (0%)														9 (0%)
Basal Drainage			2 (100%)		2 (0%)	3 (0%)		1 (0%)	4 (0%)										12 (17%)
Block Wall	6 (0%)	37 (59%)	135 (7%)	23 (22%)	19 (11%)	4 (0%)	35 (46%)	13 (15%)	115 (3%)	76 (9%)	53 (15%)	8 (13%)	35 (23%)			1 (0%)	4 (0%)		564 (15%)
Buttress	4 (25%)						1 (100%)	1 (100%)	2 (0%)		8 (100%)								16 (69%)
Cobbled Facing									2 (0%)										2 (0%)
Concrete Cladding		1 (100%)																	1 (100%)
Concrete Driven Piles		1 (100%)			1 (100%)														2 (100%)
Concrete Facing				1 (0%)	4 (0%)														5 (0%)
Concrete Rubble Facing												1 (0%)							1 (0%)
Concrete Sandbag Wall		2 (0%)		4 (25%)			1 (0%)	1 (100%)	4 (0%)		2 (50%)								14 (21%)
Contiguous Bored Pile Wall			1 (0%)	1 (0%)					1 (0%)			1 (0%)							4 (0%)
Counterfort Drain	132 (28%)	83 (14%)	12 (25%)	9 (44%)	15 (20%)	1 (0%)		6 (33%)	25 (4%)		3 (67%)	2 (100%)	16 (44%)	4 (0%)					308 (24%)
Crest Drain		1 (0%)	9 (11%)	1 (100%)		1 (100%)		2 (0%)	78 (12%)		1 (100%)	4 (0%)	2 (100%)		6 (17%)				105 (15%)
Crib Wall	8 (13%)	7 (0%)	7 (14%)	3 (0%)	2 (0%)	8 (13%)		2 (0%)		5 (0%)	3 (0%)	2 (0%)							47 (6%)
Cut off Drain		5 (20%)			3 (0%)				10 (0%)										18 (6%)
Dentition	4 (0%)	1 (100%)							2 (50%)									5 (0%)	12 (17%)
Electrokinetic				1 (0%)					1 (100%)										2 (50%)
Erosion Mat			9 (11%)	1 (0%)	3 (33%)	3 (33%)	16 (13%)	15 (0%)	2 (0%)		1 (100%)	3 (33%)	1 (100%)				2 (0%)		56 (14%)
Fibre Reinforcement				2 (50%)	1 (0%)														3 (33%)
Filter Drain	148 (46%)	136 (22%)	219 (30%)	98 (22%)	205 (29%)	82 (20%)	154 (30%)	92 (24%)	492 (18%)	227 (20%)	101 (53%)	127 (12%)	77 (34%)	8 (0%)	8 (50%)	14 (0%)	13 (15%)	2 (0%)	2203 (26%)
Frost Blanket			1 (100%)	8 (13%)															9 (22%)
Gabion Wall	31 (32%)	48 (19%)	60 (15%)	101 (5%)	47 (11%)	2 (0%)	64 (6%)	28 (32%)	80 (11%)	50 (8%)	101 (13%)	28 (4%)	24 (17%)	3 (0%)	2 (50%)	1 (0%)	5 (20%)	2 (0%)	677 (12%)
Geogrid	17 (12%)	15 (20%)	17 (12%)	33 (9%)	132 (20%)	20 (15%)	40 (10%)	27 (19%)	17 (0%)	32 (9%)	15 (40%)	7 (43%)	3 (33%)	3 (33 %)			1 (0%)		379 (17%)
Geomembrane			1 (0%)					1 (0%)											2 (0%)
Geotextile	1 (0%)	6 (0%)	16 (13%)	7 (29%)	23 (4%)	10 (10%)	4 (25%)	22 (9%)	15 (0%)	7 (14%)	24 (38%)	6 (83%)	3 (33%)		1 (0%)		2 (0%)		147 (17%)
Ground Anchor	2 (0%)							1 (0%)	1 (100%)	1 (0%)									5 (20%)
Ground Beam		2 (0%)	1 (0%)	1 (0%)															4 (0%)
Grout Injection		1 (100%)	1 (100%)	2 (0%)	2 (0%)	1 (100%)			13 (0%)										20 (15%)

	AREAS / DBFO's																		
SGM Type	1	2	3	4	5	6	7	8	9	10	12	13	14	25	27	28	32	33	Total
Herringbone Drainage		7 (0%)	2 (0%)	1 (0%)	11 (0%)	5 (100%)	49 (53%)	20 (30%)	24 (13%)	3 (67%)	2 (50%)	17 (12%)	16 (19%)	1 (0%)		11 (0%)	1 (100%)		170 (29%)
Inclined Piles				1 (0%)															1 (0%)
Internal Drainage									1 (100%)										1 (100%)
King Post Wall						2 (0%)													2 (0%)
King Sheet Pile Wall	1 (100%)																		1 (100%)
Lightweight Fill		1 (100%)		1 (100%)	2 (0%)	1 (0%)													5 (40%)
Lime Stabilisation		6 (17%)	1 (100%)	16 (13%)	48 (10%)	6 (17%)	13 (0%)	9 (22%)					9 (0%)						108 (11%)
Masonry Facing						1 (0%)						2 (100%)							3 (67%)
Masonry Wall		13 (15%)	3 (0%)	13 (31%)	19 (16%)	4 (0%)	16 (13%)	11 (0%)	77 (3%)	26 (8%)	4 (25%)	2 (50%)	5 (0%)		2 (50%)		6 (0%)		201 (9%)
Mass Concrete Wall	7 (14%)	13 (0%)	38 (8%)	35 (17%)	123 (18%)	8 (38%)	22 (18%)	25 (12%)	96 (1%)	66 (8%)	50 (10%)	7 (29%)	31 (19%)		6 (0%)	1 (0%)	1 (0%)		529 (12%)
Micro Piles											2 (100%)								2 (100%)
Natural Material Poles		1 (0%)		1 (100%)				2 (0%)		1 (0%)									5 (20%)
Non-Specific Anchor	5 (40%)	1 (100%)		3 (0%)	5 (40%)		5 (0%)		3 (33%)	12 (8%)		1 (0%)		1 (0%)	1 (0%)		1 (0%)		38 (18%)
Non-Specific Bored Pile Wall		6 (17%)		1 (0%)	1 (100%)							1 (0%)							9 (22%)
Non-Specific Pile Wall	1 (0%)	4 (0%)	3 (0%)									1 (0%)							9 (0%)
Non-Specific Retaining Wall	12 (17%)	25 (24%)	163 (15%)	39 (8%)	400 (9%)	30 (0%)	195 (17%)	59 (17%)	115 (13%)	446 (8%)	106 (23%)	75 (12%)	22 (5%)	1 (0%)	1 (0%)		2 (0%)		1691 (12%)
PVC Pile Wall								107 (7%)											107 (7%)
Raft (Mining					1 (0%)														1 (0%)
Regrade	3 (0%)	32 (19%)	19 (26%)	5 (40%)	15 (33%)	3 (33%)	3 (33%)	28 (11%)	14 (36%)	3 (33%)	38 (24%)	11 (45%)	4 (0%)				1 (0%)	1 (0%)	180 (24%)
Rock Armour												18 (11%)							18 (11%)
Rock Bolts	8 (50%)	4 (50%)		4 (0%)	6 (0%)		2 (0%)		20 (5%)	6 (17%)	12 (17%)	6 (17%)	5 (0%)		3 (0%)			2 (0%)	78 (14%)
Rock Catch Fence	1 (100%)	5 (80%)	10 (50%)		33 (12%)				2 (0%)	3 (33%)		2 (0%)	1 (100%)					1 (0%)	58 (28%)
Rock Fill	1 (100%)				1 (100%)	8 (38%)	1 (0%)	2 (0%)	2 (0%)	11 (27%)	1 (0%)	5 (0%)	1 (100%)	2 (0%)					35 (26%)
Rock Mattress				1 (0%)							2 (0%)								3 (0%)
Rock Netting / Mesh	9 (44%)	4 (0%)	11 (36%)	15 (13%)	47 (0%)	6 (0%)	2 (0%)		32 (3%)	8 (38%)	11 (0%)	10 (10%)	5 (0%)	1 (0%)	4 (25%)			3 (0%)	168 (10%)
Rock Ribs								1 (0%)											1 (0%)
Rock Trap / Catch Ditch	1 (100%)		2 (0%)		1 (0%)							5 (0%)					1 (0%)		10 (10%)
Scaling	1 (100%)								3 (0%)										4 (25%)
Shear Dowel	4 (25%)																		4 (25%)
Shear Key			1 (0%)		9 (0%)														10 (0%)
Sheet Pile Wall	1 (0%)	8 (38%)	33 (9%)	13 (38%)	137 (9%)	1 (0%)	10 (10%)	47 (9%)	35 (3%)	9 (11%)	10 (40%)	2 (0%)	2 (0%)			1 (0%)	1 (0%)		310 (11%)
Shotcrete	1 (0%)				6 (0%)				7 (14%)			1 (0%)			3 (33%)				18 (11%)
Slope Drain	48 (73%)	10 (10%)	25 (12%)	24 (25%)	22 (18%)	16 (25%)	48 (31%)	46 (26%)	58 (12%)	1 (0%)	1 (100%)	38 (3%)	7 (14%)			9 (0%)	8 (13%)		361 (25%)
Soakaway			7 (0%)		1 (0%)	1 (0%)	6 (0%)	6 (33%)	2 (0%)	1 (100%)							1 (0%)		25 (12%)
Soil Nails	4 (25%)	8 (38%)	30 (20%)	21 (5%)	59 (2%)	11 (18%)	25 (12%)	9 (0%)	37 (8%)	6 (17%)	20 (50%)		7 (29%)			1 (0%)	2 (0%)		240 (14%)

	AREAS / DBFO's																		
SGM Type	1	2	3	4	5	6	7	8	9	10	12	13	14	25	27	28	32	33	Total
Spaced Bored Pile Wall					1 (100%)												1 (0%)		2 (50%)
Stone Columns					1 (0%)														1 (0%)
Stone Pitching											1 (0%)							2 (0%)	3 (0%)
Stone Wall	23 (17%)	15 (60%)		3 (33%)		1 (0%)	1 (0%)		6 (17%)	5 (0%)	21 (24%)	23 (17%)	2 (0%)	1 (0%)			2 (0%)	1 (0%)	104 (23%)
Syphon Well					1 (100%)														1 (100%)
Timber Boards				1 (0%)															1 (0%)
Toe Berm		1 (0%)	11 (36%)	2 (0%)	4 (75%)	1 (100%)	1 (0%)	1 (100%)		1 (100%)		4 (50%)							26 (46%)
Toe Drain	7 (43%)	16 (25%)	27 (48%)	5 (60%)	16 (50%)	13 (8%)	9 (11%)	12 (33%)	353 (16%)	1 (0%)	2 (50%)	58 (10%)			3 (33%)		1 (0%)		523 (20%)
Vertical Drains				10 (10%)	4 (25%)		1 (0%)	1 (0%)	1 (0%)	5 (40%)			2 (100%)						24 (25%)
Metallic Reinforcement		8 (13%)	4 (50%)	2 (50%)	37 (8%)	3 (0%)	14 (7%)	2 (0%)	10 (10%)	5 (0%)	6 (67%)								91 (14%)
Soil Nail Mesh		2 (50%)	4 (25%)	6 (0%)		1 (0%)			3 (0%)	1 (0%)	3 (100%)						1 (0%)		21 (24%)
Grand Total	**491 (37%)**	**536 (24%)**	**885 (19%)**	**519 (16%)**	**1479 (14%)**	**257 (18%)**	**738 (22%)**	**600 (17%)**	**1765 (12%)**	**1018 (12%)**	**604 (29%)**	**478 (14%)**	**280 (24%)**	**25 (4%)**	**40 (25%)**	**39 (0%)**	**57 (9%)**	**19 (0%)**	**9830 (18%)**

Discussion:

As has been highlighted, conclusive interpretation of SGM condition from the association with co-located defect is currently compromised by the asset data hierarchy, which does not allow association of defects with individual elements of an asset. The statistics suggests that 18% of the SGMs identified on the network are coincident with a classified defect observation. Based on the known limitations in directly associating these defects with the SGMs, we believe that this will be an overestimation of potentially defective or ineffective SGMs on the network. A number of general trends can be speculated within this data, however, forming reliable conclusions on SGM performance is not possible due to the structure of the data. Improvements to data collection and structure form an important and significant element of the recommendations to this report. Improving these aspects to allow better monitoring and understanding of the true performance of SGMs from the data will facilitate future improvements in network management. Some of the overall trends identified from the data are summarised as follows:

- Area 1 has the largest percentage of defects coincident with SGMs on the network, at 37%. A large proportion of these comprise drainage SGMs, such as slope drains (73% with coincident defects), and counterfort drains (28% with coincident defects). This could suggest poor performance of the SGMs against their intended purpose and the potential hazard they were intended to mitigate.
- Geogrids and geotextiles stand out as being most significantly present within Area 5, with 20% of the 132 No. geogrid locations being coincident with defects. This is likely to be an over estimation of the proportion that is defective, as in many instances the presence of geogrid may have only been recorded due to exposure at the surface as a result of defects.
- Herringbone drainage is predominately encountered within Area 7, where 53% are coincident with an existing defect. This is likely to significantly over estimate the proportion that are defective due to the drainage being picked up in reference to other defects. However, this may also suggest a higher level of subjectivity in the design and implementation of drainage mitigation measures. Or, perhaps in combination, reinforce the need for drainage maintenance in order to ensure that the intended performance is achieved in the longer term.

8.3.1 Parametric analysis

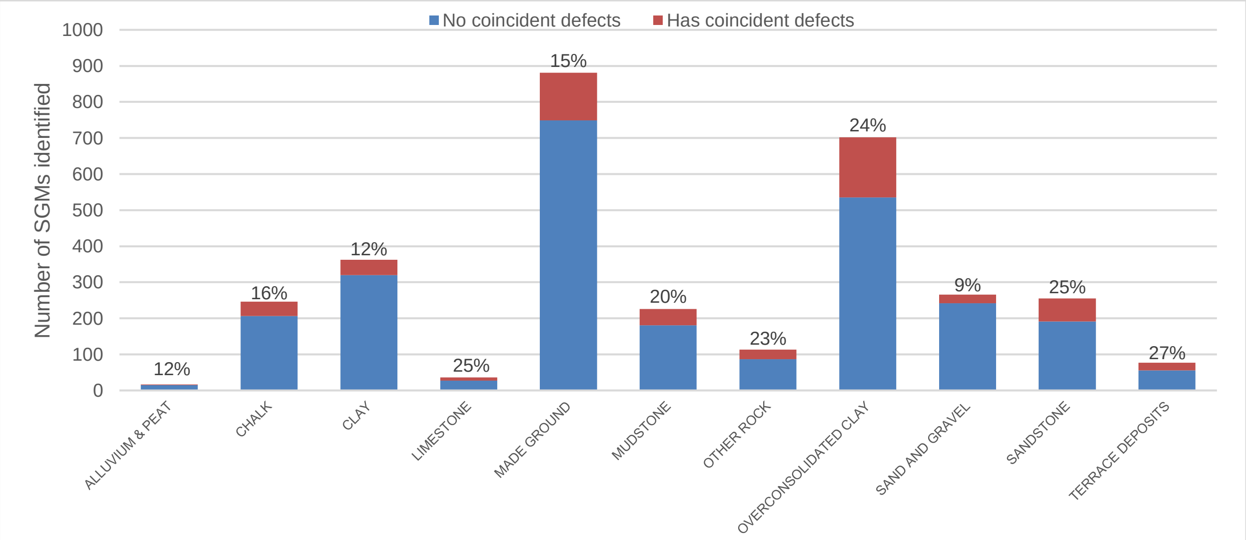
In order to analyse potential performance patterns of SGM types across the network, a series of parametric tests were proposed. However, there are potentially a large number of variables, which obscure trends in potential performance. The data utilised represents the current information that exists on the network and, for a number of the SGM types, there is likely an underestimation in the numbers recorded due to there currently being no requirement to specifically capture this detail. Subsequently the review of performance undertaken in sub-task 2.2, although able to identify a number of trends, was not able to conclude with certainty the reasons for trends given the current data completeness and format. Summaries of high level data comparisons made are presented and briefly discussed below. Full statistics generated as part of sub-task 2.2 are included in Appendix E, F & G of this report.

Test 1 – SGM performance by Geology and earthwork type

Analysing locations by geology is particularly relevant to SGMs as it is the soil interaction and long-term behaviours that are most likely to influence the performance. Understanding how the same SGM performs in different geologies could also support optioneering in future. Performance was further divided by earthwork type due to the differing engineering characteristics of in-situ, and engineering materials.

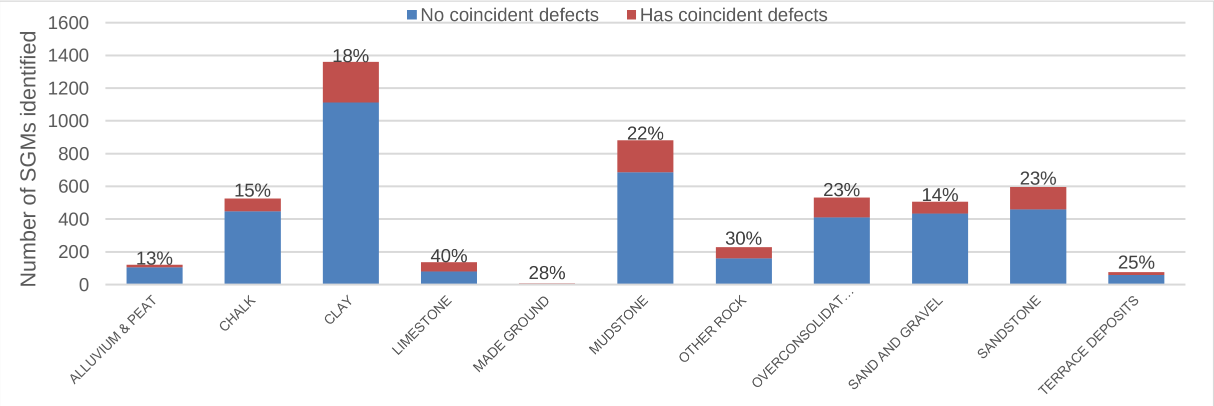
Figure 8-5 below presents a summary of the number and percentage of SGMs and coincident defects based on the embankment geology groupings. This figure indicates that the greatest number of defects that occur within embankments categorised as constructed using over consolidated clays. It also indicates that the greatest percentage of SGMs with defects are location on embankment constructed using sandstone derived fill. It should be noted that Made Ground is in this instance embankments where no specific geology code has been assigned and therefore could comprise any number of different geologies.

Figure 8-5: Coincident defects and embankment geology groups (embankments)



Similarly, Figure 8-6 presents the data for cuttings based on the assigned in-situ geology. Based on this information it is those cuttings formed within clays and mudstone geologies that have the highest number of defects, although more commonly encountered. Interestingly although a much smaller cohort, 40% of SGMs identified in cuttings comprised of limestone are identified to have a coincident defect. A full summary of the percentage of coincident defects based on earthwork type, geology and SGM type is included in Appendix E.

Figure 8-6: Coincident defects and in-situ geology groups (cuttings)

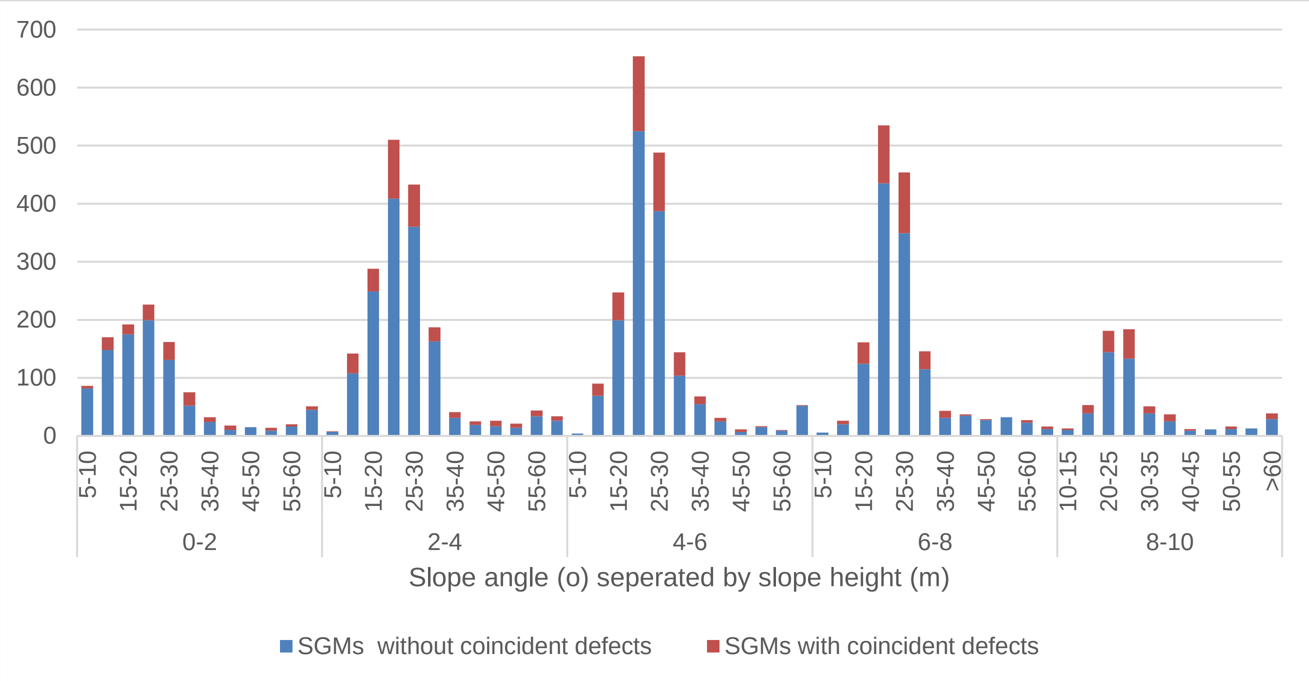


Test 2 - SGM performance by earthwork geometry

A significant factor in the stability and performance of a slope, is the angle to which it has been constructed as well influencing factor from its height. Evaluating potential angle or heights at which SGMs may not be as effective at mitigating hazards would be beneficial for both optioneering and highlighting areas of higher likelihood of performance issues across the network. Supplementing a proactive and risk based approach to network management.

Figure 8-7 below presents a summary of the heights and angles of the slope at the location of SGMs and shows the proportion of which have a coincident defect. A full breakdown of coincident defects by geometry and SGM type can be found in Appendix F & G.

Figure 8-7: SGM performance by slope geometry



The Figure demonstrates that the greatest occurrence of SGMs coincident defects occur on slopes approximately 4-6 metres in height and at a slope angle of between 20 and 25 degrees. This may be influenced by this height and slope angle also being the most common occurring slope dimensions associated with SGMs.

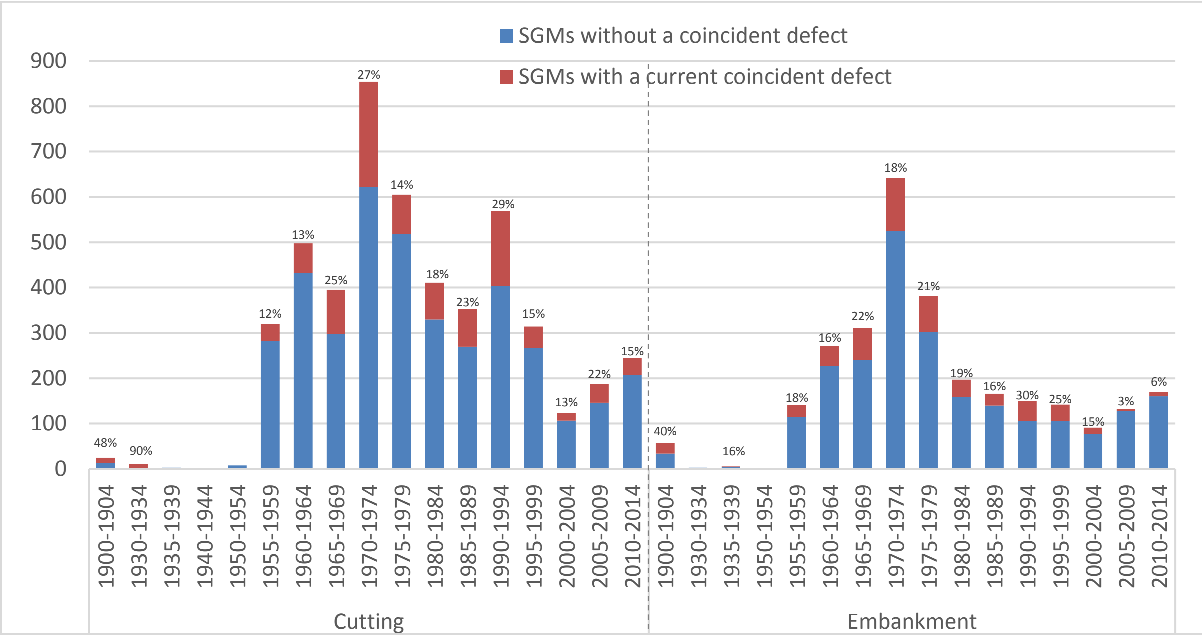
Test 3 - SGM performance by earthwork construction date and type

Earthworks and SGMs would be typically constructed with a design life of 60 years. To understand performance of an SGM through its life cycle and assess its ability to perform as intended, a review of SGM by construction date was completed. This assessment assumes that the majority of SGMs are the same age as the asset record. Performance was further divided by earthwork type due to the differing engineering characteristics of in-situ, and engineering materials.

Figure 8-8 summarises the number of SGMs with coincident defects with respect to earthwork type and construction date. This has identified that the greatest number of SGMs and SGM coincident defects to exist on earthworks built around 1970-1975. It presents a comparison between embankments and cuttings, indicating a noticeably larger number of SGMs within cuttings.

These trends are as would be expected and most likely due to the less controllable nature of cuttings, and a greater requirement to include treatment measures at construction. It is also not surprising that the most frequent age of SGMs with defects is common with the greatest period of motorway construction in the UK. Whilst this information may not be unexpected at the current time, seeing how these results may change over time will be a good indicator of performance of certain SGMs as they progress through their design life.

Figure 8-8: SGM coincident defects by earthwork type and construction date



Test 4 – SGM performance by Road

To inform potential future network management, SGMs with coincident defect by road was analysed. This was anticipated to give a potential indication of particular routes that may have a great number of problems to be considered in network management. Table 8-5 presents the top 10 No. roads with the most SGMs with coincident defects.

Table 8-5: SGM categories – number of SGMs (% with coincident defects) by Road

SGM Category	A14	A30	A38	A628	M1	M25	M4	M5	M6	M62
Drainage	149 (43%)	266 (36%)	121 (50%)	3 (33%)	113 (19%)	163 (30%)	177 (32%)	635 (18%)	272 (10%)	115 (50%)
Ground Improvement			1 (0%)			5 (0%)				3 (0%)
Material Modification (Soil Mixing)	7 (29%)				9 (0%)	41 (10%)	1 (100%)	6 (17%)		
Material Replacement	2 (0%)		1 (100%)		1 (0%)	3 (33%)		2 (50%)	5 (20%)	1 (0%)
Non- Specific Earthworks Intervention		1 (0%)	5 (40%)		5 (0%)	4 (50%)		1 (100%)	1 (0%)	
Piles		1 (0%)	2 (50%)	4 (100%)	156 (7%)	69 (10%)	24 (13%)	5 (60%)	23 (0%)	8 (25%)
Reprofiling	2 (50%)	3 (0%)		1 (0%)	29 (21%)	11 (27%)	35 (26%)	19 (32%)	13 (46%)	31 (23%)
Retaining Walls	48 (6%)	41 (17%)	94 (19%)	77 (36%)	305 (14%)	485 (12%)	156 (15%)	87 (7%)	263 (10%)	219 (10%)
Rock Cut Management	1 (0%)	2 (100%)	27 (37%)	10 (90%)	26 (15%)	128 (4%)	16 (19%)	18 (33%)	35 (11%)	14 (29%)
Slope Facing				3 (33%)	31 (6%)	2 (50%)		1 (100%)	13 (23%)	1 (0%)
Special Foundation Measures		1 (0%)				10 (0%)	3 (0%)			
Strengthened Earthwork	33 (12%)	17 (6%)	16 (25%)	6 (67%)	96 (15%)	201 (14%)	32 (13%)	18 (33%)	42 (14%)	15 (53%)
Total	**242 (31%)**	**332 (32%)**	**267 (36%)**	**104 (45%)**	**771 (13%)**	**1122 (14%)**	**444 (23%)**	**792 (18%)**	**667 (11%)**	**407 (25%)**

The A628 is apparent as having the greatest proportion of SGMs with coincident defects relative to the number of SGMs identified. Most of which are associated to defects coincident with retaining walls and rock cut management SGMs. This is most likely due to the relative age of construction and geotechnical complexities associated with crossing the Pennines, as well as greater exposure to more extreme conditions. The data indicated that the M25 has the largest number of SGMs with coincident defects. However due to the larger total number of SGMs than other roads, as percentage the number is not significant.

9 Recommendations

The following section of this report has been compiled to summarise the recommendations for the use and application of the data set generated as part of the task and to suggest further work to enhance the knowledge and understanding of the outputs. Wider opportunities for the application of the methodologies developed to investigate other areas of interest and value to Highways England are also presented.

A key activity to take place before or accompanying the implementation of any recommendations will be to inform and communicate this task to the end users and suppliers. This is anticipated to be in the form of a technical note and/or webinar, to introduce concepts, provide key definitions and to promote the benefits of user input and continual data improvement. Recommendations which correlate with ongoing parallel Highways England tasks, such as Task 1-105 Handover of Geotechnical Information, will be developed in collaboration with other project teams.

9.1 Application of Task Output

This section recommends the application and utilisation of the geospatially referenced SGM data set and Reports SGM summary, which have been produced as two of the key outputs to this project. Where these would bring significant added value by its utilisation and accessibility to the general user or to another ongoing task with in a specific time frame, this has been highlighted as part of the recommendations. The adoption, incorporation and roll out of information will require appropriate communication to the users. The type and format will be driven by the scope of data incorporation and way in which this data will be accessed and managed by Highways England.

9.1.1 Initial Roll Out

Whilst it is anticipated that full integration of this project output with Highways England's asset management system will require systems development, there are a number of ways in which the findings could be partially incorporated with less development, but with significant benefits to both Highways England and their supply chain. These are summarised as 'initial roll out activities'.

9.1.1.1 Structured Data – Observation Details

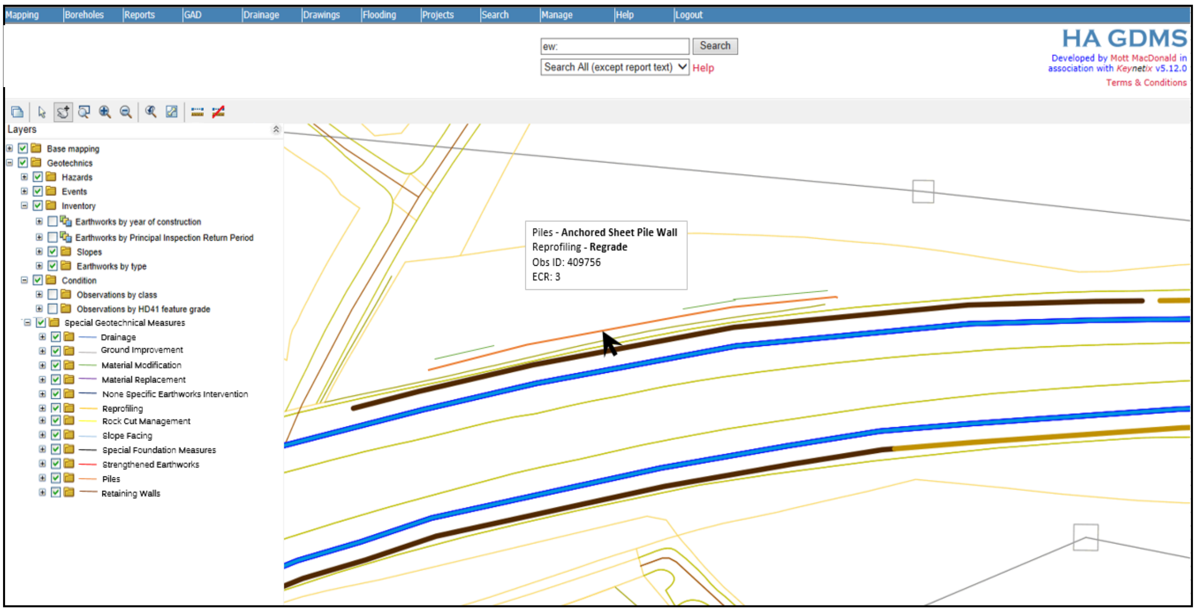
In the short term, it is recommended that a new fixed field is created which will allow the quick identification of an SGM record within the structured observation data. . This project has compiled a list of all SGM source observations that could be used to populate this field. The SGMs that have been identified by the methodology should also be displayed to allow a level of data checking/cleansing/familiarity to commence as soon as possible. By Highways England incorporating recommendations for SGM data collection into an updated version of the Inspection Field Guide, it will improve the source information and data capture going forward, therefore improving the accuracy of future SGM reporting. It should be noted that this information could only be populated where there is an existing observation and will be linked to the associated extents. Where this task has removed overlapping and duplication of SGM records and generated streamlined SGM extents, it is anticipated that incorporating these extents would require associated systems development and is therefore covered in the next section as a later activity.

9.1.1.2 Structured Data – Visualisation in GIS Viewer

Although the derived extents of SGMs are not expected to be initially amalgamated into the structured inspection data, as this information has been geospatially referenced it would be possible to create a static data layer that could be visually presented within a GIS based system. An example of national distribution has been visualised in Figure 9-1. Key attributes associated with the derived extents, including SGM type and source observation ID's could be embedded and displayed at an appropriate scale. This visualisation of SGMs would promote familiarisation of users with the data and could be used to support targeted inspections or incorporated into a risk based approach. Its main benefit would be to alert managing agents to locations of SGMs that are not currently obvious or may not be recorded in the structured GAD information. Due to the anticipated ease of incorporation into existing systems as a layer, it is recommended as a valuable task to be completed in the short term. The SGM attributes to display are flexible and would be agreed based on Highways England's preference. Figure 9-2 visualises the information displayed at SGM category level, where the location of an SGM is identified by an existing observation.

Figure 9-1: Example generated SGM extents plotted at national scale for geospatial overview

Figure 9-2: Generated SGM extents at Earthwork scale



9.1.1.3 Reports Information

Due to the significant manual process required, it was not possible within the task programme constraints to extract the detailed locations of SGMs from within the reports held by Highways England. However, the data interrogation process has produced a compiled list of reports with associated SGM types. It is recommended that in future SGMs would be assigned to a Reports summary, similarly to hazards, either manually or through inclusion within future handover specification. However, the output of this task can be used to pre-populate this information, allowing users to more easily identify SGM content within the Report Details, as visualised in Figure 9-3. It should be encouraged that users report to systems managers if this information requires edits, to allow data validation to commence immediately.

Figure 9-3: Reports summary visualisation

Report Details

HA GDMS report number	26721
Report Category	Geotechnical
Scheme Title	A14 SPCF Regrade - Girton to Fen Ditton
Report Title	A14 SPCF Regrade - Girton to Fen Ditton Geotechnical Report
Publication Date	December 2011
Publication Year	2011
Report Type	Geotechnical Design Report
Document Reference	GYS/RGD/SPI/03992-C0741-C-009
Version	Rev B
Report Author	Ramboll
Issuing Office	Ramboll UK Ltd (Manchester) - M2 7HA
Volume Information	
Project Engineer	
Project Client	
Project Contractor	

Linked Data

Report Available Online	Yes	View
Attached Certificate	No	
AGS Data Available	No	
Report Extents Status	Set	View
Attached Documents	No	
Boreholes	0 boreholes are attached to this report	
This Report Is Linked To Road(s):	A14	
Topics relevant to this Report:	None	
SGMs relevant to this Report:	Lime Stabilisation, Ground Anchor, Geogrid, Toe Drain	

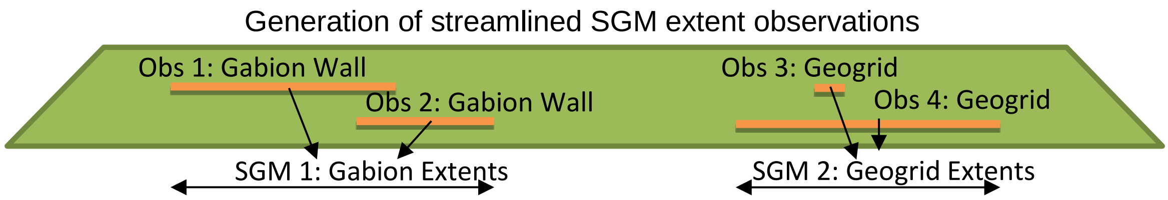
9.1.2 Future Data Implementation

9.1.2.1 Integration of derived SGM extents into GAD / GADGET

A key part of the methodology developed as part of the task was the removal of duplicate and overlapping records of the same SGM along an earthwork asset length. The simplifying of extents is important to enable Highways England to report a more accurate number and length of SGMs on the network. There will still be some exceptions where individual features have been recorded but are performing as wider solution, e.g. counterfort drains. As a result of the methodology developed, extents of each unique SGM have been generated which will often represent and correlate to multiple recorded observations. As the data has been prepared with geospatial referencing as well as by chainage to the relevant earthwork, it is recommended that these extents are used to generate new observations in GAD to represent the more accurate recorded extent of SGMs of the network. It would be these newly created observations that would form the basis of data to be reported and displayed in management systems in future.

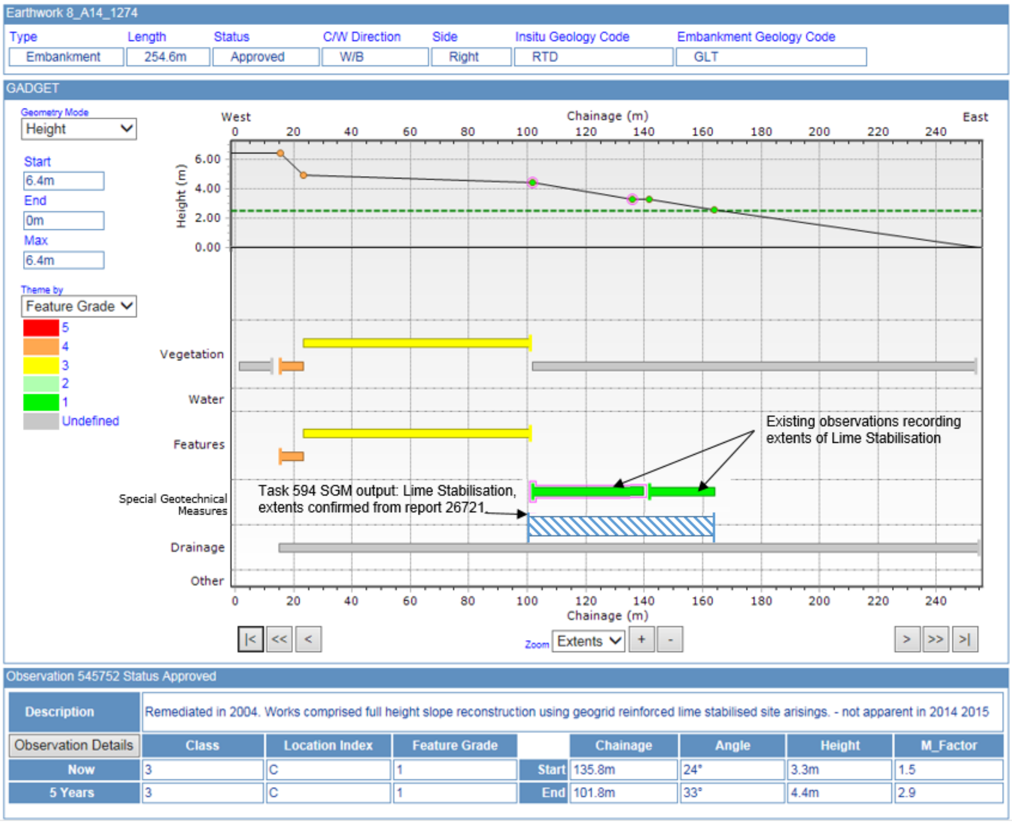
In producing the overarching SGM observation extents it is possible to review the data which these have been generated from (source observations). Going forward recommendations for best practice for the recording of SGM locations would ensure that duplicate records would be limited. Figure 9-4 demonstrates how the extents of SGMs have been generated and grouped as part of the geospatial output. A level of validation by the users during inspections would continually improve the data, but for this to be efficient it would require the streamlined output to be integrated into the structured GAD data as a baseline. Figure 9-5 shows how this might be represented in GADGET, with the overall SGM observation and associated source observations.

Figure 9-4: SGM Observation integration



Integration of extents of multiple common SGMs into SGM 1 and SGM 2 input into GAD data for review and reporting of the unique SGM. Associated observations (1 – 4) would be linked to these new overarching SGM observations.

Figure 9-5: SGM visualisation in GADGET



9.1.2.2 Interrogation and reporting against SGM data

The ability to generate queries for SGMs will be important for system users so that SGMs can be summarised and viewed against user specified attributes. It is recommended that such functionality be incorporated into an observation search function, with SGM type available for selection through the hierarchy, and therefore the ability to report at each level within the SGM hierarchy. Attributes such as coincident defect or ultimately condition would be critical selectable criteria upon which to report SGMs. An output to map function would be invaluable when assessing locations against other datasets such as geo-hazard layers.

9.1.2.3 SGM Topic search

It is envisaged that the SGM information, could be interrogated in future in a manner similar to the Topic Search for Hazards. This would allow reporting and return of observations linked to an SGM within a set offset of a specific co-ordinate. As SGMs have been linked to reports that also have geospatial extents, this too would return a list of reports that mention an SGM within the chosen offset. Due to the significant number of SGM types it would not be practical to build the functionality to search individually for each of these by this method. It is therefore recommended that the higher level SGM Categories are used to define each "SGM topic" of which there are a more manageable 12 categories.

At this stage, it would be envisaged that the topic search would be identifying observations and reports identified in the datasets produced as an output of this project.. It would be envisaged that, once SGM locations and attributes have been fully incorporated into structured data, searches would be undertaken against new fixed fields within the observations and reports dataset.

9.2 Addressing Project Limitations

Throughout the project a number of limitations were recognised which require consideration in the interpretation of final findings and use of the ultimate output of the project. A continual review of these issues, as they arose was carried out with a number of recommendations to overcome and improve the output produced. These recommendations may be related to changes and improvements to existing and future asset management systems and data capture. This section summarises those recommendations that could have significant potential to improve the accuracy and value of the work, and provide future benefit to Highways England. These recommendations aim to address the limitations as they have been summarised in the relevant earlier sections of this report.

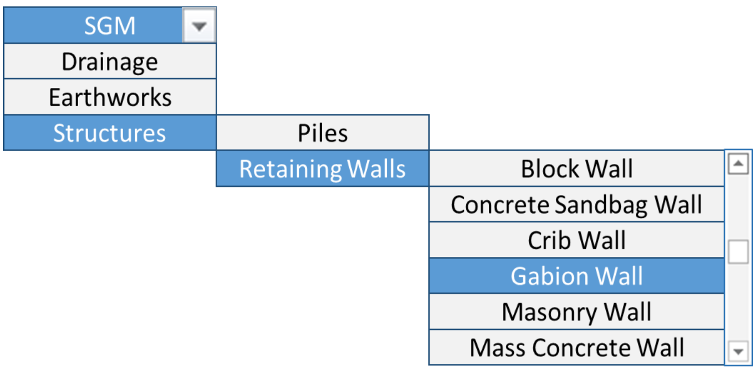
9.2.1 SGM structured data inventory

Consistent capture and completeness of SGM data will be critical to the future use and interpretation of the network wide dataset. A number of recommendations in order to provide a consistent referencing and data capture have been summarised in the following section.

9.2.1.1 SGM hierarchy

In order to gain best value from this project and allow future development and management of SGMs across the network it will be important to establish a defined hierarchy for consistent recording and reference to SGMs. It was evident at the start of the project that synonyms and common mis-referencing was a key but simple problem to overcome. It is recommended to avoid this in future the assignment of an SGM type should be done though drop down selection from a catalogue of SGM types, which will be captured within a specific SGM field in the structured observation data. This would also remove the requirement for the addition of a significant number of tick boxes within the current observation data capture and provide more consistent interpretation of SGMs as they are observed on site. The full hierarchy of SGMs is included in Annex A with a visualisation of the drop downs to data capture included in Figure 9-6 below. It should also be considered as future work to review the definition of an asset and examine the potential for an earthwork which has been characteristically changed from its original construction, to constitute a new asset.

Figure 9-6: SGM selection drop down hierarchy visualisation



9.2.1.2 SGM specific structured data

Initially the SGM observation extents should be generated based on the outputs of this project. These have been produced by the application of the structured data mining methodology deriving the overall streamlined extents of SGMs based on the surrounding observations. It is then anticipated to be the responsibility of those responsible for management of asset needs to: verify these SGM observations, capture additional information on site, and apply best practice for data capture of new SGM records in future. Information gathered through extensive historic network knowledge of Highways England's Geotechnical Advisors is also recommended to be captured in this way.

Key data attributes to support a structured catalogue of SGMs to facilitate improved understanding performance and long term management have been identified though critical review of existing data. Several of these fields should be mandatory for all SGM records where these are observable on site, and have been populated where possible from existing data extraction. Where this information may be known anecdotally, (report review or involvement), these are not mandatory on site but should be populated where possible. These fields are summarised in Table 9-1. Many of these fields do not currently exist in the asset database therefore would need to be added. Where information relevant to these new fields has been available during this project, the fields have been populated and data provided as part of the project output.

Table 9-1: New field for SGM data collection

New fields for future data collection	Mandatory on site	Description
SGM Type	Yes	This would be a hierarchical drop down list (see Figure 9-6.) to promote consistency and keep the data in an easy to manage, structured format. Where genuinely new SGM types are identified, these should be submitted to a system administrator for validation and addition to the hierarchy. This field has been generated by the project based on existing data and would be continually improved through site inspection verification.
SGM Dimensions	Yes	This information should be recorded in the same way that slope dimensions are currently recorded for an observation. This information will be critical to understanding correlations with long term performance.
SGM Geology	No	The geology assigned to the corresponding earthwork may not be reflective of the material used, or geology, which dictates the behavior and performance of the SGM. This information may only be available from reports, but should be collected on site if possible. If this is unknown the geology of the asset should be assumed.
Extents Confidence Rating (ECR)	Yes	This rating system was first developed as part of Task 416 and indicates the level of confidence of the accuracy of the SGM extents. This has been populated as part of the output and would be continually improved as the extents become verified in future inspections. (Defined in Table 7-7, application illustrated in Figures 9-7 & 9-8).
SGM Construction Date	No	This field that may not be known on site but should be populated where the information is known or available. Should be mandatory for any new SGMs constructed and recorded in the future. This will support the analysis of performance patterns going forward.
SGM Design Life	No	This will either be a generic value (i.e. 60/120 years based on typical values) or specific if extracted from a design report. This will aid in the future analysis of performance and risk on the network. A "remaining design life" field and "expiry date" could then be derived to indicate SGMs nearing the end of their design lives on the network.

New fields for future data collection	Mandatory on site	Description
SGM Purpose	No	This would come from future data extraction of the unstructured data set or project knowledge and has been populated where possible though the review of structured data. In the database, this field would be populated via a drop-down menu to promote consistency and reduce ambiguity (e.g. widening, repair, comms etc.). It has been populated in the output of this project where possible.
SGM Condition	Yes	This would be a field generated score based on associated observations influencing the SGM's condition. Criteria would be defined and potentially automated. It would need to be distinguishable as a performance indicator rather than condition due to influence from other factors/assets.
SGM Associated Reports	No	To be populated as the information becomes available. Should be mandatory when new SGMs are added to the network. Hyperlink to relevant Reports summary.
Associated Observations	Yes	This would hyperlink to the observations that have been linked to this SGM observation, including defects and other SGM observations if they are part of a solution.
SGM Specific Detail	No	This would include specific detail regarding the SGM, such as soil nail spacing, retaining wall heights, materials used etc. To be filled in on site or in the office when a new SGM is installed.
SGM Verification status	Yes	This indicates if an SGM observation has been verified by an inspection. This should only need to happen once following the initial data cleansing as part of routine inspections. Extents may be changed following the review of any available supporting reports, and may therefore require additional site conformation if applicable.

It is recommended that all terminology be confirmed through collaboration with Asset Lead Delivery and ongoing development of Uniclass 2015. Further work to define data requirements and validations for each of the proposed fields will be carried out as part of future integration into asset management systems.

9.2.1.3 SGM Standard

In order to improve data consistency, limit inaccuracies and ultimately provide a better quality of SGM record it will be important to ensure that those who are capturing and using the data are adequately informed on the process and desired outcomes. It is known that there are inaccuracies within the information as it has been produced as an output to the project, due to errors within the source data. It is recommended that the data is made available to users with a clear statement that an element of data cleansing will be required, especially in its initial roll out. This is recommended for inclusion within a future edition of the field guide to inspections.

As part of future standardisation of SGM data capture and system population, a process work flow applicable to SGM data capture, verification and continual improvement, has been produced and included below as Figures 9-7 and 9-8. A work flow for onsite or office data entry for SGM observations when visually observed on site, as well as the process to follow when confirmation of installation identified in a report. The process flow also provides guidance to the application of the extents confidence rating.

Figure 9-7: SGM data capture workflow

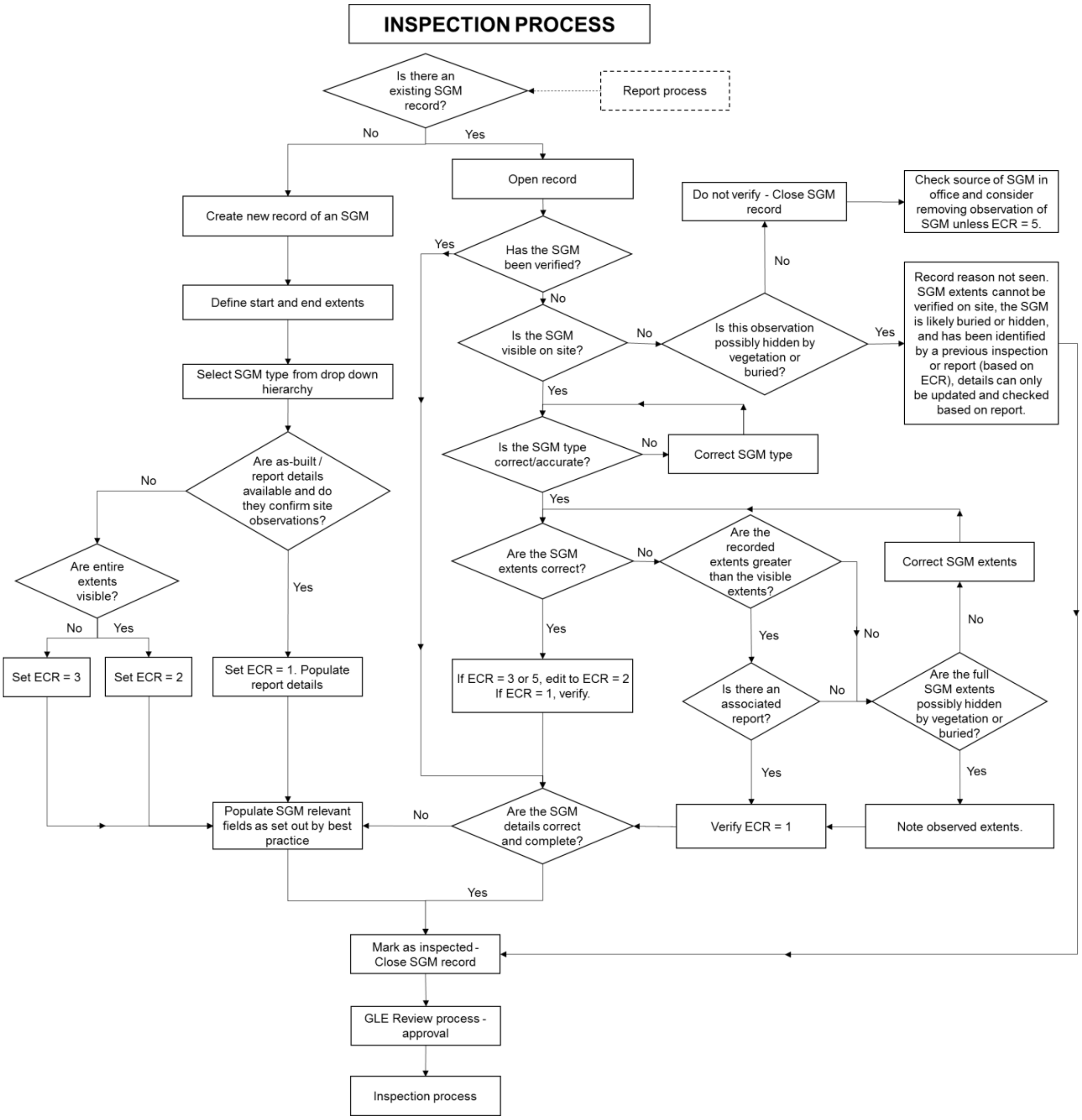
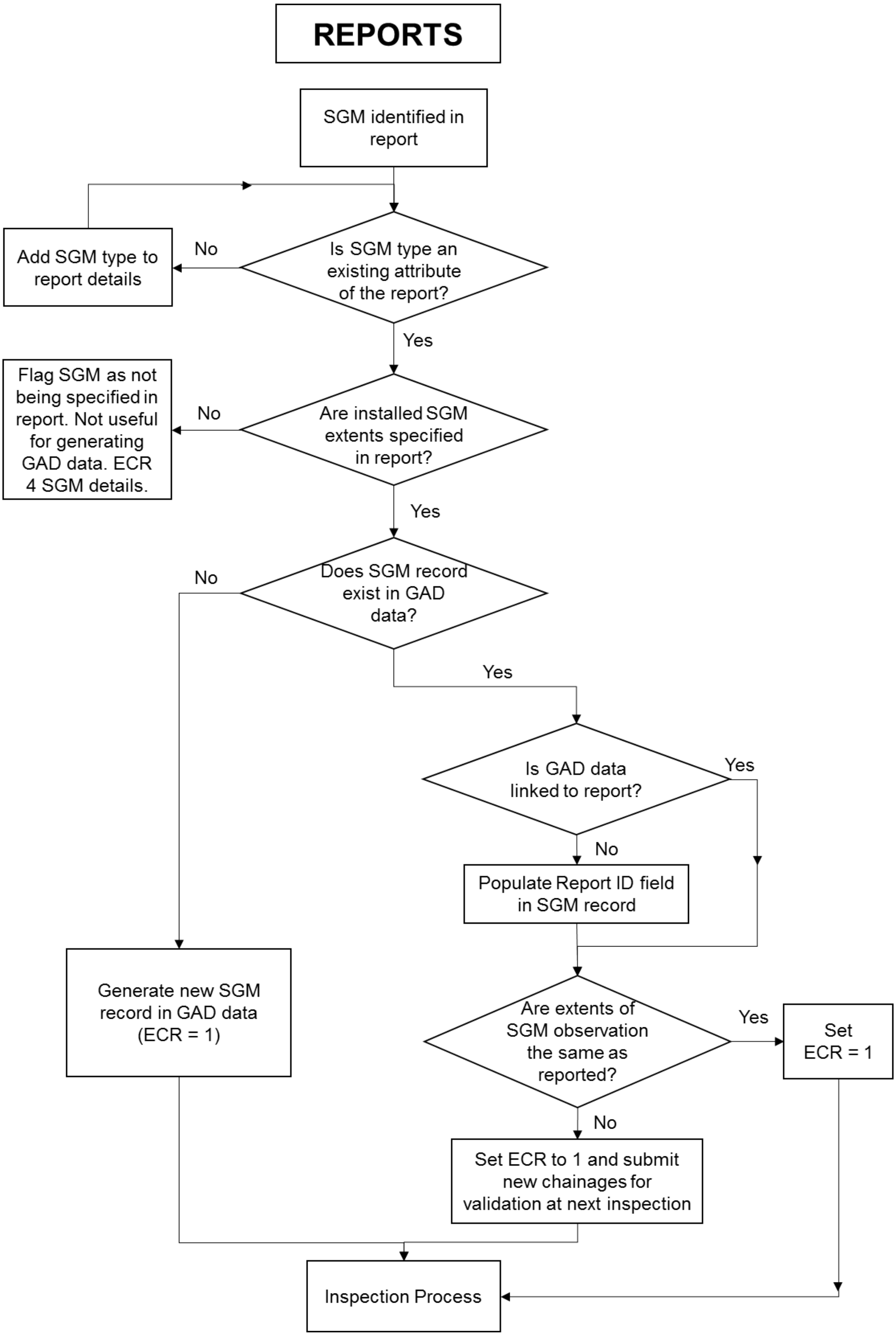


Figure 9-8: SGM report review work flow



9.2.2 Data Linkages

A key recommendation from this project is improved systems functionality to link data records. Recording a conclusive relationship between observations of any type is important to Highways England's data management in future. Such linkages would allow reporting and interpretation of observations which are geospatially coincident and recognising the potential for them to be performance interdependent. Currently the system can link data when it has a common reference number, which maintains the history of a specific feature or location, however it is not possible to associate records of multiple features together.

An important feature of this recommendation, is the ability to link multiple associated observations. To be able to provide the function to be able to understand the interaction between separate elements of an asset it will be critical to be able to link observations together. Whether that be: SGMs of different types designed and constructed together to perform as a solution, or a coincident defect due to the failure of an SGM or a coincident defect that is influencing the performance of the SGM.

9.2.2.1 SGM solutions

For reporting purposes, each SGM should have its own data entry record to ensure that the necessary SGM specific information can be associated with that specific SGM and provide the ability to analyse individually. However, not all SGMs are constructed to behave independently therefore multiple SGMs may have been construction as a composite solution and therefore it will be essential to be able to link these elements to recognise their engineering interdependencies. This linking of observations would significantly improve the understanding of observation and earthwork history moving forward as more observations are created, and in the case of SGMs, this would also potentially aid in identifying purpose.

Figure 9-9, 9-10 and 9-11 demonstrate the importance of understanding the relationship and history of co- located SGMs. The relationships even between the same SGM types, can be complex and would require a level of engineering judgement and knowledge of the history of the location to determine the performance and function of the SGMs. Establishing where SGMs that may have failed since installation and have now been superseded by a different type are one of the most complex but valuable situations to understand. This scenario could be further complicated by a situation where an SGM may have been superseded by a change in requirements rather than due to poor performance or failure.

Figure 9-9: Coincident SGMs installed to perform as a solution

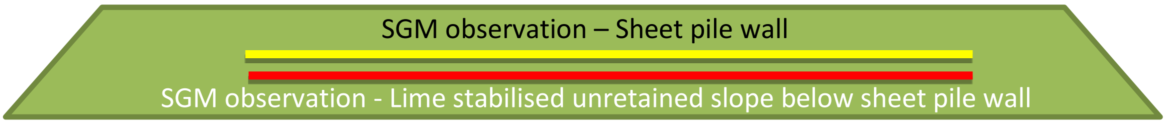


Figure 9-10: Coincident SGMs installed at different times for different unrelated purposes

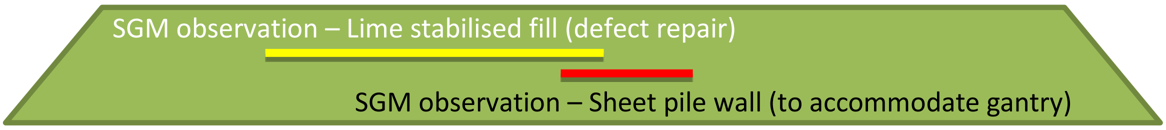
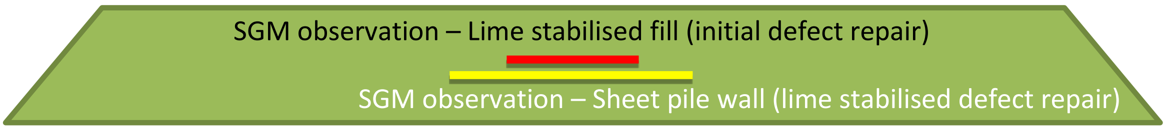


Figure 9-11: Coincident SGMs installed at different times due to poor performance of SGM



9.2.2.2 Recognising SGM and coincident defect relationships

Due to the current method of recording defects observations will be associated with discrete lengths of earthwork. In order to understand and analyse the relationship between such defects and a co-located SGM, modifications to the asset data are required. Some examples of the relationships between observations are summarised in Figures 9-12, 9-13 and 9-14 in order to illustrate potential relationships and value in being able to distinguish between these when analysing the data.

Figure 9-12: Defect is unrelated and not impacting on the performance of the SGM

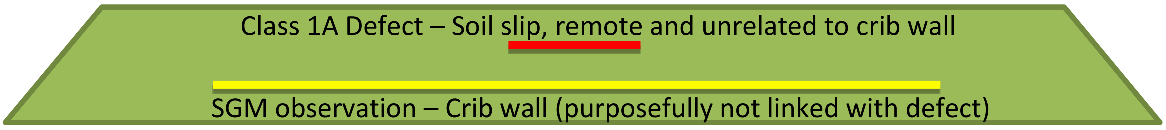


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Figure 9-13: Coincident defect is impacting on the condition of the coincident SGM

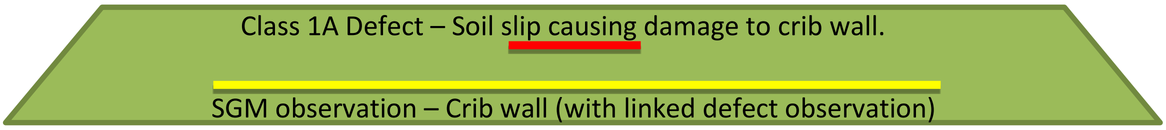
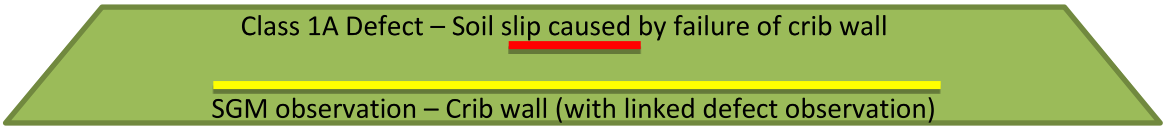


Figure 9-14: Coincident defect caused by the inadequate performance of an SGM



Highways England ultimately want to understand the condition as well as performance of the SGMs, with the above demonstrating the difference between the two. Condition is a reflection of the physical state of an SGM whereas performance relates to the ability of the SGM to fulfil it's function

9.2.3 Unstructured data improvements

One of the significant challenges of this project was to identify which of the approximately 14,000 pdf reports held by Highways England are likely to contain information on the location of constructed SGMs. Whilst each report does have a number of attributes captured as structured data, it is recommended that additional information is captured when new reports are added to the library. This would allow improved data interrogation and provide significant time savings to systems users. As summarised in Table 9-1 there are several recommendations for additional data fields based on the critical review of data and limitations identified as part of this project.

9.2.3.1 SGM Report summary

The output of this task provides a summary of SGMs to be linked to each report reviewed. It is recommended that development of systems to allow linkage of SGM types to reports summary, similarly to hazards can currently be confirmed as contained within a report.

9.2.3.2 Structured to unstructured data linkages

It is recognised that Highways England hosts a significant amount of information which forms a valuable catalogue of the network history. However, due to the format in which this information is held, it can be quite difficult to find the information that would be most helpful to understanding the history of a problem at a specific location. It is therefore recommended to introduce the facility to link observations or earthworks to the relevant Reports summary. The ability to link observations to multiple reports would be required, as multiple reports are typically produced as part of the process of geotechnical certification. It is envisaged that this functionality would be similar to the existing "Projects" functionality but is recommended at Reports summary level and with greater flexibility in creating data relationships. This would allow the reviewer of any report to link directly to inspection information which may be relevant. The reports summary is a valuable location for collating and displaying structured information for unstructured data, as visualised in Figure 9-15.

Figure 9-15: Visualises the improved structured reports summary

Report Details

HA GDMS report number	26721
Report Category	Geotechnical
Scheme Title	A14 SPCF Regrade - Girton to Fen Ditton
Report Title	A14 SPCF Regrade - Girton to Fen Ditton Geotechnical Report
Publication Date	December 2011
Publication Year	2011
Report Type	Geotechnical Design Report
Document Reference	GYS/RGD/SPI/03992-C0741-C-009
Version	Rev B
Report Author	Ramboll
Issuing Office	Ramboll UK Ltd (Manchester) - M2 7HA
Volume Information	
Project Engineer	
Project Client	
Project Contractor	

Linked Data

Report Available Online	Yes	View
Attached Certificate	No	
AGS Data Available	No	
Report Extents Status	Set	View
Attached Documents	No	
Boreholes	0 boreholes are attached to this report	
This Report Is Linked To Road(s):	A14	
Topics relevant to this Report:	None	
SGMs relevant to this Report:	LMST,GANC,GEGD,TODR	
Relevant earthworks:	1274	
Relevant observations:	545752, 230504	

9.2.4 Systems Features

9.2.4.1 GADGET

There is a significant amount of data already collated and managed through the current Highways England systems, and this will increase with continued use. A common difficulty with the current system is being able to understand the history of an earthwork and the relationships and relative timings of inspections. To aid understanding of the relationships between observations and the history/sequence of events and SGM installation, it is recommended to provide the functionality to allow the user to display the approved observation information as it was recorded at the date of each inspection. This would allow a simple review of defect and SGM history to understand potential relationships, by scrolling through the observation records over time.

9.3 Future Work

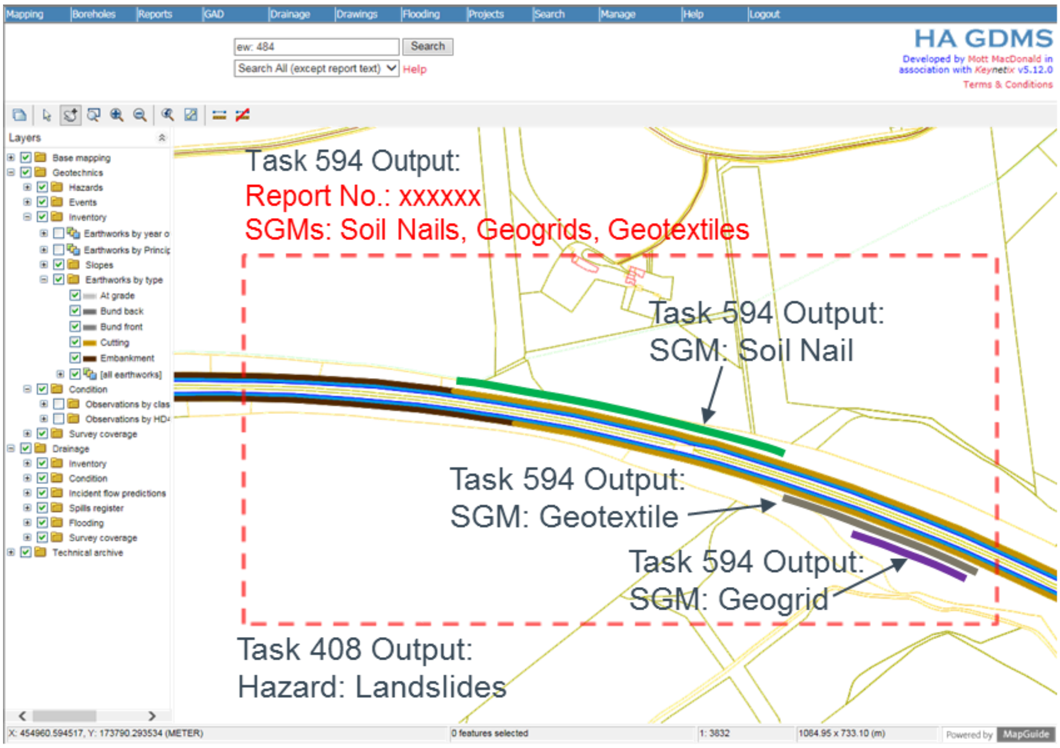
During the project a number of observations have been made in relation to further work or relationships which may be of value to Highways England.

9.3.1 Links with Other Highways England Research Tasks

Highways England has a number of active research tasks as part of their investment programme to improve network knowledge and understanding resilience of geotechnical assets. Collaboration and knowledge sharing with these tasks and their associated outputs will be important to realise best value for Highways England. It is envisaged that the information and data that has been produced to identify locations of geohazards on the network would be complementary to the output of this Task.

Understanding the interaction and relationship between the SGMs and hazards identified by the two tasks, together with confirmation of whether the SGM was installed to mitigate the hazard, would be an essential starting point to refine understanding of residual risk. Ultimately, it may be possible, through a comparison of hazard and SGM knowledge, to identify locations on the network where hazards may not have been mitigated, and therefore highlight a residual risk to the network. Figure 9-16 demonstrates how it is envisaged that the Hazard task and this task could be visually represented in an online viewer to support the evaluation process. This would also support the identification of where hazards without known mitigation may exist on the network or where a hazard has not been mitigated sufficiently by an installed SGM.

Figure 9-16: Visualisation of the output and the ongoing hazard task



The existing slope hazard index rating developed by Highways England currently considers a number of common asset attributes to evaluate the relative potential for geotechnical problems to develop. Such attributes include: slope angle, height and construction materials. Whilst the methodology does consider the presence of classified observations as an indicator of current or previous instability, it does not consider the potential that a steeper slope angle, which will produce a higher morphology factor may have been achieved through the construction of an SGM. The information resulting from this Task has the potential to support a refinement of the information need to produce the hazard rating, in order to increase the accuracy of results at locations where SGMs have been constructed.

9.3.1.1 3rd Parties

As part of this task, a review into potentially useful data sources beyond those within the existing systems and control of Highways England was carried out. It has been established that a number of other organisations may hold information that could supplement the understanding of the long-term performance of some types of SGMs. This includes research that has been undertaken in America.

The data sources identified and reviewed are summarised in Appendix H. This summary also includes key parties, to liaise and potentially collaborate with in future, to gain best value for future research.

9.3.2 Data Extraction

Although it has been identified as a manually intensive exercise, the value in reviewing pdf reports to extract location details could be significant in improving the completeness of the SGM record, especially where these SGMs are types that are not visible post construction but could be key to identifying and managing network risk. For example, reports identified as containing information relating to "mining raft" which includes search terms such as "shaft cap" could be uniquely useful in understanding where shafts were encountered and how they were treated at construction. This can indicate areas of risk in the event of failure of similar treatment methods, or areas where additional unrecorded shafts may be located.

Targeting certain SGM types depending on priority to supplement the record of implementation locations across the network could be a highly beneficial and valuable exercise for Highways England. With the continual improvement and advances in natural language processing there is potential that such records could be located more efficiently within the reports.

9.3.3 Performance Evaluation

In order to improve and support Highways England's knowledge and management of the SGMs on the network further work to understand performance of SGMs is needed. Due to the limitations with data linkages together with the need to establish the relationship between coincident SGMs and defects, this Task has not been able to significantly develop indicators of the performance of the implemented SGMs. Following improved linkages of data, analyses will only be viable for SGMs with a significant cohort size with which to draw meaningful conclusions. The ability to identify patterns is likely to increase as data is fully extracted from the unstructured data, revealing more areas with potentially non-visible SGM types that are of interest. In addition, as future inspections are carried out with a greater emphasis on identifying SGMs accurately the data will become more completed and more practical for assessment. It may be best to rank these results based on the sample size available, and therefore the likely confidence in the statistics.

9.3.4 Updates

It is recognised that the data used as a basis of this project output is based on the data available at a point in time. Additional information continues to be added to the system. Until the point at which the data capture recommendations can be implemented, there will be a period during which reports and inspection data will not be processed or catalogued with regards to SGMs. The methodologies developed during this project have been established so that they can be consistently and repeatedly applied to new information. It would therefore be beneficial for Highways England to periodically extract and provide information until such time as the data capture recommendations are implemented.

9.4 Wider Benefits

9.4.1 Text retrieval

This project has been successful in tailoring searches to identify where information relating to the location of installed SGMs is likely to be contained within reports. The development of context recognition was shown to significantly improve the number of relevant results returned by the searches. It is therefore possible that through development of this technique or similar methods, appropriate searches could be applied to identify information relating to other topics or data within the library of pdf reports. This application could also support the improvement of the structured data associated to each report record, potentially identifying associated content such as drawings or borehole records.

Improving catalogue of network performance

From experience as a maintaining agent, it is known that a limitation of the structured GAD data is that is doesn't commonly include the location of defects which have occurred and been repaired prior to the adoption of HD41/03. This knowledge is unlikely to have been retained due to the regular changes in maintaining agents. Improving the geospatial record of such locations will significantly improve and support the derivation of risk based approaches to inspections and asset management together with the understanding of residual network risk. It is recommended that a trial be carried out to determine the potential value in adapting the text retrieval software to identify reports that contain information relating to any historically repaired defect. This task is likely to have identified a significant proportion of reports which contain this information where such repairs have been carried out using SGMs. However, a number which may have been repaired using more traditional methods may not be included. This approach may also highlight areas that have been previously monitored, again supplementing the knowledge of long-term network performance and risk. A list of reports could then be generated which could be quickly reviewed to identify and digitise the location of historic repairs, linked to the source report. This information would be of significant value to Highways England in understanding and analysing whole network long-term performance.

Supporting ongoing schemes from tacit knowledge

During the period that the task has been underway, the project team has trialled the uses of the data mining and also searches of the structured data generated by this task, to test whether it is of value to other projects that are being undertaken on behalf of Highways England. These exercises have confirmed that, for typical construction projects, the enhanced structured data can allow the presence of SGMs and the historical presence of defects to be identified within a project extents more efficiently, and at an earlier stage. In addition, the output has proved valuable in facilitating investigations with potential areas where projects with no know mitigations may exist.

10 Conclusions

This project has successfully developed and applied data mining methodologies to Highway England's database of geotechnical reports and asset inspection records. The search for the 99 No. different SGM types within the unstructured reports database has identified 3,169 reports that refer to 11,373 instances of 93 No. different types of SGM installed across the network. The structured data methodology has also successfully identified 9,833 No. unique extents of SGMs across the network, covering 1,308km of earthwork. A full extraction of attributes, including location, has been performed for areas treated using lime stabilisation to demonstrate the benefits of enhancing the existing structured database. This process generated approximately 70% of the information now available for lime stabilised locations, and illustrates the value in extracting such information from the unstructured data.

Beyond the application and output of these data mining methodologies, this task has suggested how the existing systems of data management and capture should be improved to enhance Highways England's ability to model and manage its geotechnical assets. Any incorporation of data, and implementation of recommendations will need to be accompanied by additions to published field guidance and feedback routes established.

Future work and research suggestions have been presented to enhance the outputs of this task, and integrate with the research tasks that have been progressed in parallel with this one. It is anticipated that the Task output will contribute towards significantly improving Highways England's appreciation and management of geotechnical risk across the Strategic Road Network. A summary of concluding recommendations is included in Table 10-1. Each of these will provide improvements to Highways England's knowledge and further it's understanding and long-term performance of SGMs. This will be critical to the success of the successful management of the Strategic Road Network.

Table 10-1: Summary of recommendations

Ref	Recommendation	Delivery	Priority
Structured Data (Geotechnical Asset Data)			
1	Production of static SGM data layer	Use of Task output to visualise locations of derived SGM extents.	High – this will allow system users to more readily identify records of SGMs and allow visual comparison of SGMs with other geospatial data sets, such as hazard layers.
2	Adoption of SGM hierarchy	Incorporation of SGM hierarchy into data capture / reporting of SGMs.	High – standardising data structure and definition of SGMs is required before roll out, or any new data is captured, to ensure consistency across users and the whole network.
3	Improved data linkage / relationships	Development of the ability to link multiple observations.	High – additional SGM condition data needed to evaluate performance and management of SGMs in future.
4	Incorporation of identified SGM types into existing observation summary data	Use of Task output to identify existing observations containing record of SGMs.	Medium – this will allow system users to more readily recognise records of SGMs.

Ref	Recommendation	Delivery	Priority
5	Incorporation of derived SGM extents and key attributes into Geotechnical Asset Database	Use of Task output to generate derived extents of SGMs as a unique observation within the asset record. Addition of multiple new SGM specific data fields.	Medium – this will allow system users to more readily capture and update records of SGMs. It will also allow better reporting and analysis of information for Highways England.
6	Update SGM inventory	Application of methodology to observations recorded since date of task data extraction.	Medium – additional data needed to evaluate performance and management of SGMs in future. Data gap is not anticipated to be substantial.
Unstructured Data (Reports)			
7	Update SGM inventory	Further data extraction of SGM locations and key information from reports.	High – To date, only limited locations of SGMs have been extracted from reports. Further extraction for SGMs identified as priority (to be confirmed). Extraction of additional information key to understanding performance to be investigated.
8	Incorporation of verified SGMs into Reports summary	Use of Task output to identify reports likely to contain location/details of SGMs.	Medium - this will allow system users to more readily recognise records of SGMs within a report.
9	Additional structured data capture	Development of functionality to allow capture of additional data fields, including association of SGM type to reports.	Medium – this will allow system users to more readily capture, update and review records of SGMs within a report. It will also allow better reporting and analysis of information for Highways England.
10	Data linkage	Development of systems functionality to allow association of observations to reports summary.	Medium - this will allow system users to more readily review and interpret records of SGMs within a report.
11	Update SGM inventory	Application of methodology to reports produced since date of task data extraction.	Medium – additional data needed to evaluate performance and management of SGMs in future. Data gap is not anticipated to be substantial.
Knowledge			
12	Communication of Task to Geotechnical Asset community	Workshop to be held to communicate application of task findings.	High – It is a priority for those who would benefit most from the information to understand it before roll out and utilisation. This will also improve the quality, consistency and completeness of additional information to be captured.

Ref	Recommendation	Delivery	Priority
13	Communication of Task to Geotechnical Asset community	Addition to field guidance, outlining best practice for collection of SGM specific data (to be confirmed following agreed stages of systems integration). Collaboration and incorporation of appropriate fields into requirements set by Data Handover Task.	High - It is a priority for those who would benefit most from the information to understand it before roll out and utilisation. The production of guidance will also improve the quality, consistency and completeness of additional information to be captured. Current supplementary tasks are ongoing and therefore priority to incorporate key data requirements into corresponding outputs.
14	SGM knowledge sharing through links with others	Continuing liaison and collaboration with ongoing and future Highways England Tasks.	High - Current supplementary tasks are ongoing and therefore priority to incorporate key data requirements into corresponding outputs.
15	Further development of asset performance knowledge relative to deterioration.	Continuing liaison and collaboration with: ongoing Highways England Tasks, other research parties (e.g. Loughborough University, iSmart) and asset owners (e.g. Network Rail). Development of long term predictions of asset performance and deterioration.	High - Current supplementary tasks and complementary research projects are ongoing and therefore priority for liaison. This will ensure best collaborative value for Highways England and other interested parties going forward.
16	Further development of asset performance knowledge relative to existing condition.	Further research into performance patterns of SGMs following improvements in recording of SGM condition and implementation of data linkages.	High – In order for Highways England to achieve the ultimate goal of managing whole life performance, a better understanding of deterioration is required, underpinned by the ability to reliably report condition of SGMs and the wider geotechnical asset.
17	Further development of asset performance knowledge relative to geohazards.	Further research into intended function of SGMs and success of mitigating hazards. Including, linkage of existing SGMs and hazard data sets.	High – In order for Highways England to achieve the ultimate goal of managing whole life performance, a better understanding of the degree to which underlying hazards have been mitigated is key.
System Specific Functionality			
18	User defined SGM reporting/searches	Development of systems functionality to search SGM related data fields and visualise outputs.	Medium – this will allow system users to more readily utilise records of SGMs.
19	User defined SGM reporting/searches	Development of Topic Search tool, relative to SGM observations and SGMs within reports.	Medium – this will allow system users to more readily utilise records of SGMs.

Ref	Recommendation	Delivery	Priority
20	Improved access to inspection history	Development of systems functionality to allow user to review geotechnical asset data in schematic format by inspection date.	Low - this will allow system users to more readily review the history of records of SGMs

Ongoing Collaborations

During the programme, discussions have been held between the project team and multiple parties with relevant and related research interests. This has included establishing links with Loughborough University in relation to further investigation into the long-term performance of geosynthetics used in conjunction with fine grained soils. The results of such investigations will be used to inform SGM performance and assess the value of performing “forensic” investigations into the performance of other SGMs.

Liaison with NBS is also ongoing with respect to consideration of the extensive SGM library and hierarchy into the ongoing development of Uniclass 2015. This Highways England led research will inherently benefit other infrastructure owners in the UK through the development of a common resource.

It will be important for Highways England’s continued development and improvement of data management techniques, to align with the range of ongoing activities in this field and maintain close links with the rapid industry progression in data interrogation methods.

11 References

1. ATKINS Ltd

   Highways Agency Task 416 – Review of Geotechnical Asset Data, Project Initiation Document, 2014.

2. ATKINS Ltd

   Highways Agency Task 416 – Review of Geotechnical Asset Data, Task Findings Report, 2015.

3. ARUP MOTT MACDONALD

   Highways Agency Task 197 - National Geotechnical Hazard Review, 2014.

4. MOTT MACDONALD

   Highways England Task 408 – As-built geotechnical asset data, 2015.

5. HIGHWAYS AGENCY

   HD22/08 Managing Geotechnical Risk. Design Manual for Roads and Bridges, Volume 4, Section 1 Part 2, 2008.

6. HIGHWAYS ENGLAND

   HD41/15 Maintenance of Highway Geotechnical Assets. Design Manual for Roads and Bridges, Volume 4, Section 1 Part 3, 2015.

Appendix A - SGM hierarchy, types and search terms

SGM CAT	SGM Sub-Category	SGM Type & Quad Code	SGM Search Term (Accounting for common spelling errors)
Drainage	Drainage	Basal Drainage (BSDR)	Basal Drainage
			Drainage Blanket
			Granular Basal Blanket
		Counterfort Drain (CFDR)	Counterfort Drain
			Counterfort Drainage
			Counterforts
		Crest Drain (CSDR)	Crest Drain
			Crest Filter
			Crest Filter Drain
			Crest Filter Media
			Crest Filter Stone
			Crest Surface Water Drainage
		Cut off Drain (CODR)	Cut Off Drain
			Cut-Off Drain
		Filter Drain (FILT)	Filter Drain
			Filter Media
			Filter Stone
			French Drain
		Fin Drain (FIND)	Fin Drain
		Frost Blanket (FRBL)	Capillary Break
			Frost Blanket
		Herringbone Drainage (HBDR)	Herringbone
			Herring-bone
			Herringbone Drain
		Horizontal Drains (HRZD)	Fan Drain
			Horizontal Drain
		Internal Drainage (INTD)	Internal Drainage
			Raked Drain
			Raking Drain
			Sub-Surface Drainage
		Rock Ribs (RIBS)	Rock Ribs
		Sealed Drainage (SEAL)	Sealed Drainage
		Slope Drain (SLDR)	Slope Drain
			Slope Drainage
		Soakaway (SOAK)	Soakaway
		Syphon Well (SYWL)	Siphon Drain
			Siphon Well
			Syphon Drain
			Syphon Well
		Toe Drain (TODR)	Toe Drain
			Toe Filter
			Toe Filter Media
Earthworks	Ground Improvement	Band Drains (BNDR)	Band Drain
		Concrete Columns (CONL)	Concrete Columns
			Vibro Concrete Columns
		Dynamic Compaction (DYMC)	Dynamic Compaction
		Grout Injection (GROT)	Compaction Grouting
			Consolidation Grouting

SGM CAT	SGM Sub-Category	SGM Type & Quad Code	SGM Search Term (Accounting for common spelling errors)
			Fracture Grouting
			Jet Grouting
			Pressure Grouting
			Void Grouting
		Lime Slurry Injection (LMSL)	Lime Slurry Injection
		Sand Wicks / Drains (SDWK)	Sand Drain
			Sand Wick
		Stone Columns (STCL)	Stone Columns
			Vibro Stone Columns
		Surcharging / Pre-loading (SRCH)	Preconsolidated
			Preconsolidation
			Pre-Consolidated
			Pre-Consolidation
			Preloading
Earthworks	Ground Improvement	Surcharging / Pre-loading (SRCH)	Pre-Loading
			Surcharging
		Vertical Drains (VERT)	Vertical Drain
			Vertical Drainage
	Material Modification (Soil Mixing)	Cement Stabilisation (CEMM)	Cement Modification
			Cement Modified
			Cement Stabilisation
			Cement Stabilised
		Fibre Reinforcement (FBRN)	Fibre Reinforced
			Fibre Reinforcement
			Random Fibre Reinforcement
			Randomly Oriented Fibres
		Lime Piles (LMPL)	Lime Piles
			Lime Columns
		Lime Stabilisation (LMST)	Lime Improvement
			Lime Modification
			Lime Capping
			Lime Modified
			Lime Stabilisation
			Lime Stabilised
			Lime Conditioning
			Lime Treated
	Material Replacement	Lightweight Fill (LGHT)	Expanded Clay Aggregate
			Furnace Slag
			GBFS
			Light Aggregate
			Lightweight Aggregate
			Lightweight Fill
			PFA
			Polystyrene
		Rock Fill (ROCF)	Rock Fill
			Rock Infill
			Rock Replaced
			Rock Replacement
		Tyre Bales (TYRB)	Tire Bails
			Tire Bales

SGM CAT	SGM Sub-Category	SGM Type & Quad Code	SGM Search Term (Accounting for common spelling errors)
			Tyre Bails
			Tyre Bales
	Non- Specific Earthworks Intervention	Non-Specific Anchor (NANC)	Anchor
	Reprofiling	Regrade (REGD)	New Batter
			Regrade
			Regrading
			Regrde
			Reprofiled
			Re-Profiled
			Reprofiling
			Re-Profiling
		Toe Berm (TOBR)	Granular Toe Wedge
			Toe Berm
			Toe Bund
			Toe Weight
	Rock Cut Management	Buttress (BTTR)	Buttress
			Buttressing
			Rock Support Buttress
			Rock Support Buttressing
		Concrete Facing (CONF)	Concrete Facing
			Concrete Protection
		Dentition (DNTT)	Dentition
			Rock Face Pointing
Earthworks	Rock Cut Management	Rock Bolts (ROCB)	Rock Anchors
			Rock Bolts
			Rock Cables
			Rock Dowells
			Rock Dowels
			Rock Nails
			Rock Ties
		Rock Catch Fence (DBFN)	Catch Fence
			Catchment Fence
			Debris Catch Fence
			Debris Fence
			Rock Catch Fence
			Rock Fall Fence
			Rockfall Fence
		Rock Netting / Mesh (SMEH)	Galvanised Mesh
			Maccaferri Mesh
			Drapery
			Rock Catch Net
			Rock Catchment Netting
			Rock Containment Netting
			Rockfall Net
			Rock Fall Net
			Rock Net
			Surface Containment Netting
			Rock Face Netting
			Tecco netting

SGM CAT	SGM Sub-Category	SGM Type & Quad Code	SGM Search Term (Accounting for common spelling errors)
			Drape netting
			Rock-Fall netting
			Rock Netting
			Steel Mesh
			Tecco Mesh
			Wire Mesh
		Rock Trap / Catch Ditch (DITC)	Intercept Ditch
			Rock Catch Ditch
			Rock Trap
		Rockfall Shelter (ROCS)	Rock Fall Shelter
			Rockfall Shelter
		Scaling (SCAL)	Scaling
		Shotcrete (SHOT)	Shocrete
			Shortcrete
			Shotcrete
			Shotcreting
			Sprayed Concrete
	Slope Facing	Cobbled Facing (COBB)	Cobbled Facing
			Cobbled Slope
		Concrete Cladding (CLAD)	Concrete Cladding
			Dytap
			Fabriform Mattress
		Concrete Rubble Facing (CNRF)	Concrete Rubble Facing
		Erosion Mat (ERSN)	Burrow Protection
			Coir Matting
			Erosion Board
			Erosion Mat
			Erosion Net
			Erosion Protection
			Erosion Protection Mat
			Geocoir
			Erosion Control Netting
			Geoweb Facing
			Erosion Control
			Erosional Board
Earthworks	Slope Facing	Gabion Facing (GABF)	Gabion Faced
			Gabion Facing
		Masonry Facing (MSNF)	Masonry Faced
			Masonry Facing
		Rock Armour (ROCA)	Armor Stone
			Armour Stone
			Rip Rap
			Rock Armor
			Rock Armour
		Rock Mattress (ROCM)	Reno Mattress
			Rock Mattress
		Stone Pitching (PITC)	Stone Pitching
	Special Foundation Measures	Basal Layer (BASE)	Basal Layer
			Rock Blanket
			Concrete Slab Foundation

SGM CAT	SGM Sub-Category	SGM Type & Quad Code	SGM Search Term (Accounting for common spelling errors)
		Concrete Slab (Non-mining) (RAFT)	Raft Foundation
			Slab Foundation
		Geomembrane (GMEM)	Geomembrane
			Geo-Membrane
		Ground Beam (GBEM)	Ground Beam
		Raft (Mining) (MRAF)	Mine Raft
			Mine Shaft Raft
			Mineraft
			Shaft Cap
		Shear Key (SRKY)	Shear Key
		Shear Trench (SRTR)	Shear Trench
		Starter Layer (STLR)	Starter Layer
	Strengthened Earthwork	Electrokinetic (ELEC)	Electrokinetic
		Ground Anchor (GANC)	Ground Anchor
		Lime Nails (LMNL)	Lime Nails
		Metallic Reinforcement (MTLK)	Metallic Reinforced
			Metallic Reinforcement
		Natural Material Poles (POLE)	Chestnut Poles
			Willow Poles
		Geotextile (GETX)	Geo Textile
			Geotextile
			Geo-Textile
			Terram Geotextile
		Geogrid (GEGD)	Tensar Grid
			Geogrid
			Geo-Grid
			Geo Grid
			Plastic Latrice
			Plastic Lattice
			Plastic Lattrice
		Shear Dowel (SRDW)	Ground Nail
			Shear Dowel
		Soil Nail Mesh (SNMS)	Soil Nail Mesh
		Soil Nails (SNAL)	GRP Soil Nail
			Driven Nails
			Soil Nail
			Soil Nailed
			Soil Nailing
			Steel Nail
			Grouted Steel Nail
			Grouted Soil Nail
			Polymeric Nail
			Self Drilling Nail
			Grout Nail
			Dywidag
			Steel Soil Nail
Structures	Piles	Anchored Sheet Pile Wall (ASHP)	Anchored Sheet Pile Wall
		Anchored Bored Pile Wall (ABPW)	Anchored Bored Pile Wall
		Anchor Pile (ANPL)	Anchor Pile
		Concrete Driven Piles (CNPL)	Concrete Driven Piles

SGM CAT	SGM Sub-Category	SGM Type & Quad Code	SGM Search Term (Accounting for common spelling errors)
			Concrete Piles
		Contiguous Bored Pile Wall (CBPW)	Contiguous Bored Pile Wall
			Contiguous Pile Wall
		Dowel Piles (DOWP)	Dowel Piles
			Dowell Piles
		Inclined Piles (INCP)	Pile Radice
			Raked Piles
			Raking Piles
			Reticulated Piles
		King Post Wall (KPWL)	King Post Retaining Wall
			King Post Wall
		King Sheet Pile Wall (KSPW)	KSP
			King Pile Wall
			King Sheet Pile Wall
		Non-Specific Bored Pile Wall (NSBP)	Bored Pile Wall
		Non-Specific Pile Wall (NSPW)	Pile Wall
			Piled Wall
		Micro Piles (MCRP)	Micro Pile Wall
			Micro Piles
			Mini Pile Wall
			Mini Piles
			Reticulated Micro Piles
		PVC Pile Wall (PVCS)	Plastic Sheet Pile
			Plastic Sheetpile
			PVC Sheet Pile Wall
			PVC Sheetpile Wall
		Secant Bored Pile Wall (SCPW)	Secant Bored Pile Wall
			Secant Pile Wall
		Sheet Pile Wall (SHPL)	Sheet Pile Retaining Wall
			Sheet Pile Wall
			Sheet Piling
			Sheetpile
			Sheetpile Retaining Wall
			Sheetpile Wall
		Spaced Bored Pile Wall (SBPW)	Spaced Bored Pile Wall
			Spaced Pile Wall
		Helical Pile (HELI)	Helical Pile
			Screwfast
			Screw Pile
	Retaining Walls	Block Wall (BLCW)	Block Retaining Wall
			Block Wall
			Block Work
			Blockwork
			Interlocking Block
			Retaining Blocks
			Retaining Blockwork Wall
			Slab Wall
		Concrete Sandbag Wall (CNSB)	Concrete Bags
			Concrete Sack
			Concrete Sack Reinforced

SGM CAT	SGM Sub-Category	SGM Type & Quad Code	SGM Search Term (Accounting for common spelling errors)
			Concrete Sack Reinforcement
			Concrete Sandbag
			Concrete Sandbag Wall
		Crib Wall (CRIB)	Crib Retaining Wall
			Crib Wall
Structures	Retaining Walls	Gabion Wall (GABN)	Anchored Gabion Wall
			Gabion
			Gabion Basket Reinforced
			Gabion Basket Reinforcement
			Gabion Bund
			Gabion Bund Retaining Wall
			Gabion Reinforced
			Gabion Reinforcement
			Gabion Retaining Structure
			Gabion Retaining Wall
			Gabion Wall
			Gabion Wall Bund
		Masonry Wall (BKRW)	Brick R/W
			Brick Retaining Wall
			Masonry Retaining Structure
			Masonry Retaining Wall
			Masonry Wall
		Non-Specific Retaining Wall (NSRW)	Earth Retaining Structure
			Gravity Wall
			Reforcing Wall
			Reinforcing Wall
			Retaianing Wall
			Retaing Wall
			Retainging Wall
			Retaining Structure
			Retaining Wall
			Retaning Structure
			Retaning Wall
			Wall Retaining
			Wall Retaning
		Mass Concrete Wall (CNCW)	Concrete Reinforcement
			Concrete Reinforced
			Concrete Retaining Structure
			Concrete Retaining Wall
			Mass Concrete Wall
		Stone Wall (STNW)	Dry Stone Wall
			Stone Wall
		Tied Wall (TDWL)	Tied Wall
		Timber Boards (TIMB)	Timber Boarding
			Timber Boards
			Timber Reinforced
			Timber Reinforcement

Appendix B – Relevant report types

KEY: Green – Report types considered likely to hold useful SGM information.
Red – Reports not considered likely to hold useful SGM attributes.

HAGDMS Report Types	Reasoning	No. reports	%
Annex A	Preliminary certification, prior to GI.	112	0.8%
Contract Documents	Irrelevant	335	2.4%
Drainage Inspection Report	Irrelevant	2	0.0%
Drainage Schedule	Irrelevant	1	0.0%
Drainage Scheme Assessment Report	Irrelevant/none available	0	0.0%
Drawings	**Likely to contain useful locational data (as-built drawings)**	142	**1.0%**
Environmental Report	Irrelevant	1	0.0%
Evaluation Studies	Irrelevant	24	0.2%
Factual Report	Contains ground investigation (GI) data.	3063	22.2%
Feedback Report	**Reporting on works carried out so likely to contain useful information**	684	**4.9%**
Final Reports (including ES and EIA)	**Likely to contain useful factual information on SGM locations**	53	**0.4%**
Flooding report	Irrelevant	3	0.0%
Geo-Environmental Report	Irrelevant	49	0.4%
Geotechnical Asset Management Plan	**Will contain information on existing SGMs on the network**	8	**0.1%**
Geotechnical Design Report	**Contains proposed designs and likely useful information on the planned construction of SGMs (HD22/08)**	456	**3.3%**
Geotechnical Report (Factual Report included)	**Contains proposed designs and likely useful information on the planned construction of SGMs (HD22/02)**	496	**3.6%**
Geotechnical Report (Factual Report not included)	**Contains proposed designs and likely useful information on the planned construction of SGMs (HD22/02)**	3561	**25.8%**
Ground Investigation Report	Contains ground investigation (GI) data.	465	3.4%
Health & Safety Plan	Irrelevant	11	0.1%
Hydrological Report	Irrelevant	1	0.0%
Miscellaneous	**Could not be justifiably ruled out as could potentially contain useful SGM information**	571	**4.1%**
Monitoring Report	**Likely monitoring of existing SGMs**	68	**0.5%**
POPE (post-opening evaluation)	Irrelevant	3	0.0%
Preliminary Sources Study	Preliminary Certification, prior to GI.	1365	9.9%
Preliminary Studies (Scoping/Options)	Preliminary Certification, prior to GI.	15	0.1%
Principal Inspection Report	Irrelevant, already covered by structured data	122	0.9%
Priority Asset Report	Irrelevant/none available	0	0.0%
Record of Determination	Irrelevant	1	0.0%
Research Report	Irrelevant	8	0.1%
SEAF/AIP	**Strengthened Earthwork Appraisal form, likely to identify SGM information**	108	**0.8%**
Specialist Report	**May contain specific SGM details, found to contain as built information**	62	**0.4%**
Stage 1 Assessment Report	Feasibility Studies/Desk Studies	77	0.6%
Stage 2 Assessment Report	**Have been found to contain useful information on the location and construction of SGMs (appraisal forms)**	187	**1.4%**
Stage 3 Assessment Report	Geotechnical Risk Assessments	37	0.3%
Statement of Intent	Irrelevant	961	7.0%
Temporary	Irrelevant	767	5.6%
	TOTAL:	**13819**	**100%**
	TOTAL “relevant” reports:	**6396**	**46%**

Appendix C – Length of SGMs identified in structured data by area (Km)

	AREA																		
SGM Type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**12**	**13**	**14**	**25**	**27**	**28**	**32**	**33**	**Total**
Anchored Sheet Pile Wall					0.537														0.537
Basal Drainage			0.347		0.109	0.353		0.022	0.294										1.125
Block Wall	0.218	5.215	2.714	1.626	0.423	0.175	3.132	0.490	7.046	3.222	3.374	0.920	1.596			0.060	0.386		30.597
Buttress	0.183						0.014	0.000	0.011		0.122								0.330
Cobbled Facing									0.151										0.151
Concrete Cladding		0.259																	0.259
Concrete Driven Piles		0.079			0.115														0.194
Concrete Facing				0.010	0.143														0.153
Concrete Rubble Facing												0.008							0.008
Concrete Sandbag Wall		0.115		0.010			0.033	0.005	0.034		0.003								0.200
Contiguous Bored Pile Wall			0.082	0.150					0.200			0.152							0.584
Counterfort Drain	5.627	9.154	1.477	1.060	2.193	0.031		0.493	2.102		0.003	0.426	0.130	0.681					23.377
Crest Drain		0.150	1.020	1.039		0.075		0.040	14.000		0.671	1.146	0.668		1.148				19.957
Crib Wall	0.746	1.149	0.550	0.100	0.058	0.544		0.258		0.168	0.315	0.135							4.023
Cut off Drain		1.350			0.275				1.431										3.056
Dentition	0.056	1.218							0.392									0.046	1.712
Electrokinetic				0.150					0.018										0.168
Erosion Mat			0.418	0.007	0.782	0.448	3.025	0.677	0.306		0.049	0.181	0.042				0.790		6.725
Fibre Reinforcement				0.213	0.081														0.294
Filter Drain	39.083	36.231	74.332	27.299	61.899	19.750	49.746	20.237	118.693	50.122	39.308	34.067	19.356	1.012	0.696	5.755	3.660	0.970	602.216
Frost Blanket			0.460	2.301															2.761
Gabion Wall	1.658	3.318	6.676	3.292	1.800	0.026	5.767	1.676	4.274	5.475	4.586	2.227	1.944	0.231	0.033	0.029	0.521	0.003	43.536
Geogrid	2.193	1.867	1.498	7.138	30.186	1.935	5.222	1.989	1.161	3.348	2.187	1.062	0.045	0.140			0.040		60.011
Geomembrane			0.021					0.210											0.231
Geotextile	0.005	0.673	5.448	0.223	4.859	1.568	0.596	1.407	1.008	0.818	2.547	0.286	0.155		0.026		0.790		20.409
Ground Anchor	0.890							0.022	0.029	0.066									1.007
Ground Beam		0.096	0.023	0.150															0.269
Grout Injection		0.142	0.001	0.002	0.027	0.090			3.119										3.381
Herringbone Drainage		0.630	1.407	0.142	2.463	0.023	12.404	1.545	2.732	0.110	0.380	1.342	1.668	0.135		3.508	0.197		28.686
Inclined Piles				0.101															0.101
Internal Drainage									0.300										0.300
King Post Wall						0.407													0.407
King Sheet Pile Wall	0.450																		0.450
Lightweight Fill		0.078		0.020	0.087	0.001													0.186
Lime Stabilisation		0.405	0.000	3.087	2.525	0.164	1.505	0.300					3.509						11.495
Masonry Facing						0.000						0.458							0.458
Masonry Wall		1.061	0.045	0.556	0.310	0.046	1.549	0.476	4.992	0.312	0.260	0.005	0.128		0.028		0.721		10.489
Mass Concrete Wall	0.173	1.179	3.890	0.874	22.847	0.610	0.730	0.835	11.966	4.062	1.648	0.356	1.401		0.070	0.023	0.064		50.728
Metallic Reinforcement		0.852	0.166	0.077	8.475	0.611	1.296	0.062	0.586	0.555	0.843								13.523
Micro Piles											0.060								0.060
Natural Material Poles		0.025		0.104				0.035		0.018									0.182
Non-Specific Anchor	1.962	1.218		0.472	0.886		0.644		0.148	2.656		0.069		0.014	0.838		0.063		8.970

	AREA																		
SGM Type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**12**	**13**	**14**	**25**	**27**	**28**	**32**	**33**	**Total**
Non-Specific Bored Pile Wall		0.845		0.081	0.188							0.152							1.266
Non-Specific Pile Wall	0.091	0.814	0.051									0.152							1.108
Non-Specific Retaining Wall	1.327	1.545	5.018	3.048	39.742	1.538	7.621	1.912	6.036	20.243	9.484	7.196	1.028	0.057	0.178		0.135		106.108
PVC Pile Wall								5.030											5.030
Raft (Mining					0.023														0.023
Regrade	0.188	2.296	3.552	0.581	1.152	0.122	0.636	2.195	1.224	0.169	3.120	0.545	0.063				0.000	0.003	15.846
Rock Armour												1.054							1.054
Rock Bolts	1.583	2.099		0.289	0.244		0.022		1.463	0.662	2.267	2.158	0.772		0.230			0.004	11.793
Rock Catch Fence	0.193	0.563	3.007		3.301				0.238	0.473		0.076	0.015					0.008	7.874
Rock Fill	0.002				0.026	0.245	0.071	0.222	0.013	0.419	0.016	0.466	0.008	0.133					1.621
Rock Mattress				0.059							0.026								0.085
Rock Netting / Mesh	1.058	0.865	0.937	2.891	3.341	1.178	0.041		2.439	0.722	1.568	1.444	0.772	0.085	0.155			0.210	17.706
Rock Ribs								0.200											0.200
Rock Trap / Catch Ditch	0.141		0.027		0.009							0.885					0.412		1.474
Scaling	0.180								0.481										0.661
Shear Dowel	0.379																		0.379
Shear Key			0.049		0.338														0.387
Sheet Pile Wall	0.158	0.504	5.267	0.903	21.117	0.220	1.285	3.102	1.851	0.732	0.767	0.214	0.428			0.018	0.043		36.609
Shotcrete	0.015				0.036				0.968			0.006			0.216				1.241
Slope Drain	3.428	1.472	2.215	4.090	0.348	1.501	4.991	4.174	3.398	0.000	0.000	1.027	0.335			3.122	0.543		30.644
Soakaway			0.303		0.030	0.025	0.152	0.199	0.304	0.003							0.000		1.016
Soil Nail Mesh		0.125	0.651	0.764		0.022			0.048	0.044	0.306						0.015		1.975
Soil Nails	0.202	0.445	2.038	1.844	4.692	1.131	4.481	1.274	3.022	0.315	2.965		0.985			0.018	0.058		23.470
Spaced Bored Pile Wall					0.188												0.064		0.252
Stone Columns					0.015														0.015
Stone Pitching											0.211							0.018	0.229
Stone Wall	2.758	1.331		0.050		0.098	0.003		0.310	0.216	5.804	1.930	0.086	0.068			0.113	0.000	12.767
Syphon Well					0.184														0.184
Timber Boards				0.191															0.191
Toe Berm		0.060	0.824	0.042	0.350	0.107	0.000	0.101		0.121		0.524							2.129
Toe Drain	1.381	3.789	2.206	0.618	1.474	1.288	0.568	1.119	68.308	0.503	0.003	15.581			0.499		0.010		97.347
Vertical Drains				2.682	0.042		0.134	0.091	0.036	0.187			0.000						3.172
Grand Total	**66.328**	**83.217**	**126.720**	**68.336**	**217.920**	**34.332**	**105.668**	**50.398**	**265.132**	**95.741**	**82.893**	**76.250**	**35.134**	**2.556**	**4.117**	**12.533**	**8.625**	**1.262**	**1337.162**

Appendix D – SGM coincident defects by area

	Earthwork Area																		
SGM Type	1	2	3	4	5	6	7	8	9	10	12	13	14	25	27	28	32	33	Total
Anchored Sheet Pile Wall					9 (0%)														9 (0%)
Basal Drainage			2 (100%)		2 (0%)	3 (0%)		1 (0%)	4 (0%)										12 (17%)
Block Wall	6 (0%)	37 (59%)	135 (7%)	23 (22%)	19 (11%)	4 (0%)	35 (46%)	13 (15%)	115 (3%)	76 (9%)	53 (15%)	8 (13%)	35 (23%)			1 (0%)	4 (0%)		564 (15%)
Buttress	4 (25%)						1 (100%)	1 (100%)	2 (0%)		8 (100%)								16 (69%)
Cobbled Facing									2 (0%)										2 (0%)
Concrete Cladding		1 (100%)																	1 (100%)
Concrete Driven Piles		1 (100%)			1 (100%)														2 (100%)
Concrete Facing				1 (0%)	4 (0%)														5 (0%)
Concrete Rubble Facing												1 (0%)							1 (0%)
Concrete Sandbag Wall		2 (0%)		4 (25%)			1 (0%)	1 (100%)	4 (0%)		2 (50%)								14 (21%)
Contiguous Bored Pile Wall			1 (0%)	1 (0%)					1 (0%)			1 (0%)							4 (0%)
Counterfort Drain	132 (28%)	83 (14%)	12 (25%)	9 (44%)	15 (20%)	1 (0%)		6 (33%)	25 (4%)		3 (67%)	2 (100%)	16 (44%)	4 (0%)					308 (24%)
Crest Drain		1 (0%)	9 (11%)	1 (100%)		1 (100%)		2 (0%)	78 (12%)		1 (100%)	4 (0%)	2 (100%)		6 (17%)				105 (15%)
Crib Wall	8 (13%)	7 (0%)	7 (14%)	3 (0%)	2 (0%)	8 (13%)		2 (0%)		5 (0%)	3 (0%)	2 (0%)							47 (6%)
Cut off Drain		5 (20%)			3 (0%)				10 (0%)										18 (6%)
Dentition	4 (0%)	1 (100%)							2 (50%)									5 (0%)	12 (17%)
Electrokinetic				1 (0%)					1 (100%)										2 (50%)
Erosion Mat			9 (11%)	1 (0%)	3 (33%)	3 (33%)	16 (13%)	15 (0%)	2 (0%)		1 (100%)	3 (33%)	1 (100%)				2 (0%)		56 (14%)
Fibre Reinforcement				2 (50%)	1 (0%)														3 (33%)
Filter Drain	148 (46%)	136 (22%)	219 (30%)	98 (22%)	205 (29%)	82 (20%)	154 (30%)	92 (24%)	492 (18%)	227 (20%)	101 (53%)	127 (12%)	77 (34%)	8 (0%)	8 (50%)	14 (0%)	13 (15%)	2 (0%)	2203 (26%)
Frost Blanket			1 (100%)	8 (13%)															9 (22%)
Gabion Wall	31 (32%)	48 (19%)	60 (15%)	101 (5%)	47 (11%)	2 (0%)	64 (6%)	28 (32%)	80 (11%)	50 (8%)	101 (13%)	28 (4%)	24 (17%)	3 (0%)	2 (50%)	1 (0%)	5 (20%)	2 (0%)	677 (12%)
Geogrid	17 (12%)	15 (20%)	17 (12%)	33 (9%)	132 (20%)	20 (15%)	40 (10%)	27 (19%)	17 (0%)	32 (9%)	15 (40%)	7 (43%)	3 (33%)	3 (33%)			1 (0%)		379 (17%)
Geomembrane			1 (0%)					1 (0%)											2 (0%)
Geotextile	1 (0%)	6 (0%)	16 (13%)	7 (29%)	23 (4%)	10 (10%)	4 (25%)	22 (9%)	15 (0%)	7 (14%)	24 (38%)	6 (83%)	3 (33%)		1 (0%)		2 (0%)		147 (17%)
Ground Anchor	2 (0%)							1 (0%)	1 (100%)	1 (0%)									5 (20%)
Ground Beam		2 (0%)	1 (0%)	1 (0%)															4 (0%)
Grout Injection		1 (100%)	1 (100%)	2 (0%)	2 (0%)	1 (100%)			13 (0%)										20 (15%)
Herringbone Drainage		7 (0%)	2 (0%)	1 (0%)	11 (0%)	5 (100%)	49 (53%)	20 (30%)	24 (13%)	3 (67%)	2 (50%)	17 (12%)	16 (19%)	1 (0%)		11 (0%)	1 (100%)		170 (29%)
Inclined Piles				1 (0%)															1 (0%)
Internal Drainage									1 (100%)										1 (100%)
King Post Wall						2 (0%)													2 (0%)
King Sheet Pile Wall	1 (100%)																		1 (100%)
Lightweight Fill		1 (100%)		1 (100%)	2 (0%)	1 (0%)													5 (40%)
Lime Stabilisation		6 (17%)	1 (100%)	16 (13%)	48 (10%)	6 (17%)	13 (0%)	9 (22%)					9 (0%)						108 (11%)
Masonry Facing						1 (0%)						2 (100%)							3 (67%)
Masonry Wall		13 (15%)	3 (0%)	13 (31%)	19 (16%)	4 (0%)	16 (13%)	11 (0%)	77 (3%)	26 (8%)	4 (25%)	2 (50%)	5 (0%)		2 (50%)		6 (0%)		201 (9%)
Mass Concrete Wall	7 (14%)	13 (0%)	38 (8%)	35 (17%)	123 (18%)	8 (38%)	22 (18%)	25 (12%)	96 (1%)	66 (8%)	50 (10%)	7 (29%)	31 (19%)		6 (0%)	1 (0%)	1 (0%)		529 (12%)
Metallic Reinforcement		8 (13%)	4 (50%)	2 (50%)	37 (8%)	3 (0%)	14 (7%)	2 (0%)	10 (10%)	5 (0%)	6 (67%)								91 (14%)
Micro Piles											2 (100%)								2 (100%)
Natural Material Poles		1 (0%)		1 (100%)				2 (0%)		1 (0%)									5 (20%)

	Earthwork Area																		
SGM Type	1	2	3	4	5	6	7	8	9	10	12	13	14	25	27	28	32	33	Total
Non-Specific Anchor	5 (40%)	1 (100%)		3 (0%)	5 (40%)		5 (0%)		3 (33%)	12 (8%)		1 (0%)		1 (0%)	1 (0%)		1 (0%)		38 (18%)
Non-Specific Bored Pile Wall		6 (17%)		1 (0%)	1 (100%)							1 (0%)							9 (22%)
Non-Specific Pile Wall	1 (0%)	4 (0%)	3 (0%)									1 (0%)							9 (0%)
Non-Specific Retaining Wall	12 (17%)	25 (24%)	163 (15%)	39 (8%)	400 (9%)	30 (0%)	195 (17%)	59 (17%)	115 (13%)	446 (8%)	106 (23%)	75 (12%)	22 (5%)	1 (0%)	1 (0%)		2 (0%)		1691 (12%)
PVC Pile Wall								107 (7%)											107 (7%)
Raft (Mining					1 (0%)														1 (0%)
Regrade	3 (0%)	32 (19%)	19 (26%)	5 (40%)	15 (33%)	3 (33%)	3 (33%)	28 (11%)	14 (36%)	3 (33%)	38 (24%)	11 (45%)	4 (0%)				1 (0%)	1 (0%)	180 (24%)
Rock Armour												18 (11%)							18 (11%)
Rock Bolts	8 (50%)	4 (50%)		4 (0%)	6 (0%)		2 (0%)		20 (5%)	6 (17%)	12 (17%)	6 (17%)	5 (0%)		3 (0%)			2 (0%)	78 (14%)
Rock Catch Fence	1 (100%)	5 (80%)	10 (50%)		33 (12%)				2 (0%)	3 (33%)		2 (0%)	1 (100%)					1 (0%)	58 (28%)
Rock Fill	1 (100%)				1 (100%)	8 (38%)	1 (0%)	2 (0%)	2 (0%)	11 (27%)	1 (0%)	5 (0%)	1 (100%)	2 (0%)					35 (26%)
Rock Mattress				1 (0%)							2 (0%)								3 (0%)
Rock Netting / Mesh	9 (44%)	4 (0%)	11 (36%)	15 (13%)	47 (0%)	6 (0%)	2 (0%)		32 (3%)	8 (38%)	11 (0%)	10 (10%)	5 (0%)	1 (0%)	4 (25%)			3 (0%)	168 (10%)
Rock Ribs								1 (0%)											1 (0%)
Rock Trap / Catch Ditch	1 (100%)		2 (0%)		1 (0%)							5 (0%)					1 (0%)		10 (10%)
Scaling	1 (100%)								3 (0%)										4 (25%)
Shear Dowel	4 (25%)																		4 (25%)
Shear Key			1 (0%)		9 (0%)														10 (0%)
Sheet Pile Wall	1 (0%)	8 (38%)	33 (9%)	13 (38%)	137 (9%)	1 (0%)	10 (10%)	47 (9%)	35 (3%)	9 (11%)	10 (40%)	2 (0%)	2 (0%)			1 (0%)	1 (0%)		310 (11%)
Shotcrete	1 (0%)				6 (0%)				7 (14%)			1 (0%)			3 (33%)				18 (11%)
Slope Drain	48 (73%)	10 (10%)	25 (12%)	24 (25%)	22 (18%)	16 (25%)	48 (31%)	46 (26%)	58 (12%)	1 (0%)	1 (100%)	38 (3%)	7 (14%)			9 (0%)	8 (13%)		361 (25%)
Soakaway			7 (0%)		1 (0%)	1 (0%)	6 (0%)	6 (33%)	2 (0%)	1 (100%)							1 (0%)		25 (12%)
Soil Nail Mesh		2 (50%)	4 (25%)	6 (0%)		1 (0%)			3 (0%)	1 (0%)	3 (100%)						1 (0%)		21 (24%)
Soil Nails	4 (25%)	8 (38%)	30 (20%)	21 (5%)	59 (2%)	11 (18%)	25 (12%)	9 (0%)	37 (8%)	6 (17%)	20 (50%)		7 (29%)			1 (0%)	2 (0%)		240 (14%)
Spaced Bored Pile Wall					1 (100%)												1 (0%)		2 (50%)
Stone Columns					1 (0%)														1 (0%)
Stone Pitching											1 (0%)							2 (0%)	3 (0%)
Stone Wall	23 (17%)	15 (60%)		3 (33%)		1 (0%)	1 (0%)		6 (17%)	5 (0%)	21 (24%)	23 (17%)	2 (0%)	1 (0%)			2 (0%)	1 (0%)	104 (23%)
Syphon Well					1 (100%)														1 (100%)
Timber Boards				1 (0%)															1 (0%)
Toe Berm		1 (0%)	11 (36%)	2 (0%)	4 (75%)	1 (100%)	1 (0%)	1 (100%)		1 (100%)		4 (50%)							26 (46%)
Toe Drain	7 (43%)	16 (25%)	27 (48%)	5 (60%)	16 (50%)	13 (8%)	9 (11%)	12 (33%)	353 (16%)	1 (0%)	2 (50%)	58 (10%)			3 (33%)		1 (0%)		523 (20%)
Vertical Drains				10 (10%)	4 (25%)		1 (0%)	1 (0%)	1 (0%)	5 (40%)			2 (100%)						24 (25%)
Grand Total	491 (37%)	536 (24%)	885 (19%)	519 (16%)	1479 (14%)	257 (18%)	738 (22%)	600 (17%)	1765 (12%)	1018 (12%)	604 (29%)	478 (14%)	280 (24%)	25 (4%)	40 (25%)	39 (0%)	57 (9%)	19 (0%)	9830 (18%)

Appendix E – SGM coincident defects by geology

KEY: Green – Cuttings (Cut), Blue – Embankments (Emb), Blank – At-Grade (AtG)

Note: Cuttings and At-Grade data is based on "in-situ geology" description, Embankment data is based on "Embankment geology".

SGM	Earthwork	ALLUVIUM & PEAT	CHALK	CLAY	LIMESTONE	MADE GROUND	MUDSTONE	OTHER ROCK	OVERCONSOLIDATED CLAY	SAND AND GRAVEL	SANDSTONE	TERRACE DEPOSITS
Anchored Sheet Pile Wall	At Grade									1 (0%)		
	Cutting	2 (0%)							5 (0%)			
	Embankment								1 (0%)			
Basal Drainage	At Grade			1 (0%)								
	Cutting			1 (0%)			3 (0%)	2 (100%)				
	Embankment					1 (0%)			4 (0%)			
Block Wall	At Grade	7 (0%)	3 (0%)	44 (14%)	5 (40%)		18 (28%)	7 (29%)	4 (25%)	6 (17%)	13 (46%)	2 (0%)
	Cutting	10 (0%)	44 (2%)	91 (14%)	5 (80%)		24 (8%)	9 (22%)	22 (14%)	42 (7%)	46 (17%)	
	Embankment		17 (18%)	23 (9%)		46 (17%)	10 (10%)	8 (0%)	12 (25%)	8 (13%)	14 (29%)	1 (0%)
Buttress	At Grade										1 (0%)	
	Cutting		1 (100%)				1 (100%)				1 (0%)	
	Embankment					2 (100%)		3 (0%)			7 (100%)	
Cobbled Facing	Embankment										2 (0%)	
Concrete Cladding	Embankment								1 (100%)			
Concrete Driven Piles	At Grade			1 (100%)								
	Embankment								1 (100%)			
Concrete Facing	Cutting		5 (0%)									
Concrete Rubble Facing	Cutting			1 (0%)								
Concrete Sandbag Wall	At Grade	1 (0%)					1 (0%)					
	Cutting		1 (100%)								3 (0%)	
	Embankment		3 (33%)		1 (0%)		1 (0%)		2 (0%)		1 (100%)	
Contiguous Bored Pile Wall	At Grade			2 (0%)								
	Embankment			1 (0%)						1 (0%)		
Counterfort Drain	At Grade			5 (0%)			2 (50%)		2 (0%)			
	Cutting		2 (100%)	22 (59%)	7 (0%)		123 (24%)	11 (27%)	32 (25%)	8 (25%)	10 (0%)	10 (40%)
	Embankment			2 (0%)	1 (0%)	1 (0%)	7 (43%)		53 (13%)		5 (0%)	
Crest Drain	At Grade	5 (0%)		1 (0%)			23 (4%)	2 (0%)	8 (0%)		3 (0%)	1 (0%)
	Cutting	1 (0%)		3 (100%)			19 (11%)	3 (33%)	14 (21%)		4 (50%)	3 (0%)
	Embankment			2 (0%)	1 (100%)	3 (33%)	1 (0%)	1 (0%)	3 (33%)	1 (0%)	1 (0%)	2 (50%)
Crib Wall	At Grade	1 (0%)		1 (0%)				1 (0%)			1 (0%)	
	Cutting		1 (0%)	6 (17%)			4 (0%)	3 (33%)	2 (0%)	6 (17%)		1 (0%)
	Embankment		1 (0%)	2 (0%)		6 (0%)	4 (0%)	1 (0%)	3 (0%)	1 (0%)	1 (0%)	
Cut off Drain	At Grade			5 (0%)							1 (0%)	
	Cutting						5 (0%)		6 (17%)			
	Embankment										1 (0%)	
Dentition	At Grade										1 (0%)	
	Cutting				2 (50%)		6 (0%)	2 (0%)			1 (100%)	
Electrokinetic	Embankment						1 (100%)		1 (0%)			
Erosion Mat	At Grade			1 (0%)					1 (0%)			
	Cutting		2 (50%)	12 (8%)			11 (9%)	4 (25%)			1 (100%)	
	Embankment		4 (25%)	2 (0%)		5 (20%)				5 (0%)	1 (0%)	
Fibre Reinforcement	Cutting								1 (0%)		1 (0%)	
Filter Drain	At Grade	26 (8%)	12 (8%)	73 (11%)	4 (0%)		95 (13%)	15 (20%)	38 (16%)	22 (5%)	22 (0%)	15 (13%)
	Cutting	34 (32%)	117 (25%)	348 (25%)	35 (57%)		262 (32%)	54 (39%)	157 (30%)	99 (29%)	151 (36%)	30 (27%)
	Embankment		29 (34%)	60 (10%)	8 (38%)	160 (18%)	46 (26%)	15 (47%)	127 (32%)	27 (26%)	44 (27%)	14 (43%)
Frost Blanket	At Grade			1 (0%)								
	Cutting			1 (0%)								
	Embankment							1 (100%)	5 (20%)	1 (0%)		
Gabion Wall	At Grade	14 (7%)	6 (17%)	36 (0%)	3 (33%)		5 (20%)	7 (43%)	12 (17%)	4 (0%)	9 (11%)	4 (0%)
	Cutting	3 (67%)	44 (5%)	63 (6%)	7 (29%)		39 (5%)	11 (18%)	22 (9%)	35 (6%)	59 (17%)	3 (67%)
	Embankment	1 (0%)	8 (0%)	35 (11%)	4 (0%)	75 (17%)	24 (13%)	13 (38%)	28 (29%)	7 (0%)	55 (15%)	1 (0%)
Geogrid	At Grade	6 (17%)	3 (0%)	1 (0%)				5 (0%)	8 (0%)	6 (0%)	1 (0%)	2 (0%)
	Cutting	3 (0%)	17 (18%)	47 (9%)	2 (0%)		21 (14%)	9 (11%)	26 (42%)	17 (0%)	17 (18%)	1 (0%)

SGM	Earthwork	ALLUVIUM & PEAT	CHALK	CLAY	LIMESTONE	MADE GROUND	MUDSTONE	OTHER ROCK	OVERCONSOLIDATED CLAY	SAND AND GRAVEL	SANDSTONE	TERRACE DEPOSITS
	Embankment		22 (14%)	16 (0%)	1 (0%)	21 (29%)	5 (20%)	9 (11%)	51 (29%)	4 (0%)	12 (17%)	4 (0%)
Geomembrane	Embankment		1 (0%)	1 (0%)								
Geotextile	At Grade			2 (0%)			2 (0%)		1 (0%)	1 (0%)		
	Cutting	2 (0%)	3 (0%)	28 (18%)	1 (0%)		1 (0%)	3 (0%)	9 (11%)	5 (40%)	16 (31%)	
	Embankment		5 (0%)	5 (0%)	2 (0%)	12 (50%)	2 (50%)		9 (0%)	12 (17%)	8 (13%)	1 (0%)
Ground Anchor	Cutting			1 (100%)							1 (0%)	
	Embankment						2 (0%)		1 (0%)			
Ground Beam	At Grade	1 (0%)					1 (0%)					
	Embankment			1 (0%)					1 (0%)			
Grout Injection	At Grade			9 (0%)								
	Cutting		2 (0%)		1 (100%)		4 (0%)	1 (0%)	1 (100%)	1 (100%)		
	Embankment									1 (0%)		
Herringbone Drainage	At Grade			6 (0%)	1 (0%)		4 (50%)		2 (0%)		1 (0%)	
	Cutting		1 (100%)	44 (34%)	11 (55%)		34 (38%)	1 (0%)	27 (22%)	7 (14%)	10 (10%)	
	Embankment		1 (0%)	2 (50%)		10 (20%)	1 (100%)		2 (0%)		1 (0%)	1 (0%)
Inclined Piles	At Grade								1 (0%)			
Internal Drainage	Embankment						1 (100%)					
King Post Wall	Embankment	2 (0%)										
King Sheet Pile Wall	Embankment							1 (100%)				
Lightweight Fill	At Grade								1 (0%)			
	Cutting								1 (0%)			
	Embankment								2 (50%)			
Lime Stabilisation	At Grade			5 (0%)					1 (0%)	1 (0%)		
	Cutting		1 (0%)	9 (11%)				1 (100%)	4 (0%)	2 (0%)		
	Embankment		2 (0%)	5 (0%)		6 (0%)	3 (0%)	1 (0%)	48 (21%)	9 (0%)		
Masonry Facing	At Grade									1 (0%)		
	Cutting							2 (100%)				
Masonry Wall	At Grade	4 (25%)		26 (4%)			13 (0%)	5 (20%)	1 (0%)	3 (0%)	3 (0%)	1 (0%)
	Cutting	2 (0%)	8 (0%)	34 (9%)			20 (5%)	3 (0%)	6 (67%)	19 (5%)	7 (43%)	
	Embankment		1 (0%)	11 (0%)		14 (7%)		2 (0%)	2 (0%)	1 (0%)	4 (0%)	
Mass Concrete Wall	At Grade	11 (0%)	3 (0%)	37 (3%)	3 (33%)		27 (0%)	4 (0%)	20 (5%)	9 (11%)	10 (0%)	2 (0%)
	Cutting	13 (0%)	20 (15%)	60 (20%)	8 (25%)	1 (100%)	14 (14%)	10 (30%)	46 (13%)	30 (20%)	32 (3%)	1 (0%)
	Embankment	1 (0%)	12 (25%)	29 (17%)	4 (75%)	53 (11%)	18 (6%)	3 (0%)	15 (13%)	6 (0%)	11 (0%)	2 (0%)
Micro Piles	Embankment					2 (100%)						
Natural Material Poles	Embankment		1 (0%)			1 (0%)			3 (33%)			
Non-Specific Anchor	At Grade		1 (0%)				1 (100%)			2 (0%)		
	Cutting		1 (0%)	6 (0%)	1 (100%)		6 (17%)	2 (50%)			6 (17%)	
	Embankment			1 (0%)		4 (0%)			1 (0%)	3 (33%)		
Non-Specific Bored Pile Wall	At Grade			4 (25%)					2 (50%)			
	Embankment			2 (0%)								
Non-Specific Pile Wall	At Grade			2 (0%)								
	Cutting			1 (0%)					2 (0%)			
	Embankment			2 (0%)				1 (0%)				
Non-Specific Retaining Wall	At Grade	45 (11%)	14 (0%)	90 (7%)	2 (0%)	1 (0%)	24 (13%)	10 (20%)	32 (3%)	32 (0%)	48 (6%)	31 (3%)
	Cutting	27 (4%)	102 (8%)	284 (14%)	8 (13%)	5 (80%)	59 (17%)	30 (23%)	55 (18%)	96 (5%)	53 (19%)	11 (0%)
	Embankment	10 (10%)	54 (15%)	38 (18%)	4 (0%)	246 (9%)	22 (9%)	18 (17%)	88 (20%)	51 (6%)	31 (35%)	12 (25%)
PVC Pile Wall	At Grade	1 (0%)		2 (0%)							2 (0%)	
	Cutting		18 (22%)	51 (2%)					2 (0%)	9 (0%)	19 (11%)	
	Embankment					2 (0%)			1 (100%)			
Raft (Mining)	Cutting							1 (0%)				
Regrade	At Grade			3 (67%)			4 (25%)		3 (0%)	1 (0%)	1 (0%)	3 (0%)
	Cutting		5 (80%)	21 (24%)	2 (50%)		8 (13%)	1 (0%)	10 (0%)	4 (0%)	15 (27%)	1 (100%)
	Embankment		3 (0%)	7 (29%)	1 (0%)	23 (13%)	9 (33%)	4 (0%)	39 (31%)	2 (0%)	9 (33%)	1 (100%)
Rock Armour	At Grade						2 (50%)					
	Cutting			9 (0%)	2 (0%)							
	Embankment			2 (0%)		2 (0%)						1 (100%)
Rock Bolts	At Grade	1 (0%)	1 (0%)								2 (0%)	
	Cutting	2 (0%)	6 (0%)	4 (0%)	13 (15%)		15 (20%)	5 (60%)	1 (0%)	4 (0%)	18 (17%)	
	Embankment			1 (0%)		1 (0%)			2 (0%)			
Rock Catch Fence	At Grade		1 (0%)							2 (50%)		
	Cutting		31 (26%)	7 (29%)	1 (100%)		2 (50%)	4 (0%)	1 (100%)	1 (0%)	4 (25%)	

SGM	Earthwork	ALLUVIUM & PEAT	CHALK	CLAY	LIMESTONE	MADE GROUND	MUDSTONE	OTHER ROCK	OVERCONSOLIDATED CLAY	SAND AND GRAVEL	SANDSTONE	TERRACE DEPOSITS
	Embankment		3 (0%)	1 (100%)								
Rock Fill	At Grade			1 (0%)			1 (0%)					
	Cutting			9 (33%)			1 (0%)	1 (100%)	2 (50%)	5 (40%)	1 (0%)	
	Embankment			1 (0%)		5 (20%)	1 (0%)		4 (25%)			
Rock Mattress	Cutting										1 (0%)	
	Embankment					2 (0%)						
Rock Netting / Mesh	At Grade	4 (0%)	1 (0%)	4 (0%)			1 (0%)		3 (0%)	2 (0%)	3 (0%)	2 (0%)
	Cutting	4 (0%)	45 (11%)	32 (9%)	13 (8%)		20 (5%)	13 (38%)	10 (10%)	27 (0%)	25 (16%)	
	Embankment		7 (0%)	2 (50%)	1 (0%)	21 (29%)	2 (0%)	3 (33%)	10 (30%)	12 (0%)	3 (33%)	3 (0%)
Rock Ribs	Embankment								1 (0%)			
Rock Trap / Catch Ditch	Cutting		3 (0%)	1 (0%)	1 (100%)			5 (0%)				
Scaling	At Grade										1 (0%)	
	Cutting	1 (0%)						1 (100%)			1 (0%)	
Shear Dowel	Cutting						3 (0%)	1 (100%)				
Shear Key	Cutting	2 (0%)							5 (0%)	2 (0%)		
	Embankment								1 (0%)			
Sheet Pile Wall	At Grade	4 (25%)	12 (0%)	10 (0%)			1 (0%)	1 (0%)	7 (14%)	18 (0%)		1 (0%)
	Cutting	1 (0%)	18 (11%)	31 (6%)	1 (100%)		14 (0%)	4 (0%)	10 (10%)	43 (21%)	5 (20%)	
	Embankment		6 (17%)	19 (0%)	2 (0%)	15 (20%)	4 (0%)	3 (0%)	35 (23%)	42 (7%)	1 (100%)	
Shotcrete	At Grade										1 (0%)	
	Cutting	2 (0%)	4 (0%)	1 (0%)			2 (50%)	1 (0%)			5 (20%)	
Slope Drain	At Grade	1 (0%)	1 (0%)	12 (50%)	1 (0%)		2 (0%)	1 (0%)		1 (0%)	3 (0%)	2 (0%)
	Cutting	5 (0%)	3 (0%)	56 (20%)	9 (89%)		69 (30%)	13 (38%)	28 (25%)	11 (18%)	31 (23%)	5 (20%)
	Embankment		8 (13%)	32 (9%)	1 (0%)	13 (38%)	7 (43%)	2 (50%)	25 (24%)	2 (50%)	10 (10%)	5 (20%)
Soakaway	At Grade	1 (100%)	1 (0%)	1 (0%)			4 (0%)		3 (0%)			1 (0%)
	Cutting		1 (0%)		1 (0%)							
	Embankment		3 (0%)	2 (50%)		1 (0%)			1 (0%)	1 (100%)		3 (0%)
Soil Nails	At Grade	1 (0%)		7 (0%)			2 (0%)	1 (0%)	5 (40%)	1 (0%)	2 (0%)	1 (0%)
	Cutting	3 (33%)	16 (0%)	26 (12%)	2 (50%)		23 (4%)	8 (25%)	4 (25%)	22 (5%)	9 (44%)	
	Embankment	1 (0%)	3 (0%)	15 (0%)	1 (0%)	18 (28%)	6 (17%)	2 (0%)	36 (19%)	17 (0%)	4 (75%)	2 (50%)
Spaced Bored Pile Wall	At Grade								1 (100%)			
	Embankment							1 (0%)				
Stone Columns	Cutting							1 (0%)				
Stone Pitching	Cutting				1 (0%)	1 (0%)	1 (0%)					
Stone Wall	At Grade	1 (100%)		5 (20%)	3 (0%)		4 (25%)	6 (50%)		3 (67%)	11 (27%)	
	Cutting			5 (0%)	1 (100%)		3 (0%)	5 (20%)	1 (100%)	3 (0%)	9 (33%)	4 (25%)
	Embankment			6 (50%)	1 (0%)	13 (0%)		11 (9%)			8 (25%)	
Syphon Well	At Grade								1 (100%)			
Timber Boards	Embankment											1 (0%)
Toe Berm	Cutting						1 (0%)		2 (50%)	1 (0%)		
	Embankment	1 (100%)	1 (0%)	2 (50%)		2 (100%)		6 (50%)	7 (43%)			3 (33%)
Toe Drain	At Grade	19 (5%)		32 (6%)	2 (50%)		107 (7%)	1 (100%)	15 (7%)	6 (0%)	14 (0%)	12 (17%)
	Cutting	5 (20%)	3 (67%)	41 (22%)	1 (0%)		62 (21%)	4 (50%)	14 (21%)	8 (75%)	32 (25%)	7 (29%)
	Embankment	1 (0%)	2 (50%)	11 (9%)		25 (24%)	27 (33%)	2 (100%)	25 (36%)	8 (38%)	11 (9%)	12 (50%)
Vertical Drains	At Grade			2 (0%)							1 (0%)	
	Cutting			4 (100%)			1 (0%)		4 (50%)		3 (0%)	
	Embankment		3 (0%)	3 (0%)					1 (0%)		1 (0%)	1 (0%)
Grand Total	At Grade	154 (9%)	59 (3%)	432 (8%)	24 (21%)	1 (0%)	344 (11%)	66 (23%)	172 (10%)	122 (5%)	155 (8%)	80 (6%)
	Cutting	122 (13%)	525 (15%)	1360 (18%)	136 (40%)	7 (71%)	881 (22%)	229 (30%)	532 (23%)	507 (14%)	597 (23%)	77 (25%)
	Embankment	17 (12%)	200 (16%)	344 (11%)	33 (21%)	811 (16%)	204 (21%)	111 (23%)	652 (25%)	222 (10%)	246 (24%)	70 (30%)

Appendix F – SGM coincident defects by slope angle

	Slope Angle (o)													
SGM Type	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	>60	Total
Anchored Sheet Pile Wall	6 (0%)												2 (0%)	8 (0%)
At Grade	1 (0%)													1 (0%)
Cutting	5 (0%)												1 (0%)	6 (0%)
Embankment													1 (0%)	1 (0%)
Basal Drainage	1 (0%)			1 (0%)	4 (50%)	3 (0%)	1 (0%)	1 (0%)	1 (0%)					12 (17%)
At Grade						1 (0%)								1 (0%)
Cutting	1 (0%)			1 (0%)	2 (100%)		1 (0%)	1 (0%)						6 (33%)
Embankment					2 (0%)	2 (0%)			1 (0%)					5 (0%)
Block Wall	157 (13%)	6 (17%)	37 (11%)	62 (6%)	113 (19%)	99 (15%)	31 (16%)	16 (31%)	3 (33%)		6 (50%)	3 (0%)	6 (33%)	539 (15%)
At Grade	76 (21%)	1 (0%)	2 (50%)	7 (14%)	13 (23%)	4 (0%)	1 (0%)						4 (50%)	108 (21%)
Cutting	56 (7%)	3 (33%)	28 (11%)	40 (8%)	79 (16%)	56 (7%)	17 (12%)	6 (50%)	2 (0%)		5 (60%)	2 (0%)		294 (12%)
Embankment	25 (0%)	2 (0%)	7 (0%)	15 (0%)	21 (24%)	39 (28%)	13 (23%)	10 (20%)	1 (100%)		1 (0%)	1 (0%)	2 (0%)	137 (16%)
Buttress	1 (0%)				2 (50%)	3 (33%)		1 (100%)	2 (100%)	5 (100%)			2 (50%)	16 (69%)
At Grade													1 (0%)	1 (0%)
Cutting						2 (50%)							1 (100%)	3 (67%)
Embankment	1 (0%)				2 (50%)	1 (0%)		1 (100%)	2 (100%)	5 (100%)				12 (75%)
Cobbled Facing			2 (0%)											2 (0%)
Embankment			2 (0%)											2 (0%)
Concrete Cladding					1 (100%)									1 (100%)
Embankment					1 (100%)									1 (100%)
Concrete Driven Piles				1 (100%)		1 (100%)								2 (100%)
At Grade				1 (100%)										1 (100%)
Embankment						1 (100%)								1 (100%)
Concrete Facing										1 (0%)	3 (0%)	1 (0%)		5 (0%)
Cutting										1 (0%)	3 (0%)	1 (0%)		5 (0%)
Concrete Rubble Facing						1 (0%)								1 (0%)
Cutting						1 (0%)								1 (0%)
Concrete Sandbag Wall	2 (50%)	1 (0%)			5 (40%)	2 (0%)	1 (0%)				3 (0%)			14 (21%)
At Grade	1 (0%)	1 (0%)												2 (0%)
Cutting	1 (100%)										3 (0%)			4 (25%)
Embankment					5 (40%)	2 (0%)	1 (0%)							8 (25%)
Contiguous Bored Pile Wall	3 (0%)						1 (0%)							4 (0%)
At Grade	2 (0%)													2 (0%)
Embankment	1 (0%)						1 (0%)							2 (0%)
Counterfort Drain	38 (32%)		5 (0%)	30 (43%)	112 (15%)	98 (27%)	13 (38%)	3 (0%)	3 (0%)			3 (0%)		305 (24%)
At Grade	8 (13%)				1 (0%)									9 (11%)
Cutting	28 (39%)		2 (0%)	25 (48%)	76 (14%)	78 (29%)	9 (56%)	3 (0%)	3 (0%)			3 (0%)		227 (27%)
Embankment	2 (0%)		3 (0%)	5 (20%)	35 (17%)	20 (15%)	4 (0%)							69 (14%)
Crest Drain	29 (17%)		9 (22%)	14 (14%)	22 (18%)	17 (6%)	10 (20%)	2 (0%)					2 (0%)	105 (15%)
At Grade	19 (5%)		5 (0%)	7 (0%)	4 (0%)	6 (0%)	1 (0%)	1 (0%)						43 (2%)
Cutting	7 (29%)		3 (67%)	7 (29%)	11 (18%)	10 (10%)	6 (33%)	1 (0%)					2 (0%)	47 (23%)
Embankment	3 (67%)		1 (0%)		7 (29%)	1 (0%)	3 (0%)							15 (27%)
Crib Wall	7 (0%)		2 (0%)	3 (0%)	13 (15%)	10 (10%)	4 (0%)	2 (0%)				1 (0%)	2 (0%)	44 (7%)
At Grade	3 (0%)													3 (0%)
Cutting	1 (0%)		1 (0%)	1 (0%)	8 (25%)	6 (17%)	2 (0%)	2 (0%)				1 (0%)	1 (0%)	23 (13%)
Embankment	3 (0%)		1 (0%)	2 (0%)	5 (0%)	4 (0%)	2 (0%)						1 (0%)	18 (0%)
Cut off Drain	6 (0%)			3 (0%)	3 (0%)	5 (20%)	1 (0%)							18 (6%)
At Grade	6 (0%)													6 (0%)
Cutting				3 (0%)	3 (0%)	4 (25%)	1 (0%)							11 (9%)
Embankment						1 (0%)								1 (0%)
Dentition	1 (0%)					4 (25%)	1 (0%)	1 (100%)			2 (0%)	2 (0%)	1 (0%)	12 (17%)
At Grade	1 (0%)													1 (0%)
Cutting						4 (25%)	1 (0%)	1 (100%)			2 (0%)	2 (0%)	1 (0%)	11 (18%)
Electrokinetic					1 (0%)	1 (100%)								2 (50%)
Embankment					1 (0%)	1 (100%)								2 (50%)
Erosion Mat	12 (0%)		1 (0%)	2 (50%)	10 (10%)	14 (21%)	2 (50%)	3 (0%)		2 (0%)	1 (0%)	1 (0%)	1 (100%)	49 (14%)
At Grade	1 (0%)											1 (0%)		2 (0%)
Cutting	8 (0%)		1 (0%)	2 (50%)	9 (11%)	5 (40%)	1 (0%)	1 (0%)		1 (0%)	1 (0%)		1 (100%)	30 (17%)
Embankment	3 (0%)				1 (0%)	9 (11%)	1 (100%)	2 (0%)		1 (0%)				17 (12%)
Fibre Reinforcement				1 (0%)		1 (0%)								2 (0%)
Cutting				1 (0%)		1 (0%)								2 (0%)
Filter Drain	450 (15%)	21 (5%)	131 (33%)	264 (25%)	558 (28%)	470 (32%)	117 (35%)	47 (30%)	33 (12%)	9 (22%)	17 (41%)	8 (13%)	26 (19%)	2151 (26%)
At Grade	165 (9%)	9 (0%)	29 (17%)	33 (9%)	39 (18%)	34 (9%)	6 (33%)	2 (0%)	2 (0%)	1 (0%)			2 (0%)	322 (11%)
Cutting	195 (22%)	7 (14%)	73 (40%)	173 (26%)	368 (28%)	292 (39%)	81 (37%)	38 (29%)	20 (15%)	7 (29%)	14 (36%)	8 (13%)	17 (29%)	1293 (30%)
Embankment	90 (11%)	5 (0%)	29 (31%)	58 (29%)	151 (32%)	144 (24%)	30 (30%)	7 (43%)	11 (9%)	1 (0%)	3 (67%)		7 (0%)	536 (25%)
Frost Blanket	1 (0%)				6 (33%)		1 (0%)	1 (0%)						9 (22%)
At Grade	1 (0%)													1 (0%)
Cutting					1 (0%)									1 (0%)
Embankment					5 (40%)		1 (0%)	1 (0%)						7 (29%)
Gabion Wall	128 (7%)	17 (0%)	33 (12%)	60 (8%)	154 (12%)	120 (14%)	35 (43%)	18 (33%)	4 (25%)	8 (0%)	8 (25%)	10 (0%)	12 (25%)	607 (13%)
At Grade	56 (9%)	4 (0%)	2 (0%)	3 (0%)	13 (8%)	4 (0%)	4 (75%)	2 (0%)					3 (33%)	91 (11%)
Cutting	41 (0%)	2 (0%)	20 (15%)	39 (8%)	79 (9%)	53 (9%)	15 (40%)	10 (40%)	2 (0%)	3 (0%)	6 (17%)	6 (0%)	4 (25%)	280 (11%)
Embankment	31 (13%)	11 (0%)	11 (9%)	18 (11%)	62 (18%)	63 (19%)	16 (38%)	6 (33%)	2 (50%)	5 (0%)	2 (50%)	4 (0%)	5 (20%)	236 (17%)
Geogrid	48 (13%)	4 (0%)	7 (14%)	30 (7%)	72 (14%)	50 (24%)	27 (19%)	16 (19%)	17 (12%)	15 (20%)	14 (36%)	24 (17%)	12 (8%)	336 (16%)
At Grade	11 (0%)	3 (0%)	2 (0%)	3 (0%)	2 (0%)	1 (0%)	2 (0%)	1 (0%)		1 (0%)	1 (0%)	3 (0%)	1 (100%)	31 (3%)
Cutting	16 (13%)		4 (25%)	12 (8%)	39 (10%)	24 (21%)	9 (0%)	10 (20%)	9 (22%)	12 (25%)	9 (44%)	12 (8%)	2 (0%)	158 (16%)
Embankment	21 (19%)	1 (0%)	1 (0%)	15 (7%)	31 (19%)	25 (28%)	16 (31%)	5 (20%)	8 (0%)	2 (0%)	4 (25%)	9 (33%)	9 (0%)	147 (19%)
Geomembrane						2 (0%)								2 (0%)
Embankment						2 (0%)								2 (0%)
Geotextile	29 (14%)		2 (0%)	7 (0%)	21 (19%)	25 (28%)	15 (27%)	7 (29%)	1 (0%)	11 (9%)	5 (0%)	8 (13%)	2 (0%)	133 (17%)

	Slope Angle (o)													
SGM Type	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	>60	Total
At Grade	3 (0%)						1 (0%)		1 (0%)	1 (0%)		1 (0%)		7 (0%)
Cutting	21 (19%)		1 (0%)	4 (0%)	10 (10%)	9 (44%)	6 (0%)	3 (67%)		9 (11%)	3 (0%)	5 (20%)	1 (0%)	72 (18%)
Embankment	5 (0%)		1 (0%)	3 (0%)	11 (27%)	16 (19%)	8 (50%)	4 (0%)		1 (0%)	2 (0%)	2 (0%)	1 (0%)	54 (19%)
Ground Anchor				1 (100%)	2 (0%)	1 (0%)	1 (0%)							5 (20%)
Cutting				1 (100%)		1 (0%)								2 (50%)
Embankment					2 (0%)		1 (0%)							3 (0%)
Ground Beam	1 (0%)					1 (0%)	2 (0%)							4 (0%)
At Grade	1 (0%)					1 (0%)								2 (0%)
Embankment							2 (0%)							2 (0%)
Grout Injection	10 (0%)		1 (0%)		3 (0%)	3 (33%)	2 (50%)	1 (100%)						20 (15%)
At Grade	9 (0%)													9 (0%)
Cutting	1 (0%)		1 (0%)		3 (0%)	2 (50%)	2 (50%)	1 (100%)						10 (30%)
Embankment						1 (0%)								1 (0%)
Herringbone Drainage	33 (18%)	5 (0%)	5 (40%)	17 (24%)	45 (36%)	49 (33%)	8 (25%)	3 (67%)	1 (100%)		1 (0%)			167 (29%)
At Grade	11 (9%)				2 (50%)		1 (0%)							14 (14%)
Cutting	19 (26%)	5 (0%)	3 (33%)	15 (27%)	38 (34%)	45 (36%)	6 (17%)	3 (67%)	1 (100%)		1 (0%)			136 (32%)
Embankment	3 (0%)		2 (50%)	2 (0%)	5 (40%)	4 (0%)	1 (100%)							17 (24%)
Inclined Piles	1 (0%)													1 (0%)
At Grade	1 (0%)													1 (0%)
Internal Drainage							1 (100%)							1 (100%)
Embankment							1 (100%)							1 (100%)
King Post Wall					1 (0%)			1 (0%)						2 (0%)
Embankment					1 (0%)			1 (0%)						2 (0%)
King Sheet Pile Wall								1 (100%)						1 (100%)
Embankment								1 (100%)						1 (100%)
Lightweight Fill	1 (0%)				2 (50%)		2 (50%)							5 (40%)
At Grade	1 (0%)													1 (0%)
Cutting					1 (0%)									1 (0%)
Embankment					1 (100%)		2 (50%)							3 (67%)
Lime Stabilisation	10 (10%)		2 (0%)	20 (20%)	28 (14%)	18 (17%)	7 (0%)	2 (0%)		1 (0%)				88 (14%)
At Grade	3 (0%)		1 (0%)											4 (0%)
Cutting	4 (25%)			7 (14%)	4 (0%)	1 (0%)								16 (13%)
Embankment	3 (0%)		1 (0%)	13 (23%)	24 (17%)	17 (18%)	7 (0%)	2 (0%)		1 (0%)				68 (15%)
Masonry Facing	1 (0%)					1 (100%)							1 (100%)	3 (67%)
At Grade	1 (0%)													1 (0%)
Cutting						1 (100%)							1 (100%)	2 (100%)
Masonry Wall	63 (5%)	6 (17%)	7 (0%)	18 (17%)	42 (7%)	31 (10%)	9 (0%)	2 (50%)	1 (0%)	1 (100%)		2 (50%)	2 (0%)	184 (9%)
At Grade	42 (5%)	3 (0%)	1 (0%)	2 (0%)	4 (0%)	1 (0%)				1 (100%)				54 (6%)
Cutting	16 (6%)	2 (50%)	5 (0%)	9 (33%)	30 (10%)	22 (9%)	9 (0%)	2 (50%)	1 (0%)			1 (100%)	1 (0%)	98 (12%)
Embankment	5 (0%)	1 (0%)	1 (0%)	7 (0%)	8 (0%)	8 (13%)						1 (0%)	1 (0%)	32 (3%)
Mass Concrete Wall	136 (6%)	8 (0%)	34 (3%)	56 (9%)	117 (15%)	79 (22%)	30 (20%)	6 (33%)	4 (25%)	1 (0%)	2 (50%)	1 (100%)	19 (5%)	493 (12%)
At Grade	83 (4%)	4 (0%)	8 (0%)	4 (0%)	10 (0%)	5 (20%)	3 (0%)				1 (0%)		3 (0%)	121 (3%)
Cutting	28 (11%)	3 (0%)	22 (5%)	40 (10%)	61 (20%)	45 (29%)	10 (30%)	2 (0%)	3 (0%)	1 (0%)			9 (0%)	224 (16%)
Embankment	25 (8%)	1 (0%)	4 (0%)	12 (8%)	46 (11%)	29 (10%)	17 (18%)	4 (50%)	1 (100%)		1 (100%)	1 (100%)	7 (14%)	148 (14%)
Micro Piles							1 (100%)	1 (100%)						2 (100%)
Embankment							1 (100%)	1 (100%)						2 (100%)
Natural Material Poles	1 (0%)			2 (0%)	1 (100%)								1 (0%)	5 (20%)
Embankment	1 (0%)			2 (0%)	1 (100%)								1 (0%)	5 (20%)
Non-Specific Anchor	3 (0%)			3 (0%)	5 (0%)	5 (40%)	3 (0%)	4 (25%)	2 (0%)	1 (0%)	1 (0%)	3 (67%)	4 (25%)	34 (18%)
At Grade	1 (0%)					2 (50%)								3 (33%)
Cutting				1 (0%)	2 (0%)	2 (0%)	2 (0%)	4 (25%)	2 (0%)		1 (0%)	3 (67%)	4 (25%)	21 (19%)
Embankment	2 (0%)			2 (0%)	3 (0%)	1 (100%)	1 (0%)			1 (0%)				10 (10%)
Non-Specific Bored Pile Wall	3 (33%)	2 (50%)	1 (0%)	1 (0%)		1 (0%)	1 (0%)							9 (22%)
At Grade	3 (33%)	1 (100%)	1 (0%)	1 (0%)										6 (33%)
Embankment		1 (0%)				1 (0%)	1 (0%)							3 (0%)
Non-Specific Pile Wall	1 (0%)	1 (0%)		2 (0%)	2 (0%)	1 (0%)	2 (0%)							9 (0%)
At Grade	1 (0%)			1 (0%)										2 (0%)
Cutting				1 (0%)	1 (0%)		1 (0%)							3 (0%)
Embankment		1 (0%)			1 (0%)	1 (0%)	1 (0%)							4 (0%)
Non-Specific Retaining Wall	412 (9%)	12 (0%)	71 (14%)	157 (8%)	333 (17%)	285 (15%)	117 (14%)	44 (16%)	21 (24%)	12 (50%)	7 (0%)	7 (14%)	40 (8%)	1518 (13%)
At Grade	166 (6%)	7 (0%)	20 (10%)	17 (6%)	32 (13%)	10 (0%)	8 (38%)	2 (0%)	2 (0%)		1 (0%)	1 (0%)	8 (13%)	274 (8%)
Cutting	104 (11%)	2 (0%)	36 (14%)	94 (10%)	183 (16%)	151 (17%)	44 (16%)	26 (15%)	14 (14%)	6 (17%)	6 (0%)	6 (17%)	22 (5%)	694 (14%)
Embankment	142 (11%)	3 (0%)	15 (20%)	46 (7%)	118 (18%)	124 (14%)	65 (9%)	16 (19%)	5 (60%)	6 (83%)			10 (10%)	550 (14%)
PVC Pile Wall	31 (0%)	5 (0%)		3 (0%)	8 (0%)	22 (5%)	25 (12%)	13 (31%)						107 (7%)
At Grade	2 (0%)						3 (0%)							5 (0%)
Cutting	29 (0%)	5 (0%)		3 (0%)	8 (0%)	21 (5%)	21 (10%)	12 (33%)						99 (7%)
Embankment						1 (0%)	1 (100%)	1 (0%)						3 (33%)
Raft (Mining			1 (0%)											1 (0%)
Cutting			1 (0%)											1 (0%)
Regrade	20 (40%)	1 (0%)	6 (33%)	17 (18%)	39 (13%)	51 (29%)	32 (22%)	3 (0%)	3 (33%)	2 (50%)	2 (50%)	1 (0%)	3 (0%)	180 (24%)
At Grade	6 (17%)		1 (0%)	2 (50%)		1 (0%)	3 (33%)		1 (0%)				1 (0%)	15 (20%)
Cutting	8 (75%)		3 (33%)	3 (0%)	16 (6%)	17 (24%)	13 (15%)	1 (0%)		1 (100%)	2 (50%)	1 (0%)	2 (0%)	67 (24%)
Embankment	6 (17%)	1 (0%)	2 (50%)	12 (17%)	23 (17%)	33 (33%)	16 (25%)	2 (0%)	2 (50%)	1 (0%)				98 (24%)
Rock Armour	5 (20%)				2 (50%)	5 (0%)	5 (0%)							17 (12%)
At Grade	2 (50%)													2 (50%)
Cutting	1 (0%)					4 (0%)	5 (0%)							10 (0%)
Embankment	2 (0%)				2 (50%)	1 (0%)								5 (20%)
Rock Bolts	9 (0%)		1 (0%)	1 (0%)	14 (0%)	5 (40%)	4 (50%)	7 (14%)	5 (0%)	2 (50%)	4 (0%)	10 (30%)	16 (13%)	78 (14%)
At Grade	2 (0%)				1 (0%)								1 (0%)	4 (0%)
Cutting	7 (0%)		1 (0%)		10 (0%)	5 (40%)	4 (50%)	7 (14%)	5 (0%)	2 (50%)	4 (0%)	10 (30%)	15 (13%)	70 (16%)
Embankment				1 (0%)	3 (0%)									4 (0%)
Rock Catch Fence	5 (20%)			3 (33%)	6 (50%)	5 (20%)	3 (67%)	5 (40%)	7 (29%)	7 (14%)	7 (29%)	7 (14%)	3 (0%)	58 (28%)
At Grade	1 (100%)				1 (0%)					1 (0%)				3 (33%)
Cutting	3 (0%)			3 (33%)	3 (67%)	4 (25%)	3 (67%)	5 (40%)	7 (29%)	6 (17%)	7 (29%)	7 (14%)	3 (0%)	51 (27%)
Embankment	1 (0%)				2 (50%)	1 (0%)								4 (25%)
Rock Fill	4 (0%)		1 (0%)	2 (100%)	14 (29%)	6 (17%)	1 (0%)	2 (100%)					2 (0%)	32 (28%)
At Grade	1 (0%)												1 (0%)	2 (0%)

	Slope Angle (o)													
SGM Type	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	>60	Total
Cutting	2 (0%)			1 (100%)	10 (40%)	3 (33%)	1 (0%)	1 (100%)					1 (0%)	19 (37%)
Embankment	1 (0%)		1 (0%)	1 (100%)	4 (0%)	3 (0%)		1 (100%)						11 (18%)
Rock Mattress					1 (0%)	1 (0%)	1 (0%)							3 (0%)
Cutting						1 (0%)								1 (0%)
Embankment					1 (0%)		1 (0%)							2 (0%)
Rock Netting / Mesh	31 (3%)	2 (0%)	4 (25%)	20 (10%)	35 (3%)	39 (21%)	18 (22%)	13 (15%)	15 (13%)	9 (33%)	16 (6%)	31 (10%)	37 (8%)	270 (11%)
At Grade	6 (0%)	2 (0%)	1 (0%)	4 (0%)	2 (0%)		1 (0%)	1 (0%)					1 (0%)	18 (0%)
Cutting	17 (6%)		2 (50%)	11 (9%)	23 (4%)	22 (9%)	8 (25%)	10 (10%)	14 (7%)	9 (33%)	14 (7%)	24 (13%)	32 (9%)	186 (11%)
Embankment	8 (0%)		1 (0%)	5 (20%)	10 (0%)	17 (35%)	9 (22%)	2 (50%)	1 (100%)		2 (0%)	7 (0%)	4 (0%)	66 (17%)
Rock Ribs						1 (0%)								1 (0%)
Embankment						1 (0%)								1 (0%)
Rock Trap / Catch Ditch	4 (25%)									2 (0%)	1 (0%)		1 (0%)	8 (13%)
Cutting	4 (25%)									2 (0%)	1 (0%)		1 (0%)	8 (13%)
Scaling	1 (100%)												3 (0%)	4 (25%)
At Grade													1 (0%)	1 (0%)
Cutting	1 (100%)												2 (0%)	3 (33%)
Shear Dowel										1 (0%)		1 (100%)	2 (0%)	4 (25%)
Cutting										1 (0%)		1 (100%)	2 (0%)	4 (25%)
Shear Key	6 (0%)			1 (0%)		1 (0%)							1 (0%)	9 (0%)
Cutting	6 (0%)			1 (0%)									1 (0%)	8 (0%)
Embankment						1 (0%)								1 (0%)
Sheet Pile Wall	66 (3%)	2 (0%)	7 (14%)	20 (20%)	72 (15%)	85 (6%)	33 (27%)	7 (29%)	3 (0%)	2 (0%)	3 (0%)		1 (0%)	301 (11%)
At Grade	37 (3%)		1 (0%)	1 (0%)	2 (0%)	8 (0%)	2 (50%)						1 (0%)	52 (4%)
Cutting	11 (0%)	1 (0%)	2 (50%)	12 (17%)	33 (18%)	44 (9%)	11 (18%)	5 (20%)	2 (0%)	2 (0%)	2 (0%)			125 (13%)
Embankment	18 (6%)	1 (0%)	4 (0%)	7 (29%)	37 (14%)	33 (3%)	20 (30%)	2 (50%)	1 (0%)		1 (0%)			124 (13%)
Shotcrete	2 (50%)		1 (0%)		1 (0%)				1 (0%)		2 (50%)	5 (0%)	6 (0%)	18 (11%)
At Grade	1 (0%)													1 (0%)
Cutting	1 (100%)		1 (0%)		1 (0%)				1 (0%)		2 (50%)	5 (0%)	6 (0%)	17 (12%)
Slope Drain	59 (22%)	1 (0%)	10 (20%)	56 (25%)	97 (22%)	92 (26%)	29 (48%)	3 (33%)	7 (0%)	1 (100%)		1 (0%)		356 (25%)
At Grade	17 (29%)		1 (0%)	2 (0%)	2 (50%)		1 (0%)							23 (26%)
Cutting	32 (22%)	1 (0%)	8 (25%)	29 (10%)	63 (27%)	73 (27%)	20 (60%)	3 (33%)				1 (0%)		230 (27%)
Embankment	10 (10%)		1 (0%)	25 (44%)	32 (9%)	19 (21%)	8 (25%)		7 (0%)	1 (100%)				103 (21%)
Soakaway	9 (11%)			2 (0%)	3 (0%)	4 (25%)	4 (25%)							22 (14%)
At Grade	8 (13%)				1 (0%)									9 (11%)
Cutting						1 (0%)	1 (0%)							2 (0%)
Embankment	1 (0%)			2 (0%)	2 (0%)	3 (33%)	3 (33%)							11 (18%)
Soil Nails	32 (6%)	1 (0%)	9 (22%)	18 (17%)	69 (9%)	44 (23%)	23 (22%)	8 (13%)	5 (20%)	8 (25%)	8 (0%)	8 (13%)	3 (0%)	236 (14%)
At Grade	14 (0%)		3 (33%)	1 (0%)			1 (100%)							19 (11%)
Cutting	6 (17%)	1 (0%)	2 (50%)	10 (20%)	34 (9%)	20 (20%)	6 (0%)	4 (0%)	5 (20%)	7 (14%)	8 (0%)	8 (13%)	3 (0%)	114 (12%)
Embankment	12 (8%)		4 (0%)	7 (14%)	35 (9%)	24 (25%)	16 (25%)	4 (25%)		1 (100%)				103 (17%)
Spaced Bored Pile Wall	1 (100%)						1 (0%)							2 (50%)
At Grade	1 (100%)													1 (100%)
Embankment							1 (0%)							1 (0%)
Stone Columns			1 (0%)											1 (0%)
Cutting			1 (0%)											1 (0%)
Stone Pitching						1 (0%)		1 (0%)					1 (0%)	3 (0%)
Cutting						1 (0%)		1 (0%)					1 (0%)	3 (0%)
Stone Wall	32 (25%)	1 (100%)	12 (8%)	4 (0%)	9 (0%)	9 (44%)	2 (0%)	1 (0%)	7 (57%)	3 (33%)	1 (100%)	1 (0%)	16 (25%)	98 (24%)
At Grade	19 (32%)					2 (100%)			1 (100%)				7 (29%)	29 (38%)
Cutting	8 (13%)	1 (100%)	3 (33%)	3 (0%)	4 (0%)	3 (33%)	1 (0%)		3 (33%)	1 (0%)	1 (100%)		2 (50%)	30 (23%)
Embankment	5 (20%)		9 (0%)	1 (0%)	5 (0%)	4 (25%)	1 (0%)	1 (0%)	3 (67%)	2 (50%)		1 (0%)	7 (14%)	39 (15%)
Syphon Well	1 (100%)													1 (100%)
At Grade	1 (100%)													1 (100%)
Timber Boards						1 (0%)								1 (0%)
Embankment						1 (0%)								1 (0%)
Toe Berm			3 (100%)	1 (0%)	7 (57%)	12 (17%)	2 (100%)	1 (100%)						26 (46%)
Cutting			1 (100%)	1 (0%)		2 (0%)								4 (25%)
Embankment			2 (100%)		7 (57%)	10 (20%)	2 (100%)	1 (100%)						22 (50%)
Toe Drain	135 (9%)	8 (0%)	32 (28%)	56 (18%)	92 (27%)	99 (26%)	34 (26%)	17 (12%)	7 (29%)	4 (25%)	5 (20%)	2 (0%)	8 (38%)	499 (20%)
At Grade	95 (4%)	3 (0%)	20 (15%)	23 (17%)	25 (8%)	25 (8%)	4 (25%)	3 (0%)	1 (0%)	1 (0%)				200 (8%)
Cutting	29 (24%)	3 (0%)	8 (50%)	26 (19%)	36 (28%)	29 (31%)	18 (33%)	8 (0%)	2 (0%)	3 (33%)	5 (20%)	2 (0%)	8 (38%)	177 (26%)
Embankment	11 (9%)	2 (0%)	4 (50%)	7 (14%)	31 (42%)	45 (33%)	12 (17%)	6 (33%)	4 (50%)					122 (31%)
Vertical Drains	4 (0%)			7 (0%)	7 (57%)	4 (50%)	2 (0%)							24 (25%)
At Grade	3 (0%)													3 (0%)
Cutting				5 (0%)	5 (80%)	2 (100%)								12 (50%)
Embankment	1 (0%)			2 (0%)	2 (0%)	2 (0%)	2 (0%)							9 (0%)

Appendix G – SGM coincident defects by slope height

	Slope Height (m)																					
SGM Type	<1 or (blank)	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	>20	Total
Basal Drainage									(1) 100%		(1) 100%											(12) 17%
Cutting									(1) 100%		(1) 100%											(6) 33%
Block Wall	(183) 12%	(39) 15%	(58) 21%	(58) 10%	(46) 13%	(55) 18%	(51) 14%	(28) 11%				(5) 20%	(2) 50%	(2) 100%	(1) 100%	(3) 67%	(1) 100%		(1) 100%		(4) 50%	(564) 15%
At Grade	(85) 20%	(11) 9%	(12) 42%																			(109) 21%
Bund front		(2) 100%																				(20) 10%
Cutting	(61) 8%	(16) 13%	(20) 10%	(35) 14%	(31) 13%	(38) 11%	(41) 10%	(21) 10%				(5) 20%		(2) 100%		(3) 67%	(1) 100%		(1) 100%		(2) 50%	(295) 12%
Embankment		(10) 10%	(18) 28%	(18) 6%	(14) 14%	(17) 35%	(10) 30%	(7) 14%					(1) 100%		(1) 100%						(2) 50%	(140) 16%
Buttress				(2) 50%	(2) 100%	(2) 50%	(2) 50%		(1) 100%			(1) 100%	(2) 100%	(1) 100%							(1) 100%	(16) 69%
Cutting						(1) 100%			(1) 100%													(3) 67%
Embankment				(2) 50%	(2) 100%		(1) 100%					(1) 100%	(2) 100%	(1) 100%							(1) 100%	(12) 75%
Concrete Cladding			(1) 100%																			(1) 100%
Embankment			(1) 100%																			(1) 100%
Concrete Driven Piles		(1) 100%					(1) 100%															(2) 100%
At Grade		(1) 100%																				(1) 100%
Embankment							(1) 100%															(1) 100%
Concrete Sandbag Wall	(3) 33%							(3) 67%														(14) 21%
Cutting	(1) 100%																					(4) 25%
Embankment								(2) 100%														(8) 25%
Counterfort Drain	(47) 28%	(9) 44%	(25) 8%	(33) 30%	(31) 26%	(33) 24%	(33) 15%	(23) 26%	(24) 8%	(18) 22%	(11) 55%	(7) 29%	(7) 14%							(1) 100%	(1) 100%	(308) 24%
At Grade	(8) 13%																					(9) 11%
Cutting	(37) 32%	(7) 57%	(19) 5%	(18) 44%	(18) 28%	(21) 24%	(23) 22%	(20) 30%	(21) 10%	(15) 27%	(10) 50%	(6) 33%	(7) 14%							(1) 100%	(1) 100%	(229) 27%
Embankment			(6) 17%	(15) 13%	(12) 25%	(12) 25%					(1) 100%											(69) 14%
Crest Drain	(35) 17%	(16) 6%	(14) 7%	(7) 43%	(10) 20%	(9) 22%	(9) 11%															(105) 15%
At Grade	(23) 4%																					(43) 2%
Cutting	(9) 33%	(4) 25%		(7) 43%	(8) 25%	(6) 17%	(6) 17%															(47) 23%
Embankment	(3) 67%		(2) 50%			(3) 33%																(15) 27%
Crib Wall							(7) 14%	(3) 33%		(4) 25%												(47) 6%
Cutting							(7) 14%	(2) 50%		(4) 25%												(23) 13%
Cut off Drain		(1) 100%																				(18) 6%
Cutting		(1) 100%																				(11) 9%
Dentition							(4) 25%														(1) 100%	(12) 17%
Cutting							(4) 25%														(1) 100%	(11) 18%
Electrokinetic										(1) 100%												(2) 50%
Embankment										(1) 100%												(2) 50%
Erosion Mat				(2) 50%	(4) 25%	(5) 20%			(6) 17%	(2) 50%	(1) 100%	(1) 100%										(51) 14%
Cutting				(2) 50%	(3) 33%	(3) 33%					(1) 100%	(1) 100%										(30) 17%
Embankment									(2) 50%	(1) 100%												(17) 12%
Fibre Reinforcement									(1) 100%													(3) 33%
Bund front									(1) 100%													(1) 100%
Filter Drain	(552) 15%	(162) 17%	(165) 22%	(232) 31%	(204) 32%	(230) 30%	(248) 27%	(132) 30%	(88) 35%	(61) 36%	(34) 47%	(20) 35%	(18) 56%	(14) 50%	(8) 38%	(9) 33%	(8) 50%			(2) 50%	(12) 50%	(2203) 26%
At Grade	(203) 9%	(86) 12%	(32) 16%	(1) 100%																		(322) 11%
Bund back					(2) 50%				(1) 100%													(10) 20%
Bund front		(6) 17%	(14) 14%	(9) 33%																		(42) 14%
Cutting	(236) 21%	(48) 23%	(76) 28%	(150) 35%	(131) 31%	(154) 29%	(180) 26%	(110) 32%	(56) 41%	(43) 35%	(26) 50%	(18) 39%	(18) 56%	(11) 45%	(5) 40%	(8) 38%	(8) 50%			(2) 50%	(9) 67%	(1293) 30%
Embankment	(102) 14%	(21) 24%	(42) 19%	(72) 21%	(67) 34%	(76) 32%	(67) 30%	(21) 19%	(31) 23%	(18) 39%	(7) 43%			(3) 67%	(3) 33%							(536) 25%
Frost Blanket							(1) 100%											(1) 100%				(9) 22%
Embankment							(1) 100%											(1) 100%				(7) 29%
Gabion Wall	(209) 7%	(53) 15%	(55) 11%	(60) 15%	(76) 12%	(60) 15%	(58) 12%	(30) 23%	(19) 21%	(16) 13%	(9) 22%	(12) 17%	(6) 17%	(3) 33%	(2) 50%						(1) 100%	(674) 12%
At Grade	(78) 9%	(18) 11%	(3) 33%																			(100) 10%
Bund back	(5) 40%																					(8) 25%
Bund front		(1) 100%																				(19) 5%
Cutting	(61) 2%		(16) 13%	(32) 19%	(40) 10%	(24) 8%	(34) 6%	(16) 19%	(15) 20%	(14) 14%	(7) 29%			(2) 50%	(2) 50%						(1) 100%	(290) 10%

	Slope Height (m)																					
SGM Type	<1 or (blank)	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	>20	Total
Embankment	(62) 8%	(23) 22%	(27) 11%	(23) 13%	(36) 14%	(36) 19%	(22) 23%	(14) 29%	(3) 33%			(5) 40%	(2) 50%									(257) 16%
Geogrid	(76) 12%	(34) 12%	(40) 25%	(47) 19%	(32) 28%	(35) 11%	(39) 18%	(18) 6%	(14) 7%	(14) 14%	(6) 17%	(7) 14%		(2) 50%	(2) 50%	(2) 50%					(5) 40%	(379) 17%
At Grade			(3) 33%																			(32) 3%
Bund back			(1) 100%																			(7) 14%
Bund front	(9) 11%	(5) 20%	(6) 33%		(5) 20%		(2) 100%															(32) 22%
Cutting	(19) 16%	(8) 13%	(14) 21%	(29) 24%	(12) 17%	(16) 13%		(14) 7%		(5) 20%	(2) 50%	(4) 25%		(1) 100%							(4) 50%	(160) 16%
Embankment	(26) 19%	(11) 18%	(16) 19%	(12) 17%	(15) 40%	(17) 12%	(18) 28%		(6) 17%	(9) 11%					(2) 50%	(2) 50%						(148) 20%
Geotextile	(40) 13%			(18) 28%	(18) 17%		(13) 31%	(13) 31%	(9) 11%	(5) 20%	(1) 100%				(1) 100%							(147) 17%
Bund front					(2) 50%		(1) 100%															(7) 29%
Cutting	(24) 17%			(9) 33%	(4) 25%			(11) 27%		(2) 50%					(1) 100%							(73) 18%
Embankment	(10) 10%			(8) 25%	(12) 8%		(6) 50%	(2) 50%	(4) 25%		(1) 100%											(57) 18%
Ground Anchor							(2) 50%															(4) 25%
Cutting							(1) 100%															(2) 50%
Grout Injection				(3) 33%					(1) 100%										(1) 100%			(20) 15%
Cutting				(3) 33%					(1) 100%										(1) 100%			(10) 30%
Herringbone Drainage	(41) 20%	(8) 13%	(13) 31%	(14) 50%	(14) 43%	(22) 14%	(16) 50%	(14) 14%	(13) 23%	(4) 25%	(2) 50%	(2) 50%	(2) 50%	(3) 67%			(1) 100%					(170) 29%
At Grade	(11) 9%	(3) 33%																				(14) 14%
Cutting	(25) 28%		(9) 44%	(13) 54%	(12) 42%	(20) 10%	(14) 50%	(13) 15%	(11) 27%	(4) 25%	(2) 50%	(2) 50%	(2) 50%	(2) 50%			(1) 100%					(136) 32%
Embankment					(2) 50%	(2) 50%	(2) 50%							(1) 100%								(18) 22%
Internal Drainage	(1) 100%																					(1) 100%
Embankment	(1) 100%																					(1) 100%
King Sheet Pile Wall				(1) 100%																		(1) 100%
Embankment				(1) 100%																		(1) 100%
Lightweight Fill							(1) 100%				(2) 50%											(5) 40%
Embankment							(1) 100%				(2) 50%											(3) 67%
Lime Stabilisation	(30) 3%			(10) 10%	(12) 25%	(9) 22%	(13) 8%	(5) 40%	(7) 14%	(5) 20%												(108) 11%
Cutting	(9) 11%			(3) 33%																		(17) 12%
Embankment					(9) 33%	(8) 25%	(11) 9%	(3) 67%	(7) 14%	(5) 20%												(77) 13%
Masonry Facing										(2) 100%												(3) 67%
Cutting										(2) 100%												(2) 100%
Masonry Wall	(81) 5%	(18) 28%	(22) 5%		(19) 5%		(18) 22%		(2) 50%		(2) 50%									(1) 100%		(201) 9%
At Grade	(48) 4%		(6) 17%																			(56) 5%
Bund front		(2) 100%																				(9) 22%
Cutting	(21) 10%	(10) 30%					(14) 29%		(2) 50%		(2) 50%									(1) 100%		(99) 12%
Embankment					(5) 20%																	(35) 3%
Mass Concrete Wall	(189) 5%	(34) 6%	(40) 15%	(42) 10%	(54) 19%	(38) 11%	(45) 7%	(30) 30%	(27) 11%	(12) 33%			(2) 50%				(1) 100%		(2) 100%	(1) 100%	(2) 100%	(529) 12%
At Grade	(103) 3%			(1) 100%																		(126) 3%
Bund front			(2) 50%																			(9) 11%
Cutting	(41) 5%	(11) 9%	(21) 24%		(31) 26%	(25) 8%	(29) 7%	(18) 28%	(15) 20%	(9) 33%			(2) 50%						(1) 100%	(1) 100%	(2) 100%	(236) 15%
Embankment	(43) 9%	(7) 14%		(16) 19%	(21) 10%	(12) 17%	(14) 7%	(12) 33%		(3) 33%							(1) 100%		(1) 100%			(157) 13%
Micro Piles																	(1) 100%		(1) 100%			(2) 100%
Embankment																	(1) 100%		(1) 100%			(2) 100%
Natural Material Poles				(1) 100%																		(5) 20%
Embankment				(1) 100%																		(5) 20%
Non-Specific Anchor	(8) 13%	(2) 50%						(2) 50%	(3) 33%				(1) 100%	(1) 100%							(1) 100%	(40) 18%
At Grade		(1) 100%																				(4) 25%
Bund back													(1) 100%									(1) 100%
Cutting	(2) 50%								(3) 33%					(1) 100%							(1) 100%	(22) 18%
Embankment								(2) 50%														(13) 8%
Non-Specific Bored Pile Wall	(5) 40%																					(9) 22%
At Grade	(4) 50%																					(6) 33%
Non-Specific Retaining Wall	(867) 9%	(159) 8%	(233) 11%	(237) 16%	(200) 17%	(212) 13%	(176) 15%	(133) 14%	(69) 19%	(43) 21%	(25) 12%	(11) 45%	(11) 45%	(9) 44%	(5) 40%	(10) 30%			(3) 100%		(8) 25%	(2413) 13%
At Grade	(394) 8%	(71) 7%	(40) 20%	(4) 50%																		(509) 9%
Bund front			(26) 4%			(3) 33%																(66) 3%
Cutting	(228) 11%	(49) 8%	(89) 10%	(134) 18%	(117) 15%	(137) 12%	(119) 14%	(73) 15%	(40) 25%	(26) 19%	(15) 13%	(7) 57%		(6) 33%		(6) 50%			(3) 100%			(1062) 14%
Embankment	(231) 10%	(36) 8%	(77) 10%	(86) 13%	(75) 20%	(72) 15%	(51) 18%	(57) 14%	(28) 11%	(17) 24%	(10) 10%	(4) 25%	(5) 100%	(3) 67%	(3) 67%						(4) 50%	(764) 14%
PVC Pile Wall		(19) 21%			(15) 13%		(12) 8%															(100) 7%

	Slope Height (m)																					
SGM Type	<1 or (blank)	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	>20	Total
Cutting		(16) 25%			(14) 7%		(12) 8%															(92) 7%
Embankment					(1) 100%																	(3) 33%
Regrade	(26) 35%	(11) 18%	(16) 19%	(26) 19%	(21) 29%	(23) 13%	(20) 20%	(12) 33%	(6) 17%	(8) 25%		(4) 25%	(3) 33%	(2) 50%	(2) 50%							(180) 24%
At Grade	(8) 13%	(5) 20%	(2) 50%																			(15) 20%
Cutting	(9) 67%	(3) 33%	(3) 33%	(12) 25%		(9) 11%	(9) 11%	(7) 29%				(2) 50%										(67) 24%
Embankment	(9) 22%		(11) 9%	(14) 14%	(15) 40%	(14) 14%	(11) 27%	(5) 40%	(5) 20%	(4) 50%			(1) 100%	(2) 50%	(2) 50%							(98) 24%
Rock Armour	(6) 17%							(1) 100%														(18) 11%
At Grade	(2) 50%																					(2) 50%
Embankment								(1) 100%														(5) 20%
Rock Bolts	(15) 13%			(6) 50%					(4) 25%	(5) 20%		(5) 20%		(3) 33%				(1) 100%			(1) 100%	(78) 14%
Cutting	(11) 18%			(5) 60%					(4) 25%	(5) 20%		(5) 20%		(3) 33%				(1) 100%			(1) 100%	(70) 16%
Rock Catch Fence	(9) 11%			(4) 75%	(3) 33%	(7) 14%	(8) 13%		(2) 50%			(4) 25%	(3) 67%	(4) 25%		(1) 100%					(3) 100%	(58) 28%
At Grade	(2) 50%																					(3) 33%
Cutting				(4) 75%		(7) 14%	(8) 13%		(2) 50%			(4) 25%	(3) 67%	(2) 50%		(1) 100%					(3) 100%	(51) 27%
Embankment					(1) 100%																	(4) 25%
Rock Fill				(5) 20%	(2) 50%		(4) 50%	(2) 100%	(1) 100%	(1) 100%	(3) 33%											(35) 26%
Cutting				(3) 33%	(2) 50%		(3) 67%	(1) 100%	(1) 100%		(3) 33%											(19) 37%
Embankment								(1) 100%		(1) 100%												(13) 15%
Rock Netting / Mesh	(51) 10%	(18) 6%	(28) 14%	(21) 19%	(21) 10%	(27) 11%	(33) 15%	(23) 9%	(12) 8%	(14) 14%		(9) 11%			(7) 14%		(3) 67%			(1) 100%	(4) 25%	(291) 12%
Bund front			(1) 100%				(3) 33%															(11) 18%
Cutting	(26) 12%	(8) 13%	(18) 11%	(12) 17%		(18) 6%	(22) 5%	(14) 7%	(12) 8%	(11) 18%		(9) 11%			(5) 20%		(2) 100%			(1) 100%	(4) 25%	(190) 11%
Embankment	(11) 18%		(8) 13%	(8) 25%	(4) 50%	(9) 22%	(8) 38%	(8) 13%														(68) 19%
Rock Trap / Catch Ditch	(6) 17%																					(10) 10%
Cutting	(6) 17%																					(10) 10%
Scaling	(2) 50%																					(4) 25%
Cutting	(1) 100%																					(3) 33%
Shear Dowel	(1) 100%																					(4) 25%
Cutting	(1) 100%																					(4) 25%
Sheet Pile Wall	(111) 3%	(38) 11%	(23) 9%	(33) 15%	(50) 22%	(39) 10%	(39) 5%	(26) 15%	(8) 13%	(4) 25%	(8) 13%	(3) 33%					(3) 33%		(1) 100%			(391) 10%
At Grade	(43) 5%																					(59) 3%
Cutting		(22) 18%	(8) 13%	(13) 31%	(29) 10%	(24) 17%	(27) 4%	(18) 17%		(4) 25%		(2) 50%										(200) 11%
Embankment	(26) 4%		(12) 8%	(19) 5%	(21) 38%		(12) 8%	(8) 13%	(3) 33%		(1) 100%						(3) 33%		(1) 100%			(130) 13%
Shotcrete	(2) 50%										(2) 50%											(18) 11%
Cutting	(1) 100%										(2) 50%											(17) 12%
Slope Drain	(71) 18%	(13) 15%	(30) 10%	(28) 14%	(30) 33%	(51) 22%	(55) 20%	(22) 27%	(11) 27%	(14) 57%	(5) 60%	(9) 33%	(4) 25%	(3) 67%	(5) 20%		(3) 100%				(7) 100%	(361) 25%
At Grade	(19) 26%		(2) 50%																			(24) 25%
Bund back					(1) 100%																	(1) 100%
Cutting	(37) 19%	(7) 14%		(13) 15%	(18) 28%	(36) 14%	(38) 29%	(18) 22%	(4) 25%	(12) 67%	(4) 50%	(9) 33%	(4) 25%	(3) 67%	(5) 20%		(3) 100%				(6) 100%	(230) 27%
Embankment	(14) 7%	(3) 33%	(15) 13%	(15) 13%	(11) 36%	(15) 40%		(4) 50%	(7) 29%		(1) 100%										(1) 100%	(105) 21%
Soakaway	(12) 8%		(4) 25%				(2) 50%															(25) 12%
At Grade	(10) 10%																					(11) 9%
Embankment			(3) 33%				(2) 50%															(11) 18%
Soil Nails	(44) 9%	(7) 14%		(31) 16%	(18) 22%	(25) 16%	(29) 10%	(24) 17%	(15) 13%		(10) 10%	(9) 11%	(4) 25%		(1) 100%		(2) 50%		(1) 100%			(240) 14%
At Grade	(17) 6%	(2) 50%																				(20) 10%
Cutting	(7) 14%			(15) 20%	(9) 11%	(14) 21%	(17) 12%	(14) 7%	(10) 10%		(7) 14%	(8) 13%										(115) 12%
Embankment	(20) 10%			(16) 13%	(9) 33%	(11) 9%	(12) 8%	(10) 30%	(5) 20%				(1) 100%		(1) 100%		(2) 50%		(1) 100%			(105) 16%
Spaced Bored Pile Wall	(1) 100%																					(2) 50%
At Grade	(1) 100%																					(1) 100%
Stone Wall	(42) 21%	(19) 32%	(8) 13%	(8) 13%	(9) 22%		(7) 14%			(1) 100%			(1) 100%								(3) 67%	(104) 23%
At Grade	(24) 25%	(8) 50%	(1) 100%																			(33) 33%
Cutting	(11) 18%	(3) 33%		(5) 20%	(5) 20%		(2) 50%			(1) 100%												(32) 22%
Embankment	(7) 14%	(8) 13%			(4) 25%								(1) 100%								(3) 67%	(39) 15%
Syphon Well	(1) 100%																					(1) 100%
At Grade	(1) 100%																					(1) 100%
Toe Berm			(2) 50%	(3) 67%	(4) 50%	(4) 50%	(2) 100%	(5) 60%														(26) 46%
Cutting							(1) 100%															(4) 25%
Embankment			(1) 100%	(3) 67%	(4) 50%	(4) 50%	(1) 100%	(5) 60%														(22) 50%

	Slope Height (m)																				
SGM Type	<1 or (blank)	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	>20	Total
Toe Drain	(182) 9%	(76) 17%	(61) 20%	(44) 27%	(35) 37%	(32) 34%	(37) 32%	(17) 24%	(14) 29%	(7) 43%	(6) 17%		(4) 25%									(523) 20%
At Grade	(130) 5%	(48) 15%	(30) 10%																			(208) 8%
Bund front			(3) 33%																			(12) 8%
Cutting	(34) 24%	(13) 23%	(11) 27%	(24) 25%	(19) 32%	(19) 37%	(28) 29%	(10) 20%	(6) 33%	(5) 40%												(178) 26%
Embankment	(17) 12%	(10) 30%	(17) 29%	(17) 35%	(16) 44%	(13) 31%	(9) 44%	(7) 29%	(8) 25%	(2) 50%	(5) 20%		(2) 50%									(124) 31%
Vertical Drains			(3) 67%			(1) 100%	(4) 50%		(2) 50%													(24) 25%
At Grade																						
Cutting			(2) 100%			(1) 100%	(4) 50%		(1) 100%													(12) 50%
Grand Total	(3066) 11%	(771) 14%	(887) 15%	(1011) 21%	(969) 22%	(993) 18%	(1019) 19%	(608) 21%	(382) 21%	(268) 26%	(171) 25%	(130) 23%	(85) 35%	(63) 38%	(43) 30%	(42) 24%	(32) 47%	(14) 14%	(13) 77%	(7) 71%	(56) 59%	(10630) 17%

Appendix H – Third party data sources summary

WEB BASED ARCHIVES

The Motorway Archive	
Link	http://www.ukmotorwayarchive.org/ (Accessed and indexed: July 2016)
Description	The Motorway Archive holds a large collection of information and records regarding the development of the UK's motorway infrastructure, the information has been collated by a team of professionals and the former Permanent Secretary to the Department of Transport.
Potential	1,813 web pages indexed. 118 No. pages containing 563 No. occurrences of SGM search terms for 30No. Types of SGM, including lime stabilisation, surcharging, regrading, and grouting, substantial number of retaining walls.
Conclusion	These findings confirm that The Motorway Archive contains potentially useful information which is likely supplement the outputs from Task 594, it is therefore recommended that the website is considered for mining of this additional data.
CBRD (Chris's British Road Directory)	
Link	http://www.cbrd.co.uk/ (Accessed and indexed: July 2016)
Description	CBRD is a comprehensive and frequently updated road directory. The site hosts road construction information on both recent and historical schemes, in particular concerning the cost and construction chronology.
Potential	11,476 No. indexed webpages. This identified 47 No. individual pages to contain at least one SGM search term. The majority of these results were retaining walls, with a small number of french drains. Only one non-visible SGM was identified on the site and was a photograph of ground anchors being installed (http://www.cbrd.co.uk/articles/m1-a1-link-road/06.shtml).
Conclusion	CBRD does contain easily accessible and clear breakdowns of timescales regarding road scheme construction that may be utilised to validate the information contained in the structured HAGDMS information. This chronological detail may aid in confirming when particular SGMs were installed, however as a source of additional SGM location information CBRD, would not be recommended for further data mining.
SABRE – The Society for All British and Irish Road Enthusiasts	
Link	http://www.sabre-roads.org.uk/ (Accessed and indexed: July 2016)
Description	SABRE is a web-based archive of information on the British and Irish road network, including road features, designs, street furniture and mapping history. A large amount of the sites content comes in the form of a webpage developed collaboratively by its community of users who also contribute to a large number of forums discussing proposed and existing road work schemes.
Potential	7,114 No. web pages indexed. 121 No. pages containing an SGM search term. The majority of these terms being retaining walls, a small number of regrades, and one instance of ground anchors.
Conclusion	As a potential source of SGM location information SABRE roads is unlikely to enhance the existing information identified from HAGDMS during Task 594.
Pathetic Motorways	
Link	http://www.pathetic.org.uk/ (Accessed and indexed: July 2016)
Description	Pathetic Motorways is a website that discusses the history of the motorway network development, and frequently appears when searching for British road information through internet search engines. The site however is not technical based, and presents more of a satirical perspective of British roads.
Potential	900 No. webpages indexed. Only four contained an SGM search term. Two of which were retaining walls, the other two being "anchor" used in a none SGM context
Conclusion	Pathetic Motorways is not considered a good source of information regarding the performance or location of SGMs on the network and so would not be useful in identifying any additional SGM information.

RESEARCH

Geotech Tools (United States)	
Links	Brief: http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_PB_R02_2013-11.pdf Full Report: http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2prepubR02Report.pdf Online Tool Login Page: http://www.geotechtools.org/ (Accessed: July 2016)
Description	Geotech Tools, funded by the Strategic Highway Research Program (SHRP) in the United States, is an online tool that contains a catalogue of over forty different ground improvement solutions, which we anticipate to correlate to a number of the SGMs in Task 594. The online tool is a guidance system that suggests which ground improvement technique could be used based on the project information input by the user, then offering further guidance on the suitable recommended solutions.The research undertaken while developing this tool had the objective of developing performance based design specifications for the ground improvement methods it looked at. The work has created two-page fact sheets for all of the ground improvement methods, many of which are relevant SGMs searched for during Task 594. The information on these fact sheets and available from this research would likely enhance the data outputs from task 594 and help in identifying purpose and condition patterns in SGMs on Britain's strategic network. The factsheets describe methods for construction, examples of where the technology has been used, alternative solutions and advantages/disadvantages for every solution. Access to the research report is freely available and gives examples of the facts sheets, however full access will likely require contact with the SHRP at Iowa University.
Council of Scientific and Industrial Research (CSIR) – Central Road Research Institute (CRRI) (India)	
Links	http://www.crridom.gov.in/content/geotechnical-engineering (Accessed: May 2016)
Description	This research institute in India has carried out work investigating hazards and hazard mitigation techniques (such as SGMs) for highways in India. The outputs are not freely available through the website; however, their research potentially includes information regarding SGM performance and life cycle parameters. The following research and development areas are mentioned on the site: Ground improvement techniques 1. Ground Improvement by Sand/band Drains, Stone Columns, Lime piles, Lime Slurry Injection etc. 2. Mechanical and chemical soil stabilization 3. Geo-synthetics in Roads and Embankments 4. Coir and Jute Fabrics in Construction of Roads 5. Design and Construction Supervision of Reinforced Earth Structures Although the information here relates specifically to India, the research may still be of relevance to the outputs of Task 594 and aid in determining design life and likely patterns in performance. This information can likely be obtained via contact with the institute. http://www.crridom.gov.in/content/contact-us
A survey of slope condition on motorway earthworks in England and Wales, Perry J 1989.	
Links	http://www.trl.co.uk/reports-publications/trl-reports/ground-engineering/report/?reportid=5808 (Accessed: May 2016)
Description	This paper covers one of the largest slope surveys to be undertaken across the motorway network, covering 570km, focusing on areas of the motorway that include the principal geologies encountered on the road network, specifically it covers areas where pre-consolidated clays predominate in both embankments and cuttings. It discusses the factors leading to shallow slope failures on both embankments and cuttings and attempts to quantify potential long term issues. The results recognise patterns of failure with associated geology, age and geometry of the earthwork, which could help inform HE of where risk lies on the network and aid in the identification of patterns in performance from the Task 594 outputs. The paper gives recommendations on slope angles, for use in future design work and in the assessment of existing slopes that may be at risk of failing. It goes on to estimate the future extents of failures on the network, stating it will be three times greater than what has occurred so far. The report is not freely available and can be purchased through Science Direct (http://www.sciencedirect.com/science/article/pii/014890629090380K).
A Study on Ground Improvement Techniques and its Applications, Mishra B 2015.	
Links	http://www.ijirset.com/upload/2016/january/10_A_Study.pdf (Accessed: June 2016)
Description	This paper discussed a number of techniques, such as injection grouting, micro piles and dynamic compaction, used to strengthen earthworks, and discusses their performance and purpose. This may help to identify the purpose for particular SGM types, where this information is not already known.

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Some applications of ground improvement techniques in the urban environment, Serridge. C, 2006.	
Links	http://iaeg2006.geolsoc.org.uk/cd/PAPERS/IAEG_296.PDF (Accessed: June 2016)
Description	Discusses the use of vibro stone and concrete columns on British roads, could be another source for identifying the purpose of some of these SGM types where not already understood. In particular, this paper discusses widening of the M60 using band drains, CFA piles and vibro stone columns.
ASCE - Ground Improvement and Geosynthetics, Anand J et al. 2010.	
Links	http://ascelibrary.org/doi/book/10.1061/9780784411087 (Accessed: June 2016)
Description	A collection of 48 No. papers discussing recent developments in ground improvement and geosynthetics, the papers cover the remediation of a number of the hazards identified by task 408 and so could be particularly useful in determining potential SGM purpose and condition.
ASCE - Advances in Ground Improvement: Research to Practice in the United States and China, Han J et al. 2009.	
Links	http://ascelibrary.org/doi/book/10.1061/9780784410257 (Accessed: June 2016)
Description	Proceedings from the US – China workshop on Ground Improvement, the publication contains 33 No. peer-reviewed papers covering a number of SGM applications, such as column supported embankments, ground modification and surcharging. These papers are not freely available however may contain useful information regarding the performance of SGM types, potentially aiding in the assessment of the SGMs identified on the British road network.
Ground Improvement in Road Projects – Australian Experience, Ameratunga J 2013.	
Links	http://www.slgs.lk/wp-content/uploads/2013/11/Ground-Improvement-in-Road-Projects1.pdf (Accessed: June 2016)
Description	This document contains an informative list of different geotechnical hazards and the preventative measures (SGMs) available to remediate them which includes a number of the SGMs searched for in task 594 and would help in identifying potential purpose of SGMs where not known. The paper also discusses the development of the Strategic Highway Research Program (SHRP) in the US, and in particular the SHRP Renewal Focus Area 2, which has the goal of developing a systematic and consistent approach to rapid highway renewal design. The information from this research programme would likely assist in some of the research work being undertaken by Highways England.
Ground Improvement Case Histories: Compaction, Grouting and Geosynthetics, Indraratna B et al. 2015	
Links	http://library.ice.org.uk/uhtbin/cgisirsi.exe/?ps=Rd2CI9GUHL/ICE/182940002/9 (Accessed: June 2016)
Description	This publication is an international collaborative effort to document a number of case studies regarding the use of ground improvement methods (such as SGMs), offering field data and observations based on construction procedures used and the apparent effectiveness of the improvement methods, this 700 No. page publication could offer valuable insights into the performance of a number of the SGMs searched for in Task 594.
US Department of Transportation – Federal Highway Administration	
Links	http://www.fhwa.dot.gov/engineering/geotech/library_listing.cfm (Accessed: June 2016)
Description	The Geotech section of the United States Department of Transportation website references and gives access to a large number of potentially useful publications relating to SGM performance and design, as well as research into geohazards. The reports date back to the 1970s until very recent reports issued in 2015. The more recent reports tend to be freely available from the link above. The website lists a large number of research projects both complete and underway. • Example ground anchors report: http://www.fhwa.dot.gov/engineering/geotech/pubs/if99015.pdf • Example soil nails report: http://www.fhwa.dot.gov/engineering/geotech/pubs/nhi14007.pdf

BOOKS & STANDARDS

Book - Ground Improvement: Case Histories, Indraratna B et al. 2005	
Links	http://www4.hcmut.edu.vn/~cnan/CT%20tren%20dat%20yeu/Ground_Improvement_Case_Histories_hANSBO.pdf (Accessed: May 2016)
Description	This book discusses a number of SGMs that have been used on various international projects including highways schemes. The book discusses the use of the following SGMs: • Preloading and vertical drains • Modification by chemical admixture (Soil mixing) • Physical modification methods including grouting, compaction and drainage • Modification by geosynthetic and other inclusions • Electro-kinetic, thermal and explosion-based techniques The information contained in this book may help to better understand the likely effectiveness of SGMs and enable a better understanding of why particular SGMs have been installed and what their condition is likely to be dependent on their age and environment.
CIRIA Documents	
Links	(Accessed: May 2016)
Description	"C591 - Infrastructure cuttings" and "C592 - Infrastructure embankments" provide potentially useful insights into why particular SGMs may be used to mitigate and respond to geohazards, they cover a number of the SGMs covered by the task and cover a range of other very useful information regarding earthwork design in general.
United States - Department of Transport	
Links	http://www.fhwa.dot.gov/about/webstate.cfm (Accessed: May 2016)
Description	All of the US states have their own Department of Transportation (DOT), each with their own earthwork standards; examples of which can be found below. Some of these documents, many of which are freely available online, detail design life and performance characteristics, which may help to assess and compare the performance of SGMs across the strategic road network in Britain.Example:• California Department of Transport - Geotechnical Manualhttp://www.dot.ca.gov/hq/esc/geotech/geo_manual/manual.html (See "Ground Improvement")
The Foundation Engineering Handbook - Methods of Soft Ground Improvement, Hussin J 2006.	
Links	http://eirit.co.il/files/uploads/methods_of_soft_ground_improvement.pdf (Accessed: May 2016)
Description	Chapter from handbook discussing a number of the non-visible SGMs searched for as part of Task 594, when and why they might be considered, this information would likely aid in identifying potential purpose for SGMs utilised across the road network

RAILWAY

Jeremy Benn Associates (JBA) Consulting - Managing geotechnical assets effectively - CIV065 Earthworks Database (UK)	
Links	http://www.jbaconsulting.com/project/managing-geotechnical-assets-effectively-civ065-earthworks-database (Accessed: June 2016)
Description	GISmo is the data capture tool used by Network Rail for the inspection of earthwork condition, including the hazards present along the railway system. GISmo is JBA's mobile data collection software, which captures geographic features linked to GPS coordinates, linked to a web server to provide data synchronisation and a web-based mapping system for management and reporting purposes. The system has been developed since its initial inception in 2002 and remains NRs national geotechnical asset management system. This system sounds similar to the processes in place to inspect highways assets and so may contain information relevant to the outputs from Task 594.
Ground Improvement Techniques for Railway Embankments, Raju V 2003, Malaysia	
Links	http://www.fenixdigital.com.br/teste/keller/images/10-59E.pdf (Accessed: June 2016)
Description	This document discusses a number of SGMs searched for as part of Task 594 and also mentions a number of case studies, which could likely be further investigated to better understand how the mitigation techniques have worked and so likely aid in the identification of SGM performance and the recognition of performance patterns.
Railway Gazette - Ground improvement offers consistent subgrade stiffness, Brough M 2001, University of Birmingham (UK).	

RAILWAY

Links	http://www.railwaygazette.com/news/single-view/view/ground-improvement-offers-consistent-subgrade-stiffness.html (Accessed: June 2016)
Description	This news article contains a list of SGMs searched for in Task 594 and lists the geohazards they are used for. This may aid in identifying potential purpose for SGMs on the road network.
Canadian Rail Research Laboratory - Railway Ground Hazard Research Program (RGHRP)	
Links	http://www.carrl.ca/RGHRP (Accessed: May 2016)
Description	The Railway Ground Hazard Research Program (RGHRP) is a collaborative effort among industry, academic institutions and the federal government. The Program was created in 2003 to develop and evaluate scientific and technical solutions to help railways manage the risks associated with ground hazards. Phase 1 (2003-2008) and Phase 2 (2009-2015) focuses on scientific research and investigations to better understand the mechanisms that cause various ground hazards, develop guidelines to manage the risks, and develop and identify tools and technologies to mitigate the hazards. The research carried out here appears to be very similar to the work being carried out by Highways England (Task 408 & 594). Based on the information available online regarding the research being carried out it is possible that there are some useful and relatable outcomes that may come from this research project for the Canadian Rail Industry that may help to enhance the outputs from Task 594 and Task 408.

SGM SPECIFIC EXAMPLES

GEOGRIDS - The Properties and Performance of Tensar Uniaxial Geogrids	
Links	http://www.pg.gda.pl/~adusz/pliki/parametry_tensar_re.pdf (Accessed: May 2016)
Description	This research paper has been produced by Tensar International. The paper discusses the strength and long term creep rupture behaviour of geogrids at various conditions. It is likely that information such as this could be applicable in determining where the most at risk areas of geogrid are on the network based on geology and environmental conditions.
GEOGRIDS - The Properties and Performance of Tensar Uniaxial Geogrids	
Links	http://www.geofabrics.com/docs/The%20durability%20of%20geotextiles.pdf http://www.bbacerts.co.uk/CertificateFiles/49/4979PS1i1.pdf (Accessed: June 2016)
Description	In searching for specific SGM related research papers it is apparent that there are a large number of potentially useful sources of information. With papers covering a range of different areas of performance, some of which can be very specific, for example to certain geologies and soil types. This level of detail could be deemed very useful in assessing the performance of existing SGMs on the network, though would require an extensive knowledge of the environmental conditions coincident with the SGMs, some of which could be interpreted from the geology details already available on HAGDMS for each earthwork.