Proceedings of the 10th World Congress on Civil, Structural, and Environmental Engineering (CSEE 2025)
Barcelona, Spain - April 13 - 15, 2025
Paper No. ICGRE 119
DOI: 10.11159/icgre25.119

Slope Drainage Design and Operation: A Study of Legacy Assets

Elena Mugarza[1], Stephanie Glendinning[1], Ross Stirling[1], Colin Davie [1]
[1] Newcastle University School of Engineering
Newcastle Upon Tyne, United Kingdom
e.mugarza@newcastle.ac.uk

With contributions from
The Keighley & Worth Valley Railway Preservation Society
Haworth, West Yorkshire, United Kingdom

Abstract – Transport infrastructure slopes across the UK are vulnerable by their exposure to increasingly frequent inclement weather caused by climate change. Slope failures gain national press attention for the disruption they cause to essential transport links and the public expenditure required to repair and reinstate. Compacted clay soils, commonly used in the construction of embankments in the transport infrastructure sector, are subject to progressive deterioration caused by volumetric shrinking and swelling in response to wetting and drying cycles. Precipitation events in Britain are projected to increase in frequency and severity during the next decade with legacy earthworks (exceeding 80 years) enduring the effects of prolonged exposure to fluctuating weather cycles, reducing resilience of the infrastructure. They are also influenced by the prevailing construction method and design guidance of the age. The provision of slope drainage is a widely used mitigation technique used by transport infrastructure owner/operators facing slope stability challenges, and these are often retrofitted to legacy assets to capture and divert surface water. Effective drainage solutions should encompass a design that considers the slope globally; it's composition, any pre-existing instability or deterioration mechanisms, preferential flow pathways into existing desiccation cracks etc. However, it is questionable whether design details are changeable in practice, to better suit the existing earthwork and drainage baseline condition. Drainage installation method and maintenance strategies are vital components in ensuring that the drain contributes to improved slope stability, rather than allowing deeper and faster propagation of wetting fronts, causing increased pore-water pressure at depth. This paper sets out to investigate the flow path of water within legacy slope drainage, the deterioration mechanisms of the drainage material and clays surrounding. This will be evaluated through field investigation of a historic rail cutting with existing counterfort drains in place. This research aims to review the likely condition of aged slope drainage that has been negated from a frequent maintenance schedule, the subsequent impact and risk posed to the surrounding earthwork. The information gained from this research should aid understanding of deterioration mechanisms to both the slope drainage and earthwork soils surrounding these and the works that are required to avoid such a loss in performance and maintain earthwork stability.

.

Keywords: `Drainage trench, earthwork, legacy, retrofit, capillary barrier, soil columns, ground investigation'

1 Introduction

Climate change has been proven to increase air temperature globally (NASA, 2020) , changing local climates and weather patterns throughout the seasonal cycle. In the next decade Great Britain is anticipated to experience both prolonged drought events (Environment Agency 2006) as well as increased frequency and intensity rainfall events (Met Office 2020). The result of these more extreme weather conditions will be felt by infrastructure assets and their users (Dawson, 2017). These include utilities and freshwater distribution, transport networks, telecommunication systems and electric power distribution etc. The effective management of these assets in adverse weather conditions largely depends upon the accurate prediction of destructive weather events, proactive maintenance measures and continual investment.

Earthworks associated with transport infrastructure or Long Linear Assets (LLAs) are proven to be regular sources of failure, causing increased expenditure and interruption to service (Briggs, Loveridge and Glendinning 2017) Many British rail embankments and cuttings are in excess of 150 years old and do not offer the same resilience as those more recently upgraded or constructed (Power and Mian 2016). The majority of these failures are credited to increased precipitation events, with Network Rail recording 250 earthworks-related failures between 2019 and 2020 (Network Rail 2020) . The organisation has set out its plan for the £44.8 billion spend prior to 2029 with one of its key focus points being climate change response and the safety of core assets (Office for Rail and Road 2023).

The critical component of earthworks management is widely considered to be the effective control of surface and groundwater within these assets (Haines 2020). The successful design, installation and operation of suitable drainage systems is therefore arguably the most vital component of mitigation against failure for infrastructure-related slopes (Mizal-Azzmi, Mohd-Noor and Jamaludin 2011). The installation of this drainage may occur during initial construction or more commonly, as a retrofit process. Evaluation of hydraulic conductivity spatially throughout the earthwork, and particularly in the region immediately surrounding the drain, is a vital component of earthworks design (Soares Marques and Leroueil 2015) . However, conductivity will change with time and should be reassessed at progressive stages in the life cycle of drainage assets, particularly if the drain has not been maintained and therefore may have deteriorated. As an advisory report from Mott Macdonald to Network Rail states; '"Drainage can be an effective method of both controlling porewater pressures and stabilising slopes, although the presence of non-functioning drains can be detrimental to stability." (Mellor, Parry and Spink 2017).

This research aims to evaluate the capability of slope drainage to sufficiently convey water from a slope and control pore water pressure and investigate potential adverse impacts of neglected drainage. This paper focus on the investigation into deterioration mechanisms of granular trench drains and how these influence the surrounding clay soils.

2 Methods and Materials

In January 2024, access to the earthwork assets owned by The Keighley & Worth Valley Railway Preservation Society were granted for a small investigation and sample extraction for further laboratory testing, conducted over a two-day period. The site investigated was a railway cutting approximately 10 m in height 0.8 km north of Haworth train station, approximate grid reference: SE 03588 37931. This cutting was Victorian in age (prior to 1853) (National Library of Scotland 2024) and the counterfort drain is dated at approximately 1960 from anecdotal evidence. The superficial geology comprises Till, Devensian underlain by Millstone Grit Group sedimentary bedrock (British Geological Survey 2000). The location of the railway cutting and the latitude/longitude of investigation locations, together with a contextual photo are illustrated in the Figure below.

Approximate Latitude, Longitude	
Position A	53.837710, -1.9469639
Position B	53.837704 , -1.9471932
Position C	53.837615 , -1.9471423

Fig. 1: KWVR Investigatory Positions

A total of 3 locations for sampling and in-situ testing were chosen to reflect different positions along the drain, including upslope, mid-slope and downslope. The investigation comprised the hand removal of trench material (all) in three layers – each approximately 330mm deep. Observations regarding particle size, clay inclusion and an estimate of undisturbed void space were recorded at the scene. The 'trial pit' was incrementally photographed and material bagged for Particle Size Distribution (PSD) testing in the laboratory, in accordance with BS EN ISO 17892-4:2016. Neighbouring disturbed samples of clay, at corresponding depths, were extracted using hand auger methods and Dynamic Cone Penetrometer (DCP) was used in the clay bordering the drain. This in-situ testing data was used to give an accurate depiction of soil stiffness, along the depth of the interfacing clay. DCP testing was conducted in accordance with Transport Research Laboratory (TRL) technical guidance (TRL 2004). This methodology facilitated the comparison of all three investigation sites along the length of the drain, allowing for the assessment of changes in drain composition and any potential impact on surrounding clays due to soil movement, and how these changes occur spatially.

3 Results

The visual survey record for all drainage positions, with descriptions adapted to results from laboratory and in situ testing is shown in Figure 2 below. The presence of voids and clay encroachment into the drain was recorded, though this was limited to qualitative, visual observations. There is evident variation in drain compaction and clay content at locations both up and downslope. With the granular material at the most upslope position of the drainage trench noticeably more loose and with reduced fines content when compared with positions downslope. It was observed that the clay encroachment increased with depth in all positions, with Investigatory Position C completely impassible to water. Photos have been included for visual evidence of anecdotal descriptions and efforts were made to keep the materials extracted as undisturbed as possible for review and representative sampling in further laboratory testing.

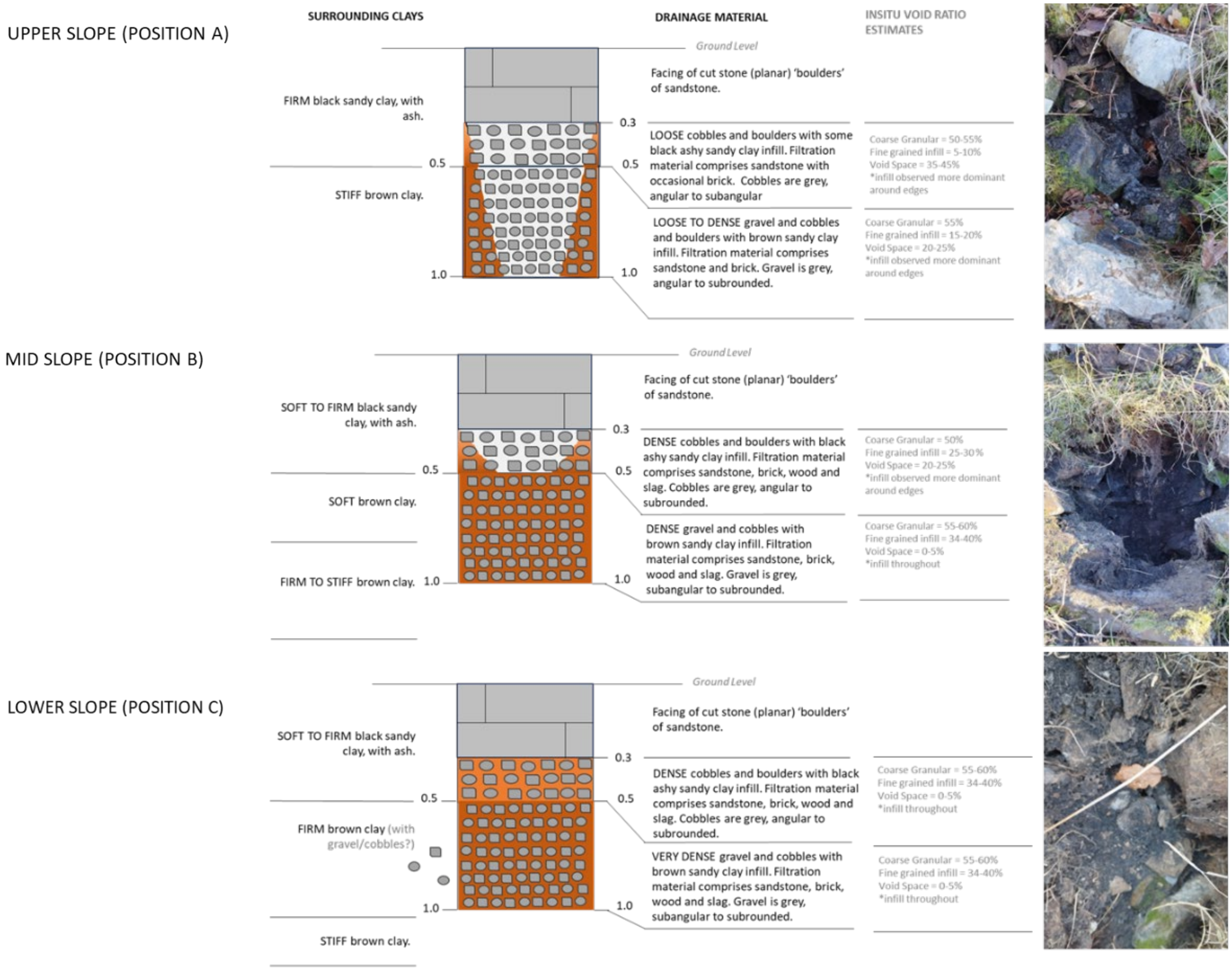

Fig. 2: Visual Investigation Record

It is notable that in modern earthwork drainage design details, gravel particle sizes are considerably smaller than those found at this site, which can be described as coarse gravel and cobbles which are not reflective of current best practice (British Standards Institute 2022). Additionally, modern design details would typically include a suitable perforated pipe connected to an outflow at the toe as well as a geotextile surrounding the drain to limit the lateral movement of fine material. The inclusion of these reduces the deterioration of the drain itself but does require increasingly frequent maintenance and replacement, up to every 10 years (Network Rail 2021).

In situ DCP results are shown in Figure 3. In the case of the investigation example, softening of the clays surrounding the mid and lower slope drains are visible, with areas of softening from 0.5m depth and below. The results circled in red are reflective of test termination due to the presence of drainage gravels that have spread into the clay surrounding. In all positions DCP tests were conducted a total of three times.

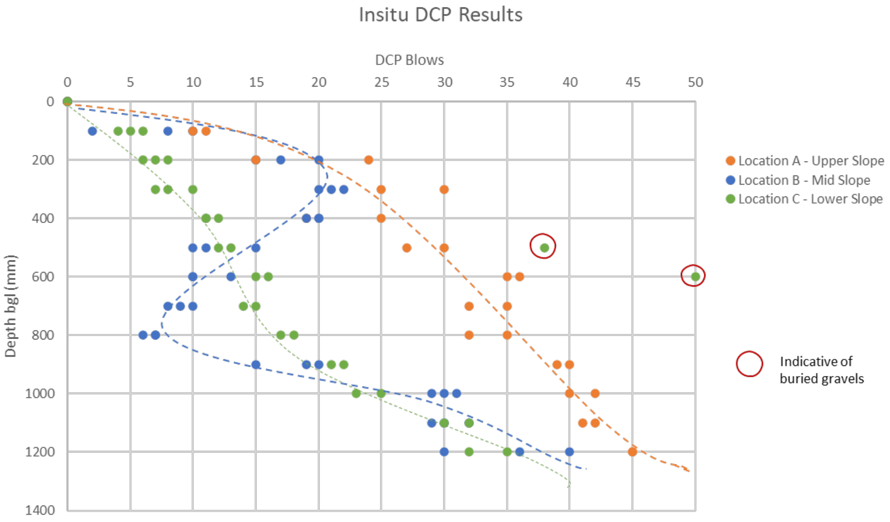

Fig. 3. In situ Dynamic Cone Penetrometer (DCP) results adjacent to drain.

4 Discussion

Clay content in drainage voids is shown to increase with both vertical depth of drain and distance downslope caused by the gravitational movement of water and carried fine particles. The presence of fines in the drain reduces the free flow of water through the drain and can cause the backing up of such water in a storm event. It is noted that these drainage assets are assumed to be more than 60 years in age, with no record of maintenance activities. This example is representative of the impact of both superseded design details that preclude the use of geotextiles for fines protection or water conveying perforated pipes, together with negligeable maintenance.

The DCP values and distribution demonstrate the softening of the clays surrounding the mid and lower slope. It is considered that this is caused by the inability of the drain to successfully convey excess water and its subsequent storage within the drain. The softening of the clay immediately around the drain is then caused by the outward egress of water from the drain of this stored water, though this mechanism is clearly not proven. The most pronounced demonstration of this mechanism is at the mid-slope (point B), where the clay encroachment into the drain is partial, but further movement of water downslope is prohibited by the completely clay encroached region of the drain beneath this point down the slope. If the DCP results are used to calculate Uniform Compressive Strength (UCS) these give a range of values of between approximately 100-1300kPa (Alshkane, Ahmad Rashed and Daoud 2020). The UCS of soils is observed to have a detrimental impact of slope stability and reflect a weakened plane the could potentially cause small scale rotational or more wide spread translational failures. There is also evidence to suggest the gradual pushing out of drainage material into the surrounding clays from its original trench location, occurring from the drain base and expectedly further up slope as the drain pore spaces fill and push outward progressively. The values that suggest this are circled and the rounding off of the drain boundary and merging of clays with filtration material was evident during the visual survey.

Figure 8 provides a visual summary of the hypothesis proposed movement processes occurring over years of repeated storm cycles, evident through this investigation. These deterioration mechanisms include the fines material wash out from surrounding clays into the drain voids, the settlement of this material vertically within the drain, and down-slope within the drain. This is accompanied by gradual lateral push-out of gravel material into clay soils surrounding the drain, causing a blurring of the drain-clay boundary. This phenomena occurs firstly at the base of the slope drain and then gradually works upwards, as the drain voids are filled at mid and upslope positions. Additionally, softening of surrounding clay occurs as it is exposed to water held within water pockets in the gravel that are surrounded by clay that is inhibiting its movement down-slope.

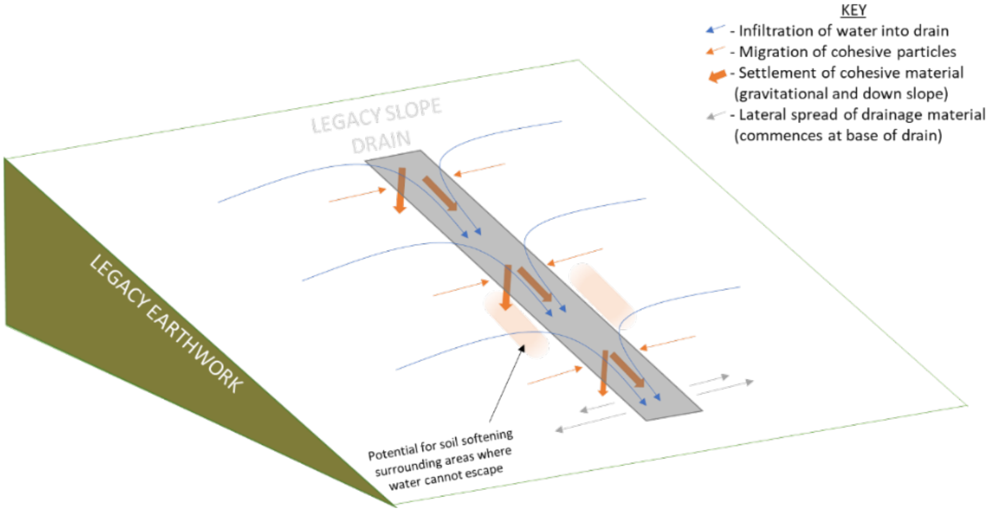

Fig.4: Movement Schematic Diagram

5 Conclusions

In summary this paper has investigated the potential adverse impacts of neglected drainage assets on slope stability. Through the field investigation of a legacy railway cutting and counterfort drains evidence was used to propose a hypothesis for drain deterioration and its adverse impact on slope stability. These deterioration mechanisms include clay encroachment within the drainage trench boundary. This is more prevalent in the lower sections of the drain and downslope, with gravity and water movement working simultaneously to occlude the poor spaces and form a blockage. The infilled void spaces are likely to prohibit the moment of water into channels at the base of the slope. The surface and stormwater water movement within the drain is likely to become trapped and this in turn may cause progressive softening of the clay soils surrounding, when exposed to wetting over prolonged and repeated time periods. This paper supports the viewpoint that "the presence of non-functioning drains can be detrimental to stability." (Mellor, Parry and Spink 2017)

ACKNOWLEDGEMENTS

I would like to thank the personnel at The Keighley & Worth Valley Railway Preservation Society who assisted me in the completion of the field investigation. Also, Richard Taggart and Richard Turland who have provided support in the field and laboratory. The work presented is an output of the collaborative research programme grant ACHILLES (programme grant number EP/R034575/1) funded by the UK Engineering and Physical Sciences Research Council (EPSRC).

REFERENCES

Abdolahzadeh, Amir M. "Evaluation of the effectiveness of a cover with capillary barrier effect to control percolation into a waste disposal facility." *Canadian Geotechnical Journal Volume 48, Number 7*, 2011.

Alshkane, Y, K Ahmad Rashed, and Hyam Daoud. "Unconfined Compressive Strength (UCS) and Compressibility Indices Predictions from Dynamic Cone Penetrometer Index (DCP) for Cohesive Soil in Kurdistan Region/Iraq." *Geotech Geol Eng*, 2020: 3683–3695.

Briggs, K.M., F.A. Loveridge, and S. Glendinning. "Failures in transport infrastructure embankments." *Engineering Geology*, 9 March 2017: 107-117.

BRITISH GEOLOGICAL SURVEY . *Bradford, England and Wales Sheet 69 Solid and Drift Geolofy 1:50,000.* Keyworth, Nottingham, 2000.

British Geological Survey . *Geological Survey of England and Wales 1:63,360/1:50,000 geological map series, New Series 69:Bradford.* Nottingham: British Geological Survey , 2000.

British Standards Institute . *BS EN ISO 17892-4. 9.4 Particle size distribution dry and wet seiving.* BSI, 2022.

British Standards Institution. "BS EN ISO 17892-12:2018+A1:2021 Geotechnical investigation and testing. Laboratory testing of soil - Determination of liquid and plastic limits." *British Standards Institution.* 2021. https://knowledge.bsigroup.com/products/geotechnical-investigation-and-testing-laboratory-testing-of-soil-determination-of-liquid-and-plastic-limits-1?version=standard (accessed 08 06, 2024).

DEFRA. "Sustainable Drainage Systems: Non-statutory technical standards for sustainable." March 2015. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/415773/sustainable-drainage-technical-standards.pdf (accessed 08 10, 2024).

Environment Agency . *Flood risk assessments: climate change allowances.* 2022. https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances (accessed 08 14, 2024).

Environment Agency. "The impact of climate change on severe droughts: Major droughts in England and Wales from 1800 and evidence of impact." 2006.

Haines, A. *Resilience of rail infrastructure: Interim report to the Secretary of State for Transport following the derailment at Carmont, near Stonehaven.* Rail, Network, 2020.

Holmes, J, R Stirling, N Thaman, C Davie, and S Glendinning. "Composite Barrier Systems for Climate Adaptation." *8th International Conference on Unsaturated Soils.* E3S Web of Conf, 2023.

HOSKIN SCIENTIFIC. *Tipping Counter KIPP004.* 2024. https://hoskin.ca/product/tipping-counter-2/.

Mainland Aggregates LTD. *40mm Gravel/Shingle.* 2024. https://www.mainlandaggregates.co.uk/40mm-gravel-shingle.html (accessed 08 06, 2024).

Mellor, R, L Parry, and T Spink. *CP6 Earthworks Asset Policy Development Task 36 – Global Stability and Resilience Appraisal Interim Report.* Mott Macdonald , 2017.

Met Office. *UK extreme events - Heavy rainfall and floods.* 2020. https://www.metoffice.gov.uk/research/climate/understanding-climate/uk-extreme-events-_heavy-rainfall-and-floods (accessed Nov 23, 2020).

Mizal-Azzmi, N, N Mohd-Noor, and N Jamaludin. "Geotechnical Approaches for Slope Stabilization in Residential Area." *Procedia Engineering*, 2011: 474-482.

NASA. *NASA - Global Climate Change: Vital Signs of the Planet.* 2020. https://climate.nasa.gov/vital-signs/global-temperature/ (accessed Nov 23, 2020).

National Library of Scotland. *Historical ordnance survey - OS One Inch 1860.* Edinburgh: Ordnance Survey, 2024.

Network Rail . *A Review of Earthworks Management, Prepared by a Task Force led by Professor Lord Robert Mair.* Network Rail , 2021.

Network Rail. *Resilience of rail infrastructure - Interim report to the Secretary of State for Transport following the derailment at Carmont, near Stonehaven.* Network Rail, 2020.

Office for Rail and Road . *Periodic review 2023 of Network Rail: draft determination.* gov.uk. 8 August 2023. https://www.gov.uk/government/consultations/periodic-review-2023-of-network-rail-draft-determination (accessed August 24, 2023).

Power, C, and J Mian. "Development of an Evidence-based Geotechnical Asset Management Policy for Network Rail, Great Britain." *Procedia Engineering*, December 2016: 726-733.

Raymond, G P, R J Bathurst, and J Hajek. *Evaluation and suggested improvements to highway edge drain.* Canada: Department of Civil Engineering, Queen's University, epartment of Civil Engineering, Royal Military College of Canada, Ministry of Transportation, 1999.

Soares Marques, M, and S Leroueil. "Vacuum Consolidation and Vacuum Consolidation with Heating." *Ground Improvement Case Histories*, 2015.

Spudulica. *Non-Woven 100gsm Geotextile Membrane Rolls.* 2024. https://spudulica.co.uk/products/non-woven-100gsm-geotextile-membrane-rolls (accessed 07 24, 2024).

Standards for Highways. *MANUAL OF CONTRACT DOCUMENTS FOR HIGHWAY WORKS VOLUME 1 SPECIFICATION FOR HIGHWAY WORKS.* Bristol: Standards for Highways, 2020.

TRL. *Dynamic Cone Penetrometer tests and analysis*. Berkshire: Department for International Development, 2004.