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The Forensic Examination of Critical Special Geotechnical Measures

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Abstract

The effective design, specification and construction of Special Geotechnical Measures (SGMs) is critical to the efficient operation of the National Highways Strategic Road Network (SRN). Given the required performance of the SRN in terms of resilience, reliability, redundancy and recovery it is essential that SGMs are themselves reliable in terms of performance and service life; resilient to external conditions such as earthworks deterioration and extraordinary conditions (e.g. climate change). This study sought to validate, or otherwise, the predicted long-term performance of selected critical SGMs, namely Counterfort Drains, Block Walls, Gabion Walls and Soil Nails. In this paper, we will present a brief summary of the findings from this work and introduce sources of our more detailed findings.

Keywords: Performance, Counterfort Drains, Block Walls, Gabion Walls, Soil Nails.

1. Introduction

The National Highways Strategic Road Network (SRN) in England relies upon a wide range of Special Geotechnical Measures (SGMs) to strengthen or enhance the natural geological materials, or engineering materials derived from them, to form earthworks. There are currently around 100 SGM-types, and the design, specification and application of many of these techniques is based on limited studies. Many of these techniques have been in service for periods approaching their predicted design lives (60 or 120 years). This project was initiated in order to take account of this timing to validate the previously predicted long-term performance of these SGMs.

SGMs are defined as "… measures over and above general earthworks construction required to; mitigate geotechnical risk associated with ground related hazards or remediate geotechnical defects that may have resulted from the presence of geo-hazards. Similar techniques implemented to facilitate widening or other improvements are, for the purposes of this task, also classified as Special Geotechnical Measures" (Atkins/Jacobs, 2020).

Planned SRN Major Projects and Operational Renewals presented a significant and innovative opportunity to undertake forensic examination, including the potential exhumation of elements, to determine the validity of existing design, specification and application guidance. As many of the SGMs were nearing the end of their design lives it was also a unique opportunity to determine their in-service performance against that predicted and relied upon in terms of design life.

Given the required performance of the SRN in terms of resilience, reliability, redundancy and recovery it is essential that SGMs are reliable and resilient to external conditions such as earthworks deterioration and extraordinary conditions (e.g. climate change). The overall aim of the project was to better understand the long-term performance of SGMs to enable investment decisions for future improvements and renewals.

The most critical SGMs on the SRN were identified from Atkins/Jacobs (2020), interrogation of National Highways' Geotechnical and Drainage Management Service (GDMS), the results from a questionnaire survey of the wider National Highways geotechnical community, and consultations with UK asset owners and operators as described by Duffy-Turner et al. (2022a). This overview report gives extensive background and commentary on the issues encountered for each of the SGMs identified and a summary of the available advice and guidance on the design, specification and construction of each SGM-type. It also details the methodology developed to prioritise site inspections to examine these SGMs and reports on the examinations and other work undertaken to produce the Information Notes. SGMs were examined where possible and information from failures, and other cases in which expert opinion had been sought, was also gathered.

Information Notes were produced for Block Walls (Winter et al. 2022a), Gabion Walls (Duffy-Turner et al. 2022b), Counterfort Drains (Nettleton et al. 2022) and Soil Nails (Duffy-Turner et al. 2022c) to guide their future design, specification, construction, maintenance and inspection. The Information Notes particularly address the need, or otherwise, for action in terms of changes to, for example, the Design Manual for Roads and Bridges (DMRB) and/or Manual of Contract Documents for Highways Works (MCHW).

At the outset it was anticipated that outcomes could follow a range of possibilities. These might include that some SGMs need further guidance to be developed for design, specification and/or construction in order to continue as viable SGM options on the National Highways SRN. Other SGMs could be reviewed and found to have limited to no potential for future use on the National Highways SRN for reasons that might include, but not necessarily be limited to, technical, environmental and safety factors. Additionally, the performance of existing applications may be found to be inadequate relative to the assumptions made at the design stage and their longer-term suitability potentially compromised; in such cases, advice would need to be provided on the potential need for decommissioning of SGMs. Other instances could lead to no further action being required.

The work will enable National Highways to appropriately employ (or otherwise) the selected SGMs on the SRN and to assess future requirements for upgrading or replacing SGMs nearing their end of life.

In this paper we report the primary conclusions made in respect of each SGM and the specific recommendations. We also present wider overarching issues and associated recommendations and point to the freely-available Information Notes that contain much more detail.

2. Block Walls

In the GDMS the different types of walls appear to not always be differentiated and Block Walls (BLCW) often appear to be the default selection for other wall types including Masonry Walls (BKRW) and Stone Walls (STNW). This may be an instance where SGM categories have become too highly resolved and it is recommended that consideration be given to combining these categories.

The interface between SGMs and structures is clearly an important issue, and it is not entirely clear which types of Block Wall (material, structure or function) are being recorded in the GDMS or in the Integrated Asset Management Information System (IAMIS). It is recommended that the Structures Manager review the SGM layer in GDMS.

There is no compelling evidence (Winter et al. 2022a) that when properly designed, specified, constructed and maintained, including an appropriate inspection regime, Block Walls cannot meet the required design life (120 years) of such SGMs (Figure 1).

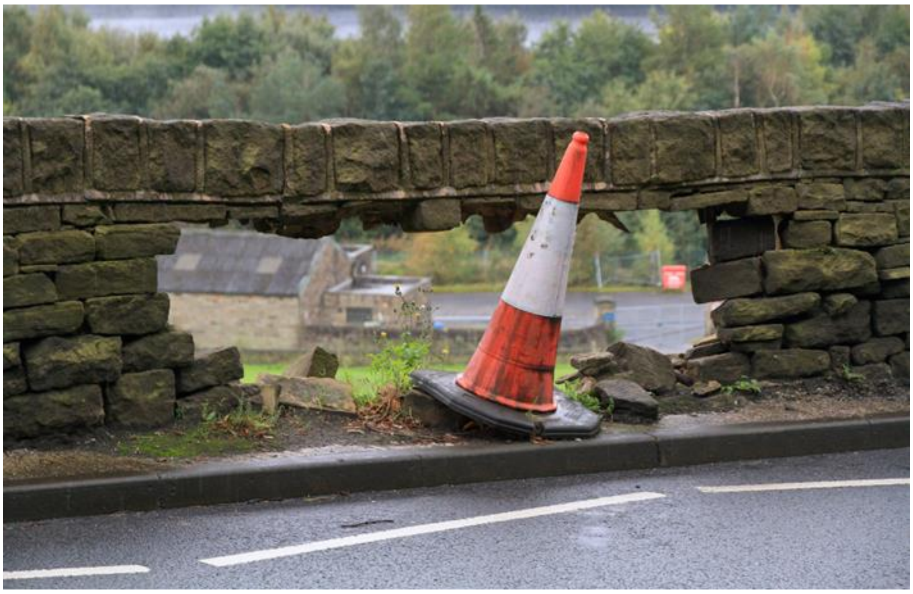

Figure 1: Upper free-standing part of a dry-stone retaining wall (mortared coping) showing the effects of vehicle impact. The wall below the carriageway retains a height of between 2m and 3m below the road.

Advice in standards and other related documents for Block Walls is clearly limited. Through the course of this work a number of key issues have been identified and these are set out as recommendations for action in the following paragraphs.

Recommendation 1: The design of Block Walls should take due cognisance of manufacturer's information, where relevant, as well as fundamental design principles.

Recommendation 2: The provision of adequate and appropriate drainage for Block Walls should be addressed through the design, specification and construction phases.

Recommendation 3: The use of argillaceous rock to form Block Walls is not recommended, due to the possibility of rapid deterioration, in particular in locations of high exposure.

Recommendation 4: It is further recommended that National Highways consider the development of a formal risk-based approach for inspection and maintenance of Block Walls. This would assign values to attributes of Block Walls during assessment to allow prioritisation of actions including maintenance and replacement. Attributes to be considered include, but are not limited to, wall type, condition, provision and effectiveness of drainage, and proximity to road users.

3. Gabion Walls

Based on the gabion walls inspected, which ranged from eight to 46 years old, there is no compelling evidence (Duffy-Turner et al. 2022b) that when properly designed, specified, constructed and maintained, including an appropriate inspection regime, Gabion Walls cannot meet the required design life (120 years) of such SGMs.

Advice in standards and other related documents for Gabion Walls is well defined in some areas (such as specification) and limited in others (such as construction). Through the course of this work a number of key issues have been identified and these are set out as recommendations for action in the following paragraphs.

Recommendation 1: That as part of the design it should be ensured that the most appropriate Gabion Wall type (woven or welded mesh) is selected for its application.

Recommendation 2: That the use of a filter/separator behind the wall should be considered in all cases.

Recommendation 3: That the requirements given in MCHW Volume 1 Clause 626 be updated to (say) 'stone fill used in gabion walls should be sufficiently durable so as not to suffer deterioration sufficient to impair the performance of the system during the design life of the installation'. This brings the recommendation broadly in line with BS 8002:2015 and would prevent the use of inappropriate stone (and other) fill (Figure 2).

Figure 2: Oversize concrete fill leading to large voids within the gabion baskets. The oversize fill also means that the gabions have been unable to be properly sealed along the top, instead they are secured at pinch points where the fill allows.

Recommendation 4: That modifying of gabion baskets on site shall be reserved for only those instances in which recognised manufacturers cannot produce a prefabricated suitable solution. Any modifications should be done in accordance with manufacturer's instructions and will require agreement as part of the technical approvals process.

Recommendation 5: As part of the technical approval process, it should be ensured that a Gabion Wall solution is the most appropriate for the environment. This includes careful consideration before designing Gabion Walls within tidal and marine environments, adjacent to public footpaths where vandalism is a possibility and low-height gabions placed in location where vehicle over-run is likely.

Recommendation 6: Gabion fill which does not meet the requirements of the MCHW should not be used on site unless there is a specific aesthetic requirement. Any deviations should be discussed in advance and agreed as part of the approvals process (Figure 2).

Recommendation 7: Issues identified during the site inspections highlighted that double corrosion protection was not always used and that the wire may be thinner than required; therefore, it is apparent that further enforcement of the specification is required by the Works Examiner.

Recommendation 8: That the inspection of SGMs should be certified by a UK Registered Geotechnical Adviser or equivalent.

4. Counterfort Drains

Counterfort Drains cannot meet the required design life for slopes of 60 years without significant intervention, as the filter/separator and drainage aggregate element are likely to need refurbishment or replacement. There is a body of evidence (Nettleton et al. 2022) that suggests that this will be required at between 15 and 25 years assuming that the Counterfort Drains are maintained. There is substantial evidence (Nettleton et al. 2022) that in the UK, counterfort drain design, specification and construction is frequently not at a level that would promote longevity of this nature.

Recommendation 1: There is confusion within the industry regarding the different types of slope drains, their function, form, design, construction and potential performance. There is a corresponding lack of specific and consolidated guidance. It is considered that the provision of such guidance is a matter of some significant need, and it is strongly recommended that this be taken forward through the auspices of the Geotechnical Asset Owners Forum.

Recommendation 2: It has been identified that there is a lack of official design guidance for Counterfort Drains. It is important that an appropriate opportunity is sought to produce a guidance document for the design of Counterfort Drains and that the outcomes are incorporated in appropriate standard(s).

Recommendation 3: It is recommended that the design of Counterfort Drains must clearly identify, assess and account for the following features and functions:

- Slope failure mechanism(s) and depth(s) of slip planes to be treated by the drains and/or buttresses.
- Whether the drains treat groundwater only or a combination of surface and ground water. If the latter is the case, then they must be specifically designed to cope with that combination. The specific issues that must be addressed are inter alia clogging of the drain surface and the higher flows implicit where surface water is additionally collected.
- In addition, consideration must be given to ensuring that the drain can be effectively maintained so that water does not back up and enter the slope, thereby decreasing stability and compromising the drain filter cake.
- Potential for the drain to receive significant surface/groundwater flows which may mobilise and transport the drainage aggregate causing a debris flow type failure onto the asset below.
- Careful consideration of the velocity of surface water flow and the slope gradient are critical, and interlinked factors, in ensuring that washout of the drainage aggregate does not occur. Such considerations should form an integral part of the design by determining appropriate limits on surface water flow velocity.

Recommendation 4: Given the potential for a variety of drainage systems to interact it is vital that the often-competing requirements of the various systems are clearly understood and accounted for in the design.

Recommendation 5: Carrier and collector drain functions should remain separate and where necessary a particular Counterfort Drain construction may incorporate the usual collector pipe and a carrier pipe to transport water from (say) the Crest Drain and/or Interceptor Drains to a suitable outfall at the toe.

Recommendation 6: The geotechnical designer should coordinate their design with the relevant landscape/environmental designer to ensure compatibility on planting schemes.

Recommendation 7: Regardless of flow rates a perforated collector pipe should be installed in a Counterfort Drain which outfalls into a catchpit at the toe. The catchpit at the toe would also assist with locating the Counterfort Drains for inspection and maintenance purposes.

Recommendation 8: Mineral filters or, more commonly, geosynthetic filters/separators are required at the trench boundaries.

Recommendation 9: Significant changes in vertical and/or horizontal alignment, in particular towards the base of steep slopes, should be made wholly within a catch pit designed to resist the forces and flow transition resultant from the flows.

Recommendation 10: Following construction of the Counterfort Drains they should be physically marked on site to allow easy identification in the field. They should have the top and bottom coordinates located in the GFR and be provided in Building Information Modelling (BIM) format or similar.

Recommendation 11: The service life of filter drains, including Counterfort Drains, is likely to be in the range of 15 to 25 years at best (Figure 3). Specific provision should be made for the appropriate inspection of such drains in order that they can be refurbished or replaced before their lack of functionality increases instability to an unacceptable level.

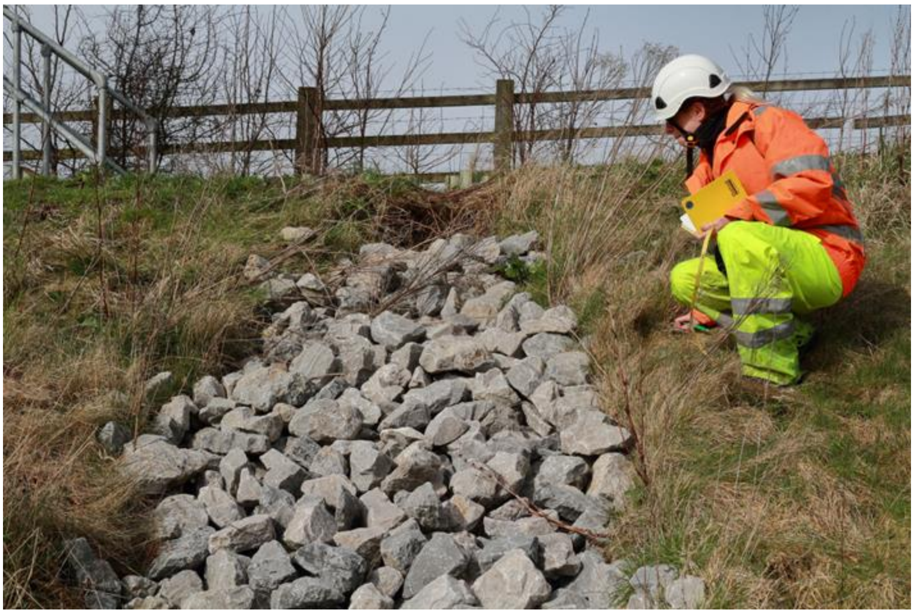

Figure 3: Settlement of large-sized drainage media at the head of a counterfort drain.

Recommendation 12: It is recommended that maintenance procedures are specifically targeted at ensuring that trees and shrubs do not grow adjacent to Slope Drains of any type. The distance between the drain boundary and such growth should be specified in the GFR.

Recommendation 13: In addition, it is recommended that vegetation maintenance precludes the deposition of vegetation debris on drain surfaces or on the surface of a slope where it can migrate onto the surface of drains.

Recommendation 14: Where Counterfort Drains and/or Slope Drains are designed to intercept surface water flows then scarification will be required to prevent clogging of the surface of the aggregate. Clearly the frequency will depend upon the site location and the environs; however, a frequency of every four years could be a reasonable starting point as this can be tied in with the maintenance required every two years.

5. Soil Nails

Soil nails systems have many components including the facing, the head plates, the method of construction and corrosion as well as the nail itself, all of which affect the design, specification and construction.

While generalisations are difficult the available information does seem to indicate that the overall design issues are generally well-understood but that, perhaps, there is room for improvement and updating of some of the design standards. This may suggest that designers are too dependent upon the standards and specifications.

Comments from the questionnaire survey (Duffy-Turner et al. 2022c), appear to demonstrate that the resultant problems are clearly understood, with drainage/water issues leading to some sort of failure, but that the solutions appear almost exclusively to address the failure with little to no attempt to address the cause. Construction practices play a key role to the issues surrounding soil nails, whether that be a failure to sequence the construction, to properly install the nails or to complete the installation by tightening the face plate nuts.

What does appear to be clear is that the original design philosophy and construction approach applied to soil nails entailing the use of double-corrosion protection appears to have been lost. While it is appreciated that considerations related to economy are important the additional resilience afforded by such protection is considered to be important. In addition, the use of self-drilled nails has come to the fore (Figure 4). This raises many issues related to the durability of nails that may be damaged during installation, including by the centralisers that are vital to ensure that the nail is centred in the hole, but which can, in turn, compromise the ability of the grout to fill the annulus between the nail and the holes. This is particularly relevant when the hole is drilled uncased.

Figure 4: Self-drilled soil nail lying on the base of the borehole due to failure to use centralisers. This reduces the grout cover for corrosion protection and potentially reduces the bond strength.

There is no compelling evidence (Duffy-Turner et al. 2022c) that when properly designed, specified, constructed and maintained, including an appropriate inspection regime, Soil Nail SGMs cannot meet the required design life for either slopes (60 years) or for structures (120 years) of such SGMs. However, there is substantial evidence (Duffy-Turner et al. 2022c) that in the UK, soil nail design, specification and construction is frequently not at a level that would promote longevity of this nature. Through the course of this work a number of key issues have been identified and these are set out as recommendations for action in the following paragraphs.

Recommendation 1: Structural applications with a hard facing and an effective retained height of more than 1.5m and slope applications in network critical locations should be double corrosion protected. Single corrosion protection should be used only for slopes, with flexible facings, in areas of lower network criticality.

Recommendation 2: It is recommended that the design process for soil nail facing be reviewed and revised in line with the issues identified in by Duffy-Turner al. (2022c). It is important that an appropriate opportunity is sought to review and revise the soil nail design process as it pertains to facings and that the outcomes are incorporated in appropriate standard(s).

Recommendation 3: During the review of soil nail facings (as per Recommendation 2), the use of flexible facings, specifically for clay slopes, should be considered further. When properly constructed these flexible facings have the ability to work well; however, poor construction can lead to large vertical and horizontal deformations which have been seen on numerous soil nail schemes.

Recommendation 4: The use of centralisers should be maintained in accordance with Phear et al. (2005) and BSI 8002:2011 to ensure a continuous grout annulus around the tendon. It is recommended that all metal should be avoided in a centraliser to reduce the risk of damage to the tendon.

Recommendation 5: It is recommended that in the case of batch construction drilling should be limited to one row at a time and only grout flush should be allowed as it will assist in stabilising the bore and assist with the formation of a continuous annulus. This is especially important in weaker or more granular soils. If grout flush is not considered to be suitable for site, then consideration should be given as to whether to case the hole to prevent collapse. A detailed assessment of the ground conditions by the designer would be required to make this decision.

Recommendation 6: The effect of de-icers on soil nail systems is an issue that has been less than fully investigated and further work may be needed. In the first instance this might take the form of estimates or modelling of the quantity of de-icers affecting SGMs both above and below road level, the associated acceleration of the corrosion rate and the consequential loss of stability. The results from such work could then inform the basis of decisions on whether more detailed and complex physical investigations and tests would be required to refine the understanding of such effects.

Recommendation 7: Facings are likely to be subject to de-icing agents and, in order to achieve the required durability for the design life of the soil nail system, steel facing materials are likely to require corrosion treatment such as plastic coating. The majority of the sites inspected as part of this project had a plastic coating on the facing mesh; however, head plates and nail ends were typically exposed. Further investigation and guidance are called for that is directly associated with soil nails.

Recommendation 8: It is recommended that the MCHW 1 should include a requirement that all reinforcing geosynthetic materials used as slope facing for soil nail slopes be fully protected against UV exposure. Further, such protection should not rely on the establishment, growth or persistence of vegetation that can be unreliable on steep slopes, particularly in the context of climate change.

Recommendation 9: Investigate further the potential for debonding at the nail grout interface due to the production of hydrogen gas from a reaction between the zinc galvanisation and the hydroxides in the cement grout (Roberts. P, personal communication, 25 February 2022; Otchere 2018). If this is a concern, as initial research may suggest, the use of any chromate passivation would need to be balanced against the risks of chromium to human health.

Recommendation 10: There is a need to ensure that the design and construction of soil nail systems on the SRN takes full account of the following issues:

- Programme for the works should take weather conditions into account as cutting into soil slopes in winter is not recommended.
- If the ground conditions are not as anticipated the soil nail system (soil nails, facings and drainage) needs to be reassessed to ensure that it is still acceptable.
- Ensure that the water conditions (ground and surface water) are completely understood prior to installation of the nails and ensure that drainage provision is a consideration from the outset.
- If using bored and grouted soil nails, a tremie pipe should be inserted to the full depth of the borehole to ensure proper grout placement. The grouting should continue at low pressure until the grout emerges from the top of the hole.
- Grout take must be recorded for assessment against the anticipated grout take as this will give an indication if a hole has not been completely filled due to a blockage or collapse of the hole.
- Ensure the facing is tensioned sufficiently in accordance with the manufacturer's specifications and installation guidance. If this is not possible then an alternative facing solution (i.e. hard facing) should be used.
- Ensure the galvanisation or epoxy coating on the tendons is checked on site for damage prior to installation of the soil nails and that damaged tendons are rejected.

- Maintenance of vegetation on soil nail slopes is required to prevent damage to the facing and nails by the growth of large shrubs and trees.

6. Overarching Issues

Throughout this project, contractor self-certification has been raised and evidenced (Duffey-Turner et al. 2022a) as one of the most significant issues that leads to poor construction. The issues may not be apparent at the time of construction and therefore may not be addressed by the designer or client, leading to subsequent poor performance and early-life failure of not only SGMs but other forms of construction. Indeed, this issue has been highlighted on other National Highways projects on which the authors have worked and in work for other infrastructure owners and operators both in the UK and overseas.

A high-profile example of this is found in the Earthworks Task Force Report (Mair, 2021) on the Carmont Rail Disaster, which notes in the context of water management, drainage assets and the associated risks that “There is very limited supervision of drainage work by [Network Rail], with a reliance on contractor self-certification”.

It is considered that a move to cease contractor self-certification and revert to a more conventional client-led Construction Quality Assurance scheme in order to ensure quality of execution of Works is strongly indicated. The use of contractor self-certification is not considered to be in the best interests of any party including the client, designer and, indeed the contractor.

Also strongly indicated is, earlier and more extensive operational and maintenance geotechnical input to Major Works in order to ensure specification compliance, acceptability for use and handover to the operator. In addition, inspections for the acceptance of constructed works should be undertaken prior to the site becoming fully operational and it is recommended that provision for early inspection should be built into the contract.

The effective implementation of these recommendations increases the likelihood of right first time construction and greatly reduces the risks associated with future defects and deterioration. This becomes even more critical in the light of predicted climate change which is expected to exacerbate geotechnical asset deterioration.

Acknowledgements

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