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Innovative Geotechnical Repair Techniques

Recommendations and Guidance for Management of Future Highways England Trials with Innovative Techniques

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Executive Summary

Work to evaluate the effectiveness of innovative geotechnical repair techniques for slopes has been commissioned by Highways England. The techniques evaluated are the planting of live willow poles, Fibre Reinforced soil (FRS) and Electrokinetic Geosynthetics (EKG). These techniques were used in place of conventional slope stabilisation approaches in order to reduce the overall impact of various challenges including environmental constraints (habitat and visual), access and utility constraints, and the need to reduce the scale and/or cost of traffic management and traffic delays.

The effectiveness of each technique has been assessed, in separate reports, on the basis of trials conducted over the last 20 years. In this report the generic lessons regarding the planning, design and execution of such trials are brought together. These generic lessons have been derived from the detailed assessment of 12 trials and practical applications of the innovative repair techniques.

This information provides guidance for future Highways England trials of innovative geotechnical repair techniques. This guidance covers the purpose of the trial, site selection (including interaction with other works), location and access, verification and monitoring, and maintenance of the trial. The aim is to ensure that future trials of such innovative techniques produce clear and tangible documented evidence of their success, or otherwise.

Issues that are addressed include ensuring that the location is precisely defined along with safe access and egress; that the duration of the monitoring programme is sufficient to truly evaluate the effectiveness of processes, such as slope movement, that can be on a decadal scale; and that the verification and monitoring is relevant to the evaluation of the geotechnical processes that are important to the trial.

1 Introduction

Work to evaluate the effectiveness of innovative geotechnical repair techniques for slopes has been commissioned by Highways England. Trials of the techniques used have been undertaken over the last 20 years and reports produced on the effectiveness of each technique. The techniques are the planting of live willow poles (Winter et al. 2018), Fibre Reinforced Soil (FRS) (Seddon et al. 2018) and Electrokinetic Geosynthetics (EKG) (Nettleton et al. 2018). The innovative techniques were used in place of conventional slope stabilisation approaches in order to reduce the overall impact of various challenges including environmental constraints (habitat and visual), access and utility constraints, and the need to reduce the scale and/or cost of traffic management and traffic delays.

The introduction of new techniques, materials and processes to any industry is fraught with difficulties; this certainly applies to the construction industry as assets impact on public safety and as a direct result the approach can be relatively conservative and risk averse. The primary motivation for change is almost always the opportunity to increase effectiveness and efficiency to save cost and increase performance and profit, be it by time or labour savings, or the reduction of risk.

Jones et al. (2017) present an interesting assessment of the introduction of EKG to the UK construction industry using the Gartner Hype Cycle (see also Hansford 2016). They note that the initial research conducted in a university environment, the ‘Technology trigger’, was closely followed by a flurry of interest and the proposal of a host of potential applications, not all of which may have been entirely appropriate. They termed this period the ‘Peak of inflated expectations’.

This experience has, to a large extent, been mirrored by the introduction of both tyre bales and waste steel aggregate (Winter et al. 2009; Gomes Correia et al. 2015) to construction. It is clear that for all of these materials and techniques that the Jones et al. (2017) ‘Peak of inflated expectations’ is followed by a period described as the ‘Trough of disillusionment’ during which less suitable applications are discarded often following unsuccessful trials. As commercialisation then successfully drives forward those applications that are most suited to the techniques, materials and processes a ‘Slope of enlightenment’ is climbed and eventually a ‘Plateau of productivity’ is reached as they enter practice, cease to become viewed as novel and no longer require to be trialled (e.g. Simm et al. 2008).

This sequence is not dissimilar to a sequence of ‘Blue Skies’, aspirational, prototype/demonstration and adopted technology. The Technology Readiness Level (TRL) is used by Highways England to classify and select pavement technology innovations and this is referred to in relation to the three techniques considered (Willow Poles, FRS and EKG) in Section 6. Whichever system is used to evaluate and classify emerging technologies it should be clear that the process of innovation leading to adoption is highly non-linear; periods of little to no progress are preceded and, hopefully, followed by rapid changes in the development process.

This report considers the lessons learned from the trials in terms of the development of guidance for the management of future trials.

There is significant interplay between, and overlap of, the issues discussed in the following sections, particularly Sections 3 and 4 that cover Site Selection, and Location and Access. It is likely that it will be necessary for these issues to be addressed in an iterative fashion during the preparatory phase of any trial.

Further to this, many issues need to be addressed at the outset of the planning of a trial and must be considered in parallel. This means that the site selection process does not lend itself well to being expressed in a flowchart. In addition, the relative importance of many of the issues under consideration may vary substantially depending on the site(s) and technique(s) under consideration, network and client requirements, and other relevant factors.

Section 5 presents information on the verification and monitoring of future trials. This includes ensuring that the validation and monitoring undertaken is relevant to the trial technique and to the site, that the duration of the monitoring is of sufficient duration so as to fully test the technique used in terms of its success, or otherwise, and maintenance is undertaken during the currency of the trial to preserve safe access and the effective operation of the instrumentation.

Section 6 considers the future level of potential application of Willow Poles, FRS and EKG and presents potential future trial techniques and areas of application to which those techniques may be applied.

2 Purpose

In order to effectively measure, and quantify or qualify, the success or otherwise of a trial there must be a clear purpose. In the Foreword to the seminal book on geotechnical instrumentation (Dunnicliff 1988), Ralph Peck wrote that *"Every instrument … should be selected and placed to assist in answering a specific question. Following this simple rule is the key to success …".* A similar approach can and should be taken to trials of innovative geotechnical repair techniques. To this end a clearly stated purpose is a prerequisite; subsequent criteria against which success or otherwise can be measured are also essential.

It is important for future trials that the purpose and limitations of the trial are clearly set-out at the start.

Clear desired outcomes should be stated along with indicators of success – depending upon the purpose these may be qualitative, semi-quantitative, quantitative or a combination thereof. This should also aid in the setting out of a clear and appropriate verification and monitoring regime (See Section 5) to realise data to support future decisions as to whether the trial has been a success.

To enable trials of innovative geotechnical remedial techniques to be rigorously evaluated and their effectiveness compared with other innovative techniques, and against conventional techniques, it is essential that specific trial project teams are set up. These should be charged with the tasks of designing, implementing and verifying/monitoring the trials.

It is important that the trial team is not limited or encumbered by the day-to-day management of the highway network. Notwithstanding this it is important to ensure that the trial does not impose any undue risks to the continued operation and maintenance of the network (and the environment associated with it) and that any such risks are identified and a plan to eliminate, manage or mitigate those risks to reduce them to a tolerable level is in place.

The importance of the continuity that a trial-specific team can bring to the trial process is illustrated by the difficulty on obtaining post-construction movement data for the M6 South of J40 willow poles scheme (see Winter et al. 2018) following a change of the managing agent responsible for the works.

The verification and monitoring of trials is likely to continue for a number of years following the actual trail, as discussed in Section 5. Hence, an adequate budget is required not only for the design and implementation of a trial; but also for post-trial verification and monitoring over a number of years appropriate to the technique on trial and the problem being addressed.

It is important to note that geotechnical procedures as set-out in the DMRB (specifically in HD22 and HD41) must be followed for trials and applications of remediation techniques that are non-standard. This has not always been the case in the recent past and the failure to follow geotechnical procedures has led to a significant reduction in the value of the work to Highways England, the misapplication of the specific repair technique and, in one extreme case, the lack of appropriate ground investigation led to the mobilisation of a repair when none is likely to have been needed.

3 Site Selection

To achieve the desired outcomes, and to broaden the knowledge and experience of using innovative geotechnical techniques, the selection of the correct location for trials is a primary requirement. Several factors need to be considered when assessing whether an earthwork is suitable for the trial of an innovative slope repair technique.

The issues that need to be addressed in terms of site selection include the need to ensure that the geology of the site is suited to the proposed technique. That the type of slope, its morphology, the type of failure(s) are all suited to the innovative technique(s) under consideration. It is also important to consider any impacts, both negative and positive, of the works on the network in order that these can be addressed at the appropriate juncture and if necessary be monitored. The important issues of access and location are addressed in Section 4.

These can be summarised as a series of requirements that need to be satisfied, as follows:

Slope Morphology:

- Primary among the considerations for site section should be to ensure that the site has a defect that is suited to repair using the proposed technique(s).
- That the earthwork type is suitable for the proposed trial technique (i.e. is the technique best suited to a cutting or embankment, for example).
- That the current and proposed slope characteristics (angle, height, aspect (or orientation), etc.) are suitable for the proposed trial.
- That the current and proposed slope morphology is representative of earthworks on the network or key part(s) of the network.

Ground Conditions:

- That the geology and ground water conditions at the site suitable for the proposed solution(s).
- That the ground conditions encountered at the site are characteristic of, and widespread, on the network and that lessons derived forma trial can thus be applied more widely.

Defect type and failure mechanism:

- That the proposed technique(s) can reasonably be expected to effectively repair the defect.
- That the type and nature of the defect to be repaired are also encountered elsewhere on the network and the knowledge and experience gained can be expected to be transferrable albeit that this should not preclude trials of unique and critical assets.
- That the nature of the defect is not likely to change with time to such an extent as to render the trial technique inappropriate or ineffective. Notwithstanding this a slip that has reached temporary equilibrium cannot always be ignored.

Accessibility and Maintenance of the Trial Site:

- That the site is accessible during the construction of the trial.
- That the site will be accessible during the period of, and at the frequency required, during the post-construction verification and monitoring period.
- That the maintenance requirements of the trial technique and the associated earthwork are known and that any associated uncertainties are assessed and can be managed.

Risk to Network:

- That the trial does not pose any undue risks to the continued operation and maintenance of the network.
- That where such risks exist they are identified, are at a level that is acceptable, and a plan to eliminate, manage or mitigate those risks is in place.

Environmental Constraints:

- That the trial does not pose any undue risks to the environment associated with the network.
- That where such risks exist they are identified, are at a level that is acceptable, and a plan to eliminate, manage or mitigate those risks is in place.

As a general rule it is to be hoped that the trial and the associated findings can be applied to other defects at other locations on the network and that any existing case studies are used to inform the structure of the trial, including its monitoring. It is also recognised that there will be exceptions to this that will need to be made for unique and critical assets.

3.1 Interaction with Other Works

It is important to ensure that if a trial is to provide value, in addition to the use of an innovative technique, that the effects of the trial will not be obscured by other facets of the works. A typical example is where significant reshaping of a slope takes place in order to allow safe access for labour and plant need to install the trial. Subsequent evaluation of the success of the trial may well be obfuscated by the lingering question as to the magnitude of the improvement that the reshaping earthworks would have had in isolation and the success of the trial cannot therefore be effectively evaluated.

There may also be questions that are raised by the nature of the repair technique, for example the effects of soil nails installed at the end of EKG construction or the effects of root development on willow poles. These are likely to be of a rather variable magnitude with the EKG soil nails potentially having a significant effect and the root development (as observed form excavation tests (Steele et al. 2004) having much more limited potential.

4 Location, Recording and Access

Knowledge of the location and safe access to a trial site are fundamental to the effective monitoring of any trial site. During the site inspections undertaken as part of this work (Winter et al. 2018; Seddon et al. 2018; Nettleton et al. 2018) some key issues arose as discussed below.

4.1 Location and Recording

The location of a trial proved difficult to establish during the fieldwork phase of this project. This was generally more difficult for older trials, especially those involving willow poles which were constructed around 2000 to 2001. Since then HAGDMS has been populated with electronic records of inspections of defects, monitoring and records of repairs and the ability to rapidly capture locational data using low-cost, high accuracy GPS (and indeed mobile telephones) has been transformed. It is a simple matter to automatically generate an accurate National Grid Reference (NGR) at a given location either when in situ or later using Ordnance Survey mapping to pinpoint a location.

It is recommended that the reporting of future trials should include the trial location expressed both on an Ordnance Survey digital map, either 1:50,000 and/or 1:25,000 and/or any other scale deemed suitable. In addition, relevant NGRs to delimit the extent of the trial area should be reported in both alphanumeric and fully-numeric formats (e.g. NY 52030 28247 and 352030 528247); the use of both alphanumeric and fully-numeric NGRs means that the location data is suitable for use with all systems, including manual systems and GIS systems some of which require a fully-numeric input.

It is considered that details of the location should be recorded in the Geotechnical Feedback Report (GFR), which is routinely placed in Highways England's Geotechnical Data Management System (HAGDMS). This is especially important where the trial may be undertaken in combination with a larger scheme. For example Willows Poles may be planted to improve a potentially marginal section of a cutting where adjacent sections are regraded and subsequently replanted. If the location of the Willow Poles is not carefully defined then they may get 'lost' as the adjacent trees mature. Equally, EKG soil nails and conventional soil nails appear similar on the surface and without detailed location information, the two methods could easily be confused, especially if both are used on the same earthwork.

HAGDMS includes a facility to specifically record 'Pilot Trials', this is a relatively new function and as yet its implementation has been limited. It is accessed from the HAGDMS home page as follows: Projects → Project Search → Project Type → Pilot Scheme: this section of HAGDMS is expected to be populated during the early part of 2018.

The Metadata related to the project can be input by either Highways England or the Maintaining Agent. This page is intended to record data on the pilot/trial and its subsequent monitoring. This information needs to be entered for existing pilots/trials, including those studied as part of this work and, in part, using the reports produced. Additional information should be added to the project details page, including actual location and access as discussed above and below.

For future pilots and trials the guidance on the Handover of Geotechnical As-Built Data (Highways England 2017) should be followed and linked to the relevant HAGDMS location.

4.2 Access

Closely linked to location is the provision and recording of information describing safe access for observation, monitoring and maintenance. This should be clearly recorded with the indication of a safe area, or areas, for parking, and where appropriate a walking route to the trial site itself should be defined. Any constraints regarding the need to obtain permission from landowners should also be itemised.

As for location details, it is considered that this should be recorded in the Geotechnical Feedback Report (GFR), which are routinely placed in HAGDMS. It is recognised that the access may change after the trial. However, this could be readily updated in HAGDMS either by means of a short, supplement to the GFR or by an update to the Project Area (see Section 4.1 above) depending upon the outcomes from the ongoing revision of HD 22.

The need to liaise with the operating organisation in order to ensure that health and safety procedures are followed for access is also, of course, considered to be a prerequisite but does not need to be specifically reported separately in the GFR. The residual risks will be defined with the Health and Safety files and the Construction Design and Management (CDM) Risk Register.

5 Verification and Monitoring

The verification and monitoring of any trial is essential if knowledge is to be gained for use in future applications. Indeed, if a trial is not verified and monitored then it is clear that it is not a trial.

5.1 Relevance

The relevance of verification and monitoring to the trial is critical. Indeed, the quote from Ralph Peck reproduced in Section 2 is even more relevant here. This implies that each monitoring position and instrument should have a clearly defined purpose that relates back to the purpose of the trial and/or to the associated indicators of success.

Often monitoring is defined in order to identify the problem that the subsequent mitigation is intended to rectify. This may or may not be suitable for post-trial monitoring but in either case the monitoring should be reviewed and adjusted in order ensure that it relates adequately to the indicators of success for the trial.

For the assessment of the effectiveness of any innovative slope remediation techniques it is likely that verification in the improvement of any ground conditions and monitoring of both slope movements and water levels are likely to be key indicators of success or otherwise. Thus adequate pre-, during and post-trial verification and monitoring are essential. Specific recommendations include:

- Pre- and post-trial ground investigation including in-situ testing, laboratory testing and where appropriate chemical/mineralogical testing and geophysical techniques should be planned to enable post-trial treatment verification in both the short- and long-term.
- Installation of inclinometers or other appropriate slope monitoring systems (e.g. GPS/GNSS and downhole shape array systems) to allow appropriate monitoring before, during and post-trial (short- and long-term) should be undertaken; where practicable the data from these should be collected and logged remotely.
- Installation of data logged or remotely monitored piezometers and rain gauges to allow appropriate monitoring before, during and post-trial (short- and long-term).
- Use of untreated or conventional remedial treatment slope areas to act as controls for the trials.

5.2 Duration

The time period over which verification and monitoring is conducted is also an important issue. Post-trial verification and monitoring, particularly for innovative solutions, is often carried out over a period of two to three years, reflecting the period over which funds for a specific research project or innovation are available. Experience of the trials of Willow Poles, FRS and EKG (Winter et al. 2018; Seddon et al. 2018; Nettleton et al. 2018) indicates that this is effective only in the sense that it typically demonstrates that the technique employed is having the type of effects that would be anticipated and is not causing unexpected problems.

The monitoring needs to be conducted over a period that is meaningful in terms of slope instability; the onset of instability is typically a slow process and a two to three year time frame for monitoring is clearly insufficient. This may be compounded by some techniques, particularly those involving the growth and establishment of vegetation, that also involve relatively slow processes.

In order to fully evaluate the effects of the treatment a verification and monitoring period of three to five years may be appropriate but in particular circumstances up to 20 years is recommended for future trials, albeit that in the latter case monitoring intervals need not be overly frequent. Failure to monitor for such a period renders the trial ineffective in the context of the required 60 year design life for geotechnical works (including repairs). A caveat is that if the monitoring frequency is insufficiently frequent then problems with continuity of process, people and data can come to the fore and it is recommended that a frequency of no less than 24 months be maintained and ideally that the organisation (and preferably people) undertaking the assessment on behalf of HE remain the same. To achieve this, it may be appropriate to resource and fund such trials separately from the highways maintenance contracts that tend to be retendered every four to five years.

5.3 Maintenance

Given the nature of innovative slope repair trials, it is essential that maintenance is required to allow monitoring to continue. During the inspections it was evident that since the end of the monitoring period the vegetation had become dense, thus making visual inspection of the slope difficult. Furthermore, if monitoring is to be undertaken in the long-term, then provision should be made for routine maintenance of the installations.

6 Future Trials and Techniques

The work presented in this and the other project reports (Winter et al. 2018; Seddon et al. 2018; Nettleton et al. 2018) cover the use of Willow Poles, FRS and EKG. Each technique is at a different stage of development and using the Technology Readiness Level (TRL) indicators, as used by Highways England for pavement innovations (Sanders 2016), the three techniques are categorised as follows:

- Willow Poles: TRL 8, "Actual technology completed and qualified through test and demonstration" with the next step being to "develop standard/specification", as presented by Winter et al. (2018).
- EKG: TRL 7, "Technology prototype demonstration in an operational environment", with the next step being "if acceptable, authorise for DfS [departure from standard] on a project basis". Nettleton et al. (2018) recommend the development of guidance to aid such work.
- FRS: The TRL state largely depends upon whether a UK or European source of the fibres that have been used to date can be located (at present they are imported from the USA). If such a source could be located then the TRL is 6 with "Technology model or prototype demonstration in a relevant environment" with the next step being "demonstration/validation of concept trial (on HE network)". However, if no such source of fibres could be found and a different type of fibre were to be used, this would mean that the TRL would be 4, "Technology validation in a laboratory environment" with the next step being "demonstration/validation of concept trial (off HE network)", albeit that depending on the fibre selected the TRL may be lower requiring physical and/or numerical modelling. Notwithstanding this the environmental issues surrounding the use of soil mixed with such plastic inclusions renders the future sue of FRS problematic.

While the three repair techniques are a good reflection of the range of techniques used for slope repairs on the Highways England network in recent years there are other techniques that could be considered. These include:

- The use of tyre bales to repair slopes and/or to construct over soft ground (Prikryl et al. 2005; Winter et al. 2009).
- Biological and/or chemical stabilisation (including, for example, the use of colloidal silica, biopolymers) (e.g. Chang et al. 2015; Correia et al. 2015; Sisakht et al. 2015).
- The use of alternative materials to form fibre reinforced soil; these might include tyre shred, geopolymer materials and/or natural materials such as vegetative products.
- The use of Willow Poles planted at an angle to the vertical so as to act as soil nails rather than to act as vertical mini-piles as has been the case in trails to date. (The design has been for the willow poles to act as a shear key to prevent further movement of the slip and any contribution from root reinforcement, root water uptake and canopy interception viewed as introducing a degree of conservatism into the design.)

- The use of other types of tree/vegetation stake to promote stability.

Innovative geotechnical repair techniques can also be used in arenas other than that of slope repairs. Particular opportunities exist around resilience and the rapid response to incidents, be they caused or triggered by heavy rainfall (for example floods, landslides or the exposure of cavities related to old mine workings or Karstic formations) or by defective drainage. Often access to plant over soft ground is an issue and rapid construction techniques using, for example, tyre bales or biodegradable fibres, such as heather, placed to form a working access and/or platform can decrease the recovery time from such events significantly.

This work has focussed on innovative repair techniques used by Highways England. There exists the opportunity to develop the knowledge base further by examining such techniques used or planned to be used by other transport network operators. In the UK these include Network Rail, Transport Scotland, Transport for Wales, Department for Infrastructure (Northern Ireland)/Transport NI and Transport for London. Transport Scotland has, for example, planned to use Willow Poles at the A83 Rest and be Thankful site as an erosion control and stream bank stability measure (Winter & Corby 2012).

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Innovative Geotechnical Repair Techniques

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Other titles from this subject area

PPR 873	Innovative geotechnical repair techniques: effectiveness of fibre reinforced soil. R Seddon, M G Winter & I M Nettleton. 2018
PPR 890	Innovative geotechnical repair techniques: effectiveness of electrokinetic geosynthetics. I M Nettleton, R Seddon & M G Winter. 2018
PPR 874	Innovative geotechnical repair techniques: effectiveness of willow poles. M G Winter, R Seddon & I M Nettleton. 2018
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