University for the Common Good

Production rate of self-drilling soil nails in a coastal slope stabilisation project in Scotland

Mickovski, S.B.

Published in:
Proceedings of XX ICSMGE

Publication date:
2021

Document Version
Author accepted manuscript

Production rate of self-drilling soil nails in a coastal slope stabilisation project in Scotland

Taux de production de clous de sol autoforants dans un projet de stabilisation des pentes côtières en Écosse

S. B. Mickovski,
Glasgow Caledonian University, Glasgow, Scotland

ABSTRACT: The aim of this study is to establish the production rate of self-drilling soil nails through different soil strata. To achieve this aim, the production rate of more than 800 self-drilling soil nails was monitored and recorded during a coastal slope stabilisation project in North-East Scotland. The recorded data was then analysed against the expected geology in order to establish the production rate in the varied soil types encountered on site which included: raised beach deposits of sands and silts, various cohesive strata comprising clays, and deeper granular deposits of gravel. The depth of installation of the soil nails ranged between 3 m and 22 m which allowed a determination of average production rate and standard deviation from the mean. The results showed that the production rate was the highest in the raised beach deposits, while most obstacles and refusals occurred in the deeper gravel deposits. The limitations of the production approach are discussed in light of the installation plant choice, the availability of skilled labour, as well as the site constraints such as perched ground water table, soil erosion, and vegetation protection. The need of relevant monitoring and quality control is highlighted from construction management point of view. The results of this study will help designers, construction supervisors, and quantity surveyors in the planning, design, construction and monitoring of similar works in the future.

RÉSUMÉ : Le but de cette étude est d'établir le taux de production de clous de sol auto-forés à travers différentes strates de sol. Pour atteindre cet objectif, le taux de production de plus de 800 clous de sol autoforants a été surveillé et enregistré lors d'un projet de stabilisation des pentes côtières dans le nord-est de l'Écosse. Les données enregistrées ont ensuite été analysées par rapport à la géologie attendue afin d'établir le taux de production dans les différents types de sols rencontrés sur le site, notamment: des dépôts de sable et de limon sur les plages, diverses strates cohésives comprenant des argiles et des dépôts granulaires plus profonds de gravier. La profondeur d'installation des clous de sol variait entre 3 m et 22 m, ce qui a permis de déterminer le taux de production moyen et l'écart type par rapport à la moyenne. Les résultats ont montré que le taux de production était le plus élevé dans les dépôts de plage surélevés, tandis que la plupart des obstacles et des refus se sont produits dans les dépôts de gravier plus profonds. Les limites de l'approche de production sont discutées à la lumière du choix de l'installation d'installation, de la disponibilité d'une main-d'œuvre qualifiée, ainsi que des contraintes du site telles que la nappe phréatique perchée, l'érosion des sols et la protection de la végétation. La nécessité d'une surveillance et d'un contrôle de la qualité pertinents est mise en évidence du point de vue de la gestion de la construction. Les résultats de cette étude aideront les concepteurs, les superviseurs de construction et les métreurs à planifier, concevoir, construire et surveiller des travaux similaires à l'avenir.

KEYWORDS: slope stability; soil nails; productivity; grouting,

1 INTRODUCTION.

One of the standard civil engineering methods for slope stabilization is soil nailing. This is a form of geotechnical stabilisation where a steel or polymeric reinforcement bars are installed within a grout surrounding into the face of a natural or engineered slope. This assemblage creates a reinforced block of soil with strength superior to the one of the surrounding soil. After the nail has been installed, it is customary to construct an appropriate facing system in order to protect the surface of the soil from failure. The soil nailed slope can be considered complete once all soil nails and the associated facing system have been installed. The last two decades have seen a rapid growth in the uptake of this method for soil stabilization in the UK, with more and more grey (buildings, roads, and other urban constructions, etc.), blue (rivers, canals, ponds, wetlands, floodplains, water treatment facilities, etc.), and green (hedgerows, copses, bushes, orchards, woodlands, natural grasslands and ecological parks, etc.) infrastructure projects undertaken. The stabilisation of all forms of transportation infrastructure has been in particular focus for this technique (Mickovski et al, 2014a; Mickovski et al 2014b).

The traditional construction method for soil nails includes the installation of a solid steel tendon into a hole with appropriate diameter which has been pre-drilled before injecting the grout to fill in the annulus between the tendon and the walls of the hole. A relatively recent development in the soil nailing technique are the self-drilled, hollow bar, soil nails which were shown to offer significant advantages when compared to the traditional solid bar system (GEO, 2008). These advantages include the relative ease of installation into loose or collapsing soils where there is no need for casing to support the drill hole because the grout injected through the hollow nail can be used as a drilling fluid. These nails are also proven to offer an increased pullout capacity due to the injected grout permeating the adjacent soil and increasing the bond diameter. This technique also allows soil nail installation by using relatively small, lightweight, more mobile, rigs within most soil types and consistencies. All of the above advantages can be interpreted to lead to increase in production rates (Porterfield et al 1994, Phear, 2005, GEO, 2008). They also point out at construction progress which is potentially much quicker than the traditional construction method and not only reduces the construction time and the overall cost of the system, but also reduces the health and safety implications of mobilising heavy plant to an already failed or unstable slope. However, this method has disadvantages which include limitations in the testing (Mickovski et al 2014) difficulties in pull-out testing, requirement for more quality control, attention to workmanship and supervision in order to ensure that the quality of the constructed nails does not suffer. The introduction of BS EN 14490 in 2010 and the code of practice for soil nail design (BS 8006-2) in 2011 do not provide any clarity on the progression rates of different types of soil nails in different soil formations, and rely on the designer's knowledge and experience of the ground conditions at the site (Richards 2010, Littlejohn and Bruce 1977) as well as the impact on the soil nail construction to confirm the installation procedure to satisfy the design assumptions.

Since the progression rate of soil nail construction depends on the nature of the soils and the drilling rig, it is desirable to have as much information as possible on both (Littlejohn and Bruce 1977*)*. It is generally accepted that no single soil property correlates perfectly with the drilling rate and there are usually a number of parameters which are correlated to the progression rates. The progression rates are a function of the torque supplied to the drill, the condition of the drill and bit, as well as the type of flushing medium and the bit diameter. The above parameters are usually difficult to measure precisely in the field so discrepancies between calculated and measured rates are to be expected. The calculated rates are usually based on experience of the contractor with similar soils and nail types and are specific to each contractor, i.e. are not published in the literature.

The aim of this case study is to report on the experiences with installation of hollow bar soil nails, investigating the effects of the underlying geology on the progression rates of the nails. The objectives are to analyse case study data in order to determine the generic soil profile for each soil nailed section, monitor and record the rate of progression of all soil nails installed in each section, and analyse the nail construction considerations and effects associated with productivity which will help designers and contractors in both costing and design of similar projects.

2 MATERIALS AND METHOD

2.1 *Site description*

The case study site is located in Stonehaven, northeast Scotland, forming the slope below the existing former trunk road (Bervie Braes Road), and including the adjacent coastal slope (Bervie Braes), as shown on Figure 1. The 40m high coastal slope above the old harbor in Stonehaven has a history of instability (Currie et al., 2009) which has resulted in the closure of the former trunk road bisecting the slope. The road runs sidelong and generally northwest-southeast across the Braes. For this case study, only the soil stabilization works carried out on the slope below the Bervie Braes road ('Lower slope' on Figure 2; Mickovski 2014b) will be considered.

A range of studies carried out before the development of the design for slope stabilization showed that the angle of the lower slope ranges between 25° and 30°, as compared to the upper slope angle which varies between 30° and 35°. The historic ground investigations (Currie et al 2009) showed that the soil on the lower slope typically (Figure 2) occurred in a sequence comprising a thin layer of vegetated topsoil (around 0.2m thick), overlying Raised Beach Deposits and Glacial Sands and Gravels which, in turn, lie over thick Glacial Till. The Raised Beach Deposits were shown to comprise weak and loose silts and silty sands, with discrete soft cohesive layers with thickness ranging from 1.5m to 5.0m. The Glacial Sands and Gravels were shown to comprise mainly medium dense glacial sands. The underlying cohesive Glacial Till was shown to have stiff consistency and thickness of up to 20 m. Sandstone bedrock was proven at few locations across the slope, below the Glacial Till.

Figure 1. Site area with delineated soil nailing sections

Two groundwater tables were recorded during the historic ground investigations. A shallow perched groundwater table was shown to originate within the Raised Beach Deposits and was connected to the presence of the discrete cohesive layers within these deposits. The second groundwater table was struck within the Glacial Sands and Gravels and occurred as perched upon the stiff cohesive Glacial Till (Mickovski 2014b).

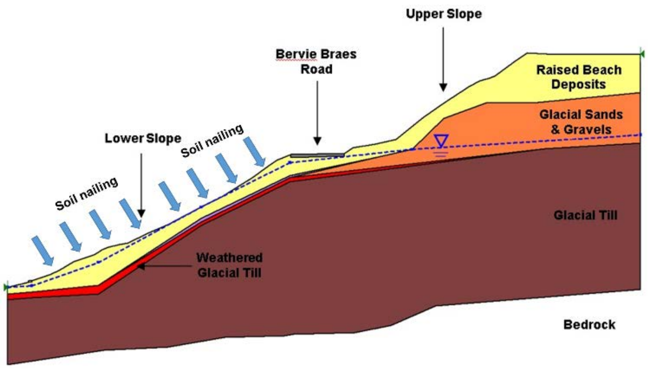

Figure 2. Typical ground profile in the site area

2.2 *Soil nail design*

Due to the limited budget available for the works and the available timeframe for completion of the project, the slope stabilization design comprised self-drilled hollow bar soil nails which were preferred to solid bar soil nails (Mickovski et al 2013, Mickovski 2014b). The design included soil nails with lengths of between 7 m and 24 m. The spacing between the nails was 1.5 m horizontally and 1.0 m vertically. The scope of the stabilization works was to provide the necessary resistance to erosion, shallow and deep seated (active zone of up to 10 m depth) slope failures. The design was developed based on characteristic ground profiles in five different sections of the site (Sections E-H, Section J; Figure 1), and comprised the installation of approximately 1700 self-drilling hollow bar soil nails.

The facing system was designed as a 'soft facing', consisting of a buried reinforced concrete soil nail head, bio-degradable matting, and a light metallic mesh to minimize the erosion risk and to also respond to the project aesthetic requirements (Mickovski et al 2013, Mickovski 2014a). The concrete nail head, designed to DMRB HA 68/94 (now withdrawn), was envisaged to provide long term stability of the slope by transfer of the soil load back to the soil nails bond length and also to provide shallow surface stability between the nails. The bio-degradable jute mat and a light metallic mesh formed part of the facing to help prevent surface erosion and support establishment of vegetation which, in turn, would provide resilience of the structure in the long term (Norris et al. 2008, Mickovski 2014a,b)

2.2 *Soil nail construction*

The soil nails installed in this case study comprised a 38 mm external and 19 mm internal diameter (753 mm^2 cross-sectional area), galvanised steel bars in mainly 3 m long sections, coupled together using galvanised steel couplers to achieve the design length and progressed using a sacrificial bit drilling a 100 mm diameter hole. The access to each nail location was cleared of vegetation and the drilling rigs were positioned at each location ensuring the safety and stability would be maintained during the construction (Figure 3)

Figure 3 Soil nailing rig positioned on site. A short section of soil nail can be seen on the slope in front of the rig.

A total of 1678 nails were installed using an Atlas Copco ROC 460 rig with an air flush through the Raised Beach Deposits, Glacial Sands and Gravels and into the Glacial Till where the majority of the design bond lengths are located. The holes were progressed using grout flush, with a continuous recording of injected grout volume and pressure. The installation of each nail was carried out by a team of two drillers, supervised by a suitably qualified geotechnical or civil engineer who, above and beyond the requirements specified in BS EN 14990:2010, recorded the time needed for installation of each section of nail tendon and scheduled material testing in accordance with the Quality Assurance and Quality Control standards.

2.3 *Data analysis*

All data collected in situ was transferred in an electronic format using custom made spreadsheets. These spreadsheets included information not only on the production rate of each nail, but also information on the location, weather conditions, drilling rig, plant operators, soil nail batch (including producer, supplier and transportation details), grout details (linked to laboratory and in situ testing). The spreadsheets were used to collate and link all relevant information which could then be stored and used in accordance with BIM standards (Mickovski, 2017).

The nail productivity data on the spreadsheets was analysed using simple descriptive statistics in MS Excel. Graphs presenting the accumulated drilling time vs the depth of installation were produced for each section. Due to the limitations of the software, not all data is shown on the section graphs. On these graphs, the conjectured ground profile was added to illustrate the conjectured geology and help in interpretation in of the range of production rates experienced in each section.

3 RESULTS AND ANALYSIS

3.1 *Soil nail installation*

After the test location was prepared, the drilling rig was secured in place and the nail was installed with simultaneous grouting under gravity during progress with air flush. With the exception of few outliers in each section, the installation time per nail ranged between 2 and 60 minutes in Section E, between 1 and 110 minutes in Section F, between 1 and 90 minutes in Section G, between 3 and 50 minutes in Section H, and between 1 and 50 minutes in Section J.

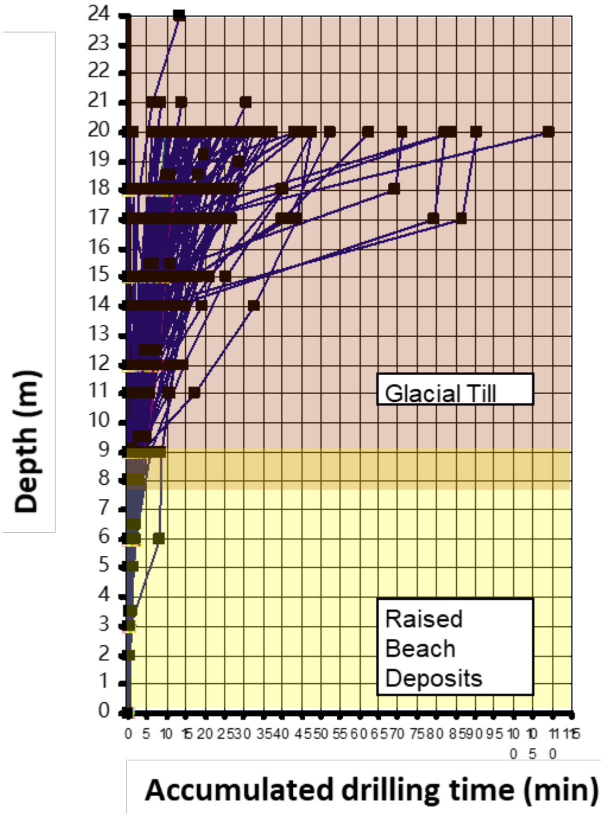

Figure 4 Drilling time required for the soil nails installed in Section E

Due to the size and the weight of the drilling rigs, the transportation to and from each nail location across the slope involved a combination of manual and plant labour, and lasted between 20 and 60 minutes depending on the transport distance and location on the slope. This time was not included in the installation time or production rate calculations.

3.2 *Soil nail production rates*

The production rates of soil nails varied between the sections depending on the underlying geology and the depth of installation. In section E, there were 321 nails installed at design depths of between 17 m and 20 m. Within this setion, it took between 0.26 and 1.14 minutes to progress one linear metre of nail in the Raised Beach Deposits, and between 0.27 and 9.25 minutes to progress one linear metre of nail in the Glacial Till. On average, in this section, the rate of progression was 3.45 m/min in the Raised Beach Deposits and 0.65 m/min in the Glacial Till.

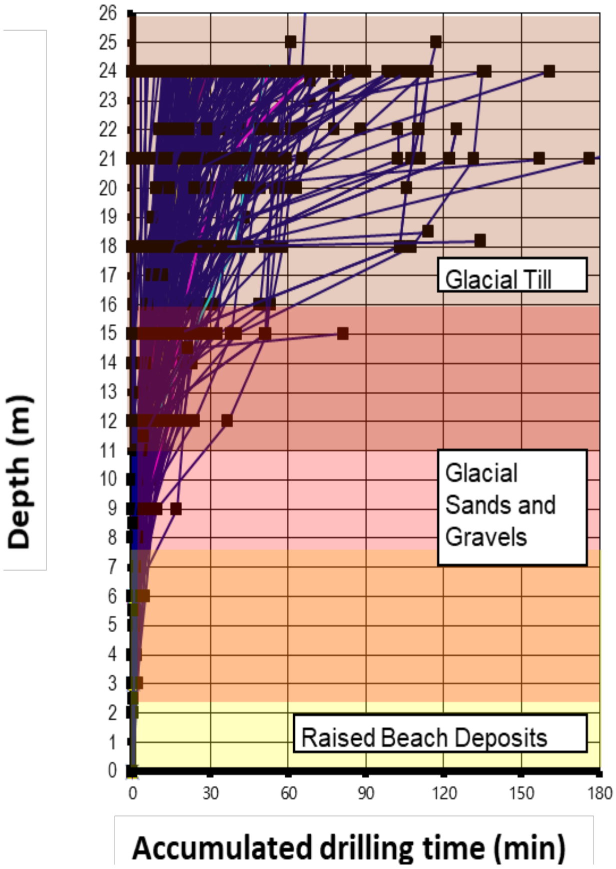

Figure 5 Drilling time required for the soil nails installed in Section F

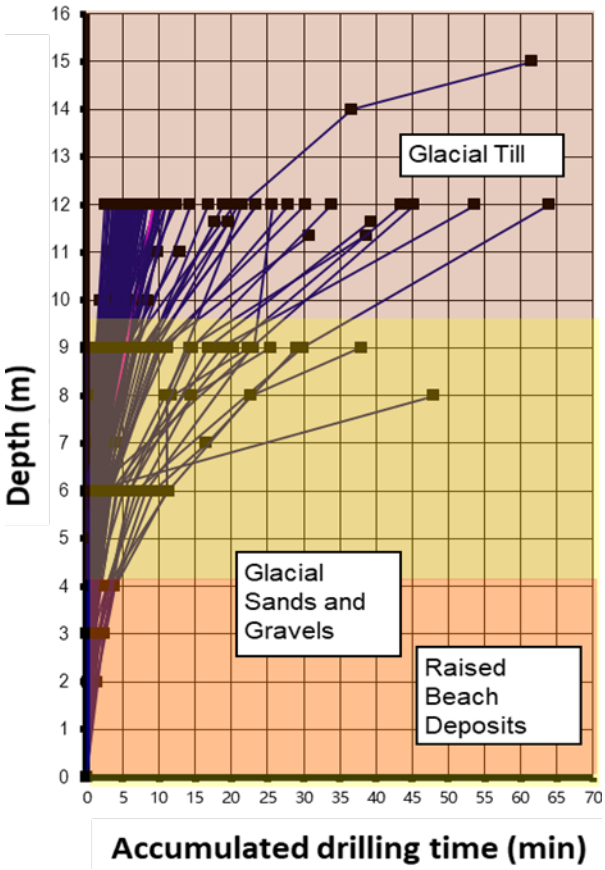

Figure 7 Drilling time required for the soil nails installed in Section H

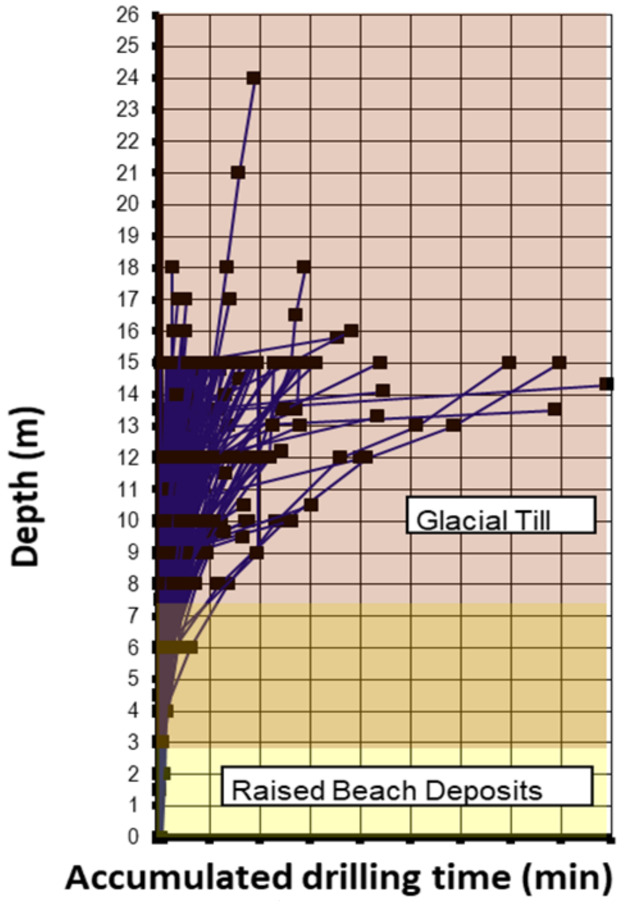

Figure 6 Drilling time required for the soil nails installed in Section G

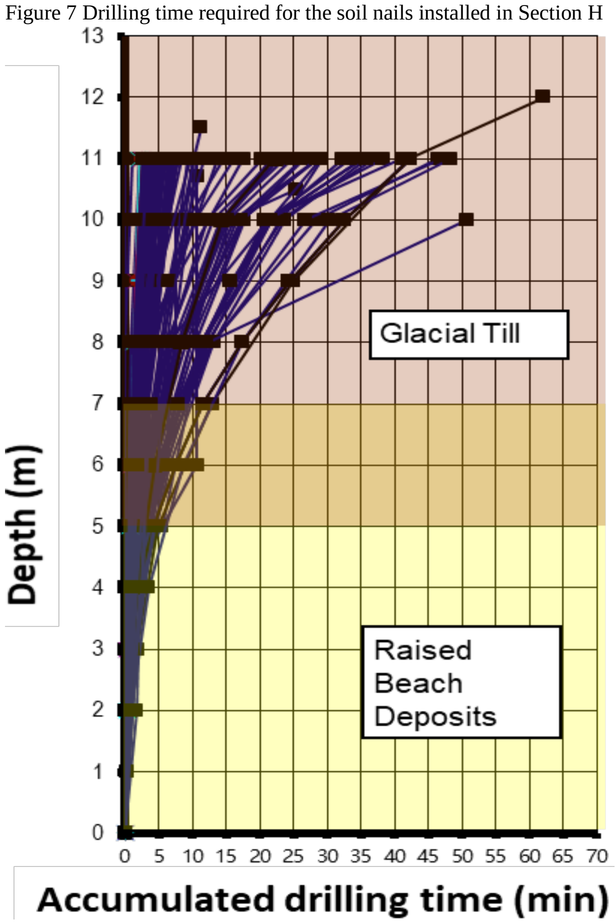

Figure 8 Drilling time required for the soil nails installed in Section J

In section F, there were 290 nails installed at design depths of between 10 m and 24 m. Within this section, it took between 0.10 and 0.45 minutes to progress one linear metre of nail in the Raised Beach Deposits, between 3.0 and 20.4 minutes to progress one linear metre in the Glacial Sands and Gravels, and between 0.45 and 13.37 minutes to progress one linear metre of nail in the Glacial Till. On average, in this section, the rate of progression was 5.0 m/min in the Raised Beach Deposits, 0.75 m/min in the Glacial Sands and Gravels, and 0.27 m/min in the Glacial Till.

In section G, there were 306 nails installed at design depths of between 10 m and 15 m. Within this section, it took between 0.10 and 1.1 minutes to progress one linear metre of nail in the Raised Beach Deposits, and between 1.07 and 16.08 minutes to progress one linear metre of nail in the Glacial Till. On average, in this section, the rate of progression was 5.56 m/min in the Raised Beach Deposits and 0.32 m/min in the Glacial Till.

In section H, there were 508 nails installed at design depths of between 9 m and 12 m. Within this section, it took between 0.025 and 1.5 minutes to progress one linear metre of nail in the Raised Beach Deposits, between 0.32 and 1.1 minutes to progress one linear metre in the Glacial Sands and Gravels, and between 0.10 and 11.75 minutes to progress one linear metre of nail in the Glacial Till. On average, in this section, the rate of progression was 2.82 m/min in the Raised Beach Deposits, 1.71 m/min in the Glacial Sands and Gravels, and 0.21 m/min in the Glacial Till.

In section J, there were 253 nails installed at design depths of between 7 m and 11 m. Within this section, it took between 0.17 and 1.71 minutes to progress one linear metre of nail in the Raised Beach Deposits, and between 0.29 and 9.01 minutes to progress one linear metre of nail in the Glacial Till. On average, in this section, the rate of progression was 4.0 m/min in the Raised Beach Deposits and 0.19 m/min in the Glacial Till.

Across the site, the average progression rate in the Raised Beach Deposits was 4.16±0.22 m/min, 1.21±0.35 m/min in the Glacial Sands and Gravels, and 0.33±0.04 m/min in the Glacial Till.

4 DISCUSSION AND CONCLUSIONS

The case study results showed that the production rate of self-drilled shallow bar soil nails was the highest in the Raised Beach deposits, followed by the production rate in the Glacial Sands and Gravels, and it was the lowest in the Glacial Till. These results show a general correlation between the consistency or strength of the soils and the rate of progression of nailing through them. The conjectured typical geological sections generally confirm this conclusion, especially near the interface of Glacial Till with the overlying deposits where the nail progression curve (Figures 4-9) inflects to a shallower slope. The progression rates recorded in this case study included only the time needed for installation of one nail or a linear metre of nail in selected soil deposits. The actual installation time, however, should also take into account the clearing and preparation time for each nail location, the time for rig transportation to each nail location, as well as the time needed for sampling and/or testing (e.g. grout consistency). Although the above were not included in the calculations, it is considered that the results of this case study will help in planning of the site activities to include the missing parameters into the overall project execution sequence and timeframe.

In each section, there was a small number of ‘outlier' nails reflecting the natural variability in the soil strength and also environmental conditions such as the presence of softer or harder soil lenses, larger granular particles or groundwater. However, the number of these nails is relatively low and the use of average and standard errors from it is fully justified in detecting and reporting the trends in progression rates.

The groundwater effects on the progression rates were not clearly visible in the analysed curves, perhaps due to the grouting pressure being higher than any groundwater pressure encountered at depth. If the effects of groundwater are of concern, the grouting pressure and use records should be investigated along the length of each nail.

From Quality Control perspective, the data collection and management, as described in this study, were time consuming. The latest developments in digitalization of construction such as in situ software and hardware solutions, as well as the advent of machine learning technologies and big data management can help in minimization of time needed for data collection, monitoring and quality assurance. Using concepts and solutions associated with BIM level 3 (Tawelian and Mickovski, 2016; Mickovski, 2017), the protocols and requirements for the soil nail installation can be incorporated in the project files from the project inception and made available for all parties throughout the project lifetime. Based on the reported case studies and available literature, ground models can be developed (Murray and Mickovski, 2018; Ballentyne and Mickovski 2019) and enhanced with a simulation of the soil nailing process. During the actual soil nail construction, the installation monitoring data can be simultaneously fed into the model and simulation in order to detect any differences between the modelled and actual process, but also to help detect and mitigate against the risks of instability (Mickovski and Pirie, 2019; Meldrum and Mickovski, 2017; McGregor and Mickovski, 2016).

The limitations of this study include the use of only one type of installation plant, one nail size and relatively few soil types. In order to increase the knowledge on the technique, in general, and on the progression rates, in particular, future research should focus on monitoring and recording these parameters in other projects, perhaps using protocols similar to the ones developed for other emerging disciplines within the civil engineering industry (Mickovski et al 2018). To this effect, the existing standards would have to be updated to include the monitoring and testing of these parameters (e.g. progression rates, type and prower of installation plant, nail size, grouting length) for Quality Assurance and Quality Control purposes.

5 ACKNOWLEDGEMENTS

Fraser Lindsay, Alistair MacArthur, and Stewart Andrew helped with provision and compilation of the results and, without them, this publication would not have been possible The help of Aberdeesnhire Council and Stonehaven Community Council is greatly appreciated. The help of Ms Julia Mickovski in data collation and analysis is also greatly appreciated.

6 REFERENCES

Ballentyne, D. and Mickovski, S. B. 2019. The effect of ground investigations on the civil engineering design for windfarms in Scotland. In: Proceedings of the XVII ECSMGE-2019: Geotechnical Engineering foundation of the future. IGS. Doi: 10.32075/17ECSMGE-2019-0202

BS EN 14490. 2010. Execution of special geotechnical works – Soil nailing. BSI, London, UK.

Currie C, Murdoch W, Sallis D, Smith, M, 2009. Forensic investigation of a failed road at Bervie Braes, Stonehaven - models and mechanisms. In: Forensic Engineering - From Failure to Understanding, B. Neale (ed.), Thomas Telford , London , 325-334.

GEO (Geotechnical Engineering Office). 2008. Geoguide 7: Guide to soil nail design and construction. The Government of the Hong Kong Special Administrative Region, Kowloon, Hong Kong, 97pp.

Littlejohn, G.S. and Bruce, D.A. 1977. Rock anchors state of the art. Foundation Publication LTD.

McGregor, G. and Mickovski, S.B. 2016. A local authority's risk-based approach to principal inspection frequency of structures. In: CETRA 2016, Proceedings 4th International Conference on Road and Rail Infrastructure. Lakusic, S. (ed.). University of Zagreb, p. 372-379

Meldrum, A. and Mickovski, S.B. 2017. Development of an independent hydrology audit methodology to support flood risk assessment in the planning process in Scotland. Water and Environment Journal 31, 559:571

Mickovski S B (2014) Resilient design of landslip prevention measures: a case study. Accepted for publication in Proceedings of ICE: Forensic Engineering, Special Issue on defining hazards from climate change for resilient design.

Mickovski SB (2014) Stabilisation of former trunk road embankment using combined structural and eco-engineering strategies. In: Proc. 3rd Int'l Conf. on road and rail infrastructure CETRA 2014, Split Croatia, 28-30 April 2014.

Mickovski, S. 2017. BIM for enhancement of civil engineering practice: integrated design and construction in civil engineering. [original title: BIM za unapreduvanje na gradeznata praktika: integrirano proektiranje i izvedba na gradezni objekti]. Pressing (2017), 33: 29-31. The Chamber of Chartered Architects and Engineers of Macedonia.

Mickovski, S.B. and Pirie, G. 2019. Practical methodology for the design and management of instability in hard rock tunnels. In: Proceedings of the XVII ECSMGE-2019: Geotechnical Engineering foundation of the future. Reykjavik: IGS. Doi: 10.32075/17ECSMGE-2019-0294.

Mickovski, S.B., Lindsay, F.M., Smith, M.J. 2016. Construction and testing of self-drilled soil nails. Geotechnical Engineering, 169(6): 541–553

Mickovski S.B., Santos O., Ingunza P.M.D., Bressani L.2015. Coastal slope instability in contrasting geo-environmental conditions. In: Geotechnical Engineering for Infrastructure and Development - Proc. XVI European Conference for Soil Mechanics and Geotechnical Engineering, Edinburgh, Scotland, September 2015: 1801-1806.

Mickovski S.B.,Thomson C.S., Gallagher C., Tardio Cerrillo G., Sangalli P. (2018). Sector-specific routines and curricula for eco-engineering in the Mediterranean. In Proc. 5th Int'l Congress on Technology, Engineering and Science. ICONTES, Kuala Lumpur 01-02 February 2018. http://procedia.org/cpi/ICONTES-5-2111082.

Murray, S and Mickovski, S.B. 2018. The importance of ground investigation findings in the design for overhead line electrification foundations. In: CETRA 2018, Proceedings 5th International Conference on Road and Rail Infrastructure. Lakusic, S. (ed.). University of Zagreb

Norris J E, Stokes A. Mickovski S B,Cammeraat E, van Beek R, Nicoll B C, Achim A (Eds.) (2008) Slope Stability and Erosion Control: Ecotechnological Solutions, Springer, pp 290.

Phear, A, Dew, C, Ozsoy, B, Wharmby, N J, Judge, J, Barley, A D (2005). Soil nailing – best practice guidance. C637, CIRIA, London, UK.

Porterfield, J.A, Cotton, D.M., Byrne, P.E.R. 1994. Soil nailing field inspectors manual – soil nail walls. Office of Technology Applications, Federal Highway Administration, Publication FHWA-SA-93-068, Washington D.C., USA.122pp.

Tawelian, L.R. and Mickovski, S.B. 2016. The Implementation of Geotechnical Data Into the BIM Process. Procedia Engineering 143 (2016): 734-741