ACHILLES

An EPSRC Programme Grant

READING GUIDE 7:
Intervention strategies and business case

ADDRESSING INFRASTRUCTURE'S ACHILLES HEEL

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Introduction

Earthworks deteriorate over time and are additionally subject to increasingly extreme weather conditions [1]. A range of intervention types is available to maintain the safety and serviceability of earthworks assets, and these should be selected and made as cost-effectively as possible, to maximise asset condition improvement within the available budget (Network Rail, 2018[A]).

Key findings on interventions

The ACHILLES Programme Grant research, outlined in the other six Reading Guides, delivered new research insights and novel modelling approaches from which it was possible to derive the following key findings related to the type and timing of interventions:

- Intervention measures such as soil nails, installed with increased length and/or reduced spacing, increase asset life and reduce rates of deterioration.
- Early intervention produces greater asset life extensions and significant serviceability improvements, as well as reducing deterioration rates. This research provides a clear indication that asset management decisions need to consider more than just economics to ensure a reliable service.
- Later intervention (prior to failure) yields smaller asset life extensions, but reduces discounted asset whole-life costs. However, this does not account for increased probability of failure.
- Further consideration is therefore required of the valuation of infrastructure asset resilience and the most appropriate metrics and tools for decision making, taking account of safety, serviceability and costs.

Aerial view of the M5 motorway crossing New Main Line canal in Sandwell with the Stewart Aqueduct and railway lines.

Key outcomes related to the efficacy of interventions

A series of intervention options were initially considered for an example 1V in 3.5H, 8 m high cut slope in overconsolidated high-plasticity stiff clay. Using the ACHILLES deterioration models [2], each intervention was installed at different degrees of slope deterioration level categorised as a 25%, 50%, 75% and 90% reduction in FoS towards failure.

This has enabled ACHILLES to address the following key issues.

Interventions extend asset life by reducing deterioration and increasing time to failure

The model in [3] was adopted as the baseline against which to investigate soil nail installation, assessing the effect on TTF of installation time, nail length and nail spacing. Nail pull-out resistance and other design data was based on the TRL[B], CIRIA[C] and ICE geotechnical manual[D] soil nailing guides.

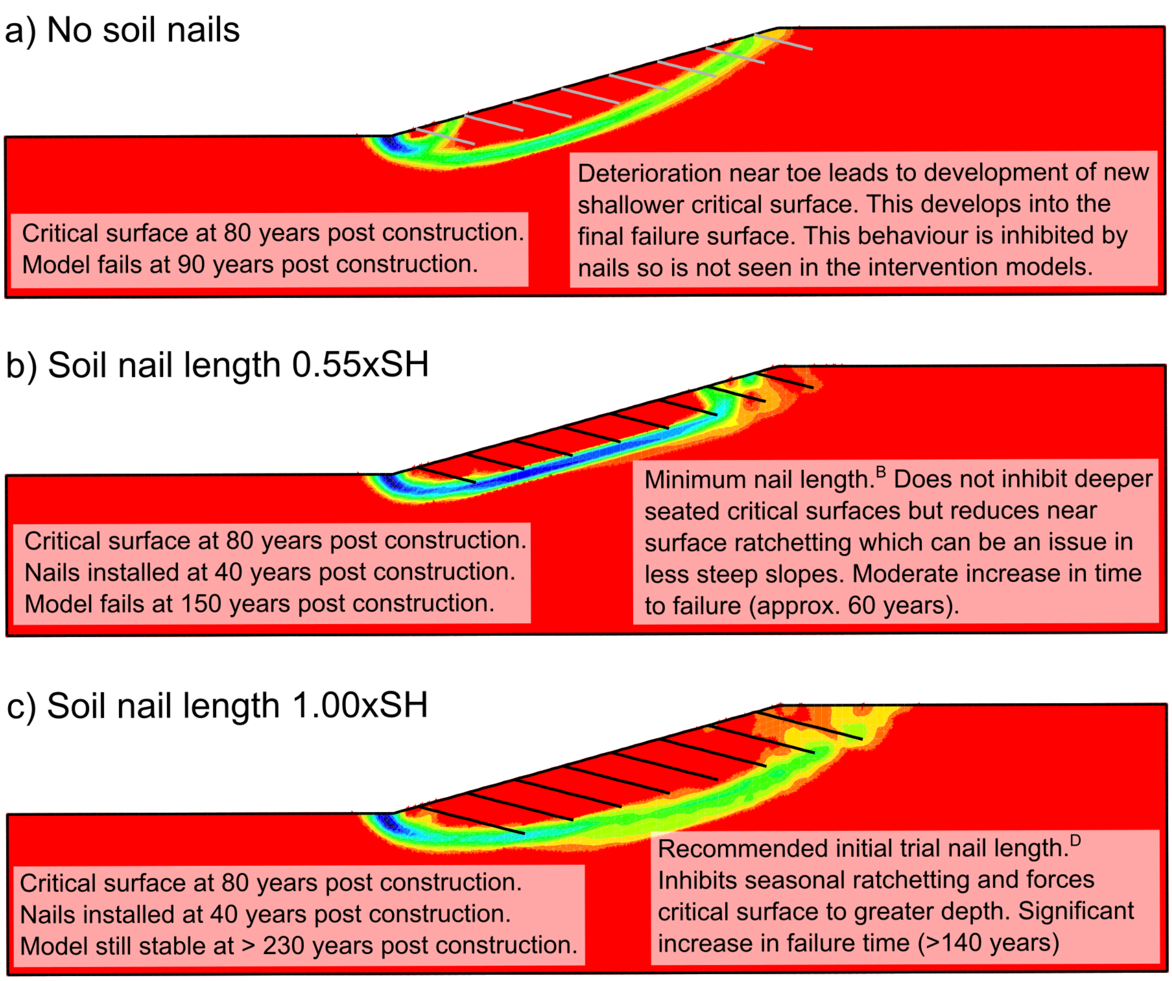

Figure 1: Illustrating the effect of differing soil nail designs on deterioration and the position of the critical shear surface with a) the baseline no intervention model, potential installation positions marked in grey; b) soil nails with length of 0.55 x slope height; c) soil nails with length of 1.00 x slope height.

Sensitivity analysis of the soil nail intervention showed there were additional geotechnical benefits to reduced soil nail spacing and increased length which led to:

- Increased time to failure;
- Reduced slope face deformations and the potential for improved serviceability (also applies to earlier interventions);
- Reduced rates of asset deterioration;
- Reduced slope toe deformations (also applies to earlier interventions), which would be expected to have positive impacts on serviceability.

Examples of a number of these effects are illustrated in figure 1.

Early intervention provides the greatest extension to asset life, but lower discounted whole-life costs can be obtained from later intervention

Infrastructure investment decisions are typically based upon a comparison of the discounted costs and benefits of alternative options. Discounting means that the valuation of costs and benefits is time dependent, with deferred investment incurring lower discounted costs. For new infrastructure appraisals, benefits typically take the form of reduced journey times, increased safety, etc. In cases of like-for-like asset renewals, however, investment does not produce additional benefits of these kinds, but rather avoids the costs (and other disbenefits) associated with reduced serviceability and potential failure [4,5]. Both the geotechnical and economic elements of the analysis are subject to considerable uncertainty [6], and a similar 'meta-analysis' can be applied to the costs and benefits of obtaining asset condition data to inform investment decisions, with the aim of the maximising the useful information obtained per the cost of obtaining it [7].

An example of the comparison of the total discounted costs of investment alternatives is set out below, based on the following assumptions:

- Current year = 2023 (the base year for discounting purposes)
- Cost of intervention = £1,000,000 (assumed to be constant in undiscounted terms, irrespective of year of intervention)
- Cost of failure and emergency repairs = £10,000,000 (assumed to be 10 times the costs of planned, preventive intervention, and again assumed to be constant in undiscounted terms)
- Discount rate = 3%

Because the interventions and investments take place over different timescales, an annualised present value of costs (APVC) is calculated to enable like-for-like comparisons, produced by multiplying the conventional present value of costs (PVC) by a capital recovery factor (CRF), calculated as follows:

$$CRF = d(1 + d)^n/((1 + d)^n - 1)$$

where d = the discount rate and n = the lifetime of the investment in years.

Taking account of this calculation only, the results indicate that, for an asset constructed now, the optimum time to intervene to reduce APVC is relatively late in its life (i.e. at around 75% deterioration as shown in Figure 1). However, this approach comes with risks and other disbenefits outlined below. A detailed example of the economic calculations used is given in [4].

Long-term safety and serviceability should be included in the analysis of whole-life costs

Figure 1 shows that, in this example, earlier interventions provide greater asset life extensions, but very early intervention incurs the highest discounted whole-life costs. Clearly, very early intervention (e.g. at 10% deterioration of FoS) is unlikely to be applied in practice. However, for example, intervention at 50% FoS deterioration still brings much more significant increase in asset life, and importantly serviceability (illustrated as reduced movements), compared with waiting until 75%. Since strain softening typically concentrates at the slope toe, reducing toe movements is therefore a reflection of the reduced deterioration rate and increased resilience of the asset. These serviceability benefits, which are significant when intervention occurs at 50%, are not accounted for in the costs analysis given above. The purely economic calculation also does not reflect the fact that more significant intervention may be required later in life, or the safety risk related to the increased probability of failure closer to end of life.

This analysis therefore illustrates the concept, now becoming more well established, that decisions should not be based purely on economic indicators. Taken alongside the fact that asset maintenance prevents disbenefits rather than providing new benefits, this reflects the need to review traditional government cost-benefit analysis practices to support improving the resilience of the UK's existing stock of long linear geotechnical assets.

Climate change will reduce the resilience of earthworks and increase the need for earlier interventions

Finally, *Reading Guides 3 [2]* and 5 [7] have illustrated that the challenge of ensuring resilience of our earthworks will only become more difficult and more pressing due to the impact of climate change. The ACHILLES analysis of interventions has not yet explicitly accounted for this major impact. However, our modelling shows that climate change will accelerate deterioration processes (see *Reading Guide 3* [2]). The TTF is thus going to reduce, and earlier interventions will therefore be required to maintain safety and serviceability in the future.

Early intervention provides the greatest extension to asset life.

This research provides a clear indication that asset management decisions need to consider more than just economics to ensure a reliable service.

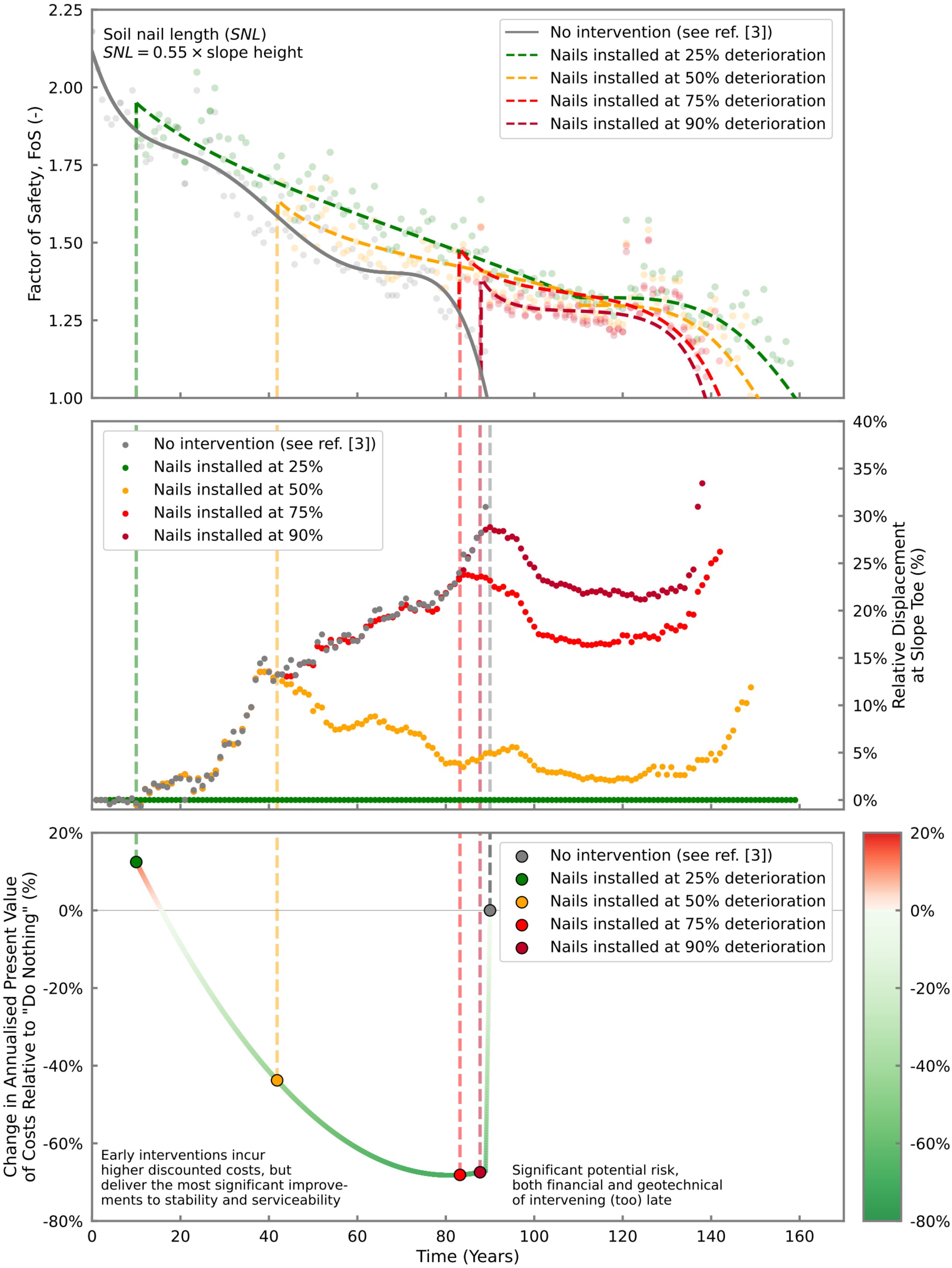

Figure 1: Changes in rates of deterioration as indicated by changing FoS and time to failure, TTF, displacements at slope toe relative to early intervention, and Annualised Present Values of Costs, APVCs, for a cut slope as functions of intervention time.

Further Reading

Please also refer the other ACHILLES reading guides where you can find out more about what we have achieved. *Reading Guide 1* explains the context of the ACHILLES Programme Grant. *Reading Guide 2* describes how we have achieved a deeper understanding of deterioration affecting the clay materials that we focused on. *Reading Guide 3* extends our understanding of deterioration to the long linear geotechnical asset scale. *Reading Guide 4* outlines the ways in which we can assess the condition of our long linear geotechnical assets. *Reading Guide 5* provides an overview of the design tools that ACHILLES has developed. *Reading Guide 6* explains how ACHILLES see data analytics playing a role in addressing deterioration of long-linear geotechnical assets.

Key references

[1] Briggs, K.M., Helm, P.R., Smethurst, J.A., Smith, A., Stirling, R., Svalova, A., Trinidad González, Y., Loveridge, F.A., Glendinning, S. (2023). **Evidence for the weather-driven deterioration of ageing transportation earthworks in the UK.** *Transportation Geotechnics*, 43:101130. DOI.org/10.1016/j.trgeo.2023.101130

[2] Helm, P.R., Morsy, A., Postill, H., El-Hamalawi, A., Stirling, R.A., Rouainia, M., Briggs, K.M. (2023). **ACHILLES Reading Guide 3: Asset scale deterioration.** The ACHILLES Programme Grant Consortium, Newcastle University, UK, 8p

[3] Postill, H., Helm, P.R., Dixon, N., Glendinning, S., Smethurst, J.A., Rouainia, M., Briggs, K.M., El-Hamalawi, A., Blake, A.P. (2021). **Forecasting the long-term deterioration of a cut slope in high-plasticity clay using a numerical model.** *Engineering Geology* 280(1):105912. DOI.org/10.1016/j.enggeo.2020.105912

[4] Armstrong, J., Preston, J., Helm, P.R., Svalova, A. (2023). **ACHILLES: Reducing Infrastructure Whole-Life Costs.** In: Proceedings of the 10th International Conference on Railway Operations Modelling and Analysis (RailBelgrade 2023). Belgrade, Serbia.

[5] Armstrong, J., Helm, P., Preston, J., Loveridge, F. (submitted). **Economics of geotechnical asset deterioration, maintenance and renewal.** *Transportation Geotechnics.*

[6] Armstrong, J., Preston, J. (2023). **ACHILLES: handling uncertainty in railway earthworks maintenance and renewals.** Accepted for presentation in: 4th International Railway Symposium Aachen (IRSA2023). Aachen, Germany.

[7] Armstrong, J., Preston, J. (2023). **ACHILLES: The benefits and costs of increased asset information.** In: Proceedings of The Fifth International Conference on Railway Technology: Research, Development and Maintenance. Montpellier, France.

Non-ACHILLES references

[A] Network Rail, 2018. Earthworks Technical Strategy [online]. Available from https://www.networkrail.co.uk/wp-content/uploads/2018/07/Earthworks-Technical-Strategy.pdf [Accessed 29 September 2023]

[B] *Murray, R.T. (1993). The Development of Specifications for Soil Nailing (Research Report No. RR380). Transport Research Laboratory, Crowthorne, UK..*

[C] *Phear, A., Dew, C., Ozsoy, B., Wharmby, N.J., Judge, J., Berley, A.D. (2005). Soil nailing – best practice guidance (No. C637). CIRIA, London.*

[D] *Whitbread, M.J. (2012). Design of soil nails, in: Burland, J., Chapman, T., Skinner, H., Brown, M. (Eds.), ICE Manual of Geotechnical Engineering: Geotechnical Design, Construction and Verification. ICE Publishing, London, pp. 1109–1114.*

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The ACHILLES Reading Guide Series

1. The ACHILLES concept
2. A deeper understanding of deterioration of engineered soils
3. Asset scale deterioration
4. Asset condition assessment
5. Design considerations for clay earthworks
6. The role of data analytics in decision-making
7. **Intervention strategies and business case**

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