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RAIL TRACKBED STABILISATION USING MICRO-PILING

INTRODUCTION

Ballasted railway track over a soft subgrade is a common cause of low trackbed stiffness and is widely associated with poorly performing rail networks. A low trackbed stiffness can cause excessive track deformations during the passage of trains. Undoubtedly, this can lead to rapid deterioration of track quality and a risk of derailment which results in costly line speed restrictions. Trackbed Stabilization (TBS) includes engineering works to improve the trackbed stiffness in areas of poor load bearing capacity due to soft subgrade. There are a variety of TBS techniques that can improve soft subgrades and enhance the ability of the track to operate safely in the railway network. However, conventional TBS techniques may not be effective for existing tracks as the TBS built on-track have required the track to be removed. This technical paper investigates the performance of trackbeds before and after a novel trackbed stabilisation with screw piles (micro-piling), taken from field measurements from case studies in the UK and Ireland. Based on the measurements, the track performance is improved after micro-piling indicating that the micro-piling can be an effective stabilisation approach for increasing the stiffness of track foundation over soft subgrades, as well as slope stability. The paper is organised as follows:

- a detailed insight into the implementation of TBS screw piles for pre-existing railway is provided
- followed by a presentation of design and construction phases with four successful case studies of micro-piling application in UK sites
- and finally different performance assessment tools and measurement techniques are discussed to evaluate the effectiveness of micro-piling.

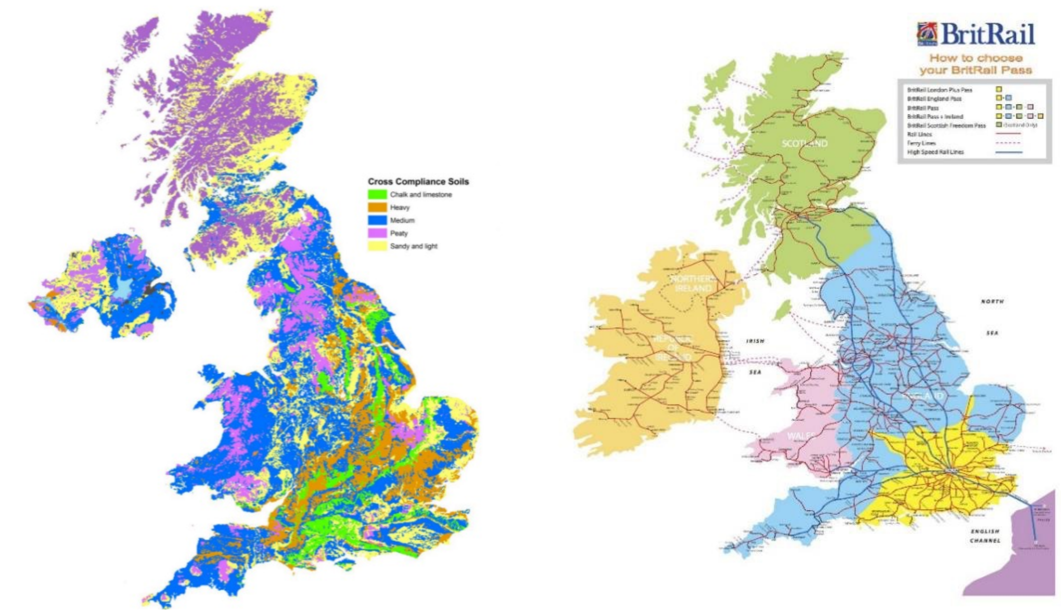

Figure 1a: Map of basic soil types in the UK (Roques et al, 2013), and **Figure 1b:** Rail map (BritRail)

The paper concludes with key pointers to aid those engineers and researchers for conducting TBS projects, and a guideline to help readers assess the performance of the micro-piling systems in trackbed stabilisation.

BACKGROUND

Installation and maintenance issues of ballasted track constructed over soft soil have long been a concern of Railway Engineers. Due to the high compressibility and inhomogeneity of soft soils, subgrade deformation in these regions is a serious issue. Adequate trackbed stiffness is required to achieve optimum performance and safe operation of passenger and freight trains, minimizing the risks of derailment (Liu et al, 2012).

It should be mentioned that the limit of the track deformation depends on a number of parameters such as train load and train speed. In general, to have a safe and comfortable ride, the track displacement is recommended to be limited to 4mm under the heaviest axle loads in UK (Rail, 2015), while overall track movement should be within a range width of 1-2mm for passenger trains (Le Pen et al, 2016).

In the UK the subgrade is variable and more difficult to control, and a very soft subgrade can have detrimental effects on the overall track stiffness of a section of track. **Figure 1a** shows a soil profile of the UK and **Figure 1b** shows the railways across the UK, some of which may pass across areas with loose sand and peat.

It is worth noting that this issue is not unique to the UK, and Irish Rail is also affected by soft subgrade. Irish Rail operate the main passenger and freight railway lines in Southern Ireland, and their network extends to approximately 1900 km. However, there is another rail network in Ireland whose network length probably exceeds this which is the narrow-gauge railway, the construction of which was required for peat removal from Irish bogs. Studies show that bog covers around 21% of the surface area of Ireland which is more than any other country in Europe except Finland (Tanneberger et al, 2017). The rail routes constructed through Ireland's central plain involved construction of many miles across bogs (Smith, 2020, O'Dwyer D, 2015) **(Figure 2)**, with depths of peat varying in thickness up to 20m (70 feet); in some areas it was obviously impossible to excavate or embank on these unstable masses (Jennings, 1994).

The stiffness of the track and track geometry deterioration can be influenced by poor subgrade (Nielsen et al, 2020). When geometry defects become too severe, maintenance – usually in the form of automated tamping or

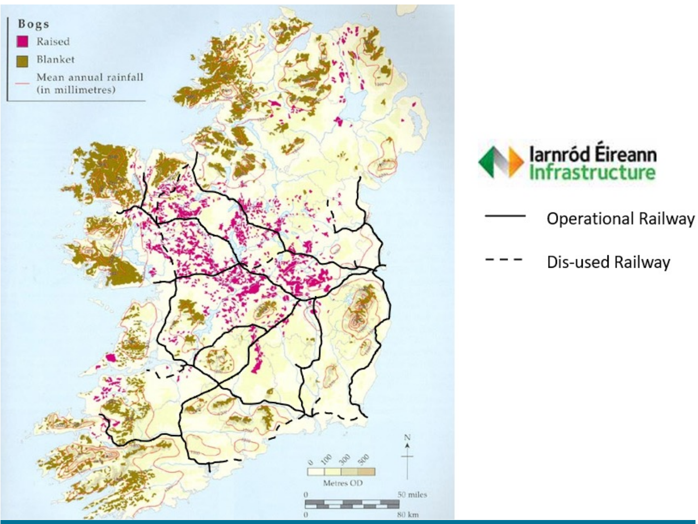

Figure 2: Map of soft soil in the Ireland and Rail map (Aalen et al, 1997)

manual packing – is carried out to realign the track and enable the continued safe running of trains. Unfortunately, regular tamping may also disrupt the load-bearing structure (Aingaran et al, 2018) and damage individual ballast particles, resulting in a diminishing return period between maintenance interventions until eventually the track-bed requires full renewal. The environmental impact of ballast replacement is also a key consideration. Where maintenance is deemed ineffective, alternative options can include speed restrictions, impacting on train performance, and associated costs for disruption to planned train timetables.

Low stiffness values generate high rail deflections, rapid deterioration in track quality and consequently increase the impact of excessive maintenance on the lifespan of track (Milne et al, 2018). For instance, rail components are influenced by large trackbed deflection due to the low stiffness. Therefore, track fails more frequently under poor trackbed support conditions. It is therefore important that track stiffness is optimised and regulated, and high rates of change of stiffness are avoided. Poor track geometry can also result in reduced line speed and underutilisation of the railway network (Brough M, 2008).

Track Bed Stabilisation (TBS) is a remediation used where track needs to be constructed over soft subgrade with a poor load bearing capacity. The general TBS methods usually proposed for these kinds of issues are: (i) mass stabilisation with dry deep soil mixing (cement columns) (Pye et al, 2012), (ii) micro-piling, (iii) geogrids (Ngo et al, 2017), and (iv) removal/replacement works (Kayes et al, 2000). Some of these treatments such as geogrids and removal/replacement are not suitable for pre-existing railway lines as they require removal of the track structure and cause a high cost for the existing railway. However, a TBS technique can be applied with minimum traffic, financial and operational impacts (Brough et al, 2000).

TBS screw micro-pile foundations, also known as helical piles, offer distinct benefits over alternative piling techniques such as grouted piles or driven tube systems. They comprise pre-manufactured piles consisting of steel helical blades and shafts placed into trackbed by screwing. The helical pile is rapid and a dry solution, meaning no wet products are used which reduces cost and environmental risks, and removes the need to allow for any curing times.

MICRO-PILING (HELICAL PILES)

Micro-piling as a TBS system can be used in pre-existing railways to reinforce the lower layers of very soft/peat subgrade, bringing the vertical deflections to acceptable levels. It can be used as an alternative method to diminish the need for excavation of very deep layers of soft subgrade. The micro-piles in the form of helical piles have been used successfully in different sites suffering from imposed Temporary Speed Restrictions (TSRs), due to the soft subgrade.

The piles are constructed using steel shafts with helical flights (the overall diameter is circa 300mm), welded at strategic positions along the shaft. The size of the shaft (ie length and diameter) varies depending on the ground conditions of the site. Installed from road/rail-mounted plant, the system utilises a modified helical pile technique with a patented pile cap. The helical flights give the foundation both tension and compression bearing capacity which enables them to be used for TBS. A typical micro-pile layout with typical size and installation depth is shown in **Figure 3**.

including numerical analyses, (finite element modelling and calculations). The design phase should be informed by a detailed trackbed and ground investigation including geophysics, SPT (Standard Penetration Test) and DPSH (dynamic probing super heavy) testing to identify the soil type and strength variation with depth. Other techniques also exist such as Falling Weight Deflectometer that can give stiffness and critical velocity parameters (Govan et al, 2015).

The helical piles are designed to suit specific site and ground conditions. The correct size and configuration of helical piles depends on multiple factors. The pile length should cover the thickness of the soft subgrade layer and it is recommended that two additional helices of 0.7m from the pile base are embedded into the competent layer of stiff subgrade (Musgrave et al, 2017).

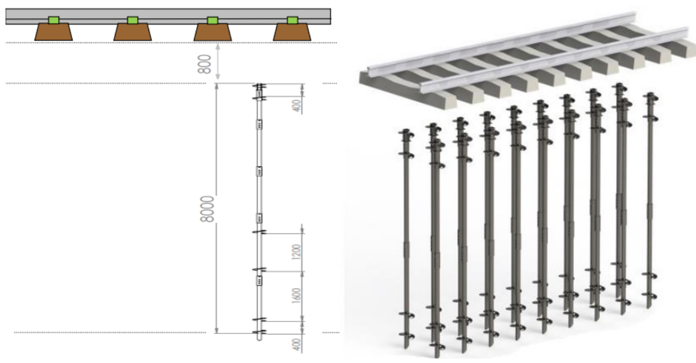

Figure 3: Schematic of micro-pile layout with 8m pile length and with double helix cap

DESIGN PURPOSE

As stated above, the purpose of trackbed micro-piling is to reinforce and reduce stresses within the soft subgrade layers (usually peat or clay), by transferring the dynamic train traffic loading from the track components to the deeper more competent substructure layers, improving the vertical and lateral stability of the track which in turn reduces the vertical rail deflections to acceptable levels. The length and depth of the piles are determined by using the ground investigation information and other track performance data

Typically, the pile consists of one cap at the top of the pile and one 2m leader at the bottom of the pile. A combination of extensions is then used between the cap and leader to achieve the required pile length. Both the leader and each extension include two flights (see figure 3). The pile cap also consists of two flights to increase the pile cap area. At each joint galvanised bolts and nuts are used to connect the piles together.

However, in some situations longer piles with more helices are suggested due to any unforeseen ground condition.

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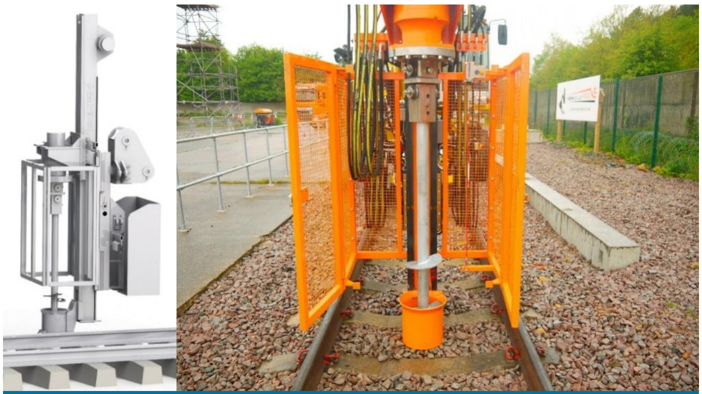

Figure 4: Schematic diagram and a photograph of piling rig attachment

Therefore, it is essential to have a consultant designed pile including a desk study and ground investigation in accordance with British Standard (BS).

The steel pile cap is typically installed at a depth of 800mm below the existing sleeper bottom layer in order to avoid the disruption of ballast tamping maintenance. The pile base section, comprised of two flights, is designed to be installed into a stiff competent soil layer at greater depth to provide a suitable foundation for the pile base.

The configuration of the micro-piles is dependant on project type; however, the following criteria is suggested for every sleeper bay vs. alternate sleeper bays (Musgrave et al, 2017), however this falls within the designer's decision:

- if (GH ≥ 0.5m) Piling in alternate sleeper bays is permitted
- if (0.4m ≤ GH < 0.5m) Piling every alternate sleeper bay is not permitted, piles should be installed every sleeper bay.

Where, GH: is the minimum thickness of the granular layer below the sleeper bottom (ie, ballast plus sub-ballast/ blanketing layer).

Finite element analysis is usually performed to determine buckling resistance of the pile. Pile design is undertaken utilising skin friction around the helical flight sections with the bottom most flight to end bear on a competent stratum.

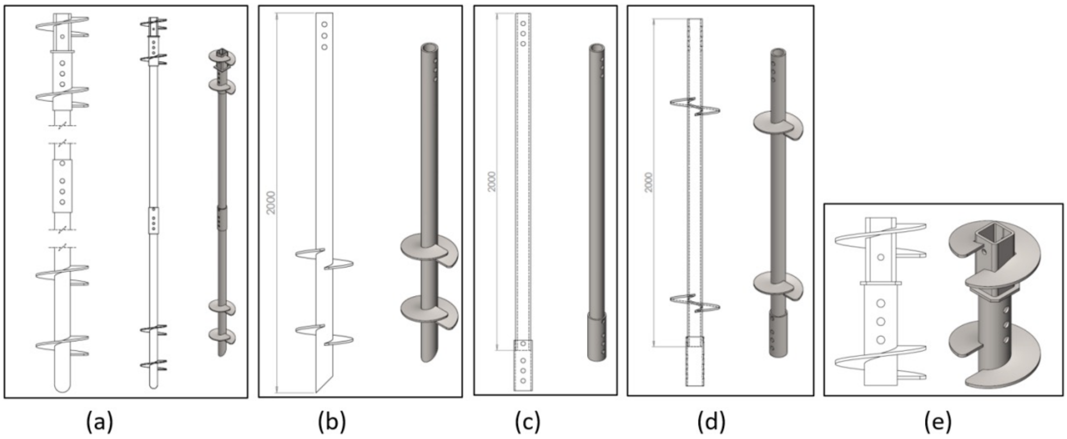

Figure 5: (a) Smartpile general assembly, (b) 2m leader, (c) 2m plain extension, (d) 2m extension with 2 flights, (e) cap with double helix

PILE INSTALLATION

The installation is undertaken using a piling specification Road Rail Vehicle (RRV), with a piling mast (SPIRIT Mast) which is designed and developed specifically for this application, and a modified and patented helical pile system with the commercial name of Smartpile (Van Elle Ltd). The SPIRIT mast is Network Rail Product Approved and is designed to ensure maximum safety with features such as interlocked rig guarding and lifting assistance for handling piles. The helical piles require installation to a high positional tolerance whilst also recording installation torque throughout the installation. This torque figure is used to verify the design capacity of the pile. **Figure 4**.

The first section (Leader) is installed by applying a downwards force and a clockwise rotational torque with the SPIRIT mast. Further sections are added as per design until the required depth is achieved. Each section is secured by bolts through the tube of the helical pile and tightened. Torque values are recorded on the installation log and are used to determine the pile bearing capacity. The installation is controlled to prevent over flighting of the helixes which would result in disturbance of the track ballast and subgrade. The final stage is to screw the pile into the ground using the drive extension until the pile cap is 800mm below sleeper base, which is measured by a guide on the last pile extension. The same procedure is repeated for every pile location. The general sequence of Smartpile assembly is shown in **Figure 5**.

The Smartpiles can be installed in the sleeper crib either in the 4-foot or outside of sleepers depending on design requirements. There are some suggested Smartpile installation patterns shown in **Figure 6**, which are selected based on project and site conditions.

In some cases, the track geometry will not be restored to acceptable levels only by micro-piling. It is essential that designed tamping is undertaken on completion of the micro-piling works so the system enables trains to run smoothly on their tracks. Depending on traffic tonnage at the site, it is recommended the tamping is completed within 4-8 weeks of the micro-piling works (Musgrave et al, 2017).

Micro-piles have been used on a number of different sites to improve the trackbed quality. In the following section, the performance of micro-piling on the improvement of trackbed performance is discussed based on the measurements obtained from different types of case studies.

PERFORMANCE MONITORING, DESIGN AND OPTIMISATION

Real-time monitoring systems for railway trackbeds, combined with numerical analysis to simulate the trackbed response under train loading, can provide optimal design for trackbed systems. Monitoring solutions for the railway system have gained popularity in recent years, with two basic categories of monitoring systems: lineside and onboard train monitoring systems. These tools can assess track performance for both short term and long-term periods. The following are some examples of trackbed monitoring systems and techniques for design and optimization.

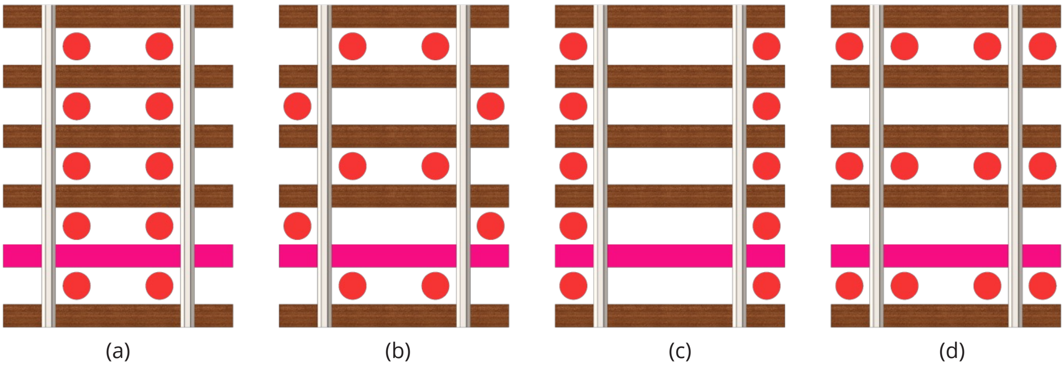

Figure 6: Various micro-piling layout configurations: (a) inside 4-foot, every sleeper bay, (b) alternate inside 4-foot and outside 4-foot every sleeper bay, (c) out of the 4-foot every sleeper bay and (d) both inside and out of the 4-foot every other sleeper bay

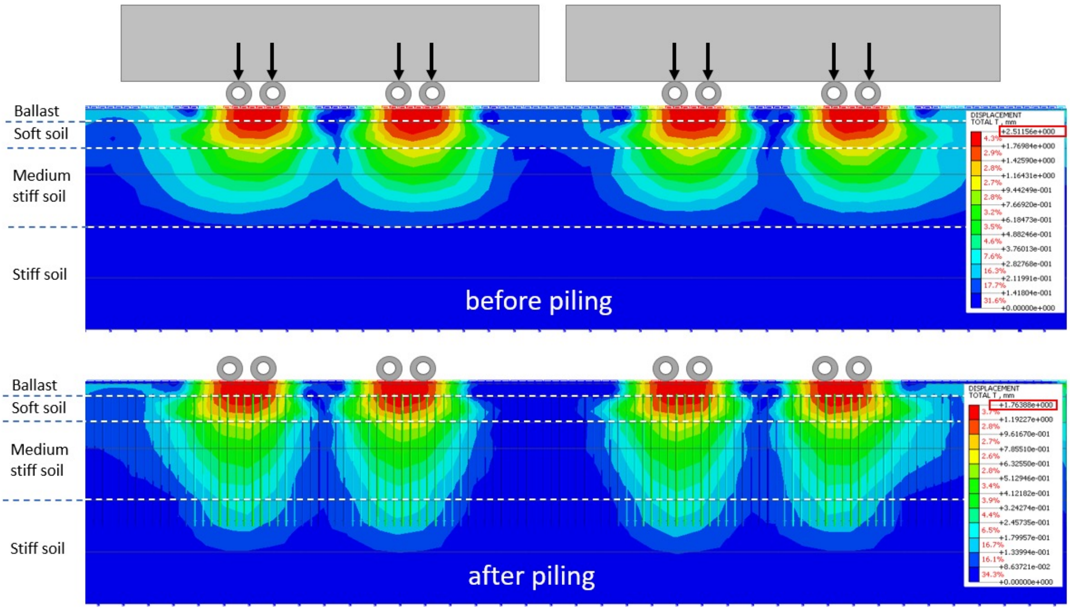

Figure 7: Typical contour plots of total track deflection for train speed of 40m/s, before and after piling

Non-contact measurement techniques: Vision based monitoring (VBM) systems comprised of high-speed cameras based on digital image correlation principles (Gallou et al, 2020, Gallou et al, 2017) can easily be deployed on-site to measure accurately the rail or sleeper deflections at a high frequency over large track lengths in multiple positions at a time without requiring time-consuming installation or site access. The track stiffness is estimated before and after TBS by using VBM measurements. The comparison of measurements obtained by VBM before and after TBS enables designers to provide an optimum design based on project requirements and limitations.

On-board measurement train - Track geometry: Network Rail regularly collect track geometry data on main lines using the New Measurement Train (NMT) (Sharpe et al, 2015). The NMT was launched in 2003 and assesses the condition of track so that engineers can determine where work is required. It was assembled from High-Speed Train Class 43 power cars and Mark 3 coaches and can check the condition of all main lines in Great Britain in a fortnight. The track quality can be evaluated by using the standard deviation (SD) of the geometric variables recorded periodically by means of the NMT.

Digital Void meters: Void meters are a more traditional lineside monitoring system, which are typically used to continuously measure the vertical displacement of the rail on the critical components of the track over a long period of time for multiple train runs. Digital void meters were used in some TBS projects to measure the track deflection before and after micro-piling.

Numerical analysis: Finite element computer programs are also other tools which have become widespread and popular in geotechnical practice for controlling and optimizing engineering tasks. Numerical simulation can be useful to investigate the dynamic response of the track.

In TBS projects Finite Element Analysis (FEA) is typically used to simulate the dynamic response of ballasted railway tracks subjected to train passages and evaluate the effectiveness of micro-piling for a range of train–track–ground system conditions **(Figure 7).**

CASE STUDIES

CASE STUDY 1: (PHASE 1 AND PHASE 2)

Site description and history: The site was an at-grade double-track railway section in Berkshire, England. The track at the study site is on straight section with a nearby level crossing and a station. Passenger and freight service trains are travelling at up to the line speed of 60-100 mph. However, the Up line suffers from track quality problems due to very poor deep seated subgrade conditions.

Previous field measurements established that vertical track deflections are not proportional to the existing rail traffic loads. Deflections of up to 10mm were recorded for heavy freight trains and up to 8mm (including 3mm voiding) for high-speed passenger trains, leading to a TSR of 50mph for freight operation. Based on the site investigation, and Ballast Sampling (ABS) / Window Sampling results, the Up line comprises flatbottom rail and concrete sleepers constructed on 1m dirty ballast laid on a very soft soil (peat and soft organic clay), continuous to 10m and potentially beyond this depth. Therefore, micro-piling was proposed to be installed in pairs in the sleeper crib with the track in-situ (at 4-foot), to reinforce sub-grade layers and reduce stresses within soft subgrade.

Design specifications: The piling works were carried out in two phases. In Phase 1, with very soft ground condition, a total of 238 micro-piles, with a pile length of 8m were installed in 6ft and cess **(Figure 8).**

A series of micro-piles 10m long were installed in Phase 2, with slightly better ground condition, but still peaty. Depth of the pile cap is located 800mm below sleeper bottom level.

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Figure 8: Trackbed stabilisation with micro-piling and site condition at Case Study 1, Van Elle Ltd

CASE STUDY 2:

Site description and history: Part of the Dublin to Galway rail route through Corracullin Bog on the border of County Westmeath and County Offaly in central Ireland suffered from track quality problems due to presence of blanket bog. In some locations the track needed to be lifted by nine to twelve inches every day to compensate the settlement that had occurred overnight. This continued for many weeks. The maintenance of this permanent way has continued to require specialist attention.

The trackbed has been stabilised using an innovative piled solution. Just over 4km of the rail line runs across the bog and it is one of several on the line that require regular maintenance to keep track geometry within tolerance. Site conditions are shown in **Figure 9**.

Based on the desk study exercise, key points noted as below:

- Drift Geology – Peat and Till in proximity to the site.
- Ground Probing Radar Plots – considerable ballast thickness (>1m)
- In summary, the windowless samples were advanced to refusal, encountering obstructions between 7.2m and 8.2m below ground level (bgl). The dynamic probes achieved depths ranging 6.3 to 8.8m bgl and the panda probes achieved depths ranging from 2.2 to 4.6m bgl.

Design specifications: In total 146 piles were installed to depths of up to 7m at 600mm centres at Case Study 2.

CASE STUDY 3:

Site description and history: The Down line suffered from historical track quality problems due to poor subgrade materials used in the construction of the low embankment. These materials were locally sourced from "borrow pits" adjacent to the railway line. This has resulted in poor vertical and horizontal alignment and high rates of track quality deterioration, particularly following heavy rainfall. The subgrade conditions did not adequately support the dynamic loading of trains at line speed (90mph), which resulted in high levels of maintenance intervention, rough rides reported and TSRs. The treated location was a long-standing problem which could not be rectified by conventional track renewal methods as it was a deeper-seated embankment problem. Maintenance staff also reported loss of cross level and misalignment towards the cess direction following periods of heavy rain fall due to the poor-quality embankment material being sensitive to changes in moisture content.

Due to the above site conditions, a desktop study and Site Investigation were conducted at Case Study 3. A soft layer with low dynamic probing values of 0 – 2 / 100mm were found at site during the heavy dynamic probing survey to a depth of 3.5m, within the soft fibrous peaty clay layers. Beyond this depth the probing values increased to 5 – 20 / 100mm, as the ground increased in stiffness. No significant drainage problems were identified during the site investigation, and ground water was encountered at a typical depth of 5.5m.

Design specifications: Van Elle were appointed to the Track-Bed Stabilisation Framework through Network Rail's TrackBed Team in 2016. One of the sites with track-bed issues suffered from the track losing 25mm+ of cant, along with a cross-level-fault of 70mm+ all towards the cess. The track is founded on top of an embankment 3m above the surrounding fields.

Van Elle worked in collaboration with Network Rail to come up with a solution to the problem of stabilising track over weak/ poor ground. The current method trialled was a grouted drill rod that consisted of drilling a 220mm diameter hole pumped full of grout to transmit the load from passing trains in the ballast past any weak/ poor layers into competent ground below. This system had proven itself as a viable method, but the process was slow and very messy, with large volumes of soil, water and grout returning to the surface, causing a lot of contamination. Van Elle developed the Smartpile system which utilises helical pile technology. The technical problem to overcome was how to apply the torque required to drive the pile into the ground and disconnect from a load bearing cap at a specific depth below ground.

A total number of 290 micro-piles, 4.0m long were installed in Case Study 3 - Phase 1. The pile caps were to be left 800mm below the bottom of the sleeper to allow tamping.

CASE STUDY 4:

Site description and history: The railway embankment slope itself ranges between 2 and 6 metres in height and stands at an angle of up to 35° **(Figure 10a)**. The site has suffered from a history of track quality issues that had been attributed to track bed settlement and possible movement of the Down-side embankment. The initial proposed solution was the complete excavation and replacement of the embankment and track bed and formation under both lines. However, micro-piling comprises a solution that steers away from the more traditional route of digging out the trackbed, replacement and formation renewal, by providing a more cost-effective remedy.

Design specifications: In total 250 piles were installed to depths of up to 8.5m at the embankment to reduce track settlement and improve track quality **(Figure 10b)**.

Six inclinometers and one standpipe piezometer (two 19 mm diameter piezometer installations within) were installed in addition to five existing inclinometers and

Figure 9: Site condition at Case Study 2, before Trackbed stabilisation

Figure 10a: Case Study 4 site condition. Inclinometers (left), and the limit of the site with river and the surrounding topography (right)

Figure 10b: Case Study 4 pile installation.

two existing groundwater monitoring installations to help inform and monitor for any future movements associated with the embankment, and to monitor pore water pressures within the cohesive and granular soils identified at the site.

RESULTS AND DISCUSSIONS

For an overview of micro-piling performance, a list of case studies described above, with details of micro-piling conducted by Van Elle is provided in **Table 1.** The micro-piles were installed out of 4-foot and in every sleeper bay in all cases.

The performance assessment was conducted for the case studies based on the trackbed deflection measured before and after micro-piling. The general methods used for the assessment were discussed in the earlier section.

Figures 11a and 11b show the vertical track deflection versus time at Case Study 1 Phase 1 obtained by Video Gauge system for a freight and passenger train before and after stabilisation respectively. The track deflection under freight trains has diminished from 10mm to 6mm (40% reduction), and the track deflection under high-speed passenger locomotive has diminished from 7mm to 3.7mm (47%).

Similar measurements obtained by VBM at Case Study 1 Phase 2, are shown in **Figures 12a and 12b**. The maximum range of the negative displacement (downward deflection) at the rail web under the passage of the first bogie of a passenger train with constant speed measured approximately 3.1mm **(Figure 12a)**, while the displacement reduced by approximately 1mm after installation of helical piles **(Figure 12b).** The tests were repeated during several train passages (passenger and freight), and the downward track deflections at rail web were compared. Based on the VBM measurements, and comparing the downward peak displacements after and before, it was concluded that the micro-piling reduced the track deflection by approximately 30%. It is worth highlighting that micro-piling alone will not restore the track geometry at a site always to a good or satisfactory state. Design tamping following the installation of micro-piles is recommended due to the ballast disturbance during the installation.

Case study	Number of piles installed	Pile length (m)	Average reduction in track deflection/ slope stability (%)
Case study 1 (phase1)	232	8.0	50
Case study 1 (phase2)	92	10	30
Case study 2	146	7.0	50
Case study 3 (phase1)	290	4.0	39
Case study 3 (phase2)	802	4.0	39
Case study 4	250	8.5	45

Table 1: A summary of micro-piling projects, Van Elle

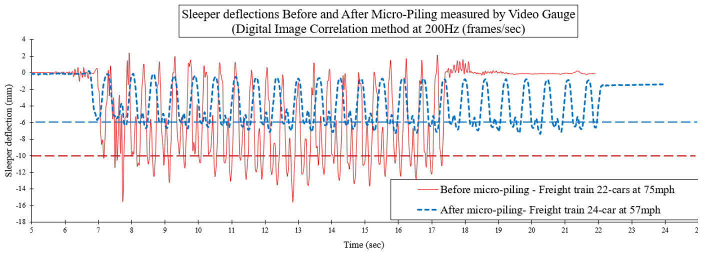

Figure 11a: Deflection – time history measured by Video Gauge, before and after piling, freight train, Case Study 1 - Phase 1

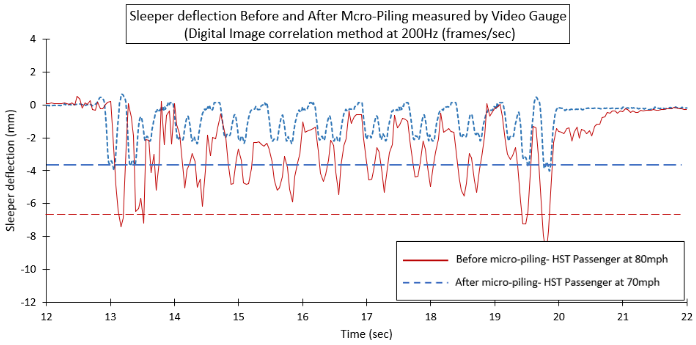

Figure 11b: Deflection - time history measured by Video Gauge before and after micro-piling, Intercity 125 passenger train, Case Study 1 - Phase 1

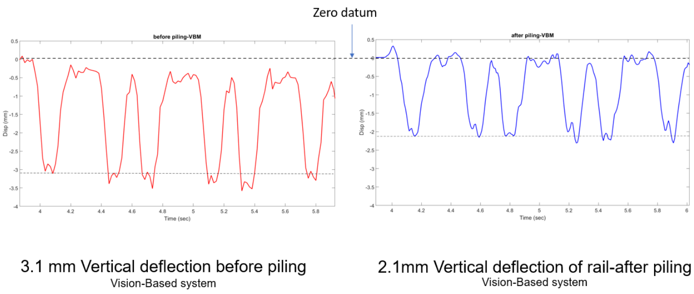

Figure 12a and 12b: VBM results, before and after piling, Case study 1 - Phase 2

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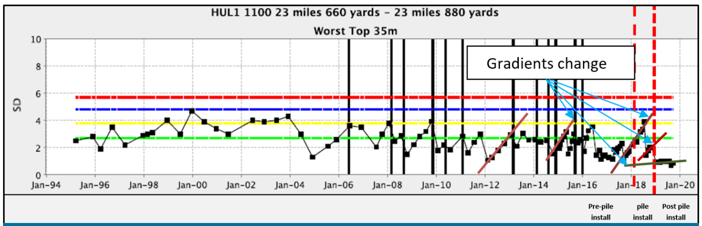


Figure 13: Track geometry -Top 35m at Case Study 3, recorded by NMT

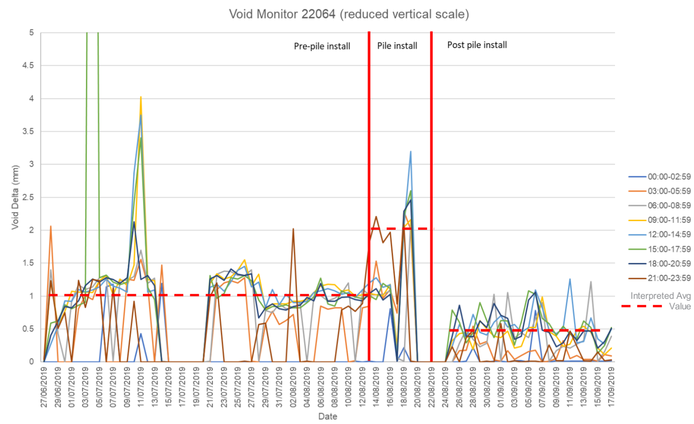


Figure 14: Digital Void Monitoring results

Figure 13 presents the historical SD of vertical Top 35m trace over an 8th of a mile at a micro-piling site, in Case Study 3, delivered in 2018. Prior to the micro-piling works the vertical alignment had an annual SD deterioration rate of approximately 2mm per year (as shown by the steep gradients in the traces). Following the installation of steel micro-piles in alternate sleeper bays at the site in 2019, this SD deterioration rate was decreased to less than 0.4mm per year (relatively flat gradients). This reduction in deterioration rates has removed the requirements for speed restrictions at the site and has significantly reduced the number of maintenance interventions required.

Based on the average numbers measured by void meters, an improvement of the deflection behaviour of the site after micro-piling was achieved. A typical time-void history before and after micro-piling is shown in **Figure 14**. By observing **Figure 14**, during the installation phase the installation of helical piles has resulted in reduced vertical track deflections, and higher reduction was achieved after the completion of the piling followed by tamping.

Figure 14 shows typical contour plots of total track deflection for train speed of 40m/s and soft subgrade, before and after piling, simulated using FEA.

Based on the monitoring data recorded by different techniques, the micro-piling system was effective in reducing the track deflection.

In most of the case studies presented above, trackbed deflection was measured to assess the trackbed performance before and after micro-piling, expect for Case Study 4 where slope movement was monitored. Based on results from inclinometers installed at the embankment (Case Study 4), the average level of movement on the slope (downslope movement), is significantly reduced after piling (0.004-0.11 mm/day now reduced to 0.02-0.06 mm/day).

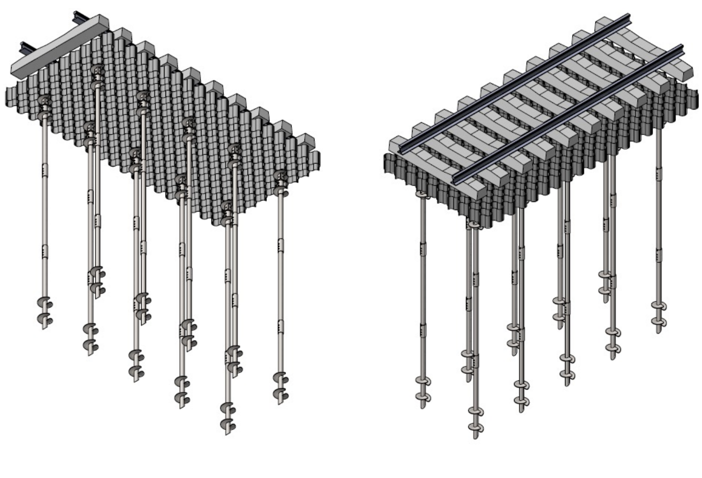
The above evidence demonstrates that micro-piling effectively reduces vertical track deflections, enhances track stiffness over soft subgrades, improves ride quality, minimizes track geometry deterioration rates, and enhances the lateral stability of the track. However, the efficacy of micro-piling depends on site and ground conditions. For example, at Case Study 1, micro-piling was successfully installed with handback to maintenance at the end of the shift. However, very deep soft sub-grades that exceed the design length of the piles, eg a very deep peat layer, may still be left untreated. In such situations, the installation of longer piles becomes necessary to transfer the load to the competent layers and provide adequate support. Another factor that may affect the performance of micro-piling is the condition of the ballast, as fine content and ballast quality can cause disturbances in load transfer and other arching effects.

Overall, the use of micro-piling yielded significant time savings, leading to increased cost-effectiveness in both labour and plant expenses. Moreover, it resulted in a decrease in material transportation to and from the site, resulting in a reduced impact on the local environment and fewer road journeys for lorries. These outcomes contributed to a more favourable and efficient work environment on the site.

HYBRID DESIGN METHODS

There are some locations where the micro-piling may not be sufficient to support the trackbed. Where the subgrade conditions or the condition of existing ballast and sub-ballast/capping layer are not competent, hybrid remediation techniques can obviously have a significant effect on the trackbed quality. Some additional techniques are recommended below, that can be used in combination with the micro-piling to achieve better trackbed performance.

Micro-piling with Geocells: A robust formation treatment is recommended to be installed between the ballast layer and the top of piles. Geocells layer filled with granular material is recommended to be installed during the piling installation or during the next planned track renewal works, to further reinforce the trackbed and maximise the load transfer onto the micro-piles and surrounding soft subgrade **(Figure 15).** However, this should be designed and checked to ensure that the combination of the hybrid technique can meet the project needs.



(a) Bottom surface (b) Top surface

Figure 15: The design of the Smartpile integrated with Geocell

Micro-piling with grouting: In general, grouting of the micro-pile shaft is not required for all cases. However, micro-piling can be installed with grouting for different purposes. Micro-piles are recommended in some conditions to be filled with grout to increase the stiffness of the pile and reduce lateral pile deflections. This leads to the following benefits: by filling the micro-pile shaft with grout, pile bending stiffness increases which can improve the lateral resistance of the piles and consequently the lateral resistance of the trackbed. Additionally, the durability of bolted pile connections subject to dynamic loading improves and corrosion on the inside of the pile reduces. In considering the grouting option, a proper design analysis should be undertaken to define the pile movement according to site specific conditions and project requirements. Furthermore, grouting on the bases and sides of the micro-piles can be used to improve their bearing capacity by increasing the tip friction and the shaft friction. However, risk of grout contamination and ground surface heave must be controlled. Therefore, an appropriate design procedure is always needed to be adopted for a given set of conditions.

With appropriate remediation and the use of above-mentioned suitable TBS techniques, the life of specific sites with soft subgrades suffering from high rates of deterioration and critical speed effects can be extended, their maintenance needs can be reduced, and the railway performance and capacity will be improved. However, the choice of TBS technique depends on project circumstances and limitations.

CONCLUSIONS

Trackbed micro-piling (helical piles) offers distinct benefits in comparison with alternative TBS techniques by improving track stiffness and track performance on existing railways. It is a cost-effective TBS solution, particularly where the trackbed is constructed over thick, soft subgrades and suffers from large deformation. This technique has been applied successfully in different projects in the UK and Ireland. Post-piling track monitoring and on-site measurements from delivered projects indicate that the micro-piling offers various benefits. It has been proved that it reduces vertical track deflections, increases the track stiffness over soft subgrades, enhances the ride quality of the track, reduces the track geometry deterioration rates, reduces track maintenance, and improves the lateral stability of the track.

However, further research and more case studies are recommended to provide insight into the benefits of trackbed micro-piling, including comprehensive and long-term monitoring. This will help the track owners to evaluate the effectiveness of the technique more accurately and help the designers to achieve the optimum micro-piling design for various ground and site conditions (train speeds, axle loads, tonnage). In that way, the solution can be standardised as business as usual.

REFERENCES

AALEN F H A, WHELAN K & STOUT M, 1997. Atlas of the Irish rural landscape, University of Toronto Press.

AINGARAN S, LE PEN L, ZERVOS A & POWRIE W, 2018 Modelling the effects of trafficking and tamping on scaled railway ballast in triaxial tests. Transportation Geotechnics, 15, 84-90.

BROUGH M, STIRLING A, GHATAORA G & MADELIN K Improving railway subgrade stiffness-assessment of traditional in-situ ground improvement techniques. PROCEEDINGS OF THE INTERNATIONAL CONFERENCE, RAILWAY ENGINEERING 2000, HELD LONDON, UK, JULY 2000-CD-ROM, 2000.

BROUGH M, 2008 Trackbed investigation, design and construction: Part 1: Investigation, PWI Journal, Volume 126, Part 4, pp 175-181

GALLOU M, FROST M, EL-HAMALAWI A & HARDWICK C. The application of track deflection measurements made by video gauge. Proceedings of the Institution of Civil Engineers-Transport, 2020. Thomas Telford Ltd, 245-257.

GALLOU M, FROST M, EL-HAMALAWI A, TEMPLE B & HARDWICK C, 2017. Applicability of video gauge for the assessment of track displacement.

GOVAN C, SHARPE P & BROUGH M, 2015 The Rail Trackform Stiffness Tester—Development and Early Trials to Assess Stiffness Characterisation of Novel Trackforms. Railway Engineering, Edinburgh.

JENNINGS 1994. I've been Workin' on the Railway. The Institution of Engineers of Ireland Presidential Address.

KAYES I, NISSEN D & ADAMSON J. Stabilisation of rail track formation and embankments. CORE 2000, Railway Technology for the 21st Century, Conference on Railway Engineering, Glenelg, South Australia, May 21-23, 2000, 2000.

LIU X, SAAT M R & BARKAN C P, 2012 Analysis of causes of major train derailment and their effect on accident rates. Transportation Research Record, 2289, 154-163.

MILNE D, LE PEN L, WATSON G, THOMPSON D, POWRIE W, HAYWARD M & MORLEY S, 2018. Monitoring and repair of isolated trackbed defects on a ballasted railway. Transportation Geotechnics, 17, 61-68.

MUSGRAVE P, WEHBI M, JACKSON L, STEVENS A & O'NEIL L, 2017. A Guide to Track bed Micro Piling. Network Rail.

NGO N T, INDRARATNA B & RUJIKIATKAMJORAN C, 2017. Stabilization of track substructure with geo-inclusions—experimental evidence and DEM simulation. International Journal of Rail Transportation, 5, 63-86.

NEILSON J C, BERGEEREN E G, HAMMAR A, JANSSON F & BOLMSVIK R, 2020. Degradation of railway track geometry–Correlation between track stiffness gradient and differential settlement. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 234, 108-119.

O'DWYER D C R, 2015. Early Irish Railway Construction. The proceedings of the Second Conference of the Construction History Society.

PYE N, O'BRIEN A, ESSLER R & ADAMS D, 2012. Deep dry soil mixing to stabilize a live railway embankment across Thrandeston Bog. Grouting and Deep Mixing 2012.

RAIL N, 2015. Track Bed Investigation, Design and Installation (NR/L2/TRK/4239). London: Network Rail.

ROQUES S, KENDALL S, SMITH K, PRICE P N & BERRY P, 2013. A review of the non-NPKS nutrient requirements of UK cereals and oilseed rape, HGCA.

SHARPE P, HUTCHINSON D & HOUSE G S. Prediction of earthwork failures using track recording car data. Proceedings of the Railway Engineering Conference, Edinburgh, UK, 2015.

SMITH C, 2020. Future of Rail | Embankment stabilisation maintains Irish line speed [Online]. www.newcivilengineer.com.

TANNEBERGER F, MOEN A, JOOSTEN H & NILSEN N, 2017. The peatland map of Europe.

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TECHNICAL ARTICLE

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AS PUBLISHED IN

THE PWI JOURNAL **JULY 2023**

VOLUME 141 PART 3