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Track Bed Total Route Evaluation for Track Renewals & Asset Management "A Network Rail Perspective"

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Abstract: Over the last 10 years there have been significant developments and improvements in the understanding of railway track bed in the UK and its relationship and impact on track quality, ballast life and maintenance following track renewals. This paper aims to describe the process adopted by Network Rail for track bed investigation and design which offers Network Rail optimum design solutions and value for money from an investigation and construction perspective, balancing design with possession availability to maximise construction output. It also describes innovative investigation and construction techniques that have been developed over the last 5 years maximising the use of rail mounted asset condition data collection systems which run at line speed, allowing targeted investigations and in some case removing the requirements for physical site investigation. It also allows Network Rail to predict sections of track bed which may be affected by line speed increases which would cause the track bed to fail prematurely or, retain its ability to maintain good track geometry post line speed increase. These problems can manifest themselves as stiffness related problems such as critical velocity issues (surface wave velocity, Rayleigh Wave velocity) or, sub-grade erosion resulting in high rates of deterioration in the vertical track geometry. The paper also describes the development and installation process for Enhanced Axial Micropiles to address stiffness related track bed problems whilst leaving the track in-situ a technique which is new to the UK railways.

Key words: Track bed, data analysis, route evaluation, asset management, track bed piling and design.

1. Introduction to Railway Track Bed

Over the last 10 years there have been significant developments in the understanding of railway track bed, its relationship and impact on track quality and maintenance following track renewals. This paper aims to describe the process developed by Network Rail for track bed investigation and design of the track bed which offers whole life of track bed and optimum cost efficient design solutions from an investigation and construction perspective. It also describes innovative investigation and construction techniques that have been developed over the last 5 years.

The quality of a ballasted track system, i.e. its ability to retain good geometry and its response to mechanical maintenance (tamping, stone blowing) is directly related to the design and condition of the track bed, drainage and earthworks on the railway.

The track bed is normally considered to consist of two elements from a track renewal point of view, ballast and formation see figure below:

The ballast allows for adjustment of the line and level of the track. Ballast deteriorates with traffic and maintenance activities and therefore requires periodic replacement. The required depth of ballast gives the desired life before it needs to be replaced and should not be confused with the total depth of track bed which includes the formation layer (typically a sand blanket), this combination distribute the dynamic load over the sub-grade. The typical design life of track ballast on a well-constructed formation layer and good sub-grade is approximately 25 years on a high speed main line and up to 50 years on secondary rural lines with appropriate maintenance interventions during its life cycle.

The formation layer typically consists of sand known as the blanketing layer this overlays the sub-grade,

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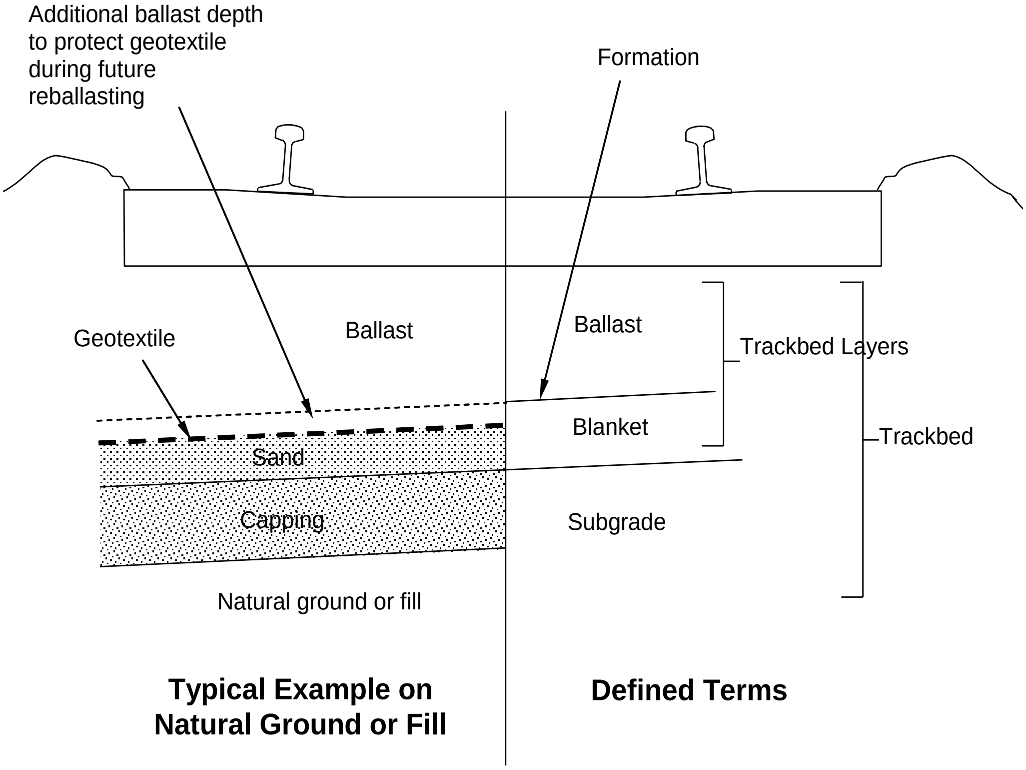


upon which the required depth of ballast is placed. The formation layer is permanent, and should not require replacement or maintenance providing the track drainage system is adequate.

The Capping Layer (prepared sub-grade) consist of suitable imported material whose purpose is to enhance the properties of a poor sub-grade prior to placing the blanket in particular where there are poor stiffness qualities associated with the natural ground.

On a well-built formation with adequate drainage the only track bed treatment required should be ballast replacement. However, in the UK there are many locations where the formation does not provide the ideal support conditions resulting in the reduction of the service life of the track bed and poor track quality. It is therefore important that adequate and accurate investigation of the track bed is undertaken to determine the required remedial measures. Track bed stiffness is an important factor to consider when investigating the track bed because this influences track quality and the frequency of subsequent maintenance intervention [maintenance tamping reduces the life of the ballast]. On a well-constructed mainline railway with a stiff track bed, tamping should normally be required only at a 3 yearly cycle. This will gradually increase over time as the ballast breaks down until the frequency of tamping is greater than once a year and it becomes economic to replace the ballast.

When new, the ballast layer is clean, free draining, resistant to settlement and responds well to tamping. As it ages it breaks down gradually under the action of traffic and mechanical maintenance until the voids eventually become filled with fines. While this will reduce the effectiveness of tamping, the performance of the ballast is not significantly affected until the fines reduce permeability to the point at which pore pressures cannot dissipate under train loading, particularly when the ballast becomes saturated during heavy rainfall. This normally occurs first beneath a rail irregularity, such as a dipped weld, where dynamic loading is higher and damaging to the ballast. The onset of this type of failure is characterised by the appearance of "wet spots" and rapid deterioration of track geometry measured as a standard deviation (SD).

In addition to the products of ballast breakdown, fines may be deposited from the environment (e.g. wind blown) or from freight vehicles (e.g. open topped coal wagons). This type of failure (dirty ballast failure) is the most common failure mode and should not be confused with sub-grade pumping.

1.1 Types of Track Bed Failure

Track bed failure or inadequacy relates to its ability to retain good vertical geometry. The point of failure is not always clearly defined, unlike earthwork failures where movements are often large and rapid.

Various mechanisms can result in poor track geometry due to failure of the track bed. These can be divided into three main categories:

a) Ballast deterioration (dirty ballast failure) as described above

b) Sub-grade erosion (pumping)

c) Poor stiffness characteristics

1.1.1 Sub-grade Erosion (Pumping)

The symptoms of sub-grade erosion are similar to those caused by extensive ballast breakdown (dirty ballast failure), i.e. poor track geometry accompanied by the appearance of wet spots.

Sub-grade pumping occurs when slurry rises into the ballast under the pumping action of dynamic train loading because there is no adequate blanket present to filter the fine particles and prevent them from entering the lower ballast layer. Slurry is normally formed by erosion of a fine-grained sub-grade, such as silt, clay or fine sand, although weakly-cemented sedimentary rocks and poorly-graded blanket layers can also be susceptible.

Small amounts of slurry in the base of the ballast layer have no effect. The problem becomes serious only when the slurry migrates upwards towards the base of the sleepers and affects the load bearing properties of the ballast. Soon afterwards the characteristic 'pumping' sub-grade failure normally becomes evident. Track geometry then deteriorates rapidly and cannot be rectified by tamping or stone blowing. Within a short time speed restrictions may be required for the safe passage of trains. A sub-grade erosion problem cannot be cured entirely, even if there is good drainage, without replacing or modifying the blanket. Where a serious sub-grade erosion problem exists it is likely the drainage system and filters will have to be renewed as the slurry is pumped into the track drainage system worsening the track bed conditions. Slurry is generated by a dynamic process, and once present is self-perpetuating and eventually the track bed becomes un-maintainable.

The worst pumping problems often occur shortly after re-ballasting where the track bed has not been adequately investigated and designed, either on a track already affected by sub-grade erosion or occasionally where the re-ballasting operation removes any sub-grade protecting materials in severe cases the track bed can fail within 6 months resulting in a temporary speed restriction until the track bed is renewed again.

1.1.2 Poor Stiffness Characteristics

Stiffness is a very important consideration in track design, affecting vehicle ride characteristics, wheel/rail forces, bending stress in rails and track component damage, ballast breakdown and rate of deterioration of track geometry. Stiffness at the rail-head is affected by many factors, including rail section, sleeper spacing, pad and sleeper stiffness. However, the most variable, and the most critical from the point of view of track bed behaviour, is track bed stiffness.

Ballast stability requires a stiff track bed. Research shows that soft support will result in excessive deflections at rail level under dynamic loading, resulting in ballast mobilisation and loss of vertical alignment. High differential settlements will result from repetitive traffic loading patterns, leading to poor vertical track alignment. Variable track bed stiffness also results in poor track geometry.

While a stiff track bed is desirable for good track geometry it is equally important to ensure that it is not too hard. On very hard formations, e.g. on shallow rock head or on bridge decks with low ballast depths, the resulting high modulus can lead to damage of track components, ballast breakdown and even erosion of the bedrock. The track does not distribute loads as far on a hard track bed, which further increases the likelihood of track damage due to loading.

It should be noted that there are now a number of areas on the Network where the existing track bed stiffness is less than the desired stiffness due to increases in traffic gross annual tonnage, axle loads and line speed increases. These locations tend to be short length sites, some having manifested into critical velocity sites (Surface Wave Velocity Rayleigh Wave Velocity). This is where the sub-grade is unable to cope with the pulse of energy generated by the train at line speed as it travels over the sub-grade and the vehicle starts to catch the wave up. It can be likened to "breaking the sound barrier". Where this problem occurs the track becomes difficult to maintain economically and results in the need for a speed restriction to a level where it can be effectively maintained. A novel and effective solution has been developed to address this problem and is describe later in this paper.

1.2 Track Drainage

The performance of a track bed treatment can be affected by the quality of drainage on a site. Poor drainage can, to some extent, be compensated by adopting a more robust track bed treatment. Whenever track bed treatments are carried out, existing track drains and the surrounding backfill should be assessed to determine their condition and effectiveness. Three drainage categories have been defined to help with the assessment of track drainage on site and subsequent drainage renewal and replacement. These are used to assess the site drainage conditions.

Poor Drainage - a site which has a history of drainage problems, e.g. where standing water is frequently found within 0.5m of the base of the sleeper.

Satisfactory Drainage - a site where water is maintained at 0.5m below base of sleeper or lower except during heavy rainfall when surcharging may occur.

Good Drainage - a site which has no history of drainage problems and surcharging of the drainage system does not occur on average, more than one occasion in ten years. (i.e. the site is either on embankment, with an uninterrupted drainage path to the embankment shoulder, or in a cutting, where the drainage has been specifically designed to achieve the desired performance).

1.3 The Track Bed Desk Study

Network Rail's in-house Track Bed team have developed smart and effective ways of analysing track bed condition and performance without any physical site investigation taking place. This is a data driven process using Network Rails own data and other data sources. The following key data sources are utilised during the desk study:

- 1/8th mile Standard Deviation (SD)
- Line speed and annual tonnage equivalent million gross tons of traffic per year (EMGTPA)
- Raw trace data (HSTRC) used to pinpoint problem areas within the 1/8th mile section
- Rate of deterioration of the vertical track quality over an 1/8th mile
- Track geometry rolling SD value rate of track quality deterioration over short length problems down to 35metre length or less
- Track gradient information is used to assist with drainage assessment
- Ground Probing Radar (GPR)
- Ballast fouling index (BFI)
- Underlying Geology
- OMNICOM & High Definition Video
- Component age of road GEOGIS

Where the line speed is to be increased the resultant track quality banding is calculated based on the proposed line speed. This is important because any line speed improvement project remit will require steady state or better track quality post line speed increase to ensure that a maintainable and sustainable railway is delivered.

1.4 Omnicom and High Definition Video

Both of theses are used to undertake a virtual site walkover to identify any specific track bed related features such as drainage catch pits and runs, topography and the location of structures. A site diagram is then produced detailing the tracks and all relevant site features. A track side mile post is identified as a reference point to ensure the site investigation and design recommendation match. This eliminates the need for people on track to inspect a live operational railway and is therefore is a safety benefit.

1.5 Component Age

GEOGIS (asset data register for the age of the track components) is used to identify the age of the track components rails, sleepers and ballast. This data is automatically populated into the site schematic. Ballast age is important to determine how the ballast has performed since it was installed. The existing track components may be impacting on the track quality information which is not track bed related, one example of this would be jointed track.

1.6 Geology & Previous Coverage

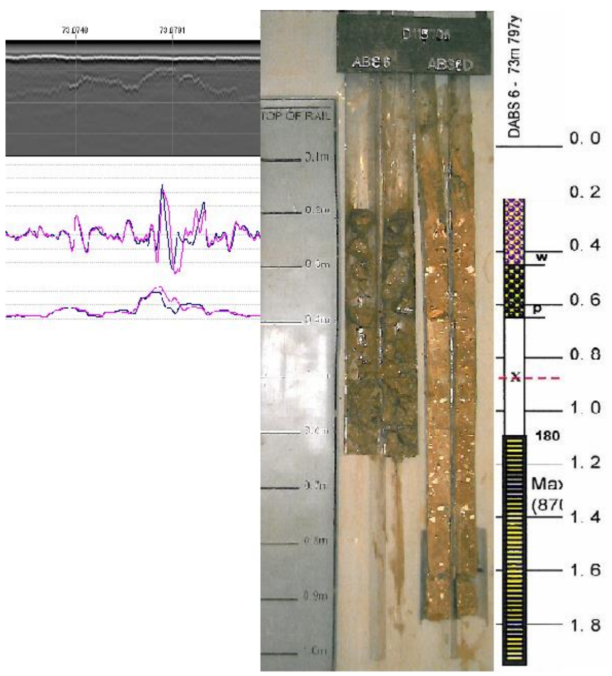
The underlying geology is obtained from the Network Rail GI portal recorded and summarised along with any previous track bed investigation reports, bore hole logs or other relevant site information. It is important the underlying geology is understood as it may be susceptible to erosion or stiffness related problems.

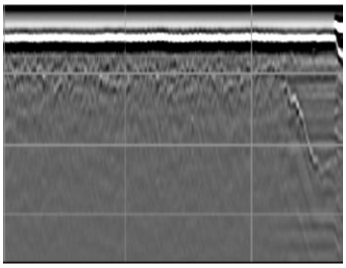
1.7 Ground Probing Video (gpr)

GPR is a non intrusive investigation technique which is used to determine the depth and condition of the ballast and formation layer by sending a pulse of energy in the form of radar waves which is emitted from transmitters (2GHz antenna) recorded and analysed. As the wave penetrates the ground and meets a change in materials the speed of the wave is changed and as a result of this some of the energy is reflected whilst the remaining energy continues to penetrate the ground. The reflected energy bounces back to the receiver at various stages and the time it reaches the receiver is recorded. This is a continuous recording process producing data sets recorded on the computer. For the recorded data points there is a set of data which shows the depth of reflections as a factor of time not depth. This information is then processed to produce the traces known as GPR radiograms. The reflections are known as interfaces which can then be interpreted by the Track Bed Engineer. For sometime now GPR has been rail mounted recording track bed condition on the network covering approximately 10,000 miles 90% of the network. The recording is undertaken at line speed. The in-house track bed investigation team is the main user of this data source and it provides the following information:

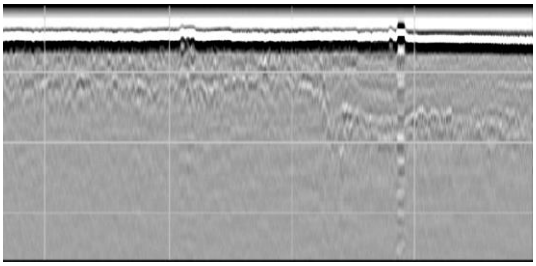
- Ballast fouling known as the Ballast Fouling Index (BFI)
- Interface at formation layer to identify the presence of sub-grade erosion
- Theoretical ballast depths on structures
- The location of older dirty ballast
- Settlement at structures
- Poor drainage

Below are some examples of typical GPR responses and what they represent in the track bed:

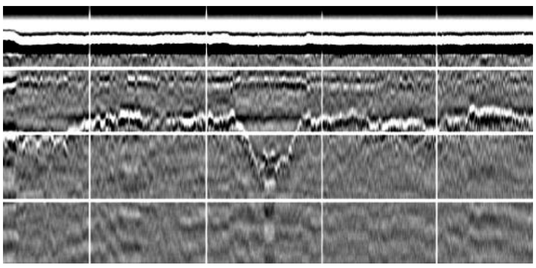




Example of settlement at a structure



Example of ramp between old and new ballast



Example of an Under Bridge

A good example of sub-grade erosion that is evident from both the GPR and HSTRC trace and the bore hole.

2. Track Bed Route Evaluation

This part of the paper sets out to describe how all of the information detailed in part 1 the track bed desk study of this paper is combined into ½ mile route sections and presented on A3 size schematics by the Network Rail Track Bed Engineer. Each of the data sources are aligned to the corresponding site mileages. No one data source is considered in isolation as it is very important that all of the data sources are considered during the desk study analysed, and appropriate interpretation and recommendations are made per 1/8th mile or less. This allows targeted cyclic renewal at the right time maximising the life of the asset and reducing the risk of condition of track speed restrictions. It also allows the Network Rail Route Asset Manager to prioritise and plan timely and effective renewals.

2.1 Route Evaluation Site Schematic Improvements Example Definitions

The Network Rail in-house Track Bed team have made a number of additional improvements to the site schematic in the last 6 months as detailed below:

- Ballast fouling index (BFI) 1D and 4D plots
- 2GHz GPR radiogram
- Track quality predictions based on a line speed increase
- A rolling standard deviation measured over a short wave length 35m (allows very accurate targeting of the track bed problems within the 1/8th mile section)
- Component age and track construction (it is important we understand what the existing components are and the ballast age to make an informed decision on the track)
- Ballast residual life prediction
- Areas of higher vertical forces, transitions, gradient changes and vertical curves
- Track geometry, vertical curves and transitions

2.2 Rolling Standard Deviation Programme for the Rate of Deterioration for Track Quality

This is a fully automated programme which provides a rolling SD value for 35 top rate of deterioration. It plots a rolling SD for the previous 6 runs of track quality data (can be expanded to include more runs as required). It works out the rate of change of SD for every recorded point at 200mm intervals along the rail surface. It also adjusts the output value where maintenance intervention has been undertaken allowing an accurate rate of deterioration to be calculated.

2.3 Automated Geogis Plotter

Developed a macro which automatically obtains age of road data from GEOGIS for a particular location and populates the site schematic.

2.4 Ballast Returns Prediction Study Underway

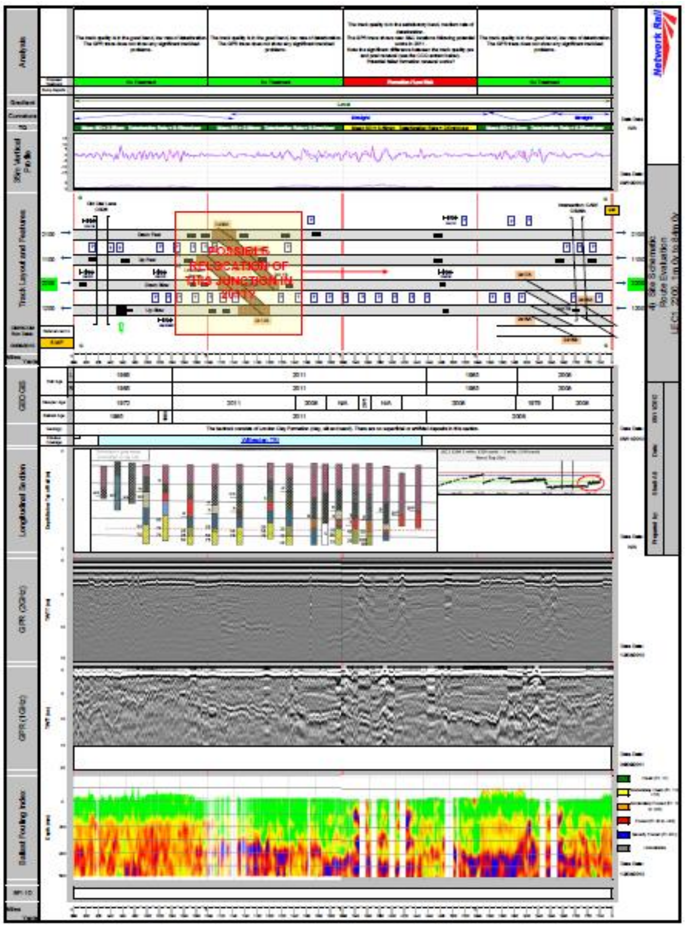
To correlate actual ballast returns against the BFI 4D Plot. This will help with site planning for ballast volumes, rates of return and production rate. This is a joint study between the High Output Renewals Programme and the Track Bed Investigation Team. The aim is to use the GPR BFI plot to predict ballast returns within +/-10% of the actual achieved at renewal.

Based on the route schematics the following predictions can be made:

- Stiffness related problems such as critical velocity and rapid changes in stiffness resulting in track quality problems at the run on and run off points of structures
- Areas of sub-grade erosion which may be accelerated due to the line speed increase and increase in annual tonnage
- Rate of track quality deterioration for the vertical parameter (top 35 metre). The rate at which track deteriorates is a key indicator of underlying formation and sub-grade problems
- Ballast fouling and the approximate remaining residual life of the ballast and predicted returns that will be achieved if the site is ballast cleaned
- Potential track drainage problems
- Accurate targeting of site investigation (trial holes and window sampling)

Typically on a line speed improvement project route evaluation desk studies have shown that circa 15% of the route is likely to be affected by proposed change in terms of the track bed and further detailed targeted investigation [mainly for sub-grade erosion and track bed stiffness] will be required to determine where the works will be implemented to ensure a maintainable railway is delivered at the enhanced speed. Below is an example of a Track Bed Route Evaluation Schematic

2.5 Route Evaluation Schematic Output Example



3. Innovative Design Solution

3.1 Background

Over the last 10 years route up-grades have been implemented to increase line speed up to 125mph and gross annual tonnage. As a result of this a number of localised sections of track have suffered with poor track quality and high rates of track quality deterioration to the point where the railway cannot be maintained at the required line speed due to *poor track bed stiffness*. In the more severe cases the railway has suffered with "critical velocity problems" where the ground is too soft and it cannot dissipate the dynamic loading generated by the train at high speed resulting in very poor track quality, and damage to the track components such as broken clips and rails.

The traditional solution to address softer track bed problems would have been deep excavations to remove the soft sub-grade materials and replace them with well graded granular fill. This method is very expensive and requires long track possessions to undertake the work on routes where possession access is very limited.

Based on this problem an innovative solution was trialled and proved to be very successful. It is believed this technique is unique to UK railways.

3.2 Enhanced Axial Micropiles Technique & Methodology

This method has full product acceptance and involves installing steel piles by rotating the piles and simultaneously grouting through the drilling head at the base of the pile, as the pile progress deeper into the ground couplers are fitted and another section of pile connected, it is a continuous process until the pile is located at the correct depth usually 1m – 1.5m below the layer of soft material, it is therefore essential adequate ground investigation is undertaken to accurately determine the depths of sub-strata materials so the correct length of the pile can be designed and installed at any one location.

The finished pile arrangement is a 140mm diameter Trapezoidal threaded hollow core steel bar, grouted internally and externally to a diameter of 220mm (diameter can be increased) with a steel grouted pile cap positioned at 800mm below sleeper bottom level to optimise dynamic load distribution, maintain clearance for future ballast cleaning and if required allow the construction of a reinforced granular slab over the piled area to further improve system stiffness. Piles are installed in pairs in the 4ft close to the foot of the rail every alternate sleeper bay to ensure all sleepers are bearing on to a pile and the arching effect between the piles is effective once the residual stresses have built up in the ballast layer.

To avoid any surface ballast contamination with grout or extracted materials during the drilling process a small portable vacuum unit is used to remove the ballast down to formation level and a circular steel mesh grid is inserted at a diameter greater than the drilling head before piling is undertaken to retain the ballast, the vacuum unit is also used to remove any residual excavated materials. On completion of the piling the existing extracted ballast is replaced.

The Enhanced Axial Micropile offers the following advantages:

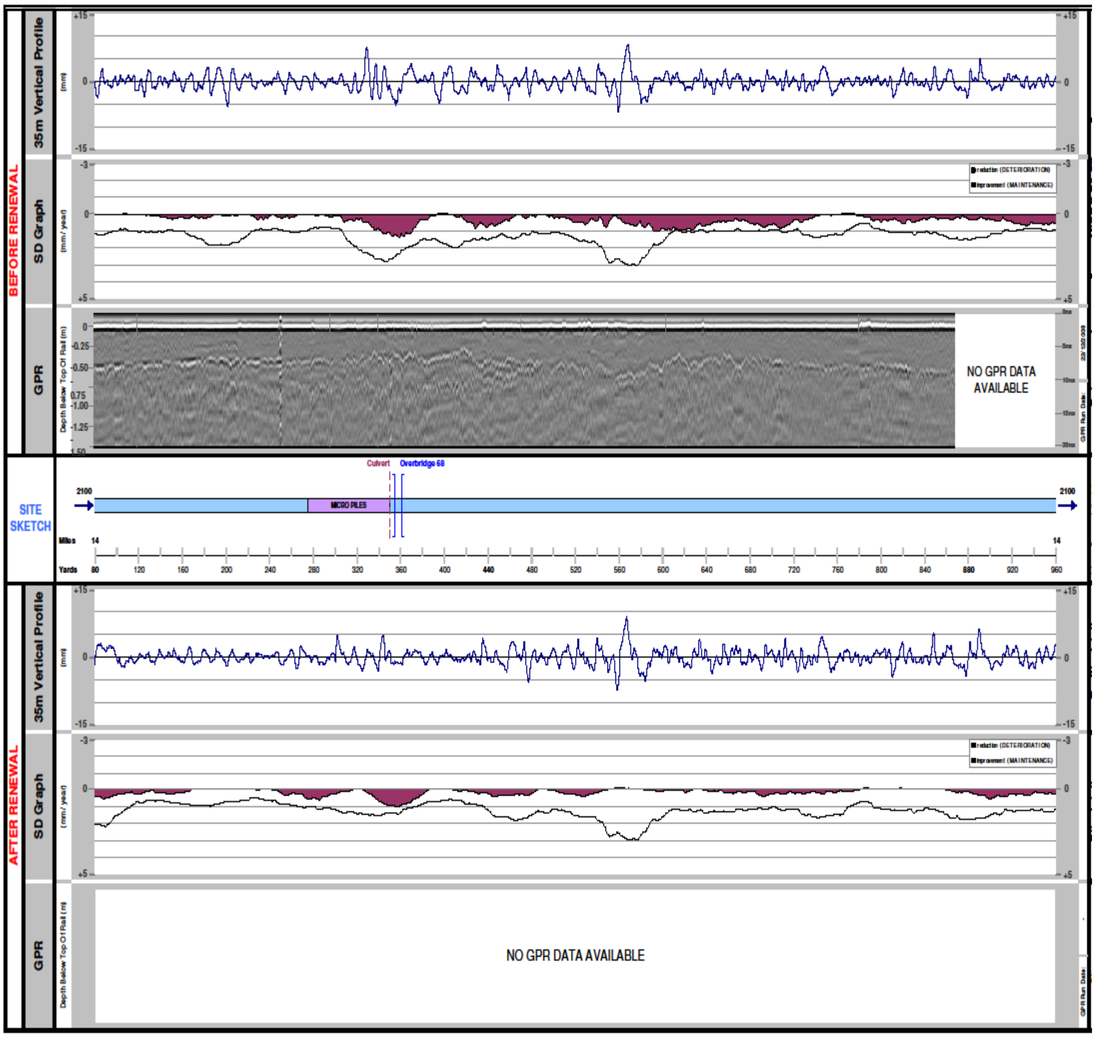
- Piles can be easily installed beneath overhead line equipment
- Can be installed below Switches & Crossings units
- Up to 120yr design life
- Piles can be installed to any lengths with a robust jointing system
- Installation method enable noise and vibration risks to be minimised and managed
- Low levels of vibration during construction reduces loss of residual stresses which have already built up in the ballast, and track settlement post construction
- The piles are installed easily & quickly, mobilisation and demobilisation time on site is quick (less than 30 minutes) allowing work to be undertaken during short possessions
- Controlled grouting under pressure is undertaken on the inside & outside of the pile and at the steel pile cap level

- Limited heave as track bed materials are displaced by the grout at the surface
- The method allows treatment of run on / run off problems at structures without any vibration issues
- No cross contamination of ballast layer
- Offers multi-solutions for track bed stiffness & embankment stability problems
- Reduced costs with the track and signalling equipment left in-situ

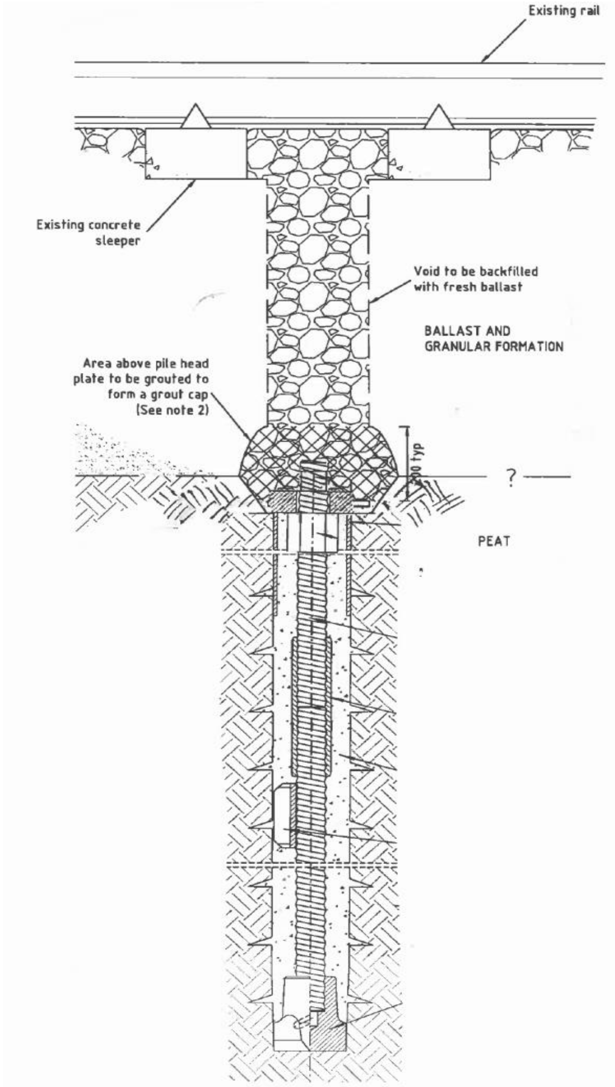
3.3 Piling of the Track bed Case Study Gravel Hole Wcml

The schematic below shows the track quality results at a site on the Down line on WCML at Gravel Hole. The site location is shaded on the schematic and the track quality trace at the top of the schematic shows the track quality response and rate of deterioration with the speed restriction of 80mph in place before the piling work was undertaken. The track quality trace below shows the track quality response after the piling work was completed running at line speed 125mph.

From the schematic it can be seen that there is some improvement in the track quality at line speed (125mph). There was also a noticeable reduction in ground vibration on site after the piling was completed.



This piling was undertaken using a vibration method to insert the piles into the track bed, the Enhanced Micropiles offers an improved installation process and pile construction as detailed below:



3.4 Cost Benefits of Micro Axial Piling

Piling of the track bed offers a cost effective alternative solution to the more traditional methods. This method has been successfully implemented at two different locations on the WCML resulting in reinstatement of the line speed. More problem areas are to be addressed using this method.

Typical costs savings over the traditional methods where the track has to be removed and deep excavation undertaken are detailed bellow:

- 70m of track treated with traditional method using deep excavation and imported granular fill & track bed reinforcement £600K
- 70m of track treated with piling method £160K

4. Conclusions

Track Bed route evaluation creates a systematic, business led and data driven approach to the management of the track asset and investigation, resulting in specifications and design that delivers a sustainable track asset at an efficient price.

References

[1] NTR-158 Technical Remit for the provision of Track Bed Investigation Site Works, Analysis and Reporting Network Rail Track Bed Framework Specification.

[2] NR/L2/TRK/4239 (Network Rail Draft standard) The Investigation, Design and Installation of Track Bed.