ADAPTING INNOVATIVE TRACKBED INSVESTIGATION TECHNIQUE FOR THE UK

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KEYWORDS

Track bed investigation, sub-ballast layers, data-driven decisions, quantitative data

ABSTRACT

The need for better asset condition data is driving change within the UK rail industry in terms of embracing new technology. With good quantitative data, we can better analyse asset condition and deterioration rates which will improve decision making on maintenance interventions and track renewals specifications. This is particularly true for track bed investigations. The Pandoscope is a simple and quick non-intrusive test that produces quantitative data to make site specific decisions. It can replace the time-consuming trial holes and the automatic ballast sampler, generally used in the UK. A case study is described in this paper to highlight the difference in approaches between the UK and France. The outputs of both methods are compared and the benefits of using the Pandoscope are demonstrated by a reduced track bed specification. Finally, proposals are made with the quantitative outputs with limits for potential changes to Network Rail standards.

INTRODUCTION

The need for better asset condition data is driving change, albeit slowly, within the UK rail industry in terms of embracing new technology. With good quantitative data, we can better analyse asset condition and deterioration rates which will improve decision making on maintenance interventions and track renewals specifications. Network Rail, and UK railways in general, still rely on visual inspections carried out by staff who give relatively subjective opinions on the condition or deterioration rate of a given infrastructure asset. However, there has been a drive, of late, to introduce technology which can capture more accurate condition data and process this data to generate more objective information on asset condition. One such tool is the Panoscope which is used extensively outside the UK, namely in France, the US to give quantitative data when carrying out track bed investigations.

THE NEED FOR CHANGE

Current practice in the UK for track bed investigations (TBI) is to use trial holes and the automatic ballast sampler (ABS), as part of a wider analytical process, which produces visual data and some measurements such as depth of layers and possibly ballast sizes. However, performing these tasks on site is labour-intensive, time-consuming and therefore relatively expensive. Furthermore, the physical nature of these tasks does not align to the major Infrastructure Managers stated objectives of reducing operatives exposure to risk in terms of personal safety by removing boots from ballast.

The Pandoscope can negate the need for trial holes and the ABS whilst giving quantitative and qualitative outputs and accurate measurements from which the condition of the track bed layers can be analysed more effectively. In addition, the Pandoscope process is non-instrustive, can be done more quickly therefore making better use of limited track access. It is important to note that like the above methods, the Pandoscope is to be used as part of a larger desk study and site analysis process.

WHAT IS THE PANDOSCOPE?

The Pandoscope is a geotechnical investigation tool that combines dynamic cone penetration testing with visual imaging, enabling detailed assessment of subsurface conditions beneath railway track beds. It consists of two parts; a Panda cone penetrometer (Panda for short) which is driven into the track bed and supporting layers with a hammer or anvil, and a geo-endoscope which is inserted the ground after the Panda is removed, by means of a slotted steel rod (Figure 1).

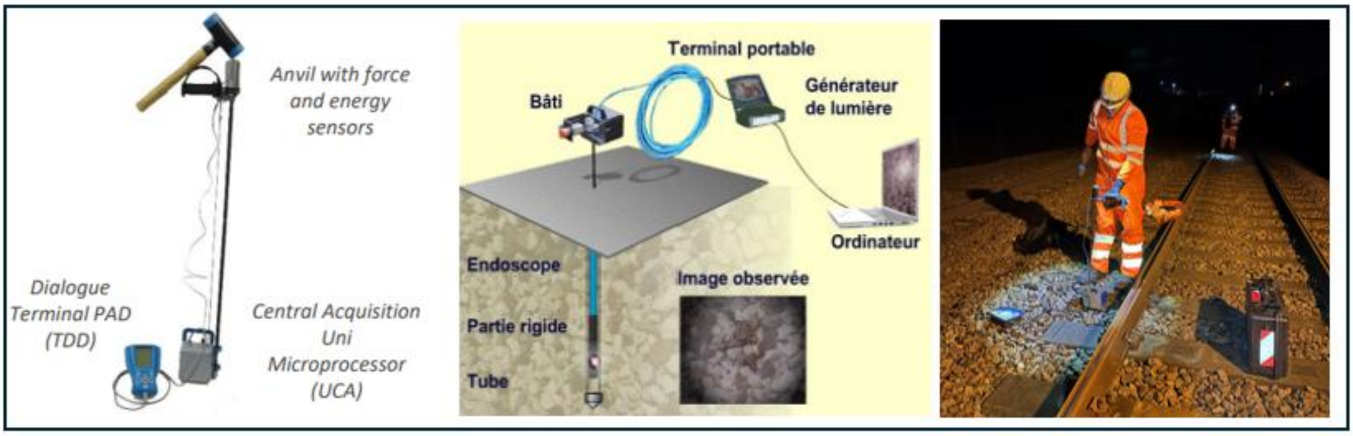

Figure 1. The Pandoscope system: the Panda (left), the endoscope (centre) and on-site (right)

Each Pandoscope test (or "sounding") consists of driving the probe into the ground using manual impact energy (either with a hammer or a guided weight). There are sensors on the anvil measuring force and depth to generate a cone resistance (qd) curve which is calculated by the formula (R. Gourvès, R. Barjot 1992):

$$q_d = E \times \frac{1}{Ae} \times \frac{m}{m+m'}$$

where E is the energy imparted by the hammer; A is the cross-sectional area of the cone; e is the depth of penetration; m is the mass of the head of the cone; m' is the mass of the tube + the cone.

When the Panda is removed, the endoscopic camera is fed down the hollow rod to record visual information in high definition, identifying material composition, interfaces, level of fouling and moisture content.

The system produces a layered representation of the ballast, and supporting layers including the subgrade, delivering both cone resistance values (in MPa) which can then be used to interpret the bearing capacity of the track support platform. The output can be seen in Figures 2 and 3 below.

There are three qualitative levels of moisture determined by the high definition images:

- Dry
- Wet, presence of water but not all voids filled
- Saturated, all voids filled with water.

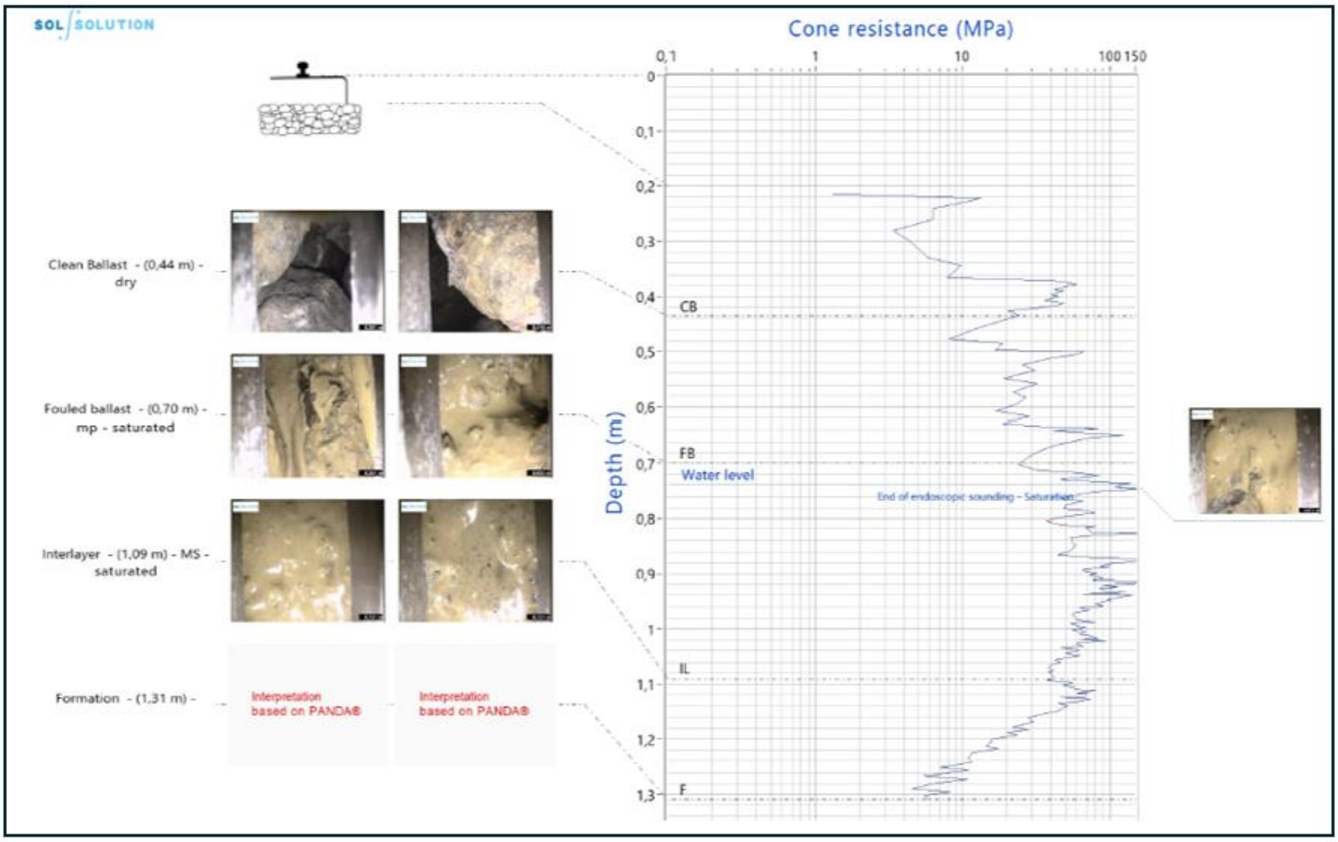

Figure 2. Pandoscope outputs showing the qd curve and the corresponding photos of the different layers including the condition and the moisture level.

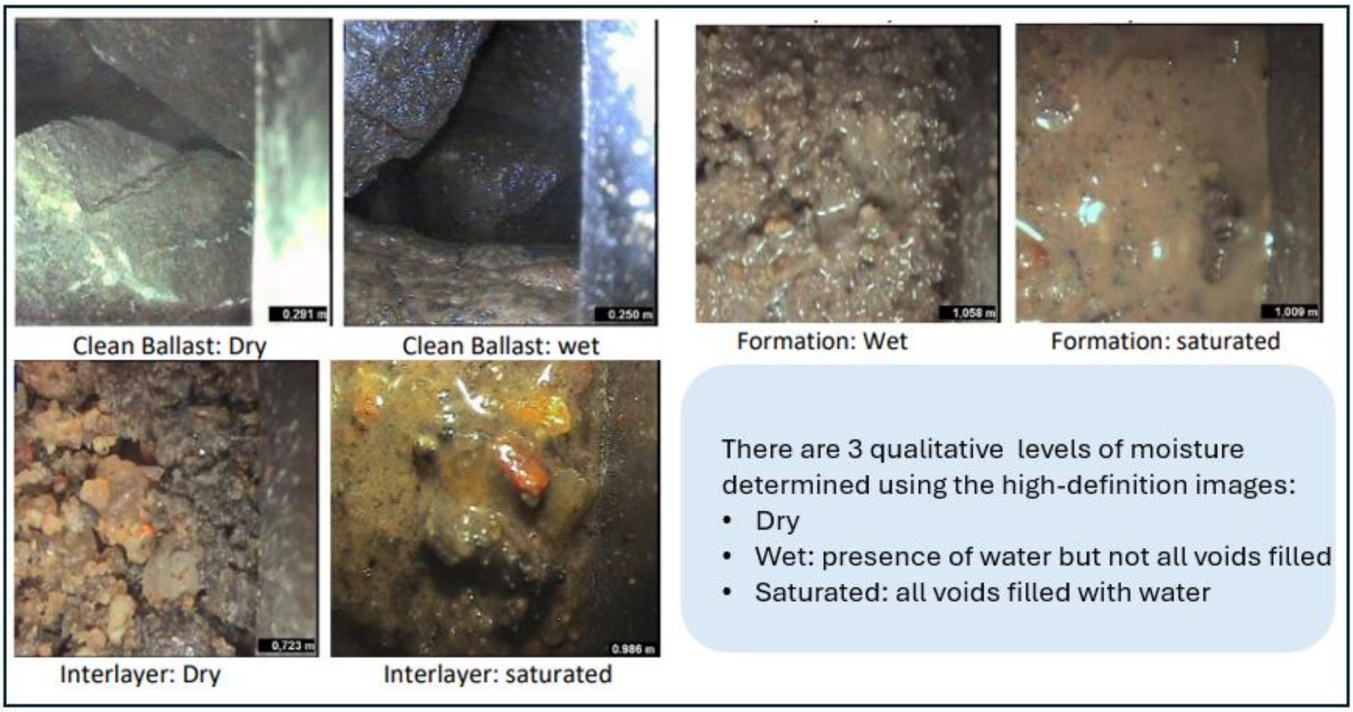

Figure 3. High definition images of ballast, fines and moisture levels

BENEFITS OF USING A TECHNIQUE WITH QUANTITATIVE DATA

Pandoscope testing provides:

- Cone resistance vs. depth graphs, to quantify stiffness profiles of track bed layers
- Visual classification of materials (e.g. clean or fouled ballast, interlayer, subgrade)
- Indicators of water ingress or fine material contamination
- Estimates of grain size distribution based on image capture and analysis

These outputs are used to:

- Assess formation quality and uniformity
- Support decisions on treatment or excavation requirements
- Integrate with complementary data sets such as TQ, GPR and drainage records

Field trials suggest that each sounding typically requires 11 to 15 minutes, depending on local ground conditions and access, making it suitable for use during constrained working windows. Productivity in the field has been demonstrated at a rate of approximately 4 soundings per hour.

This methodology supports a more targeted and quantitative understanding of formation condition, particularly in scenarios where conventional approaches such as trial holes and ABS may be impractical, time-consuming, or overly disruptive.

TRACK SUPPORT STIFFNESS AND CONCEPT OF THE INTERLAYER

For the track system to function effectively in the longer term, the ballast layer should be supported by a competent sub-grade or sub-ballast layer which has a uniform stiffness and a functioning drainage system. It is well known that there are optimum stiffness ranges associated with the ballast supporting layer which help reduce differential settlement of the ballast over time. This, in turn, will reduce track geometry deterioration and the requirement of associated tamping.

However, in reality the supporting layer beneath the ballast should have a minimum stiffness to provide consistent support to the track system. Internationally, there are stiffness values specified using the 'Plate Loading Test' which gives outputs as Ev2 values in MPa (IRS70719, UIC, 2020). It must be noted that that the qd values which are also in MPa do not correlate with EV2 values.

Over the years whilst using the Pandoscope technology throughout the rail network in France, SNCF has discovered that over time, the interface between the ballast layer and the supporting soil layer has developed its own characteristics under repeated traffic loading (Nicolas Calon, 2017). It was initially observed that when the bottom ballast particles had migrated into the supporting layer, the interface developed characteristics which could be different to either the ballast layer or the sub-ballast layer in terms of stiffness values. These observations have since been validated by tests (Nicolas Calon, 2017) and as a result the concept of an 'Interlayer' has now been incorporated into SNCF national track standards (IG05016V, SNCF, 2021).

The Interlayer is not designed or constructed but is formed over many years under traffic loading and its presence can be identified from the outputs of the Pandoscope tests. The principle is simply, if the Interlayer exhibits a stiffness of a specified value or above, then it is performing the function of providing adequate support to the track system and need not be removed or replaced during renewals. This is true even if the layers below it has lower values that would normally require intervention. The implication here is that we have been removing perfectly good material supporting the track layers in the UK which has cost, time and productivity implications.

COMPARISON BETWEEN UK AND FRENCH METHODOLOGIES

A planned track renewal at Boreham Wood was used as a case study in order to compare the traditional approach to TBI in the UK and the French approach using the Pandoscope. Network Rail Capital Delivery, Eastern Region, retained geology experts within SNCF, supported by Sol Solutions, to review the Network Rail TBI report and then analyse a Pandoscope report carried out by Sol Solutions.

The proposed renewal was planned for the UP Slow Line in 2020-21 between 13m 1137y and 14m 440y. The specification was to renew the rails, sleepers and ballast with various formation treatments.

The Network Rail TBI process was carried out in the following way. In addition to the desktop review of various records including GPR and track quality over time, the site investigation consisted of a drainage survey, ABS logs and trial holes. On this occasion the trial holes were to investigate the proximity of structures rather that the track bed layers. Examples of the outputs are shown below in Figures 4 and 5.

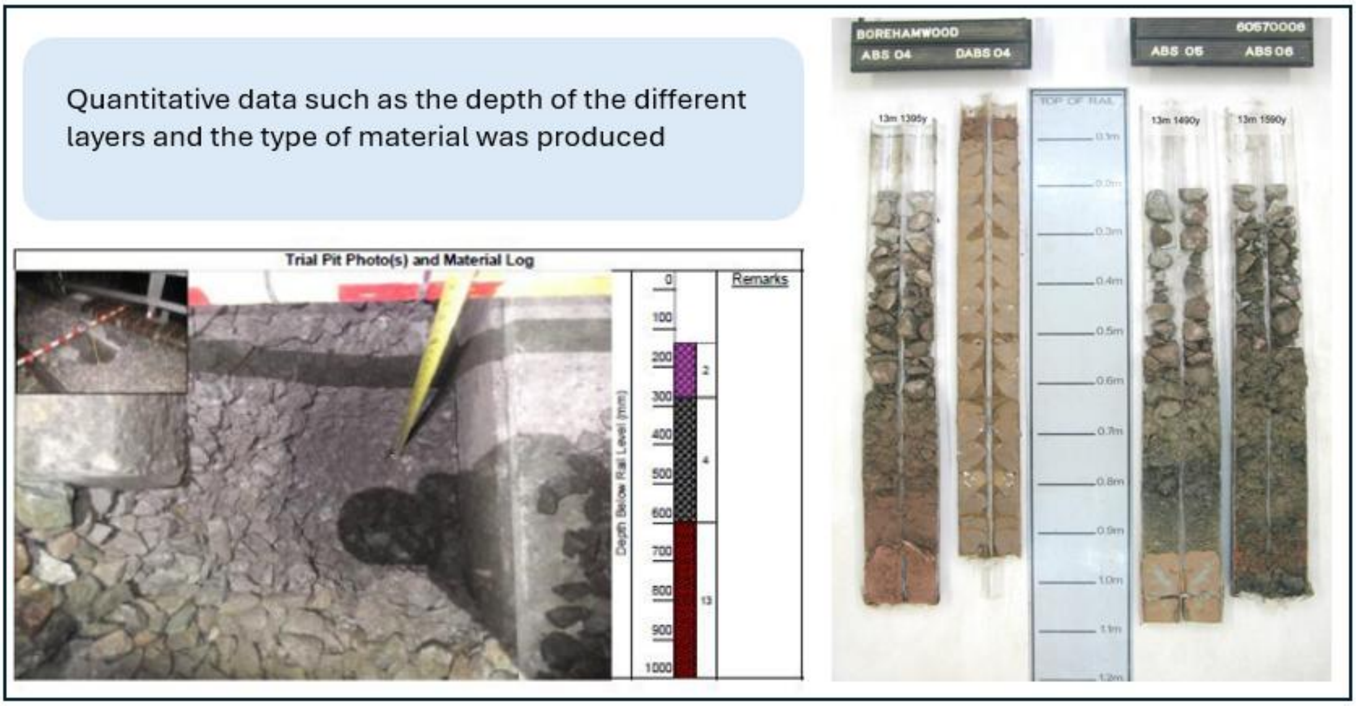

Figure 4. Trial hole and ABS photos from the Network Rail track bed investigation report

The trial holes and ABS logs show the ballast condition and depths of the supporting layers, and the contamination and possibly the water content. However, there is little other quantitative data that could be used to determine the ability of the existing track bed layers to carry out their function of supporting the track system.

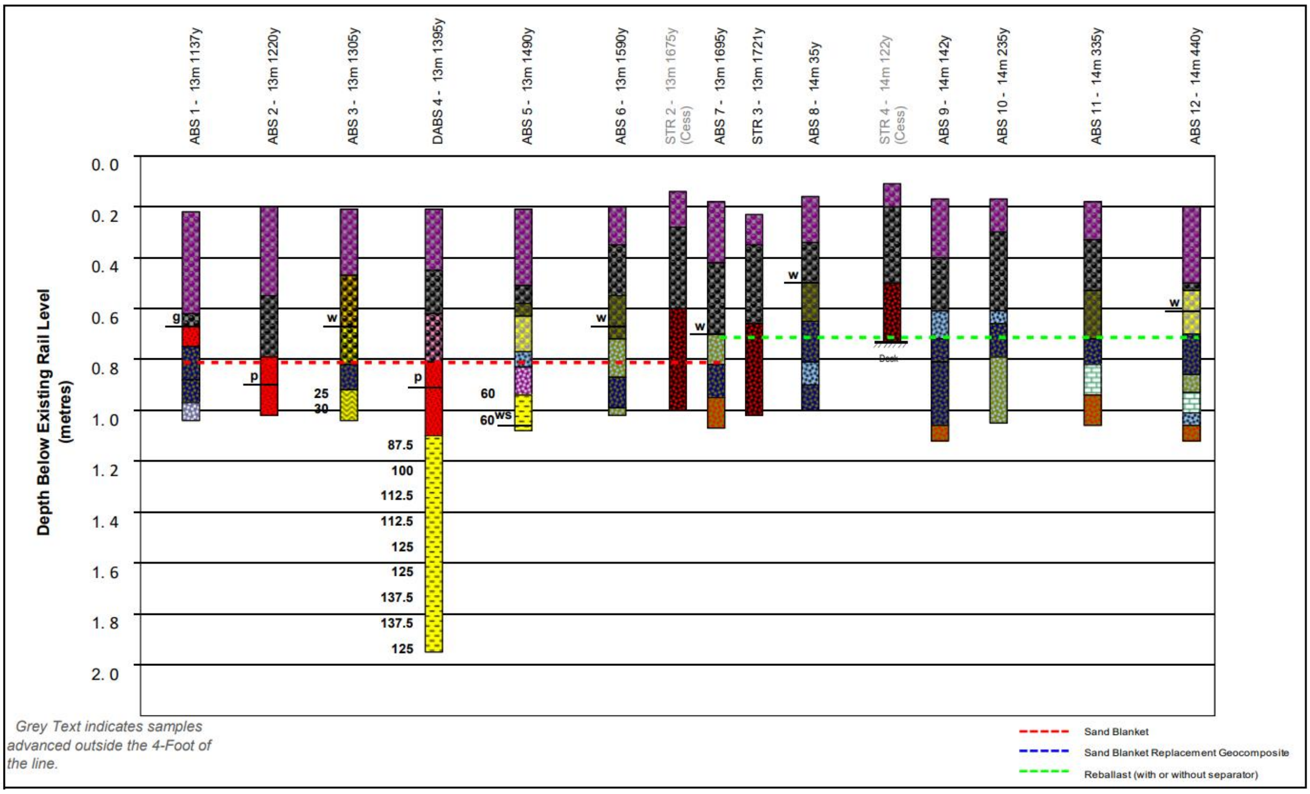

Figure 5. Longitudinal section showing the ABS and the trial hole logs

In contrast, the Pandoscope tests were undertaken on the same site and the following outputs were produced. Figure 6 shows not only the condition and extents of the materials but also gives quantitative data in terms of the bearing capacity of the sub-ballast layers. This is what enables the engineers to make more data-driven decisions in terms of maintenance and renewals specifications.

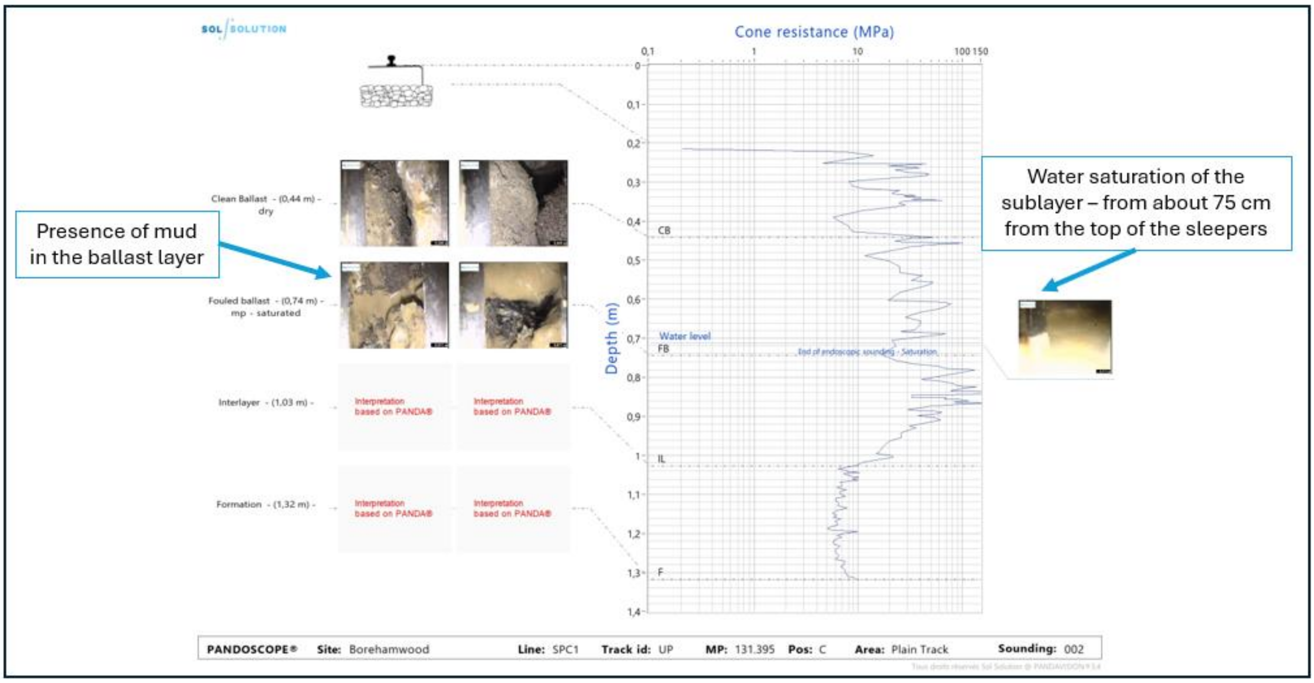

Figure 6. Typical Pandoscope output showing the presence of water and mud while still exhibiting satisfactory mechanical properties

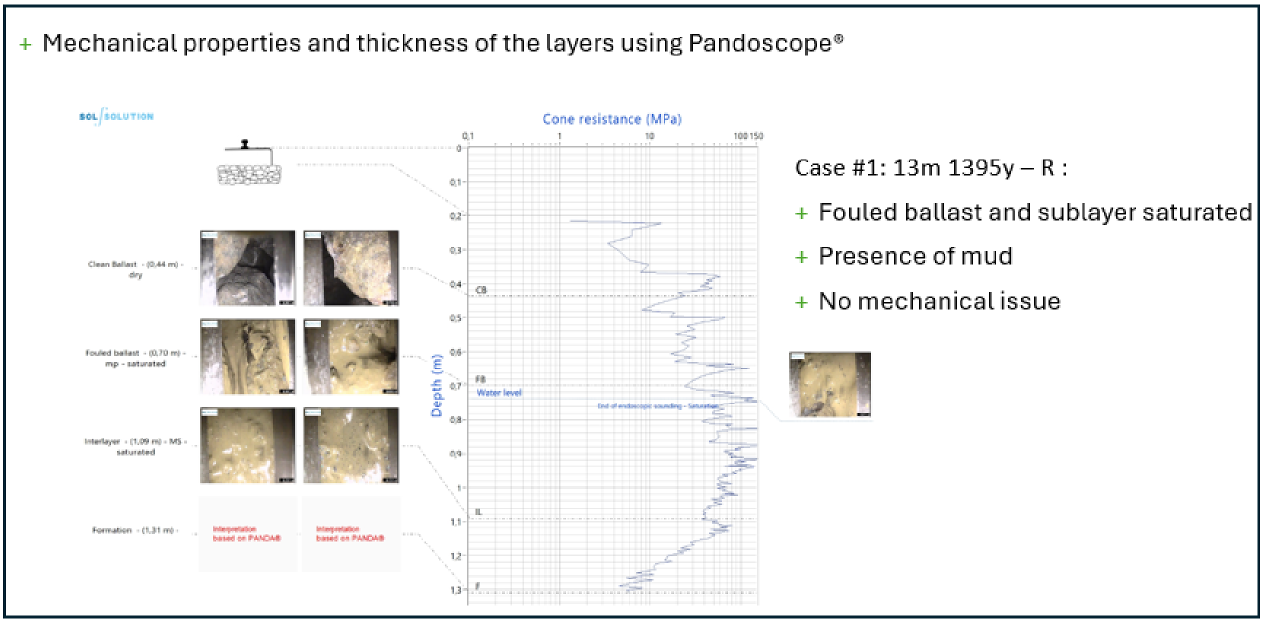

Figure 8. This sounding shows that even with the presence of water and mud, the mechanical properties of the supporting layers are satisfactory

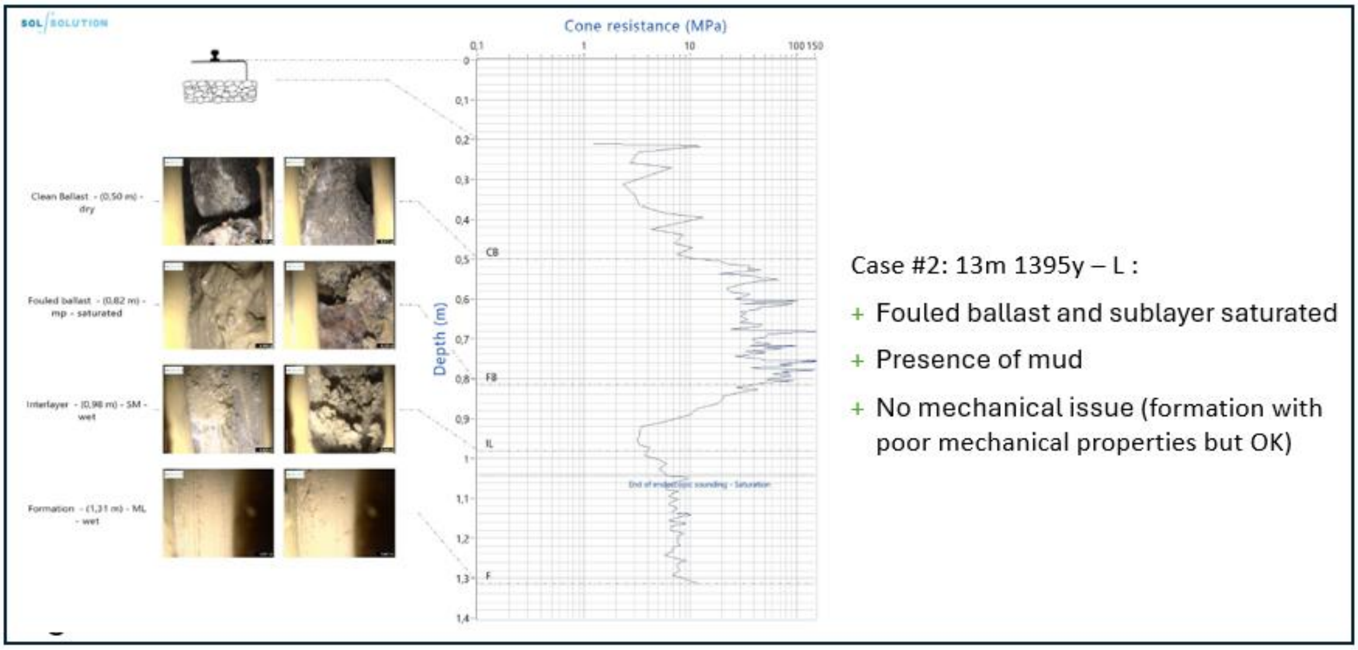

Figure 9. This sounding shows that even with the presence of water and mud, and a poor subgrade, the mechanical properties of the interlayer are satisfactory.

This is a key change of engineering philosophy in terms of using a quantifiable value of 'bearing capacity' to make a decision on what specification is required in terms of whether formation treatment is required.

Overall, there were 7 soundings taken on site and the results processed back at the office. The mechanical properties are tabulated in Table 1. Here it can be seen that the Interlayer has distinctly different mechanical properties to those of the formation or subgrade. In this case the interlayer has better geo-mechanical properties (≥20 MPa) and therefore the track renewal specification can be made more efficient in so far as the supporting layer does not need to have a formation treatment.

				PANDA-Endoscope						
sounding no	MP	position	ballast thickness (cm/toit traverse)	interlayer thickness (cm)	interlayer Qd (Mpa)	formation Qd (Mpa)	Water	Mud	Geotextile	Track-bed quality
1	131.220	Central	80	30	20	5	x		x	OK
2	131.395	Central	50	50	30	7	x	x		NOK
3	131.395	Left	50	45	30	6		x		NOK
4	131.395	Right	70	50	50	6	x	x		NOK
5	131.695	Central	62	50	35	60	x			OK
6	140.142	Central	70	40	40	30	x			OK
7	140.355	Central	60	35	18	25	x			OK

Mechanical properties → Pandoscope ®

Table 1. Summary table of Pandoscope outputs per sounding

This approach can be clearly seen in the comparison between the Network Rail and the SNCF specifications, Table 2. SNCF has proposed the use of a geotextile layer only under the new ballast layer whereas the NR experts have proposed geogrid, geotextile and sand blanket, which is expensive and, and in this case, unnecessary. Both reports recommend repairing the drainage which is essential for a fully functioning track system.

Zone(s)	Network Rail		SNCF-R	
	Detected Issue(s)	Solutions	Detected Issue(s)	Solutions
13m1337y – 13m1695y	Drainage + Formation failures	Reballast + Geogrid + Geotextile + Sand blanket	Drainage	Diagnostic (drainage) + geotextile under the ballast layer
13m1695y – 14m0440y	Drainage	Reballast + Geogrid + Geotextile	Drainage	Diagnostic (drainage) + geotextile under the ballast layer

Table 2. Comparison of NR and SNCF proposed specification for Boreham Wood renewal

This case study demonstrates that quantitative data enables a more efficient specification as it enables engineers to assess the capability of the track supporting layer to fulfil its function. Whereas the traditional approach identifies the presence of mud and water and clay subgrade which leaves engineers with little choice other than to specify formation treatments.

UK ENGINEERING STANDARDS

Typical renewal specifications tend to comply with Network Rail standards (NR/L2/TRK/4239 and NR/L2/TRK/2102) but not all requirements in the standards are mandatory. Consequently, the TBI reports do not specify increased bearing capacity often relying on the use of a sand blanket if there is a weak clay subsoil as a filter layer to prevent future contamination of the ballast. However, other

Infrastructure Managers use the measured data to specify an increase in bearing capacity which is likely to be achieved by installing a layer of compacted granular fill.

The premise behind the alternative methodology of site investigation and specification is that the geo-mechanical properties of the supporting layers are assessed using quantitative data to determine whether they are competent to accommodate the track loading. In order to implement this approach, the current UK engineering standards would need to be amended to set out the parameter limits associated with q/d values of the supporting layers and the thickness of the interlayer. Standards from other countries cannot simply be copied in so we have developed a proposal that is aligned with how standards are set out and specified in the UK.

It is proposed to divide the parameter limits into 2 groups (in line with track categories defined in the UK), and introduce the concept of the Interlayer. This will give UK engineers enough information to determine whether the existing sub-ballast layers are capable to supporting the track loading or whether remedial works need to be specified during a planned track renewal. It is envisaged that this will actually reduce the amount of formation treatments specified and therefore saving costs and time on renewal projects.

Pandoscope outputs	**Cat 1A - 3**	**Cat 4-6**	**Formation Classification**	**Recommended Action**
q/d value (MPa)	<10	<5	Soft	Formation treatment required
	10 - 20	5 – 15	Medium	Assess need for treatment*
	>20	>15	Stiff	No further action
*Note: assess other indicators such as track geometry deterioration over time etc				

Table 3. Pandoscope outputs where no Interlayer has been identified

Table 3 proposes a simple formation classification of soft, medium and stiff based on the measured outputs where no Interlayer has been identified and the track system and associated loading is being taken by the subgrade or sub-ballast layer, if present.

Track Category	**Interlayer Thickness (mm)**	**Interlayer q/d (MPa)**	**Formation classification* (Table 3)**	**Recommended Action**
	<300	<10	Soft/medium	Formation treatment required
		10 – 20	Soft	Assess need for treatment
		>20	Soft	No further action
	≥300	<10	Soft/medium	Assess need for treatment
		10 – 20	Soft	No further action
		>20	Soft	No further action
	<300	<5	Soft/medium	Formation treatment required
		5 – 15	Soft	Assess need for treatment
		>15	Soft	No further action
	≥300	<5	Soft/medium	Assess need for treatment
		5 – 15	Soft	No further action
		>15	Soft	No further action
*Note: where the formation classification omits Medium or Stiff, this should be taken as no further action				

Table 4. Pandoscope outputs where Interlayer present and actions

Where the Interlayer is present and has been identified by the analysis of the Pandoscope outputs, there can be a clear difference in geo-mechanical properties exhibited by the different layers. If the properties of the Interlayer meet the above conditions the assumption is that it is competent to support the track system, even if the layer below has poor characteristics.

The threshold values are taken from current and past practices in France but modified to align with the UK approach of using track categories to manage risk and therefore target interventions accordingly. The values for track categories 1A-3 are taken from current practice, whilst the values for track categories 4-6 are slightly lower and are based on former limits set out in France (Y. Haddani et al, 2016). It is assumed that when these tables are implemented in the UK it would be subject to on-going review and amendment, if necessary.

CONCLUSIONS

There is a real need to improve how railway infrastructure is managed in the UK, especially when specifying maintenance and renewals of the track asset. Better use of available technology is essential to ensure that the most appropriate, cost-effective decisions are taken to give better value for the taxpayer. The Pandoscope enables this to be achieved by producing quantitative data, as well as qualitative outputs during track bed and ground investigations. The simple comparison between the UK and French methods at the Boreham Wood site demonstrated the effectiveness of a data driven decision making in terms of specifications. However, to facilitate the use of this technology there are several challenges to be overcome.

The engineering philosophy of track system and track bed design needs to change. The sub-ballast layers should be be considered in terms of strength or bearing capacity, with the intention of increasing the strength of weak subgrades. The implication of this is that the used of sand blankets would be phased out, to be replaced by compacted granular fill where required.

Changes are also required to the current engineering standards covering track and track bed treatments. It is hoped that the issue of a Technical Instruction within Network Rail's Eastern Region will be a precursor to changes in the relevant standards.

Finally, the most difficult challenge is to transform the industry culture of resisting change, especially around the use of new technology and new ways of working. To achieve this, industry engineers must be better educated in engineering principles so that risks associated with change are better understood and therefore can be managed effectively.

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