Procedia Engineering
Volume 143, 2016, Pages 1043–1050

Advances in Transportation Geotechnics 3 . The 3rd International Conference on Transportation Geotechnics (ICTG 2016)

Remediation of Mud Pumping on a Ballasted Railway Track

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Abstract

Maintenance of ballasted railway tracks is a major cost for railway infrastructure owners. In many developed countries, much of the railway infrastructure is mature and was built for service requirements long since superseded. The increased demands on historic infrastructure can lead to the development or exacerbation of localised trackbed problems that require disproportionate levels of maintenance. Identifying these and applying cost effective remediation has the potential to reduce maintenance spend in the long term. However, it is not always clear what the most cost effective remediation will be. One type of localised maintenance issue is the development of wet beds or wet spots, which can occur where saturated clayey subgrade soils are overloaded and result in the development of mud pumping as trains pass. This leads to the migration of fines into the ballast bed and a deterioration in local track performance. Over time the track overlying the wet bed settles disproportionately more, sleepers become progressively more voided, and train ride quality deteriorates. Maintenance of the wet bed may involve locally digging out and replacing the ballast; however, unless the underlying cause is addressed the problem is likely to recur, requiring repeated localised maintenance interventions. This is costly, reactive and ultimately an ineffective approach to managing the problem. This paper presents a study of a wet bed in the UK, both prior to and after a full track renewal. Transient track deflections during train passage were monitored using sleeper mounted geophones and high speed filming techniques. Loaded track geometry data were obtained from a track recording vehicle. It is shown that local maintenance interventions were generally ineffective, but that a renewal of the top 200 mm of the trackbed including placement of a geotextile filter and geogrid appears to have been successful in remediating the problem, at least in the short term.

Keywords: Wet bed, ballasted track, renewal, mud pumping, clay pumping,

Selection and peer-review under responsibility of the Scientific Programme Committee of ICTG 2016

doi:10.1016/j.proeng.2016.06.103

1 Introduction

Ballast is generally specified as a uniformly graded, crushed, angular rock with particles ranging from 20 mm to 65 mm in size. The current specification has arisen historically as a compromise between the competing needs to create (1) a stiff and stable support, best achieved by a well graded aggregate, and (2) a free draining material. A uniformly graded material gives a large void space that continues to be free draining even after a large proportion of the initial void space is filled. Typically fresh ballast has a porosity of 40%. However, the performance of ballast is generally held to deteriorate progressively as the void space fills with foreign material (e.g. Selig & Waters, 1994; Li & Selig, 1998; Selig & Cantrell, 2001; Tenakoon *et al.*, 2012), a process that is known as fouling. Fouling can inhibit drainage and may lead to deterioration in the mechanical properties of the medium.

Selig & Waters (1994) define fouling material as that passing a 9.5 mm sieve. Ballast can be fouled by material arising by: attrition of the ballast and sleeper, infiltration from the subgrade or sub-ballast layers (e.g. mud pumping) and ingress from the surface of the ballast (e.g. coal dust, desert sand). A variety of fouling indices have been developed (e.g. Selig & Waters, 1994, Feldman & Nissen, 2002 and Indraratna *et al.*, 2011) for quantifying the extent of fouling in ballast. Such indices may also be empirically correlated to fouled ballast performance.

The loss of performance of fouled ballast can be explained at the grain scale as resulting from progressive reductions in ballast to ballast contact as the fouling proportion increases so that the mechanical properties of the fouled ballast tend towards those of the fouling material (Tutumluer *et al.*, 2008). Fouling material mineralogies vary geographically, both due to the varying subgrades present and the prevalent line use. For example, a major source of ballast fouling in the US is from coal dust generated during the transport of coal to power stations (Tutumluer *et al.*, 2008). In the UK, this is much less common but fine subgrade materials, such as clay, are prevalent in the south of the UK and are a major source of ballast fouling. In the worst cases, this leads to mud pumping. Several researchers (e.g. Trinh *et al.*, 2012; Cui *et al.*, 2014; Duong *et al.*, 2013 & 2014) have investigated the behaviour of a zone consisting of ballast mixed with material from the subgrade which they refer to as the "interlayer". Duong *et al.* (2013) suggest that the interlayer is formed primarily by the penetration of ballast into the subgrade. This occurs in older railways built prior to the introduction of engineered sub-ballast layers, usually consisting of graded sand to separate the ballast and the sub-grade.

Duong *et al.* (2014) performed cyclic triaxial tests on ballast over a subgrade of kaolin and crushed sand. They found that when water ponded over saturated subgrade material, the ballast sank into the kaolin and sand mixture and, in the tests where the subgrade density was lowest (1.4 and 1.5 Mgm^{-3}), the cyclic loading led to runaway displacements and failure. A third saturated test at 1.6 Mgm^{-3} did not lead to cyclic failure but did show substantially higher plastic (permanent) settlement than the unsaturated case for a given number of load cycles. Indraratna *et al.* (2013) investigated the behaviour of clay and silt fouling of ballast in drained monotonic triaxial tests. In these tests, the samples were prepared by mixing a high moisture content clay with ballast. The tests showed that, as the proportion of fouling increased, the peak strength of the material decreased, a result that was in part put down to lubrication of the ballast contacts by the fouling material. A combination of subgrade material moving into the ballast and ballast sinking into the soft subgrade, can lead to voiding below the sleepers, increased track deflection and erratic, localized, dynamic loads which exacerbate the problem. In most cases where clay/silt subgrades are present, mud pumping does not occur. A combination of adverse factors needs to be present for the development of mud pumping. Mud pumping may develop due to high, localised dynamic loads softening a saturated clay subgrade with water ponded on its surface. Indeed, it is a commonly held among practising engineers that some kind of trigger event leads to a softening of a fine subgrade before it can ultimately develop into a mud pumping site.

This paper describes measurements at a mud pumping site before and after a complete track renewal where previous, localised gravel packing interventions had been shown to be ineffective.

2 Study Site

The track at the study site is on a 1:100 upward gradient and a transition curve (Figure 1a) between a curve (2510 m radius, 40 mm cant) and a preceding straight section. Service trains are class 171 diesel multiple units typically in 2, 4 or 6-car formations travelling at up to the line speed of 113 km/h (70 mph). During the weekday visits the off-peak service frequency was one train an hour.

Figure 1a shows the localised wet bed area on the left hand track as a lighter region caused by the drying of clay pumped to the surface. Figure 1b, shows the localised dip within the wet bed area.

The wet bed lies roughly in the middle of a cutting with the local terrain rising to a high of 4 m above the track at the wet bed location. It is possible that a contributing factor for the development of the wet bed is water runoff from the surrounding higher ground ponding on top of the underlying clay, along this section of track. The underlying geology is alluvial clay, silt, sand and gravel overlying mudstone of the Weald Clay formation. In Figure 2a, the nearer line crosses the wet bed, while the adjacent line is unaffected. The severity of the mud pumping is apparent in Figure 2b, where ponded water can be seen within the crib. Several previous attempts to remediate the problem were evident when the site was first visited from the condition of the wet bed and heaps of fouled ballast piled adjacent to the track. These had consisted of local ballast removal and repacking beneath the voided sleepers with chippings or pea gravel.

Figure 1: (a) View from bridge in the direction of travel (left line). (b) View from beyond the wet bed area looking back towards the bridge. The wet bed area is circled. Arrows indicate the direction of travel on the affected line.

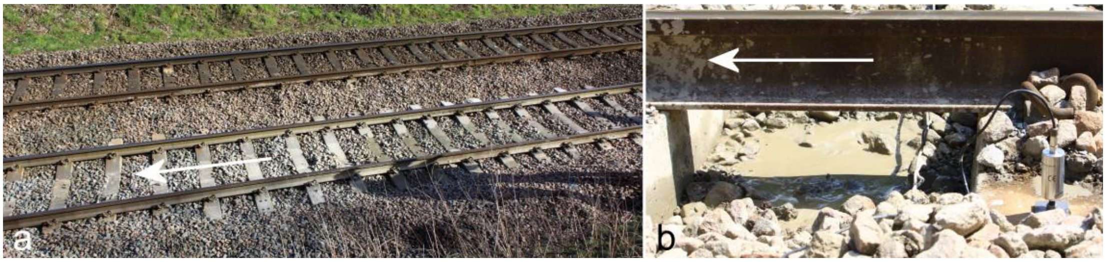

Figure 2: (a) Wet bed prior to track renewal. (b) Close-up of worst region – slurry and pea gravel also visible. Arrows show direction of travel on affected line.

Prior to renewal, Network Rail described the stretch of track which includes the wet bed, as "very poor" with a mean standard deviation over a 35 m wavelength vertical top of 4.9 mm. The rate of deterioration of 1 mm/year was noted as 'high - indicative of potential formation problems'. In the renewal, the track (rail and sleepers) was replaced over a length of 820 m and the ballast was dug out to a depth of 200 mm below sleeper base level. The full depth of the ballast was not known. Over a stretch of about 135 m which spanned the wet bed area, a micro-porous filter (TRACKTEX) sandwiched between geotextile (Tensar SSLA30) layers was used to separate the subgrade and fouled sub-ballast from the ballast. This is a type of renewal that, while relatively extensive falls short of a complete replacement of the track bed and omits the placement of a subballast layer (sand blanket). Trackside measurements were taken prior to, immediately after and 5 months after renewal to determine the efficacy of the renewal in eliminating the recurrence of the wet bed. These data were compared with data from the track geometry recording car (TRC).

3 Materials and Methods

3.1 On Train Measurements

The TRC operated by Network Rail passes over the site and records the track geometry using axle-mounted accelerometers near both wheels. These data are recorded every 0.2 m of travel and the accelerations processed to determine displacement. The data are filtered with a 35 m and 70 m wavelength. These data are used to evaluate changes in track geometry over time and to identify when maintenance interventions are required. Pre- and post-renewal data have been obtained (section 5.1).

3.2 On Track Measurements

Two techniques have been used for obtaining trackside measurements.

3.2.1. Geophones

The use of geophones for determining of sleeper movements as trains pass is well established (e.g. Bowness *et al*., 2007; Coelho e*t al*., 2011; and Priest *et al*., 2013). Each geophone is contained within a small cylinder (80 mm height and 30 mm diameter) and is wired to a data logger beside the track (Figures 2b & 3). The geophones are attached to sleepers using glued brackets. Geophones provide a voltage proportional to velocity; the recorded data are converted to displacement by applying the appropriate calibration and integrating. A summary of the data they provide and their interpretation can be found in Le Pen *et al*. (2014).

3.2.2. Digital Image Acquisition and Analysis

High speed video and digital image correlation (DIC) can be used to obtain track movements (e.g. Bowness *et al.,* 2005, Le Pen *et al*., 2014 and Murray *et al.,* 2014) as a measurement system complementary to geophones. A target is usually attached to the sleeper end (Figure 3) and videoed. Analysis is carried out using a variant of the DIC technique described by Bhandari *et al*. (2012). The technique involves identifying corresponding patterns in the subsequent images using a normalized cross-correlation algorithm.

There are two major sources of noise in DIC data due to camera movement caused by ground- or air-borne vibration. Details of mitigation techniques are provided in Le Pen *et al.* (2014).

Figure 3: Sleeper end with DIC targets on sleeper and rail and a pair of horizontal and vertical geophones.

4 Monitoring

10 vertical and 4 horizontal geophones were placed on 7 alternating sleepers spanning a run of 13 sleepers labelled as shown in Figure 4. The instrumented section of track spans the apparently unaffected track ahead of the wet bed and the major portion of the wet bed prior to renewal.

During the renewal, a micro-porous geotextile filter was placed below 200 mm of new ballast. The use of the geoetextile filter was intended to prevent future mud pumping by diverting water away from the subgrade and preventing subgrade material migrating upwards. However, its use in this context does not conform with accepted filter design practice, in that the transition from clay sized particles to ballast sized particles is not graded through suitably small steps. Thus although the geotextile filter saves the cost of a sand blanket, there is a risk that it may be ineffective. It is also normal practice during renewal to locally dig out and replace any very poor quality subgrade material; and it is likely that, in the region of the wet bed, local excavation and replacement of material extended deeper than 200 mm. To ensure that the same location was monitored after renewal, markers were identified on the adjacent, unrenewed line. The sleepers were slightly closer together after renewal but the overall lengths monitored remained similar (sleeper 1 to 7 was 8.14 m pre-renewal and 7.83 m after renewal).

Figure 4 shows a weld next to sleeper 3. This could have been a potential trigger for the development of the wet bed. However, it was noted that welds were present on the adjacent track where no wet bed was present. Thus although the weld could have been partly responsible for the development of the wet bed, there is no proof of this.

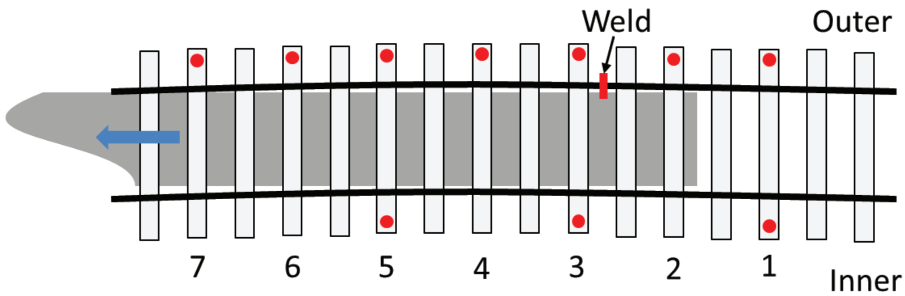

Figure 4: Site layout prior to renewal showing the approximate extent of the wet bed (in grey) and the vertical geophones (red circles). The arrow indicates the direction of travel.

5 Results and Discussion

5.1 Train Data

Figure 5 shows TRC vertical loaded geometry data for the outside rail (adjacent to the area between the tracks – known as the ‘six foot’ on UK railways) for a run, prior to and two runs after renewal. As is usual with this type of data, the relative distance along the track for different runs can vary by some tens of metres. The data can be manually aligned, although finding the exact location in relation to track features remains subject to some uncertainty. The pre-renewal data showed the track was performing very poorly and it is clear that the wet bed location lies between 35 and 50 metres. The post-renewal runs show substantial improvement.

The TRC data pre-renewal indicates a substantial localized dip of some tens of millimetres compared with the adjacent track (as was apparent visually in Figure 1b). The TRC data represents relative loaded geometry, whereas the geophone and DIC data presented in the next section measures the relative range of movement during loading.

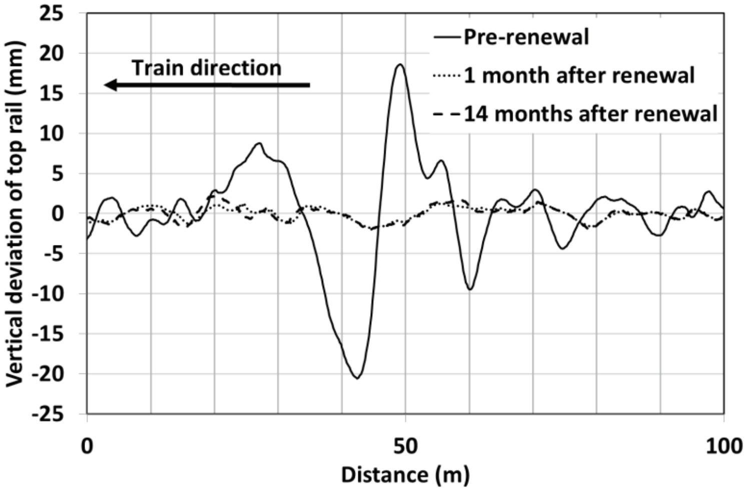

Figure 5: TRC data, for the top right rail (from the train) over a 35 m wavelength, pre- and post-renewal.

5.2 Track Data

Track deflection measurements were made immediately before and immediately after the renewal and again 5 months later. On each visit, data from Class 171 trains in 2, 4 and 6 car configurations were obtained. The trains were generally travelling at between 100 km/h and 113 km/h (60 – 70 mph).

Figure 6 compares the movements of sleeper 1 on the cess side for some middle axles (6 bogies can be identified) of a 6 car Class 171 train, measured using a geophone and DIC after renewal. The geophone data have been migrated to adjust for the relative movement introduced in processing, so that zero is an estimate of the unloaded sleeper level. The DIC data give the correct level directly, provided vibration has not influenced the data. DIC and geophone traces show close agreement. Figure 6 is annotated to show the range of movement from a single axle (used to produce Figure 7).

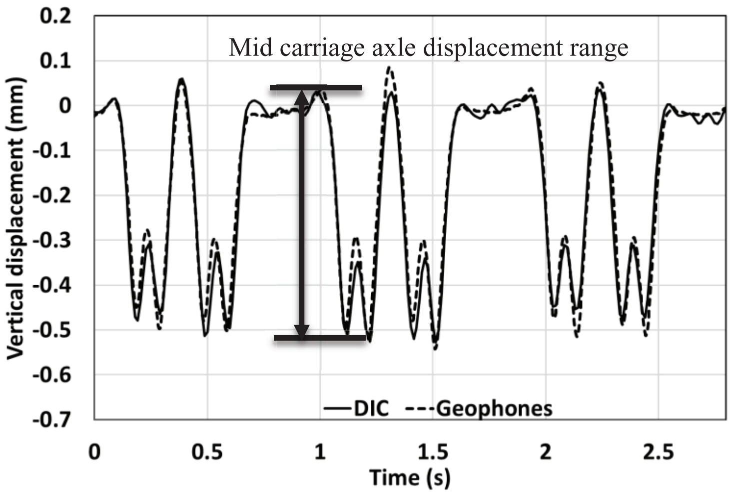

Figure 6: Post-renewal comparison of DIC and geophone movements for a 6 car 171 on sleeper 1 inside.

Figure 7 compares the averaged mid-carriage axle displacement ranges obtained from the geophones installed adjacent to the six foot (on the outside of the transition curve). Each bar is the average from at least three train passes. Prior to renewal, sleepers 2, 3, and 4 were performing exceedingly badly and were voided. Sleeper 5 also showed larger displacements than the remaining sleepers. The inner geophones showed similar behaviour. It is apparent that the problem was at its most severe over a localised zone covering just 3 or 4 sleepers with the adjacent sleepers (1, 6 and 7) performing much better. The post-renewal data show that there are no longer any voided sleepers and that the sleeper deflection is much more uniform across the monitored zone. There was little change in displacement between the two post-renewal visits.

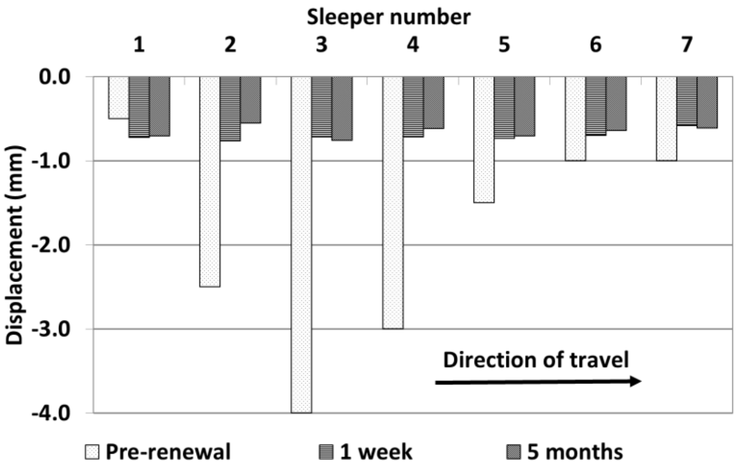

Figure 7: Average sleeper vertical deflections for each sleeper across several visits (Class 171)

6 Conclusions

Measurements presented and evaluated have shown that of the two remediation methods applied, the repeated localised digging out and re-packing with chippings pea/gravel had been ineffective whereas the renewal appears to have resolved the problems at this site, at least over the period of monitoring. Measurements will continue to be made to determine the long-term effectiveness of the renewal in remediating the mud pumping issues at this site. Good agreement between the geophones and DIC method was obtained during site monitoring.

Acknowledgements

The authors are grateful for the financial support of the Engineering and Physical Sciences Research Council (EPSRC) through the programme grants Track 21: EP/H044949/1 and T2F (EP/M025276/1) and to Network Rail for their support in kind. This work would also not have been possible without the kind assistance given by a number of current and past Network Rail employees including Daren Smith, Robert Holbrow, Mike Edwards and Andrew Cornish.

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