Railway Subgrade Performance after Repeated Flooding – Large-scale Laboratory Testing

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ABSTRACT

A rail track system comprises a number of components and, in order to analyse and predict track behaviour, it is essential to understand the function of each component as each will have a major influence on overall track performance. Historically, rail track substructure, particularly the subgrade, has been given less attention than the superstructure despite its importance in track design. This paper presents a full-scale experimental investigation to study the behaviour of subgrade in both saturated and unsaturated conditions, and how this behaviour changes with soil suction. Further, the investigation also studies the role of sand-blanketing during and after repeated flooding events. The results show that as soil suction reduces, flooding results in a continual reduction in both soil stiffness and track stiffness. It is also shown that the introduction of a sand-blanket has limited effectiveness as a drainage material, particularly after prolonged and repeated flooding.

Keywords: Full-scale railway testing, rail track settlement, soil suction, sand-blanket, railroad flooding, saturation.

1 INTRODUCTION

Subgrade evaluation and maintenance is both difficult and costly as it depends on several factors which include soil type, moisture content, shear strength, stiffness and consolidation (McHenry and Rose, 2012). Cui et al (2013) observed that the shear strength decreases with the increase of moisture content and hydraulic conductivity decreases with increasing soil suction. Ishikawa et al. (2016) also noted that shear strength decreases significantly due to both water content and fine particles increase. Toloukian et al. (2018 a, b) reported that ballast contamination with sand significantly decreased shear strength and lateral strength with the result that the ballast layer could not provide adequate support to the structure due to the presence of fine particles. Furthermore, poor subgrade and inadequate drainage can cause problems including ballast fouling, ballast pockets and pumping of fine particles. Train speed, cyclic loading, soil fineness, and low-bearing capacity of the formation layer all contribute to subgrade performance. Brough et al. (2003) reported that repeated loading, excess moisture content and poor drainage leads to subgrade failure. Water impacts on the ballast, sub-ballast and subgrade, but it is the sub-ballast and the subgrade which experiences a greater impact compared to the ballast layer (as the latter is a single sized rock (Ghataora et al., 2004; Ghataora and Rushton, 2012). The substructure of rail track is primarily focussed on the ballast and correction of track geometry, with subgrade invariably a second priority. Selig and Cantrell (2001) reported that the cost of maintenance and deterioration of track components are directly associated with drainage or subgrade conditions. Ghataora and Rushton (2012) observed that the subgrade soil had a major influence on the upper subgrade surface layer, particularly under cyclic loading and in the presence of water. Doung et al. (2013) reported that ballast behaviour significantly depends on subgrade state; in unsaturated conditions, the ballast and sub-soil interface did not change but, in a near-saturated state, a significant number of fine particles migrated into the ballast. Brough et al. (2006) also noted that the global track stiffness depends on the subgrade, thus the deterioration of vertical track geometry.

Progressive shear failure occurs due to overstressing of a clay subgrade, an event which can be avoided by placing granular material to enhance drainage. Wenty (2005) reported that particle attrition resulted in the development of a slurry at the ballast-subgrade interface due to the presence of water and heavy dynamic loading. Overloading of the subgrade creates water-pockets which cause attrition and can be avoided through the use of a granular blanket. Sharp and Caddick (2006) reported that sand-blanketing prevents upward movement of the slurry by filling the voids within the subgrade. If a slurry is formed under the clay it is retained in the clay and, in time, it dries out with the sand blanket increasing the stiffness of the granular layer. Sand blanketing is a common method of protecting subgrade soil and is generally a permeable layer of fine granular material thereby allowing water to drain from the subgrade surface (Bonnet, 2005). However, in a wet condition, the track becomes vulnerable - a situation which impacts on each component of the rail track system, in particular, the subgrade soil.

2 EXPERIMENTAL TECHNIQUES AND MATERIALS

2.1 Materials and Track preparation

In the current work, rail track behaviour during flooding and recovery was studied using a full-scale test-rig; hereinafter, this facility is called GRAFT- 3m long × 1.15m high × 1.072m wide (Geopavement and Railway Accelerated Fatigue Testing). The experimental track set-up comprised a 700 mm bed of kaolin clay subgrade layer, a 100 mm kaolin clay formation layer, a 150 mm sand-blanketing and a 300 mm ballast layer. Three, hardwood, half-sleepers were placed on the ballast layer and a steel Ibeam, representing a rail section, secured on the sleepers. The ballast layer was placed according to Network Rail line specification (RT/CE/S/006, 2000). The ballast grading is presented in Figure 1. The subgrade soil had been used in an earlier experiment (undertaken approximately 12-months previous). The purpose of using this subgrade soil was to investigate the track performance on an operational track - if new subgrade had been used, then it would have been considered as a *new track* and not representative of an operational track. Furthermore, a newly constructed track experiences significant track settlement from the subgrade as it experiences rail-traffic load. Table 1 presents the kaolin clay properties. Initially, the subgrade soil was in an unsaturated state, the moisture content and void ratio of the surface layer (100 mm) were ≈10 % and 0.91, respectively, and the degree of saturation was 30 %. The matric and total suction were ≈1300 kPa and ≈2000 kPa, respectively. At other locations within the GRAFT, soil suction (matric and total) was found to be less than the surface layer; for example, at depths between 100-500 mm, the moisture content was ≈15 % and the degree of saturation was ≈50 % and the matric and total suction were, respectively, ≈700 kPa and ≈1500 kPa.

The track was flooded (1st event) to investigate the track behaviour without a sand blanketing layer (Hasnayn et al., 2017). After 14 weeks, the track was then prepared with a 150 mm sand-blanket to investigate its influence on track behaviour during and after the 2nd flooding event (see Figure 2). A 150mm sand blanket was placed on the subgrade according to Network Rail standard RT/CE/S/033. The optimum moisture content of sand was 12.8%.

Table 1 Kaolin clay (subgrade) properties

Physical Property	Value
Specific Gravity	2.64
Maximum dry density (Mg/m^3)	1.54
Optimum moisture content (%)	23.8
Liquid limit (%)	55.0
Plastic limit (%)	32.0
Plasticity index (%)	23.0

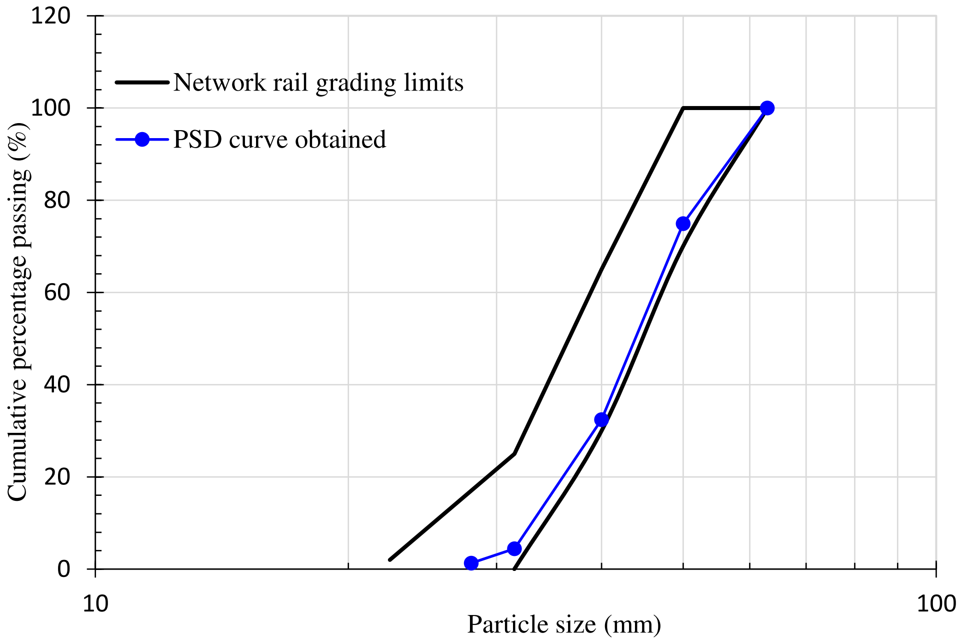

Figure 1 Network rail specified and obtained ballast PSD curve

Figure 2 The GRAFT facility showing the 150mm sand blanket layer placed on clay subgrade

2.2 The GRAFT Facility

To understand track behaviour after a flooding event, the GRAFT facility was used for this investigation which allowed testing at full-scale. A longitudinal cross-section of GRAFT is presented in Figure 3. As noted earlier, the track was constructed with three, half sleepers and a 3m long steel I-section which had similar stiffness properties to a BS 113A rail section (Kennedy, 2010) . The axle load was 25 tonnes as this is the maximum load permitted on UK track. The sleeper load factor was accounted for at 85% due to the reduced load distribution as three sleepers were used (a 100% load distribution is found in 5 sleepers (Profillidis, 2006)). The load area stress factor was 35%, evaluated from the deflection profile along a sleeper on the ballast surface (Selig and Waters, 1994). The dynamic load factor was 120% (Kennedy et al., 2012). The axle load used in the current study is only a guide as the exact load depends on several factors, such as type of sleeper, spacing and dimensions, subgrade quality etc. (Selig and Waters, 1994; Profillidis, 2006). The applied load is P was calculated from the following equation (1), (Li et al., 2007, Kennedy, 2010),

$$P = \text{Axle Load (W)} \times \text{Sleeper Load Factor } (S_{lf}) \times \text{Load area Stress Factor } (L_{sf}) \times \text{Dynamic Load Factor } (D_{lf}) \quad (1)$$

$P = 250KN \times 85\% \times 35\% \times 120\% = 90KN$

To allow water to drain from the tank, a sealable drainage port was located above the formation layer as shown in Figure 3. Two additional ports were located at the bottom of the tank. The drainage design was not focused in this work. Figure 3 shows the track testing arrangement and loading actuator.

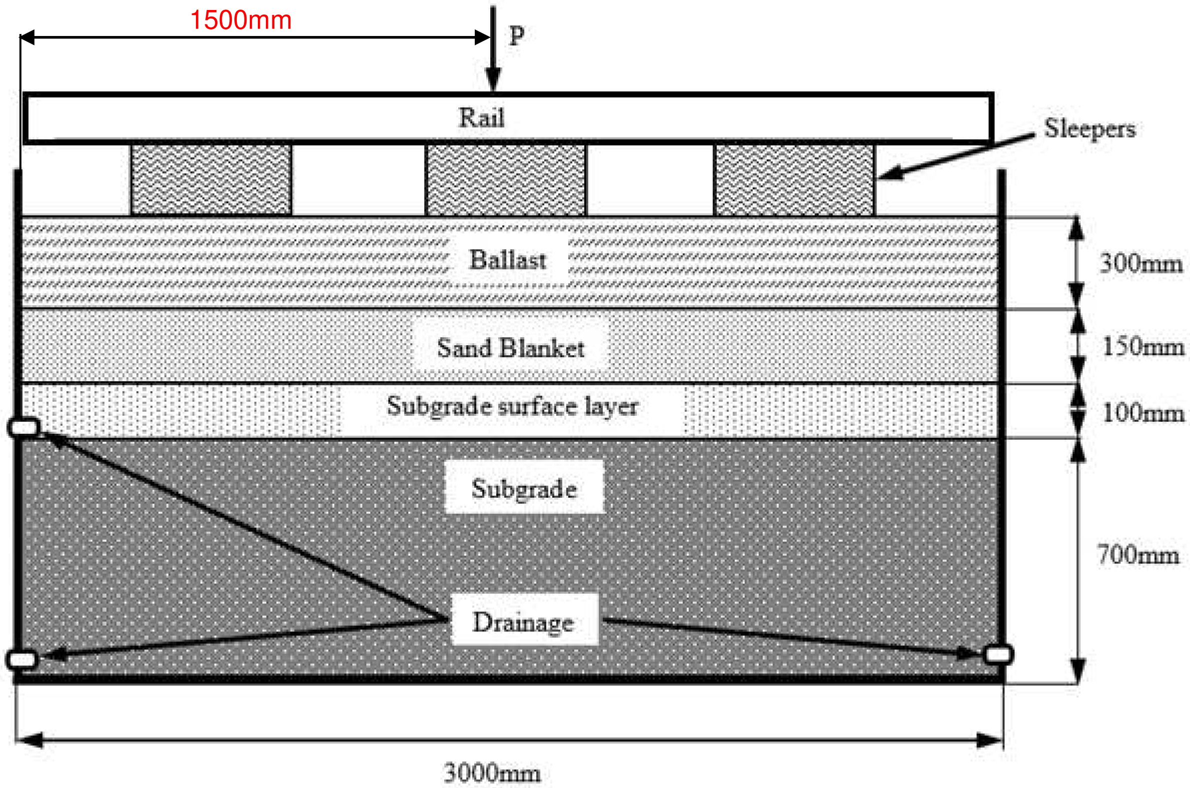

Figure 3 Longitudinal cross-section of the GRAFT facility

A plate load test (PLT) was undertaken in accordance with BS EN 1997-2:2007 to evaluate the subgrade stiffness. A series of stacked circular plates were placed in the middle of the tank which comprised a 440 mm diameter plate placed on the subgrade surface, a 400 mm diameter load-cell and a further three, 300 mm diameter plates as shown in Figure 4. The corresponding vertical deflection of the bottom plate was measured using two linear variable displacement transducers (LVDT's). The stressed zone of influence of the PLT was considered to be approximately two times the diameter of the plate (Ping et al., 2002), hence the zone of influence of the test covered the full depth of subgrade in the GRAFT.

Figure 4 Plate load test set-up in the GRAFT

Initially, five, monotonic loading cycles were applied at a rate of 1 kN/s which was, subsequently, followed by 50 cycles applied at a rate of 0.1 Hz to obtain the load-deflection curve. Data were recorded at a frequency of 30 Hz and the applied load for the test was 15 kN. Regarding the latter, this value was used to avoid any substantial plastic settlement of the subgrade surface, as well as maintaining a stress level of approximately 100 kPa below the plate.

Both the initial tangent modulus and reloading tangent modulus (obtained from the reloading curve) were calculated using equation (2) (Alshibli et al., 2005, Kennedy, 2010). In both cases, the second cycle was used to obtain the respective modulus,

$$E_{PLT} = \frac{2P\,(1-v^2)}{\pi r \delta} \qquad (2)$$

where, E_{PLT} is the elastic modulus (MPa), P is the applied load (kN), r is plate radius (mm), v is Poisson's ratio and δ is deflection of the plate (mm). The values of Poisson's ratio used in the current study were assumed to be 0.30 and 0.49 for the unsaturated and saturated clay subgrade, respectively (Bowles, 1997).

2.3 Soil Suction Measurements – The Filter Paper Method

This is a straightforward and accurate method to measure soil suction (Chandler et al., 1992, Ridley and Burland, 1993, Houston et al., 1994, Bulut et al., 2001, Leong et al., 2002, Rahardjo and Leong, 2006, Marinho and Oliveira, 2006). A piece of filter paper (Whatman's No. 42) is placed between two larger protective filter papers alongside a soil sample, with a further filter paper on top of the sample. As the filter paper is in contact in the middle of the two soil specimens, it then gives matric suction through the formation of water menisci. In order to measure the total suction, a piece of filter paper was placed on top of the sample but not in direct contact. The soil specimen was then placed in an airtight container at a constant temperature (25°C±1°C) to achieve moisture equilibrium condition between the filter paper and soil specimen. Generally, the filter paper comes into equilibrium with the soil either through vapour (total suction) or fluid flow (matric suction); at equilibrium, the soil and the filter paper suction value are the same. The filter paper water content was calculated using the calibration curve presented by Haghighi et al. (2012),

$$\mathrm{Ln}\psi = (a + bW_f + cT + dW_fT) / (1 + fW_f + gT + hW_f\,T) \qquad (3)$$

where, ψ is the soil suction (in kPa), W_f is the filter paper water content (%), T is temperature in Kelvin (K), and a = 10.86, b = -6.376×10^{-2}, c = -4.056×10^{-2}, d = 2.186×10^{-4}, f = 1.908×10^{-2}, g = -3.648×10^{-3}, h = -7.650×10^{-5} are constant parameters.

2.4 Testing Regime

To understand the influence of sand blanketing and subgrade behaviour after flooding and during the recovery period (post-flooding), the experimental programme was divided into four phases as presented in Figure 5 and Table 2:

- Phase-I (Flooded period): On completion of the 1st flooding test, all ballast was removed and soil samples were collected at different depths under the three sleepers to measure the soil properties. The aim of this phase was to investigate the influence of a sand blanket under saturated conditions. The moisture content of the subgrade surface was ≈27% (see Figure 6a). The subgrade matric and total suction were in the range 150-570kPa (see Figures 6c & d). The track was then flooded (2nd flooding) up to ballast level for one week. After this time, the water was then allowed to drain for a week, before being placed under the load. This was ensured by observing that no water was exiting the drainage ports.
- Phase-II (Recovery period): On completion of the first Phase, the track was allowed to dry for two weeks before placing the track under load. The track was again left for another two weeks (i.e. four weeks after the start of Phase II) for drying then the track was placed under load. The test was repeated again after another two weeks (i.e. six weeks after the start of Phase II) to record any change in the track subgrade properties and settlement.
- Phase-III (Flooded Period): On completion of Phase-II, the ballast and sand blanket were removed and the track was allowed to dry for a week, before

preparing the track in a similar manner to Phase-I. The track was flooded for a third time with a 150 mm sand blanket. In this Phase, the track was placed under load without the water being drained. After completing Phase-III, the water was then allowed to drain from the track for a week.

- Phase-IV (Recovery period): After completion of Phase-III, the track was then allowed to dry for two weeks; however, no load was applied to avoid further damage to the subgrade. After a further two weeks drying (i.e. 4 weeks after the start of Phase-IV), the track was placed under load. This was repeated after another two weeks (i.e. 6 weeks after the start of Phase-IV).

Figure 5 presents a time-line for the experimental programme.

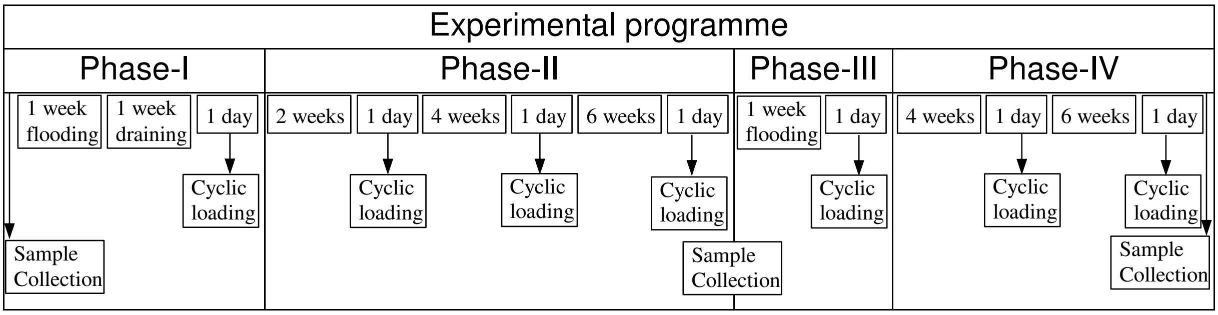

Figure 5 A summary of the experimental programme (start = left, end = right)

Table 2 The different phases of the experiment

Experimental phase	Applied cycles	Surface layer Matric suction (kPa)	Surface layer moisture content (%)	Maximum Settlement (mm)	Loading frequency (Hz)
Phase I: before 2nd flooding	---	150	27	---	---
Phase I: after 2nd flooding	1400	None observed	37.02	48	2Hz, 1Hz
Phase-II: Recovery period					
After drainage	---	None observed	34.14	---	---
After 2 weeks	2000	Not measured	Not measured	41	2HZ
After 4 weeks	10,000	Not measured	Not measured	41	2Hz
After 6 weeks	10,000	Not measured	Not measured	42	2Hz
Phase III: After 3rd flooding (without drained water)					
Immediately	1500	None observed	35.14	66	1Hz
Phase-IV: Recovery period					
After 4 weeks	2000	Not measured	Not measured	62	2Hz
After 6 weeks	10,000	Not measured	Not measured	41.6	2Hz

3 RESULTS AND DISCUSSION

3.1 Soil Suction, Saturation and Subgrade Modulus

The moisture content of the subgrade surface layer (100mm) before the 2nd flooding was ≈27 % and the degree of saturation was ≈90 %, as presented in Figures 6 (a) and (b). The matric and total suction were ≈150 kPa (Figure 6c) and ≈570 kPa (Figure 6d), respectively. At the other depths (up to 500 mm), the moisture content averaged 25% and the degree of saturation averaged 80%. However, at 300 mm depth, the moisture content was found to be ≈21 % and the degree of saturation was ≈70 %. The matric and total suction were measured as ≈540 kPa and ≈720 kPa, respectively. To compare the results with a layer of sand blanketing (150mm), the track was flooded to the upper ballast level and held in a saturated state for a week (note that flooding was performed using a low-pressure hose to prevent any possible subgrade erosion). Water was then allowed to drain out for five days; after drainage, the track was placed immediately under cyclic loading. The experiment was repeated at two-week intervals i.e. after 2, 4- and 6 weeks. At the end of the test (end of Phase I), soil samples were collected under the three sleepers to a depth of 400mm to measure the moisture content, void ratio and soil suction. The surface layer moisture content was ≈37% (Figure 6a) which was fully saturated therefore no soil suction was measured. On removal of ballast and sand-blanket layer, a plate loading test was conducted to measure the subgrade stiffness. The subgrade tangent and reloading moduli were evaluated as 25MPa and 32MPa, respectively.

Subgrade soil properties were measured after the test to investigate the subgrade soil behaviour. Before the 2nd flooding (At the end of Phase II and prior to 2nd flooding in Phase III, the moisture content of the subgrade soil varied at different depths from between 30-38% (see Figure 6a). The matric suction was in the range 50-80kPa (Figure 6c) and the total suction in the range 100-300kPa (Figure 6d). Compared to the first experiment (without sand blanketing - Hasnayn et al., 2017), the track displayed improved performance than with sand blanketing in the saturated state. After completing the test, soil samples were again collected to measure the moisture content, soil suction and void ratio. The moisture content of the surface layer was >35% and overall soil suction of the entire subgrade soil had decreased; within the surface 200mm of subgrade, no soil suction was observed. The void ratio was 0.79;

however, the moisture content of the middle section of the subgrade (22%) was found to be less than the surface layer (100mm) and the lower section (500mm). With every simulated flooding event, the flood water directly affected both the upper and lower sections, whereas, the central section experienced increasing moisture content which was attributed to a capillary effect.

After the 3rd flooding,Phase III, the entire subgrade soil properties changed significantly. The entire subgrade moisture content was almost similar. The top and bottom sections of the subgrade layer were affected most as these sections were contacted by water first. After completing the test, soil samples were collected to a depth over 600mm to evaluate moisture content, soil suction and void ratio. At depths 100-600mm, the moisture content varied between 30-35% (Figure 6a) and the matric suction varied between 20-100kPa (Figure 6c); the void ratio was 0.79.

Figures 6 (a) and (b) present the depth-related variation of moisture content and degree of saturation, matric suction and total suction at different test stages. After flooding, the upper layer of the subgrade was affected the most; however, after 4 and 6 weeks, the moisture content and suction were similar throughout the entire subgrade indicating that an equilibrium condition had now been reached.

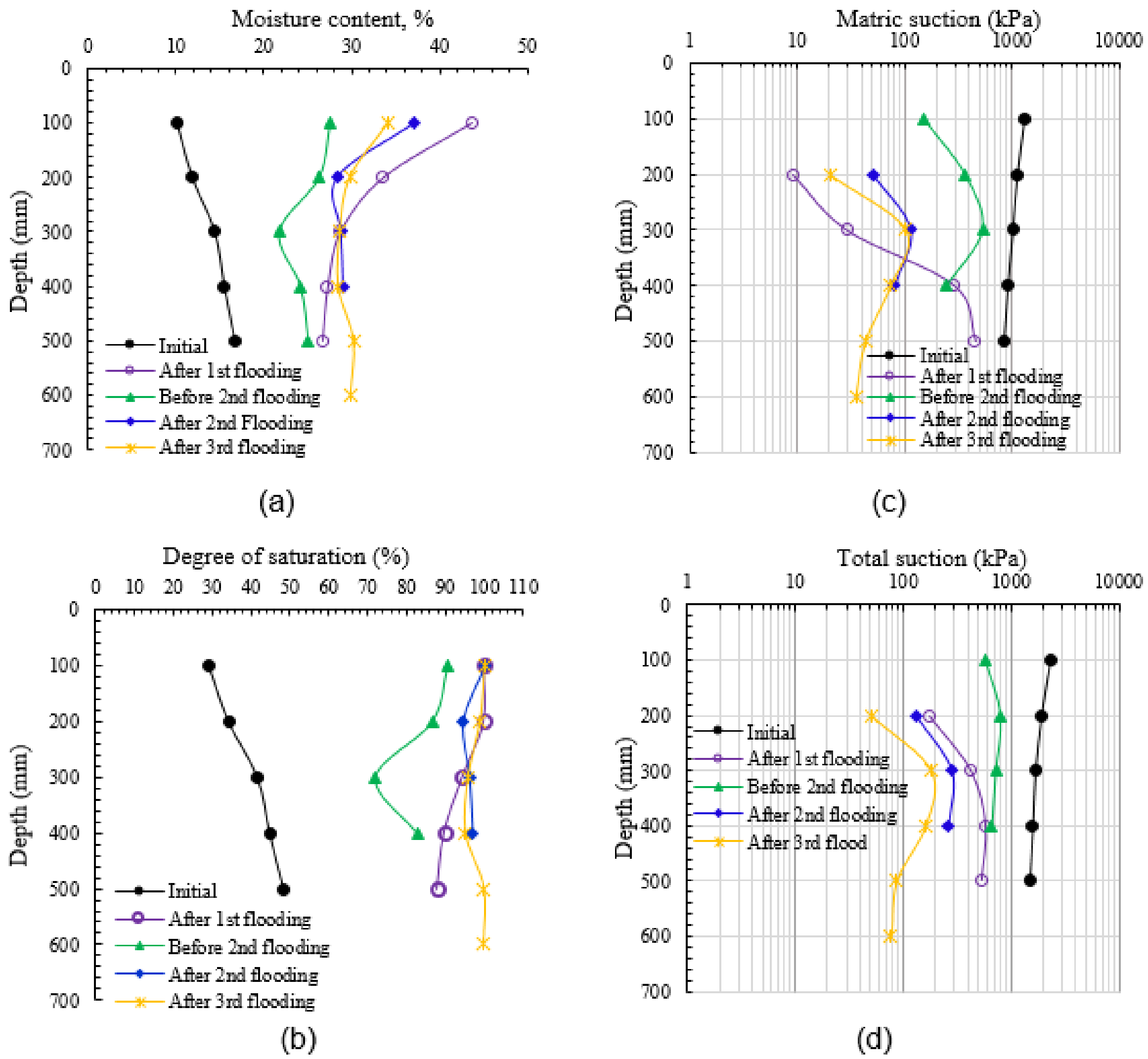

Figure 6 Variation of (a) moisture content (b) degree of saturation, (c) matric suction, and (d) total suction in different phases at different depth under the middle sleeper

The subgrade tangent and reloading modulus were measured before and after the test. Regarding the former, the subgrade modulus was not measured immediately after drainage as the ballast layer had to be removed. After flooding, the subgrade modulus decreased by ≈78% and Table 3 summarizes the moduli before and after flooding. The results clearly indicate a relationship between subgrade stiffness and soil suction as the subgrade modulus decreased significantly after flooding resulting from a decrease in soil suction (130kPa). It is also evident that soil suction plays an important role in the variation of subgrade stiffness.

Table 3 Subgrade modulus after flooding

Test	Formation Moisture content, w (%)	Formation Matric suction (kPa)	Subgrade tangent modulus (MPa)	Subgrade reloading modulus (MPa)
Initial	10.05	1300	109	122
1st Flooding	27.48	150	30	35
2nd Flooding	31.01	120	25	32
3rd Flooding	31.34	90	24	29

3.1 Track settlement behaviour: Phase –I

On placement of the track under load (and after drainage of water), the track settlement is presented in Figure 7. It is apparent that the initial track settlement was rapid (≈25mm after only 110 cycles), resulting from the saturated surface of the sand-blanket. After 1500 cycles, the track settlement was ≈45mm, which is 5 times higher than the track without sand blanketing after the same number of loading cycles and attributed to liquefaction of the sand-blanket due to the flooding regime; additionally, fine particles migrated into the ballast which induced additional track settlement. Tabatabaei et al. (2017) found that the maximum settlement occurred in an embankment resting on loose sand with loss of overall stability due to liquefaction. The initial cyclic loading rate was 2Hz but was, subsequently, reduced to 1Hz to avoid further damage to the subgrade; it was also evident that the rail tilted to the drainage side at the tank. After the 2nd flooding event, the entire subgrade moisture content had increased and soil suction decreased (Figure 6). The test was eventually stopped after 1500 cycles due to the excessive settlement of the track (30mm/1000cycles).

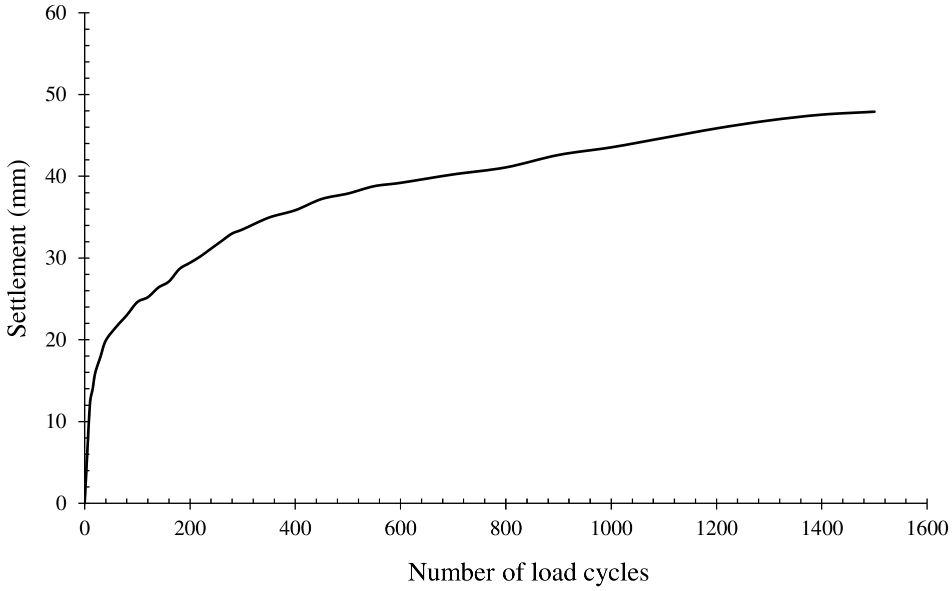

Figure 7 Middle sleeper settlement behaviour during Phase-I

Traditional sand blanketing is used as a means for surface drainage and protection of the subgrade from erosion related problems such as upward migration of fines, ballast fouling and slurry formation. As a consequence, this can cause maintenance and performance issues for engineers (Sharpe and Caddick, 2006). After removing the top ballast, fine particles were observed in the ballast. Mud-pumping is a serious problem with track-bed, which occurs due to a combination of fine particles and water. Ayres (1986) stated that, despite a high strength subgrade, poor track performance could be as a result of slurried ballast.

Figures 8 (a) - (c) shows a layer of ballast which has penetrated into the sand blanket and Figure 8 (d) highlights the settlement under the three sleepers. In this situation, the track performance was deemed to be poor as sand-blanketing was unable to provide appropriate support to the track resulting in reduced ballast stiffness. However, sand blanketing protects the subgrade from erosion. After removal of the sand-blanket on completion of Phase-I, a noticeable settlement of the subgrade under three sleepers was observed (Figure 8). Sharpe and Caddick (2006) also reported that, on a number of occasions, sand blanketing failed to protect the subgrade from erosion.

Figure 8 (a) Ballast penetration into the sand blanket after the test-Phase II, 2nd flooding, (b) clogged ballast after flooding, (c) the ballast layer after digging out from the sand blanket, and (d) settlement under three sleepers (dashed lines indicate the position of the sleepers)

3.2 Track settlement behaviour: Phase – II

Track performance after two weeks

It was evident that there was no improvement in track performance two weeks after the 2nd flooding event. Figure 9 presents the settlement behaviour of the middle sleeper after two weeks of drying. The first stage track settlement was approximately 20mm (after 240 cycles) which doubled to ≈40mm after 2000 cycles. The track settlement after two weeks without sand blanketing (20mm) was almost 50% lower than the track settlement with sand blanketing (Hasnayn et al. 2017). It was noticeable that some water became trapped between the subgrade and the sand-blanket which trickled from the bottom drainage holes during loading. It is proposed that the sand layer and subgrade soil with ballast had created a ballast pocket. Additionally, fine particles migrated into the ballast, giving higher track settlement with the sand-blanket compared with to that without.

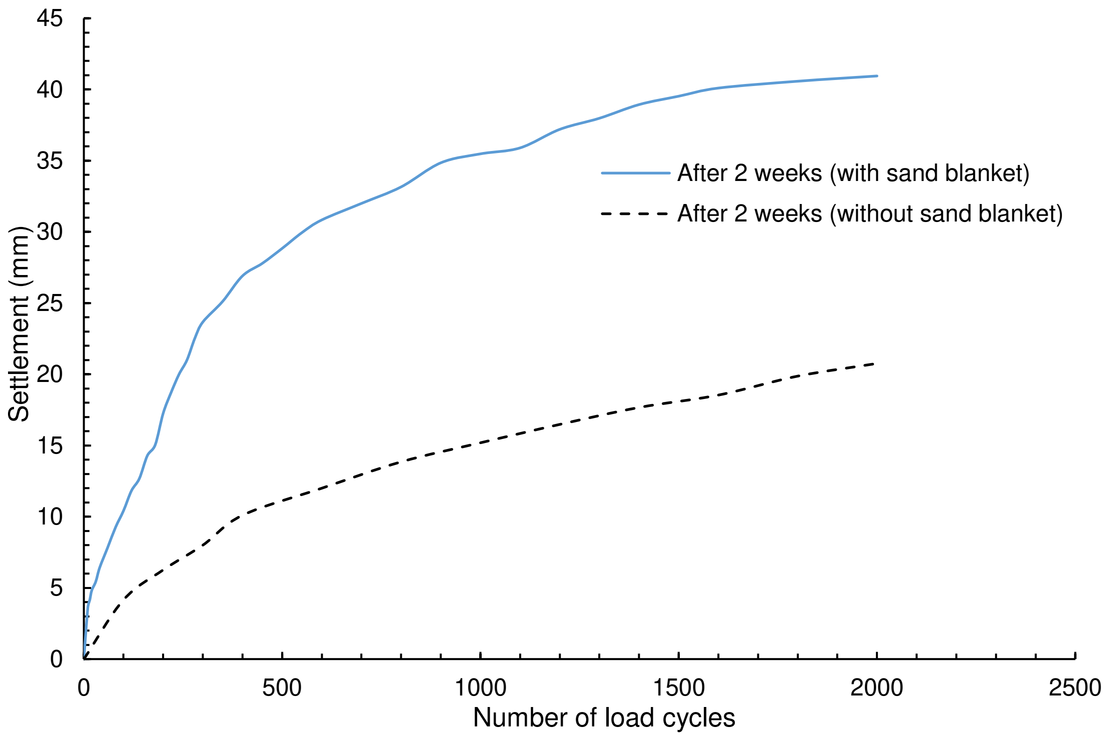

Figure 9 Phase II: Track settlement after two weeks with and without the sand-blanket

Track performance after four weeks

Four weeks from the start of Phase II, the improvement in track performance was only marginal as shown in Figure 10. The settlement decreased by ≈30% compared to that observed at two weeks settlement. The first stage settlement was ≈25mm (1000 Cycles), whereas after 10,000 cycles the settlement was ≈40mm. In comparison with the trackbed without a sand-blanket (25mm) (Hasnayn et al. 2017). After four weeks the track settlement with the sand-blanket was approximately 60% higher.

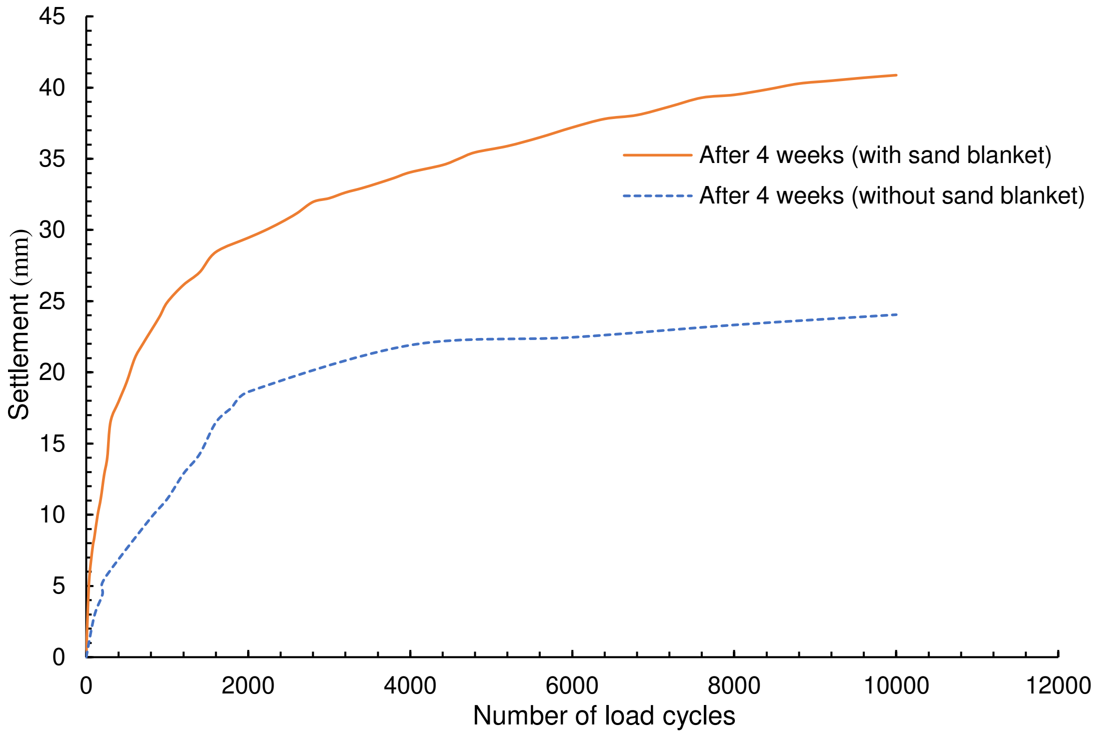

Figure 10 Phase II: Track settlement after four weeks with and without sand blanket

Track performance after six weeks

With reference to Figure 11, six weeks after the start of Phase-II) the settlement was similar to the previous stage at four weeks (Figure 10). However, the track settlement was almost 70% higher than the track settlement without the sand-blanket (25mm) after the same period. The settlement was measured as ≈42mm after 10,000 cycles.

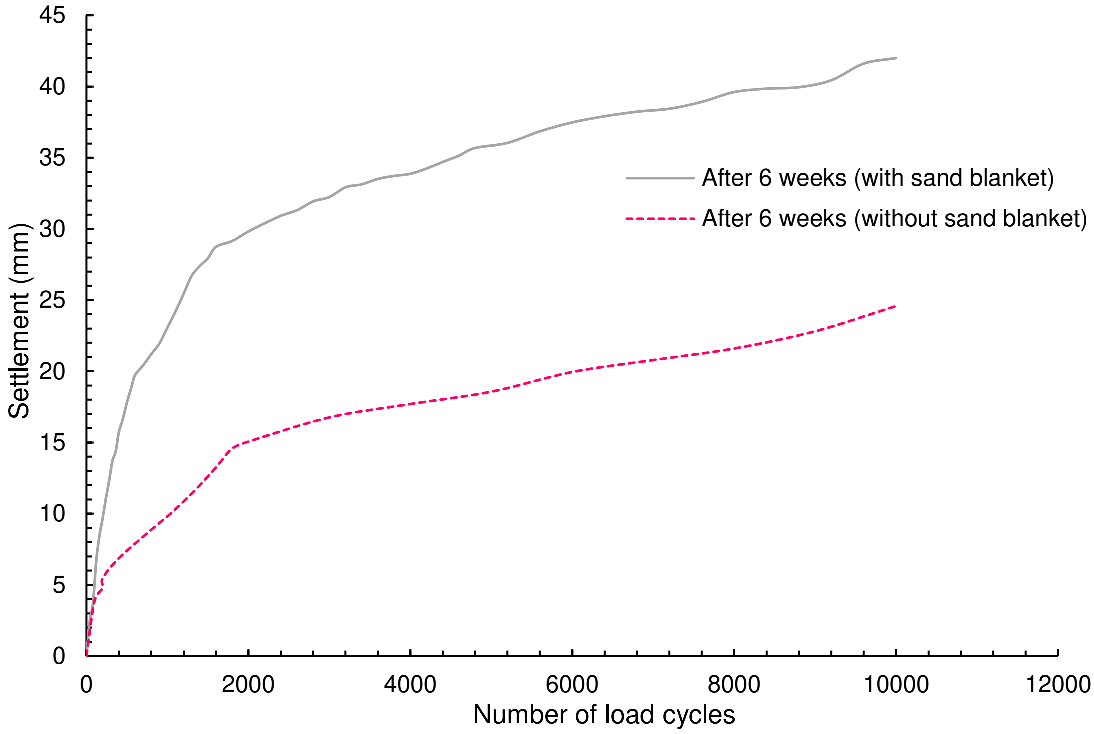

Figure 11 Phase II: Track settlement after six weeks with and without sand blanket

3.2 Track settlement behaviour at Phase –III

For this Phase, the track was prepared using a new 150mm sand-blanket and then flooded for the 3rd time. The ballast was marked (see Figure 12a) to investigate changes during and after loading.

After one week of flooding, the track was then loaded without drainage; Figures 12 (b) and (c) show the track before and after loading, respectively, and (d) shows the track after the complete test. After only 1500 cycles, the track had submerged; repeated flooding reduced the subgrade stiffness (M_r = 29MPa) and the surface layer became saturated (degree of saturation = 100%). Without undertaking further maintenance, the track was deemed unsuitable to withstand further loading.

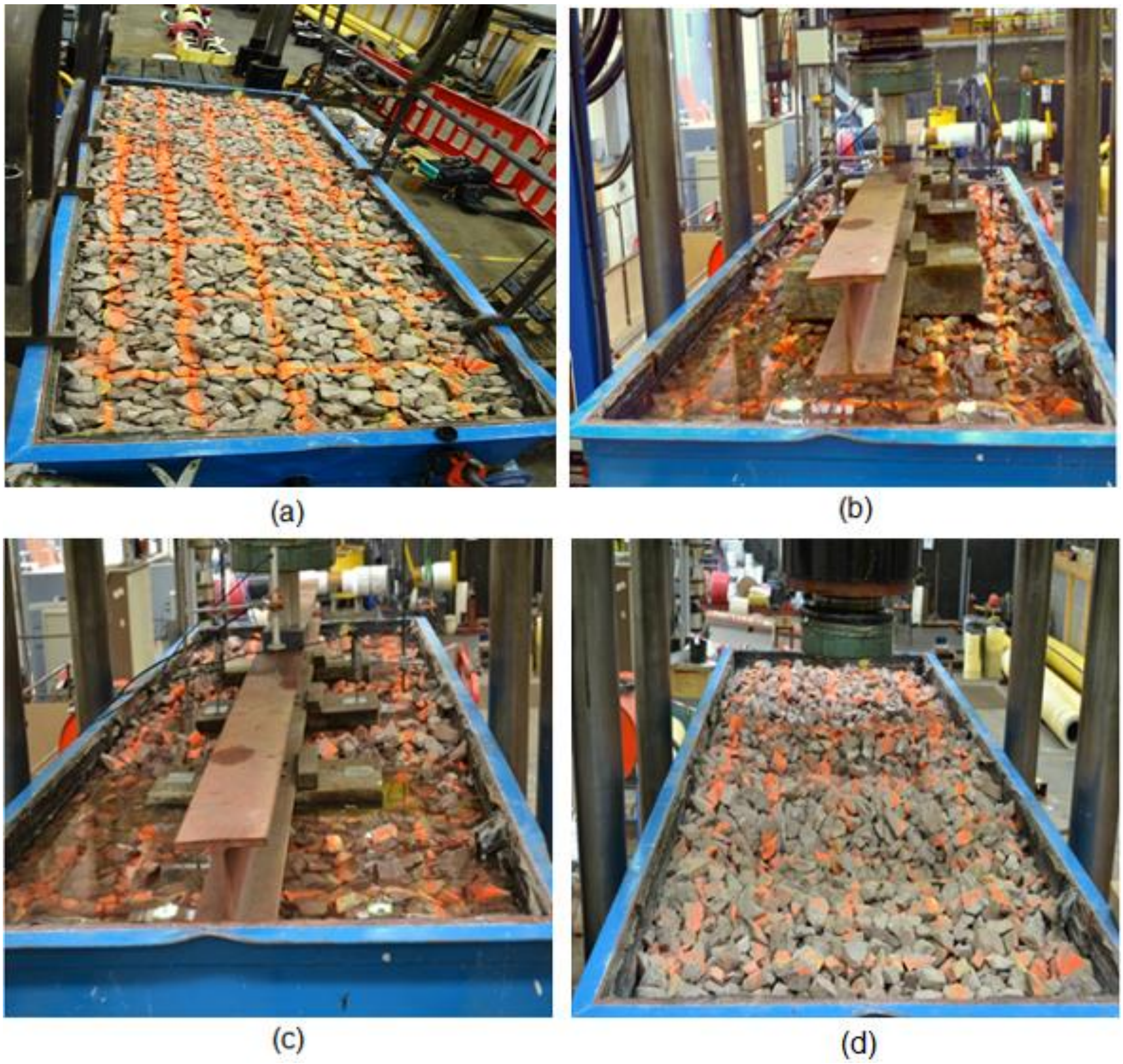

Figure 12 (a) Prepared track before flooding with sand-blanketing with *marked-up* ballast, (b) Flooded track before loading, (c) flooded track after loading, and (d) track after the test

Figure 13 presents the track settlement during loading when under flooded conditions. The first stage settlement was ≈20mm after only 50 cycles, while after 1500 cycles, the presence of water resulted in a track settlement of ≈65mm (loading applied at 1Hz).

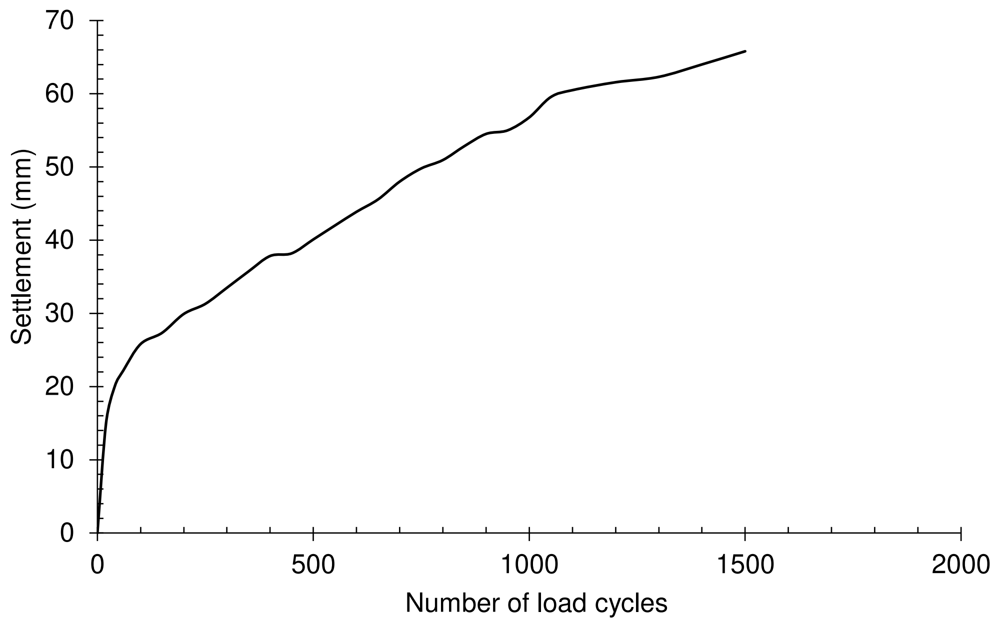

Figure 13 Phase-III: Track settlement during flood

3.3 Track settlement behaviour at Phase –IV

Track behaviour after four weeks

After drainage, the track was allowed to dry for four weeks before loading again. The track settlement was ≈50% higher than the previous phase (Phase-II) and this was attributed to the combination of saturated conditions and the applied cyclic loading which caused the fine particles to migrate upwards, and the ballast to penetrate downwards into the soft soil. The track settlement was ≈60mm after only 2000 cycles. In Figure 14, curve-c presents the track performance after four weeks with the load applied at 2Hz. During this, it was observed that water weeped out of the drainage ports during loading.

Track behaviour after six weeks

After six weeks (from beginning of Phase IV), the track was placed under a load for 10,000 cycles applied at 2Hz. The track settlement was ≈48mm (Figure 14, curve-d) which was 20% higher than at the same stage during Phase-II.

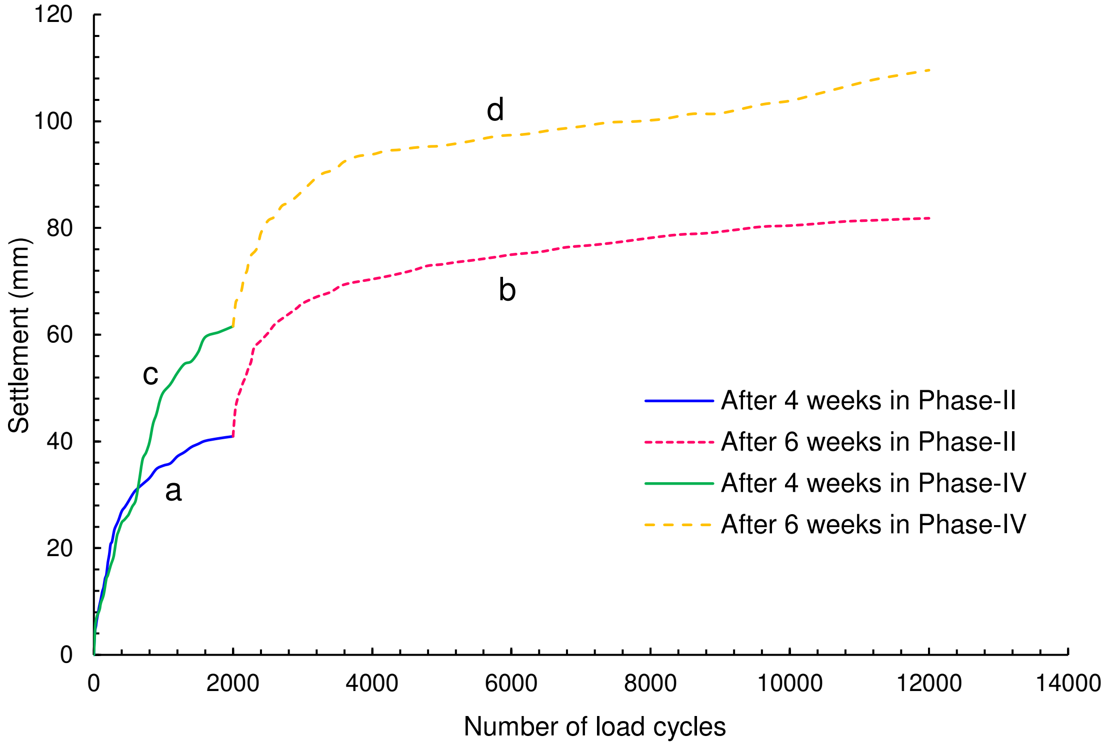

Figure 14 Comparison track settlement between Phase-II and Phase-IV at four and six weeks

Blocked or poor drainage causes numerous track problems including ballast fouling, entrapped water and higher track settlement, some of which are illustrated in Figures 15. Wenty (2005) also observed a similar subgrade failure problem due to the development of water pockets where there was insufficient drainage.

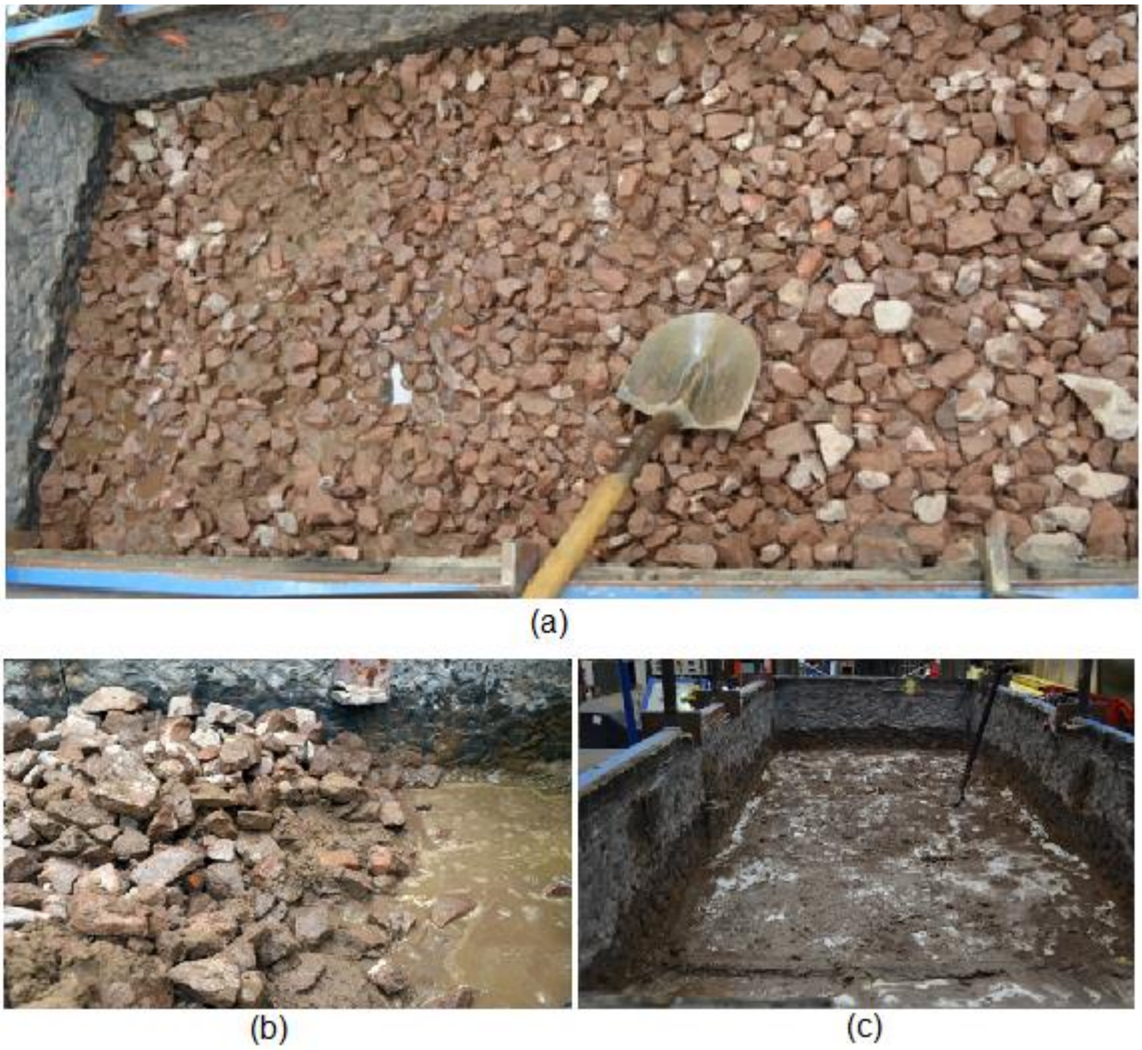

Figure 15 (a) Fine sand which has migrated into the ballast, (b) Water entrapped between the sand-blanket, ballast and subgrade and (c) Saturated subgrade surface layer

4 CONCLUSIONS AND CONCLUDING COMMENTS

The performance of rail-track depends on the behaviour of subgrade materials. In the event of a flood, the upper layer of the subgrade is affected most, being sensitive to changes in water-content and soil suction. However, with time, the entire subgrade can be affected if the water remains in the track for a prolonged period. In the current experimental programme, it was observed that the wetting process was considerably faster than the drying process. Additionally, repeated flooding changed the properties of the entire subgrade, such as moisture-content, soil suction and the degree of saturation. This resulted in track settlement increasing significantly after each flooding event. Sand blanketing was found to be an effective method in alleviating subgrade problems such as subgrade erosion, slurry formation, mud-pumping and attrition. The following conclusions were drawn:

Sand blanketing is not a panacea for all water-related problems and, in certain situations, can cause challenges. Sand blanketing prevents clay migration into the ballast, militates against subgrade erosion and ballast penetration into the subgrade; however, it was found that it also facilitates sand moving into the ballast, resulting in poor track performance.

In real-life situations, subgrade condition is often ignored or is not assessed appropriately. Most of the case, a layer of sand blanket and geotextile placed on top of the subgrade without assessing the subgrade condition. One of the key findings in this paper, is that if the subgrade is soft or near-saturated, then placing a sand blanket is not a long-term solution and an appropriate subgrade assessment required.

The presence of water results in poor track performance when measured in terms of high settlement rates when the track is submerged. The results show that track settlement is higher with sand blanketing than without. After four weeks of drying (drainage) the track with sand blanketing displayed some improvement (in terms of overall track settlement) and a more rapid recovery in comparison to the track without sand-blanketing.

. In the work presented, the worst-case scenario was considered using only a sand-blanket as a filter layer., It was shown that water can become trapped due to insufficient drainage and even after six weeks of drying, the presence of trapped water between the ballast and the sand blanket resulted in excessive settlements.

Soil suction and water-content have a significant impact on subgrade performance as, after each flooding event, the soil stiffness reduces which results in excessive settlements of the track. As a result, these are important factors which must be considered in subgrade assessment and service-life prediction.

Acknowledgements

The Authors wish to thank the School of Energy, Geoscience, Infrastructure and Society, Heriot Watt University where the work was undertaken.

Conflict of Interest

The Authors declare that this is no conflict of interest.

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