CHARACTERIZATION OF CLEAN AND FOULED RAIL TRACK BALLAST-
MODEL AND FIELD STUDIES

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ABSTRACT: The efficiency of track foundation material gradually decreases due to insufficient lateral confinement, ballast fouling, and loss of the shear strength of subsurface soil under cyclic loading. This paper presents characterization of rail track subsurface to identify ballast fouling and subsurface layers at Wollongong, Australia and Bangalore, India. Seismic surface wave method of multi-channel analysis of surface wave (MASW) has been carried out in the model track and field track for finding out shear wave velocity (SWV) of the clean and fouled ballast and track subsurface. The SWV of fouled ballast increases with increase in fouling percentage, and reaches a maximum value and then decreases. Critical fouling percentage of 15% is noticed for coal fouled ballast and 25% is noticed for clayey sand fouled ballast. Fouling of ballast reduces voids in ballast and thereby decreases the drainage. Combined plot of permeability and SWV with percentage of fouling shows that after critical fouling point drainage condition of fouled ballast goes below acceptable limit. Shear wave velocities are measured in the selected location in the Wollongong field track by carrying out similar seismic survey and compared with model track values. In situ samples were collected and degrees of fouling were measured. Field SWV values are more than that of the model track SWV values for the same degree of fouling, which might be due to sleeper’s confinement. Ballast samples from selected locations in Bangalore (south western railway) had been collected and analyzed for fouling. Study shows that Indian ballast fouling increases with age of track, but ballast fouling is not scientifically studied in India. Indian ballast engineering needs extensive research to improve present track conditions.

INTRODUCTION
Railways are the massive means of transport in all countries to carry goods as well as passengers. The important component in railways is the rail track, which consists of two parallel steel rails, anchored on perpendicular sleepers, these rails and sleepers being placed on a foundation. The foundation is normally compressed soil, on top of which a bed of ballast (aggregates) to distribute the load from the sleepers to the capping layers and formation soils. A ballast bed performs two major roles in the railway network, i.e., drainage and load bearing capacity. Rail ballast comprises of uniformly-graded coarse aggregates, produced from crushing locally available rocks such as granite, basalt, limestone, slag or gravel. During the operation, ballast fouling can take place due to ballast breakdown, infiltration of other materials from ballast surface or from base of ballast layer by filling of its voids. Major fouling reported worldwide is attributed to the breakdown of ballast (fine ballast), outside contamination by coal dust from trains carrying coal and due to soil intrusions from the base.

Fouled ballast can cause the following major problems.

i. Reduction in vertical (including uplift), lateral and longitudinal forces applied to the sleepers to retain the track in its required position.

ii. Decrease in resilient modulus/strength and energy absorption capacity

iii. Reduction in the voids space thereby leading to a considerable decrease in the movement of particles through the ballast.

iv. Poor drainage of water falling onto track

v. Vegetation growth in the rail track

vi. Increased noise level and

vii. Inadequate electrical resistance between rails.

Therefore evaluation of the degree of fouling is necessary to ensure the optimum maintenance cycle thereby increasing track stability.

MODEL RAIL TRACK
A section of full-scale railway track has been built in the Civil Engineering Laboratory, University of Wollongong for this study. The model track has all the components of a Railway track system, including sub grade, capping layer, and ballast (clean/fouled). No loading tests were carried out on the model track and hence the box was constructed with two layers of plywood boards. The internal dimensions of the box were 4.76 m (length), 3.48 m (width), and 0.79 m (height). A sub grade layer of clayey sand, a capping layer of road base material and a ballast layer, forms the track. The thicknesses of these layers were 15 cm for the sub grade, 15 cm for the capping layer and 49 cm for the ballast. The materials used in the construction were clean ballast (CB), fine ballast/ pulverized rock (FB), coal (C), and clayey sand (SC). Detailed discussion on construction
of model track and materials used can be found in Anbazhagan et al (2010).

SEISMIC SURFACE WAVE SURVEY
MASW is the new improved technique by incorporating a multichannel analysis of surface waves using active sources (Park et al., 1999; Xia et al., 1999; Xu et al., 2006). In particular, the MASW is used in geotechnical engineering for the measurement of shear wave velocity and dynamic properties (Sitharam and Anbazhagan, 2008; Anbazhagan and Sitharam, 2008d; 2010), identification of subsurface material boundaries and spatial variations of shear wave velocity (Anbazhagan and Sitharam, 2009). MASW systems consisting of 24 channel SmartSeis seismograph with 12 geophones of 10 Hz capacities were used. The seismic waves were created by impulsive source of 1 kg sledgehammer with 70 mm X 70 mm aluminum plate with a number of shots. 12 geophones were arranged parallel to the y-axis along section 1 – 9 and survey was carried out. Source to receiver distance and spacing of geophones were investigated, and a good signal was obtained for a geophone spacing (ΔX) of 0.25 m and source to first receiver spacing (X) of 0.5 m in the model track. These spacing were adjusted in the field based on sleeper locations and a good signal was obtained for ΔX of 0.6 m and X of 1.2 m. This configuration was used to survey all the sections and was similar to hard material (pavement) mapping field configuration (Anbazhagan and Sitharam 2008d). Each section had been surveyed three times and the seismic signals were recorded at a sample interval of 0.125 ms and record length of 256 ms (Anbazhagan et al., 2010).

SHEAR WAVE VELOCITY OF BALLAST
Shear wave velocity (SWV) of the subsurface material is an important dynamic property which is mainly used in vibration analysis. SWV is also a recognized parameter to indicate the behavior of subsurface materials during earthquake. Dynamic moduli of ballast and subsurface are widely used to understand and model the subsurface behavior of track structure and below layers due to train loading. Seldom attempts have been made by the researchers to measure the shear wave velocity of ballast in the laboratories. Bei (2005) carried out free-free Resonant Column Test (Kalinski and Thummaluru, 2005) in a clean ballast sample of density 1.75 ton/m³ considering two vacuum levels of 37 kPa and 64 kPa. Author reported that the shear wave velocity of clean ballast is 156.4 m/s and 169.4 m/s for above vacuum levels. Ahlf (1975), Narayanan et al. (2004) and Suiker et al. (2005) have also reported shear modulus of fresh ballast. The top layer of the section 8 has an average SWV of about 148 m/s, which corresponds to clean ballast having a bulk density of 1.66 ton/m³. An average SWV of 135 m/s corresponds to the second layer of clean ballast having a bulk density 1.59 ton/m³. The average SWV of 115 m/s and 103 m/s corresponds to the capping layer and sub grade layer below the ballast layer. Below the sub-grade the SWV values increase because of the concrete floor under the model track.

Shear wave velocity obtained for clean ballast is well comparable with Bei (2005) results

RESULTS OF MODEL TRACK
The shear wave velocity of model track sections 1 to 9 was determined by averaging three sets of results, which had a standard deviation of less than 9. The average shear wave velocity of clean ballast and fouled ballast are given in Table 1 column 4. Shear wave velocity of section 6 is slightly less than section 8, which may be due to the difference in the densities (see Table 1). From Table 1 it can be observed that the SWV of fouled ballast is more than that of the clean ballast for lower percentage of fouling and less than clean ballast for higher percentage of fouling. The slightly higher shear wave velocity in coal fouled ballast in lower percentage of the fouling may be attributed by the particle size the coal (See Figure 1). However, a higher degree of fouling with coal leads to a lower shear wave velocity.

Table 1: Sectional detail with degree of fouling and densities of model track.

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Fouling percentage</th>
<th>Density (ton/m³)</th>
<th>SWV (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ballast+ Coal</td>
<td>4.94</td>
<td>1.675</td>
<td>141.24</td>
</tr>
<tr>
<td>2</td>
<td>Ballast+ Coal</td>
<td>11.51</td>
<td>1.807</td>
<td>148.78</td>
</tr>
<tr>
<td>3</td>
<td>Ballast+ Fine Ballast</td>
<td>20</td>
<td>2.017</td>
<td>142.75</td>
</tr>
<tr>
<td>4</td>
<td>Ballast +Clayey sand</td>
<td>19.35</td>
<td>2.096</td>
<td>142.0</td>
</tr>
<tr>
<td>5</td>
<td>Ballast +Clayey sand</td>
<td>8.76</td>
<td>1.753</td>
<td>137.69</td>
</tr>
<tr>
<td>6</td>
<td>Clean Ballast-I</td>
<td>0</td>
<td>1.587</td>
<td>125.0</td>
</tr>
<tr>
<td>7</td>
<td>Ballast +Clayey sand</td>
<td>32.43</td>
<td>1.899</td>
<td>125.29</td>
</tr>
<tr>
<td>8</td>
<td>Clean Ballast-II</td>
<td>0</td>
<td>1.636</td>
<td>155.00</td>
</tr>
<tr>
<td>9</td>
<td>Ballast +Coal</td>
<td>20.64</td>
<td>1.770</td>
<td>100.53</td>
</tr>
</tbody>
</table>

If the fouling material fills all the ballast voids and the ballast is also in good contact with each other, the corresponding degree of fouling can show a maximum strength/SWV. These phenomena can also be observed in Figure 1. The point corresponding to highest shear wave velocity because of ballast fouling, this can be called as the optimum fouling point (OFP). OFP of coal-fouled ballast is 8% and clayey sand is 15%. Beyond this peak point, the shear wave velocity decreases. Even though the SWV of fouled ballast decreases after the OFP, it is greater than the SWV of
A shear wave velocity of 0.07 m was obtained. Shear wave velocity of 150 m/s for location 2 and 173 m/s for location 2 up to track are shown in Figure 2. Average shear wave velocity profiles obtained from both the locations in the up sliding track as discussed previously. Typical shear wave velocity used for dispersion analysis to extract shear wave velocity from the subsurface is more than 180 m/s for both the locations indicating good sub ballast and sub-grade. Here it can be noted that both field ballast shear wave velocities are much more than model track shear wave velocities. In order to find out the degree of fouling in the up sliding field track, ballast samples were collected and tests were carried out in the laboratory.

PERMEABILITY AND SHEAR WAVE VELOCITY

The shear wave velocity gives an idea about the boundary for the optimum and critical degree of fouling. The SWV is indicative of only the strength of ballast foundation. In order to sustain good track performance, it is essential to maintain proper drainage conditions in the ballasted track apart from strength. The combined results of strength and permeability/Hydraulic conductivity are not available in the literature for the fouled ballast samples. Many studies have reported that the increase in the degree of fouling leads to the decrease in permeability in the field track and there by reducing the track resilience modulus, leading to growth of vegetation and reduction in performance. Permeability of fouled ballast of $10^{-4}$ m/s and less is unacceptable (Selig and Waters, 1994). Degree of fouling was related to permeability of track ballast (Selig and Waters, 1994). In this study the degree of fouling is related to SWV of fouled ballast. Anbazhagan et al (2010) has compiled permeability of clayey sand fouled ballast and coal-fouled ballast from experimental studies at University of Wollongong, Australia. More discussions on permeability can be found in Anbazhagan et al (2011a and 2011b).

INDIAN BALLAST GRADATION

Very limited literature or studies are available in ballast fouling and its related research in India. In order to understand the problem in Indian rail tracks an attempt has been made to study the dimensional requirements of particle size distribution (grading) and particle shape by collecting different aged track ballast samples from the field. Figure 2 shows gradation of ballast collected from different tracks in Bangalore along with modified gradation suggested by Indraratna and Salim, (2005). It can be noticed that after several years Indian ballast gradation is coarser than a modified gradation suggested by Indraratna and Salim, (2005), which means that resilience of Indian (course gradation) ballast is lower than that given by Indraratna and Salim (2005). The new (clean) and old (fouled) ballast gradation followed in Indian railway is poorly graded and more favorable for drainage criteria and may not be favorable for the other important factors like track stability, settlement and breakage of ballast. More information and discussion on the Indian railway ballast and comparison of Indian railway ballast with other country’s railway ballast can be found in Anbazhagan et al (2011a).
CONCLUSIONS

Model track has been constructed with different fouling material and degree of fouling. MASW survey had been carried out in model track and shear wave velocity has been measured. Shear wave velocity of clean ballast is found to increase due to the addition fines (fouling) and reach peak and then decrease below that of clean ballast. Two degree of fouling points has been defined, degree of fouling corresponding to peak SWV which is defined as the optimum fouling point and degree of fouling at which SWV of the fouled ballast equals the SWV of clean ballast which is defined as the critical fouling point. Variation of SWV with degree of fouling is similar to the typical compaction curve of soil. SWV of fouled ballast after reaching optimum fouling point decreases irrespective of fouling materials. Rate of decrease is more for coal fouled ballast compared to clayey sand fouled ballast. The SWV of the field samples are much more than that of model track sample for similar degree of fouling, which may be attributed to the sleeper confinement in the field track. More field studies may be needed to confirm the model track SWV values and pattern. Shear wave velocity obtained from MASW can be used to identify the track conditions.

Indian ballast gradation and fouling were evaluated to assess Indian railway track condition. Ballast gradation analysis shows that Indian ballast has larger particle size, which is poorly graded when compared to American and Australian railways. Indian railway ballast gradations are comparable with British and French railways gradation. Ballast gradation followed in India differs much from the modified gradation followed in Australia. Degree of fouling in Indian ballast increases with increase in the age of the track. The ballast gradation followed by Indian railways is poorly graded and favorable for drainage. Fouling measurements and identification in India is in infant stage with limited research.

REFERENCES