EVALUATION OF THE FOULING CONDITIONS, MECHANISM AND STRENGTH CHARACTERISTICS OF THE FOULED RAILWAY BALLAST OF BANGLADESH- A CASE STUDY

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ABSTRACT

Ballast is the most frequently used structural component of ballasted railway tracks that acts as a layer of free-draining media and provides tensionless elastic support for resting sleepers. However, during service life, the ballast becomes fouled and fails to perform as desired. The presence of fine particles(fouling materials) in the railway ballast alters the original particle size distribution, thereby deteriorating the performance of the ballast. Highly fouled ballast needs to be either cleaned or replaced to restore the expected track resiliency, load-bearing capacity, drainage facility and track geometry. so, it is important to identify the ballast fouling intensity, sources and characteristics of fouling materials along with their effect on the performance of the railway ballast. For the present study, six numbers of fouled ballast samples are collected from the three locations of the running track of Bangladesh Railways. First, the field identification of the samples is made according to the survey and laboratory tests with the assessment of the fouling conditions and the characteristics of the fouling materials. Based on the results of field identification, two 1/5th scaled samples are simulated to replicate the gradation and properties of the field samples, one represents fouling materials with plastic and other non-plastic properties. After that compaction tests and a series of consolidated drain cyclic triaxial tests are performed considering the consistency properties of the fouling materials and moisture content. The field investigation indicates that four samples out of six are highly fouled containing both plastic and non-plastic fouling materials. Surface infiltration and sub-grade intrusion are identified as the main source of fouling on the selected track. The reasons behind the lower contribution of ballast degradation in fouling are identified as the lower train speed, lower axel load, fewer frequencies and the high strength of Bangladesh Railway ballast grading. The result of the compaction tests indicates, that the samples with non-plastic fouling materials exhibit better compaction properties and attain higher maximum dry density than the samples with plastic fouling materials at lower optimum moisture content. Triaxial test results indicate the consistency properties of the fouling materials, moisture content, and stress level significantly affect the strength and deformation characteristics of the fouled railway ballast. The present study reveals that fouled ballast with plastic properties has lower strength and stiffness, and the situation worsens in the presence of moisture which needs to be taken care of, with priority.

Keywords: *Ballasted Railway Track, Ballast Fouling, Fouling Materials, Fouling Index, and Cyclic triaxial test.*

1. INTRODUCTION

Ballast is the most frequently used structural component of ballasted railway tracks that acts as a layer of free-draining media and provides tensionless elastic support for resting sleepers. This layer comprises uniformly graded crushed stone, gravel, moorum, or any other granular material placed and packed below and around sleepers for distributing the load from sleepers to the formation. It provides drainage along with longitudinal and lateral stability to the track (Chandra and Agarwal, 2013). According to Indraratna, Tennakoon, Nimbalkar, and Rujikiatkamjorn(2013), ballast is a commonly used structural component of ballasted railway tracks for its economy, high load-bearing capacity, resiliency, and good drainage properties. However, in the course of service life, ballast gets fouled by mixing with fines come from different sources as shown in Figure 4. Fouling is a major cause that controls ballast strength and settlement characteristics, sand and fine gravel-sized fouling materials sometimes increase the shear strength and resistance to plastic strain due to the formation of broadly graded mix with better compaction properties (Seilg& water, 1994). On the other hand, the shear strength can be reduced with the presence of fines such as clay and silt by reducing the internal friction of coarse aggregates (Indraratna, Tennakoon, Nimbalkar, and Rujikiatkamjorn, 2013). According to Ebrahimi at el. (2012), the mechanical properties of railway ballast (e.g., vertical plastic deformation, resilient or elastic deformation, and particle deterioration) continuously alter during the whole service life of ballast because of moisture variation, loading condition, and generation and accumulation of fouling material. Ballast fouling can create several detrimental effects on the railway track structure, demanding the need to understand and mitigate the fouling process. Increased ballast settlements were reported by researchers when the amount of fouling material in ballast increased (Ebrahimi, Tinjum, and Edil, 2012; Chiang, C. C.,1989; Han, and Selig, 1997).The performance of ballast becomes much worse when fouling materials have plastic properties compared to non-plastic fouling materials- granular properties and the characterization (plasticity, grain size, etc.) of fouling materials become an important factor for the determination of track performance and maintenance requirements (Li, Hyslip, Sussmann, and Chrismer, 2106). Again, in the presence of high moisture content, the excess fines in ballast may lead to the generation of surplus pore water pressure which will threaten the overall track stability (Nimbalkar, Tennakoon and Indraratna, 2015). Highly fouled ballast needs to be either cleaned or replaced to restore the expected drainage, track resiliency, load-bearing capacity, and track geometry(Indraratna at el., 2013). According to Nimbalkar at el. (2015), the understanding of the mechanisms of ballast fouling and particle breakage is vital for improved design and cost-effective maintenance of ballasted railway tracks. So, it is important to identify the sources, quantification of ballast fouling, and the characteristics of fouling materials along with their effect on the strength and deformation behaviour of the railway ballast. Therefore, in this study attempts are made to understand the concept of ballast fouling and to explore the fouling condition, sources and properties of the fouling materials of the railway ballast of Bangladesh along with characteristics of the fouled ballast considering properties of the fouling materials and moisture variations.

2. BALLASTED RAILWAY TRACK SYSTEM

A ballasted railway track consists of two main components: the superstructure and the substructure. The most important parts of the track as the rails, fastening system and the sleepers are referred to as the superstructure. The substructure is associated with a geotechnical system consisting of ballast, sub-ballast and subgrade (formation). For safety, the comfort of passengers and the quality of the ride, both superstructure and substructure are mutually important (Kaewunruen and Remennikov,2008). **Error! Reference source not found.** represents the shape and the components of a conventional ballasted track. The geotechnical component of rail track i.e. ballast bed plays an important role in maintaining the gauge between sleepers and thereby the alignment of the rails. Defects in the ballast bed may lead to settlements and deformation of the ballast section, which in turn leads to distorting the geometry of the railway track. (Anbazhagan, Bharatha, and Amarajeevi, 2012). According to Selig and Water (1994), the ballast contributes the major portion of track settlement, compared to sub-ballast and subgrade as shown in Figure 2.

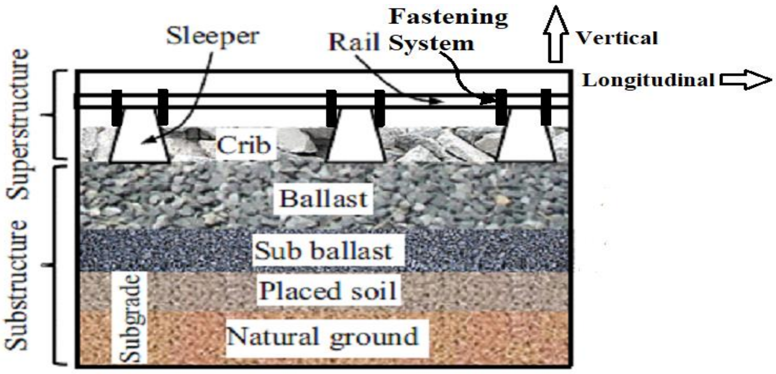


Figure 1: Schematic diagram of the typical ballasted railway track (Modified after Kumara & Hayano, 2016)

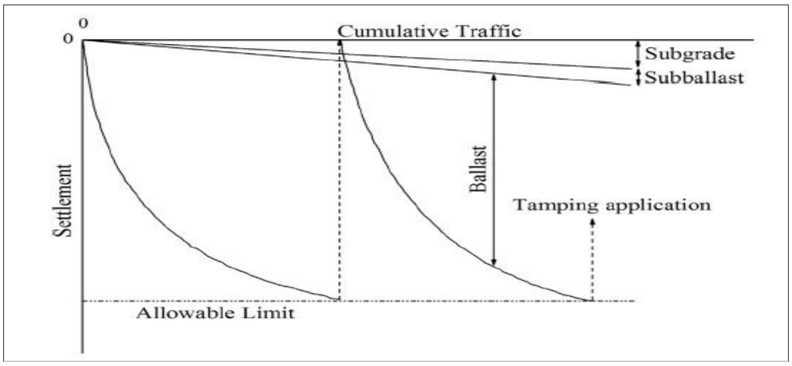


Figure 2: Substructure contributions to settlement (Kumara and Hayano, 2016 after Selig and Waters, 1994).

3. BALLAST FOULING, MECHANISM AND QUANTIFICATION

Ballast fouling is a problematic track condition due presence of undesirable fines in the ballast layer which hinders the designed performance of the ballast. Anbazhagan, et al. (2012), opine that ballast contamination or the filling of void space with fine from ballast breakdown and infiltration of other materials from the ballast surface or intrusion from the subgrade layer is called ballast fouling. Fouling reduces the friction angle of the granular assembly leads to differential settlement of the track, as well as decreases the load-bearing capacity. The fouling materials ultimately lead to loss of contact between the large ballast particles and eventually contribute towards ballast settlement because of unstable track support conditions and a heavily fouled ballast situation, resulting in the loss of ballast strength and hence compromising the stability of the railway track (Huang, Tutumluer, and Dombrow, 2009)

3.1 Ballast Fouling Mechanism

Railway ballast gets fouled through the breakdown of ballast due to mechanical forces, ballast degradation (fine particles that migrate downwards), coal/iron ore from the railcars, dust from surroundings- naturally occurring: dust, dirt, plant life decay etc., traction sand-slurried (pumped) formation soil (soft clays and silts liquefied under saturated conditions), brake shoe dust, diesel soot and railroad maintenance practices. Typical fouling and fouled ballast sections of the rail track are shown in Figure 3. Figure 3(a) shows infiltrations of fines due to the breakdown of ballast and fines from railcars, surrounding area migrates from top to bottom. In this case, the subgrade will be hard (and provided with a sub-ballast layer) enough so that fines will be accumulated in the base of the ballast layer as shown by the arrow. On the other hand, rail track with soft soil subgrade (and without subballast layer) induces fouling from the top as well as from the bottom as shown in Figure 3(b). In such a case, the rate of fouling and amount of fouling will be much more than the previous case and this is the worst fouling condition.

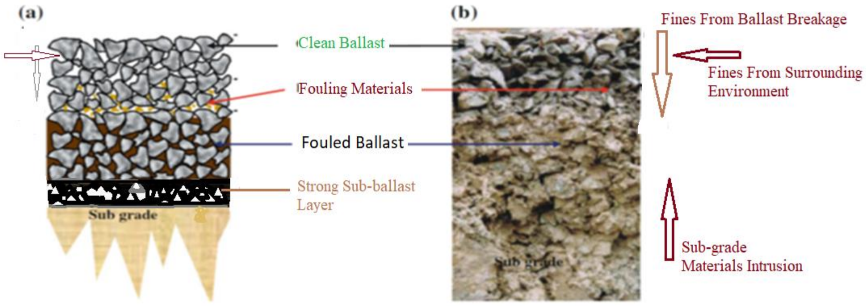


Figure 3: Typical fouled ballast sections. (a) Fouling due to migration from the top and (b) fouling due to infiltration from the base and migration from the top (Modified after Azhabaghan et al., 2012)

According to Selig and Waters (1994), ballast fouling was caused through five primary modes:

- Abrasion and breakdown of ballast due to rail loading, tamping, and freeze/thaw
- Degradation of rail ties
- Migration of subgrade material into the ballast layer
- Migration of sub-ballast or subgrade material into the ballast layer
- Migration of environmental material into the surface of the ballast

These five ballast fouling mechanisms can be grouped into three general categories as reported by Bailey (2011) is shown in Figure 4.

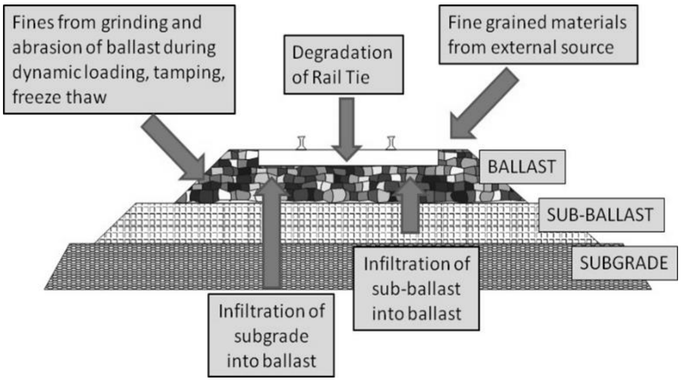


Figure 4: Possible modes of ballast fouling (Bailey, 2011)

3.2 Ballast Fouling Quantification

Quantification of ballast fouling is a unique problem in geotechnical engineering because of the presence of dissimilar materials that are represented in a single value. Ballast fouling results due to the mixing of several distinct materials having a large variation in particle size, particle shape, and specific gravity. Researchers have proposed several fouling indices to categorize ballast fouling severity based on parameters obtained from either field or laboratory investigations (Anbazhagan at el., 2012 and Bayley, 2011). Selig and Waters (1994), is the pioneer in the field to propose the first quantitative fouling index for North American rail ballast considering clay pumping and the infiltration of foreign materials as the other major sources of fouling which include objects delivered with the ballast, dropped from trains, or wind and water-blown matter.

$$\text{Fouling Index (FI)} = P_{4.75} + P_{0.075} \quad (1)$$

where $P_{4.75}$ and $P_{0.075}$ are percent by the weight of ballast sample passing 4.75 mm sieve and 0.075 mm sieve. However, for this study in the case of 1/5th scaled fouled ballast samples this formula is rearranged as:

$$\text{Fouling Index (FI)} = P_{0.95} + P_{0.015} \quad (2)$$

Indraratna, Su, and Rujikiatkamjorn (2011), introduce the Relative Ballast Fouling Ratio (RBFR), with the view to overcome the shortcoming of the Fouling Index and Percentage Void Contamination (PVC). The defining equation of RBFR is given by,

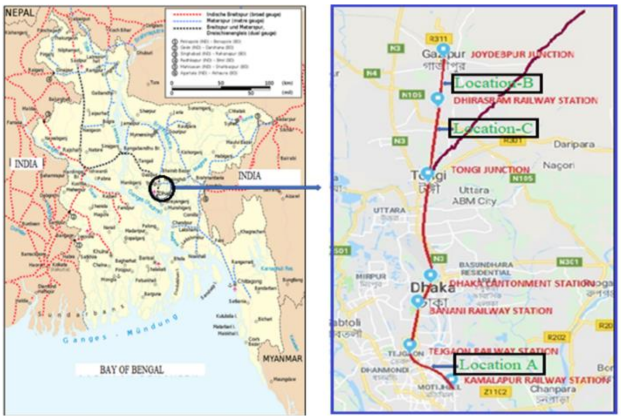
$$R_{b\text{-}f} = \frac{Mf\left(\frac{Gb-f}{Gs-f}\right)}{Mb} \times 100\ldots \quad (5)$$

Where, $R_{b\text{-}f}$=Relative ballast fouling ratio, M_f=Mass of ballast fouling materials, $G_{b\text{-}f}$= Specific gravity of ballast fouling materials, M_b=Mass of ballast and $G_{s\text{-}f}$= Specific gravity of ballast.

4. FIELD IDENTIFICATION

The railway track near Dhaka, Dhaka-Tongi, and Tongi-Joydebpur sections were nominated for the study due to the importance of the track and the feasibility of sample collection. After a careful survey, disturbed fouled ballast samples from three selected locations were collected. A total of six numbers of fouled railway ballast samples were collected from the running track of the Dhaka-Tongi and Tongi-Joydebpur sections of the Bangladesh Railway as shown in Figure. Since the deep cross-sectional trench used by Wenty (2005), is not feasible in the case of busy-running railway tracks. So, hand excavated shallow test pits like Brough, Stirling, Ghataora, and Madelin(2003), are used for sample collection in the present study. The situation of sampling, position, physical appearances and surrounding environment of fouled ballast collected from the railway track is shown in

Figure 5, Figure 6 and Figure 7. Each of the collected samples was stored in a separate bag, marked previously. The samples collected from the railway track are carried to the laboratory for performing grain size analysis, density, and consistency tests following ASTM standards. The grain size distribution curve of the field samples are plotted with the gradation limits of Bangladesh Railway and Japan are shown in Figure 8. From the figure it is quite clear that all six samples are fouled because their particle size distribution curve exits the boundary limits. Consistency characteristics of the fouling materials have both plastic and non-plastic properties. Samples of railway track A and C are non-plastic whereas samples, FB-3: B-S, and FB-4: B-R of location B has shown plastic property, with plasticity index of 21.6 and 28.3 respectively as shown in Table 1.



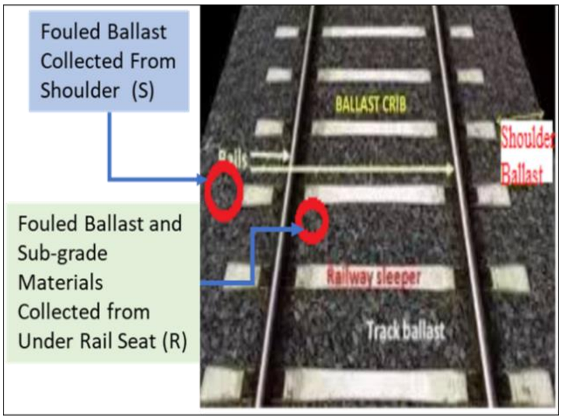


Figure 5: Sampling location and position.

(a) Sampling Location A

(b) Sampling Location B

(c) Sampling Location C

(d) Location A

(e) Location B

(f) Location C

Figure 6: Situation of sampling and surrounding environment

(a)Fouled ballast sample

(b) Polythene (FB-1: A-S & A-R)

(b) Fouled ballast over 4.75mm

Figure 7: Air-dried fouled ballast, Polythene and fouled ballast over 4.75mm size

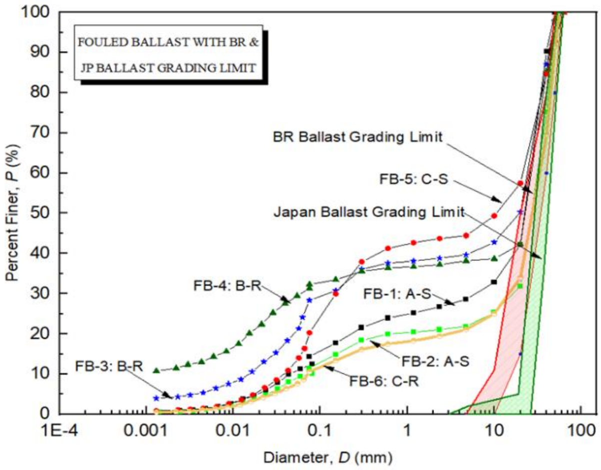


Figure 8: Fouled ballast gradation curves with Bangladesh Railways and Japan gradation limits

Table 1 Consistency and fouling characteristics of scaled fouled ballast samples (Fouling materials)

Samples	Location & Depth from Sleeper top	Sample type	Liquid limit, w_L (%)	Plastic limit, w_p (%)	Plasticity index, *PI*	Fouling index	Relative ballast fouling ratio(RBFR)
FB-1: A-S	A 340 mm	Fouled ballast	Non-Plastic			43.0(H.fouled)	37.7 (Fouled)
FB-2: A-R						33.4 (Fouled)	26.9 (Fouled)
FB-3: B-S	B 340 mm		36.8	15.2	21.6	68.0(H. fouled)	64.8(H.fouled)
FB-4: B-S			45.4	17.1	28.3	70.5(H. fouled)	59.4(H. fouled)
FB-5: C-S	C 340 mm		Non-Plastic			64.7(H.fouled)	80.7(H. fouled)
FB-6: C-R						31.7 (Fouled)	27.7 (Fouled)

In the case of railway track A, fouling material contains mainly sand and silt (Table 2). Polythine is also seen found in track which is very rare instance in railway track (Figure 7 (b)). During survey and sample collection it has been revealed that the railway track of that area is surrounded by slums, grocery and fish markets, as well as railway track level is lower than the adjacent area (Figure 6 (a,d)). As the level of the area beside the railway track rises continuously with the activities of people, so to keep the track dry, ballasting in that area is frequently done along with the spreading of sand when the ballast becomes scarce. So the silt and sand portion of the fouling material is the contribution of human activities, water flows from side to side of the railway track, which carries silt from surroundings and sand spreading by BR which entered through ballast surface infiltration. Going up to a depth of 100 cm, a continuous fouled ballast layer was discovered. For railway track B, activities of people around this area are low along with good drainage facility as low land exist on either of the track (Figure 6(b,e)), but there was no sub-ballast layer as a result clayey sub-grade soil intrusion was responsible ballast fouling in that portion of the railway track. Intact brick chips sub-ballast layer was revealed in railway track C, with no red mark on the upper ballast layer chancel chance of sub-grade intrusion in this particular location of railway track. The environment of surroundings indicates rainwater flows from one side to the other side of the embankment through the railway track meaning silty clay of the area inter into the ballast by infiltration of the ballast surface. Again, the sharp angular shape of the collected six field ballast samples indicates less contribution of the ballast degradation in fouling rather than ballast surface infiltration mainly responsible for fouling in the case of railway tracks A, C, and sub-grade materials intrusion is the case of railway track B. The reasons behind the lower contribution of ballast degradation in fouling which is identified as the major cause that contributes about 76% of ballast fouling in North American railway tracks as reported by Selig and Water (1994), are the less train speed (average 70 km/hr), lower axel load (13 ton), fewer frequencies and the high strength of BR ballast grading. According to Bayley

(2011), sources depend on fouling mechanisms which differ by several factors, including; ballast grain size and characteristic specifications, rock types of ballast, embankment geometry, types and loading weights of trains, speed of trains, frequency of trains, maintenance practices, weather conditions and climate, surrounding land use (forest, fields, urban area).

Table 2: Constituents of the fouling materials

Types		Particles Size range (mm)	Fouling Materials					
			FB-1: A-S	FB-2: A-R	FB-3: B-S	FB-4: B-R	FB-5: C-S	FB-6: C-R
Sand	Coarse	4.75 to 2.00	7.70%	4.50%	2.40%	2.80%	2.20%	9.01%
	Medium	2.00 to 0.425	12.60%	7.80%	4.20%	2.80%	8.00%	11.21%
	Fine	0.425 to 0.075	29.30%	35.20%	22.14%	9.70%	42.50%	27.60%
	Total		49.60%	47.50%	28.74%	15.30%	52.70%	47.81%
Silt		0.075 to 0.005	44.30%	45.20%	53.06%	38.90%	42.10%	44.29%
Clay		<0.005	5.10%	5.30%	14.40%	31.70%	3.50%	5.50%
Colloid		<0.001	1.00%	2.00%	3.80%	14.10%	1.70%	2.40%
Total			100 %	100 %	100 %	100 %	100 %	100 %

5. GRADATION AND MATERIALS SELECTION FOR COMPACTION AND TRIAXIAL TEST

According to the properties of the field samples, two 1/5th scale samples are considered for the next part of the study. As there were plastic and non-plastic properties in the fouling materials of the field samples, two samples with close gradation curves were targeted to simulate, one to reflect plastic properties other for non-plastic of the fouling materials. Scaled fouled ballast samples with plastic property, SFB-1(P) and with non-plastic property, SFB-2(NP) were prepared with aggregates, Natom sand, Kasaoka clay, F-2.5, and AO clay in the proportion, with the shape of gradation curve as shown in **Error! Reference source not found.** and **Error! Reference source not found.** respectively.

Table 3 Constituents and properties of the scaled samples

Scaled fouled ballast samples	Constituent materials	Consistency		Fouling index considering 1/5th scale
SFB-1:P	Aggregates (53.48%)	Non-plastic	w_L=48.0, w_p=23.4, I_p=24.6	65.6
	Natom sand(13.58%)	Non-plastic		
	Kasaoka Clay(32.94%)	w_L=60.4%, w_p=26.0%		
SFB-2:NP	Aggregates(57.60%)	Non-plastic	Non-plastic	63.1
	AO Clay (20.13%)	w_L=40.5%, w_p=23.7%		
	F-2.5 above 0.075 mm(5.28%)	Non-plastic		
	F-2.5 below 0.075 mm(16.99%)	Non-plastic		

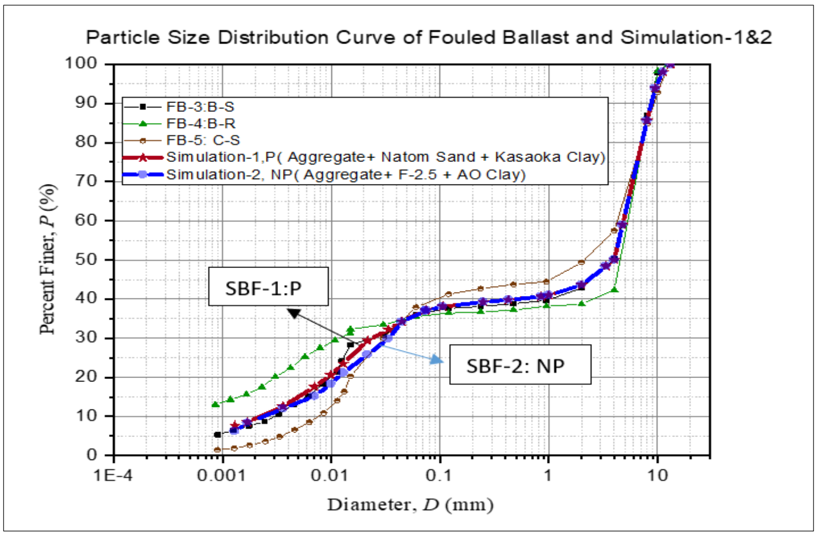


Figure 9 Grain size distribution curve of 1/5th scaled fouled ballast samples, targeted samples, SBF-1:P and SBF-2: NP.

6. COMPACTION AND TRIAXIAL TEST

The compaction and triaxial tests were performed with 1/5th scale fouled ballast samples to investigate the compaction, strength, and deformation characteristics considering properties of the fouling materials, moisture content etc.

6.1 Compaction Test and Effect of Consistency Property on The Compaction Characteristics

First, aggregates, Natom sands, stone dust (F-2.5), AO clay, and Kasaoka clay were taken by measured weight and mixed to a fixed proportion to get targeted fouled ballast samples (SFB-1: P & SBF-2:NP) with desired gradation and consistency characteristics. The test was performed according to JGS 0711/JIS A1210 and A-a method was used however, a mechanical compaction rammer was used instead of a hand rammer.

The non-plastic scaled fouled ballast sample, SFB-2 (NP) exhibits better compaction properties than the plastic ballast sample, SFB-1(P) as shown in Figure 10. The maximum dry density of SFB-2, $\rho_{d\ max}$=2.04 g/cm^3 is higher than that of SFB-1(P), $\rho_{d\ max}$=1.84g/cm^3 at a lower optimum moisture content that has been obtained during the compaction test. One of the reasons for the better compaction properties of the non-plastic sample is the higher percentage, 22.28% of stone dust (F-2.5) used to prepare that sample. The laboratory test results aligned with the findings of Agarwal (2015), which indicate that the maximum dry density of soil increases and optimum moisture content decrease with the increase in the percentage of stone dust. Furthermore, Sabat (2012), made a series of tests mixing stone dust with expansive soil and concluded that the addition of quarry/stone dust decreases liquid limit, plastic limit, plasticity index, optimum moisture content, cohesion of soils and increases shrinkage limit, maximum dry density, angle of internal friction of the soil. Again, sample SFB-1(P) contains a high percentage of clay (32.94%) that promotes occupying more space as a water film forms around the clay particles, and subsequently, less dense arrangement occurred which resulted in the low dry density.

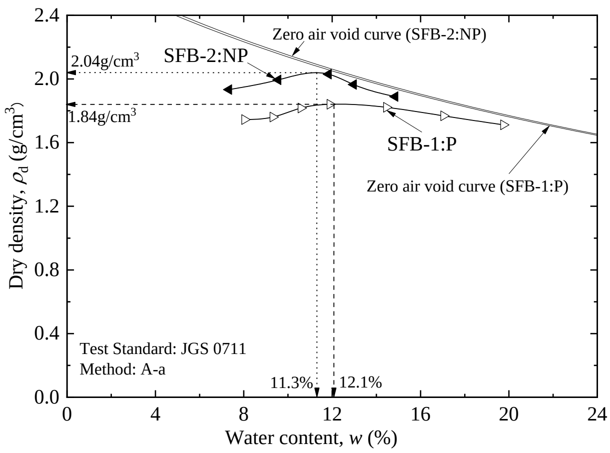
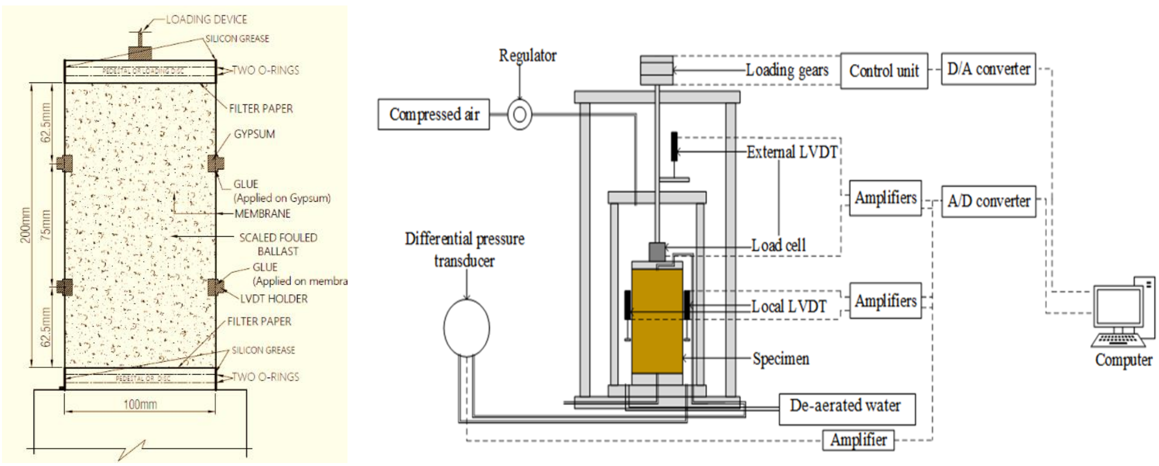


Figure 10: Compaction curves of scaled fouled ballast samples

6.2 Triaxial Test Process and Test Condition

Samples SFB-1(P) and SFB-2(NP) are prepared with the materials as mentioned in the Table 3 and water sprayed to attain a degree of saturation as shown in These wet samples are compacted in a mould of 100 mm inside diameter and 200 mm height to achieve the required dry density and compaction (Table 4). The samples are then arranged on the pedestal of the triaxial machine with LVDTs and other components as shown in Figure 11. The samples were consolidated with isotropic cell pressure of 30kPa in drained conditions. The test was conducted by strain control procedure and the loading rate of 0.125 % strain per minute was used. Local Strains were measured by LVDT reading which was calibrated beforehand for each test. Pre-programmed computer software Lab View with imputing related data and parameters was used to control the test and get output data. A schematic diagram of the test process is shown in Figure 11. After the consolidation, the samples were pre-loaded with 0- 40 kPa deviator stress for 200 cycles. Then the main load was applied with an 80 kPa increase in steps for the 500 cycle cycles in each step repeatedly done until the failure of the specimen. The applied load cycle is shown in Table 4.



(a) Sample arrangement (b) Schematic diagram

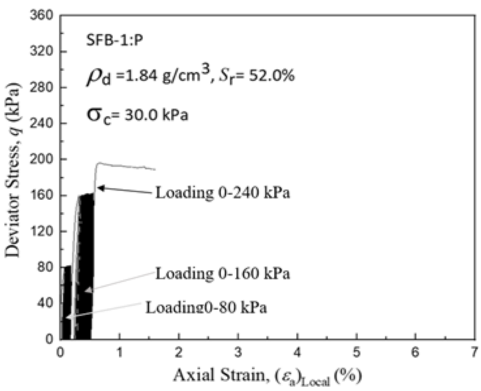
Figure 11 Sample arrangement and schematic diagram of the cyclic triaxial test process.

Table 4 Test condition and cases

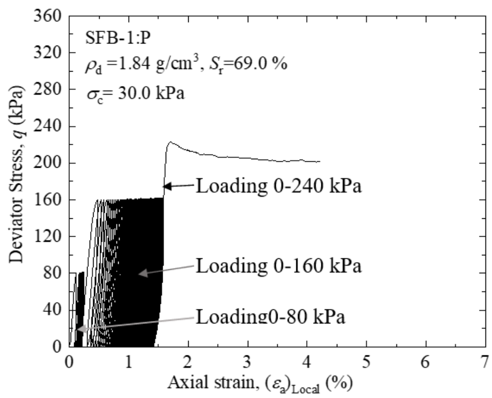
Samples and test cases	Dry density, ρ_d (g/cm^3)	Degree of Saturation,Sr(%)	Deviator Stress (kPa)	Number of Load Cycle	Comments
SFB-1:P 3 tests case	1.84	52.0	0-80	500	80 kPa load was increased in each step up to the failure of the specimens
		69.0	0-160	500	
		85.0	0-240	500	
SFB-2:NP 2 test case	2.00	63.0	0-320	500	
		85.0			

6.3 Triaxial Test Results and Discussion.

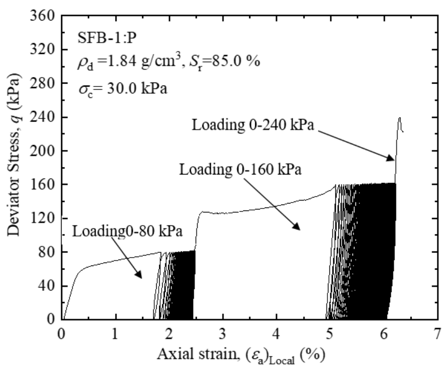
Cyclic triaxial test results indicate that fouled ballast samples with non-plastic fouling materials have higher strength than samples with plastic fouling materials. With a similar degree of saturation 85%, q_{max}=315 kPa for SFB-1:P and that value for SFB-2:NP is 239.24 kPa. Again, sample SFB-2:NP) has higher stiffness properties than SFB-1:P, experienvce lower strain even at higher stress (Figure 12 and Figure 13). Reasons of higher strength of SFB-2:NP are the combined effect of compaction characteristics and non-plastic consistency properties. The results indicate that the response to water of the sample contains non-plastic fouling materials are less hence exhibit higher strength and stiffness property than that of the sample with plastic fouling materials. Considering the case of both the samples with the same degree of saturation, S_r =85.0%, axial strain in every stage is much higher for SFB-1:P than that of SFB-2: NP and SFB-1:P fails after two-stage of loading (total 1000 cycles, q_{max}=239 kPa), whereas SFB-2: NP stands for three-stage of loading (more than 1500 cycles, q_{max}=320 kPa), indicating non-plastic fouling materials has less effect on the strength and stiffness of railway ballast even in presence of moisture content (Figure 12 and Figure 13).



(a) S_r= 52%

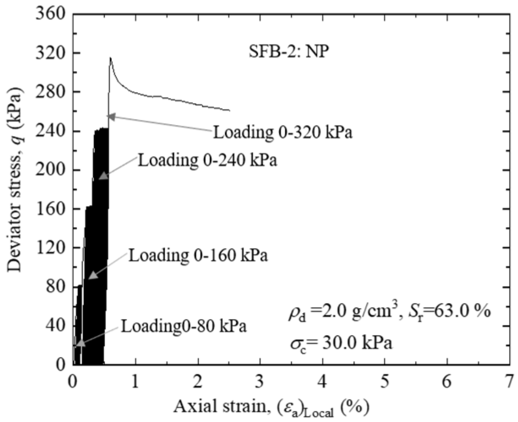


(b) S_r = 69%

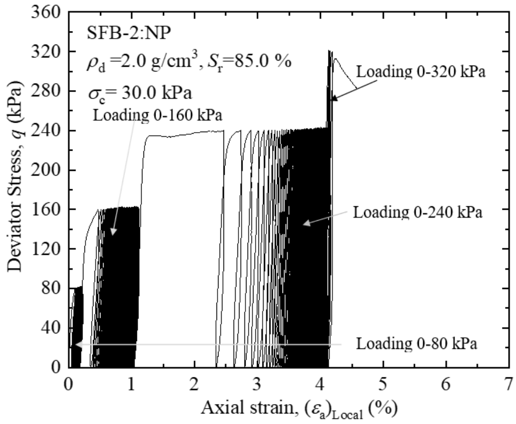


(c) S_r= 85%

Figure 12: Local axial strain and deviator stress relationships of the sample SFB-1:P



(a) S_r= 63%



(b) S_r= 85%

Figure 13: Local axial strain and deviator stress relationships of the sample SFB-2:NP

7. CONCLUSION

This study aimed to investigate the fouling condition, sources of fouling, compaction and strength characteristic of the fouled railway ballast of Bangladesh which involves field investigation along with laboratory tests. A total of six numbers of disturbed fouled ballast were collected from three different selected locations of the running track of the Bangladesh railway and tested in the laboratory for grain size, specific gravity, and consistency. According to the findings of the field identification, two 1/5th scaled fouled ballast samples were prepared to replicate the gradation, properties, and fouling characteristics of the field samples. Compaction tests and consolidated drained cyclic triaxial tests with multi-stage loading (along with varying water content and deviator stress) were performed with those samples. The investigation yields the following conclusions:

i. The fouling materials contain both plastic and non-plastic properties.
ii. Sub-grade intrusion and ballast surface infiltration are identified as the main source of ballast fouling rather than ballast breakage.
iii. The non-plastic fouled ballast sample exhibits better compaction properties than the ballast sample with plastic fouling materials and attains higher maximum dry density at a lower optimum moisture content.
iv. The consistency properties of the fouling materials, degree of saturation, and deviator stress have significant effects on the strength and deformation characteristics of the fouled railway ballast. The fouled ballast with the plastic property has lower strength and stiffness, the situation worsens in the presence of water which needs to be taken care of, with priority.

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