ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

INVESTIGATION OF BALLAST DEGRADATION ON SEBETA- ADAMA RAILWAY LINE

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A RESEARCH SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN RAILWAY ENGINEERING (CIVIL INFRASTRUCTURE)

NOVEMBER, 2021G.C

DECLARATION

I certify that thesis work titled "(Investigation of ballast degradation on Sebeta-Adama railway line.)" is my work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged/referred.

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ABSTRACT

Railway ballast is an important part of the track support structure. Knowing the extent (condition) and performance of the ballast is essential in the railway service in order to anticipate and prolong ballast life, hence decreasing maintenance costs and ensuring a good ballast layer. fouling is recorded as the main reason for ballasted track settlement and high maintenance costs and the main reason for fouling is ballast degradation The major goal of this thesis is to assess the level of ballast degradation on the Sebeta-Adama railway line, which is part of the Ethio-Djibouti Railway line and includes the sole double track segment with design speeds of (120 and 70)km/h for passengers and freight trains, respectively. For this study, eight locations were chosen based on access and the criticality of the area, all laboratory test material was collected along railway track at 8 distinct sites (chainages) at the stations of (02+800, 17+400, 35+00, 56+300, 67+687, 70+280, 93+500, 112+800). And the evaluation was conducted using laboratory tests such as sieve analysis, Los Angeles abrasion test, Flakiness and elongation Index, and Fouling index, as well as design and as-built data reviewed. Ballast particles are classified as flaky when they have a thickness (smallest dimension) of less than 0.6 of their mean sieve size, this size is taken as the mean of the limiting sieve apertures used for determining the size fraction in which the particle occurs. The ballast material grading is discovered within the designed range of 63-16 mm, standard sieves except at location 93+500, according to the test results. However, the materials going through each sieve are found to be above or below the specified limit in this range. The elongation and flakiness index of the particles also shows a considerable rise in flaky and elongated particles, indicating there is practice breakage. The findings of the fouling index test indicate that the ballast bed is relatively clean. According to the field inspection, the new materials used for ballast maintenance do not match the standards, and some of the crossing places are more susceptible to fouling from external sources. Because the line is intended for both freight and passenger trains, freight trains had not been operating for more than a year, implying that the loads applied to the track (ballast) were lower than the predicted operation load. Only track geometry conditions were used to maintain the line. That is, it does not reflect the mechanical state of the ballast or the possibility of ballast degradation. To minimize unexpected track breakdown owing to significant ballast degradation, a proper maintenance plan and investigation should be implemented.

Key terms: Ballast Degradation Railway

ACKNOWLEDGMENT

I would like to acknowledge Addis Ababa University African railway center of excellence for giving me the opportunity to undertake the research. I'd like to thank my advisor Dr. Ing. Henok Fikre and Mr. Ayele Tessema for their advice, encouragement, constant counsel, and innovative ideas in assisting me with my thesis. I'd also want to express my gratitude to the Ethio-Djibouti Standard Gauge Railway Share Company for providing me with the required route information. Finally, I'd want to thank my friends and family for their assistance during the study process.

APPROVAL PAGE

The undersigned have examined the thesis entitled "**Investigation of Ballast Degradation on Sebeta-Adama Railway Line in Ethiopia**" presented by Israel Tadese Irago (GSR/5494/12), submitted to African Railway Center of Excellence, Addis Ababa Institute of Technology, School of Graduate Studies in partial fulfillment of the requirement of the award of Degree of Masters of Science in Railway Engineering (Civil Infrastructure).

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ABBREVIATIONS

AAREMA	American Railway Engineering and Maintenance of Way Association.
AASHTO	American Association of State Highway and Transportation Officials
ABLL	As-built lower limit
ASUL	As-built upper limit
BS	British standard
Cu	Coefficient of uniformity
Cc	Coefficient of Curvature
DLL	Designed lower limit
DUL	Designed upper limit
FI	Fouling index
GPR	Ground-penetrating radar
LA	Los Angeles
LAA	Los Angeles abrasion test\
PSD	Particle size distribution
USCN	Unified soil classification

1. INTRODUCTION

1.1. Background

Railway ballast is a critical element in the railway track support structure. The ballast is often overlooked when inspection tools are developed for track. When the ballast is not functioning properly, the strength of the track structure may be inadequate and thus compromise track stability. The ability of a ballast layer to perform its intended functions is dependent on the ballast being free of fine-grained particles (fines). The process of fines accumulating within the ballast void space is referred to as ballast degradation (sometimes also referred to as ballast fouling) [1].

In railway track, repeated wheel loads transferred from sleepers to the ballast layer cause abrasion and degradation of ballast aggregates over time which contributes to the fouled (degraded) content in the ballast layer and alter the gradation. To predict and prolong ballast life thereby reducing maintenance cost and providing a good ballast layer knowing the degradation (strength) condition of the ballast is fundamental [2].

The main function of ballast is resisting the forces applied to the track and retaining the track in the required position for safety (Sussmann, Ruel, and Chrismer, 2016). Desirable ballast is angular stone material with a nominal size of approximately 0.75 to 2 in. and a uniform grain size distribution. Desirable ballast material is strong, hard, and durable crushed rock (aggregate) that does not readily deteriorate from applied loading, vibration, or environmental conditions or variations. This stone material will form a layer below and around the sides of the tie that provides direct vertical support and lateral stability. In this layer, the inter-particle contacts between ballast particles will be points at which each angular particle interacts with an adjacent particle to transfer applied load. These small contact points deform substantially under load to provide the high level of resilience common to clean ballast layers. The high loads involved and the small area of contact cause each ballast particle to deform substantially, potentially resulting in the fracture of particles or wear at particle contacts when the applied stress approaches or exceeds the strength[4,5].

Ballast resilience is obtained through the inter-particle ballast contact points that provide for substantial vertical and lateral elastic deformation as long as the ballast stress remains tolerable and the ballast does not break down. The desired resilience in a ballast layer is elastic, meaning that the deformation is recoverable and the ballast will return to the position it was before loading. Deformation of fouled ballast is most often inelastic, meaning the deformation is often only partially recovered with significant plastic (permanent) deformation. In these locations, the plastic ballast deformation results in track settlement and track geometry defects. According to Selig and Waters, the ballast layer is generally the largest source of track settlement. Ballast-related track settlement can affect as little as one tie in the initial stages, and short-wavelength track geometry parameters such as cross-level, short-wavelength profile, or short-wavelength warp can be the initial indication of track support problems. As the track is repeatedly loaded, another inelastic deformation mechanism may occur in the ballast.

Scholars [6,7] discussed the ballast layer functions of which the most important are:-

- Retain the track in its required position by withstanding vertical, lateral, and longitudinal forces applied to the sleepers
- Provide the required degree of elasticity and dynamic resilience to track superstructure
- Distribute stresses from the sleeper bearing area to acceptable stress levels for the underlying material
- Facilitate maintenance surfacing and lining operations by an ability to rearrange ballast particles with tamping
- Provide immediate drainage of water falling onto the track
- Provide sufficient voids for storage of fouling material in the ballast, and to accommodate the movement of particles through the ballast.

It is implied that the ballast must perform these tasks with tolerable degradation from load and environment, and must resist the external entry of fine particles such that maintenance and renewal cycles are acceptable. Experience has shown that good quality crushed rock, of volcanic origin, satisfies most of these requirements when properly installed and compacted [1].

The stability of the railway ballast is critical to the efficient performance of railway tracks. Ballast breakdown is inevitable under heavy load and heavy tonnage. However, when the ballast is kept clean from contamination and drains freely, the ballast breakage that develops might temporarily enhance stability by contributing to the interlocking of adjacent particles (Sussmann, Ruel, and Chrismer, 2016). However, the breakdown will occupy void space and potentially inhibit drainage and reduce ballast life. When ballast breakdown becomes contaminated with other ballast-fouling material, the common muddy fouled ballast problem develops as a result of the presence of silt and clay that can blow or wash into the track structure or be pumped or mixed from other track structural layers[8].

Sebeta-Adama Railway route is part of Ethio-Djibouti Railway line is a standard gauge ballasted railway line Constructed three years ago Using class II Chinese railway standards. The railway line is located in the central plateau of Ethiopia starting from Sebeta (South West of Addis Ababa) and stretching to Bishoftu, Mojo, and Adama). Sebeta-Adama railway route is the only double track and has a length of 115km. the design speed reaches 120km/h for passenger trains and 80km/h for freight trains. The ballast materials used for the track are produced from three quarries (Gelan, Bishoftu, and Adama) along the railway line. From Chinese standard, the ballast used for the line is class I Crushed stone. Passengers and freight trains have been operating on the line for around three years[9].

Therefore, this study is planned to investigate the degradation level of of the Sebeta-Adama railway line

1.2. Statement of the Problem

The primary component of ballasted track, on which maintenance is concentrated and which has a high contribution to the safety of the overall track is the ballast itself. Ballast must fulfill the two competing requirements of achieving high permeability for rapid drainage and high stiffness for spreading train loads efficiently to the sub-base. To ensure these two basic requirements keeping the ballast bed within its required strength and standard is fundamental[10].

From Many research and investigations[1,11,12], fouling is recorded as the main reason for ballasted track settlement and high maintenance costs and the main reason for fouling is ballast degradation. if the ballast degradation is known and prevented early immediate failures, accidents and frequent maintenances will be minimized. Since every track construction details and materials are unique degradation level, causes and mechanisms also became different so that for every railway line its investigation is needed. To predict & prolong ballast life, thereby reducing maintenance costs & attain effective maintenance daily and periodically deep investigation results are basic.

1.3. Objective

1.3.1. General objective

- The general objective of this study is to evaluate the current condition/level of the Sebeta-Adama railway line ballast condition and suggest ways to maximize ballast lifespan and minimize maintenance costs in the future.

1.3.2. Specific objective

- To evaluate the current condition/level of degradation in the Sebeta-Adama railway line ballast condition.
- To evalutate railway line ballast design requirements to suggest ways to maximize ballast lifespan of railways
- To forward recommondations to minimize maintenance costs in the future

1.4. Research questions

- How is the current degradation extent of ballast on Sebeta-Adama railway line?
- Does Sebeta-Adama railway line ballast meet the design requirements?
- What are methods to minimize the maintenance cost of Sebeta-Adama railway line ballast?

1.5. Significance of the Study

Researchers and practitioners can potentially benefit from the output of this research work. Among other things,

- Increasing awareness on the current degradation extent of ballast in railway line ballast as well as design requirements to suggest ways to maximize ballast lifespan of railways of railway ballast.
- To have a better understanding of indicators of degradation of railway ballast bed.
- To study essential techniques in studying inspection, testing, and maintenance of ballast bed.
- To understand the expected behavior potential degradation of the ballast layer before its repair or rehabilitation period.

1.6. Scope and Limitation of the study

This investigation is carried out for Sebeta–Adama railway line ballasted rail track which is found in Ethiopia using four types of laboratory tests and field inspection investigation methodologies. sampled locations for the inspection and laboratory tests are limited due to the accessibility of the line by car and time. Thus, the study is limited to a single line however multiple stations and locations.

2. LITERATURE REVIEW

2.1. Concept of Ballast

2.1.1. Definitions and blast layer

Ballast is derived from a nautical term for the stones used to support a ship during loading and transit [13]. Ballast is a granular substance that drains freely and is used as a load-bearing material in railway rails. It is made up of medium to coarse gravel-sized aggregates (10–60 mm) with a trace of cobble-sized particles[14]. According to the other source, ballast is a crushed granular substance that is deposited as the top layer of the substructure into which the sleepers are implanted. Crib ballast is inserted between the sleepers as well as in the shoulders above the sleeper ends [15].

This demonstrates to provide track stability; railway ballast is a crushed rock material put beneath the track superstructure and above the sub-ballast and subgrade. According to [16] ballast is a fundamental railroad track structural component that refers to the coarse rock particles put beneath track crossties and rail.

The ballast layer can be divided into four zones in constructed and operating track:

1. Crib ballast zones between the sleepers
2. Shoulder: the sloppy zone between the end of the sleeper and down to the top of sub-ballast
3. Top ballast: the top portion of the ballast structure which is usually exposed to tamping;
4. Bottom ballast: the bottom and lower part of the structure which supports the overall structure; depending on the quality of the sub-ballast material, loading condition, presence of water, and drainage property of the structure; it is the more fouled part of the structure than the rest of the structure. Only the top and bottom ballast distributes the load transmitted from a sleeper down to the sub-ballast and further on to the

subgrade. The role of crib ballast and shoulder ballast is mainly to provide minimum confinement against the lateral and longitudinal movement for track stability (Sadeghi, Zakeri, and Najar, 2016).

The ballast layer is the main structural part of the railroad where the sleepers are laid on and also it is the largest component of the track more than 1600 m3 and 2500 metric tons by volume and weight respectively for a single track in one kilometer[17].

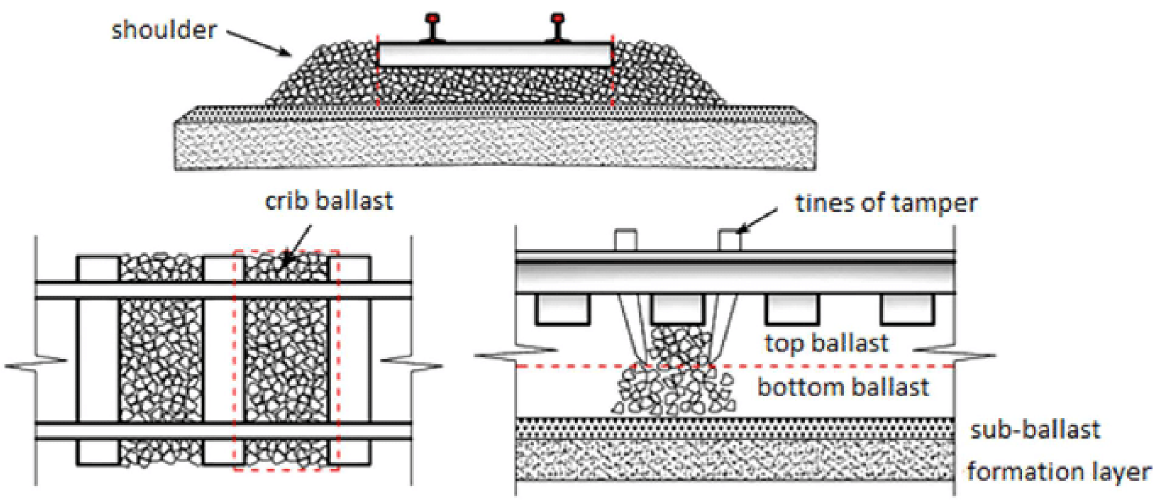

Figure 1 . Schematic of ballast zones in railway track [18]

2.1.2. Functions of ballast

The Functions of ballast includes facilitating load distribution and drainage, maintaining track geometry and track stability, and providing track resilience and noise absorption.[19] According to [16] “In the United States, Federal Track Safety Standard (FTSS)The ballast safety standard set forth under §213.103 requires a ballast to perform the following functions

- Transmit and distribute the load of the track and railroad rolling equipment to the subgrade;
- Restrain the track laterally, longitudinally, and vertically under dynamic loads imposed by railroad rolling equipment and thermal stresses exerted by the rail;
- Provide adequate drainage for the track; and

- Maintain proper track cross-level, surface, and alignment."

According to (Sadeghi, Zakeri, and Najar, 2016) The contribution of each part in playing the roles of ballast function to perform duties is presented as follows

Table 1 - Contribution of ballast portions to perform ballast duties

Ballast Duties	Crib	Shoulder	Bottom	Top
Vertical strength			✓	✓
Lateral strength	✓	✓		✓
Longitudinal strength	✓			✓
Resiliency			✓	✓
Adjusting and track leveling	✓		✓	✓
Drainage	✓	✓	✓	✓
Load distribution and dispersing			✓	✓
Prevent growth of the plant	✓		✓	✓
Shock absorption and noise attenuation	✓	✓	✓	✓
Electrical resistivity	✓			✓
Subgrade protection layer	✓	✓	✓	✓

Robnett et al. (1975) and Selig and Waters (1994) discussed "the ballast layer functions of which the most important are:-

- Retain the track in its required position by withstanding vertical, lateral, and longitudinal forces applied to the sleepers
- Provide the required degree of elasticity and dynamic resilience to track superstructure
- Distribute stresses from the sleeper bearing area to acceptable stress levels for the underlying material

- Facilitate maintenance surfacing and lining operations by an ability to rearrange ballast particles with tamping
- provide immediate drainage of water falling onto the track
- provide sufficient voids for storage of fouling material in the ballast and to accommodate the movement of particles through the ballast"

In conclusion, blast serves various functions, and it is critical to monitor the ballast shoulder on a regular basis. As previously stated, the shoulder is responsible for the track's lateral stability. The shoulder gains some stability over time as traffic compacts it, but maintenance procedures like tying, tamping, and ballast cleaning can disrupt that stability. After those duties are completed, trains must either travel at a slower speed on the restored portions or use machinery to compact the shoulder again.

2.2. Properties and specifications of ballast

Conventional ballast is a coarse-sized, angular, hard aggregate that is uniformly graded, free from dirt, and without cementing properties [20]. The most important parameter of ballast is its size and gradation. Ballast size should be chosen such that it supports the track superstructure, allows for drainage of water, and also lends itself to maintenance for correcting track geometry faults [21].

Good-quality railway ballast should have

- Angular particles,
- High specific gravity,
- High shear strength,
- High toughness and hardness,
- High resistance to weathering,
- Rough surface and minimum hairline

However, the sources of high-quality ballast are limited, and under dynamic loading conditions, most ballast properties change progressively because of breakage(degradation), deformation, and fouling[14].

The physical properties of ballast are largely responsible for successful ballast performance in the field. They can be divided into two categories. The first group is concerned with the properties of individual particles and includes a petrological examination, durability test, and shape and surface examination before the ballast can be declared suitable. The second category considers the physical properties of ballast particles that are in contact with each other but do not influence deformation. These properties are permeability, void ratio, bulk density, and specific gravity. And Three important aspects of mechanical properties of Ballast are shear strength, settlement, and degradation [14].

Ballast needs to be placed as high as the sleepers, and for a substantial “shoulder” to be placed at their ends. This is most important, since this ballast shoulder is, for the most part, the only thing restraining lateral movement of the track(Note, 2009). The study held on Analysis of influential parameters for accelerated degradation of ballast railway track, it is concluded that the condition of layers beneath the sleepers (gravel, heterogeneity) amounts up to 22% on the overall state, while the geometrical parameters (maximum rail displacement, gauge, and twist) amount to 29%. The presence of welds with its 40% rate has the most important influence on ballast deterioration (Uranjek et al., 2020). The characteristics of the ballast layer can be divided into four categories, mechanical, environmental, physical, and geometry that quantifies its performance based on the report of reference [17].

Generally, Ballast specifications favor uniform grading to fulfill drainage requirements. On the other hand, ballast must provide high shear strength to provide stability with minimal track deformation and this is normally best achieved with well-graded ballast. Over the years, concrete and highway aggregates have become more broadly graded. Despite this, railway ballast particles tend to be uniformly graded worldwide, with the uniformity coefficient (C_u) ranging between 1 and less than 3. And the coefficient of curvature (C_c) between 1 and 3.

C_u & C_c is defined as:

$$C_u = \frac{D_{60}}{D_{10}} \qquad C_c = \frac{(D_{30})^2}{D_{60} \cdot D_{10}}$$

Where D_{60}, $D_{30,}$ and D_{10} are the particle size that 60% 30%, and 10% respectively of the sample will be finer than [22].

2.3. Ballast degradation

Is degradation of the ballast aggregate in which breakage and abrasion of coarse angular particles result in the production of fine grains[19]. From the study of [4] The main form of ballast degradation is sharp corner loss, so the ballast particles with corners that are not very sharp should be used more in ballast beds.

2.4. Causes of ballast degradation

The main causes of ballast degradation are excessive cyclic loading and vibration, temperature and moisture fluctuation, and impact load on ballast due to severe braking. The degradation of ballast particles can occur in three ways (Raymond and Diyaljee, 1979):

- The breakage of particles into approximately equal parts (this is responsible for the long-term stability and safety of the track)
- The breakage of angular projections, which influences the initial settlement
- The grinding-off of small-scale asperities (the presence of fines can cause fouling and reduce drainage)[14].

In this paper also the main factors that have effects on ballast breakage (degradation) are described as the following categories

- Ballast properties related to the characteristics of the parent rock (e.g. hardness, specific gravity, toughness, weathering, mineralogical composition, internal bonding, and grain size)
- Particle properties associated with the blasting, crushing, and transportation processes (e.g. soundness, particle shape, particle size, and surface smoothness)
- Factors related to the field/experimental variables (e.g. confining pressure, initial density or porosity, the thickness of ballast layer, ballast gradation, presence of water or ballast moisture content, dynamic loading pattern, including train speed and frequency).

In general, severe heat causes railway track buckling, which is a critical problem that results in a significant loss of assets in railway systems. When the compression force approaches the buckling strength, a rise in rail temperature can produce a compression force in the continuous welded rail (CWR), which can cause track buckling. In order to deal with excessive temperatures, it is critical to guarantee the lateral stability of railway tracks. In reality, railway track can deteriorate with time, resulting in decreased track stability.

2.5. Effect of ballast degradation on the track

From most of the works of literature, we can see that the main cause of track settlement is fouling and the main cause of fouling is ballast degradation. According to (Sussmann, Ruel, and Chrismer, 2016) Ballast-fouling material is most often the result of ballast breakdown under load. The fouled ballast problem areas that are most often investigated are muddy fouled ballast zones that contain gravel from ballast breakdown combined with fine-grained clay and silt particles that result from ballast deterioration or that may fall or blow onto the track.

These authors (Sussmann, Ruel, and Chrismer, 2016) briefs the effect of fouling as Ballast resilience is obtained through the interparticle ballast contact points that provide for substantial vertical and lateral elastic deformation as long as the ballast stress remains tolerable and the ballast does not break down. The desired resilience in a ballast layer is elastic, meaning that the deformation is recoverable and the ballast will return to the position it occupied before loading. Deformation of fouled ballast is most often inelastic, meaning the deformation is often only partially recovered with significant plastic (permanent) deformation. In these locations, the plastic ballast deformation results in track settlement and track geometry defects. According to Selig and Waters, the ballast layer is generally the largest source of track settlement [7].

Ballast-related track settlement can affect as little as one tie in the initial stages, and short-wavelength track geometry parameters such as cross-level, short-wavelength profile, or short-wavelength warp can be the initial indication of track support problems. As the track is repeatedly loaded, another inelastic deformation mechanism may occur in the ballast, and for this fouling

76% of the cause is degradation. The breakage (degradation) of ballast causes differential track settlement and excessive lateral movement. Accumulation of crushed particles in the void spaces between larger aggregates decreases the permeability of ballast[14].

In conclusion, fouled ballast has a considerable impact on track settlement, with an increase in ballast fouling resulting in an increase in track settlement. Ballast fouling is a term used to describe the contamination of railway ballast produced by ballast particle deterioration, external debris fouling from surface spills, and clay fouling from subgrade pumping. The presence of these particulates in the ballast layer might obstruct the quick drainage required for excellent track performance.

2.6. Investigation methods of ballast degradation

Different research topics related to railway ballast material degradation have internationally wide-range literature. The researchers used the methods below:

- Laboratory tests
- DEM (discrete element method) simulations and/or 3D particle shape developments
- FEM (finite element method) simulations
- field tests [2]

To investigate the effects of ballast aggregate breakdown and degradation on the mechanical behavior (shear strength)[19], performed the two laboratory tests which are the Los Angeles abrasion test and the large scale triaxial test. The triaxial testing efforts focused on (a) the effects of gradation considering those finer materials or fines, i.e. particles less than 9.5 mm (3/8 in.), generated through ballast degradation, and (b) the effects of aggregate shape properties, such as angularity and flatness and elongation, for particles larger than 9.5 mm (3/8 in.). Accordingly, triaxial tests were also performed only on those aggregate particles still kept after the LA abrasion tests larger than 9.5 mm (3/8 in.) in size, which would constitute the skeleton of the fouled ballast layer in the field[19].

Since it is mandatory to identify the degree of fouling which is mostly caused by the degradation of ballast and to remove the fine materials before critical problems occur, to increase the performance of the rail track. The scales that are widely used to determine fouling quantities are the Fouling Index, Percentage of Fouling, the D-Bar method, and Percentage Void Contamination. The percentage of fouling (% fouling) is the ratio of the dry weight of material passing through a 9.5 mm sieve to the dry weight of the total sample. The first three measures are commonly used; the fourth one is used by Queensland Railways. These methods are laboratory-based and require field sampling and testing, which are normally carried out by digging out trenches with even spacing. These processes require a lot of resources (i.e., time, money, and manpower). The non-destructive testing of ground penetration radar, infrared imaging, seismic surveys, and electrical resistivity are the other popular methods for identifying fouling in the field. Various studies have been carried out using non-destructive testing of Ground Penetration Radar (GPR) to map the sub-surface of ballast sections. GPR is a modern geophysical approach, which can provide information about the formation of the track-bed interface. Most GPR results depend on a visual interpretation and are qualitative. However, a railway engineer still needs quantitative numbers to establish an appropriate design and maintenance program. GPR can be used to obtain information on fouling depth but it cannot clearly define the degree or type of fouling. it measured shear wave velocity and density in the model track sections and estimated the shear modulus of clean and fouled ballast. Authors have highlighted that MASW gives shear stiffness of ballast bed and are more effective than any other method but it may require more time to carry out the test in the field (Anbazhagan, Buddhima, and Amarajeevi, 2011).

To summarize, most GPR results are qualitative and rely on visual interpretation. A railway engineer, on the other hand, need quantitative data to develop a proper design and maintenance schedule. GPR may be used to determine the depth of fouling, but it cannot accurately determine the degree or kind of fouling. It evaluated the shear modulus of clean and fouling ballast by measuring shear wave velocity and density in model track sections.

Table 2. Track ballast layer specification indices[17]

Ballast properties	Characteristics	Test method	Terms of evaluation
Mechanical	Hardness &Toughness	Los Angeles	Abrasion, attrition, and fragmentation
	Hardness	Deval attrition test (dry, wet)	Surface abrasion test
	Hardness	Micro Deval	Surface abrasion test
	Toughness	Aggregate Crushing Value	Fragmentation and crushing resistance
	Hardness	Scratch (Mohs)Hardness	Surface abrasion to produce fines
	Toughness	Point load Strength	Fragmentation(splitting
	Toughness	Aggregate impact Value	Aggregate resistance to sudden shock, fracturing
	Hardness	Dorry abrasion	Surface abrasion to produce fines
	Hardness	Mil abrasion	Surface abrasion to produce fines
	A clue to Hardness, toughness, and soundness	Petrography analysis (intact particles/Fines)	Mineralogy, Chemical alteration
Physical	Gradation	Particle size distribution	Compaction energy and drainage ability
	Gradation	Fineness of material	Drainage
	Stability	Particle density	Stability and indirect toughness
	Stability	Bulk density	Interparticle void, drainage, and track stability

Ballast properties	Characteristics	Test method	Terms of evaluation
Physical	Shape index	Particle shape	Fragmentation(splitting) and drainage
Enviromental	Soundness	Dry-wet	Durability and weathering resistance
	Soundness	Freeze and Thaw	Durability and weathering resistance
	Soundness	Water absorption	Saturation and weathering resistance
	Soundness	Aggregate Porosity	Durability and weathering resistance Durability and weathering resistance
	Soundness	Magnesium/Sodium sulfate	Durability and weathering resistance
	Soundness	Friable particles, clay lumps	Durability and weathering resistance
Geometrical	Cross profile	Thickness	Track structural stability, resiliency, and damping Track
		Shoulder width	Track lateral stability Track
		Side slope	Track structural stability
	Layer deviation	Unevenness, misalignments	stability to ride comfortably

In general (J. M. Sadeghi et al., 2016) stated that To identify ballast testing methods that provide results reflecting the field performance of different ballast materials, various tests are recommended and performed by researchers. In the case of achieving appropriate ballast recognition regarding its characteristics needs to perform these general and well-known tests as categorized in table 2.

To measure needful indices in terms of evaluation of ballast specifications. These tests are concerned with establishing a quantitative estimate of the resistance to in track instability and degradation under loading. Besides mentioned tests, some supplementary tests are being used to simulate actual ballast field performance to assess the reliability compared to using simple laboratory tests. Odometer, ballast box test, triaxial test, and full-scale railway track model test are supplementary tests to find out more realistic behavior of ballast under cyclic loading; however are costly and time-consuming [17].

2.7. Maintenance and Renewal of Degraded Ballast

As the track strength and stability are greatly dependent on the appropriate functioning of the ballast [24]. The ballast is considered as the main component in any railway track maintenance. The effectiveness of a ballast maintenance approach is dependent on the accuracy of the recording and assessment of ballast conditions Still current years, the assessment of the ballast is made based on only track geometry conditions[25]. The considered track geometry conditions include track profile, gauge, alignment, and twist. Various geometry indices have been developed based on these parameters.

In other words, the current practice concentrates on the ballast short-term behavior and its long-term behavior has been omitted. While the track geometry conditions may appear normal, the track can be on the verge of failing due to severe ballast fouling. It means that track geometry by itself cannot lead to precise maintenance planning. Addressing this limitation, the current ballast maintenance approach was improved by developing a new maintenance algorithm that takes into account both short and long terms behavior of the ballast. For this purpose, two ballast conditions indices called BFI and BGI are developed. A ballast fouling index (BFI) was developed to indicate the level of ballast contamination which has been known as the main cause of ballast mechanical deterioration. This index was developed by analyzing the results obtained from GPR machines. For this purpose, compressive laboratory tests were carried out to derive a correlation between ballast contamination levels and the output of GPR machines. The correlation was used to drive a mathematical expression for the ballast contamination (BFI). A ballast geometry index

(BGI) was developed based on the ballast geometry deviations in the vertical and lateral directions. It was made by analyses of the track geometry parameters deviations obtained from a track recording car.

The main futures of these indices are:

- They directly reflect both short and long term behavior of the ballast;
- They are easy to be derived as the required data are obtained from automated inspections (i.e., cost-efficient method)[26].

From the study of" Principles of Degraded Ballast and Their Track Safety Implications" [27]stated that the trend of ballast settlement increases at a decreasing rate under loading, even when it is fouled. After considering possible mechanisms under which fouled ballast settlement could affect safety, it is concluded that the main effect of high levels of fouling on ballast settlement is to allow the track to more quickly return to the rough profile that it had before tamping. Following surfacing maintenance, the ballast layer compacts under traffic at a decreasing settlement rate, and the overall stability of the ballast layer increases. However, a potential source of a safety-critical increase in the ballast settlement rate could be the formation of voids under the tie due to the buildup of slurry and erosion of ballast support directly under the tie. If ballast remains in track beyond its life, the slurry of fine material can form under and around the tie which also allows the formation of voids between the bottom of the tie and ballast, increasing track deflection under load. To avoid this condition, it is recommended that ballast be replaced before its permeability decreases to the fouling level associated with the end of ballast life. This amount of fouling is estimated as 30 using the Selig Fouling Index. Once ballast fouling exceeds a Fouling Index of approximately 30, ballast maintenance becomes less effective and renewal of the ballast layer thorough cleaning or replacement becomes necessary. Left untreated, the ballast layer can eventually deteriorate to the point where voids and slurry begin to form around the tie, which can be a potentially unsafe condition [27].

Worldwide, rail track maintenance is an expensive and routine exercise. A major portion of the maintenance budget is being spent on geotechnical problems. Maintenance is mandatory because of ballast fouling and the weakening of track subsurface layers (sub-ballast and subgrade). The major fouling reported worldwide is attributed to the breakdown of ballast (fine ballast), outside contamination by coal dust from trains carrying coal, and soil intrusions from the base. Fouled ballast can cause many major problems including a reduction in vertical resistance, reduction in the void space thereby leading to a considerable decrease in the movement of particles through the ballast, poo, or drainage of water falling on the track and vegetation growth over the rail track. It is therefore mandatory to identify the degree of fouling and to remove the fine materials before critical problems occur, to increase the performance of the rail track (Anbazhagan, Buddhima, and Amarajeevi, 2011).

Worldwide Ballast cleaning and renewal is an expensive and time-consuming process that is also highly disruptive to train traffic. Thus, the need for this process must be considered carefully. Ballast cleaning and renewal are required when the ballast becomes extremely fouled that it cannot fulfill its functions. Many modern non-destructive tests such as ground penetration radar (GPR), infra-red imaging, seismic surveys, and electrical resistivity are widely used for identifying fouling in the field. Most of the GPR testing was carried out on actual railway lines. There are a lot of uncertainties within the actual rail track and it is difficult to calibrate the GPR data with actual ground conditions because of a limited number of trenches and time constraints. Most of these GPR results are dependent on a visual interpretation and are qualitative. However, a railway engineer still needs quantitative methods to establish an appropriate design and maintenance program. GPR can be used to obtain information on fouling depth but it cannot clearly define the degree or type of fouling. [28].

To summarize, a variety of sophisticated non-destructive techniques, such as ground penetrating radar (GPR), infrared imaging, seismic surveys, and electrical resistivity, are routinely employed in the field to detect fouling. The majority of the GPR testing was done on actual railway tracks. There are many uncertainties inside the real rail track, and due to a limited number of trenches and time restrictions, calibrating the GPR data with actual ground conditions is problematic. The majority of these GPR data are qualitative and rely on visual interpretation. A railway engineer, on the other hand, need quantitative methodologies to develop an acceptable design and maintenance schedule.

2.8. Summary

Ballast performance in the field is mostly determined by the physical qualities of the ballast. They are classified into two types. Before the ballast can be deemed appropriate, the first group examines the qualities of individual particles and comprises a petrological analysis, durability test, and form and surface examination. The second group takes into account the physical qualities of ballast particles that come into touch with one another but do not affect deformation. Permeability, void ratio, bulk density, and specific gravity are examples of these qualities. The main causes of ballast degradation are excessive cyclic loading and vibration, temperature and moisture fluctuation, and impact load on ballast due to severe braking. Moreover, literatures indefinitely identify Deformation of fouled ballast is frequently inelastic, which means that the deformation is frequently only partially recovered with considerable plastic (permanent) deformation. Plastic ballast deformation causes track settling and track geometry faults in these places. According to Selig and Waters, the ballast layer is the most common cause of track settling. It is necessary to detect the degree of fouling, which is usually caused by ballast deterioration, and to remove the fine debris before serious issues emerge. The Fouling Index, Percentage of Fouling, the D-Bar technique, and Percentage Void Contamination are popular scales for determining fouling amounts. The principal fouling recorded globally is due to ballast disintegration (fine ballast), outside contamination by coal dust from coal-carrying trains, and soil incursions from the base. Fouled ballast can create a variety of serious issues, including a decrease in vertical resistance, a decrease in empty space, resulting in a significant drop in particle movement in the ballast, feces, or drainage of water falling on the track, and plant growth over the rail track.

3. METHODOLOGY

3.1. Introduction

To evaluate the ballast degradation of the Sebeta-Adama railway line, four laboratory tests (Sieve analysis, Los Angeles abrasion test, elongation and flakiness index test, and fouling index test) are conducted based on the three main factors that affect ballast degradation (properties related to the characteristics of the parent rock, physical properties associated with individual particles, factors related to particle assembly and loading) (Indraratna, et al, 2009). Field investigations are also conducted to determine the amount of deterioration as well as the mechanical, physical, and strength qualities of the ballast. In addition, a substantial amount of literature has been evaluated and researched. Furthermore, this inquiry includes a thorough assessment of the literature and practice of ballast standards utilized in Ethiopian railroads, during which current practice and the justification for it are developed. Ballast samples were collected from the Ethiopian Railway Corporation and the Ethio-Djibouti railway line for laboratory testing, field data was recorded, ballast specifications, design data, and maintenance data were collected for the inquiry, which included a thorough study.

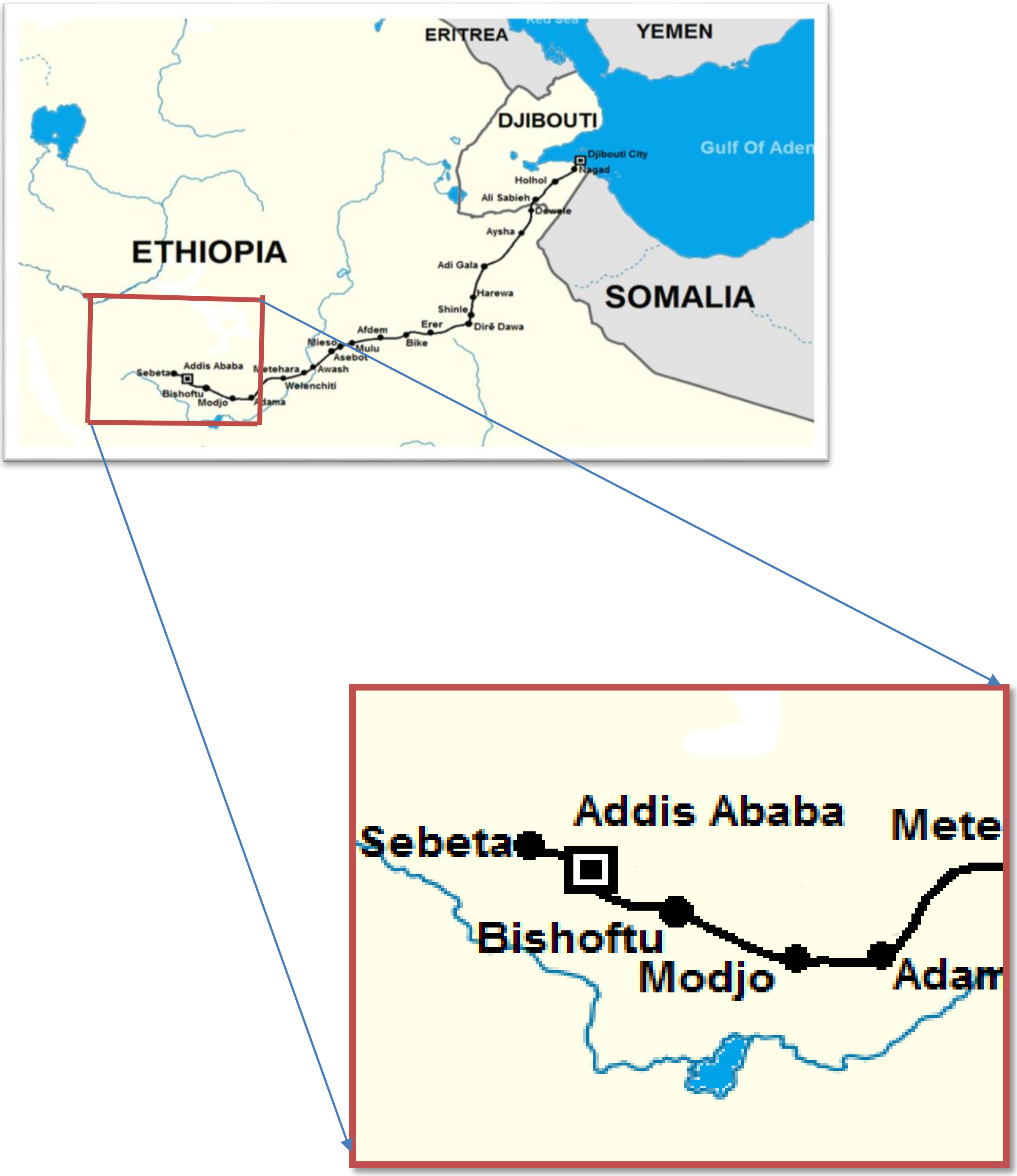

Figure 2: Map of Sebata Adama rail way line

3.2. Field Inspection

Field inspection is a visual examination of the track, particularly the ballast layer and its attributes such as gradation, form, fouling condition, plant growth, and the most deteriorated places. The field condition was visually inspected to acquire a better understanding of the issue and the course of ballast deterioration. The drainage condition, material grading, fouling condition, and track activities were analyzed and their indication was investigated during the field inspection for this study. The main properties that got focused during site inspection are summarized as:

- Ballast Material type and grading
- The fouling condition and drainage
- The difference of materials at critical and non-critical sections of the line.
- Depth of ballast bed.

3.3. Laboratory Tests

3.3.1. Sampling According to AASHTO R 90 and R248

All laboratory test material was collected along railway track at 8 selected locations at the stations of (02+800, 17+400, 35+00, 56+300, 67+687, 70+280, 93+500, 112+800). These locations and (chainages) were chosen based on their criticality for degradation and based on prior field inspection results (locations those showed different signs of degradation like mud and vegetation, particle size, elongated and flaky materials) and ease of access to the line by vehicle. Samples were taken from various areas (locations) of the track, with three spots chosen at random at each location (around rail seat, under the sleeper, and between sleepers). Full-depth increments of about identical size were obtained from each of the three sites. The increments from the three spots were added together to create a single sample for the given location. Sample size is provided below.

3.3.2. Reducing Samples to Test Size According To AASHTO R 76

Following AASHTO R 76-16the field samples were reduced to an appropriate size for testing. Method A which is quartering is used for the study because of its ease to work and sensitivity of the material (sample) for breakage other methods to use.

3.3.3. Material Testing

3.3.3.1. Gradation (Sieve Analysis) According to AASHTO T 27/T11

Gradation of ballast is critical for track strength, deformation, deterioration, stability, and drainage. Since the physical properties of ballast are largely responsible for successful ballast performance in the field Ballast size distribution significantly influences the deformation characteristics of the track and it can show the breakage/degradation level of the ballast. A higher level of uniformity of ballast aggregates leads to a higher elastic stiffness and lower breakage. However, the density and angle of internal friction decline with higher levels of particle uniformity. Ballasts with broad gradation contain fewer voids, thereby offering higher strength than uniformly graded ballasts. All ballast requirements, on the other hand, require uniform gradation to ensure proper drainage which can also reduce breakage by protecting the ballast from moisture. Ballast that is uniformly graded settles faster and is also more prone to breaking than ballast that is well graded [31].

Since the physical properties of ballast are largely responsible for successful ballast performance in the field Ballast size distribution significantly influences the deformation characteristics of the track and it can show the breakage/degradation level of the ballast. Grading of ballast is the most commonly requested test within the railway construction and maintenance. The purpose of the test is to determine the varying amounts of material contained in the standard size segment.

A higher level of uniformity of ballast aggregates leads to a higher elastic stiffness. However, the density and angle of internal friction decline with higher levels of particle uniformity. Ballasts with broad gradation contain fewer voids, thereby offering higher strength than uniformly graded ballasts. In this study, the current grading is compared with the designed/As-built grading. For these tests, sample sizes were chosen depending on the Nominal Maximum Size of Aggregate as shown in table 3 below. In this project, the Nominal Size of the Aggregate was found to be 63 mm. as per AASTO T-27/ASTM C136-84A

Table 3. Test Sample Sizes for Aggregate Gradation Test

Sieve size (mm)	**sample size(g)**
125	300,000
100	150,000
90	100,000
75	60,000
63	35,000
50	20,000
37.5	15,000
25.0	10,000
19.0	5000
12.5	2000
9.5	1000
6.3	1000
4.75	500

3.3.3.2. Los Angeles Abrasion Test according to AASHTO T 96

The most common way of predicting ballast degradation under train loads is through the use of the Los Angeles abrasion test(LAA) which celebrated its 100th anniversary in utilization in 2016 (Woolf and Crandell 1936). Los Angeles Abrasion Test is a quick and easy test that mainly measures coarse aggregate resistance to crushing [30].

Usually, the LAA test is used to test durability and strength properties of ballast, with the evaluation method of mass loss rate named LAA loss (%), and it is a vital quantity evaluation of ballast. LAA test can be applied to the study of ballast attrition, for it could create dynamic impacts It is suggested that it is too good to be true that such a simple test can separate in all aspects good performing ballast materials from the poor performance ones in a reliable way [30]. The LAA test measures the degradation of a coarse aggregate sample that is placed in a rotating drum with steel spheres. As the drum rotates the aggregate degrades by abrasion and impact with other aggregate particles and the steel spheres (called the "charge"). Once the test is complete, the calculated mass of aggregate that has broken apart into smaller sizes is expressed as a percentage of the total mass of aggregate. Therefore, lower LAA values indicate aggregate that is tougher and more resistant to abrasion.

$$\text{Aggregate abrasion value(LAA loss } = (\mathrm{A}-\mathrm{B})/\mathrm{B}\ \mathrm{x}\ 100\%$$

The test sample size was chosen according to the grading of the test sample as shown in table 4. For this project, 10kg sample and 12 steel balls of 500g each were placed in an abrasion machine drum rotating with 30-33rpm to provide 1000 revolutions.

$$\text{Los Angeles Abrasion Value} = \frac{(\text{Original Weight} - \text{Weight Retained on \#12}) \times 100}{\text{Original Weight}}$$

Table 4. Grading of LAA Test

Sieve Sizes		Mass of Indicated Sizes (g)						
Passing	Retained	A	B	C	D	1	2	3
76.2 mm (3 in)	63.5 mm (2.5 in)	—	—	—	—	2500 ± 50	—	—
63.5 mm (2.5 in)	50.8 mm (2 in)	—	—	—	—	2500 ± 50	—	—
50.8 mm (2 in)	37.5 mm (1.5 in)	—	—	—	—	5000 ± 50	5000 ± 50 is	—
37.5 mm (1.5 in)	25.0 mm (1.0 in)	1250 ± 25	—	—	—	—	5000 ± 25	5000 ± 25
25.0 mm (1.0 in)	19.0 mm (3/4 in)	1250 ± 25	—	—	—	—	—	5000 ± 25
19.0 mm (3/4 in)	12.5 mm (1/2 in)	1250 ± 10	2500 ± 10	—	—	—	—	—
12.5 mm (1/2 in)	9.5 mm (3/8 in)	1250 ± 10	2500 ± 10	—	—	—	—	—
9.5 mm (3/8 in)	6.3 mm (1/4 in)	—	—	2500 ± 10	—	—	—	—
6.3 mm (1/4 in)	4.75 mm (#4)	—	—	2500 ± 10	—	—	—	—
4.75 mm (#4)	2.36 mm (#8)	—	—	—	5000 ± 10	—	—	—
TOTAL		5000 ± 25	5000 ± 20	5000 ± 20	5000 ± 10	10000 ± 100	10000 ± 75	10000 ± 50

3.3.3.3. Flakiness Index According to BS 812:1989

As the research review, the effects of shape and size on degradation and deformation of ballast are still controversial. study on particle shape shows that flaky or elongated particles at a limited percentage could increase the shear strength of ballast bed, and reduce the settlement for the lower rate of settlement accumulation. However, it was also reported that flaky or elongated particles would lead to increased particle degradation and higher deformation.

Ballast particles are classified as flaky when they have a thickness (smallest dimension) of less than 0.6 of their mean sieve size, this size is taken as the mean of the limiting sieve apertures used for determining the size fraction in which the particle occurs. The flakiness index of an aggregate sample is found by separating the flaky particles and expressing their mass as a percentage of the mass of the sample tested. The test does not apply to material passing a 6.30 mm BS test sieve or retained on a 63.0 mm BS test sieve. On this test, samples are prepared as per the direction of BS 812-102:1989.clause 5

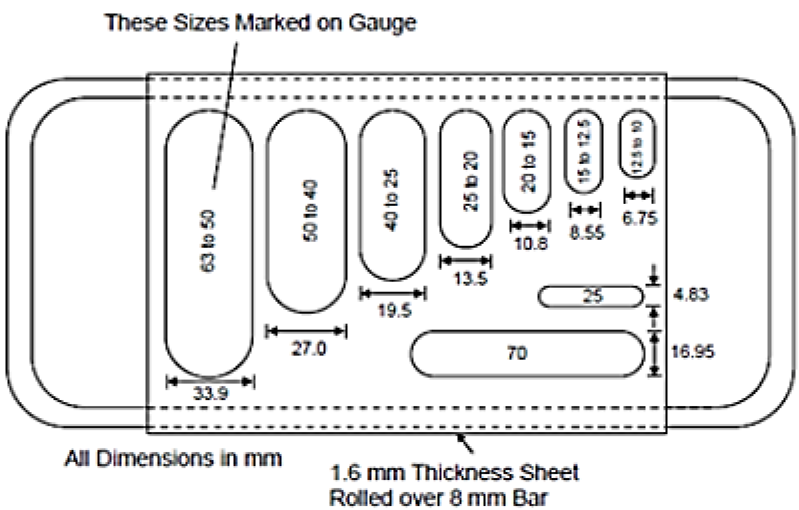

Figure 3. Flakiness index gauge

Table 5.The minimum mass of the test portion

Nominal size of material	The minimum mass of test portion after the rejection of oversize and undersize particles
mm	kg
50	35
40	15
28	5
20	2
14	1
10	0.5

Calculation and expression of results

The value of the flakiness index is calculated from the expression:

Flakiness index=$(M_3)/(M_2)$

Where M2=total mass of material passing sieve size 50mm and retained on sieve size 6.3mm.

M3=total mass of material passed through flakiness gauge.

Table 6. Data for determination of Flakiness index

Aggregate size fraction		Width of a lot in thickness gauge or special sieve	Minimum mass for subdivision
BS test sieve nominal aperture size			
100% passing	100% retained		
Mm	mm	mm	kg
63	50	33.9±0.3	50
50	37.5	26±0.3	35
37.5	28	19.7±0.3	15
28	20	14.4±0.15	5
20	14	10.2±0.15	2
14	10	7.2±0.1	1
10	6.3	4.9±0.1	0.5

3.3.3.4. Elongation Index According to BS812:1990

Aggregate particles are classified as elongated when they have a length (greatest dimension) of more than 1.8 of their mean sieve size, this size is taken as the mean of the limiting sieve apertures used for determining the size fraction in which the particle occurs. The elongation index is found by separating the elongated particles and expressing their mass as a percentage of the mass of the sample tested. This test does not apply to material passing a 6.30 mm test sieve or retained on a 50.0 mm test.

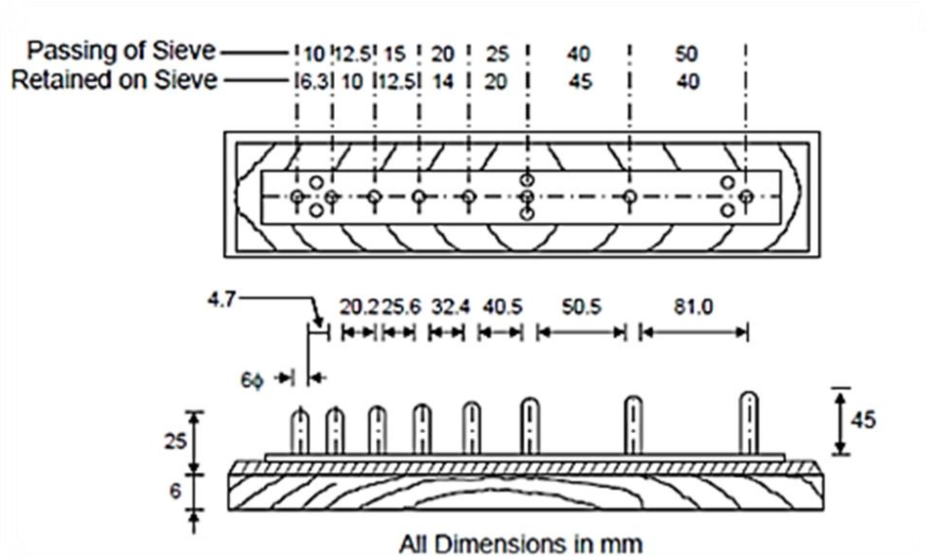

Figure 4. Elongation index gauge

Table 7. The minimum mass of the test portion

Nominal size of material (mm)	The minimum mass of test portion after the rejection of oversize and undersize particles (kg)
40	15
28	5
20	2
14	1
10	0.5

Table 8.Data for determination of elongation index

Aggregate size fraction		The gap between pins of the length gauge	Minimum mass for subdivision
Test sieve			
100% passing	100% retained		
Mm	mm	mm	kg
50	37.5	78.7±0.3	35
37.5	28	59±0.3	15
28	20	43.2±0.3	5
20	14	30.6±0.3	2
14	10	21.6±0.2	1
10	6.3	14.7±0.2	0.5

- Calculation and expression of results

  The value of the elongation index is calculated from the expression:

$$\boldsymbol{Elongation\ index} = (\boldsymbol{M_3})/(\mathbf{M_2})$$

Where M_3=total mass of material passed through sieve size of 50mm and retained on sieve size of 6.3mm.

M_2=total mass of material retained on elongation gauge.

3.3.3.5. Fouling Index test According to Waters and Silegs' recommendation

Qian, Yu Boler, Huseyin Moaveni, Maziar Tutumluer, Erol expressed that the experimental study indicated that the fouling index (FI) commonly used by practitioners was indeed a good indicator of fouling conditions, especially when all voids created by larger particles were filled by fine materials as FI values approached 40 [31]. In this study also, it is concluded that the main reason fouling is degradation and up to 76% of the ballast fouling was due to ballast breakdown, in other words, ballast degradation. so calculating the fouling index can show the extent of fouling and degradation of ballast.

So, calculating the fouling index can show the extent of fouling and degradation of ballast. FI is the summation of the percentage by weight of ballast material passing the 4.75-mm (No. 4) sieve and the percentage passing the 0.075-mm (No. 200) sieve. The resultant% classifications based on FI are presented in the following table.

Table 9. The extent of ballast fouling as a function of computed FI values

% Finer Than 0.075 mm	Fouling Index (FI)	Adjudged Fouling Extent
-	<1	Clean
-	1–9.99	Reasonably clean
25–35	10–19.99	Moderately contaminated
40–50	20–39.99	Contaminated
>50	>40	Highly contaminated

- Calculations

$$\text{Fouling index(FI)} = PNo.4 + PNo.12$$

Where PNo.4= the percentage by mass of the sampled ballast material finer than the 4.75 mm (No.4) sieve

PNo.200= the percentage by mass finer than the 0.075 mm (No. 200) sieve

3.4. Data analysis and Interpretation

First of all, as-built data are compared with the designed standard used and the result interpreted. The laboratory tests results are recorded carefully for each test and location on different result recording sheets, after the test was done the results are calculated according to the formulas of the standard used and results are compared with the design and as-built data. Three laboratory test results (grading, flakiness and elongation index, fouling index) are used to compare the As-built data of ballast with the current condition and show the degradation extent. Los Angeles abrasion test results are used to estimate the resistance of the current ballast against abrasion to know and avoid future risks.

Field inspection was done through the line to have a better interpretation of the laboratory test results and the ballast bed condition is investigated. Services on the line, maintenance works, and the current activities are assessed and their relation with the degradation of ballast is interpreted.

4. RESULTS AND DISCUSSIONS

4.1. Field Inspection

Inspection has a significant impact on the line's safety and maintenance costs in railway service and operation. The majority of maintenance work is based on inspection results, indicating that after the line has been built, maintenance services are primarily guided by inspection results. The Sebeta-Adama railway line ballast bed is inspected in this inquiry to determine the extent of its degradation and the track's condition. The following main elements of the ballast bed are investigated as a result of the inspection.

A. Ballast Material type and grading report

The ballast material used in this line is class one crushed rock, according to the line's as-built data, and the field examination confirms that the initial material used is proper. Certain materials, however, are new and do not match the as-built materials at various spots along the line, and the color variance is readily visible on the field. The sieve test also reveals that the grading is out of the prescribed standard in numerous places. Furthermore, the materials used for maintenance are of poor quality and do not satisfy the required grade.

Figure 5. New ballast different from the designed standard (grading, strength) around Bishoftu

B. The fouling condition and drainage report

Inspection fouling can be seen at a higher level from the track. Since this line has only been operational for about three years, the ballast bed appears to be clean on most of its sections, but it has a high mud cover on the ballast in places where there are level crossings, notably near cities, where the top of the ballast bed is coated with dust and mud. This problem may be seen around Sebeta station, even on the rail portion that is not a level crossing. It has been modified to serve as a pedestrian and livestock crossing, resulting in the contamination of the ballast bed with dust, mud, and other animal wastes. The shoulder ballast is also gone in this place, and the bottom of the sleepers' edge is revealed at the shoulder's edge. This is a risk that can diminish lateral stability, and unless people are prohibited from using the main track as a crossing, accidents and losses of life and property are possible. It will also add to the cost of upkeep. Except for a few locations near the crossing, the drainage is in good shape.

Figure 6. Fouled ballast around level crossing (Furi)

Figure 7. Fouled track ballast around undesigned crossings(Sebeta)

C. The difference of materials at critical and non-critical sections of the line

Different sections of railway lines are classified as critical or non-critical based on various criteria. Stations, transitions, curves, level crossings, and turnouts are the sections of the line rated as crucial for this inquiry based on the degree of ballast that may be degraded on the sections. During the examination, the materials on these sections also revealed differences, such as significant fouling around the crossings, high ballast breakage around transitions and bends, and smaller grading and fines than straight lines without bridges and culvert transitions. The degradation around stations and turnouts appears to be minor, but different materials utilized for repair are of inferior quality. The ballast beds in other non-essential portions are better than those in critical sections.

Figure 8. Ballast around turnouts and transitions(Furi,Indode) (fouling)

D. Depth of ballast bed report

The ballast depth is 25cm all the way down the line. Except for those sections where the ballast bed is used as a crossing without being a level crossing, the depth of the ballast bed at the shoulder of the track is above the top of the sleeper, indicating that it meets the planned depth requirement. The ballast bed is also thoroughly inspected in the center of the railway. In general, the ballast depth is maintained according to the design requirements, however repair around informal crossings and level crossings is required in the future before it impairs the overall track performance and causes an accident.

Figure 9. Deteriorated ballast(Sebeta)

4.2. Grading (Sieve Analysis)

This grading test was carried out by dry sieving, where the ballast sample was dried and agitated through a nest of selected sieve sizes from biggest to smallest for each sample obtained from 8 separate important sites previously evaluated. Except for the position of (93+500) in Table 10, which is the grading tests summary table, all of the other places ballast. Curve PSD Shows that the normal Ballast grade is found between 16mm and 63mm. According to the design and as-built test findings, 60-75 percent of the ballast size should be between 35.5 and 63(mm), with more than 97 percent passing through a 63mm sieve.

The sieve analysis test results show two different cases at different locations samples. The first case shows that the five locations (02+800, 17+400, 35+00, 56+300, and 67+687) test results show that since as-built data shows that only 25-40% of material should pass through sieve size 35.5, more than 60% of particles are found passing sieve size 37.5mm. More than 15% (which is greater than the planned upper limit for the sieve size) of materials passed at sieve number 25mm, indicating that the bigger ballast particles are being degraded and becoming fine. The second case involved material detected at three locations (93+500, 70+280, and 112+800) with a sieve size of 37.5mm less than 40% and a sieve number of 25mm less than 5%. These findings demonstrate that the materials in the three locations contain more boulder particles than the as-built data and are outside of the designed range. The PSD curve below depicts these scenarios.

Table 10. Test result from the summary of sieve analysis % pass

		Percentage passing											
Locations		2+800	17+400	35+00	56+300	61+687	70+280	93+500	112+800	As-built upper limit	Designed upper limit	As-built lower limit	Designed lower limit
sieve sizes													
63	63	100	100	100	100	100	97.24	79.68	97.69	100	100.00	99.00	97.00
56.00	50.00	91.1	88.36	91.56	77.35	90.61	60.01	39.17	71.96	96.00	97.00	92.00	92.00
45.00	37.50	54.9	60.02	71.55	46.41	75.13	27.92	24.87	36.12	79.00	75.00	56.00	55.00
35.50	28.00	23.3	36.06	42.75	22.91	46.50	10.40	12.76	6.21	38.00	40.00	25.00	25.00
25.00	25.00	15.7	26.14	33.75	16.49	32.20	6.84	8.81	3.66	13.00	15.00	5.00	5.00
16.00	16.00	2.0	1.84	2.11	2.10	1.23	3.50	1.97	1.38	2.00	5.00	0.00	0.00

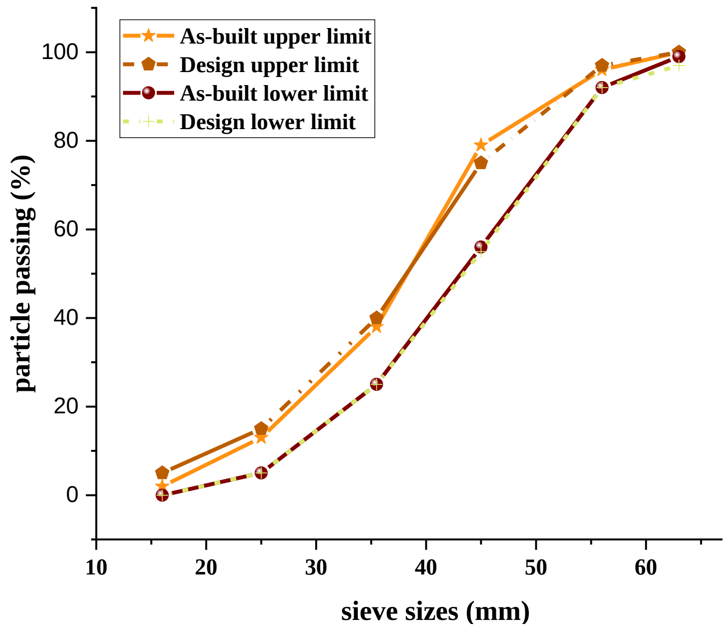

Figure 10. PSD Curve for Designed grading compared with as-built grading

Before comparing current ballast grading to As-built data, make sure the ballast was constructed according to the design specifications. The as-built (constructed) ballast grading was within the planned limit, as seen by the PSD curve above. As a result, we can state that the built ballast bed meets the specified grading. Now we may compare the current situation to one of the two scenarios (designed standard or as-built data)

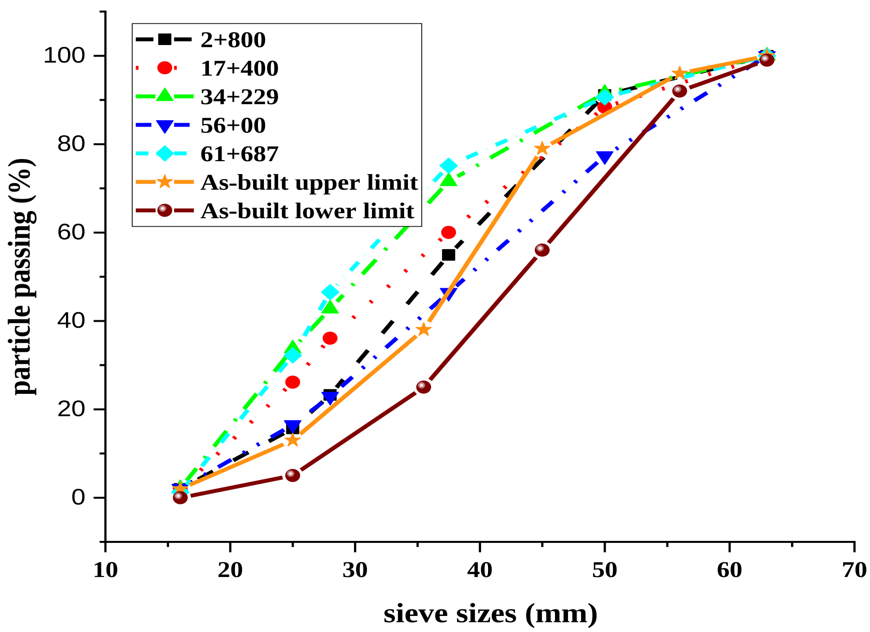

Figure 11.PSD Curve for ballast sampled from the location 2+280, 17+400, 35+00, 56+300 & 67+687

The present ballast grading at these five places (2+280, 17+400, 35+00, 56+300, and 67+687) reveals that the particle size is decreasing as compared to as-built data. This demonstrates that the ballast has been cracking and losing its broad grading at these areas. At these areas, there is severe ballast degradation.

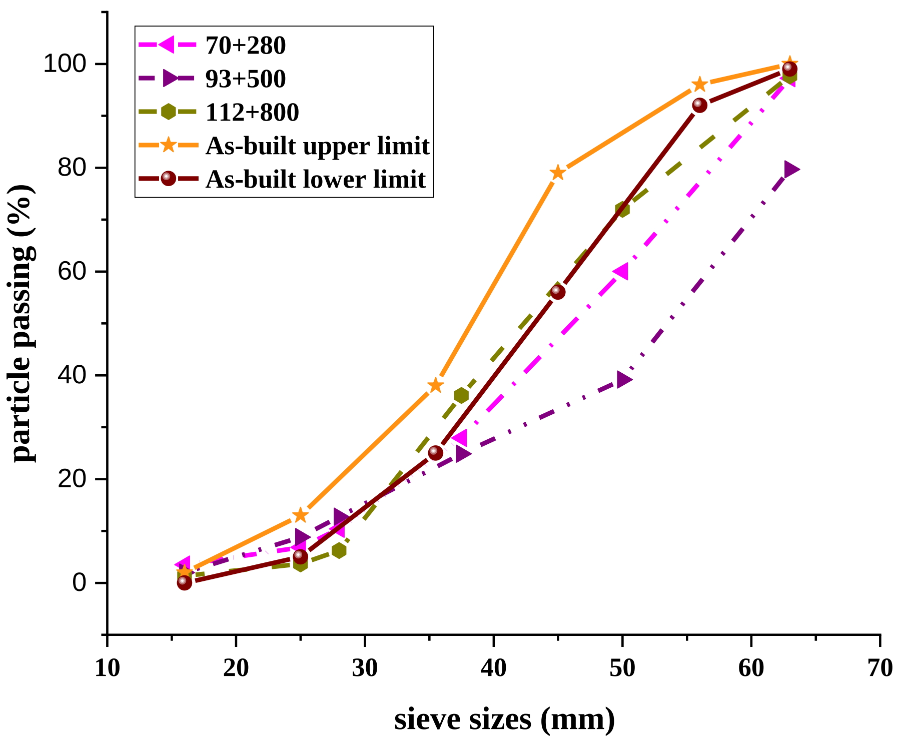

Figure 12. PSD Curve for ballast sampled from the locations 93+500, 70+280, and 112+800

Ballast particle size distribution (grading) at three of the eight crucial locations (changes) demonstrates that the material grading at these places is increasing (93+500, 70+280, and 112+800). (shows boulder particle size than as-built data). Since it is well known that ballast cannot be expanded after it has been distributed, this indicates that either the ballast has been maintained using material that does not meet the intended requirement or the as-built test data is incorrect.

Ballast should be graded consistently and extensively. The current ballast's coefficient of uniformity is compared to the designed standard and as-built test data, and the result is found to be within the designed range for all eight locations, indicating ballast material grading (particle size distribution still meets the designed requirement) except for chainge of 93+500. The Cu value is larger than two at this site, which is also greater than the specified limit; nevertheless, because it is less than three, we can still declare that the ballast is uniformly graded.

Table 11. Cu and Cc of the sampled location designed standard and as-built data.

Summary of C_u and C_c Values		
Locations	**C_u=D_{60}/D_{10}**	**Cc=$(D_{30})^2/(D_{60}D_{10})$**
02+800	1.85	1.08
17+400	1.97	0.96
35+00	1.85	0.93
56+300	2.05	1.06
61+687	1.75	1.00
93+500	2.19	1.20
70+280	1.75	1.06
112+800	1.81	0.94
DUL	2.00	1.17
DLL	1.68	1.07
ABUL	1.80	1.13
ABLL	1.68	1.07

The upper limit of the Coefficient of Uniformity for the ballast material should be 2 based on the previous tables' values and the PSD Curves. This number has above the planned upper limit, according to the test findings at 35+00 and 56+300. No less low value has been reported at the designed lower limit value of the coefficient of Uniformity. According to design and USCS, the value of coefficients of curvature must be between one and three.

According to the USCS, the value of Cu for consistently graded material, such as ballast material, should be Cu 4 when uniformly graded. When Cu > 4 and 1 Cc 3 are present, the gradation classification can be classified as well-graded or broadly graded [32].

Three places' current Cc levels were discovered to be less than one following this research.

This shows that the material's gap/broad grading is eroding. These can indicate that the material is degrading from its initial values by being inside a restricted range of gradation. Because ballast must be consistently and broadly graded, all of the sampled places Cu reveal that the ballast is losing its homogeneity and becoming well-graded, indicating that there is ballast deterioration beyond the intended limit that should be remedied by maintenance.

4.3. Los Angeles Abrasion test (LAA)

These tests were carried out as dry tests in accordance with AASHTO-T 96 protocols to determine the toughness or tendency for breaking of ballast particles. In comparison to the original sample weight, the Los Angeles abrasion value is the quantity of material finer than 1.7 mm sieve created during the test (ballast breakage). For trains with a larger axle load, this dimension is more important than the ballast used in the track. Tests were done on 8 separate locations along the Sebeta-Adama Railway Line, with a maximum of 22% and a minimum of 15% Los Angeles abrasion values reported.

Figure 13. LAA tested Material

Table 12. Summary of Los Angeles Abrasion Values of selected locations.

Summary of LAA test	
Locations	LAA Value %
56+00	18
61+687	21
02+00	17
17+400	15
35+00	15
93+500	19
70+280	17
112+800	22
Max	22

Because the rock type employed on this line is class one crushed rock, it is well known that it is abrasion resistant. And the test findings revealed that the material has a maximum LAA of 22%, indicating that it is still class one according to Chinese standards (Railway Ballast (2008)). [33]. When we compare these test results to several Standards, we find that they have a good ratio. The LAA Value for Railway Ballast should not exceed 40%, according to ASTM C131 (AREMA) and AS 2758.7 (Australian Standard).

4.4. Flakiness and Elongation Index

A good ballast particle interlock requires a minimum of elongated or flaky. Particle shape and texture have been recognized as having a major effect on railway track structure stability [22]. The tests for particle shape and texture are many as presented in different works of literature according to availability and time table the two common tests for shape factor are used in this study below.

4.5. Flakiness Index

Flatness and flakiness are different names for the same shape characteristic. Flaky particles are defined as one in which the ratio of thickness to width is less than 0.6.and flakiness index is the percentage by weight of flaky particles passing the gauge In The British Standard " BS EN933-3:199." For this study flakiness test is conducted according to Bz 812-105.1by following the procedures and the result recorded is presented in table13 that shows the as-built and material test results

Table 13. Summary for flakiness index test results

Flakiness Index Test Results summary	
Locations	**Flakiness Index(%)**
56+00	30
61+687	33
02+800	20
17+400	36
35+00	43
93+500	13
70+280	15
112+800	14
Max	43
Min	13
As-built Max values	27
As built Min values	12
Standard Used	<50

Within three years of service, the maximum and minimum flakiness index obtained for the test locations of the Sebeta-Adama Railway line showed a substantial increase. This may indicate that the ballast's sharp corners are prone to fracturing. It is usual to see significant/high sharp corner breaking when using new ballast for the first time. However, this is insufficient evidence to indicate that sharp corner breaking is the sole source of the rising flakiness index. According to site investigation and maintenance data, new materials used for maintenance could be the reason of these results, and according to the grading test, the original test result could also be incorrect. Because the normal (planned) flakiness index criterion for this line is less than 50.

4.6. Elongation Index

Elongation is another shape character of ballast material that affects the interlocking between particles and resilience of the ballast bed. According to British Standard BS 812-105.2: 1990, aggregates have a length (greatest dimension) of more than 1.8 of their mean sieve size. Following the procedure of "BS 812-105.2: 1990," in this study, the elongation index is found by separating the elongated particles and expressing their mass as a percentage of the mass of the sample tested.

Table 14. Summary for Elongation index test result

Elongation Index Test Results Summary	
Locations	Elongation Index %
56+00	29
61+687	29
02+800	27
17+400	47
35+00	39
93+500	16
70+280	28
112+800	20
Max	47
Min	16
As-built Max values	25
As-built Min values	14
Standard Used	<50

The elongation index of the material tested from all sampled locations shows an increase in elongation index, with two locations recording a very high elongation index of around 47 percent, according to the summary table of the test conducted concerning the designed standard and as-built test reports on table 14. This result indicates that the shape of the first ballast has changed, or that there is ballast breakage/degradation that requires attention, particularly in regions with >35 percent elongation index.

However, at a small proportion, these two shape features of ballast particles could boost shear strength and diminish settling for a lower rate of settlement accumulation. Flaky or elongated particles are also known to lead to greater particle breakdown and deformation [4]. As a result, the flakiness and elongation indexes recorded during these tests have revealed that there is significant ballast degradation in those areas of the line that require attention. In order to avoid a cumulative effect/deformation on the track, these shape factors should be considered, and maintenance materials should be kept to the designed standard.

4.7. Fouling Index Test

The fouling of ballast is progressive and can be influenced by many factors. In cases in which no environmental or operational detritus contaminates the ballast, ballast breakdown/degradation can be expected and may initially enhance stability by retaining ballast particles in place [34]. As Selig and Waters propose,

$$\begin{gathered}\mathrm{FI} = \text{Percentage by weight passing the sieves number four} + \\ \text{the percentage by weight passing the sieve number two hundred}\end{gathered}$$

The test is conducted in the laboratory for all of the eight locations of ballast sampled by sieving 35 kg of ballast through sieve number 4 and sieve number 200, respectively, and then adding the percentage passes of each sieve. So, according to the classification criteria of Fouling Index that Waters and Selig recommended, the fouling condition of the ballast is very low, which means that the FI is found below 2% in all locations, and the ballasts are classified as clean in three locations and moderately clean in five locations. Based on these FI data, we can assume that ballast breakage or deterioration is minimal, but given that the line has only been operational for about three years, these numbers are not entirely inconsequential. They can be utilized as a starting point for routine inspections and maintenance. According to other reports it is one of the most serious issues in reverse osmosis systems is the presence of suspended particles and colloidal elements in the feed water. Despite the fact that most systems include some pretreatment, such as 5 mm prefilters, tiny particles are to blame for fouling of reverse osmosis membranes.

Table 15.Summary of Fouling Index Test results

FI Test results summary		
Locations	FI %	Category
56+00	1.76	reasonably clean
61+687	0.63	Clean
02+800	0.4	Clean
17+400	1	reasonably clean
35+00	1.16	reasonably clean
93+500	0.27	Clean
70+280	1.5	reasonably clean
112+800	1.1	reasonably clean
Max	1.76	reasonably clean
Min	0.27	Clean

5. CONCLUSIONS AND RECOMMENDATIONS

Since January 1st, 2018G.c, the Ethio-Djibouti Railway line has been operational for three years. During this time, no serious examination of ballast degradation has been done. The purpose of this inquiry is to determine the state of the Sebeta-Adama railway line, which is part of the Ethio-Djibouti railway line and covers 115 kilometers. Eight spots were chosen based on their vehicle accessibility, criticality to save time and money, and the fact that these portions are crucial means the investigation's findings can be applied to the line's other non-vital sections. With the use of laboratory experiments, field inspections, and literature reviews, the level of line ballast deterioration, particle size distribution, ballast particle form, the Fouling index, and abrasion resistance is studied. Work on the ballast bed has also been examined for maintenance.

5.1. Conclusions

From the investigation held on Sebeta-Adama railway line ballast degradation, ballast particles are deteriorating and losing their designed grading, although they are still within the upper and lower limits of the designed grading. The coefficients of uniformity and curvature demonstrate that the ballast is still within the intended Cc and Cu ranges, although it is losing its broad grading and uniformity in both situations. This indicates that there is some ballast degradation or bigger particle fracture. Furthermore, the elongation and flakiness index shape property tests show that particle shape has been rapidly changing and the material is deteriorating. Even if these values are high after three years, it's fortunate that they haven't reached their maximum, and it's predicted that they would drop with time because ballast can break easily during the first few years of service.

The fouling index test shows that the fine materials found in the ballast are low, indicating that the ballast is clean or moderately clean. This indicates that even if the large particles are breaking and the designed grading's arrangement is changed at most of the locations, there is no high content of fouling in the ballast or that the material is not heavily contaminated with fines from other external sources. Based on the field inspection, it is concluded that the new materials used for maintenance are different from the original materials used in terms of grading, strength, durability, shape, and kind of parent rock because it is known that the designed and fabricated ballast materials are different.

According to the laboratory test results and field inspection, the ballast material on the Sebeta-Adama railway line has shown some degradation, which is not inconsequential given the service it has provided and the length of time it has been in service. On the line, the traditional ballast maintenance strategy (maintenance planning) is discovered to be based solely on track geometry conditions. That is, it does not reveal the mechanical properties of the ballast (i.e., the potential of ballast degradation). In other words, present practice focuses on the ballast's short-term activity while neglecting its long-term behavior. If this is not remedied, maintenance costs may rise, and the track's safety may be jeopardized.

5.2. Recommendations

The ballast layer deforms and degrades in railway operation as a result of traffic loads, material quality, design, construction, and maintenance processes, subgrade issues, weather conditions, and activities and incidents on the track. As a result, the ballasted foundation is subjected to numerous maintenance cycles such as tamping, ballast cleaning, and replacement processes in order to preserve the track performance within the acceptable requirements. Better planning, combined with a thorough examination of the ballast material's performance, is the key to extending ballast life and lowering maintenance costs. The following main points are provided as a recommendation from the inquiry done on the degradation of the Sebeta-Ada ma railway line.

•Maintenance should be done according to regular grading findings and required sizes to keep the ballast grading within the prescribed standard. And the maintenance method should be adjusted to focus on assessing the state of ballast materials utilizing various technology such as GPR (Ground-penetrating radar) to investigate ballast degradation.

•The elongation and flakiness index have increased at several areas of the track, indicating that the material is degrading, as evidenced by the experiments. The materials utilized for maintenance are different from the original materials and do not meet the requisite size and shape, according to the field inspection. As a result, the maintenance materials must be created and tested in accordance with the established standards.

•Other human activities, in addition to railway traffic, have been identified as the principal contributors of fouling material on the ballast bed surrounding undesigned crossings. This is because the fence around certain locations is damaged, allowing people to freely wander through the track without regard for their own safety, their cattle's safety, or the track's safety. As a result, fences should be maintained along the track to regulate human and animal activities. The source of fouling elements will be reduced, and the ballast bed will be protected from degradation.

• Regular inspections of the ballast materials and the ballast bed as a whole are required to protect the line from increased maintenance costs and ensure safe operation.

•As this analysis has revealed, the ballast material degrades at such a rapid rate that it necessitates frequent inspection and repair before reaching the intended standard's ultimate limit and failure.

•Additional studies of the material sources, reasons of degradation, and field tests on the ballast bed should be conducted, as well as the impact of this degradation on the track.

•The firm in charge of the line's operation and maintenance should be willing to allow external bodies to conduct such investigations and execute other performance evaluations.

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7. APPENDIX

Laboratory tests analysis

Test Method : BS EN 1097-2:1998 and ASTM C-535, Large Size Los Angeles Abrasion, LAA

sample
Location:56+300

Sieve Size, mm		Weight of Indicated Sizes, g		
		Grading		
Passing, (mm)	Retained, (mm)	1	2	3
75	63.0	2500 ± 50g	------	------
63.0	50.0	2500 ± 50g	------	------
50.0	37.5	5000 ± 50g	5000 ± 50g	------
37.5	25	------	5000 ± 25g	5000 ± 25g
25	19	------	------	5000 ± 25g
Total		10 000 ± 100g	10 000 ± 75g	10 000 ± 50g
No. of Spheres		12		
Number of Revolution		30 to 33r/min for 1000 Revolution		
Weight of Surcharge, g		5000 ± 25g		

Sieve Size, mm		Grading	Weight of Surcharge, (g)	Weight of Sample (g)	Total Weight of Sample (g)	Weight Retained on sieve No. 12 1.70-mm
Passing, (mm)	Retained (mm)					

50.0	37.5	2	5000	5000	10000	8247
37.5	25			5000		

Los Angeles Abrasion, LAA = 17.53%

Sample Location:	02+800					
Sieve Size, mm		Grading	Weight of Surcharge, (g)	Weight of Sample (g)	Total Weight of Sample (g)	Weight Retained on sieve No. 12 1.70-mm
Passing, (mm)	Retained (mm)					
50.0	37.5	2	5000	5000	10000	8380.1
37.5	25			5000		

Los Angeles Abrasion, LAA = 16.20%

Sample Location:	17+400					
Sieve Size, mm		Grading	Weight of Surcharge, (g)	Weight of Sample (g)	Total Weight of Sample (g)	Weight Retained on sieve No. 12 1.70-mm
Passing, (mm)	Retained (mm)					
50.0	37.5	2	5000	5000	10000	8513.1
37.5	25			5000		

Los Angeles Abrasion, LAA = 14.87%

Sample Location:	35+00

Sieve Size, mm		Grading	Weight of Surcharge, (g)	Weight of Sample (g)	Total Weight of Sample (g)	Weight Retained on sieve No. 12 1.70-mm
Passing, (mm)	Retained (mm)					
50.0	37.5	2	5000	5000	10000	8575.1
37.5	25			5000		

Los Angeles Abrasion, LAA = 14.25%

Sample Location:	93+500	

Sieve Size, mm		Grading	Weight of Surcharge, (g)	Weight of Sample (g)	Total Weight of Sample (g)	Weight Retained on sieve No. 12 1.70-mm
Passing, (mm)	Retained (mm)					
50.0	37.5	2	5000	5000	10000	8141.29
37.5	25			5000		

Los Angeles Abrasion, LAA = 18.59%

Sample Location:	61+687

Sieve Size, mm		Grading	Weight of Surcharge, (g)	Weight of Sample (g)	Total Weight of Sample (g)	Weight Retained on sieve No. 12 1.70-mm
Passing, (mm)	Retained (mm)					

50.0	37.5	2	5000	5000	10000	7932.2
37.5	25			5000		

Los Angeles Abrasion, LAA = 20.68%

Sample Location:	70+280					
Sieve Size, mm		Grading	Weight of Surcharge, (g)	Weight of Sample (g)	Total Weight of Sample (g)	Weight Retained on sieve No. 12 1.70-mm
Passing, (mm)	Retained (mm)					
50.0	37.5	2	5000	5000	10000	8380.1
37.5	25			5000		

Los Angeles Abrasion, LAA = 16.20%

Sample Location:	112+800					
Sieve Size, mm		Grading	Weight of Surcharge, (g)	Weight of Sample (g)	Total Weight of Sample (g)	Weight Retained on sieve No. 12 1.70-mm
Passing, (mm)	Retained (mm)					
50.0	37.5	2	5000	5000	10000	7857.2
37.5	25			5000		

Los Angeles Abrasion, LAA = 21.43%

Summery	
Locations	LAA Value %

56+00	18
61+687	21
02+800	17
17+400	15
35+00	15
93+500	19
70+280	17
112+800	22
Max	22
Min	15

Elongation and flakiness index analysis and results

Sample Location: 56+300

Test Method : BS 812-105.1 and ASTM D-4791, Flakiness Index, and Elongation Index

Total Weight of Ballast 35000 Gm

Sieve Size mm	Retained on BS Sieve, (mm)	Width of Slot in thickness gauge or special Sieve, (mm)	Weight Retained on Each Sieve, (gm)	Weight Passing Each Flakiness Gauge (gm)	Individual Percentage Passing Flakiness Index (%)
63.00	50.00	33.9 ± 0.3	7467.6	1979.43	7.19
50.00	37.50	26.3 ± 0.3	10199.6	3475.15	12.62
37.50	28.00	19.7 ± 0.3	7746.1	1754.73	6.37
28.00	20.00	14.4 ± 0.15	2115.4	1016.05	3.69
20.00	14.00	10.2 ± 0.15	0.0	0.00	-------
14.00	10.00	7.2 ± 0.1	0.0	0.00	-------
10.00	6.30	4.9 ± 0.1	0.0	0.00	-------
Total			27528.7	8225.4	

Flakiness Index = (Total weight Passing Flakiness Gauge,(gm) / Total weight of Ballast Sample)

Flakiness Index = 29.88%

Sieve Size mm	Retained on BS Sieve, (mm)	Width of Slot in thickness gauge or special Sieve, (mm)	Weight Retained on Each Sieve, (gm)	Weight Passing Elongation Each Gauge (gm)	Individual Percentage Passing Elongation Index (%)
50.00	37.50	78.7 ± 0.3	10199.6	2194.50	9.88

37.50	28.00	59.0 ± 0.3	7746.1	1481.73	6.67
28.00	20.00	43.2 ± 0.3	2115.4	1455.65	6.55
20.00	14.00	30.6 ± 0.3	2155.8	1223.60	5.51
14.00	10.00	21.6 ± 0.2	0.0	0.00	-------
10.00	6.30	14.7 ± 0.2	0.0	0.00	-------
Total			22216.9	6355.5	

Elongation Index = (Total weight Passing Elongation Gauge,(gm) / Total weight of Ballast Sample)

Elongation Index = 28.61%

02+800					
Sieve Size mm	Retained on BS Sieve, (mm)	Width of Slot in thickness gauge or special Sieve, (mm)	Weight Retained on Each Sieve, (gm)	Weight Passing Each Flakiness Gauge (gm)	Individual Percentage Passing Flakiness Index (%)
63.00	50.00	33.9 ± 0.3	3113.6	184.24	0.83
50.00	37.50	26.3 ± 0.3	12668.3	2112.52	9.51
37.50	28.00	19.7 ± 0.3	11077.5	2351.24	10.58
28.00	20.00	14.4 ± 0.15	2155.8	1044.49	4.70
20.00	14.00	10.2 ± 0.15	0.0	0.00	-------
14.00	10.00	7.2 ± 0.1	0.0	0.00	-------
10.00	6.30	4.9 ± 0.1	0.0	0.00	-------
Total			29015.2	5692.5	

Flakiness Index
=27%

Sieve Sizemm	Retained on BSSieve, (mm)	Width of Slot inthickness gaugeor special Sieve,(mm)	Weight Retained on Each Sieve, (gm)	Weight Passing Elongation Each Gauge (gm)	Individual PercentagePassing Elongation Index(%)
50.00	37.50	78.7 ± 0.3	12668.3	1628.76	75.55
37.50	28.00	59.0 ± 0.3	11077.5	2893.55	134.22
28.00	20.00	43.2 ± 0.3	2155.8	2461.39	114.18
20.00	14.00	30.6 ± 0.3	2155.8	521.64	24.20
14.00	10.00	21.6 ± 0.2	0.0	0.00	-------
10.00	6.30	14.7 ± 0.2	0.0	0.00	-------
Total			28057.4	7505.3	

Elongation Index = (Total weight Passing Elongation Gauge,(gm) / Total weight of Ballast Sample)=37%

Sample Location:	17+400				
Sieve Size mm	Retained on BS Sieve, (mm)	Width of Slot in thickness gauge or special Sieve, (mm)	Weight Retained on Each Sieve, (gm)	Weight Passing Each Flakiness Gauge (gm)	Individual Percentage Passing Flakiness Index (%)
63.00	50.00	33.9 ± 0.3	4073.13	1173.23	5.28
50.00	37.50	26.3 ± 0.3	9921.29	2608.64	11.74
37.50	28.00	19.7 ± 0.3	8383.22	3368.25	15.16
28.00	20.00	14.4 ± 0.15	3473.84	1968.32	8.86
20.00	14.00	10.2 ± 0.15	0.0	0.00	-------
14.00	10.00	7.2 ± 0.1	0.0	0.00	-------
10.00	6.30	4.9 ± 0.1	0.0	0.00	-------
Total			25851.5	9118.4	

Sieve Size mm	Retained on BS Sieve, (mm)	Width of Slot in thickness gauge or special Sieve, (mm)	Weight Retained on Each Sieve, (gm)	Weight Retained Elongation Each Gauge (gm)	Individual Percentage Passing Elongation Index (%)
50.00	37.50	78.7 ± 0.3	9921.29	2632.19	122.10
37.50	28.00	59.0 ± 0.3	8383.22	3206.55	148.74
28.00	20.00	43.2 ± 0.3	3473.84	4316.46	200.23
20.00	14.00	30.6 ± 0.3	0.0	0.00	0.00
14.00	10.00	21.6 ± 0.2	0.0	0.00	-------
10.00	6.30	14.7 ± 0.2	0.0	0.00	-------
Total			21778.4	10155.2	

Elongation Index = (Total weight Passing Elongation Gauge,(gm) / Total weight of Ballast Sample)

Elongation Index =

47%

Sample Location:	35+00				
Sieve Size mm	**Retained on BS Sieve, (mm)**	**Width of Slot in thickness gauge or special Sieve, (mm)**	**Weight Retained on Each Sieve, (gm)**	**Weight Passing Each Flakiness Gauge (gm)**	**Individual Percentage Passing Flakiness Index (%)**
63.00	50.00	33.9 ± 0.3	2953.22	1127.24	5.07
50.00	37.50	26.3 ± 0.3	7004.57	2621.49	11.80
37.50	28.00	19.7 ± 0.3	10081.15	2084.98	9.38
28.00	20.00	14.4 ± 0.15	3147.93	3973.55	17.89
20.00	14.00	10.2 ± 0.15	0.0	0.00	-------
14.00	10.00	7.2 ± 0.1	0.0	0.00	-------

10.00	6.30	4.9 ± 0.1	0.0	0.00	-------
Total			23186.9	9807.3	

Flakiness Index = (Total weight Passing Flakiness Gauge,(gm) / Total weight of Ballast Sample)

Flakiness Index = 42.30%

Sieve Size mm	Retained on BS Sieve, (mm)	Width of Slot in thickness gauge or special Sieve, (mm)	Weight Retained on Each Sieve, (gm)	Weight Retained Elongation Each Gauge (gm)	Individual Percentage Passing Elongation Index (%)
50.00	37.50	78.7 ± 0.3	7004.6	1679.40	77.90
37.50	28.00	59.0 ± 0.3	10081.2	2844.44	131.94
28.00	20.00	43.2 ± 0.3	3147.9	3374.95	156.55
20.00	14.00	30.6 ± 0.3	0.0	0.00	0.00
14.00	10.00	21.6 ± 0.2	0.0	0.00	-------
10.00	6.30	14.7 ± 0.2	0.0	0.00	-------
Total			20233.7	7898.8	

Elongation Index = (Total weight Passing Elongation Gauge,(gm) / Total weight of Ballast Sample)

Elongation Index = 39%

Sample Location:	93+500

Sieve Size mm	Retained on BS Sieve, (mm)	Width of Slot in thickness gauge or special Sieve, (mm)	Weight Retained on Each Sieve, (gm)	Weight Passing Each Flakiness Gauge (gm)	Individual Percentage Passing Flakiness Index (%)
63.00	50.00	33.9 ± 0.3	14180.77	1275.60	5.74
50.00	37.50	26.3 ± 0.3	5002.98	656.69	2.96
37.50	28.00	19.7 ± 0.3	4239.44	631.94	2.84
28.00	20.00	14.4 ± 0.15	1382.44	517.93	2.33
20.00	14.00	10.2 ± 0.15	0.0	0.00	-------
14.00	10.00	7.2 ± 0.1	0.0	0.00	-------
10.00	6.30	4.9 ± 0.1	0.0	0.00	-------
Total					

Flakiness Index =13%

Sieve Size mm	Retained on BS Sieve, (mm)	Width of Slot in thickness gauge or special Sieve, (mm)	Weight Retained on Each Sieve, (gm)	Weight Retained Elongation Each Gauge (gm)	Individual Percentage Passing Elongation Index (%)
50.00	37.50	78.7 ± 0.3	14180.77	1596.52	74.06
37.50	28.00	59.0 ± 0.3	5002.98	1006.02	46.67
28.00	20.00	43.2 ± 0.3	4239.44	1044.84	48.47
20.00	14.00	30.6 ± 0.3	0.00	0.00	0.00
14.00	10.00	21.6 ± 0.2	0.0	0.00	-------
10.00	6.30	14.7 ± 0.2	0.0	0.00	-------
Total			23423.2	3647.4	

Elongation Index = (Total weight Passing Elongation Gauge,(gm) / Total weight of Ballast Sample) =16%

Sample Location: 61+687					
Sieve Sizemm	Retained on BSSieve, (mm)	Width of Slot inthickness gaugeor special Sieve,(mm)	Weight Retained on Each Sieve, (gm)	Weight Passing Each Flakiness Gauge(gm)	Individual PercentagePassing Flakiness Index(%)
63.00	50.00	33.9 ± 0.3	3287.55	339.37	1.53
50.00	37.50	26.3 ± 0.3	5415.28	1083.03	4.87
37.50	28.00	19.7 ± 0.3	10022.72	2651.77	11.94
28.00	20.00	14.4 ± 0.15	5003.87	3592.96	16.17
20.00	14.00	10.2 ± 0.15	0.0	0.00	-------
14.00	10.00	7.2 ± 0.1	0.0	0.00	-------
10.00	6.30	4.9 ± 0.1	0.0	0.00	-------
Total			23729.4	7667.1	

Flakiness Index = (Total weight Passing Flakiness Gauge,(gm) / Total weight of Ballast Sample)

Flakiness Index = 33%

Sieve Size mm	Retained on BS Sieve, (mm)	Width of Slot in thickness gauge or special Sieve, (mm)	Weight Retained on Each Sieve, (gm)	Weight Retained Elongation Each Gauge (gm)	Individual Percentage Passing Elongation Index (%)
50.00	37.50	78.7 ± 0.3	5415.28	870.15	40.36
37.50	28.00	59.0 ± 0.3	10022.72	1519.92	70.50
28.00	20.00	43.2 ± 0.3	5003.87	3480.71	161.46
20.00	14.00	30.6 ± 0.3	0.0	0.00	0.00
14.00	10.00	21.6 ± 0.2	0.0	0.00	-------
10.00	6.30	14.7 ± 0.2	0.0	0.00	-------
Total			20441.9	5870.8	

Elongation Index = (Total weight Passing Elongation Gauge,(gm) / Total weight of Ballast Sample)

Elongation Index = 28.72%

Sample Location:	70+280				
Sieve Size mm	Retained on BS Sieve, (mm)	Width of Slot in thickness gauge or special Sieve, (mm)	Weight Retained on Each Sieve, (gm)	Weight Passing Each Flakiness Gauge (gm)	Individual Percentage Passing Flakiness Index (%)
63.00	50.00	33.9 ± 0.3	13997.6	2307.13	10.38
50.00	37.50	26.3 ± 0.3	11232.13	1145.25	5.15
37.50	28.00	19.7 ± 0.3	6131.43	1038.50	4.67
28.00	20.00	14.4 ± 0.15	1245.74	381.75	1.72

20.00	14.00	10.2 ± 0.15	0.0	0.00	-------
14.00	10.00	7.2 ± 0.1	0.0	0.00	-------
10.00	6.30	4.9 ± 0.1	0.0	0.00	-------
Total			32606.9	4872.6	

Flakiness Index = 14.94%

Sieve Size mm	Retained on BS Sieve, (mm)	Width of Slot in thickness gauge or special Sieve, (mm)	Weight Retained on Each Sieve, (gm)	Weight Retained Elongation Each Gauge (gm)	Individual Percentage Passing Elongation Index (%)
50.00	37.50	78.7 ± 0.3	11232.1	2255.72	104.63
37.50	28.00	59.0 ± 0.3	6131.4	1812.80	84.09
28.00	20.00	43.2 ± 0.3	1245.7	1047.76	48.60
20.00	14.00	30.6 ± 0.3	0.0	0.00	-----
14.00	10.00	21.6 ± 0.2	0.0	0.00	-------
10.00	6.30	14.7 ± 0.2	0.0	0.00	-------
Total			18609.3	5116.3	

Location 112+800					
Sieve Size mm	Retained on BS Sieve, (mm)	Width of Slot in thickness gauge or special Sieve, (mm)	Weight Retained on Each Sieve, (gm)	Weight Passing Each Flakiness Gauge (gm)	Individual Percentage Passing Flakiness Index (%)
63.00	50.00	33.9 ± 0.3	809.81	788.36	3.55
50.00	37.50	26.3 ± 0.3	9004.92	1930.03	8.69
37.50	28.00	19.7 ± 0.3	12543.04	1416.02	6.37
28.00	20.00	14.4 ± 0.15	10467.32	165.12	0.74
20.00	14.00	10.2 ± 0.15	0.0	0.00	-------
14.00	10.00	7.2 ± 0.1	0.0	0.00	-------
10.00	6.30	4.9 ± 0.1	0.0	0.00	-------

Total			32825.1	4299.5

Flakiness Index=14%

`Sieve Size mm	Retained on BS Sieve, (mm)	Width of Slot in thickness gauge or special Sieve, (mm)	Weight Retained on Each Sieve, (gm)	Weight Retained Elongation Each Gauge (gm)	Individual Percentage Passing Elongation Index (%)
50.00	37.50	78.7 ± 0.3	9004.92	2720.94	126.21
37.50	28.00	59.0 ± 0.3	12543.04	2850.55	132.23
28.00	20.00	43.2 ± 0.3	10467.32	817.05	37.90
20.00	14.00	30.6 ± 0.3	0.0	0.00	0.00
14.00	10.00	21.6 ± 0.2	0.0	0.00	-------
10.00	6.30	14.7 ± 0.2	0.0	0.00	-------
Total			32015.3	6388.5	

Elongation index=<u>20%</u>

Summary		
Locations	**Flakiness Index%**	**Elongation Index %**
56+00	30	29
61+687	33	29
02+800	20	27
17+400	36	47
35+00	43	39
93+500	13	16
70+280	15	28
112+800	14	20

Max	43	47
Min	13	16
Max values recorded from First Test	**27**	**25**
Max values recorded from First Test	**12**	**14**
Standard Used	**<50**	**<50**

Fouling Index analysis and results

Sieve Size,	56+300	02+800	35+00	70+280	61+687	17+400	112+800	93+500

mm								
Total Sample in (gm)	35000	35000	35000	35000	35000.00	35000.0	35000	35000
Material Passing through 4.75mm sieve, in (gm)	416.50	87.5	238.0	402.5	162.00	275.0	289.85	94.5
Material Passing through 0.075mm sieve, in (gm)	199.50	52.5	168.0	122.5	58.50	66.7	98.11	0.0
Material Passing through 4.75mm sieve, in (%)	1.19	0.25	0.68	1.15	0.46		0.79	0.27
Material Passing through 0.075mm sieve, in (%)	0.57	0.15	0.48	0.35	0.17	0.19	0.28	0.00
Fouling Index FI = % Pass 4.75mm + % Pass 0.075mm	1.76	0.40	1.16	1.50	0.63	1.0	1.1	0.27
Ballast Categories fouling defined by (Selig and Waters 1994)	reasonably clean	Clean	reasonably clean	reasonably clean	clean	reasonably clean	reasonably clean	Clean

Summery		
Locations	FI %	category
56+00	1.76	reasonably clean

61+687	0.63	clean
02+800	0.4	clean
17+400	1	reasonably clean
35+00	1.16	reasonably clean
93+500	0.27	clean
70+280	1.5	reasonably clean
112+800	1.1	reasonably clean
Max	1.76	reasonably clean
Min	0.27	clean

Grading(sieve analysis) &results

total Weight of Ballast Before Wash=35kg

		sample location =56+00					Design standard		As-built data	
Standard Sieve Size used during construction (mm)	Sieve Size used for the test (mm)	Mass Retained (gm)	%, Retained	Cumulative %, Retained	%, Passing	Commulative %, Passing	Lower Limit	Upper Limit	min	max
63.00	63.00	0.00	0.00	0.00	100.00	100.00	97.00	100.00	99.00	100.00
56.00	50.00	7928.58	22.65	22.65	77.35	77.35	92.00	97.00	92.00	96.00
45.00	37.50	10829.23	30.94	53.59	46.41	46.41	55.00	75.00	56.00	79.00
35.50	28.00	8224.28	23.50	77.09	22.91	22.91	25.00	40.00	25.00	38.00
25.00	25.00	2246.01	6.42	83.51	16.49	16.49	5.00	15.00	5.00	13.00
16.00	16.00	5038.44	14.40	97.90	2.10	2.10	0.00	5.00	0.00	2.00
	Passing 16mm Sieve, Pan	733.46	2.10	100.00	0.00	2.10				

Total Weight of Ballast Before Wash=35kg

		sample location =02+800					Design standard		As-built data	
Standard Sieve Size used during construction (mm)	Sieve Size Standard , (mm)	Mass Retained (gm)	%, Retained	Cumulative %, Retained	%, Passing	Commulative %, Passing	Lower Limit	Upper Limit	min	max
63.00	63	0	0.00	0.0	100	100	97	100	99.00	100.00
56.00	50	3113.64	8.90	8.9	91.1	91.1	92	97	92.00	96.00
45.00	37.5	12668.25	36.20	45.1	54.9	54.9	55	75	56.00	79.00
35.50	28	11077.47	31.65	76.7	23.3	23.3	25	40	25.00	38.00
25.00	25	2650.23	7.57	84.3	15.7	15.7	5	15	5.00	13.00
16.00	16	4798.13	13.71	98.0	2.0	2.0	0	5	0.00	2.00
	Passing 16mm Sieve, Pan	692.28	1.98	100.0	0.0	2.0				

Total Weight of Ballast Before Wash=35kg

		sample location =17+400					Design standard		As-built data	
Standard Sieve Size used during construction (mm)	Sieve Size Standard , (mm)	Mass Retained (gm)	%, Retained	Cumulative %, Retained	%, Passing	Commulative %, Passing	Lower Limit	Upper Limit	min	max
63.00	63.00	0.00	0.00	0.00	100.00	100.00	97.00	100.00	99.00	100.00
56.00	50.00	4073.13	11.64	11.64	88.36	88.36	92.00	97.00	92.00	96.00
45.00	37.50	9921.29	28.35	39.98	60.02	60.02	55.00	75.00	56.00	79.00
35.50	28.00	8383.22	23.95	63.94	36.06	36.06	25.00	40.00	25.00	38.00
25.00	25.00	3473.84	9.93	73.86	26.14	26.14	5.00	15.00	5.00	13.00
16.00	16.00	8506.26	24.30	98.16	1.84	1.84	0.00	5.00	0.00	2.00
	Passing 16mm Sieve, Pan	642.25	1.84	100.00	0.00	1.84				

		sample location =35+00					Design standard		As-built data	
Standard Sieve Size used during construction (mm)	Sieve Size Standard , (mm)	Mass Retained (gm)	%, Retained	Cumulative %, Retained	%, Passing	Commulative %, Passing	Lower Limit	Upper Limit	min	max
63.00	63.00	0.00	0.00	0.00	100.00	100.00	97.00	100.00	99.00	100.00
56.00	50.00	2953.22	8.44	8.44	91.56	91.56	92.00	97.00	92.00	96.00
45.00	37.50	7004.57	20.01	28.45	71.55	71.55	55.00	75.00	56.00	79.00
35.50	28.00	10081.15	28.80	57.25	42.75	42.75	25.00	40.00	25.00	38.00
25.00	25.00	3147.93	8.99	66.25	33.75	33.75	5.00	15.00	5.00	13.00
16.00	16.00	11074.87	31.64	97.89	2.11	2.11	0.00	5.00	0.00	2.00
	Passing 16mm	738.26	2.11	100.00	0.00	2.11				

	Sieve, Pan									

		sample location =Mojo					Design standard		As-built data	
Standard Sieve Size used during construction (mm)	Sieve Size Standard, (mm)	Mass Retained (gm)	%, Retained	Cumulative %, Retained	%, Passing	Commulative %, Passing	Lower Limit	Upper Limit	min	max
63.00	63.00	7110.65	20.32	20.32	79.68	79.68	97.00	100.00	99.00	100.00
56.00	50.00	14180.77	40.52	60.83	39.17	39.17	92.00	97.00	92.00	96.00
45.00	37.50	5002.98	14.29	75.13	24.87	24.87	55.00	75.00	56.00	79.00
35.50	28.00	4239.44	12.11	87.24	12.76	12.76	25.00	40.00	25.00	38.00
25.00	25.00	1382.44	3.95	91.19	8.81	8.81	5.00	15.00	5.00	13.00
16.00	16.00	2393.67	6.84	98.03	1.97	1.97	0.00	5.00	0.00	2.00
	Passing 16mm Sieve, Pan	690.05	1.97	100.00	0.00	1.97				

		sample location =61+687					Design standard		As-built data	
Standard Sieve Size used during construction (mm)	Sieve Size Standard, (mm)	Mass Retained (gm)	%, Retained	Cumulative %, Retained	%, Passing	Commulative %, Passing	Lower Limit	Upper Limit	min	max
63.00	63.00	0.00	0.00	0.00	100.00	100.00	97.00	100.00	99.00	100.00
56.00	50.00	3287.55	9.39	9.39	90.61	90.61	92.00	97.00	92.00	96.00
45.00	37.50	5415.28	15.47	24.87	75.13	75.13	55.00	75.00	56.00	79.00
35.50	28.00	10022.72	28.64	53.50	46.50	46.50	25.00	40.00	25.00	38.00
25.00	25.00	5003.87	14.30	67.80	32.20	32.20	5.00	15.00	5.00	13.00
16.00	16.00	10840.55	30.97	98.77	1.23	1.23	0.00	5.00	0.00	2.00

	Passing 16mm Sieve, Pan	430.02	1.23	100.00	0.00	1.23				

		sample location =70+280					Design standard		As-built data	
Standard Sieve Size used during construction (mm)	Sieve Size Standard, (mm)	Mass Retained (gm)	%, Retained	Cumulative %, Retained	%, Passing	Commulative %, Passing	Lower Limit	Upper Limit	min	max
63.00	63.00	967.56	2.76	2.76	97.24	97.24	97.00	100.00	99.00	100.00
56.00	50.00	13030.05	37.23	39.99	60.01	60.01	92.00	97.00	92.00	96.00
45.00	37.50	11232.13	32.09	72.08	27.92	27.92	55.00	75.00	56.00	79.00
35.50	28.00	6131.43	17.52	89.60	10.40	10.40	25.00	40.00	25.00	38.00
25.00	25.00	1245.74	3.56	93.16	6.84	6.84	5.00	15.00	5.00	13.00
16.00	16.00	1167.47	3.34	96.50	3.50	3.50	0.00	5.00	0.00	2.00
	Passing 16mm Sieve, Pan	1225.62	3.50	100.00	0.00	3.50				

		sample location =112+800					Design standard		As-built data	
Standard Sieve Size used during construction (mm)	Sieve Size Standard, (mm)	Mass Retained (gm)	%, Retained	Cumulative %, Retained	%, Passing	Commulative %, Passing	Lower Limit	Upper Limit	min	max
63.00	63.00	809.81	2.31	2.31	97.69	97.69	97.00	100.00	99.00	100.00
56.00	50.00	9004.92	25.73	28.04	71.96	71.96	92.00	97.00	92.00	96.00
45.00	37.50	12543.04	35.84	63.88	36.12	36.12	55.00	75.00	56.00	79.00
35.50	28.00	10467.32	29.91	93.79	6.21	6.21	25.00	40.00	25.00	38.00
25.00	25.00	892.91	2.55	96.34	3.66	3.66	5.00	15.00	5.00	13.00
16.00	16.00	799.35	2.28	98.62	1.38	1.38	0.00	5.00	0.00	2.00

	Passing 16mm Sieve, Pan	482.64	1.38	100.00	0.00	1.38				

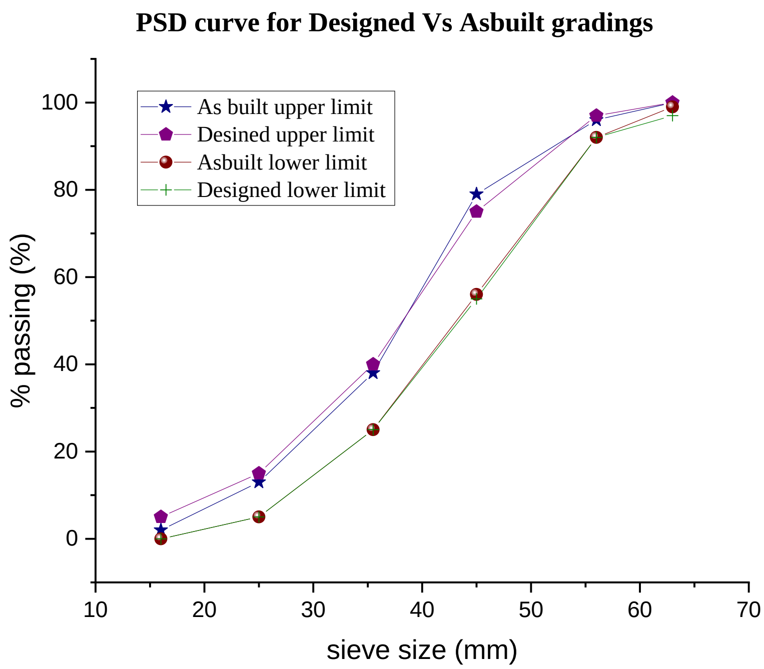
		Percentage passing											
locations		02+800	17+400	35+00	56+300	61+687	70+280	93+500	112+800	max of the first	uper limit of standard	min of the first	lower limit standard
sieve sizes													
63.00	63.00	100	100.00	100.00	100.00	100.00	97.24	79.68	97.69	100.00	100.00	99.00	97.00
56.00	50.00	91.1	88.36	91.56	77.35	90.61	60.01	39.17	71.96	96.00	97.00	92.00	92.00
45.00	37.50	54.9	60.02	71.55	46.41	75.13	27.92	24.87	36.12	79.00	75.00	56.00	55.00
35.50	28.00	23.3	36.06	42.75	22.91	46.50	10.40	12.76	6.21	38.00	40.00	25.00	25.00
25.00	25.00	15.7	26.14	33.75	16.49	32.20	6.84	8.81	3.66	13.00	15.00	5.00	5.00
16.00	16.00	2.0	1.84	2.11	2.10	1.23	3.50	1.97	1.38	2.00	5.00	0.00	0.00

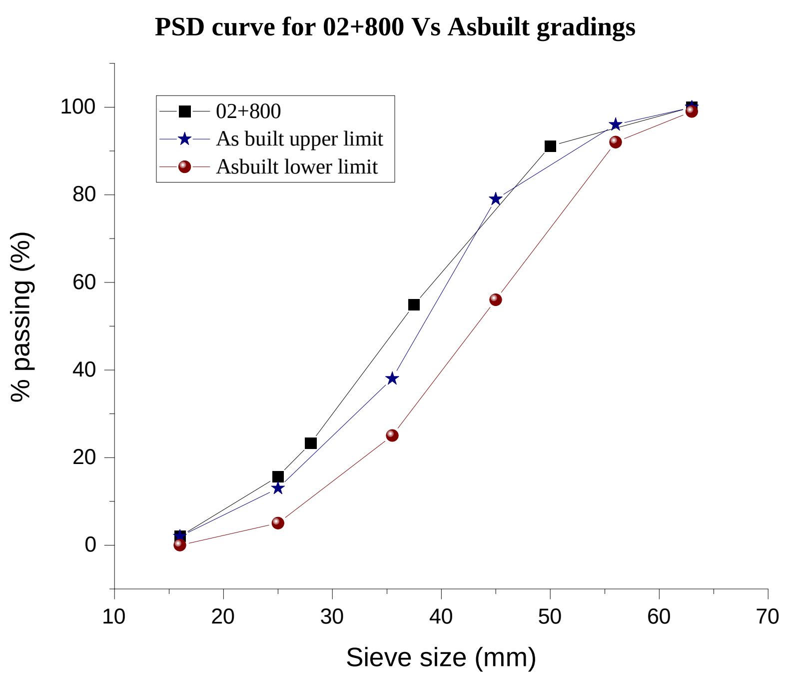
				D30
02+800	D60	39.26	1.85	30.02
	D10	21.27		
17+400	D60	37.49	1.97	26.17
	D10	19.02		
35+00	D60	33.69	1.85	23.93
	D10	18.24		
56+3	D60	42.9	2.0	30.8

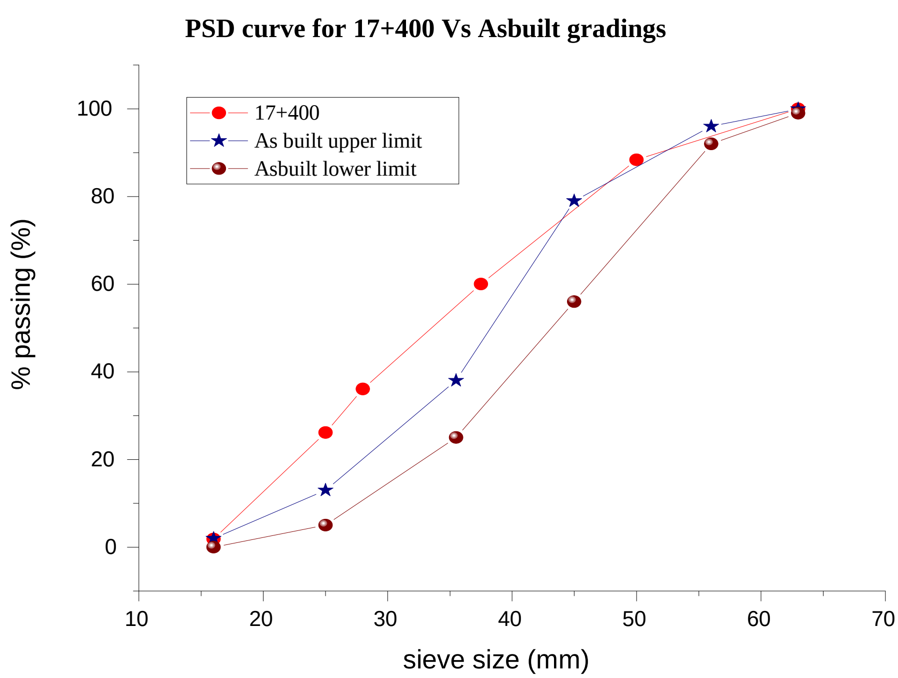
Summary of Cu Values		
Locations	**Cu= D60/ D10**	Cc=(d30)²/(D60D10)
Sebeta	1.85	1.08
Furi	1.97	0.96
Indode	1.85	0.93

00		9	5	7			
	D10	20.94			56+300	2.05	1.06
93+500	D60	56.68	2.19	41.98	61+687	1.75	0.99
	D10	25.90			Mojo	2.19	1.20
61+687	D60	32.48	1.75	24.36	Bishoftu	1.75	1.06
	D10	18.55			Adama	1.81	0.94
70+280	D60	50.00	1.81	38.31	DUL	2.00	1.17
	D10	27.67			DLL	1.68	1.07
112+800	D60	45.83	1.57	35.56	CUL	1.80	1.13
	D10	29.20			CLL	1.68	1.07
DUL	D60	40.93	2.00	31.30			
	D10	20.50					
DLL	D60	46.49	1.68	37.08			
	D10	27.63					
CUL	D60	40.60	1.80	32.14			
	D10	22.55					
CLL	D60	46.49	1.68	37.03			
	D10	27.63					

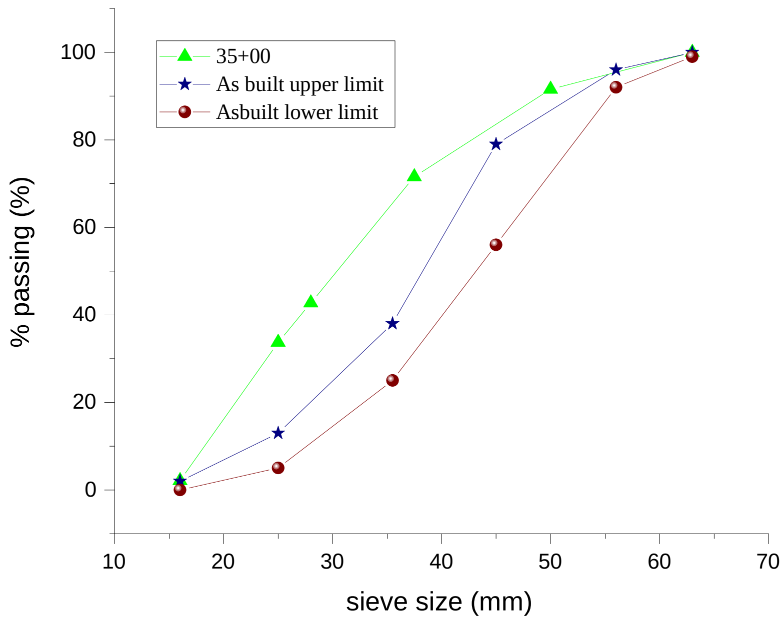
PSD Curves for all sampled locations' as-built grading


PSD curve for Designed Vs Asbuilt gradings
As built upper limit
Desined upper limit
Asbuilt lower limit
Designed lower limit
% passing (%)
sieve size (mm)
0
20
40
60
80
100
10
20
30
40
50
60
70

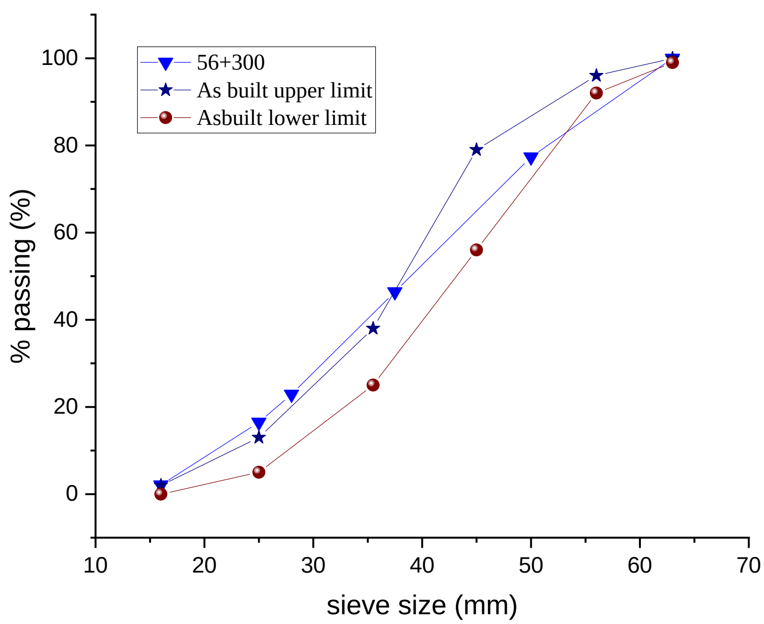

PSD curve for 02+800 Vs Asbuilt gradings
02+800
As built upper limit
Asbuilt lower limit
% passing (%)
Sieve size (mm)
0
20
40
60
80
100
10
20
30
40
50
60
70

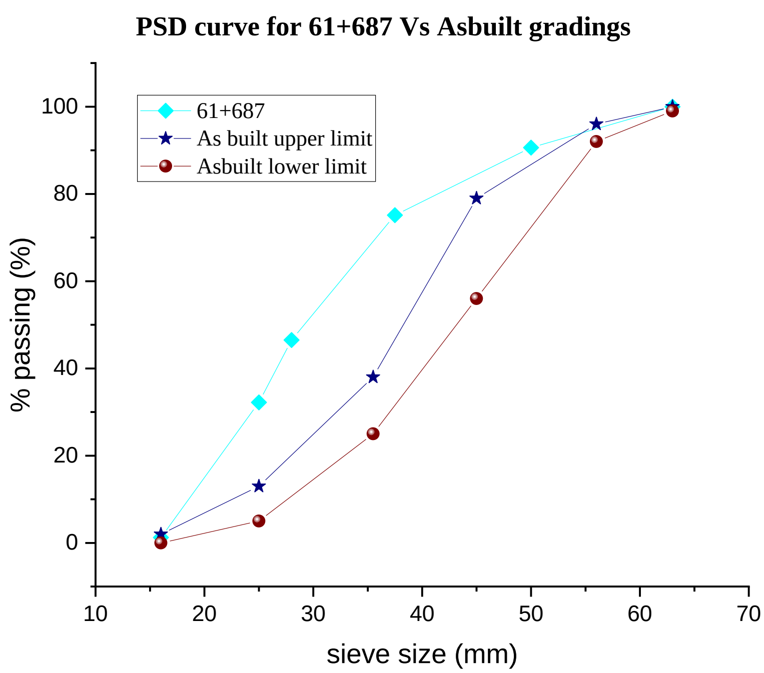

PSD curve for 17+400 Vs Asbuilt gradings
17+400
As built upper limit
Asbuilt lower limit
% passing (%)
sieve size (mm)
0
20
40
60
80
100
10
20
30
40
50
60
70

PSD curve for 35+00 Vs Asbuilt gradings

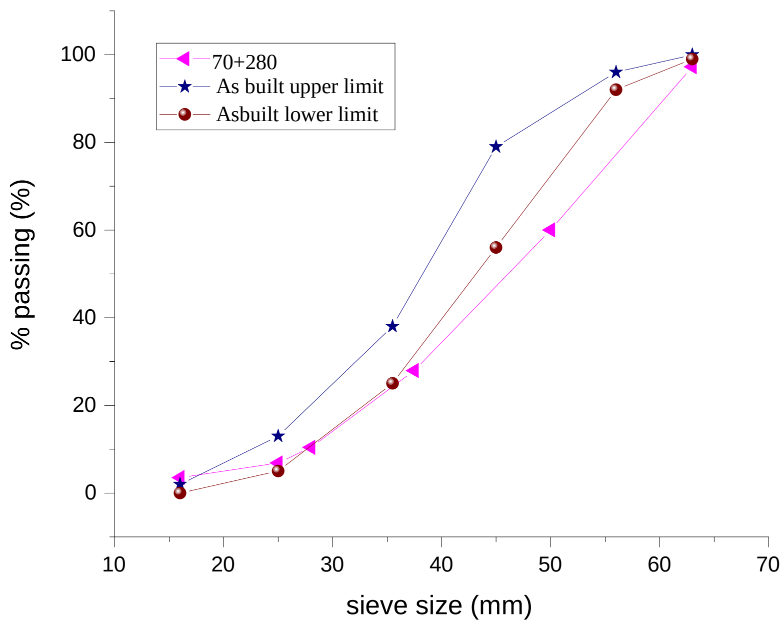


PSD curve for 56+300 Vs Asbuilt gradings

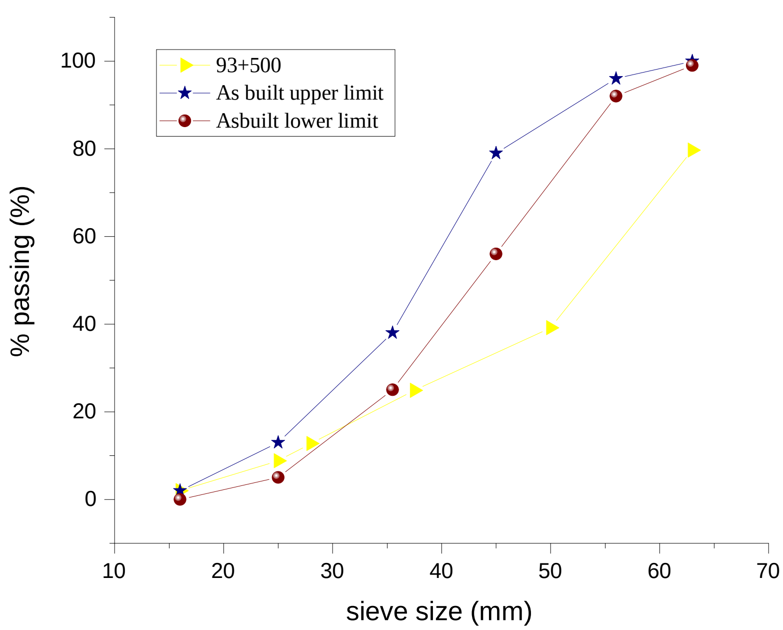


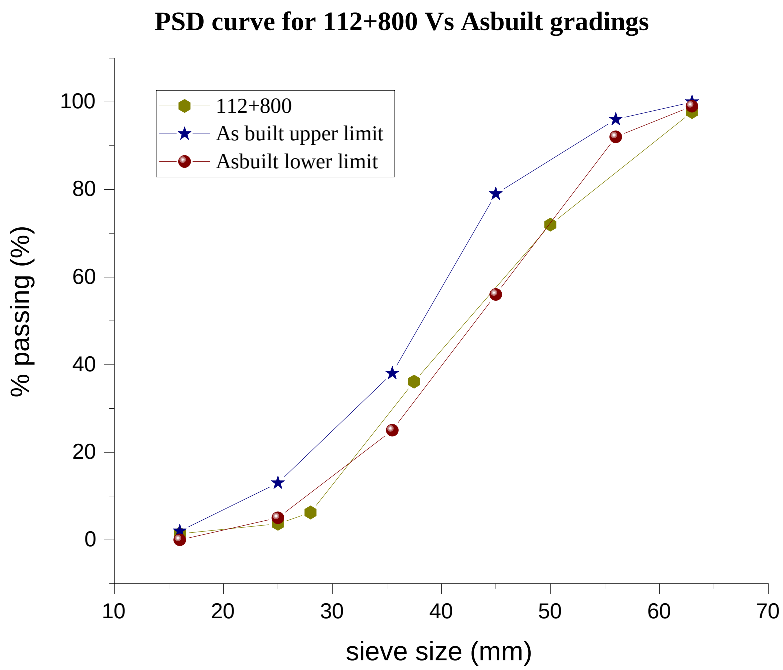

PSD curve for 61+687 Vs Asbuilt gradings
61+687
As built upper limit
Asbuilt lower limit
% passing (%)
sieve size (mm)
0
20
40
60
80
100
10
20
30
40
50
60
70

PSD curve for 70+280 Vs Asbuilt gradings

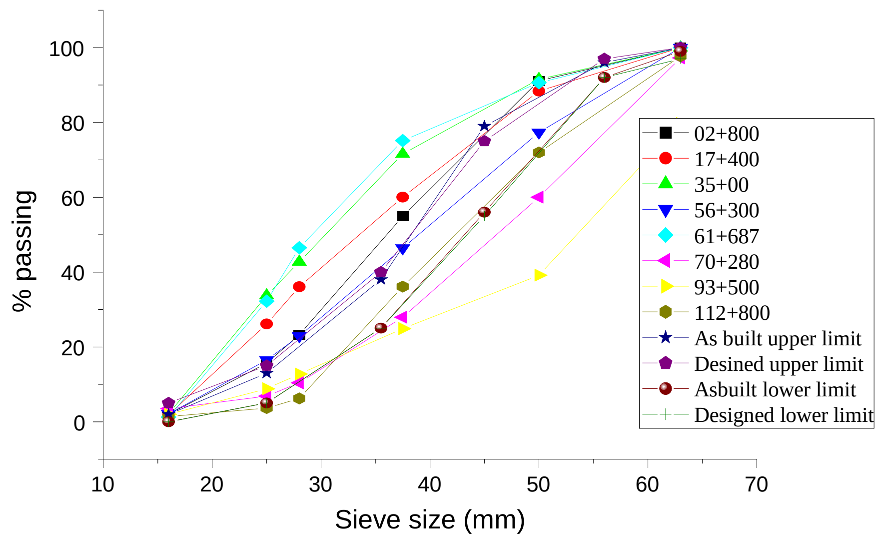


PSD curve for 93+500 Vs Asbuilt gradings




PSD curve for 112+800 Vs Asbuilt gradings
112+800
As built upper limit
Asbuilt lower limit
% passing (%)
sieve size (mm)
0
20
40
60
80
100
10
20
30
40
50
60
70

PSD curve for 8 locations Vs Asbuilt gradings



good ballast on straight line (non-critical)