



***Identifying and optimizing suitable source of ballast material
(Case study on Sebeta-Meiso-Dewalle railway project)***

**A thesis Submitted to the School of Graduate Studies of Addis
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Science in Civil Engineering in Railway stream**

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To My Parents Gebremedhin Mesfin & Belaynesh Equbaye

Table of content

Table of content-----	ii
Acknowledgment-----	v
List of tables -----	vi
List of figures -----	vii
Abstract-----	viii
1. Introduction-----	1
1.1 Background-----	1
1.2 General and specific objective of the thesis-----	2
1.3 scope of the thesis-----	3
1.4 Methodology of the study-----	3
1.5 research overview-----	3
2. Literature review-----	6
2.1 Ballast Material-----	6
2.2 Ballast function-----	6
2.3 Ballast structure-----	7
2.4 Ballast Characteristics evaluation-----	8
2.4.1 Mechanical property evaluation-----	11
2.4.1.1 Los Angeles Abrasion Test-----	11
2.4.1.2 Aggregate crushing value-----	12
2.4.1.3 Percentage finer passing no.200 sieve-----	12
2.4.1.4 Deval Attrition Test (DA) -----	13
2.4.2 Physical property evaluation-----	14

2.4.2.1 Loose and rodded unit weight-----	14
2.4.2.2 Bulk, Apparent specific gravity and Water absorption-----	14
2.4.2.3 flakiness/flatness index (FI) -----	14
2.4.2.4 Elongation index (EI) -----	15
2.4.3 Weathering test-----	15
3 Review of previously selected quarry site of the project -----	16
3.1 Selected quarry sites for different projects-----	16
3.2 currently selected quarry sites for Sebeta-Meiso-Negad project-----	25
4 Existing condition of the section project-----	27
4.1 Topography and Landform-----	27
4.2 Stratigraphical lithology and structure-----	27
4.3 Hydrogeological characteristics-----	28
4.4 Unfavorable geology and special rock & soil-----	28
4.4.1 Over hanging rock & rockfall-----	28
4.4.2 Talus-----	28
4.4.3 Ground fissures-----	29
4.4.4 Weak intercalated layer of bedrock-----	29
4.4.5 Seasonal flood-----	30
4.5 Geothermal energy-----	30
4.6 Seismic ground motion parameter-----	30
4.7 soil coverage-----	30
4.7.1 Swelling soil-----	31
4.7.2 Soft soil and mellow soil-----	31
4.8 Meteorological characteristics-----	31

5. Sample Collection and Detailed laboratory Test Results-----	33
6. Discussions and economic evaluation-----	42
6.1 Available volume on the quarry sites-----	42
6.2 Volume estimation for the case of single track from Adama to Awash-----	42
6.3 Economic Evaluation -----	46
6.3.1 Cost for fuel consumption of the train per km per m ³ -----	46
6.3.2 Cost for plantation of crushing plant and machineries (birr) -----	49
6.3.3 Cost of manpower (birr) -----	49
6.3.4 Cost for transportation of blending material from 4.3 km(birr) -----	49
6.3.5 Cost for general project time-----	50
7. Conclusions and Recommendation-----	51
7.1 Conclusions-----	51
7.2 Recommendation-----	52
8. Reference-----	53
9. Appendices: Detailed laboratory results-----	55
Appendix I. Gradation -----	55
Appendix II. Detailed laboratorial Tests for Sample A and B-----	56
Appendix III. Test for stabilizing agent-----	61
Appendix IV. Test for 20%- 80% mix-----	63
Appendix V. Test for 40%- 60% mix-----	65

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List of tables:

Table 2.1 AREMA 4A gradation-----	10
Table3.1 Consta JV’s suggested ballast requirements-----	18
Table3.2 Consta JV’s suggested ballast gradation-----	18
Table3.3 Consta JV’s suggested sub-ballast requirements-----	18
Table3.4 Consta JV’s suggested sub ballast gradation-----	19
Table3.5 Potential sources selected for Addis Ababa- Adama express way-----	20
Table3.6 Scot Wilson identified potential quarry stone sites-----	21
Table3.7 ERA’s Potential quarry stone sites along Addis-Mojo highway-----	22
Table.3.8 Proposed Quarry Sites for Ballast and Sub-ballast. -----	23
Table 5.1 limiting value for ballast material-----	36
Table 5.2 summary for test result (original sample, 20%-80%, 40%-60% mix) -----	36
Table 6.1summary for economic evaluation of quarry alternatives-----	50

List of figures:

Figure 2.1 cross sectional rail track structure-----	7
Figure 2.2 commutative frequency curve for AREMA 4A gradation-----	10
Figure 3.1 General topographical map for quarry sites in Ethio-Djibouti railway project ----	24
Figure 3.2 General location map of the currently selected quarry sites by the contractor-----	26
Figure 6.1 Typical single rail track substructure AREMA (2009) -----	43
Figure 6.2 assumed single rail track section for volume estimation. -----	43
Figure 6.3 General location map of quarry sites selected for study-----	45
Figure 6.4 General location map of the study areas with their respected coverage areas-----	46
Figure 6.5 simple sketches for Alternative 1 quarry configuration-----	47
Figure 6.6 simple sketch for Alternative 2 quarry configuration-----	48

Abstract:

Previously great attention has been given for the quality of track superstructure to improve the general technology of the railway scheme. But frequent research on track supporting materials show a good result which improves the general overall performance; safe ride with smooth wheel-rail steering ,high speed, minimum initial cost and accepted tolerance with respect to noise, and vibration .Generally positive whole life cycle analysis are the basic concern on the railway technology. And such a good quality in strength and life cycle of railway track component contribute high for the performance of the general track structure in different angles.

In Ethiopia, on the new projects of railway; ballast as a basic constitute and determinant part of the selected ballistic electrified track; many researches not yet done in maximizing its efficiency on the coming project.

And General selection of uneconomical quarry sites which is not located on the logical acceptable radius of the project , stated as the core problem of the thesis and their respected cost variation they experienced on the project studied in depth.

In order to elaborate it , case study is selected on recently undergoing Ethio -Djibouti railway project of section Sebeta - Meiso ; two uneconomical quarry sites (Adama-Awash) selected by the contractor which are located out of the logical economic radius pointed down.

The aim of this thesis is to access and study many different aspects which affect the general selection of the ballast materials; exploring additional quarry site in between Adama and Awash quarry sites and came with solution with minor blending with neighboring quarry to meet the required standard engineering properties.

Finally this thesis finds alternative and reasonable solution of quarry configuration (Adama-Arole-Awash) after detailed economic evaluation and acceptable laboratorial results which experience high cost minimization than currently selected quarry site configuration (Adama-Awash) by the contractor.

KEY WORDS: Railway; ballast quarry; engineering properties; economic evaluation, cost minimization

1. Introduction:

1.1 Background

The performance and required life span of the railway should become economically safe project. Tracks and switches are assets which will last for quite some years. The choice of a particular track system and the decision to use this system on certain lines, therefore, generally involves a decision which will hold good for 20 to 50 years. Consequently, such decisions must be taken with the future in mind, however it may be difficult to make a valid prediction. The only sure factor is that a certain degree of objectivity must be maintained vis-à-vis the present day situation and not too much emphasis placed on random everyday events.

When choosing a track system, every single track component requirements must be given due consideration and it is clearly necessary to form some idea of the axle loads and maximum speeds to be expected in the decades to come. After this the situation regarding the various track components, such as rails, sleepers, fastenings, switches, and ballast should be examined so that the optimum track design is obtained. Hence the cheapest ballast means that, a structure having low cost all over its service period. The overall service period is depend on the initial cost, duration of renewal, track and equipment maintenance and cost of train operation [1].

One of the biggest national projects undergoing in Ethiopia which is in Growth and Transformation Period of this decade is the national railway project .Even though, the new railway project is not the first railway network in the country, it can be put as one of the basic inspiration of the developing economy of trade and business.

Besides the Light Rail Transit (LRT) that is being built in the capital, Addis Ababa; there are eight corridors that centered the city; planned to the most efficient flow of economy, trade, national projects, large farms and general national interest.

In very broad, mega projects like the railway projects are center of financial, social, political and environmental questions. To reason out and answer for such questions engineers and socio-economical planner , have to put their deep knowledge. Beside this all, as a developing nation the project must attract and persuade international financial institutes to fund the project.

Generally speaking, we as a nation passed all thus steps and enter to the construction phases. Ballasted electrified railway track / classical railway track/ conventional track have been selected among many different types of railway tracks; passing different technical, economical, environmental and social perspectives.

Even ballasted railway track is new technology for this recent Ethiopian generation though it is one of the aged railway track through the world .On sighting efficiency , many researchers have been trying to improve and replace the old technology by the new one.

Since the beginning of the railways, the principle of the ballasted track structure has not changed substantially. Important developments after the Second World War include: introduction of continuous welded rail, use of concrete sleepers, heavier rail-profiles, innovative elastic fastenings, mechanization of maintenance, and introduction of advanced measuring equipment and maintenance management systems. As a result, the traditional ballasted superstructure can still satisfy the high demands, as demonstrated by the TGV-tracks in France.

As a railway infrastructure is a constitute of different schemes; its economical and technical evaluation resides on its different superstructures and divisions.

In such, Ballast is the basic constitute of the railway road substructure component of the selected ballasted electrified railway track, and functionally it distributes the train loads to the underlying supporting structure without failure.

Ballast can be constructed from different material sources like basalt, granite, slag and gravel [1]. The mechanical, physical and chemical composition of the construction material affects the performance of the ballast structure in general. Studying the ballast material composition in depth; identifying and optimizing suitable source in different angles of economics and structural acceptability, helps us in choosing the best source.

This research concentrates on the case study of the section project Adama-Awash section which is the largest corridor of the Ethiopian Railway Corporation project ; Sebeta -Meiso-Dewalle, It deals on quarry sites assessment and detailed economic evaluation within the currently selected Adama (E 0533787 N 0944624) - Awash (E 686376 N 1018032) quarry site by the contractor and alternative newly selected Adama Arole-(E 39⁰ 43' 15.14" N 8⁰ 57' 19.68") -Awash quarry site integration.

1.2 General and specific objective of the thesis

General objective:

- ✓ To evaluate mechanical and physical properties of alternative quarries and their economical feasibility.
- ✓ To comment on the currently selected quarries by the contractor with respect to the new alternative unselected quarries of close vicinity.

Specific objective:

- ✓ To investigate if the currently selected quarries (specific stretch of the project section) of ballast material are located on the accepted economical radius or not.
- ✓ To study and identify the lack/deficiency of the new alternative unselected quarry by the contractor which make it neglected.
- ✓ To investigate the unselected quarry can stabilize mechanically by blending or not?

- ✓ Evaluation of the currently selected quarries by the contractor and the new unselected quarries with its respective stabilizing agent.
 - economical feasibility(using detail economic breakdown)
 - structural feasibility.(using laboratorial test results)

1.3 scope of the thesis

The scope of the research on identifying and optimizing suitable source of the ballast material on the segment section of the railway project is:

- To identify an economical quarry site as good sources of ballast material along the corridor, taking into considerations:
 - Overburden thickness
 - Ease to exploit
 - Proximity to the route
 - Available volume
- To investigate the physical, mechanical and geometric properties of identified source. Using standard laboratory tests and checks whether the test results comply with standard Specifications for ballast material.
- To clarify detailed economic cost breakdown evaluation between currently selected quarry site by the contractor and unselected quarry sites configuration.
- Define geographic coordinates and locate on suitable topographic map.

1.4 Methodology of the study

The methodology followed to conduct the research for track ballast consists of literature review, secondary data collection, and primary data collection using field survey, evaluation using laboratory test results, detail laboratory tests and report compilation.

1.5 research overview

The study and alternative evaluation between the quarry sites; is done referencing the selected quarry sites by the Ethio -Djibouti railway project by the contractor:

- Adama quarry site , E 0533787 N 0944624
- Awash-Meiso quarry site, E 686376 N 1018032

These quarry sites are selected because they are literally within more than 120 km distances and though in practice , haulage distances of 30 km to 50 km are considered to be normal when compared with the costs and delays in shifting the rock crushing and batching plants, they are not logically accepted as they are economically feasible.

Therefore detailed assessments and field studies were carried on overall areas of the section project between Adama and Awash.

After detail study of the area based on overburden thickness ,ease to exploit ,available volume and proximity to the route a place called ' Arole ' Dk 196+300 , around 16 km from Metahera selected for study ; to scrutinize the variability of the material within a quarry site, two samples on the average are taken the identified sites. sample A (E 39⁰ 43' 15.14" N 8⁰ 57' 19.68") and sample B (E 39⁰ 43' 16.13" N 8⁰ 57' 21.76") are selected for laboratorial checkup and mechanical blast stabilizing agent around Beru hill Dk 192+000 selected.

The required volume of the selected places is estimated by the crew of field survey together with senior Chinese surveying, staff of CREC on site.

- ✓ Arole > 800,000 m³
- ✓ Beru (blast stabilizing Agent) > 300,000 m³

Selected quarry stones are grouped in family of basaltic rock; the blasting rocks which are much more strong and fresh than the two samples (A and B) are selected for the study.



Picture 1.1 Arole quarry site at Dk 196+300



Picture 1.2 Exploded materials near Mt. Beru at Dk 192+000

2. Literature review

2.1 Ballast Material:

Ballast as the main structure part of the railroad where the sleepers/ties are laid, its main function is to transfers the loads coming from the super structure to the subgrade without failure and providing good drainage, and an aggregate with the following property traditionally consider to be best material [2] i.e.

- Angular, crashed,
- Hard stones and rock
- uniformly graded
- free of dust, dirt and resistant to cementing action

2.2 Ballast function

Even though there are many more functions of the ballast structure, the following are the most important functions of ballast structure [2]:

1. Withstand the actions coming from the sleepers to the substructure. Those actions can be grouped as uplift, lateral and longitudinal forces.
2. Act as resiliency and energy absorbent for the track structure.
3. The voids between the aggregates provide space for movement and accumulation of crushed aggregates due to fouling.
4. Provide quick drainage system down to the structure.
5. Pressure reducing ballast structure to the allowable stress for the underlying structure just below the slipper.
6. Tamping will rearrange ballast particles while adjusting track geometry. This eases and speed up the maintenance operations.

Even though there are many more functions of the ballast structure, the following are the most important functions of ballast structure as a railroad structure:

1. Distribute wheel loads at reduced pressure to the subgrade
2. restrains the tack laterally and longitudinally
3. helps maintain track surface and
4. allows track structure to drain

Besides their structural functionality and flexibility there are some listed and proven advantage of ballasted track [3]:

- ✓ proven technology for over a century
- ✓ Relatively low construction costs
- ✓ simple replacement of track component
- ✓ relatively simple correction of track geometry (maintenance)
- ✓ small adjustments of track lay-out (curves) possible
- ✓ good drainage properties
- ✓ good elasticity
- ✓ good damping of noise etc

Even if it has same defects and disadvantages it is one of majorly chosen alternative type of railway track.

2.3 Ballast structure

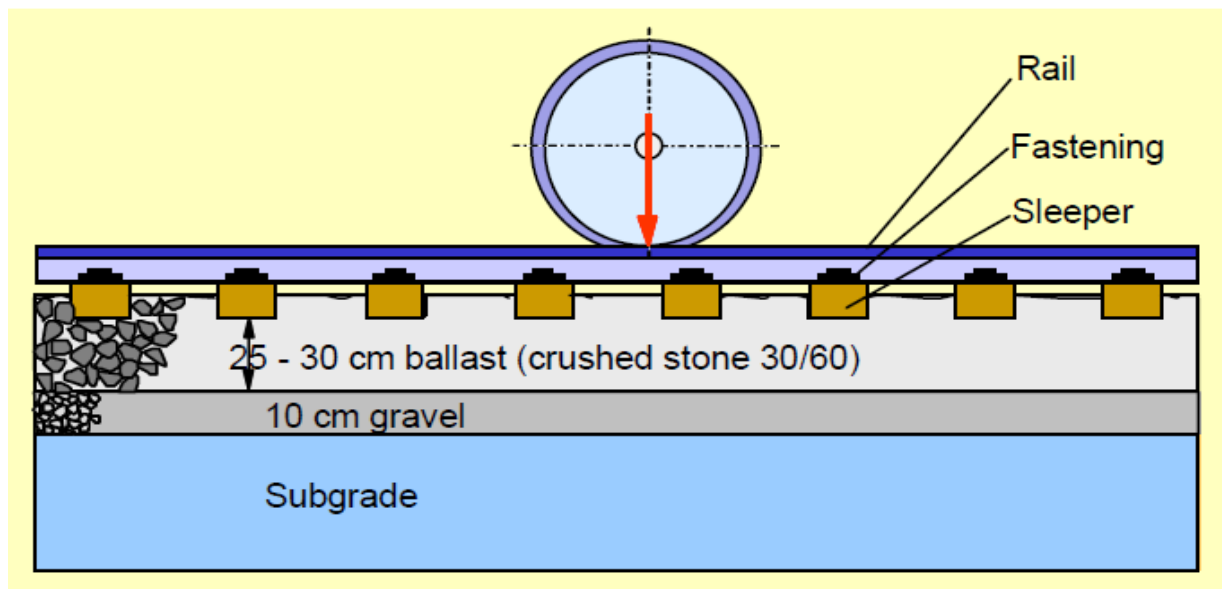


Figure 2.1 cross sectional rail track structure

The ordinary simplified ballasted track is a flexible track with cross sectional structure of [4]:

- Rail (continuously welded or jointed)
- Rail pad / fastening
- Prestressed concrete sleepers
- Ballast bed 25-30 cm
- Subballast bed 10cm
- Track formation layer/subgrade

A good mechanical property of ballast can be obtained from the combination of physical properties of the individual ballast material (i.e. particle size, shape, angularity, hardness, surface texture and durability) and its in-situ (i.e. in-place which results from compaction process) [2]. The degradation resulted due to train traffic and maintenance operation will round the aggregate particles and the traffic loading will break the aggregates consequently reduces the interlocking between inter-particles [5].

Ballasted track generally have the following shortcomings which arise due to “high frequency vibrations and uneven settlements”,

- It has irregular or uneven settlements with defects in different track positions.
- There is irregular ballast damage in rail defects, insulating rails, bridge approaches, and welded joints.
- After 30-60 million tons of service, when the settlement of the track exceeds 20 mm, general track maintenance is required and after 30 years of service the entire ballast structure needs to be changed [6]

2.4 Ballast Characteristics evaluation

Ballast material; as a basic component of the structural unit of the railway system ; should be resistant and free from the following individual or combined effect of chemical (failure coming due to reactions between different wastages and dust fines), mechanical (failure from moving train and dynamic loading on areas of weak joint like bolt of the rail), and environmental (repeated cycle of weather change, i.e. intensive wetting, drying , freezing and thawing). To get these parameters in a reasonable range, the ballast material should be naturally crushed aggregate. For better interlocking , the crushed aggregate should be angular with sharp edges. Generally, ballast material should be sufficiently tough to resist breakage under impact, hard to resist abrasion due to inter particle contact, dense enough to resist lateral forces and finally holding the ties in place [7].

In ballast structure construction for the sake of drainage requirement and major problem in degradation and permanent deformation ,uniformly graded aggregates are used. But when broadly graded aggregates used, more fines will be produced, it is because of train loads, which is the main reason for ballast contamination.

The typical material size used in ballast construction is having a nominal size of 20 to 50 mm. Most of the time, particles size between 6 to 64 mm diameters are used [8].

Naturally obtained and crushed, angular, rock material is good for ballast construction. To achieve better particle interlocking and to get the required resistance to dynamic loading in the transverse and longitudinal direction, angular stones are better than rounded shape.

When particles used bigger than the maximum size of the particle, there will be only some particles beneath the tie or sleeper which will distribute the load insufficiently to the subgrade. On the other hand, when too much smaller size particles are used than the minimum, the void between the bigger sizes will be filled with these particles exposing the structure for further drainage problem. [9] .

Class I ballast is used in the upper ballast layer of railway bench and **Class II** is used for sub ballast or as upper and sub ballast together at the private low traffic railways [10].

The preferred ballast materials would be a clean and graded crushed stone aggregate and/or processed slag with a hard, dense, angular particle structure providing sharp corners and cubicle fragments with a minimum of flat and elongated pieces. These qualities will provide for proper drainage of the ballast section. The angular material will provide interlocking qualities which will grip the ties more firmly to prevent movement. Flat and elongated particles in excess of the maximum as specified in the specification could restrict proper consolidation of the ballast section. The ballast must have high wear and abrasive qualities to withstand the impact of traffic loads without excessive degradation. The stability of the ballast section is directly related to the internal shearing strength of the assembly of ballast particles. The material must possess sufficient unit weight as set out in the specification to provide a stable ballast section. The ballast must also provide high resistance to temperature changes, chemical attack, exhibit a high electrical resistance and low absorption properties. A ballast material should be free of cementing properties .Deterioration of the ballast particles should not induce cementing together of the degraded particles ; Cementing reduces drainage capabilities, reduces resiliency, and provides undesirable distribution of track loads and in most instances results in permanent track and roadbed deformations. Cementing also interferes with track maintenance. Basically, all ballast materials are placed and tamped in the ballast section in accordance with similar maintenance practices. The materials are then subjected to basic loading patterns, however, There are several factors which will materially affect the in track performance and stability of ballast materials.

The gradation of a ballast material is a prime consideration for the track performance of ballast materials. The gradation must provide the means to develop the compactive or density requirements for the ballast section and provide necessary void space to allow proper run off of ground water; therefore, ballast gradations should be graded uniformly from the top limit to the lower limit to provide proper density, uniform support, elasticity and to reduce deformation of the ballast section from repeated track loadings [11].

A very important consideration is the selection of the proper gradation of the ballast material for concrete ties; which is heavier and less flexible to absorb impact loading and transmit greater loads to the ballast section than wood tie installation and transmit greater loads to the ballast

section and thus create higher crushing loads on the individual ballast particles. Consequently, the selection of ballast materials for concrete ties must be very restrictive to provide satisfactory track performance.

The early concrete tie installations were placed on ballast materials graded to the AREMA No. 4 (1½ inch- ¾ inches), resulting in good track performance, for the basic reasons of listed below:

- A consideration in the selection of the proper ballast gradation is the selection of ballast that will limit the amount of material removed from the track section during **undercutting** operations. Most undercutting operations remove all of the material below the ¾ inch size (below sieve size 4A). Limiting the amount of the inch material in the original gradation will reduce the amount of ballast removed when undercutting operations are used to clean and restore the track ballast section.
- The larger ballast gradations being used on the railroads today do not increase the **cost of tamping**, mechanization has eliminated most of the necessity for manual labor in the roadway maintenance practices.
- Difficulties of finer material in filling void space for track drainage.[11].

Table 2.1 AREMA 4A gradation

Sieve size (inch)	Sieve size (mm)	Percentage passing by weight
2½	63.5	100
2	50.8	90-100
1½	38.1	60-90
1	25.4	10-35
¾	19.05	0-10
⅜	9.525	0-3

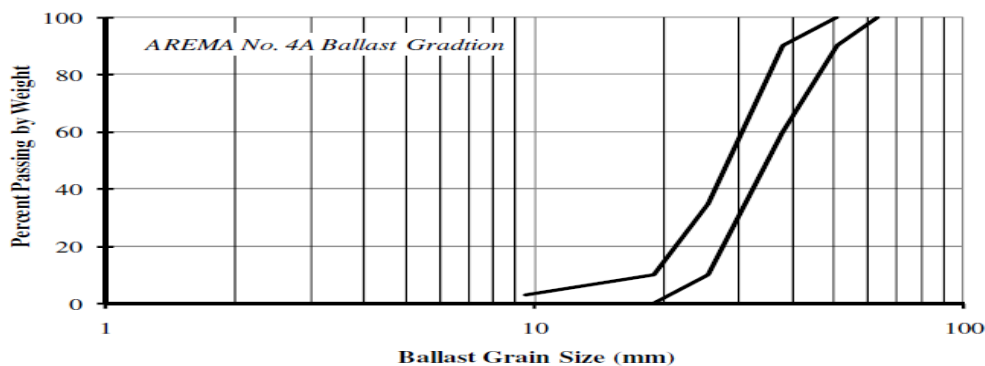


Figure 2.2 Commutative frequency curve for AREMA 4A gradation

Generally speaking, the performance of a ballast structure can be optimized by controlling particle characteristics and its physical state of the general assembly.

This dictates, the ballast structure can be affected not by single element behavior but by the cumulative effect of the mixed aggregate characteristics. The cumulative effect of the ballast material characteristics can be evaluated by its mechanical, physical and weathering test of the given material sample [2]

2.4.1 Mechanical property evaluation

This property evaluation, highly influenced by the aggregates characteristics of internal friction which helps to transmit the upcoming load to the underlying layer and then to sub grade and the particle needs to be characteristics hard enough to resist crushing, degradation and wear. The characteristics of the ballast particles can be measured by the following basic testing methods.

- Los Angeles Abrasion Test
- Aggregate crushing value
- percentage finer passing no. 200 sieve
- Deval Attrition Test (DA)

The American Railway Engineering Association (AREA) manual states, LAA is right now the first and the best way of measuring the potential to breakdown of ballast materials under loading. But this test can only measure the degree of abrasion ; in spite of the predominance of LAA test on North America railroads, it come up with lot of uncertainty or doubt on dependability of the test. The association is now found a supplementary test for LAA ; Deval test , the primary test recently used by British rail way is the [2].

2.4.1.1 los Angeles Abrasion Test

This test is a measure of degradation of mineral aggregates of standard grading resulting from a combination of actions including abrasion or attrition, impact, and grinding in a rotating steel drum containing 12 steel spheres. As the drum rotates, a shelf plate picks up the sample and the steel spheres, carrying them around until they are dropped to the opposite side of the drum, creating an impact-crushing effect. The contents then roll within the drum with an abrading and grinding action until the shelf plate picks up the sample and the steel spheres, and the cycle is repeated. After the prescribed number of revolutions, the contents are removed from the drum and the aggregate portion is sieved to measure the degradation as percent loss.

And this test has been widely used as an indicator of the relative quality or competence of various sources of aggregate having similar mineral compositions.

The results do not automatically permit valid comparisons to be made between sources distinctly different in origin, composition, or structure. Assign specification limits with extreme care in consideration of available aggregate types and their performance history in specific end uses[12].

Excessive abrasion loss of an aggregate will result in reduction of particle size, fouling of the ballast section, reduction of drainage and loss of supporting strength of the ballast section [11].

2.4.1.2 Aggregate crushing value

This test is a measure of degradation of mineral aggregates of standard grading resulting from continuously applied compression load. A test specimen is compacted in a standardized manner into a steel cylinder fitted with a freely moving plunger. The specimen is then subjected to standard loading regime applied through the plunger. This action crushes the aggregate to a degree which is dependent on the crushing resistance of the material. This degree is assessed by a sieving test on the crushed specimen and is taken as a measure of the aggregate crushing value (ACV).

Procedurally, Place the cylinder of the test apparatus in position on the base plate and add the test specimen in three layers of approximately equal depth, each layer being subjected to 25 strokes from the tamping rod distributed evenly over the surface of the layer and dropping from a height approximately 50 mm above the surface of the aggregate. Carefully level the surface of the aggregate and insert the plunger so that it rests horizontally on this surface. Take care to ensure that the plunger does not jam in the cylinder. Place the apparatus, with the test specimen prepared plunger in position, between the platens of the testing machine and load it at as uniform rate as possible so that the required force of 400kN is reached in $10 \text{ min} \pm 30 \text{ s}$.

After releasing the continually applied compression load, Sieve the whole of the test specimen on the tray on the 2.36 mm test sieve, and to get the ACV value calculate the percentage loss of the sample from the given sieve [13].

2.4.1.3 Percentage finer passing no.200 sieve

This test method is mainly important for the ballast structure drainage perspectives which excessive fines are produced in some types of crushing and processing operations and could restrict drainage and experience fouling of the ballast section [11].

A sample of the aggregate is washed in a prescribed manner, using either plain water or water containing a wetting agent, as specified. The decanted wash water, containing suspended and dissolved material, is passed through a 75- μm (No. 200) sieve. The loss in mass resulting from the wash treatment is calculated as mass percent of the original sample and is reported as the percentage of material finer than a 75- μm (No. 200) sieve by washing.

Material finer than the 75- μm (No. 200) sieve can be separated from larger particles much more efficiently and completely by wet sieving than through the use of dry sieving.

Therefore, when accurate determinations of material finer than 75 μm in fine or coarse aggregate are desired, this test method is used on the sample prior to dry sieving. The results of this test method calculated as the percentage loss of the sample from the given sieve.

Plain water is adequate to separate the material finer than 75 μm from the coarser material with most aggregates. In some cases, the finer material is adhering to the larger particles, such as some clay coatings and coatings on aggregates that have been extracted from bituminous mixtures. In these cases, the fine material will be separated more readily with a wetting agent in the water [14].

2.4.1.4 Deval Attrition Test (DA)

This test was initially used for highway materials quality measurement (attrition) in England. By then the British Rail (BR) use it for ballast performance testing method since it gives some clue about minimum durability of the ballast life corresponding to their climate and sleeper type [2].

The test can be conducted either in dry state or by adding equal amount of clean water. These states of testing ballast material have its own effect on the quality of the test. The value of wet attrition test has been to decrease as the test done repeatedly. This is because, the particle will be removed from the surface through testing and the degree of resistance of the particle attrition will be increased [2].

It can be evaluated by:

$$DA \equiv \left(\frac{W_i - W_r}{W_i} \right) \times 100 \text{ [\%]},$$

Where; W_i and W_r are the initial weight of the sample retained on 1.6 mm or 2.36 mm sieve size after test respectively, according to French railways and British railways [15].

2.4.2 Physical property evaluation

The physical behavior of ballast material can be estimated by evaluating the general properties of unit weight, bulk specific gravity, apparent specific gravity, water absorption, flakiness/flatness index and elongation index of the given sample.

2.4.2.1 Loose and rodded unit weight

Loose unit weight test method covers the determination of bulk density (“unit weight”) of aggregate in a compacted or loose condition, and calculated voids between particles in fine, coarse, or mixed aggregates based on the same determination.

The bulk density also may be used for determining mass/volume relationships for conversions in purchase agreements. However, the relationship between degree of compaction of aggregates in a hauling unit or stockpile and that achieved in this test method is unknown.

Further, aggregates in hauling units and stockpiles usually contain absorbed and surface moisture (the latter affecting bulking), while this test method determines the bulk density on a dry basis. A procedure is also included for computing the percentage of voids between the aggregate particles based on the bulk density determined by this test method [16].

The only way the rodded unit weight differs from the loose one, it involves placing the ballast in three layers having equal depth in the container. Each layer should be tamped twenty five times with a steel road

2.4.2.2 Bulk, Apparent specific gravity and Water absorption

The following three formulas can be used to estimate the bulk, apparent specific gravity and water absorption [2];

$$G_b = \left(\frac{D}{C - (A - B)} \right), \quad G_a = \left(\frac{D}{D - (A - B)} \right), \quad A_b = \frac{100 * (C - D)}{D}$$

Where:

G _b - Bulk specific gravity	A - Weight of container + sample + water
G _a - Apparent specific gravity	B - Weight of container + water
A _b - Water Absorption (%)	C - Weight of sample in surface dry and saturated condition
	D - Weight of oven dried sample.

2.4.2.3 flakiness/flatness index (FI)

This test is required to know the proportion of flaky aggregate from a given sample; as an aggregate became flakier the tendency of the ballast block to slip and crush into pieces increase because of the interlocking of the aggregate material decrease.

The Aggregate particles are classified as flaky when they have a thickness (smallest dimension) of less than 0.6 of their mean sieve size, this size being 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. And calculated as percentage pass from the flakiness sieve over the total sample [17].

2.4.2.4 Elongation index(EI)

This test is required to know the proportion of elongated aggregate on a given sample; as an aggregate became elongated the capacity to carry certain specified load decrease also the failing of ballast section follows.

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 being 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 sample tested. And calculated as percentage retain from the elongation sieve over the total sample [18].

2.4.3 Weathering test

Soundness test by sodium and magnesium sulfate is the mainly used tests for checking of an aggregates resistance due to environmental effect.

Thus test method covers the testing of aggregates to estimate their soundness when subjected to weathering action in concrete or other applications. This is accomplished by repeated immersion in saturated solutions of sodium or magnesium sulfate followed by oven drying to partially or completely dehydrate the salt precipitated in permeable pore spaces. The internal expansive force, derived from the rehydration of the salt upon re-immersion, simulates the expansion of water on freezing. This test method furnishes information helpful in judging the soundness of aggregates when adequate information is not available from service records of the material exposed to actual weathering conditions.

Values for the permitted-loss percentage by this test method are usually different for fine and coarse aggregates, and attention is called to the fact that test results by use of the two salts differ considerably and care must be exercised in fixing proper limits in any specifications that include requirements for these tests. The test is usually more severe when magnesium sulfate is used; accordingly, limits for percent loss allowed when magnesium sulfate is used are normally higher than limits when sodium sulfate is used[19].

3. Review of previously selected quarry site of the project

Different investigations have been made in the past with the aim of developing major roads passing through the vicinity of the project area. More importantly, a recent study has been made for the rehabilitation of the existing Ethiopia – Djibouti railway line, which is over 100 years old and has been in a very bad shape for a long time [20]

3.1 Selected quarry sites for different projects

Summaries of the available reviewed documents are given below

I. Italferr-sis. t.a.v.s.p.a., Rome, Italy

“Evaluation of the minimum emergency physical repair works needed on the " chemin de fer Djibouto-Ethiopien, 1997.”

This is one of the studies made on the rehabilitation of the old Ethiopia-Djibouti railway line. However, it does not have relevant information with regard to available construction materials for ballast and sub-ballast because material investigation was out of the scope of the study. The main tasks of the study were inspection of the old railway structure (horizontal and vertical trend, typical section, ballast, condition of tracks, drainages, tunnels), evaluation of safety of steel bridges, analysis of the running system (traffic, organization and safety), priority ratings of measures to be taken, design major components of the emergency measures, and preliminary recommendation for long-term rehabilitation.

II. Ethiopian Road Authority and Gauff JBG Ingenieure

“Awash – Hirna – Dengogo & Dire Dawa – Dengogo – Harrar Road Upgrading Project, Design Review, Material Report, 1998.”

This study was aimed at the rehabilitation and upgrading of the existing Awash – Hirna – Dengogo and Dire Dawa – Dengogo – Harrar road and structures, to a two lane asphaltic surfaced road with a 7 m carriage-way width and 1.5 m shoulders over the existing total length of 312 km. It should be noted that this study will not be of direct use to the bankable feasibility study because most part of the project route is far away from the proposed railway corridor. Material investigation for this project was carried out by Messrs. DHV Consultants BV in association with Associate Engineering consultants, Pr. Ltd and reviewed by Gauff JBG Ingenieure. The review was done with respect to:

- Soils existing along the road alignment.
- Properties and suitability of existing embankments.
- Sources, quality and quantity of construction materials available along the project road.
- Testing methods and criteria adopted in selecting materials for earthworks, pavement layers, and concrete works.

Potential rock sources, which can be considered for providing suitable aggregates and crushed rock for concrete works, base and asphalt concrete, have been identified at several stations along the alignment. The identified rock sources include basalt, limestone and sandstone rock types.

According to the report, dismantling of a hardstone crushing and batching plants from one site and re-erecting the same on another site haulage distances of 30 km to 50 km are considered to be normal when compared with the costs and delays in shifting the rock crushing and batching plants. During the review study, samples tested were hand-picked from the surface of the rock outcrops which have been exposed to the weathering agents, hence, marginal mechanical strength test results of aggregate crushing value (ACV), Los Angeles Abrasion (LAA), and Soundness were obtained but are expected to improve with depth. Therefore, the report recommended that selection of materials from such sources and assessment of the hardness properties with depth be monitored during exploitation.

III. Consta JV and Addis Environmental Services

“Basalt Quarry Investigation for Djibouti-Ethiopia Railway Line Rehabilitation Project (Dire Dawa – Lassarat Section).”

This is the most recent study on the rehabilitation of the old railway line and contains the most relevant information on material investigation for ballast and sub-ballast. However, the study covers about 114 km stretch only-from Dire Dawa to Lasarat section, Where the rehabilitation project has been implemented. The investigation identified and located the following three quarry sites that

- El Bahay- 20 km from Dire Dawa
- Millo - 64.4 km from Dire Dawa
- Adigalla - 111.4 km from Dire Dawa

In addition to this, specifications of Ballast and Sub- ballast materials to be used in the rehabilitation project have been provided s summarized below.

i) Ballast material shall comply with the following requirements:

- It shall consist of crushed stone, and be free from clay, debris, and organic or other deleterious matter. Weathered rock shall not be accepted.
- It shall be angular in shape with all dimensions approximately equal, it shall be free from dust.

Table 3.1 Consta JV's suggested ballast requirements[20]

Parameter	Values
Density	- minimum 1400 kg/m ³
Abrasion	- < 22%
Crush resistance	- 120/ 140 N/mm ²
Aggregate Impact Value	- < 22%
Water Absorption Value	- < 0.5%
Elongation Index	- < 25%
Flakiness Index	- < 25%
Contamination with fine material	- < 1%
Grading	- See Table below

Grading of crushed stone truck ballast shall be in accordance with the following table.

Table 3.2 Consta JV's suggested ballast gradation

Sieve (mm)	70	64	45	32	1
% passing	100	93-100	25-55	0-7	0-1

ii) **Sub-ballast material** shall comply at minimum with the following requirements:

Table 3.3 Consta JV's suggested sub-ballast requirements

Parameter	Recommend values
Organic content	- < 0.2% of the weight of the material fraction passing sieve size 2 mm (UNE 103 – 204: 1993)
Sulphate content	- < 0.2% of the weight of the material fraction passing sieve size 2 mm (UNE 103 – 201: 1993)
Los Angeles Abrasion	- < 28%
Water Absorption	- < 22%
Coefficient of permeability measured on samples compacted at 100% Proctor MDD should be less than or equal to 10 ⁻⁶ m/s. If the coefficient of Permeability is greater than 10 ⁻⁶ m/s, the test has to be repeated on other similar representative samples to obtain the coefficient of permeability of the real situation. It has to be noted that this test on Sub-ballast is applicable only if it is laid on top of an impermeable embankment.	
CBR	- > 20 at 95% of modified AASHTO density
Grading	- See table below.

Grading of crushed stone truck sub-ballast shall be in accordance with the following table.

Table 3.4 Consta JV's suggested sub ballast gradation

Sieve size (mm)	40	31.5	16	8	4	2	0.5	0.2	0.063
% passing	100	90-100	85-95	65-80	45-65	30-50	10-40	5-25	3-9

The following parameters have to be satisfied along with the gradation:

- Coefficient of Uniformity, $C_u \geq 14$.
- Coefficient of Curvature, $1 \leq C_c \leq 3$.
- Sand equivalent shall be greater than 45% for the material passing through sieve size 2 mm.
- For cases where sub-ballast material is in contact with the sub grade (embankment) material in which the percentage passing of fine materials (passing sieve size 0.063 mm) is greater than 15% of the weight of material passing through Sieve 63; one has to make sure that the following conditions are satisfied for the sub-ballast.
 - Percentage of Sand material (2 to 0.063 mm) has to be more than 30% of the total weight of the sub-ballast sample.
 - Percentage fraction passing sieve size 0.2 mm has to be in the range from 20 to 25% of the total weight of the sub-ballast sample.

IV. Scot Wilson Kirkpatrick & Co Ltd

“Addis Ababa – Adama Express way,2007.”

This study deals with the Addis Ababa – Adama express highway. The aim of the construction material investigation was to locate suitable construction material sites along the project route.

The investigation and search for construction materials included:

- Natural granular material for use as subbase.
- Borrow material for embankment fill.
- Hard rock/ Quarry stones for crushed aggregate and masonry works
- Sand for concrete structures.
- Water for compaction and for use in concrete

During the investigation, emphasis was given to identify potential material sites taking into consideration the following factors as appropriate.

- Overburden thickness
- Suitability of extraction and quarry development
- Proximity to the alignment and ease for developing access
- Sufficient quantity
- Impact on the environment and local settlement

The most relevant information to this report is the availability of quarry stone sources. According to the report, suitable quarry stone sources for aggregate are available at points along the project corridor although some hauling will be required. The majority of the identified quarries comprise basalts that are often fresh and strong. A total of three potential sources have been identified as summarized below.

Table 3.5 Potential sources selected for Addis Ababa- Adama express way[20]

Sr. No.	Station	Material Type	Overburden	Est. Quantity	Access
1	Km 10.00, Lt, 250 m	Basalt	Nil	300,000 m ³	Existing earth road
2	Km 41.5, Rt 3.5 km	Basalt	Nil	> 300,000 m ³	Needs earth road
3	Km 76.5, Rt 500 m	Basalt	Nil	> 250,000 m ³	Needs earth road

V. Ethiopian Road Authority and Scot Wilson

“Preparatory Study for the Upgrading of Meiso – Diredawa –Dewelle Road” (2008)

This study deals with the Meiso – Diredawa – Dewelle road upgrading Project and provides very useful and detailed geotechnical investigation data. Tasks in this study included a detailed geotechnical evaluation to assess the current road condition, subgrade material properties, sources of construction materials along the alignment, bridge site investigations and pavement design. The subgrade investigation in this study (which included study and treatment of expansive soils along the route) can be used as a very good basis for the subgrade investigation of the part of the railway passing through this route (Meiso – Dire dawa junction). In this study, a thorough search has been conducted to locate suitable construction material sites along the project road. Identification of suitable new and existing material sites was carried out taking into consideration the following factors.

- Overburden thickness
- Suitability of extraction and quarry development
- Proximity to the alignment and those with existing access, otherwise those that are simple for opening access;
- Sufficient quantity
- Impact on the environment and local settlement

The report indicated that suitable quarry stone sources for aggregate crushing are fairly available between Hidinu and Dewelle and moderately scarce between Mieso and Hidinu junction. They are mostly basalts, limestone and trachytic tuff that are often fresh and strong.

A total of 13 potential quarry stone sites have been identified .

Table 3.6 Scot Wilson identified potential quarry stone sites[20]

Sr. No.	GPS	Material Type	Overburden	Est. Quantity	Access
1.	E 698608 N 1024583	Basalt	Nil	>100,000 m ³	Existing earth road
2.	E 720753 N 1049059	RHYOLITE	Nil to 0.5	> 100,000 m ³	Adjacent to the road
3.	E 731827 N 1054059	RHYOLITE	Nil	> 100,000 m ³	Adjacent to the road
4.	E 737609 N 1056294	RHYOLITE	Nil to 0.5	> 80,000 m ³	Adjacent to the road
5.	E 763516 N 1053695	LIMESTONE	Nil	50,000	Existing earth road
6.	E 813250 N 1071602	LIMESTONE	Nil	>100,000	Existing earth road
7.	E 826054 N 1071917	LIMESTONE	Nil	>100,000	Existing earth road
8.	E 187415 N 1087897	BASALT	Nil	>50,000	Adjacent to the road
9.	E 209393 N 1105846	BASALT	Nil	>100,000	Adjacent to the road
10.	E 226821 N 1132901	BASALT	Nil	>50,000	Needs to construct accesses road
11.	E 234369 N 1160659	LIMESTONE,	Nil	>100,000	Existing earth road
12.	E 235108 N 1189779	BASALT	Nil	>100,000	Existing earth road
13.	E 244358 N 1206574	LIMESTONE	Nil	>50,000	Existing earth road

VI. Ethiopian Road Authority

“Addis Ababa – Modjo Road Maintenance Project.” (2009)

This study deals with the Addis Ababa–Modjo road maintenance project. In this study, a search has been made to locate suitable construction materials for the pavement maintenance/rehabilitation measures along the project route. The search included:

- Quarry stone for crushed aggregate and masonry works.
- Borrow material for sub-base/ embankment and improved sub grade of capping layer on realignment and detour (if any)
- Water for compaction and concrete work.
- Sand for concrete and mortar works.

The report indicated that suitable rock, which can be used for crushing and production of quality aggregate, is generally available along the project route. Most of the quarries identified are made of fresh and strong basalt. Their top part is, however, mostly weathered and fractured that could be used as sub base layer. A total of four potential sources have been identified as summarized below.

Table 3.7 ERA’s Potential quarry stone sites along Addis-Mojo highway[20]

Station	Offset	GPS	Est. Quantity (m ³)
10+00	LHS/500 m	Easting 488451 Northing 973355	> 100,000
10+500	RHS	Easting 481836 Northing 975565	100,000
34+500	RHS 1.5 km	Easting 503759 Northing 983680	4000
38+500	RHS 500m	Easting 506724 Northing 956694	75,000

vii. Material Investigation for Track Ballast and Sub-ballast for BFS of Addis Ababa-Djibouti Railway Project ,AAIT (2011)

On this study different scholars with different disciplines involve on selection of twelve potential quarry sites on the required project.

Table 3.8 Proposed Quarry Sites for Ballast and Sub-ballast. [20]

No.	Site Name	GPS	Type	Overburden (m)	Vegetation	Access	Est. Qty (m ³)	Remark
1.	Dukem	E 487476 N 973316 (37P)	BASALT	Nil to 0.5	Nil	Existing earth road	>1,000,000	Existing quarry site
2.	Feto	E 553626 N 959115	BASALT	Nil to 0.5	Nil	Existing earth road	>1,000,000	Existing quarry site
3.	Beru	E 580619 N 988489	BASALT	Nil to 0.5	Nil	Existing earth road	>400,000	New quarry site
4.	Sabober	E 584582 N 988241	BASALT	Nil to 0.5	Nil	Existing earth road	>1,000,000	New quarry site
5.	Mieso-Awash Q1	E 659291 N 1008175	BASALT	Nil	Very few	Adjacent to the road	>300,000	New quarry site
6.	Mieso-Awash Q2	E 686376 N 1018032	BASALT	Nil	Few	Adjacent to the road	>300,000	Existing quarry site
7.	Mulu	E 698401 N 1024547	BASALT	Nil	Few to moderate	Existing earth road	>300,000	New quarry site
8.	Melka Jebdu	E 806202 N 1062466	LIMESTONE	Nil to 0.5	Nil	Existing earth road	>1,000,000	Existing quarry site
9.	El Bahay	E 814407 N 1079882 (38P)	BASALT	Nil to 0.5	Nil	Adjacent to the railway	>400,000	Existing quarry site
10.	Millo	E 837036 N 1114669	BASALT	Nil to 0.5	Nil	Adjacent to the railway	>300,000	New quarry site
11.	Adi Gala	E 875670 N 1179198	BASALT	Nil	Nil	Adjacent to the railway	>400,000	New quarry site
12.	Aysha	E 232613 N 1188118	BASALT	Nil	Nil	Adjacent to the railway	>300,000	New quarry site

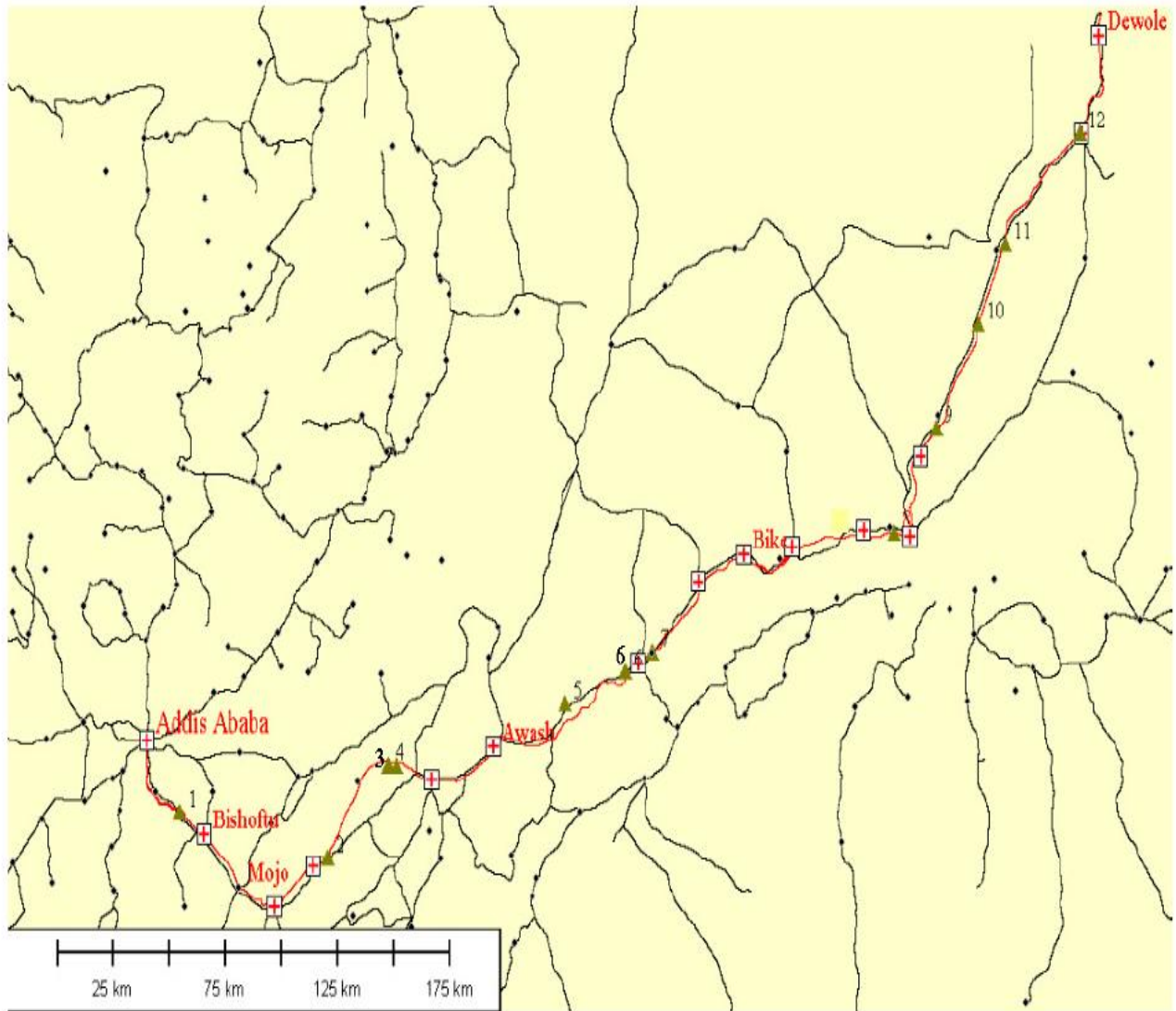


Figure 3.1 General topographical map for potential quarry sites in Ethio-Djibouti railway project

3.2 Currently selected quarry sites for Sebeta-Meiso-Negad project

Ballast can be constructed from different material sources like basalt, granite, slag and gravel, but for specific concrete tie installations *must be limited* to either crushed granites, traprocks or quartzite[11].

To identify specific quarry sites as good sources of ballast and sub-ballast materials along the corridor, taking into considerations[20].

- Overburden thickness
- Ease to exploit
- Proximity to the route
- Impact on the environment and
- local settlement

Depends on requirements listed above , around five quarry sites are selected by the contractor for the undergoing Ethio-Djibouti railway project ; as illustrated with location as below

- Gelan
- Adama
- Awash
- Shinelle
- Dewalle

As it is clearly stated before in section 1.5, from thus recently selected quarry sites, Adama and Awash quarry sites are selected for this case study.

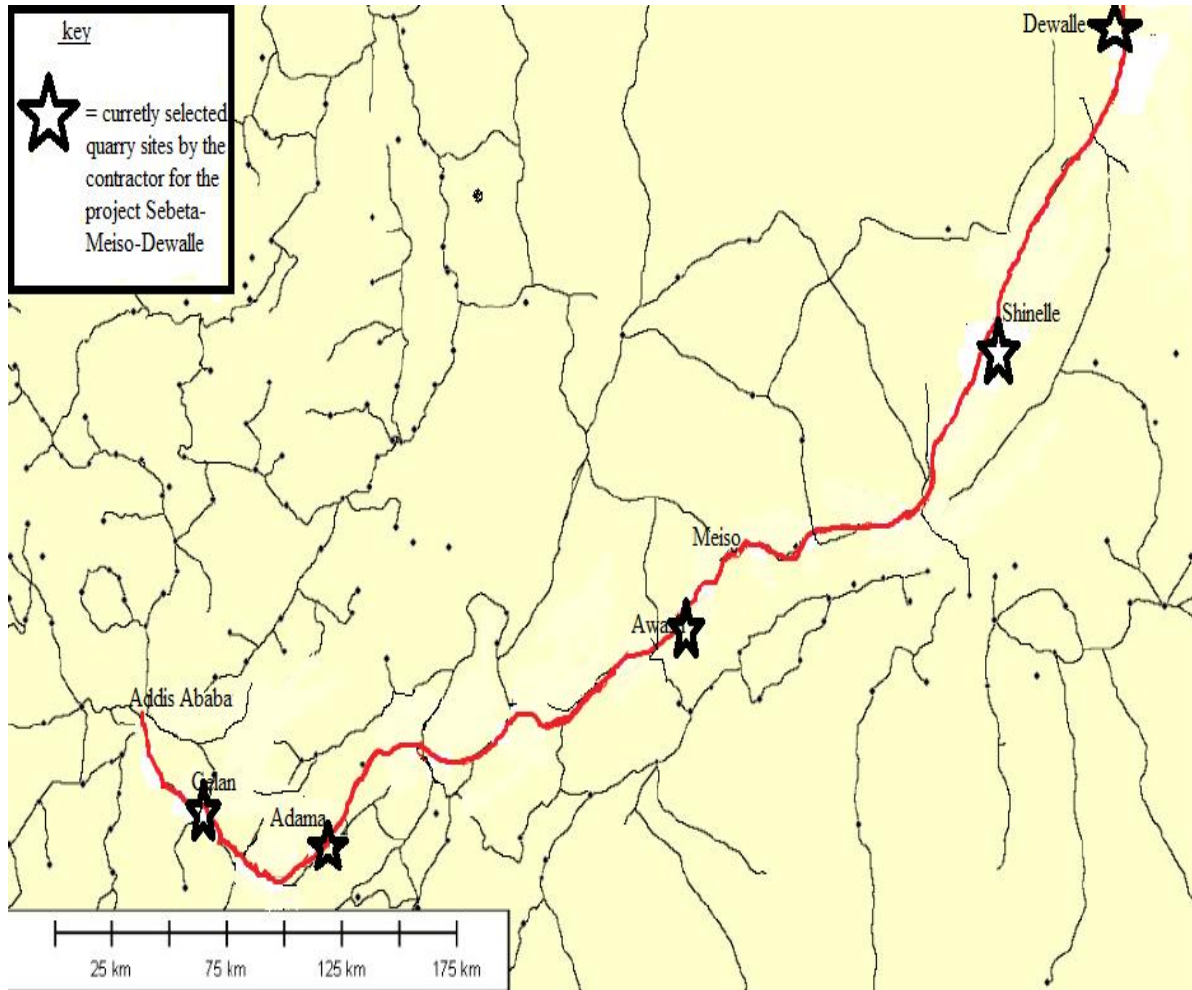


Figure 3.2 General location map of the currently selected quarry sites by the contractor

4. Existing condition of the section project

In depth , the practical project site condition is clarified in such a way the project stretch on the Great East African rift valley it features the majority climatic condition of the valley.[21]

4.1 Topography and Landform

The newly-built railway from Sebeta-Mieso belongs to the Ethiopian plateau platform, low mountain, shallow hill, alluvial, coastal landform and some parts are river valley landform. The ground is wide and the topographical relief is not great; part of the zone has low mountain and river valley landform. The elevation of road surface ranges from 2 - 2300m. The relative elevation difference is scores of meters, and the traffic condition is relatively poor. Due to perennial scouring and undercutting of seasonal flood, the surface incised dry gullies can be seen everywhere with width of 2-5m, depth of 3-12m, length of hundreds kilometers. Both sides of the trench wall are almost vertical sidewalls and the bottom of the trench is mainly sandy soil.

4.2 Stratigraphical lithology and structure

In Ethiopia, there are quaternary alluvium, diluvial layer, elurium and colluvial deposit, swelling soil, silty clay, soft soil, crushed stone soil, stony soil and cinerite on the surface. It is 2-40m thick and the soft soil is not developed. The underlying bedrock is tertiary-quaternary igneous rock. The lithology is mainly basalt, tuff, tuff lava, trachyte and other slag. In Hurso-Shinile, Mesozoic sedimentary rocks appear. The lithology is mainly limestone, marlite and sandstone.

The railway line is located in the East African Great Rift Valley which is an active zone of crustal movement. The geological structures dominated by faults and volcanoes are extraordinarily developed. The faults are mostly feather fractures and the majorities of them are secondary faults (mostly compression and torsion faults) of Ethiopian Great Rift Valley. The general strike of the faults is NNE and the main extension direction is NE-SW. At some sections, the faults dissect each other so that the stratum is distributed in a block manner. The railway line intersects most of the faults at small angles and these faults have a great impact on the railway line. It is seen from the regional geological map that major faults are much developed in the area of Adama - Metehara and the fractures are densely distributed in and around the Rift Valley.

4.3 Hydrogeological characteristics

The whole line has undeveloped surface water and rich underground water, mainly Quaternary pore water and bedrock fissure water with deep groundwater level, generally below scores of meters. Part of the sections has low groundwater level. The ground basically has no perennial-flowing river. The annual precipitation amount is 300-1100mm. When the surface water and ground water are under chemical erosion and chlorine salt condition, aquatic SO_4^{2-} , acid erosion, Mg^{2+} , corrosive CO_2 and Cl^- are generally not corrosive to concrete structure.

However in some part of the ground water, the erosion grade of Cl^- towards the concrete structure is L1; the erosion grade of Cl^- towards the concrete structure in Beseka Lake is L2; the erode grade of SO_4^{2-} towards the concrete structure is H1.

4.4 Unfavorable geology and special rock & soil

The unfavorable geology of this section is mainly dangerous rockfall, talus, karst, seasonal flood, weak intercalated layer of bedrock. There might be geothermal energy in some parts.

4.4.1 Over hanging rock & rockfall

The geological structures along the line are complicated, and the joint fissure of igneous rocks are extremely developed, part of the sections undergo obvious spherical weathering, parts of the rocks are isolated and exposed on the slopes and mostly have a diameter of 0.2-1.0m, up to 2-3m at part of the sections. The overhanging rock & rockfall of the whole line are primarily distributed at the excavation section of subgrade slope, tunnel entrance and the bridge sections under steep slopes. The total length of line affected is approximately 15km. It is recommended to rectify the overhanging rock & rockfall sections by taking comprehensive measures such as supporting, supplementing, embedding, anchoring, retaining, and clearing, etc.

4.4.2 Talus

Parts of the sections along the line are topographically steep and the topography is strongly dissected. The rock masses are liable to avalanche under the action of dissection by unfavorable structural planes and accumulate in the gentle slope zones under the steep slopes to form taluses. The rock masses are mostly crushed stone soil and block stone soil; the rock compositions are basically the Tertiary - Quaternary basalt and tuff. The total length of line affected is approximately 6km. Bridge foundation excavation has a large impact on the talus stability. It is recommended to clear away or strengthen the talus before excavation of the foundation pit and to reinforce the retaining of foundation pit so as to ensure the safety in construction.

4.4.3 Ground fissures

In parts of the sections, the regional active fractures are extraordinarily developed due to the affection of the volcanic seismic activity and are primarily embodied on the surface by ground fissures and directly fissured bedrock with width ranging from a few centimeters to a few meter and length of about a few meters to a few kilometers. It mainly distributed near Beseka Lake, the regional active fractures are extraordinarily developed due to activity of Fantale Volcano and are primarily embodied on the surface by ground fissures and directly fissured bedrock.

Groundwater can be seen in some of the ground fissures. The maximum width of ground fissures is about 7m and the minimum width is several centimeters. The difference in the height of both sides of some fissures is as large as more than 10m. With very good extensibility, the fissures extend to Beseka Lake in the south and to the foot of Fantale Volcano in the north and are more than 4km in length. In the area there are primarily three large ground fissures and many small poorly connected ground fissures, which can also be seen on Google Earth. According to the interview with the local residents, there is smoke rising from below the fissures every night, which indicates that there is certain-scale magma activity underground in the area and that there probably exists geothermal anomaly. It is suggested that the railway line shall bypass the turning, branching and both ends of large ground fissures as well as the intersection of several ground fissures and shall pass the area from the section where the ground fissure is the narrowest rather than in parallel with the ground fissure; it shall pass the area from the earthquake-friendly sections such as topographically wide and flat sections and the gentle mountain slope sections with stable bedrock preferably in the manner of low embankment; major works with poor earthquake resistance such as high fill, deep cut and part-cut part-fill subgrade works as well as major and high bridges shall not be built, and taphrogenic displacement monitoring shall be strengthened.

4.4.4 Weak intercalated layer of bedrock

Due to multiple intermittent eruptions of volcanic activity, the igneous rocks show an uneven degree of weathering along the line, occur obviously in alternation with the clay layer, volcanic breccia and volcanic ashes, form a weak intercalated layer and have a large impact on the tunnel, bridge and deep cutting works. For a tunnel, presence of a weak intercalated layer near the tunnel trunk will result in reduced surrounding rock grade and poor surrounding rock stability. Local or large-scale geological hazards such as spalling, collapse and cave in, etc. will take place easily in the construction process. The exposure time upon excavation of the surrounding rocks shall be reduced as much as possible in the construction process and the tunnel shall be lined and supported in time. For a bridge, a weak intercalated layer will have a large impact on the checking calculation of bridge foundation stability as well as type and length design of piers and piles.

Exploratory holes shall be arranged for the piers to find out the distribution of weak intercalated layer. For the deep cutting works, presence of a weak intercalated layer will affect

the classification of earth & rock excavation, design of ratio of excavation slope and design of protective measures, etc.

4.4.5 Seasonal flood

Plain physiognomy is the main feature from DIREDAWA to DEWELE with flat and open topography. When the rainy season comes, rain from highland or peripheral mountains converges in the rift basement and flat low-lying place. The permeability in quaternary overburden layer is relatively better; however, when the rainfall is too big to completely permeate into the ground, surface runoff is easily formulated. From DIREDAWA to DEWELE, the ground features Arenosol. The slope in the embankment is prone to become undercutting and scouring. It is suggested to set enough drainage ditch and water-collected ditch from certain distance away from two sides of the lines and periodically clean the alluvial materials brought by rainfall of the ditch.

4.5 Geothermal energy

Geothermal energy lies in west of TADJOURA, zone of active volcanic activity in the modern times and west of NW-directional large fault zone. There is linear natural heat escape belt, natural hot spring with shallow burial and high temperature. There are also sinter and solid sediment.

4.6 Seismic ground motion parameter

The East African Great Rift Valley subject to tension fracture at an average speed of 2-4cm every year crosses the central Ethiopia, extending to the Red Sea of Djibouti. The action of tension fracture is now continuing and the Rift Valley is still expanding towards both sides continuously. As a result, the sections where the railway line passes are active zones of crustal movement and volcanic earthquakes are frequent in some areas.

4.7 soil coverage

Soil of this project are largely derived from recent volcanic rocks ,by comparison with many areas of Africa ,their bases stratus is generally good ;even, constraints to forage production include low phosphorus levels, micronutrients imbalances and in some cases poor physical structure. Special rock & soil is mainly swelling soil, soft soil and mellow soil.

4.7.1 Swelling soil

The locally called black cotton soil is grayish black and dark brown. It cracks under natural condition. Crisscrossed fissure is mature. It is formed from the residual surface due to long-time rainfall after complete weathering of igneous rock such as basalt and mainly distributes from Addis to Mojo. It affects about 120km of the route length with 2-10m thick. According to the trail test of swelling soil by exploration sample, $F_s=61-120\%$, $M=36-64\%$, $CEC (NH_4^+) = 420-680 \text{ mmol/kg}$. It shows that this layer is highly expansive and shall not be padding.

4.7.2 Soft soil and mellow soil

The soft soil and mellow soil of the whole line are mostly inter-hill ravine facies, soft plastic - flow plastic. It affects about 6km of the route length. Distributed in the form of lens, the soft soil and mellow soil are 0-12m in thickness. The soft soil and mellow soil have a large impact on embankment.

It is suggested, for the embankment fill section, the surficial soft soil and mellow soil shall be subject to removal, turnover for drying, packing sedimentation by throwing stones, drainage by means of ditch excavation and tamping before filling; the sections where the soft soil and mellow soil are thick or buried deeply can be strengthened by the drainage consolidation method and composite foundation method, etc.

4.8 Meteorological characteristics

Ethiopia is located in the east of Africa, where there are many plateaus. Although the country is in the tropical zone, the temperature varies dramatically as the latitude and altitude change greatly. In general, the country is dominated by tropical plateau climate, and some areas are characterized with the climate of plateaus and mountain lands and the climate of tropical desert. In general, the climate is mild. June to September is rainy season, October to May is dry season, March to May is the hottest period when the temperature may reach 37°C , November to January is the coolest period when the temperature in plateau may be as low as 0°C ; and July to August is the wettest season.

The average annual rainfall in the plateau regions is 1000-1500mm, and that in the lowland and valley is 250-500mm. Since rainfall is of overriding importance in determining plant growth, the main basis of comparison has been the annual quantity and duration of rainfall.

Seasonal distribution has also been taken into account. Temperatures have been considered, but only where extreme temperatures are likely to influence the distribution of tropical or subtropical plant species.

Generally, the climatic condition characterized as diverse and range from hot and arid to cool(subtropical) and humid similar to the semi arid and semi humid regions of east Africa with their bimodal rainfall.



photo 4.1 Photos taken on the existing site



photo 4.2 Photos taken on the existing site

5. Sample collection and detailed laboratory test results:

After detail methodological procedure of site investigation secondary data collection, field survey, preliminary site visit, field survey for quarry site identification and for sampling; representative sample was taken to their respected laboratories.

In detail;

i) Secondary data collection

Prior to the field survey all information or data relevant to the study have been gathered, reviewed and analyzed. The main sources of data and information are:

- Ethiopian Railway Corporation staffs
- Previous studies
- Other Reports from governmental and nongovernmental (Chinese) organizations.

As the basic objective of this research is in finding an alternative economic quarry site within the alignment and the fact that the country has limited experience in Railway construction, little information is available from previous studies regarding rock materials for track ballast. Consequently, a great deal of the investigation has been assessed by extensive field survey.

ii) Field Survey

The field survey consists of three stages, namely, preliminary site visit, quarry site identification, And sampling. The ballast quarry exploration has been carried out with the help of government officials and Ethiopian Railway corporation right of way personnel.

iii) Preliminary Site Visit

The main objectives of the preliminary site visit were:

- To get insight and overall picture of the section route.
- To assess the geologic nature and acquire information on the nature of rocks.
- To get insight on the accessibility conditions off the route.
- To acquire information regarding settlement and vegetation
- To visit previously identified quarry sites by the Chinese companies.

From May 13, 2014 to May 14, 2014, with the guidance of Section 5 Ethiopian Railway Corporation right of way personnel (Tadele) made two day first field visit to the proposed section (Adama-Awash) railway corridor.

During the field visit, it has been briefly looked into potential quarry sites for ballast and material at different locations with the help of the right of way personnel and some data from previous studies.

Several potential ballast sources were preliminarily identified and visited by different companies though some fail due to accessibility to the alignment or due to lack of the required volume; among the visited locations, extensive sources of basalt material at around middle range between the selected quarry site of Adama and Awash suggested for study.

iv) Field survey for quarry site identification

At this stage from June 06, 2014 to June 07/2014 a thorough exploration of the suggested rock quarry for ballast conducted .

Factors considered during field survey for quarry site identification

- Rock source quality
- Availability in sufficient quantity
- Overburden thickness
- Suitability of extraction and quarry development
- Proximity to the alignment and ease for developing access
- Impact on the environment and local settlement

v) Field survey for Sampling

On June 11/2014 samples were taken to be tested in the laboratory from different positions on sealed ,coded and transported to the AAIT highway testing laboratory to ensure the usability of the suggested quarry site,

The two main samples and a single sample for blasting are taken arbitrarily from different sides of the quarry site, each having a total weight of about 100 kg rock.

The collected rock samples were first crushed according to specified sizes. To fix the crushing size for the rock samples, the gradation requirement for the ballast has to be initially selected. The AREMA No. 4A gradation for ballast, which is recommended for main track line, is adopted.

After three samples each 100 kg samples of ballast material are transported to the material and highway laboratories; detailed laboratorial test procedures experienced until a solid deduction is made.

Depending on ASTM(Americans) and BS(British) test procedure and AREMA's limiting value; test for specific gravity,% absorption , loose unit wt ,comp. unit wt , elongation index, flakiness index ,% finer than 75- μm , ACV and LAA has been done.

Though, the result for all tests not fall within the standard limiting value ;solution have been made by blending the material with Beru sample which is more fresh and strong.

Blending the sample done on trial mixing of 20%-80% mix and 40%-60% mix by mass. Finally, better mix sample is done by 40%-60% mix by mass of the sample which falls within the standard limiting value which is listed on AREMA.



Picture 5.1 sample preparation at AIT highway laboratory.



Picture 5.2 sample preparation at AIT highway laboratory.

Acceptable results shall fall within recommended limiting values given in AREMA below.

Table 5.1 limiting value for ballast material

Bulk specific gravity	≥ 2.60
unit weight (kg/m ³)	≥ 1400
Absorption %	$\leq 1.0\%$
Degradation	$\leq 25\%$
SSS (5 cycles)	$\leq 5.0\%$
flat/elongated particles	$\leq 5.0\%$

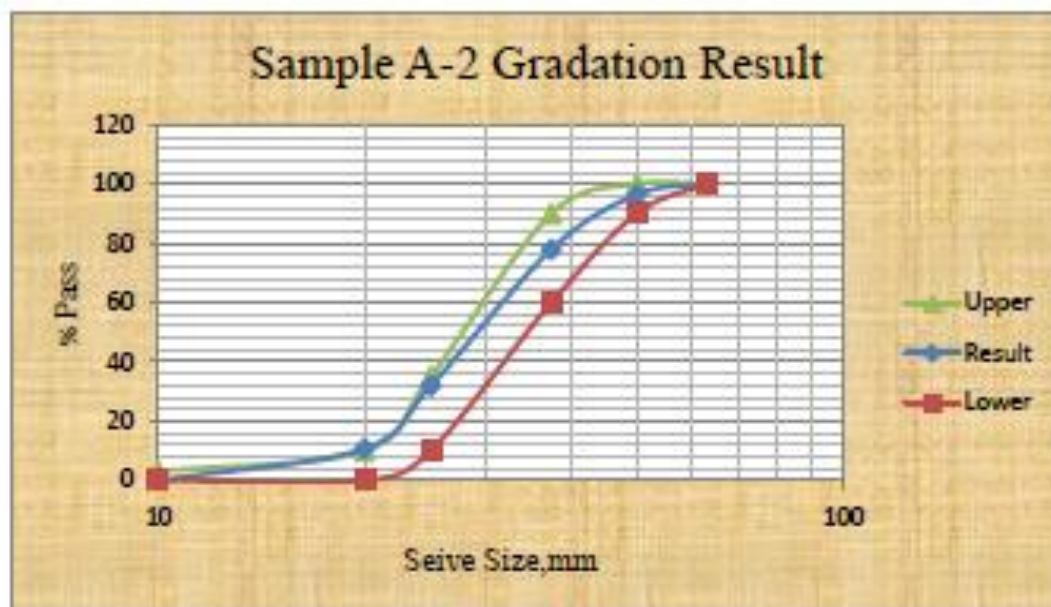
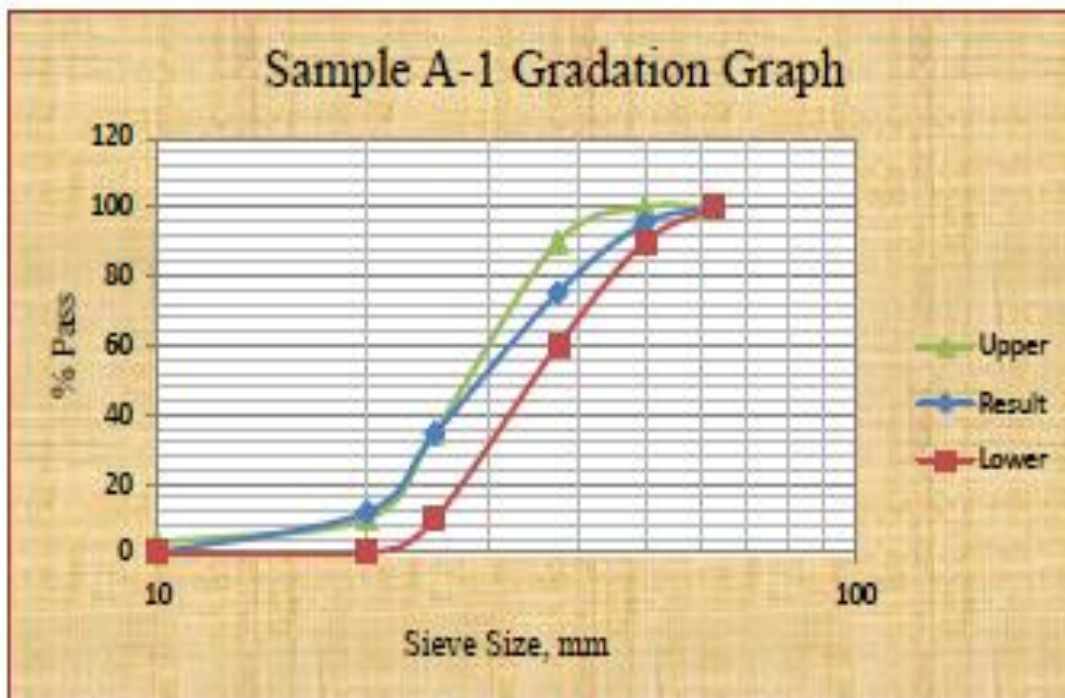
limiting values not found in AREMA but used in study in accordance to other standards and practices in Europe are given below

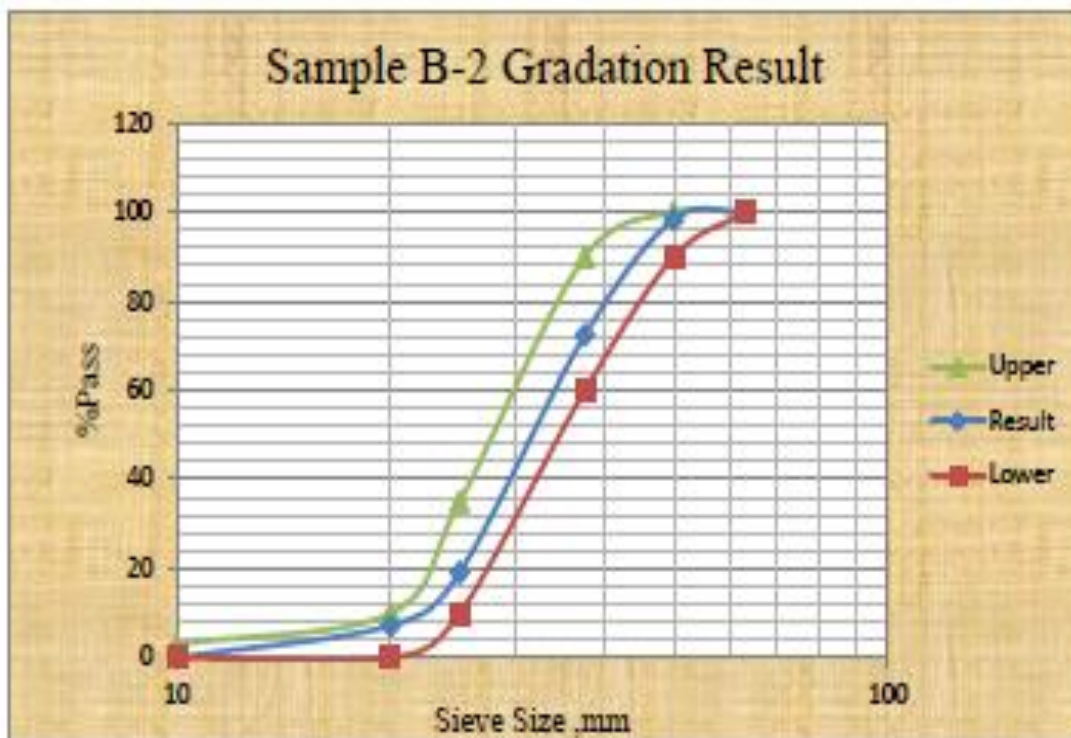
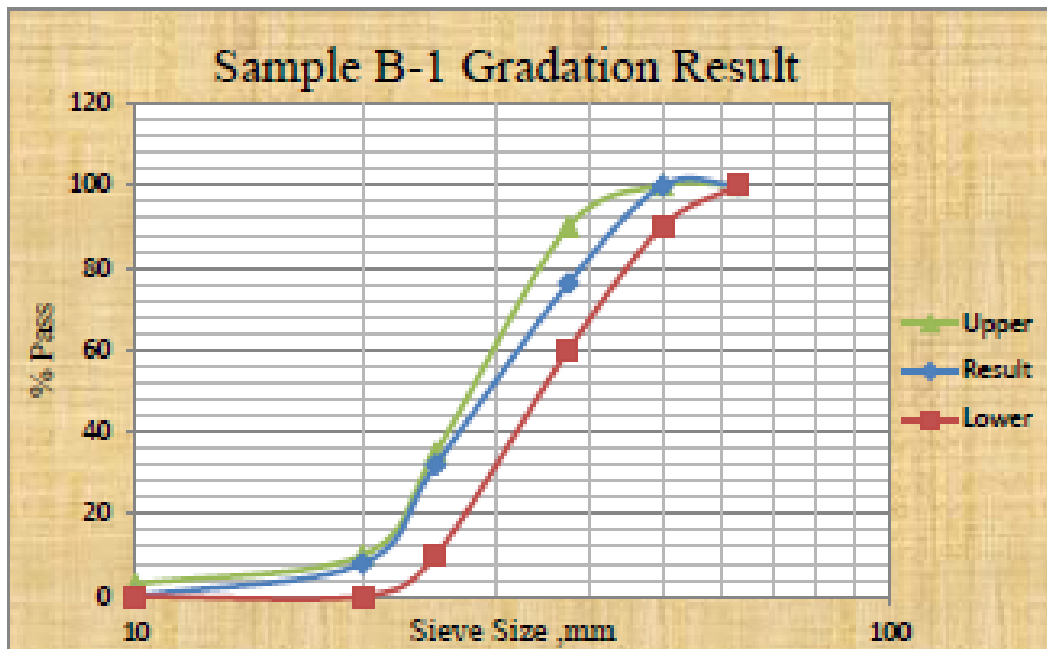
flakiness /elongation Index	$\leq 25\%$
Aggregate crushing value	$\leq 25\%$

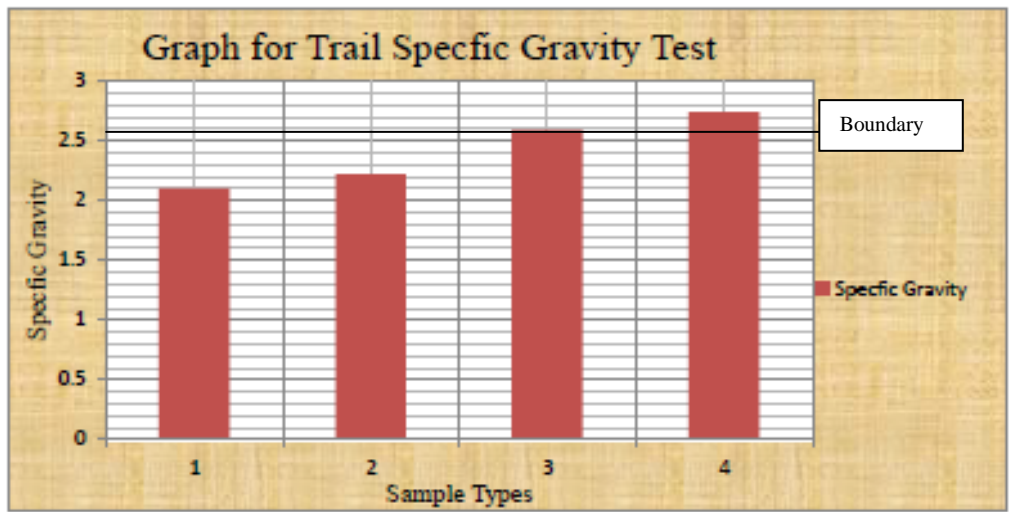
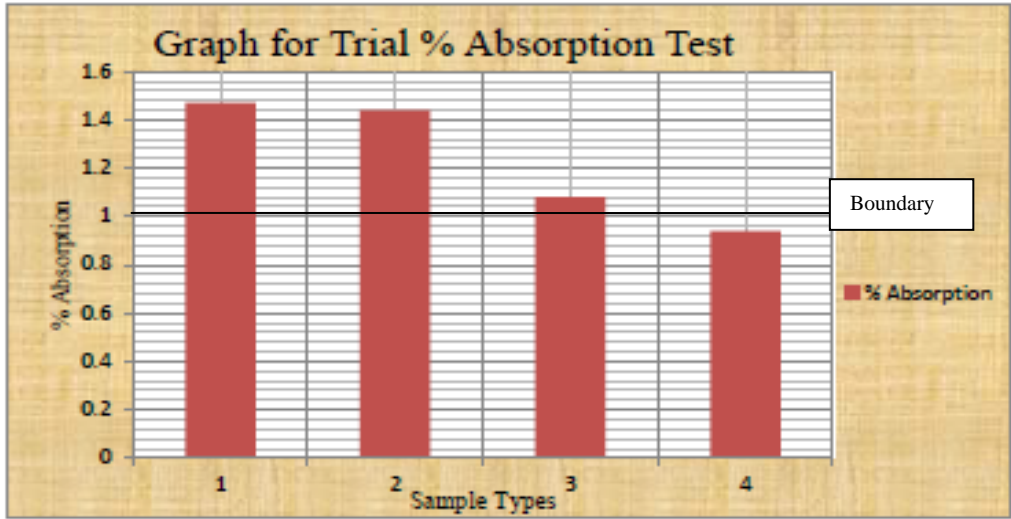
Table 5.2 Summary for test result (original sample, 20%-80%, 40%-60% mix)

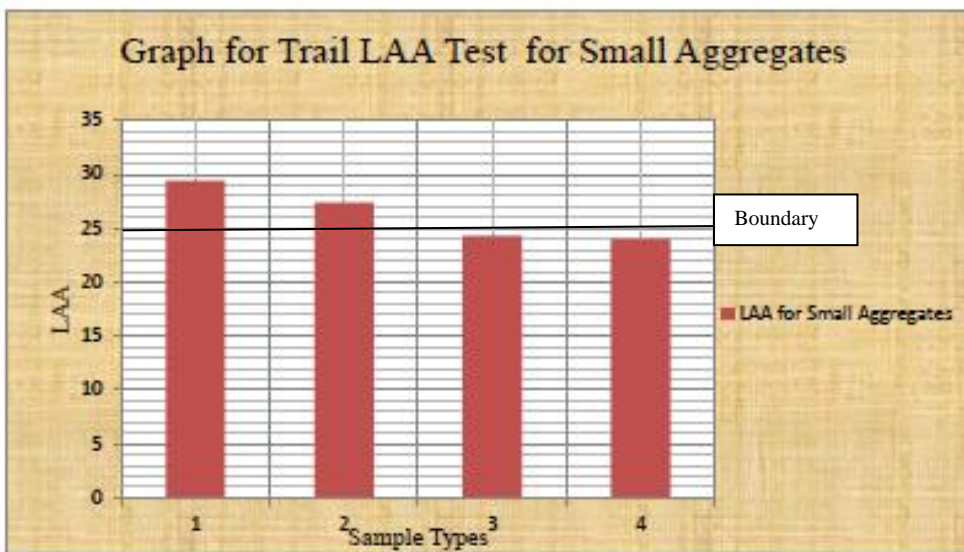
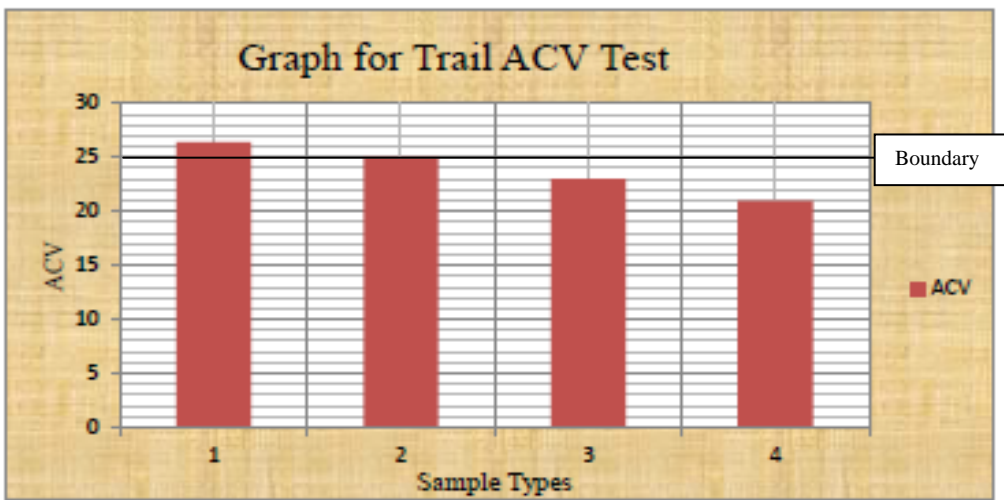
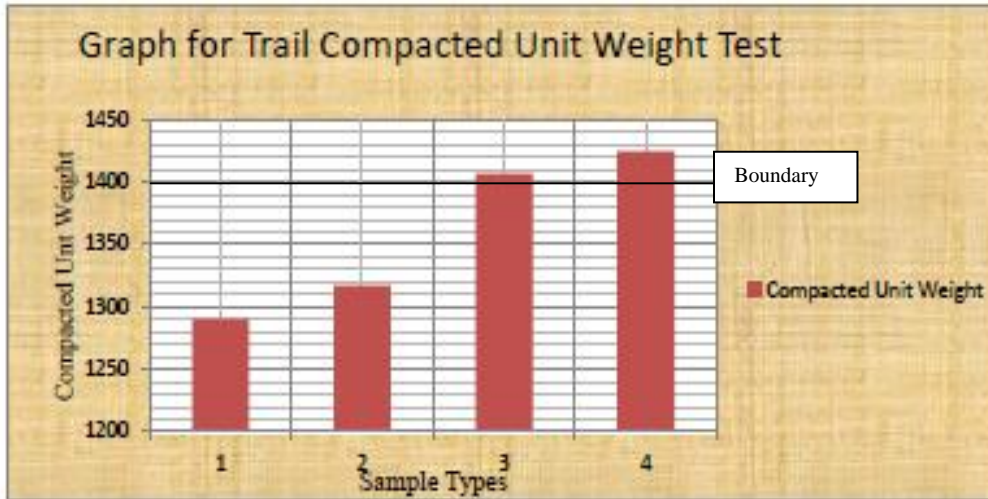
Tests	Result(org sample)		Result Blending Material	Result (20%-80%)		Result(40%-60%)	
	A(1)	B(2)		A	B	A(3)	B(4)
specific gravity	2.1	2.22	2.92	2.32	2.38	2.59	2.74
% absorption	1.47	1.44	0.83	1.25	1.21	1.08	0.94
loose unit weight	1145.14	1225.9	1407			1309.87	1316.8
comp. unit weight	1290.1	1316.8	1501			1407	1424.87
Elongation Index	26	23	24				
Flakiness Index	24	19.22	22				
% finer than 75- μ m	0.96	0.91	0.32				
ACV	26.4	25	19			23	21
LAA(for small size)	29.4	27.4	22			24.3	24
LAA(for large size)	28.2	27.7	21			24.6	23.9

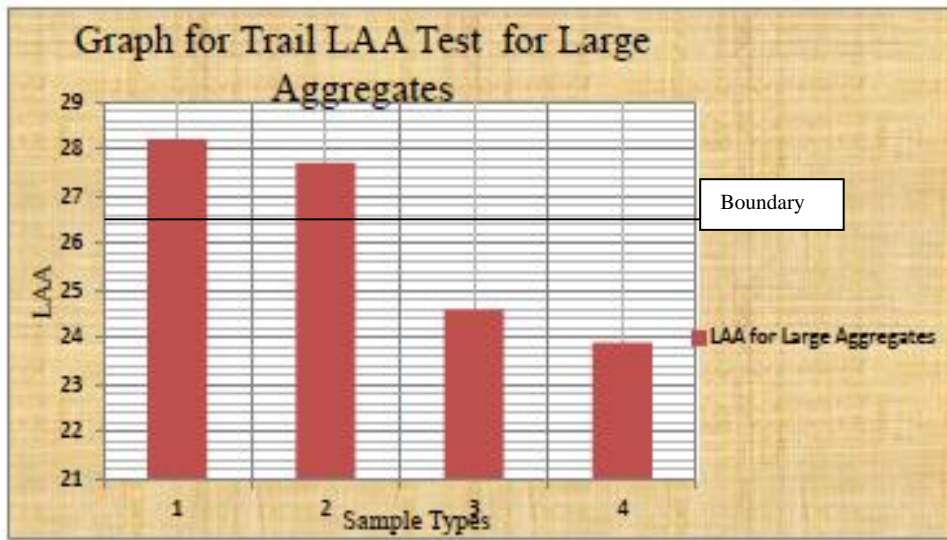
Detailed graphical representation of test results can be putted as follows :











6. Discussions and economic evaluation

As such the basic objective of this study is to evaluate beside the structural functional compositions of the material properties of different alternative quarries; its economical feasibility and generally to comment on the selected quarries with respect to the unselected quarries of close vicinity is also mandatory.

And mainly, selection between assessed quarry sites within aspects of ballast selection criteria of [22]:

- Traffic requirement
- Economy
- particle size
- unstable location
- Availability

Beside thus aspects of ballast selection criteria's , the required volume calculation with respect to available volume of the material on the quarry sites must be calculated.

6.1 Available volume on the quarry sites

- ✓ Arole (Dk 196+300) > 800,000 m³
- ✓ Beru (blast stabilizing Agent) (Dk 192+000) > 300,000 m³

6.2 Volume estimation for the case of single track from Adama to Awash

Generally, the proposed route for the currently undergoing Ethio -Djibouti railway project is to be double track from Addis Ababa to Adama and single track from Adama to Dewelle- Negad . The length of the double rail track is 100km and that of the single rail track is 552km; though, this study specifically underlines and covers the railway section between Adama and Awash, only the corresponding volume of ballast and sub-ballast required for this section of the project is summarized below:

For the estimation of volume of ballast, the ballast depth under the soffit of sleepers is taken to be 300 mm and the total ballast depth up to top of sleepers is 500 mm, as provided by ERC and also recommended by AREMA (2009). However, appropriate ballast depth shall be determined during design. A typical section of railway track substructure is shown in Figure

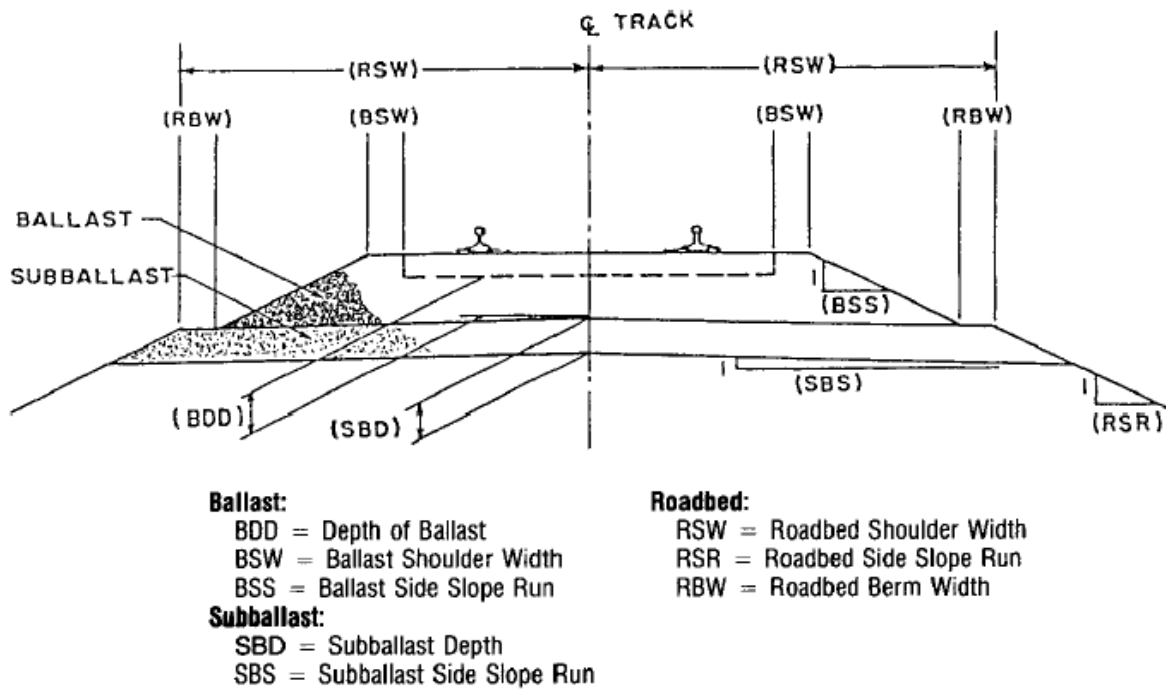
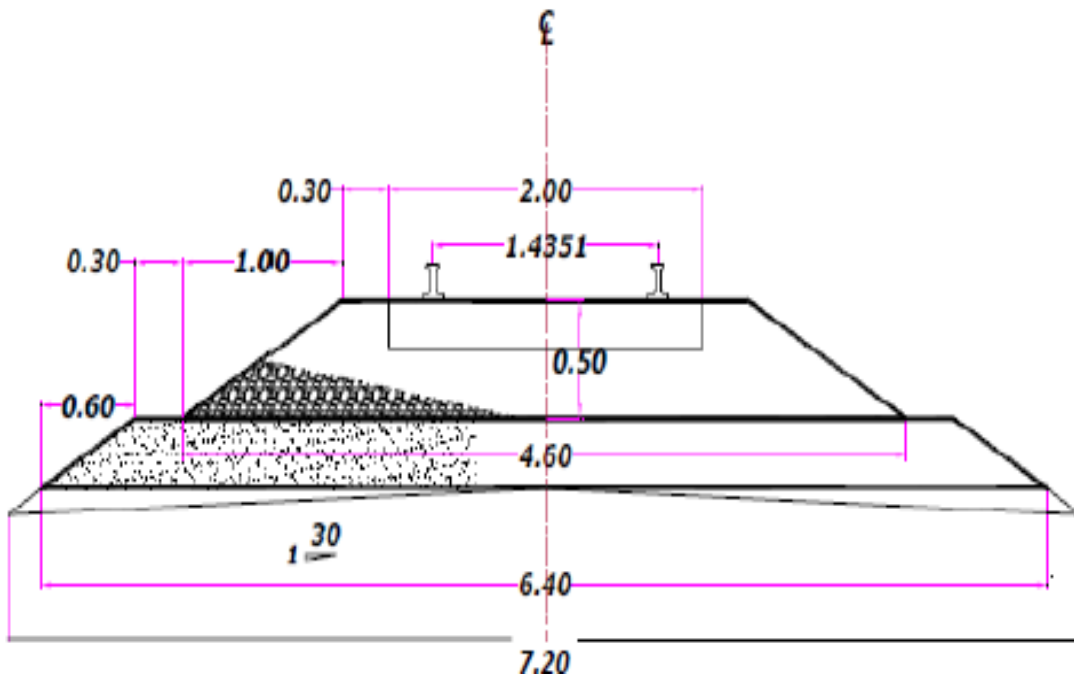


Figure 6.1 Typical single rail track substructure AREMA (2009)



All dimensions in m

Figure 6.2 assumed single rail track section for volume estimation.

In addition to the typical section shown in Figure 6.2, the following assumptions have been used to estimate the ballast volume.

- The track gage (TRG) is taken to be 1.4351 m standard gage (AREMA, 2009).
- The sleeper length is assumed to be 2 m.
- The ballast section shoulder width (BSW) is taken to be 300 mm (AREMA, 2009).
- A ballast side slope (BSS) value of 2H: 1V is used (AREMA, 2009).

Hence,

$$\text{Top width of ballast section} = 2 + 2 \times 0.3 = 2.6 \text{ m.}$$

$$\text{Bottom width of ballast section} = 2.6 + 2 \times 0.5 \times 2 = 4.6 \text{ m.}$$

$$\text{Volume occupied by the sleepers per meter of track} = 0.13 \text{ m}^3/\text{m}$$

$$\text{Volume of ballast per meter of track} = 0.5 \times (2.6 + 4.6) \times 0.5 - 0.13 = 1.67 \text{ m}^3/\text{m}$$

Considering additional 10% for passing loop, depots and station requirements (ERC recommendation), the total volume of ballast per meter length of track becomes **1.84 m³/m**.

Due the consideration of project segment from Dk 100+000 (the end of double track section) -- Dk 265+000 (Awash quarry damping station); $1.84 \text{ m}^3/\text{m} * 165000 \text{ m} = \mathbf{3.04 * 10^5 \text{ m}^3}$

Similarly, it is necessary to calculate the sub ballast volume because it is not logical to separate the source and considering the ballast only.

therefore , the following assumptions have been used to estimate the volume of sub-ballast.

- The sub-ballast thickness (SDD) is taken to be 300 mm (AREMA, 2009).
- Roadbed berm width (RBW) is assumed to be 300 mm.
- A roadbed side slope (RSR) value of 2H:1V is used (AREMA, 2009).
- A sub-ballast side slope run (SBS) value of 30H:1V is used (AREMA, 2009).

Hence,

For the assumed value of SBS, the maximum thickness of sub-ballast = 500 mm

$$\text{Top width of sub-ballast section for single track} = 4.6 + 2 \times 0.3 = 5.2 \text{ m.}$$

$$\text{Bottom width of sub-ballast section for single track} = 5.2 + 2 \times 0.5 \times 2 = 7.2 \text{ m.}$$

$$\text{Volume of sub-ballast} = 0.5 \times (5.2 + 7.2) \times 0.5 - 0.5 \times 7.2 \times 0.2 = 2.38 \text{ m}^3/\text{m.}$$

Considering additional 10% for passing loop, depots and station requirements, the total volume of sub-ballast becomes **2.62 m³/m** similarly $2.62 \text{ m}^3 / \text{m} * 165000 \text{ m} = \mathbf{4.32 * 10^5 \text{ m}^3}$

Overall, the total volume of compacted ballast and sub-ballast is approximately **4.46 m³/m** ($\gg 1.84 + 2.62$).

Therefore, for the study of the required section of Adama-Awash railway line a total net volume of about $4.46 \text{ m}^3/\text{m} * 165000 \text{ m} = 7.36 * 10^5 \text{ m}^3$ is required.

After the feasible study on traffic requirement, particle size, required location, availability and volume estimation; the basic economic evaluation of cost breakdown is studied between the two currently selected quarry sites by the contractor with respect to newly added alternative configuration of quarry sites.

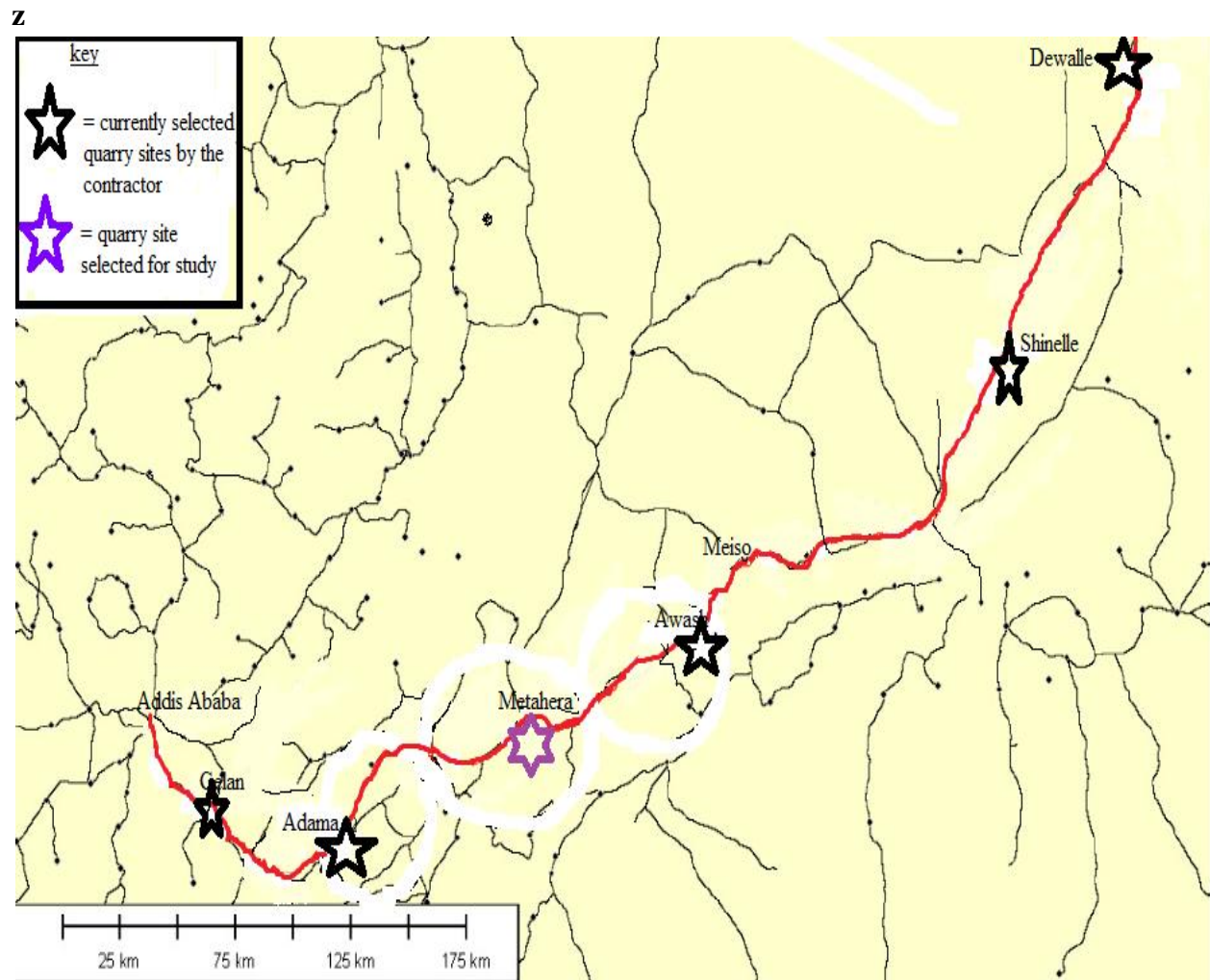


Figure 6.3 General location map of the quarry sites selected for study

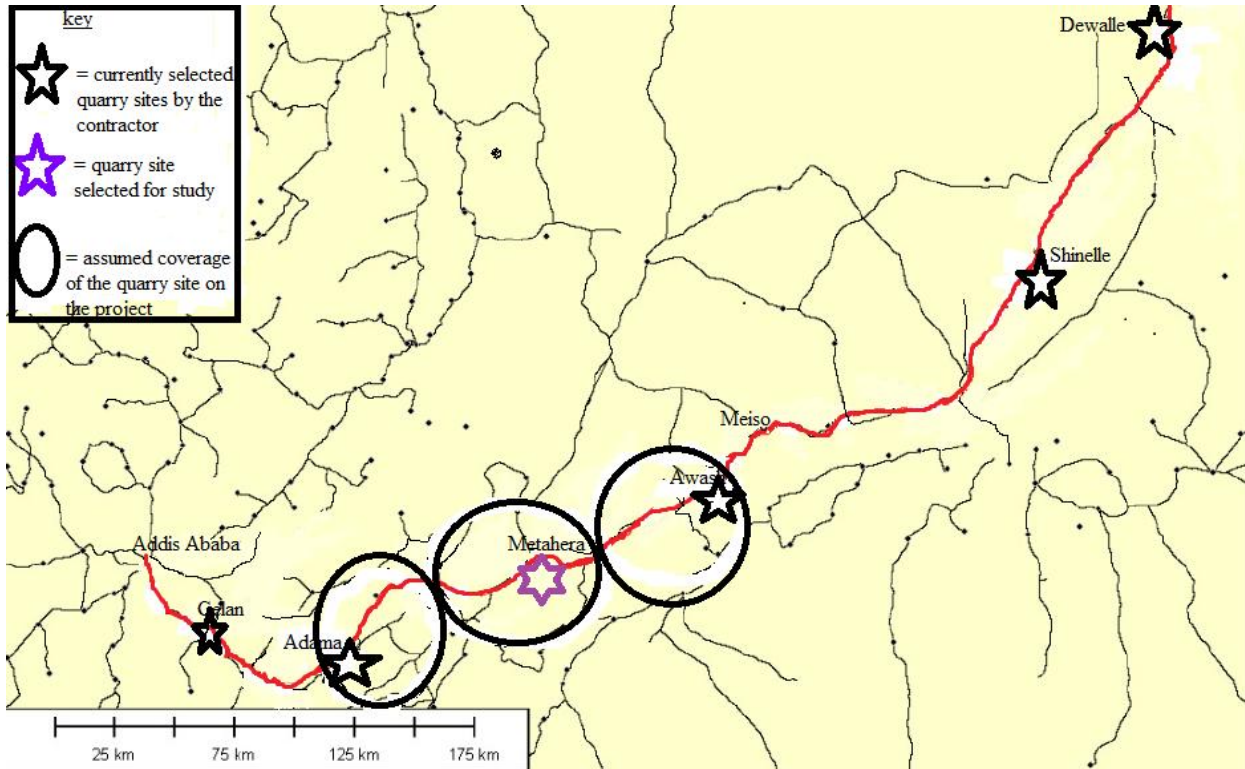


Figure 6.4 General location map of the study areas with their respected coverage areas

6.3 Economic Evaluation

The economic evaluation is basically featured and studied between quarry sites:

- cost for fuel consumption of the train per km per m^3
- cost for plantation of crushing plant and machineries (birr)
- cost of manpower (birr)
- cost for transportation of blending material from 4.3 km
- cost for general project time

6.3.1 Cost for fuel consumption of the train per km per m^3

The amount of liters a train engine consumes is calculated per unit of energy the train engine operates; 1 liter per 3.15 units of energy operated. On other hand it also depends on the speed of the train pulling the rolling stone ; 6 liters per km for 100 km /hr and to 45 liters per km for 15km/hr.

Generally speaking, in felid experience the amount of liters the diesel engine consumes ranges between 4 km/hr-14 km/hr and for freight engine for transporting the ballast for its own track construction is put to be **10 liters / km**.

Simple sketch of quarry sites configuration alternatives using two or three quarry sites.

Alternative 1: Adama and Awash quarry sites that are currently selected by the contractor

When the project use the two quarry sites on the two ends of the project section; Adama and Awash quarry sites.

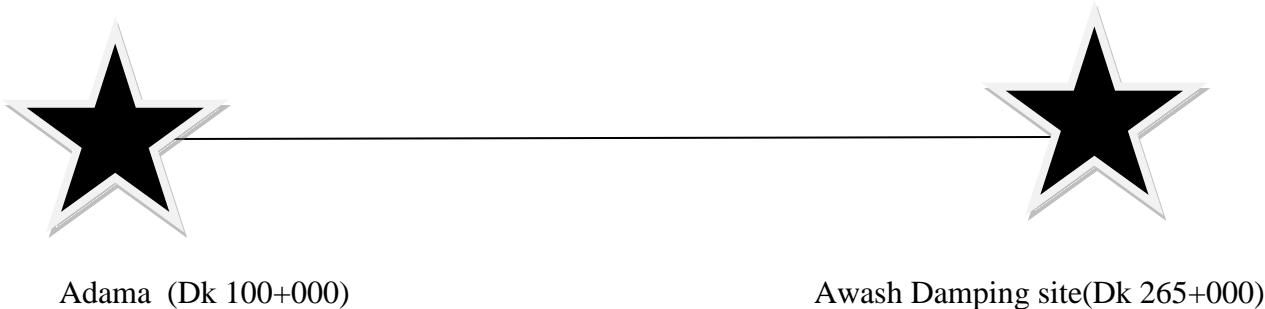


Figure 6.5 simple sketches for Alternative 1 quarry configuration

The following assumptions were made to calculate the cost for fuel consumption

- ✓ The two quarry sites share equal range of work of spreading volume within the railroad section; 82.5 km.
- ✓ The diesel train used to transport the ballast material is assumed to have twenty haulage rolling stock ; with each of 20 m³ capacity.
- ✓ The train consumes 10 liters/ km as listed above.
- ✓ 2.62 m³/m volumes of ballast and sub ballast is required for the track section as calculated in the volume calculation.

$$\text{Train capacity} = 20 \text{ m}^3 * 20 \text{ rolling stock} = 400 \text{ m}^3$$

$$\text{One trip coverage} = 400 \text{ m}^3 / 2.62 \text{ m}^3/\text{m} = 152.67 \text{ m}$$

$$\text{Trip} = 82500 \text{ m} / 152.67 \text{ m} = 526.6 ; 527 \text{ trips}$$

$$\text{km coverage} = 2(152.67) * \sum_{n=1}^{527} (1 + 2 + 3 \dots + n) = 42,481,344 \text{ m} = 42,481.344 \text{ km}$$

$$\text{Job executed from both two sides of the quarry sites} = 2 * 42,481.344 \text{ km} = 84,962.688 \text{ km}$$

$$\text{Overall liters consumed by the diesel train to execute the job} = 10 \text{ liters/km} * 84,962.688 \text{ km}$$

=

$$\text{Fuel cost} = 849,626.88 \text{ liters} * 18.70 \text{ birr/liter} = \mathbf{15,888,022.66 \text{ birr}}$$

Alternative 2: Adama, Arole and Awash quarry sites configuration selected by this study

When the project use three quarry sites , two at the ends of the project section and one near at the mid range ; Adama , Arole and Awash quarry sites.

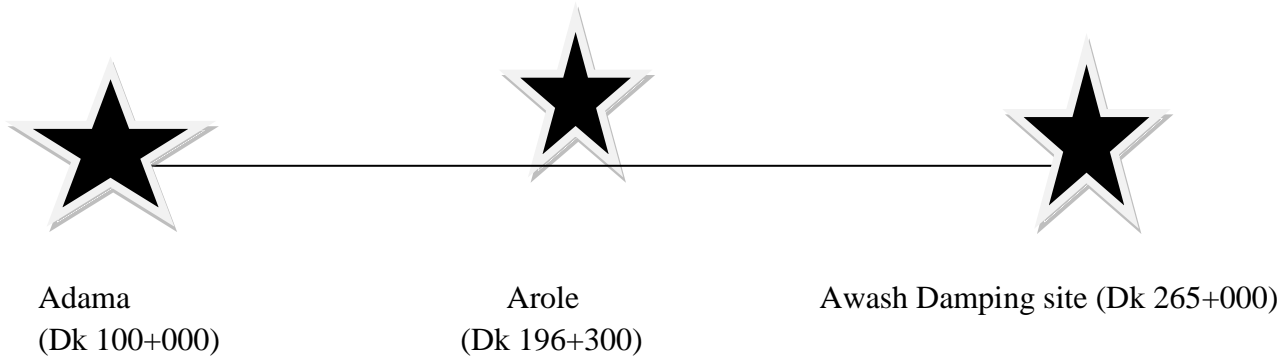


Figure 6.6 simple sketches for Alternative 2 quarry configuration

Beside the above assumptions used to calculate fuel consumption for alternative 1 , the following assumption were made to calculate for alternative 2

- ✓ the three quarry sites share equal range of work of spreading volume within the railroad section ; 55 km.

$$\text{Train capacity} = 20 \text{ m}^3 * 20 \text{ rolling stock} = 400 \text{ m}^3$$

$$\text{One trip coverage} = 400 \text{ m}^3 / 2.62 \text{ m}^3/\text{m} = 152.67 \text{ m}$$

$$\text{Trip} = 55000 \text{ m} / 152.67 \text{ m} = 360.25; 361 \text{ trips}$$

$$\text{km coverage} = 2(152.67) * \sum_{n=1}^{361} (1 + 2 + 3 \dots + n) = 19,951,221 \text{ m} = 19,951.221 \text{ km}$$

Job executed from the three sides of the quarry sites

$$= 2 * 19,951.221 \text{ km} + 1,306.245 \text{ km} + 11,088.422 \text{ km} = 52,297.109 \text{ km}$$

Overall liters consumes by the diesel train to execute the job = 10 liters/km * 52,297.109 km

$$= 522,971.09 \text{ liters}$$

Fuel cost = = 522,971.09 liters * 18.70 birr/liter = **9,779, 559.383 birr**

6.3.2 Cost for plantation of crushing plant and machineries (birr)

The cost for crushing plant from Zenith machinery company, China ; capacity of 120 tone/hr - 150 tone/hr , main machine : feeder, jaw crusher, impact crusher, vibrating screen, belt conveyor,

motor, control panel etc and spare parts for common wearing parts for 1 year with consulting one mechanical engineer excluding transportation cost for two containers (200,000 birr) is 256,259 USD.

6.3.3 Cost of manpower (birr)

In modern construction scheme , the cost for manpower is the very concern in the project cost ; though in average around 9 crew personnel , 7200 birr/month are in need for a single crushing plant stand. And the cost is done assuming the crushing plant is utilize for two years project time.

6.3.4 Cost for transportation of blending material from 4.3 km(birr)

Assumptions :

1. Hourly rental rate, (A)	350.00	Birr/Hr.
2. Fuel Consumption,(B)	1.50	Km/lit
3. Fuel cost, (C)	18.70	Birr/lit.
4. Loading and Unloading time, (D)	0.13	Hr.
5. One trip, (E)	14.00	m ³
6. Min working hour per day, (F)	10.00	Hr./Day
7. Average assumed speed (k)	30.00	Km/Hr.

Calculation:

Hauling Distance ; single trip in Km (G)= 4.3 Km

Fuel Cost ; Fuel consumption in Lit/trip (H) = $2 * G / B = 5.73$

Fuel consumption in Lit/m³ (I) = $H / E = 0.41$

Fuel consumption rate in Birr/m³(J) = $I * C = 7.66$

Production; Time for one trip in Hr/trip (L) = $((2 * G / K) + D) = 0.42$

No. of trip per hour in Trip./hr (M) = $1 / L = 2.38$

Volume per hour in m³ /hr (N) = $E * M = 33.36$

Birr per Volume in Birr/m³ (O) = $A / N = 10.49$

Total rate with fuel ; Total rate per volume in Birr/m³ (P) = $O + J = 18.15$

Total rate per kilometer per volume in Birr/Km/m³ (Q) = $P / G = 4.22$

Required Volume for the whole stretch = $4.46 \text{ m}^3/\text{m} * 55000 \text{ m} = 245,300 \text{ m}^3 \text{ total.}$

Required Volume for the blending material= 40% * 245,300 m³ = 98,120 m³ of blending material.

Cost for transporting the material from 4.3 km = 4.22 Birr/ Km/ m³ * 4.3 km* 98,120 m³

=1,780,485.52 Birr

Summary for economic evaluation

Assuming single crushing plant with rotation is used:

Table 6.1 summary for economic evaluation of quarry alternatives

Alternatives	cost (Birr)				Total
	fuel consumption	crushing plant	cost for Blending	Manpower	
Alt. 1	15,888,022.66	5,273,928.20	-	1,555,200	22,717,150.86
Alt. 2	9,779, 559.383	5,273,928.20	1,780,485.52	1,555,200	18,389,173.10

And the evaluation ,dictates that alternative 2 is more economical than alternative 1 ; without additional cost for the replantation of the crushing plant and the cost for additional machineries and transportation cost for the blast material production at Dk 192+000 is excluded.

6.3.5 Cost for general project time

Due the logic behind ,the general cost for the project can be affected by re planning the resources within the project ; the reward for the contractor differs within the contract that binds and the project time, so as increasing the quarry sites that exists within the economic radius vicinity comes something positive that follows for stake holders.

Generally speaking, Alternative 2 that uses three quarry sites that exists within economic radius of the project is more economical and saves the cost of the project in acceptable way.

7. Conclusion and Recommendation

7.1 conclusions

The defined scope and objective of the thesis; in identifying an alternative economic quarry site as a good source of ballast material along the corridors, investigating the physical, mechanical and geometric properties of identified source using standard laboratory tests and finally economic evaluation using clear economic break down is for the practical solution for the section project of Ethio -Djibouti railway project.

Referring to the results and discussions part of the thesis; the thesis concentrated on single track section of Adama-Awash project which covers 165 km. And this section is selected as a case study due to uneconomical radius of the quarry sites selected by the recent ongoing project..

As it clearly dictated on the result part of the thesis ; the samples from Arole , Dk 196+300 failed to satisfy some of the standard limiting value of AREMA's and came with solution of satisfying the specification by simple blending the sample with Beru sample, Dk 192+000 in mass proportion of (40%-60%) which is more fresh and strong.

Finally, detailed economic cost evaluation and comparison has been done between the two alternatives; one the current contractor selection (Adama-Awash) quarry site configuration and the other (Adama-Arole- Awash) quarry site configuration by this thesis. And has been found out that alternative 2 with three quarries is more economical and acceptable than the other alternative which is currently selected by the contractor.

7.2 Recommendation

Even though; the economic evaluations underline that Alternative 2 is more economical than the other, it doesn't mean in every aspect of project planning. When the project use, re plan or schedule using two diesel trains or any other inputs the result can be shifted to the other side because the basic entity is the time schedule and project time that the contract binds; therefore, it is recommended to study in detail in many aspects of project planning using different project inputs.

Chemical stabilizing agents were not used in the study for improving overall properties of the rock due to the reason that it changes the basic useful requirement of the ballast material as drainage ,flexibility nature and the stabilizing agent have unworkable properties in conducting tests and experiments.

Therefore, for better utilization of the material; it is recommended for detailed future studies in improved technological ways.

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9. Appendices : Detailed laboratory results

Appendix I . Gradation

Gradation for sample A 1

sieve size	weight (gm)	% retained	% passed	4A gradation(%pass)	
				Lower	Upper
63	-		100	100	100
50	498	4.66	95.34	90	100
37.5	2149	20.09	75.25	60	90
25	4370	40.85	34.40	10	35
20	2412	22.55	11.85	0	10
10	1268	11.85	0.00	0	3
	10697				

Gradation for sample A 2

sieve size	weight (gm)	% retained	% passed	4A gradation(%pass)	
				Lower	Upper
63	-	-	100	100	100
50	310.5	3.53	96.47	90	100
37.5	1632	18.53	77.94	60	90
25	4057	46.07	31.87	10	35
20	1868.6	21.22	10.65	0	10
10	938	10.65	0.00	0	3
	8806.1				

Gradation for sample B 1

sieve size	weight (gm)	% retained	% passed	4A gradation(%pass)	
				Lower	Upper
63	-	-	100	100	100
50	-	-	100	90	100
37.5	2326	23.78	76.22	60	90
25	4323	44.20	32.02	10	35
20	2349	24.02	8.01	0	10
10	783	8.01	0.00	0	3
	9781				

Gradation for sample B 2

sieve size	weight (gm)	% retained	% passed	4A gradation(%pass)	
				Lower	Upper
63	-		100	100	100
50	136	1.63	98.37	90	100
37.5	2158	25.92	72.45	60	90
25	4438	53.31	19.14	10	35
20	994	11.94	7.20	0	10
10	599.5	7.20	0.00	0	3
	8325.5				

Appendix II . Detailed laboratorial Tests for Sample A and B

Test for Specific gravity and % Absorption**Sample A**

Wt air=3249 gm

Wt water=1547 gm

Wt oven= 3202 gm

Sample B1

Wt air=3467 gm

Wt water=1555 gm

Wt oven=3418.5gm

Sample B2

Wt air=3424 gm

Wt water=1559 gm

Wt oven= 3375 gm

Specific gravity= Wt air/Wt water

Sg A=3249 gm/1547 gm=2.1

Sg B1=3467 gm/1555gm=2.23

Sg B2=3424 gm/1559 gm=2.2

Sg B=(2.23+2.2)/2=2.22

% Absorption=(Wt air-Wt oven)/ Wt oven*100

% Absp A=(3249-3202)/3202*100

% Absp A=1.47

% Absp B1=(3467-3418.5)/3418.5*100

$$\% \text{ Absp B1} = 1.42$$

$$\% \text{ Absp B2} = (3424 - 3375) / 3375 * 100$$

$$\% \text{ Absp B2} = 1.45$$

$$\% \text{ Absp B} = (1.42 + 1.45) / 2 = 1.44$$

Unit wt for sample A

$$\text{Wt of the cylinder considered} = 4252 \text{ gm}$$

$$\text{Volume of the cylinder} = 3739.28 \text{ cm}^3$$

Loss unit wt

$$\text{Wt of the cylinder + wt of loss} = 8534 \text{ gm}$$

$$\begin{aligned} \text{Loss unit wt for sample A} &= (8534 - 4252) \text{ gm} / 3739.28 \text{ cm}^3 = 1.145 \text{ gm} / \text{cm}^3 \\ &= 1145.14 \text{ kg} / \text{m}^3 \end{aligned}$$

Compacted unit wt

$$\text{Wt of the cylinder + wt of compacted} = 9079.4 \text{ gm}$$

$$\begin{aligned} \text{Compacted unit wt for sample A} &= (9079.4 - 4252) \text{ gm} / 3739.28 \text{ cm}^3 = 1.29 \text{ gm} / \text{cm}^3 \\ &= 1290.1 \text{ kg} / \text{m}^3 \end{aligned}$$

Unit wt for sample B

$$\text{Wt of the cylinder considered} = 4252 \text{ gm}$$

$$\text{Volume of the cylinder} = 3739.28 \text{ cm}^3$$

Loss unit wt

$$\text{Wt of the cylinder + wt of loss} = 8836 \text{ gm}$$

$$\begin{aligned} \text{Loss unit wt for sample A} &= (8836 - 4252) \text{ gm} / 3739.28 \text{ cm}^3 = 1.226 \text{ gm} / \text{cm}^3 \\ &= 1225.9 \text{ kg} / \text{m}^3 \end{aligned}$$

Compacted unit wt

Wt of the cylinder + wt of compacted = 9176 gm

Compacted unit wt for sample A = $(9176 - 4252) \text{ gm} / 3739.28 \text{ cm}^3 = 1.317 \text{ gm} / \text{cm}^3$
 $= 1316.8 \text{ kg/m}^3$

Test for material Flakiness**Flakiness Index for sample A**

sieve size	passed (gm)	retained(gm)	
50	135	171	
37.5	503	1129	
28	638	1737	
20	410	1612	
10	164	1198	
	1850	5847	7697

FI A = $1850 / 7697 * 100 = 24$

Flakiness Index for sample B

sieve size	passed (gm)	retained(gm)	
50	130	-	
37.5	389	89	
28	393	1507	
20	432	2738	
10	257	2393	
	1601	6727	8328

FI A = $1601 / 8328 * 100 = 19.22$

Test for material Elongation**Elongation Index for sample A**

sieve size	passed (gm)	retained(gm)	
37.5	1412	219	
28	1938	437	
20	1534	488	
10	586	778	
	5470	1922	7392

$$EI A = 1922/7392 * 100 = 26$$

Elongation Index for sample B

sieve size	passed (gm)	retained(gm)	
37.5	838	-	
28	1732	52	
20	2744	307	
10	1004	1527	
	6318	1886	8204

$$EI B = 1886/8204 * 100 = 23$$

Materials Finer than 75- μ m (No. 200) Sieve in Mineral aggregates by washing

Sample A before washing = 2805 gm

Sample A after washing and oven dry = 2778 gm

$$\% \text{ finer} = (2805 - 2778) / 2805 * 100 = \underline{\underline{0.96\%}}$$

Sample B before washing = 2964 gm

Sample B after washing and oven dry = 2937 gm

$$\% \text{ finer} = (2964 - 2937) / 2964 * 100 = \underline{\underline{0.91\%}}$$

ACV for sample A

Mass of sample prepared (Grade A) = 1981 gm

Mass after compression (400 KN) = 1458 gm

calculation

$$\% \text{ loss} = 1981 - 1458 / 1981 * 100 = \underline{\underline{26.4 \%}}$$

ACV for sample B

Mass of sample prepared (Grade A) = 2039 gm

Mass after compression (400 KN) = 1529gm

calculation

$$\% \text{ loss} = 2039 - 1529 / 2039 * 100 = \underline{\underline{25 \%}}$$

For small sized aggregate**LAA for sample A**

Mass of sample prepared (Grade A) = 5000 gm

Mass after crushing (12 balls) = 3530 gm

calculation

$$\% \text{ loss} = 5000 - 3144 / 5000 * 100 = \underline{\underline{29.4\%}}$$

LAA for sample B

Mass of sample prepared (Grade A) = 5000 gm

Mass after crushing (12 balls) = 3630gm

Calculation

$$\% \text{ loss} = 5000 - 3630 / 5000 * 100 = \underline{\underline{27.4\%}}$$

For large sized aggregate**LAA for sample A**

Mass of sample prepared (Grade 3) = 10000 gm

Mass after crushing (12 balls) = 7180 gm

Calculation

$$\% \text{ loss} = 10000 - 7180 / 1000 * 100 = \underline{\underline{28.2\%}}$$

LAA for sample B

Mass of sample prepared (Grade 3) = 10000 gm

Mass after crushing (12 balls) = 7230gm

calculation

$$\% \text{ loss} = 10000 - 7230 / 10000 * 100 = \underline{\underline{27.7\%}}$$

As numerical results inducts , there are some results that don't fall within the limiting values ; another trial mixing or blasting with stabilizing agent experienced.

Appendix III. Test for stabilizing agent

EI for stablizing material

sieve size	passed (gm)	retained(gm)	
37.5	1429	215	
28	2155	449	
20	1651	468	
10	824	782	
	6059	1914	7973

$$EI = 1914 / 7973 * 100 = 24$$

Gradation for stabilizing material

sieve size	weight (gm)	% retained	% passed	4A gradation(%pass)	
				Lower	Upper
63	-		100	100	100
50	493	4.61	95.39	90	100
37.5	2256	21.09	74.30	60	90
25	4393	41.07	33.23	10	35
20	2520	23.56	9.68	0	10
10	1035	9.68	0.00	0	3
	10697				

Test for Specific gravity and % Absorption

Wt air=3763 gm

Wt water=1289 gm

Wt oven= 3732 gm

Specific gravity= Wt air/Wt water

Sg stabilizing=3763 gm/1289 gm=2.92

% Absorption=(Wt air-Wt oven)/ Wt oven*100

% Absp stabilizing =(3763-3732)/3732*100

% Absp =0.83

Unit wt for sample

Wt of the cylinder considered = 4252 gm

Volume of the cylinder=3739.28 cm³

Loss unit wt

Wt of the cylinder + wt of loss =9513 gm

Loss unit wt for stabilizing sample =(9513-4252) gm/3739.28 cm³ = 1.407 gm/ cm³

=1407 kg/m³

Compacted unit wt

Wt of the cylinder + wt of compacted =9865 gm

Compacted unit wt for stabilizing sample =(9865-4252) gm/3739.28 cm³ = 1.501 gm/ cm³

=1501 kg/m³

Materials Finer than 75- μ m (No. 200) Sieve in Mineral aggregates by washing

Sample stabilizing before washing = 3213.3 gm

Sample stabilizing after washing and oven dry=3203 gm

% finer= (3213.3-3203)/3213.3 *100= 0.32%

ACV for sample stabilizing

Mass of sample prepared (Grade A) = 4267 gm

Mass after compression (400 KN) = 3456 gm

calculation

$$\% \text{ loss} = \frac{4267 - 3456}{4267} * 100 = \underline{\underline{19\%}}$$

For small sized aggregate**LAA for sample stabilizing**

Mass of sample prepared (Grade A) = 5000 gm

Mass after crushing (12 balls) = 3900 gm

calculation

$$\% \text{ loss} = \frac{5000 - 3900}{5000} * 100 = \underline{\underline{22\%}}$$

For large sized aggregate**LAA for sample stabilizing material**

Mass of sample prepared (Grade 3) = 10000 gm

Mass after crushing (12 balls) = 7900 gm

Calculation

$$\% \text{ loss} = \frac{10000 - 7900}{10000} * 100 = \underline{\underline{21\%}}$$

Appendix IV. Test for 20% - 80% mix

A sample prepared mixing the main sample with stabilizing agent in proportion of 20%-80% by mass

Test for specific gravity and % absorption, blending with stabilizing agent.**sample A**

wt Air = 3606.4 gm

Wt Water = 1554.5 gm

wt oven=3562 gm

sample B1

wt Air=3713 gm

Wt Water=1548 gm

wt oven=3668.6gm

sample B2

wt Air=3658 gm

Wt Water=1556.4 gm

wt oven= 3614.6 gm

Specific Gravity= Wt air / Wt water

Sg A=3606.4gm/1554.5gm=2.32

Sg B1=3713 gm/1548 gm =2.4

Sg B2=3658 gm/1556.4 gm=2.35

Sg B= (2.4+2.35)/2=2.38

% Absorption=(Wt Air-Wt Oven)/ Wt Oven*100

% Absp A = (3606.4-3562)/3562*100

% Absp A= 1.25

% Absp B1 =(3713-3668.6)/3668.6*100

% Absp B1=1.21

% Absp B2 =(3658-3614.6)/3614.6*100

% Absp B2=1.2

% Absp B=(1.21+1.2)/2=1.21

Appendix V . Test for 40%- 60% mix

A sample prepared mixing the main sample with stabilizing agent in proportion of 40%-60% by mass.

sample A

Wt air=3652 gm

Wt water=1410 gm

Wt oven=2647gm

sample B1

Wt air=4129 gm

Wt water=1496 gm

Wt oven=2653 gm

sample B2

Wt air=3857.4gm

Wt water=1423.4 gm

Wt oven= 2651 gm

specific gravity= Wt air/Wt water

Sg A=3652 gm/1410 gm=2.59

Sg B1=4129 gm/1496gm=2.76

Sg B2=3857.4gm/1423.4 gm=2.71

Sg B= (2.71+2.76)/2=2.74

% Absorption=(Wt air-Wt oven)/ Wt oven*100

% Absp A=(3652-3613)/3613*100

% Absp A=1.08

% Absp B1=(4129-4091.7)/4091.7*100

$$\% \text{ Absp B1} = \underline{0.91}$$

$$\% \text{ Absp B2} = (3857.4 - 3820.7) / 3820.7 * 100$$

$$\% \text{ Absp B2} = \underline{0.96}$$

$$\% \text{ Absp B} = (0.91 + 0.96) / 2 = \underline{0.94}$$

Unit weight for sample A blast with stabilizing agent ; A sample prepared mixing the main sample with stabilizing agent in proportion of 40%-60% by mass.

Unit wt for sample A

$$\text{Wt of the cylinder considered} = 4252 \text{ gm}$$

$$\text{Volume of the cylinder} = 3739.28 \text{ cm}^3$$

Loss unit wt

$$\text{Wt of the cylinder} + \text{wt of loss} = 9150 \text{ gm}$$

$$\text{Loss unit wt for sample A} = (9150 - 4252) \text{ gm} / 3739.28 \text{ cm}^3 = 1.31 \text{ gm} / \text{cm}^3$$

$$= \underline{1309.87 \text{ kg/m}^3}$$

Compacted unit wt

$$\text{Wt of the cylinder} + \text{wt of compacted} = 9513 \text{ gm}$$

$$\text{Compacted unit wt for sample A} = (9513 - 4252) \text{ gm} / 3739.28 \text{ cm}^3 = 1.407 \text{ gm} / \text{cm}^3$$

$$= \underline{1407 \text{ kg/m}^3}$$

Unit wt for sample B

$$\text{Wt of the cylinder considered} = 4252 \text{ gm}$$

$$\text{Volume of the cylinder} = 3739.28 \text{ cm}^3$$

Loss unit wt

$$\text{Wt of the cylinder} + \text{wt of loss} = 9176 \text{ gm}$$

$$\text{Loss unit wt for sample B} = (9176 - 4252) \text{ gm} / 3739.28 \text{ cm}^3 = 1.317 \text{ gm} / \text{cm}^3$$

$$= \underline{1316.8 \text{ kg/m}^3}$$

Compacted unit wt

Wt of the cylinder + wt of compacted = 9580 gm

Compacted unit wt for sample A = $(9580 - 4252) \text{ gm} / 3739.28 \text{ cm}^3 = 1.425 \text{ gm} / \text{cm}^3$

$$= \underline{\underline{1424.87 \text{ kg/m}^3}}$$

ACV for sample A blast with stabilizing agent ; A sample prepared mixing the main sample with stabilizing agent in proportion of 40%-60% by mass.

ACV for sample A

Mass of sample prepared (Grade A) = 2021 gm

Mass after compression (400 KN) = 1556 gm

Calculation

$$\% \text{ loss} = (2021 - 1556) / 2021 * 100 = \underline{\underline{23 \%}}$$

ACV for sample B

Mass of sample prepared (Grade A) = 2046 gm

Mass after compression (400 KN) = 1616 gm

Calculation

$$\% \text{ loss} = (2046 - 1616) / 2046 * 100 = \underline{\underline{21 \%}}$$

LAA for sample A blast with stabilizing agent ; A sample prepared mixing the main sample with stabilizing agent in proportion of 40%-60% by mass.

Mass of sample prepared (Grade A) = 5000 gm

Mass after crushing = 3785 gm

Calculation

$$\% \text{ loss} = (5000 - 3785) / 5000 * 100 = \underline{\underline{24.3 \%}}$$

LAA for sample B blast with stabilizing agent .

Mass of sample prepared (Grade A) = 5000 gm

Mass after crushing = 3800gm

calculation

$$\% \text{ loss} = \frac{5000 - 3800}{5000} * 100 = \underline{\underline{24 \%}}$$

LAA for sample A blast with stabilizing agent ; Sample prepared mixing the main sample with stabilizing agent in proportion of 40-60% by mass

Mass of sample prepared (Grade 3) =10000 gm

Mass after crushing = 7540 gm

Calculation

$$\% \text{ loss} = \frac{10000 - 7540}{10000} * 100 = \underline{\underline{24.6 \%}}$$

LAA for sample B blast with stabilizing agent

Mass of sample prepared (Grade 3) =10000 gm

Mass after crushing = 7610gm

calculation

$$\% \text{ loss} = \frac{10000 - 7610}{10000} * 100 = \underline{\underline{23.9 \%}}$$

