ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
DEPARTMENT OF CIVIL ENGINEERING

INVESTIGATION OF THE PERFORMANCE OF UNSEALED ROAD SUB BASE MATERIALS USED AS WEARING COURSE OF GRAVEL ROAD

(In The Case of Kamashi –Yaso Road)

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(ROAD AND TRANSPORT ENGINEERING STREAM)

BY

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ABSTRACT

A good road structure may help in reducing the number of accidents. Wearing course is the top layer of the road structure which is the layer exposed to the vehicle tyre and environment. The international roughness index and Present Serviceability Index are both indices that can be used as indicator of road roughness and serviceability.

Objective of the study is primarily to determine the performance and the durability, serviceability and service life of unsealed gravel road wearing course above sub grade.

In evaluating the serviceability of the road, roughness is an important indicator of pavement riding comfort and safety. It is condition indicator that should be carefully considered when evaluating pavement performance. At the same time, the use of roughness measurements plays a critical role in the pavement management system.

There are many devices used for roughness evaluation. In this thesis, roughness measurement was done by Merlin manual instrument. The methodology used to carry out the thesis work is carry the field data measurement for roughness and gathering user assessment for the case study site and taking sample data of soil for strength test of CBR.

International roughness index was measured by using Merlin roughness index measuring instrument. And used for calculating present serviceability index as independent parameter.

Both international roughness index and present serviceability index were measured along 200m section of the road for about 19.7km of the study route. This studies only focuses on one type of road which was gravel pavement located on western part of Ethiopia in Benishagul Gumuz regional state in Kamashi Zonal state.

The work has generated that this unsealed gravel road is running with in the design limit without sever deterioration as the result of serviceability, user assessment, CBR strength test and roughness value shows.

1. INTRODUCTION

1.1Back ground

Generally, it has been universally witnessed that both traffic volume and loads on roads are going on increasing from year to year with alarming rate all over the world. Such heavy traffic growth demands better performance roads for efficient transport of agricultural, commercial and industrial products without delay. The repetitive traffic loading that the road experiences during its service life combined with environmental factors causes deformation, fatigue cracking, instability and other forms of deterioration which ultimately degrade the serviceability and durability of pavement structures.

Pavement performance is one of the most important measures for pavement surface performance condition. Pavement roughness and other performance indicators is also an important indicator of pavement riding comfort and safety. Roughness condition has been used as the criteria for accepting new construction of pavement including overlay and also as the performance measure to quantify the surface performance of existing pavements in a pavement management system at both network level and project level in most of the time this research make use both user assessment and roughness for measuring the performance of the road. The longitudinal unevenness of a road’s surface normally termed as roughness; its roughness is an important measure of road condition and a key factor in determining vehicle operating costs on poor quality surfaces.

For example, roughness can be used for dividing the network into uniform sections, establishing value limits for acceptable pavement condition, and setting maintenance and rehabilitation priorities, or roughness measurements are used to locate areas of critical roughness and to maintain construction quality control.

According to the 2011 data of Ethiopian Road Authority (ERA) the country has 8,295 asphalt road networks 14,136 Gravel road networks and 30,712 rural road networks which sum up to total of 53,143km road networks, out of this ,44,848 which is about 84.4% of the country road network is unsealed, with road density of 0.65 per 1000 population .in kilometer.

These unpaved roads are located in the agricultural, forest areas, in cities, town and villages, although they are low-volume and low load bearing roads. Unsealed gravel roads are vital first link in the local economy as the Ethiopian economy is based on agriculture and the agricultural products are transported on these unpaved gravel surfaced roads. Out of this total road net work 60% of the total road is in good condition and performing well persuade to the authority 2011 data[1].

Studying the performance of these gravel pavement structure under traffic, climatic condition which they undergo after construction is essential. Even though the cause for the deterioration of this low volume road is too many, studying the material loss on the environmental and structural strength of the material with the traffic influence causes is desirable.

In the last few years there has been a dramatic increase in the proportion of paved roads due to the increased comfort and reliability provided by concrete and bituminous surfaces.

While the length of sealed roads increased, the importance of unsealed roads was still there, in fact the vast majority of the network will remain unsealed in most part of our country and emerging economies for some time to come. As for all economies, the adequate maintenance of the road network is paramount for socioeconomic development.

For most developing and emerging economies the road maintenance challenge is dominated by the maintenance of unsealed roads. Over the years, engineers have become knowledgeable at optimizing resources for maintaining unsealed roads. Various manuals and guidelines have been produced by authorized organizations like ERA and Addis Ababa City Road Authority (AACRA), with extensive unsealed road networks.

Most of these manuals also touch on principles underlying the decision to upgrade from unsealed to paved roads. Studying the road performance serviceability and longevity of the unsealed roads which are paved by gravel wearing, sub-base material, is one important way to minimize the pavement failure problem. Unsealed roads are defined as roads without a permanent waterproof surface. These include engineered and un-engineered roads.

Under this definition, three types of unsealed roads can be distinguished.

- **Unformed Roads or Earth Roads:** have no drainage, cross fall, added granular material or other features that would ensure all-weather access.
- **Formed Roads:** have a reasonably well defined cross section, including drainage. They usually consist of locally available earth material with no added surfacing material.
- **Graveled Roads:** are built and designed to certain engineering principles, including the supply, where warranted, of gravel wearing surface. Construction of these roads also involves a defined cross section, drainage and structures (bridges, culverts). This research will focus on the study of the performance of Kamashi –Yaso gravel road fond in Benishagul Gumuz Regional State Kamshi Zone [2].

The case study site location and the material property with the climate condition of the area with the grading and plasticity components of the sub base material specifications were plotted as shown below in Figure 1.2.

Climatic factor varies throughout the country this case study site fall under" Kolla" as shown in the Figure1.1.below in the western part of Ethiopia.

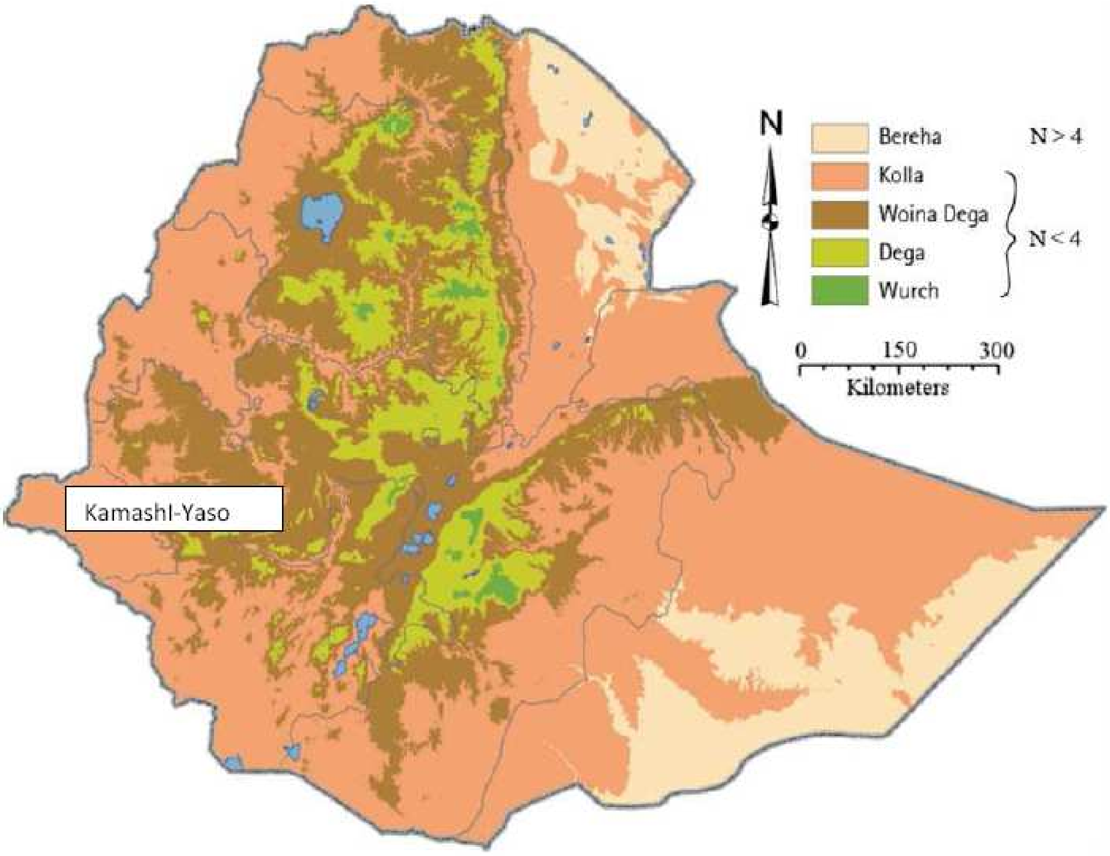

Figure1.1: Benishagul Gumuz Regional road map

Source: From the Benishagul Gumuz regional road Authority net work division

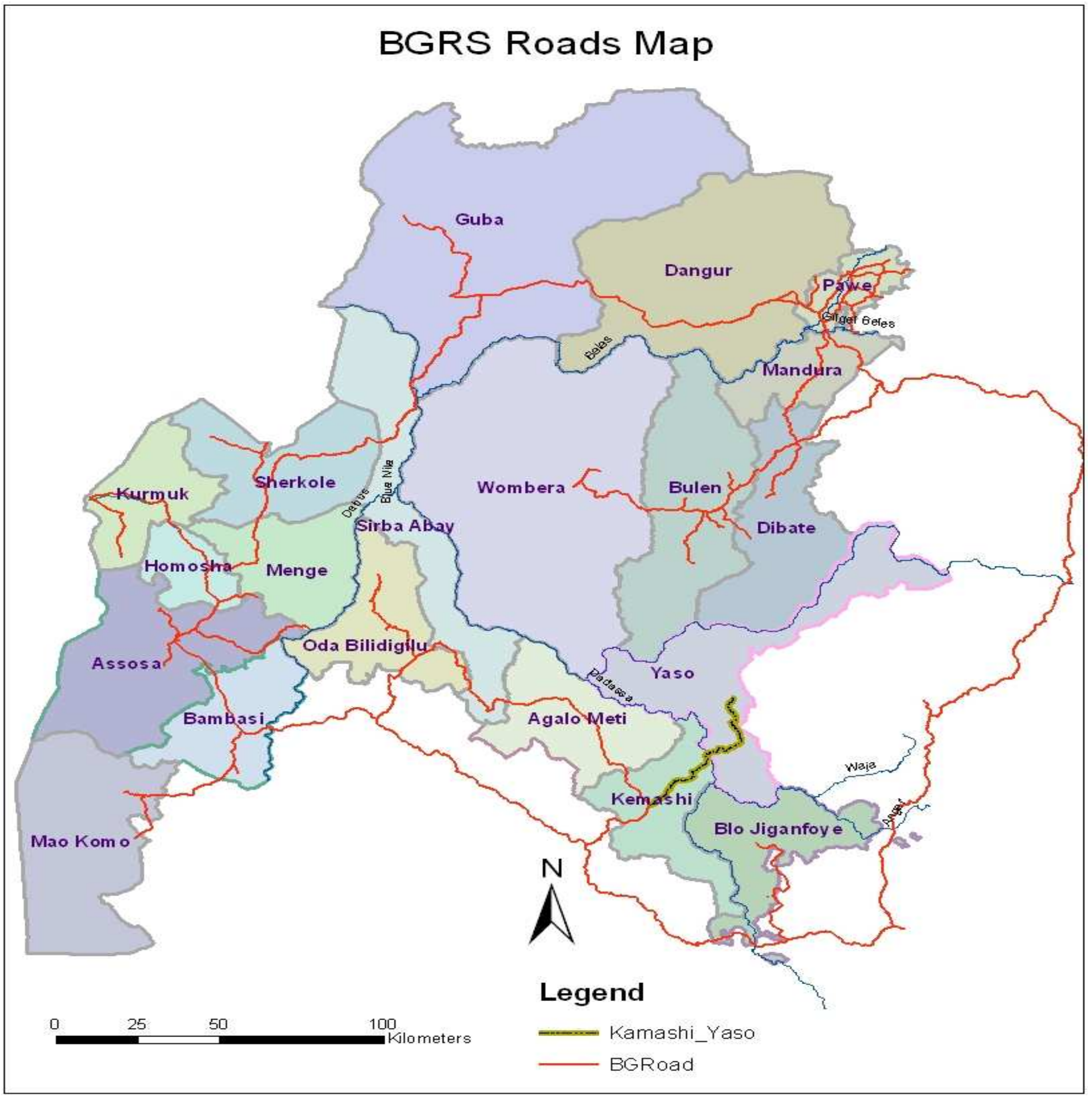

Figure1.2: Ethiopian climate zone for material classification

Source: - ERA LVR manual 2011

1.2 Statement of the Problem

Different factors affect the overall performance of roads whether they are asphalt surfaced or gravel surfaced. A road is designed for parameters like traffic, surrounding atmospheric condition, and material property based on certain design principles and the standard for the intended use of the road.

Pavement failure of roads in Ethiopia is becoming a common problem and great challenge, consuming a lot of money, in some cases failure is appearing even before the completion of a project in certain road projects. In most projects road surface condition defects like rutting, cracking and surface deformation are common before the design life and require a lot of maintenance cost.

Under low volume road context and other higher standard roads to have better performing and long lasting nature of the road is basically depends on the material it wears; therefore studying the performance of the road surface material is key to the selection of alternative sub base materials with better load bearing capacity and longevity.

This research will focus on the study of the performance of gravel surfaced road, sub base material used as the wearing course of the gravel road, taking a case study of the Kamashi – Yaso gravel road having a wearing course of selected natural gravel material located at western part of Ethiopia in Benishagul Gumuz Regional state Kamashi Zone.

1.3 Objective of the Research

- General objective of this research is to evaluate the performance and the durability, serviceability and service life of sub base materials of the unsealed gravel road above sub grade.
- The specific objective of this research is to determine and judge the serviceability index of unsealed gravel wearing roads from the specific highway of kamashi- yaso road data and to generalize for unsealed graveled roads.
- Determine whether sub base materials used for the wearing course of unsealed gravel roads attain the intended design period.

1.4 scope of the research

The scope of this research is limited to evaluation of serviceability index, service life and determination of design period attainability of the specific highway of Kamashi –Yaso road on the basis of the sampled sub base materials used as the wearing course of gravel surface of the road, measured roughness result and road users performance rating assessment to investigate how the road is performing. The riding comfort or quality of the road depends on the erodability of surface materials by erosion and other forces; presence of surface distresses which are directly depends on the material strength of the wearing course sub base materials.

2. LITERATURE REVIEW

2.1 Engineering property of sub base material used as wearing course of roadway

Pavement materials are an important component of pavement design, the selection of appropriate quality of materials for selected, sub grade, sub base and road base courses determine the capital and whole life costs of the road which primarily determines the performance of the road. In the selection of pavement materials guide line principles used for the material performance indication are: California bearing ratio (CBR) strength, gradation, Unterberg limits (liquid limit and plasticity limit) and plasticity indexes.

Design of Pavement depends on the materials to be used and the conditions which the pavement must meet [3].

Major components of a pavement structures are:

1. Surface
2. Base } pavement
3. Sub base
4. Compacted sub grade } sub grade
5. Natural sub grade

Bases and sub bases are usually granular materials or aggregates. The sub base which is lower in the structures does not require as high –quality material as the base; as loads are reduced considerably. The compacted sub grade may be the surface layer of the sub grade, compacted in cut areas, or the embankment materials in fill zones. The main function of a pavements is to reduce the high unit stress imposed by the vehicle on the surface to stress on the sub grade that are low enough to be carried without failure due to rutting, excessive settlement or other type of distress. The magnitude of stress reduction is mainly is the function of the thickness of the pavement structure. Therefore the main variable in the design of pavement structure is the thickness [4].

The major factors involved in the design of pavement thickness are:

1. The magnitude of imposed loads
2. The strength of sub grade soil

Base courses in pavement structures are composed of either solely granular materials (aggregate), or soil or granular materials stabilized by an additive. Granular base courses are mainly aggregates from sand or gravel deposits or from quarries. The properties required in the materials vary with the type of pavement and the depth of the material in the pavement structure [5].

Granular sub base material for road sub base shall consist of hard, durable natural screened gravel or crushed stone and shall be free from clay balls or other deleterious substances. Granular sub base shall be well graded and lie within the grading envelope stated below Table 2.1.1 when tested and the material shall have a minimum CBR of 30% at 95% of maximum dry density and should comply with as state below with relevant tests and standards.

Table2.1. 1: Granular sub base materials gradation envelope with material sieve size

SIEVE SIZE	% PASSING
63mm	100
37.5mm	85-100
9.5mm	40-85
4.75mm	25-45
0.60mm	8-25
0.075mm	0-10

Source: Atkins, highway material and soil

Road base material shall be delivered to the roadbed as uniform mixture and shall be spread in layers or windrows. Segregation shall be avoided and the sub base shall be free from pockets of coarse or fine material. Particle size analysis of soils for sieve analysis of fine and coarse aggregate shall be carried out in accordance with the specification in the table2.1.1.

It is essential to check the grading and plasticity of the proposed sources of natural material, both prior to construction and during it progress of construction to assure sustainable performance.

2.1.1 Sub base materials properties

The engineering property of sub base materials used for the wearing course of gravel road are determined by their components or ingredients of the material, generally the sub-base materials consists of granular material ,gravel, crushed stone, reclaimed(blended) material or a combination of these materials but the material used for gravel road is the natural selected material which fulfills the specification listed under 2002 Pavement design manual of ERA volume I and 2011 ERA LVR manuals in our country since this materials are used as pavement and pavement is the portion of the highway which is most obvious to the motorist [6]. The condition and adequacy of the highway is often judged by the smoothness or roughness of the pavement. Deficient pavement conditions can result in increased user costs and travel delays, braking and fuel consumption, vehicle maintenance repairs and probability of increased crashes [7].

The sub-base material used as wearing course for the surfacing of unsealed road should fulfill the following specification.

Table2.1.1 1: Specification for sub base materials used as wearing course of unsealed (gravel) road

Sieve size(mm)	Alternate Grading(% passing)		
	A	B	C
50	100	100	-
25	-	75-95	100
9.5	30-65	40-75	50-85
4.75	25-55	30-60	35-65
2	15-40	20-45	25-50
0.425	8-20	15-30	15-30
0.075	2-8	5-20	5-15
PI	6-12	LA	50% max
LL	-	CBR	30% min
LS	-	Compaction	95% min

Source: Atkins highway material and soil

The granular material should meet the material property requirement specified above table.

For the surfacing of gravel road the material from the quarry run is used. The term “Quarry Run” is used as a general term to cover naturally occurring rock and weathered rock materials excavated from a quarry or borrow area and delivered to site without processing, apart from any required selection or screening for the removal of oversize boulders or cobbles.

In areas where hard rock quarries have been developed primarily for aggregate production, the use of quarry run in rural road construction provides a use for materials that may otherwise be considers as waste for dumping. Provided they are acceptable, this use of these materials, therefore, brings with it an environmental advantage.

This type of material is by its nature highly variable and care should be taken in initially assessing the suitability of the source; in addition and equally importantly supervision resources must be available to ensure the continued consistency of its properties throughout the contract. Even if they meet specified criteria, any materials with excessive variation within the acceptable envelopes should be rejected due to the consequent problems caused in compaction control.

For the purposes of the construction of rural road sub-base the target for acceptable quarry run material will be to meet the established requirements for naturally occurring gravel used for the same purpose according to the gravel road specification.

The materials must comply with specified grading and plasticity criteria as well as compacted strength and particular care must be taken in ensuring the removal of oversize material.

During the construction of gravel road and at the time of Construction and Supervision the following points should be assured.

1. Ensure that any deformations, ruts, soft spots or other defects in the formation have been corrected to the satisfaction of the Engineer i.e. fulfill gravel road specification.
2. Secure lateral support for the sub-base shall be in place prior to the construction of the sub-base layer which is used as wearing course.
3. After ensuring appropriate amounts of quarry run are loaded, spreading and compaction should start immediately as it is generally known that soil or selected material used for the wearing course of gravel road exists in three forms or volumes;

bank volume, loose volume and compacted volume. From this three states bank state is the natural state [8].

If labour-based methods are a construction option, the workers should use special spreading rakes, appropriate hand tools or hoes to spread the material evenly onto the sub-grade. Work should progress from the centre line towards the shoulder, and material should be spread from one side of the centre line at a time.

Oversize pieces of rock should be removed or crushed, if possible, using sledge hammers.

4. If the material is in a dry condition then water should be added prior to compaction. Make sure that there is a sufficient supply of water, to maintain close to optimal moisture content in the quarry run during compaction.
5. An inspection should be made of the laid out material prior to compaction to identify and remove any oversize to attain the required quality and performance of the road.
6. Compaction should be carried out along the road line starting at the shoulder of the road and gradually working towards the centre line, ensuring an adequate overlap between passes.
7. The first passes of the vibrating roller should be done without vibration in order to avoid that the roller getting "bogged down" in loose material.
8. Water should be added as necessary to facilitate compaction. Make sure that the camber of the road is always maintained for both the base layers as well as the gravel layer.

Materials used for sub-base should be tested and inspected to ensure that it:

1. Is clean sand free from clay coating, organic debris and other deleterious materials?
2. Has a Sand Equivalent Value (SEV) of greater than 70 if the material is sand.
3. Complies with the target grading that is specified.

The material used as wearing course source should be capable of producing a material with consistent engineering properties throughout the construction period.

The materials source should be sampled and tested to ensure it is capable of providing a consistent supply of coarse and fine materials that comply with the specified grading, strength, and shape criteria.

From the visual assessment viewpoint it should be noted that the coarse material should have a virtually single size distribution. The road-base or existing surface should be visually checked for compliance with the Specification and by templates, levels or survey equipment for the correct shape and cross fall.

Surfacing aggregates should be stored on site in clean dry areas adjacent to the road. As-delivered materials should be checked for specification compliance. Where it is necessary to temporarily store material on the roadway, ensure that care is taken to minimize the extent of this and provide a suitable hazard warning for road users [9].

Granular pavement materials are aggregate materials used in different layers of pavement structure alone or in combination with various types of cementing materials to support the main stresses occurring within the pavement and resist wear due to abrasion by traffic as well as the direct weathering effects of the natural elements in the road surface.

These materials include:

- Crushed rock
- Semi-crushed
- Mechanically stabilized
- Modified or naturally occurring “as dug” or “pit run” gravel [10]

2.1.2 General highway material and structural property

2.1.2.1Material characteristics

The selection of pavement materials is a critical element in the design, construction and maintenance of pavements if performance is to be optimized.

Construction materials have their own characteristics suited to a specific design and construction use.

For gravel wearing courses the gravel gradation, utterberg limits and the CBR value are the highly evaluation criteria for the surfacing material behaviors where as for asphaltic materials the following conditions are followed:

The two basic materials in asphalt concrete (AC) pavement are the bitumen and the aggregate which have their own distinct behaviors.

The asphalt binder is what gives an asphalt pavement its flexibility, binds the aggregate together, and gives waterproofing properties to the pavement.

Even though the binder content is a key mixture design parameter, the binder grade plays a significant roll on the performance of pavement. Selecting a binder grade is essential in insuring that the asphalt will not experience significant levels of distress at the prevailing climatic condition. Asphalt binders are visco-elastic materials in nature whose resistances to deformation under load are sensitive to loading time and temperature. Less viscous asphalts make the mixture less stiff and therefore more susceptible to irrecoverable deformations, i.e. rutting. On the other hand, if asphalt is too hard, it would be brittle at low temperatures ultimately leading to cracking under loading [11].

2.1.2.2 Binder

Even though this research deals about pavements without binder and natural selected materials aggregate surfaced road of unsealed road it is essential to say some literature about the binding agents (materials and the binders).

Binder (sometimes termed as bitumen or asphalt) is a general description for the adhesive or glue used in asphalt pavements, either petroleum derived or naturally occurring material [12], the asphalt binder is what gives an asphalt pavement its flexibility, binds the aggregate together, and gives waterproofing properties to the pavement.

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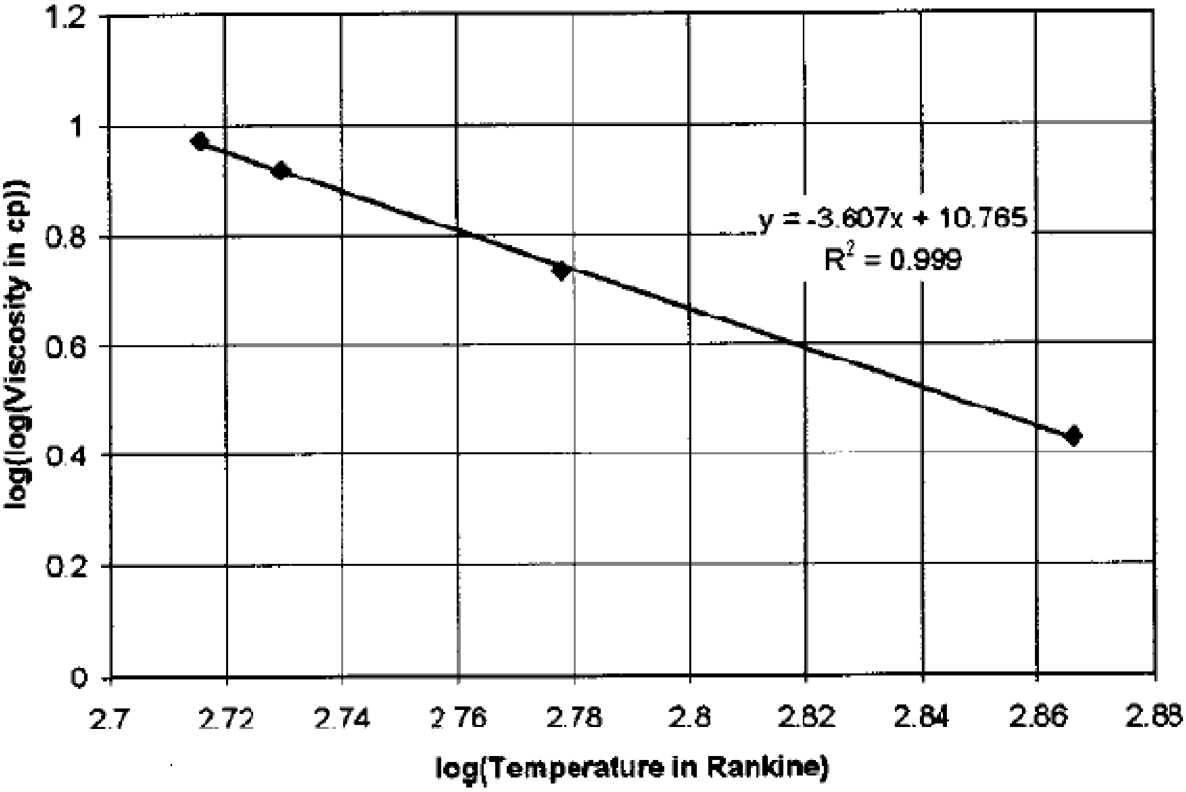


Source: - [Rasmussen et al. 2002]

Figure2.1.2.2. 1: Plot and least-squares fit for binder

2.1.2.3 Aggregates

Aggregates are the key materials used in the construction sector and the largest portion of an asphalt pavement. Aggregates are generally derived from stone minerals and sometimes further mechanically processed to suite for specific applications. Synthetic aggregates, most commonly blast furnace slag from the steel industry, slate wastes and ashes, are also used in the construction of asphalt pavements [13].

Mineral aggregate, predominantly of coarse aggregate constitutes approximately 90–95% of hot-mix asphalt (HMA) by weight. Generally aggregate characteristics such as particle size, shape, and texture influence the performance and serviceability of hot-mix asphalt pavement. Aggregate shape is one of the important properties that are considered in the mix design of asphalt pavements to avoid premature pavement failure [14].

Aggregate shape is one of the important properties that are considered in the mix design of asphalt pavements to avoid premature pavement failure. Flat and elongated particles tend to break during mixing, compaction and under traffic loading.

It has been found a direct correlation between the rutting potential of HMA mixtures and the shape and texture of coarse aggregate particles. Some mixes with flaky aggregates have been found to exhibit higher fatigue life than mixes with non flaky aggregates [15].

Mixtures made from angular aggregates (obtained by crushing) deform to a minor extent and are more stable than mixtures having the same composition and grading but made from rounded aggregates, river gravel.

The percentage of crushed coarse particles has a significant effect on laboratory permanent deformation properties. As the percentage of crushed coarse particles decreased, the rutting potential of the HMA mixtures increased. It is emphasized in literature that cubical, rough-textured aggregates have better interlocking mechanisms; reduce the potential for rutting and more resistant to the shearing action of traffic than rounded and smooth-textured aggregates.

Some researches indicate that dense aggregate properties and gradations are desirable to mitigate the potential effects of rutting of asphalt concrete pavement. When properly compacted, mixtures with dense or continuous aggregate gradations have fewer voids [16].

A gap-graded mixture exhibits more deformation than a continuously graded mixture due to less aggregate interlock in the gap-graded mixture.

Aggregate interlock becomes more important at higher temperatures; gap-graded mixtures may be even more susceptible to rutting at higher temperatures. As well as, the use of larger maximum aggregate size (about two-thirds of layer thickness) would be beneficial in reducing the rutting propensity of mixtures subjected to high tire pressures.

For better rutting resistance the surface texture of the aggregate plays an extremely important role. Particularly in thicker asphalt-bound layers and hot climates, a rough surface texture is required.

For the gravel wearing course the gravel materials of naturally selected materials are used, Gravel is formed from the breakdown of any natural rock. Gravel particles are found in existing or ancient waterways, and the particles are usually smooth and typically rounded or sub rounded by wear as the materials is moved along the waterway by the action of water. Gravel is usually required to be crushed prior to use in HMA [17].

2.1.3 Structural characteristic

A rapid growth in heavy traffic demands better performance road and hence requires better construction materials. The utilization of new materials type and modification of materials characteristics are under steady state to improve the performance and durability of gravel wearing and asphalt concrete pavement.

The thickness of the pavement layer is the most significant part of the structural integrity of the gravel as well as asphalt pavement, Variables evaluated when determining thickness of gravel road are sub grade, sub base and gravel wearing material properties, traffic loading and environmental factors, where as for asphaltic pavement AC material properties are further evaluated in addition to the above.

Thickness determination of a pavement is a structural evaluation process, ensuring that the traffic loads are so distributed that the stresses and strains developed at all levels in the pavement structure and in the sub grade are within the capabilities of the materials used at those levels. It involves the selection of materials for the different pavement layers and the calculation of the required thickness. The traffic or load carrying ability of a gravel pavement is a function of both the thickness of the material and its material property and stiffness [18].

The structural failure of a pavement is associated with the strength characteristics of the constituent materials and the thickness of each layer. Major failure types are surface rutting and crack formation either at the top surface or bottom layers. The required thickness of each layer of the flexible pavement varies widely depending on the materials used, magnitude and number of repetitions traffic load, environmental conditions, and the desired service life of the pavement [19].

These factors are generally considered in the design process so that the pavement would last for the required designed life without excessive distresses and increase the longevity of the pavement for both the gravel wearing and asphalt sealed.

It can be seen that the load is distributed on a small area at the surface. As the depth increases, with same load, the stress developed is distributed over larger area; therefore, the highest stress occurs at the surface and it decreases as the depth increases.

Thus, highest quality materials are required at the top of the pavement and as the depth increases lower quality materials can be used.

The primary function of surface course is to provide a safe, smooth, stable riding carriageway for traffic and to contribute to the structural stability of the pavement and protect it from the natural elements perform well with in the design period of the pavement.

The base and binder courses are the main structural component of an asphalt pavement. Both courses transmit and distribute the traffic loading so that the strength capacities of the weaker sub-base and sub grade are not overstressed. They are designed to be dense and highly stable to resist permanent deformation and fatigue cracking caused by repeated traffic loading and distresses induced by temperature fluctuations throughout the structure during the service life. A sub base layer further distributes the induced stress to the weaker sub grade layer. Whilst the Sub base material is of a lesser quality than the road base material, it has to be able to resist the stresses transmitted from the superstructure and at the same time be stronger than the sub grade soil. When the sub grade soil is weak or if there is frost action, a capping or frost protection layer may be provided above the sub grade for better bearing capacity and longevity performance.

2 .2 Sub base materials used for surfacing of unsealed road

2.2.1 Unsealed roads

The construction of engineered unsealed roads with improved material selection processes alone can result in significant improvements in road performance and reductions in material usage but unsealed roads remain environmentally unsustainable in the long term.

Where the traffic volumes in rural areas are low and consist mostly of light vehicles, the need to construct high quality sealed pavements using conventional design techniques is usually unnecessary. Very light and economical pavements can be constructed to provide highly appropriate accessibility in rural areas.

The materials used for the construction of wearing courses for unsealed roads need to fulfill a number of functions and comply with a number of basic engineering properties [20].

The most important of these are to:

- Have sufficient cohesion to resist raveling and erosion
- Have a particle size distribution that facilitates a tight interlock of the individual material particles.
- Have sufficient strength to support the applied traffic loads without significant plastic deformation.

Deficiencies in any of these properties result in poor riding quality and high maintenance requirements as well as an increased loss of material from the road low performance level for road user. It is thus essential that the best available material is used for construction of unsealed roads. Such materials are, however, usually not suitable for use as structural layers in sealed roads.

Typical specifications for unsealed road materials are very similar to those for sub base materials for sealed roads [21]. These do not necessarily provide the best performance in the unsealed road situation (depending on the climate) and often require high maintenance inputs. They also utilize materials that should perhaps be better conserved for future upgrading of the roads. Specifications for wearing course gravels have been derived from a large performance-related study of unsealed road in southern Africa [22].

2.2.2 Wearing Course Specification for Unsealed Roads

According to paige –green and Netter berg literature the specification for unsealed roads were developed from roads selected using a factorial design including material types, traffic and climate and cover a wide range of environments and conditions [23].

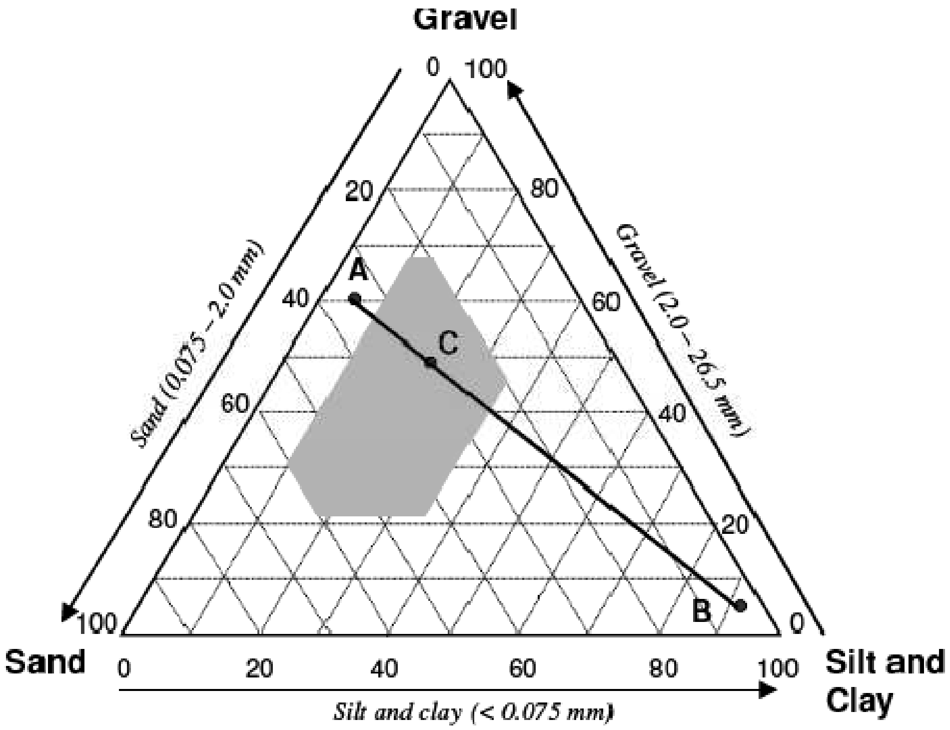
The major advantage of the specification developed is the ability to identify potential problems associated with materials not meeting the specifications. This allows the implementer to make judgments regarding the consequences of using material outside the specifications and to assess whether these can be accommodated in terms of the local traffic, climate or maintenance capacity.

And this specification finding are well applicable for different maintenance strategies to control corrugation or wash boarding, example more frequent but possibly lower cost techniques, such as dragging, or making use of potentially slippery materials in areas with minimal rainfall.

A very important aspect is to control the amount of oversize material. Excessive oversize material is one of the major contributors to road roughness (and increased vehicle operating costs associated with tire and suspension damage to vehicles) as well as making routine grader maintenance difficult and less effective. Although an Oversize Index of up to 5 per cent is specified, the maximum size of the oversize material should not exceed about 75 mm according to the specification [24].

The applicability of the specifications over a wider area than that from which they were derived has been confirmed during their implementation in a number of countries. Where only materials with unsuitable grading are available locally, two or more where necessary materials may be blended to produce one with the correct grading mechanical stabilization. This can reduce the haulage costs associated with using better sources at greater distances from the project. It is more difficult to blend materials to correct the plasticity but this can often be done using materials with a high silt and clay content.

On the figure 2.2.2.1 below coarse material with a grading plotted at a lacks fine. If blended with a fine silty clay material B in the ratio of BC: AC gravel: fines, i.e., about 4 coarse material (A) to one fines (B), the resultant material will have a grading represented by C thus falling within the grading requirements of the “good” envelope shown as E in Figure below.



Source:-South African unsealed road material specification [Paige-Green, 1989; CSRA, 1990].

Figure2.2.2. 1: Example of blending technique

In order to improve material performance, all compaction should be carried out at optimum moisture content for the material and to refusal for the plant utilized based on the specification above.

The heavier the plant, the lower the compaction moisture required and the higher the density achieved.

Most natural gravel materials will result in dust being generated from the road under traffic, and even during windy periods. Apart from the social problems associated with this dust (safety, health and pollution), the natural soil fines (binder) in the wearing course material are lost and the material properties slowly deteriorate. The effect of this is that the wearing course properties slowly move down both the vertical and horizontal scale in Figure above shown, resulting in a good material becoming increasingly prone to corrugation and erosion.

The use of material complying with the specifications in rural areas will reduce the required frequency of grader maintenance and regravelling but not the need. It is still essential that this be regularly and carefully carried out. It is possible, however, in many cases to carry out the maintenance using labor (preferably from the local communities making use of the roads).

Despite the best material selection and construction techniques, roads in mountainous terrain (a frequent occurrence associated with rural access) are likely to erode on steep grades. Careful control of the camber to remove the water laterally from the road surface as quickly as possible can assist in reducing erosion, but a point is achieved where erosion is inevitable. Small water control humps can also assist with reducing erosion but this need to be designed and maintained carefully.

2.2.3 Bearing Capacity

California bearing capacity (CBR) is one of the most widely used tests for evaluating the strength of sub grade, sub base and base course support value that is the bearing capacity of the pavement [25].

The CBR strength of the material evaluation method covers the laboratory determination of the California Bearing Ratio (CBR) of a Compacted or undisturbed sample of soil. The principle is to determine the relation between force and penetration when a cylindrical plunger with a standard cross-section area is made to penetrate the soil at a given rate. At certain values of penetration the ratio of the applied force to a standard force, expressed as a percentage, is defined as the California Bearing Ratio (CBR).

Based on ERA manual, for the sub-base material the minimum soaked California Bearing.

Ratio (CBR) shall be 30% when determined in accordance with the requirements of AASHTO T-193. The Californian Bearing Ratio (CBR) shall be determined at a density of 95% of the maximum dry density when determined in accordance with the requirements of AASHTO T-180 method D [26].

According to ERA specification, all sub-base materials shall have a maximum plasticity index of 6 when determined in accordance with AASHTO T-90. The plasticity product (PP = PI x percentage passing the 0.075mm sieve) shall not be greater than 75% [27].

Design of the various pavement layers is very much dependent on the strength of the sub grade soil over which they are going to be laid for the thickness of the gravel wearing course the CBR is deterministic strength factor for the sub grade and the top wearing sub base material. Sub grade strength is mostly expressed in terms of CBR (California Bearing Ratio). Weaker sub grade essentially requires thicker layers whereas stronger sub grade goes well with thinner pavement layers. The pavement of the gravel bearing capacity and the sub grade bearing capacity mutually must sustain the traffic volume [28].

A minimum CBR of 30 per cent is required at the highest anticipated moisture content when compacted to the specified field density, usually a minimum of 95 per cent of the maximum dry density achieved in the ASTM Test Method D 1557 (Heavy Compaction) for gravel surface wearing course material used according to ERA 2002 manual.

In these circumstances, the bearing capacity should be determined on samples soaked in water for a period of four days.

The CBR test should be conducted on samples prepared at the density and moisture content likely to be achieved in the field. In order to achieve the required bearing capacity, and for uniform support to be provided to the upper pavement, limits on soil plasticity and particle distribution may be required, materials which meet the recommendations of the required specification.

Particle size distribution for sub -base materials which will meet the strength requirements to use as wearing course in gravel unsealed road.

Table2.2.3. 1: Particle size distribution for sub base materials which will meet the strength requirements to use as wearing course in gravel unsealed road

Test sieve(mm)	Percentage by mass of total aggregate passing test sieve (%)
50	100
37.50	80-100
20	60-100
5	30-100
1.180	17-75
0.30	9-50
0.0750	5-25

2.3 Performance and property of sub base materials used as gravel wearing course

2.3.1 Performance Criteria

Performance of a pavement is measured by its serviceability to the expected use; it is the change in pavement performance with time. The concept is to design a pavement, which at the end of the proposed performance period will still have a predefined minimum level of serviceability (PSI).

The terminal level of serviceability is selected based on the lowest index the user will tolerate, or as defined in a pavement management strategy before rehabilitation, resurfacing or reconstruction becomes necessary. The goal of a pavement design is to produce a pavement that when placed will perform functionally and structurally while maintaining its safety characteristics for at least the selected service life [29].

Functional performance of a pavement identifies how well a pavement will serve the user. The characteristics identified are riding comfort and ride quality.

This concept is called serviceability- performance and provides a means to measure functional performance. In the pavement design procedure, this factor is expressed in terms of the present serviceability index (PSI).

PSI is a measurement of roughness and distress of a pavement during the service life of a pavement. Therefore, a reliable method of measuring roughness and maintaining and updating historical performance data is an integral part of pavement design.

The major factors influencing the loss of serviceability are traffic, age, and environment.

The structural performance of a pavement relates to its physical condition; including occurrence of cracking, faulting, raveling, or other conditions which would adversely affect the load-carrying capability of the pavement or would require maintenance.

A pavement's safety performance primarily relates to its ability to provide adequate skid resistance during its service-life but also can be affected by its ability to maintain a smooth and rut free surface. Age, traffic, physical properties of materials used to construct the pavement and environmental conditions influence a pavement's safety performance.

In order to achieve the required deliverable in the design of gravel road this is not sealed by binder but sealed with the selected natural gravel to the design depth so in the design of such roads the strength of the lower material that is in situ sub grade material property or knowledge is very essential.

So in the design of unsealed roads, the most important factors include the choice of selected fill and wearing course materials, and consideration of strength of in situ material. The first stage is to determine whether the in-situ material is suitable for use as sub-grade and it can fulfill the requirement for sub grade material specification more over Plasticity index and grading are adequate for this purpose. In weak soils it may be necessary to determine the in-situ CBR by carrying out DCP tests.

Below is a table giving guidance on parameters that can be used for the selection of sub-grade materials for the construction of gravel roads.

Table2.3.1. 1: Parameters for the selection or acceptance of sub-grade, selected sub-grade or fill material

Parameter	**Acceptable**	**Conditionally Acceptable**	**Not Acceptable**
Reject index (I_R)	< 15%	15% – 25%	> 25%
Grading Modulus (GM)	1.0 – 2.7	0.3 – 1.0 2.7 – 2.9	< 0.3 >2.9
Maximum size (mm)	37.5	60	> 60

Source: pavement design principle module for rural roads

On the conditional acceptance the following points should noted:

1. Material may be used on condition that there is a substantial amount of fines, essentially > 25% passing 2.36mm sieve. If this condition is not satisfied then the fill material may not be easily compactable unless specialized compactors are used.
2. Material may only be used on condition that the $\mathbf{I_p}$ is less than 25 otherwise the material would be essentially clay and in that case specialized compaction equipment such as sheep's foot rollers would be required and the material would not be easily workable.
3. Material lacks fines and it is considered to be generally unstable as a road pavement layer and may only be considered if its intended for use in confined areas or if there is a high proportion of medium size particles (> 25% passing 10mm sieve). Materials that have relatively low particle strength such as laterite, calcrete, cinder gravels, etc. which tend to break down during compaction may also be used.

4. Material may be used on condition that the reject index is less 10% and that the rest of the soil is generally fine otherwise lighter compactors would just walk on top of the layer without effecting any reasonable compaction at all[30].

2.3.2 Expected Performance of the materials used for unsealed roads

Low-volume road performance considerations include functional performance, structural performance, and safety.

This thesis mainly concerned with functional and structural performance. The structural performance of a low volume roads (LVR) surface relates to its physical condition; i.e., occurrence of cracking, rutting, faulting, raveling, or other conditions which would adversely affect its load-carrying capability or would require maintenance [31].

The functional performance of 'a low-volume road concerns how well it serves the user. In this context, riding comfort or ride quality is the primary concern. In order to quantify riding comfort, the "serviceability-performance" concept was developed by the AASHO Road Test staff in 1957. Since the serviceability-performance concept is used as the measure of performance for the thickness design equations for low volume road and gravel surface roads.

The serviceability-performance concept is based on five fundamental assumptions, summarized as follows:-

1. Highways are for the comfort and convenience of the travelling public (User).
2. Comfort, or riding quality, is a matter of subjective response or the opinion of the User.
3. The serviceability rating is the mean of the ratings given by all highway Users. The current rating on a road is its present serviceability rating (PSR).
4. There are physical characteristics of a pavement which can be measured objectively and related to the subjective serviceability rating. This procedure produces an objective present serviceability index (PSI).
5. Performance is the serviceability history of a pavement through time.

The serviceability of a pavement is expressed in terms of the present serviceability index (PSI). The PSI is obtained from measurements of roughness and distress, e.g., cracking, patching and rut depth, at a particular time during the service life of the pavement. Roughness is the dominant factor in estimating the PSI of a pavement. Thus, a reliable method for measuring roughness is important in monitoring the performance history of pavements [32].

The scale for PSI ranges from 0 through 5, with a value of 5 representing the highest index of serviceability. For design it is necessary to select both an initial and terminal serviceability index. The terminal serviceability index (Pt) is the lowest acceptable level before resurfacing or reconstruction becomes necessary for the particular class of highway. An index of 2.0 is often suggested for use in the design of low-volume roads, reducing the performance period.

Expenditures may also be minimized by since a relatively small contribution to PSI is made by physical distress many agencies rely only on roughness to estimate PSI. However, physical distress is important in the decision to initiate maintenance or rehabilitation.

Thus most low-volume road owners use a visual condition survey of distress to help plan maintenance and rehabilitation actions.

It is recommended that these visual condition surveys be formalized and that LVR managers need only to estimate roughness by assigning a PSR value or to contract for roughness measurements [33].

Either gravel wearing pavement or asphalt concrete or any other pavement thickness is determined by four factors: environment, traffic, base characteristics and the pavement material used.

Environmental factors such as moisture and temperature, significantly affect pavement.

For example, as soil moisture increases the load bearing capacity of the soil decreases and the soil can heave and swell. Temperature also affects the load bearing capacity of pavements. When the moisture in pavement freezes and thaws, it creates stress leading to pavement heaving. The detrimental effects of moisture can be reduced or eliminated by: keeping it from entering the pavement base, removing it before it has a chance to weaken the pavement or using moisture resistant pavement materials.

Sub grade strength has the greatest effect in determining pavement thickness.

As a general rule, weaker sub grades require thicker the pavement layer including asphalt layers to adequately bear different loads associated with different uses.

The bearing capacity and permeability of the sub grade influences total pavement thickness.

There are actually two or three separate layers or courses below the paved wearing surface including: the sub grade, sub base and base. The sub grade is either natural, undisturbed earth or imported, compacted fill [34].

The bearing capacity and permeability of the sub grade influences total pavement thickness. The sub base consists of a layer of clean course aggregate, such as gravel or crushed stone.

Sub bases are installed where heavy-duty surfaces require an additional layer of base material. The base consists of a graded aggregate foundation that transfers the wearing surface load to the sub grade in a controlled manner. The base should also prevent the upward movement of water.

The pavement material or wearing surface receives the traffic wear and transfers its load to the base, while at the same time serving as the base's protective cover. Pavements are classified as either flexible or rigid. Flexible pavements are resilient surfaces that distribute loads down to the sub base in a radiant manner.

Flexible pavements generally have thin wearing surfaces and thick bases.

Asphalt is an example of a flexible pavement. Hot mix asphalt has more strength than cold mixes therefore it can be laid in thinner layers. Rigid pavements distribute imposed loads over broader area than do flexible pavements and therefore require thicker wearing surfaces and thinner bases [35].

2.4 Serviceability of unsealed roads and their design life expectancy

Serviceability is the ability of a specific section of pavement to serve traffic in its existing condition. There are two ways to determine serviceability. One method is to use the present serviceability index (PSI) developed at the AASHO Road Test which is based both on pavement roughness and on distress conditions such as rutting, cracking, and patching. The other method is to use a roughness index based on the roughness only.

In order to identify important properties and performance parameters of granular materials that relate to field performance and developed a plan for the sub base material performance with the performance indicator and road user assessment result obtained from the particular road segment of the study site and will evaluate selected methods.

Through comprehensive laboratory tests and correlate the test results to aggregate properties and pavement performance of the route sub base material performance.

The California Bearing Ratio (CBR) test (both soaked and unsoaked) is recommended as a validation test because of its widespread use as a strength parameter in pavement structural design and because of its long-term historical acceptance as an indicator of performance.

CBR tests on granular materials must be conducted with extreme caution, and several samples will be used to ensure satisfactory and accurate results.

The present serviceability concept (PSI) relates pavement failure directly to riding quality and the acceptance or satisfaction of the riding public. It is indeed more definitive of true performance than roughness alone and strong consideration should be given to resurrecting it in pavement studies and designs [36].

2.5 Permanent deformation of unsealed road surfacing materials

Roads are one of society's most essential components. Without them, it would be very difficult to go from one place to the other in a timesaving and smooth way. Roads are therefore facing a major challenge in order to deliver these functions and consequently increase the quality of life. In order to fulfill these functions, roads must be properly designed and durable. However, there are roads built on weaker sub grade material and thus perform worse and cause losses in both serviceability and economy. Therefore, in recent decades, further demands on the design of roads have been made. Thus the construction costs shall be reduced and the miscellaneous maintenance work performed in small extent as possible. The major causes of loss in the serviceability and maintenance work is rutting and surface roughness [36].

In order to investigate the permanent deformation sub base materials series of sections are taken in the roads segment in terms of:

- rutting,
- cracking
- surface roughness
- Potholes those mostly visualize in gravel road surfacing.

2.5.1 Rutting

Rutting is the greatest distress causing loss of serviceability and thus very undesirable. Rutting reduces driving comfort and worsens road safety, especially during wet conditions when the risk of hydroplaning increases significantly due to water gathered in the ruts. The reason behind the phenomenon of rutting is both material (compaction, grain shape, grain size distribution and organic contents etc). And structural related properties (load repetitions, stresses and moisture content) in the unbound layers. These properties are in its turn affected by other additional parameters such as cracking, degree of direct sunlight, sub grade material, its E-modulus and water content of unsealed material surfacing of the road [37].

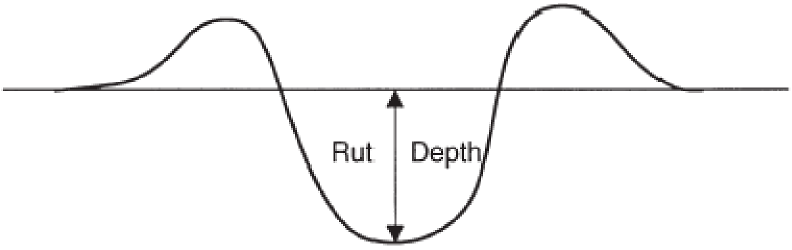


Figure2.5.1. 1: Rut depth description

The permanent deformation in the unbound layer, permanent deformation development will stagnate with increasing load repetitions. Studies of roads in reality have shown faster rutting initially (pre-compaction phase), which latter gradually decreases. The increase of the permanent deformation continues in a stable and slow rate until cracks are developed. Subsequently, the rate of the rutting development drastically increases. The theories stating that the rutting should stagnate over time are only applied for stresses below a certain limit. Further studies have shown that when the stresses exceed a certain level, “Plastic Shakedown Limit”, the material in the unbound layer reaches an unstable condition and plastic deformation takes place this result in an increase of the permanent deformation, as shown below in figure 2.5.1.2

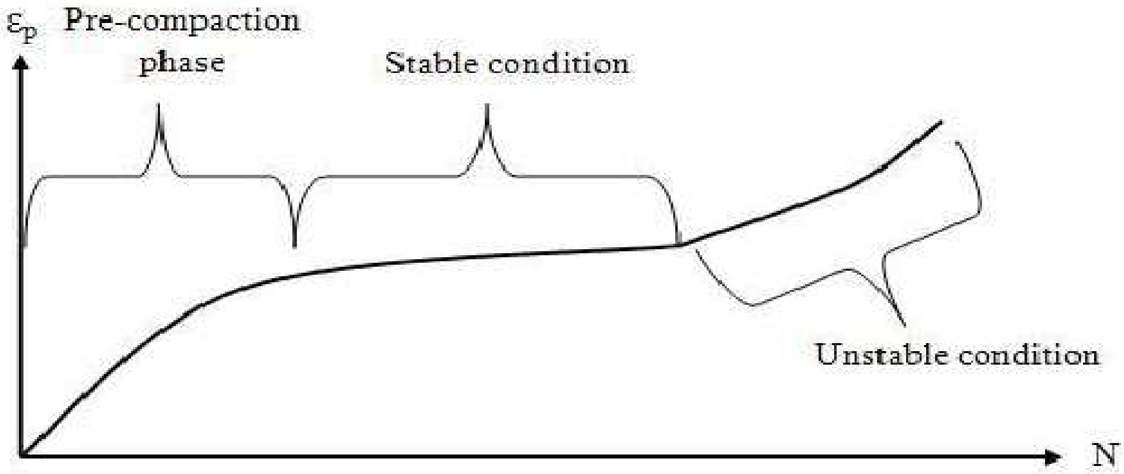


Figure2.5.1. 2: The material deformation at various compaction stages

Source: - Manual for the visual assessment of gravel pavement distress. 1984. Pretoria: Department of Transport manualM3-1.

Other deformation problem associated with gravel roads is traffic-generated dust. This involves public economics and environmental quality and is also a nuisance to the public. But even then dust is more than just a nuisance from unpaved roads by generating the following problems:

1. By obscuring the vision of drivers, dust clouds are traffic hazards.
2. Dust particulate can be carried several hundreds of feet, penetrating nearby homes and covering crops. Crop growth can be stunted due to the shading effect and clogged plant pores.
3. In human health dust is a common cause of allergies and hay fever and a conveyor of diseases according to a United Nation study of [37].
4. The fine dust particles can be abrasive and therefore greatly increase wear of moving parts of vehicles.
5. The losses of fines (road binder), as dust, represent a significant material and economic loss [38].
6. The fine dust particles are washed off during precipitation and carried into streams, creeks and lakes increasing their respective turbidities.

The severity of a dust problem is determined primarily by the amount of speed of traffic on the unpaved road. The condition can be aggravated by long dry spells, softer road aggregates and initially excessive soil binder in the road surface. Without binder material (enough fines) and adequate moisture, the coarser material will be thrown and washed away from the road surface. When that happens the road begins to ravel, rut and washboard leading to costly repairs. In addition to the problems associated with permanent deformation of dust the appearance of distress is varied and often extremely complex. The task of describing this is achieved by recording its main characteristics.

These distresses are named as attributes of distress.

The attributes may classify as:

- Type
- Degree
- Extent

These attributes are defined below in general terms. Each of these attributes is described in their broad term below.

2.6 Types of Distress

The type of distress evaluated will depend on the purpose of carrying out the assessment. The modes of distress needing assessment for strategic network level decisions may differ from those needed for detailed network level decisions. A number of assessment parameters are considered essential for any type of evaluation, while detailed descriptions of distress are often desirable, particularly for detailed network level investigations, project level investigations and research investigations [39].

Include other assessment items that have proved useful in research studies and for complementing the more detailed distress attributes and material properties. Typical types of distress encountered on unsealed roads are:

- Loss of gravel
- Potholes
- Rutting
- Erosion
- Corrugations
- Loose material
- Stoniness
- Dust
- Cracking

These can be assessed individually or in terms of their interactive effect on the functional performance of the road together with material properties, road profile, drainage etc.

An example of this is the development of corrugations or potholes, which result in deterioration of overall functionality, particularly riding quality.

For detailed investigations, aspects such as cracking or rutting, although not directly related to riding quality for instance, are indicative of material quality or a potentially problematic situation such as periodic slipperiness or water pounding respectively.

2.6.1 Degree

The degree of a particular type of distress is a measure of its severity. Since the degree of distress can vary over the pavement section, the degree to be recorded should, in connection with the extent of occurrence, give the predominant severity of a particular type of distress. The degree is described by a number where:

- Degree 1 indicates the first evidence of a particular type of distress ‘’slight’’.
- Degree 3 indicates a warning condition. This would normally indicate that intervention might be required in order to avoid the distress deteriorating to a severe condition.
- Degree 5 indicates the worst degree ‘’severe’’. Urgent attention is required.

The general descriptions of degree of each type of distress are presented in Table 2.6.1 below, these descriptions relate to the possible consequences of each type of distress and therefore also to the urgency of maintenance or rehabilitation. Degree 0 is recorded if the defect does not occur. Degree 1 generally indicates that no attention is required; degree 3 indicates that maintenance or improvement might be required in the near future, whereas degree 5 indicates that immediate maintenance or improvement is required.

Specific classifications for the various types of distress have been compiled, based on these general descriptions.

Table2.6.1. 1: General description of degree classification gravel road damage

degree	Severity	Description
0	None	distress visible
1	Slight	Distress difficult to discern. Only the first signs of distress are visible.
2	Between slight and warning	
3	Warning	Distress is distinct. Start of secondary defects. (Distress notable with respect to possible consequences. Maintenance might be required in near future e.g. potholes can be removed by blending).
4	Between warning and sever	
5	Sever	Distress is extreme. Secondary defects are well-developed (high degree of secondary defects) and or extreme severity of primary defect. (Urgent attention required e.g. potholes require manual repair).

Source: - TRL training module on pavement design principle ORN 31[1993]

With the flow diagram the five –point classification system can be described as

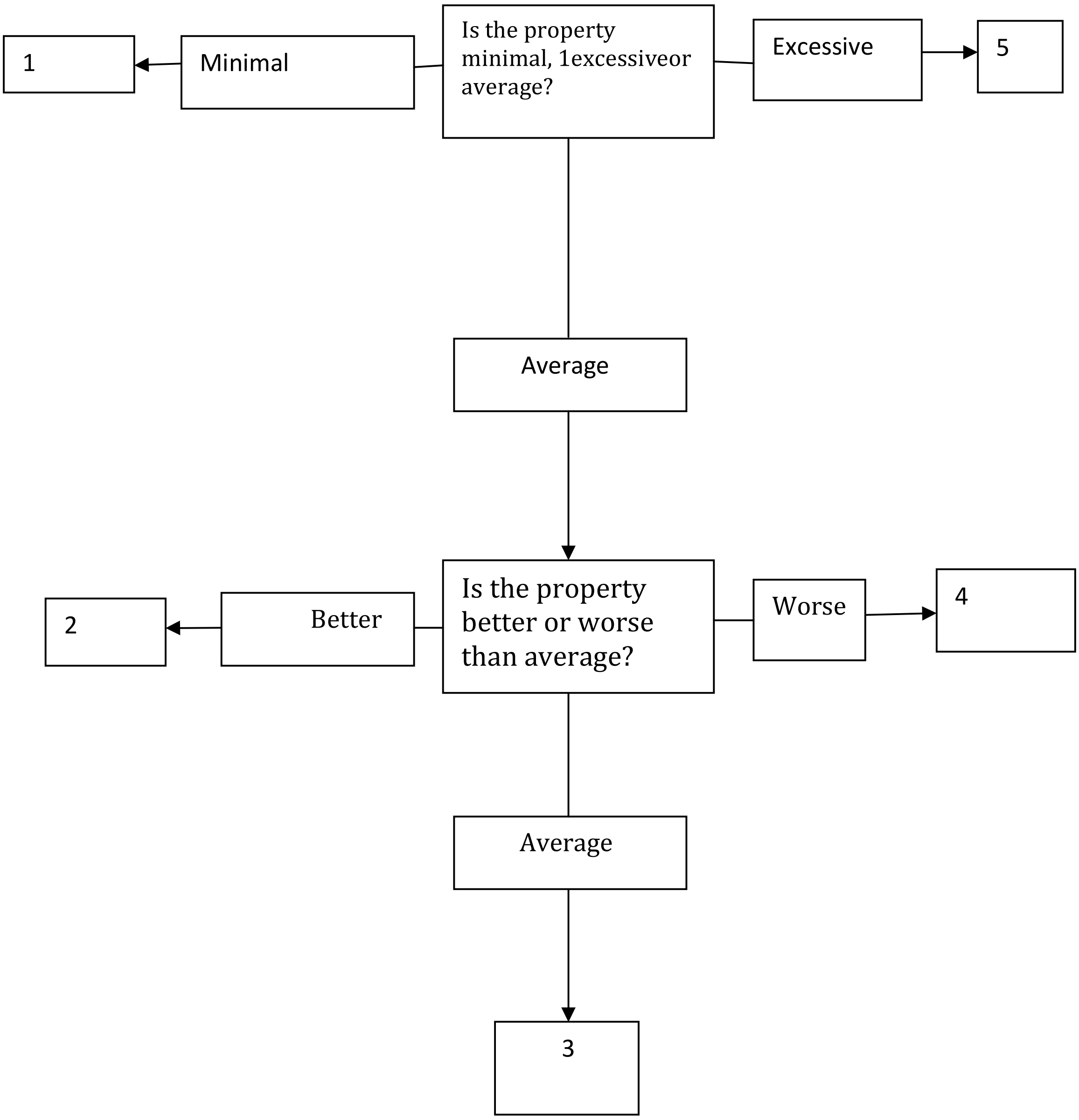


Figure2.6.1. 1: Flow diagram of five –point classification system

2.6.2 Extent

The extent of distress is a measure of how widespread the distress is over the length of the road segment. The extent is also indicated on a five-point scale in which the length of road affected by the distress is estimated as a percentage. The general description of the extent classifications is given in Table 2.6.2.1

The extent of the distress should be recorded only for that width of the road affecting the traffic**.**

Table2.6.2. 1: General descriptions of extent classification

Extent	**Description**	**Estimate %**
1	Isolated occurrence, not representative of the segment length being evaluated. They are usually associated with localized changes in the material, sub grade or drainage conditions. Intersections, steep grades or sharp curves may also result in isolated occurrences.	< 5
2		**5-20**
3	Intermittent occurrence, over most of the segment length, or extensive occurrence over a limited portion of the segment length. When occurring over most of the segment length, problems are usually associated with the material quality or maintenance procedures. When occurring over limited portions, the problem is usually a result of local material variations or drainage problems.	**20-60**
4		**60-80**
5	Extensive occurrence. This is usually a result of poor quality or insufficient wearing course material, or inadequate maintenance.	**80-100**

Source: standard visual assessment manual for unsealed roads

2.7 Previous study on serviceability of pavement materials performance

Except certain in direct studies like"Development of direct road roughness evaluation system by Fengxuan Hu" implementation of internal roughness by Dr. W. James Wilde, P.E. And:" the little book of profiling "study by Michael.W.Sayers Steven.M. Karamahias in, 1998. The broad study on serviceability of pavement is AASHTO road test serviceability study carried to investigate the serviceability surfacing materials.

The basic study of the AASHTO road test centre design Serviceability Loss (ΔPSI).

Serviceability is the ability of a specific section of pavement to serve traffic in its existing conditions. The present serviceability index (PSI) is the primary measure of serviceability. PSI ranges from 0 to 5 where 0 means the existing road condition is impossible for driving, and 5 means the road is in perfect condition for driving. The lowest serviceability motorists can tolerate, before rehabilitation, resurfacing or reconstruction, is called terminal serviceability (Pt). Common values for terminal serviceability index are Pt=2.5 for higher when used for the design of major highways and P t=2.0 when used for low volume roads. The minimum level of serviceability is mostly dependent on people's acceptance. There are some minimum levels of Pt, which are obtained from AASHTO road tests, and which are given below the table:

Table2.7. 1: Terminal serviceability level obtained from AASHTO road test

Terminal serviceability level (Pt)	3.0	2.50	2.0
Percent of people stating unacceptable	12%	55%	85%

Source: AASHTO Road Test.

For minor highways like aggregate surfaced roads where funds or economy is the main factor, the design is done by reducing the traffic or design life rather than reducing the terminal serviceability to a number lower than 2.00. Generally, the recommended terminal serviceability index value pt is 3 for major roads, 2.5 for intermediate roads and 2 for secondary roads. For a well constructed new pavement has initial serviceability index (PSI0) of 4.2 to 4.5

In designing new roads the terminal serviceability is set up based on original or initial serviceability (P**o**). It is observed that the difference between P**t** and P**o**, change in present serviceability index (ΔPSI) has a great influence in the design of aggregate surfaced road and therefore must be determined as part of the design[39].

2.8 Highway condition survey and serviceability evaluation

The condition of pavement materials deteriorates with time due to the following factors: design inadequacies, traffic loading, material ageing, construction deficiencies, and environmental forces.

The pavement condition with time can be described graphically as following figure 2.8.1

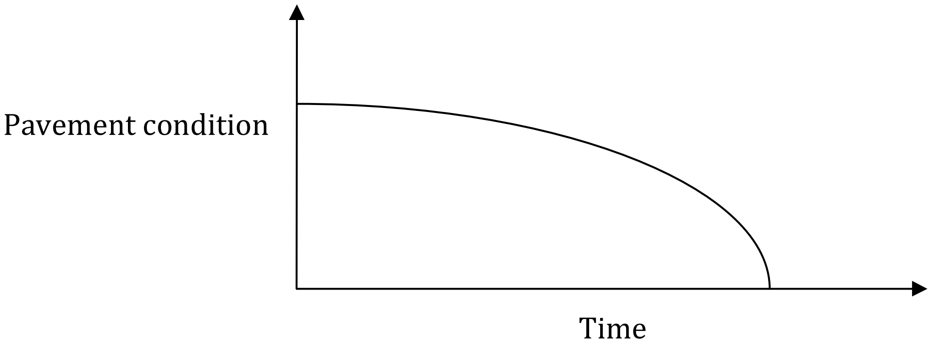


Figure2.8. 1: Pavement condition versus Time

Pavement condition surveys, also known as distress surveys, are conducted as a part of Pavement Management System (PMS) in order to assess current pavement condition and the need for maintenance and rehabilitation treatments [40].

Though distress surveys generally provide detailed distress information including distress type, severity, extent and location, the level of information collected in a condition survey depends on the intended use of the data. For a network level study, for example, some highway agencies consider it adequate to conduct windshield survey. On the other hand, for project level survey, detailed distress information is often required. It is desirable that a distress survey must also identify, classify, and quantify the causes of all distresses and factors that may influence pavement performance.

In order to identify the pavement condition status the knowledge of the pavement and Serviceability is essential.

Pavement serviceability refers to the ability of a pavement to provide the desired level of service to the user. The ability of a pavement to perform at its desired level of service is affected by pavement condition. Figure below2.8.1 shows a general trend of loss of serviceability due to pavement condition affected by time or traffic loading. The "serviceability-performance-concept" was developed by Carey and Irick, 1960, during the

AASHO Road Test (HRB, 1962) to evaluate pavement performance in terms of pavement ride quality. The Present Serviceability Index (PSI) is the subjective assessment of "serviceability" by a panel of raters and is related to objective measures of surface condition by response-type road roughness measuring systems (RTRRMS).

PSI is expressed on a scale of zero to five where scale five refers to an excellent ride conditions and scale zero indicates a very poor ride quality, i.e., the pavement has failed to provide any level of service. The serviceability of a pavement section is obtained from a group of raters who drive on the pavement and assign ratings based on their subjective judgment of the ride condition. Jan off et al. (1985) questioned if the public's perception of serviceability was still the same as it was during the AASHO Road Test (HRB, 1962) due to the fact that many travel parameters such as vehicle and road characteristics had changed. He argued that serviceability is not exclusively a measurement of readability but is confounded by surface defects and readability, and surface defects should have separate measures.

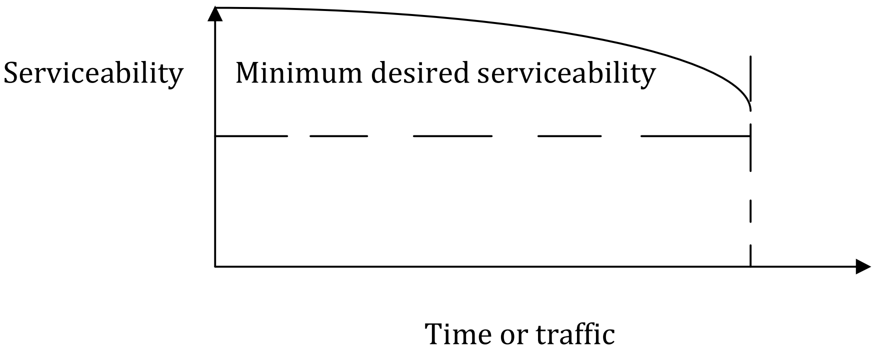


Figure2.8. 2: Pavement serviceability versus time or traffic

Source: hand book of highway engineering.

2.9 Performance indicators role on the service life of a road and its evaluation methodology

Performance indicators of pavement structure are measureable parameters that show the degree of a pavement structure deterioration amount and the rate with which certain pavement material is changing through time. These Measurable characteristics (performance indicators) are:

- Visible distress (cracking & rutting)
- Surface friction
- Roughness (slope variance)

Figure2.9. 1: Slope variance from the horizontal along the direction of traffic

Roughness (slope variance) is the measure of how much slope varies from horizontal along the direction of traffic as demonstrated in the figure above.

The use of performance indicators by a road administration depends on the particular needs for development or improvement in performance.

The main aspects that influence decisions on the use of performance indicators are:

- The main characteristics of the road transport vision in the country concerned.
- The position of the road administration in the process of organizational reform.
- The management style of the organization.
- The specific functions that require development or learning.

In order to compare and understand why particular indicators are used and the reasons for their values, the indicators have to be viewed in the perspective of the role of the road administration in the road transport system and in society as a whole. The driving force behind performance indicators is the vision for the road transport system and the mission of the road administration in fulfilling that vision.

2.9.1. Evaluation methodology of the performance of gravel wearing course

The evaluation method of performance or serviceability of specific section any pavement to serve traffic in its existing condition can be categorized in to two. One method is to use the present serviceability index (PSI) developed at the AASHTO Road Test, which is based both on pavement roughness and on distress conditions, such as rutting, cracking and patching. Second method is using roughness index based on the roughness only [41].

The performance of the gravel surface depends on material quality, the location of the road and the traffic volume using the road. Gravel roads passing through populated areas in particular require materials that do not generate excess dust in dry weather.

Steep gradients places particular demands for gravel wearing course materials that do not became slippery in wet weather or erode easily. Strengthening of the pavement is normally required for the road to carry further traffic at an acceptable level of serviceability after the end of the design period. Normally maintenance is assumed to take place throughout the design period of the design to be valid. Premature failure may result if normal maintenance is neglected during the design period. The specified strength of the design period shall be depends on the type of pavement [42].

Serviceability evaluation equation was developed in order to predict the pavement serviceability rating (PSR) to a satisfactory approximation.

PSI was the first and most commonly used method to relate the objective measures of surface condition to the public's perception of serviceability [43].

The original PSI equations were:-

I- **For flexible pavement**

The model developed at AASHTO Road Test to evaluate PSI is shown in the equation (2.9.1.1).

$$PSI = 5.03 - 1.91 \text{Log}\,(1 + Sv) - 0.01\sqrt{(C1 + pa)} - 1.38Rd^2 \text{------------------------------} 2.9.1.1$$

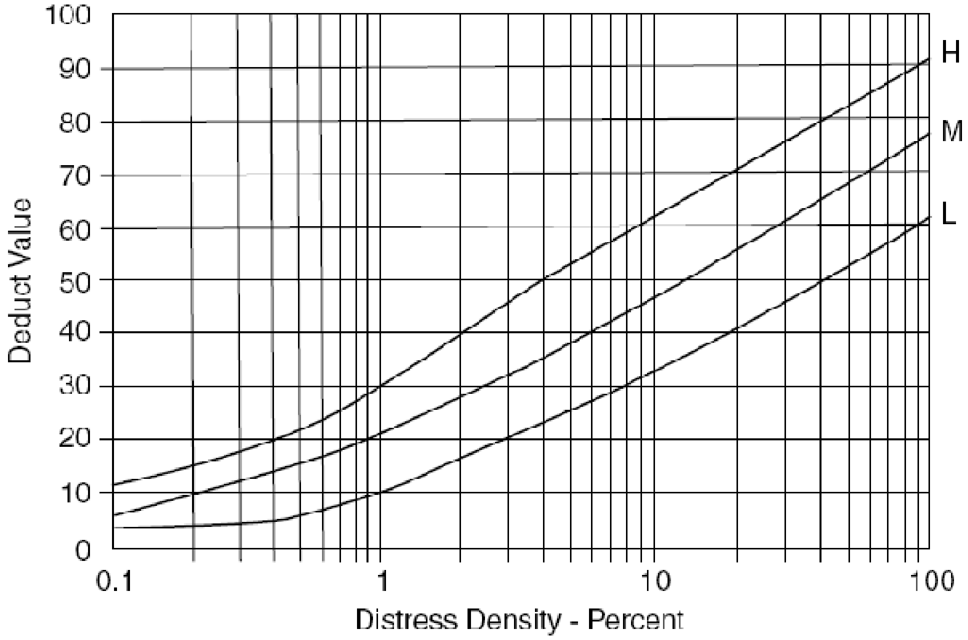


Figure2.9.1. 1: Deduct value curves for crocodile cracks in flexible pavements

[Source: Shahin and Walther, 1990].

II-For Rigid Pavement

$PSI=5.41-1.8Log\ (1+S_v)-0.09\sqrt{}\ (C_1+P_a)$ --2.9.1.2

Where:-

S_v =slope variance [Log (1+Sv) = function of profile roughness]

C_l =crack length in inch (1 in= 25.4 mm).

P_a = patching area in ft^2.

R_d =Rut depth in inch.

E_r =Statistical error.

Equation for Subjective panel ratings (PSR) relation with the present serviceability index (PSI)

PSR=PSI+Er---2.9.1.3

Where:-

Er is statistical error term

Carey and Irick [44] pointed that PSI was developed by multiple regression techniques and was only intended to predict the Pavement Serviceability Rating (PSR) to a satisfactory approximation. In this process, a number of objective measurements (i.e., PSI) of physical parameters were related to the subjective panel rating (PSR).

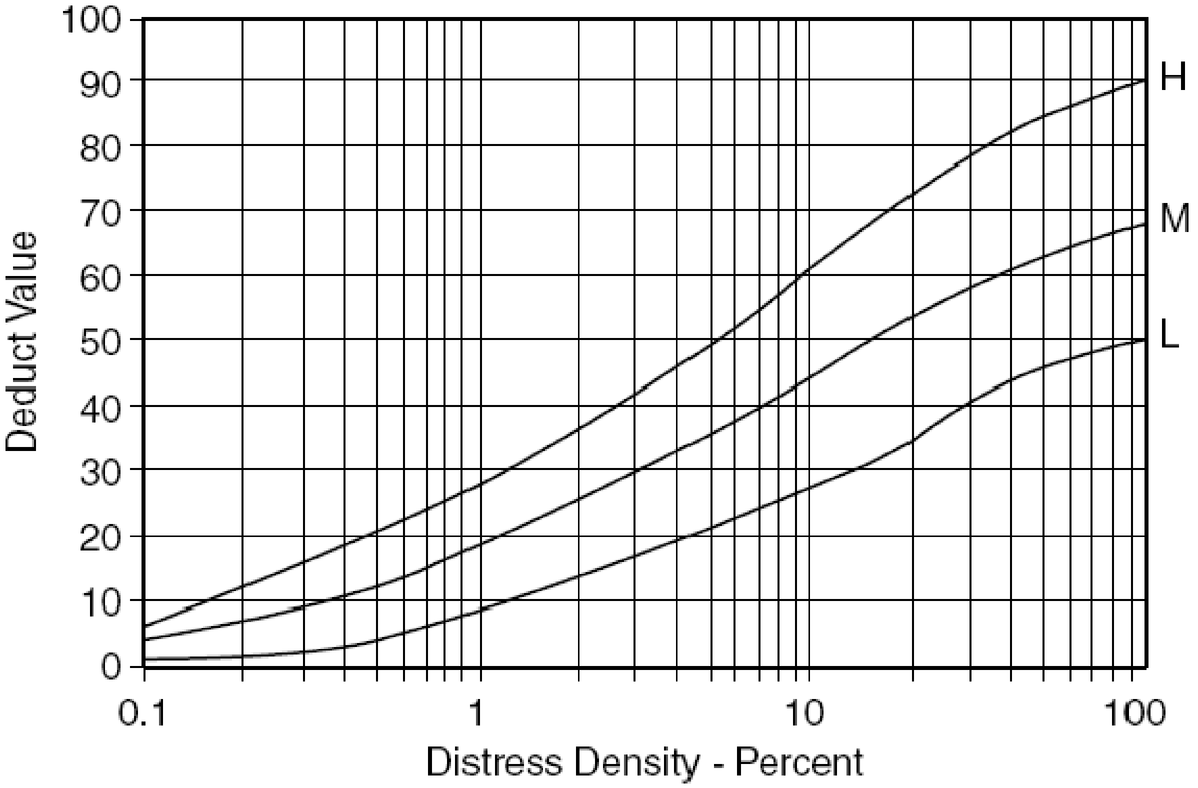


Figure2.9.1. 2: Deduct value curves for crocodile cracks in flexible pavements

[Source: Shahin and Walther, 1990].

2.9.2 User assessment

The road test historical back ground on AASHO Road Test performance, based on user assessment.

User assessment is:

- Difficult to quantify (subjective)
- Highly variable

Present Serviceability Rating (PSR) rating value expressed as:-

0-1 – very poor
1-2 - poor
2-3 – fair
3-4 - good
4-5- very good

A panel of experts drove around in standard vehicles and gave a rating for the pavement [45].The AASHTO road Test study was conducted to expand the results of the **AASHTO** Road by studying the effects of the various sub grades, the local construction procedures, the local paving materials, and climatic effects in of the pavement. Emphasis was on deflection response and long-term performance of flexible pavements. Sections were evaluated so as to include a wide variation in soils type, pavement structure, and traffic the findings resulted in a new flexible pavement design procedure for any pavement design [46].

2.9.3 Present serviceability index (PSI) and terminal serviceability index (PSt)

Pavement serviceability refers to the ability of a pavement to provide the desired level of service to the user. The ability of a pavement to perform at its desired level of service is affected by pavement conditions by traffic and environmental conditions with time. The Present Serviceability Index (PSI) is the subjective assessment of "serviceability" by a panel of raters and is related to objective measures of surface condition by response-type road roughness measuring systems (RTRRMS). PSI is expressed on a scale of zero to five where scale five refers to an excellent ride conditions and scale zero indicates a very poor ride quality, i.e., the pavement has failed to provide any level of service. The serviceability of a pavement section is obtained from a group of raters who drive on the pavement and assign ratings based on their subjective judgment of the ride condition.

Terminal serviceability index (PST) is the pavement performance after which the pavement is failed to perform the intended purpose pavement is no longer functional [47].

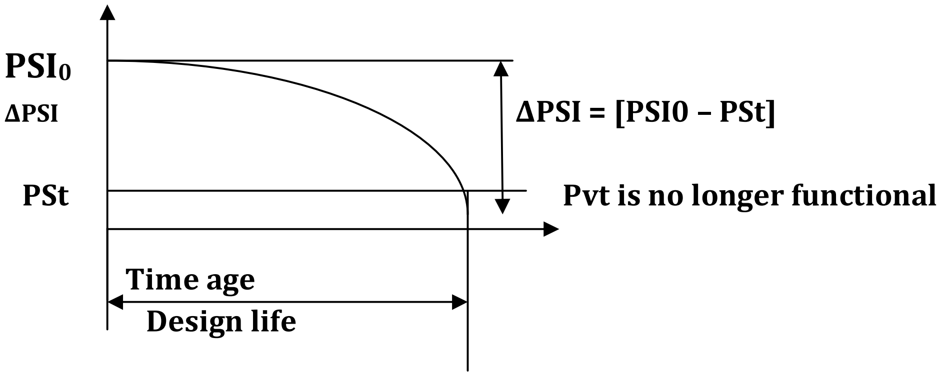


Figure2.9.3. 1: Material performance change with design time period

Source:-[Carey and Irick (1960), AASHO Road Test (HRB, 1962) to evaluate Pavement performance].

2.9.4 Different Models on serviceability index

1. AASHTO road test model

This model was developed during evaluation of pavement performance and the equation for present serviceability index was formulated as shown below.

PSI= A_0 + (A1R1+A2R2+. . .) + (B1D1+B2D2+. . .) --2.9.4.1

In R1, R2 . . . are functions of profile roughness and D1, D2,. . . are functions of surface deteriorations.

1. Model of AASHTO performance relation by Dr. Christos Drakos[48]

Present Serviceability Index (PSI).

PSI = A0 + A1F1 + A2F2 + A3F3---2.9.4.2

A0 … A3 = Regression Coefficients

F1 = Measure of roughness

F2 = Measure of rutting

F3 = Measure of cracking

How does the true (user) performance correlate to the measured performance is calculated by the regression coefficients for the PSI equation [49].

3. METHODOLOGY

The core objectives of this research is to evaluate the performance or present serviceability index of unsealed road sub base material used as wearing course of Kamash- Yaso gravel road.

This is the study route selected to take data and to develop the performance level for other gravel roads in order to determine whether materials used for the wearing course of gravel roads to attain the intended design period.

In order to achieve the objectives of the research goal requires review of applicable practices, research findings, information on serviceability of road and AASHTO road test and other pavement performance related study and relevant literatures on current design approaches; more over adaption of various models of pavement performance with initial and final serviceability as in put for the research work is reviewed.

The methodologies adopted to achieve the objectives are outlined as follows:

1. Review of applicable practices, research findings and other relevant information on sub base material pavement performance and materials used for the wearing course of gravel road.
2. Relevant literatures on current pavement material performance and serviceability approach various modes of failure and damage propagations have been reviewed.
3. Data collection has been carried out in the study site “Kamashi–Yaso road route” the necessary data collected were :
    - ➢ Roughness index by marline measuring equipments at six sections on 200m stretch of each, according to TRL manual for the marlin operation and format.
    - ➢ Questionnaire had been filled by the users (drivers) on the site.
    - ➢ Sample data for CBR test had been collected on site in the case study site within 5km interval for strength test.

4. Serviceability determination, user assessment and performance indicator(measurable parameters like roughness, rutting cracking) measurement had been taken: User assessment has been conducted by distributing questionnaire for drivers that use the study road route and filled the questionnaire; the result is analyzed from various drivers’ opinions gathered from distributed questionnaire.

Performance indicators (roughness index, rutting and cracking on the surface of the road) are surveyed by surface road condition survey continuous for the certain length of the road and both performance indicators and user assessments data were used to estimate the present serviceability index of the road.

Finally the sampled sub base material data collected from the field was tested in highway laboratory, and the strength result on the test to indicate performance level of the materials strength and correlation between user assessment and true performance indicators collected from the field were correlated by statistical method and report were prepared on the finding.

To achieve the objectives of this thesis as stated above, certain applicable pavement materials background knowledge is in sighted. The knowledge and experience gained during this period helped the writer of this paper in developing reliable, efficient and effective study approach to focus on stated goals.

Before data collection was carried out; training was provided to enumerators to arm them with knowledge on how to gather reliable data and how to operate the Merlin instrument during data gathering.

3.1 DATA COLLECTION

Data collected for the analysis were obtained from design documents and through field measurements and have shown different characteristics. Roughness, user assessment and performance indicators measurement and strength test data were well collected in the site for the analysis of the performance level of the gravel of the study route.

The types of data gathered during field data collection were:

1. Road roughness data at six sections,
2. Rut depth
3. Wearing course sampling for strength test,
4. Distribution of prepared questionnaire and collecting rating of the drivers.

Figure 3.0 roughness data measuring at the site

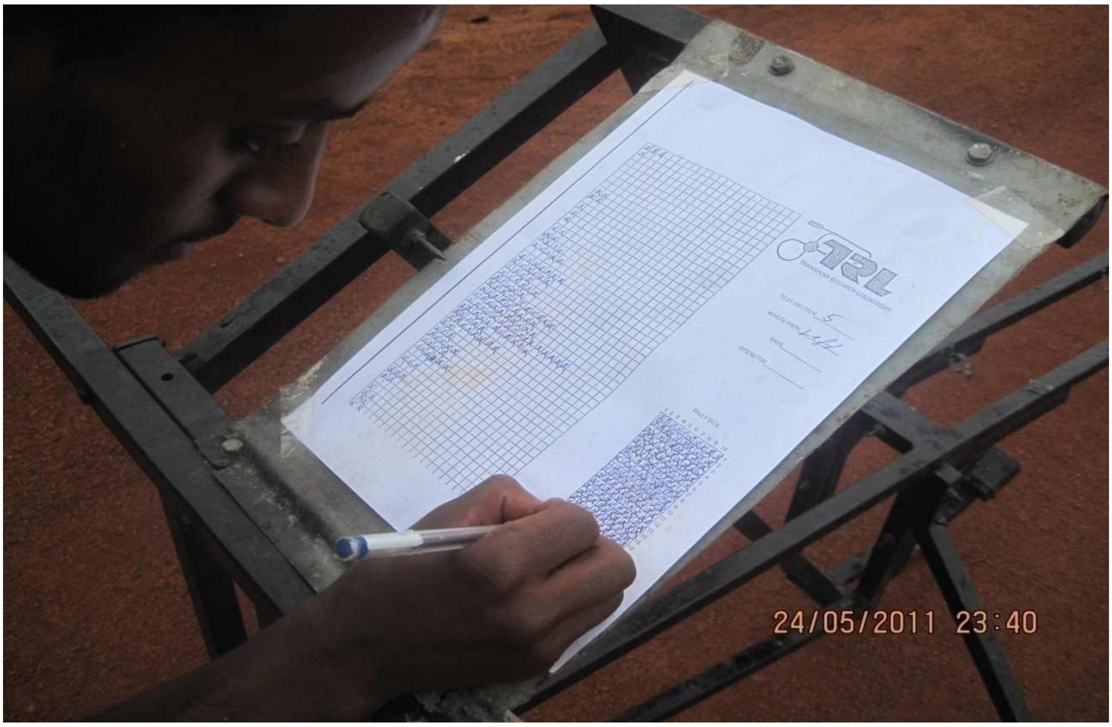


Figure3. 1: Roughness data collection on site

Figure3. 2: Roughness data collection on site

Figure3. 3: Merlin manual data collection for roughness

Figure3. 4: Estimation of rut depth at the site

Figure3. 5: Gravel Rut depth measuring at the site

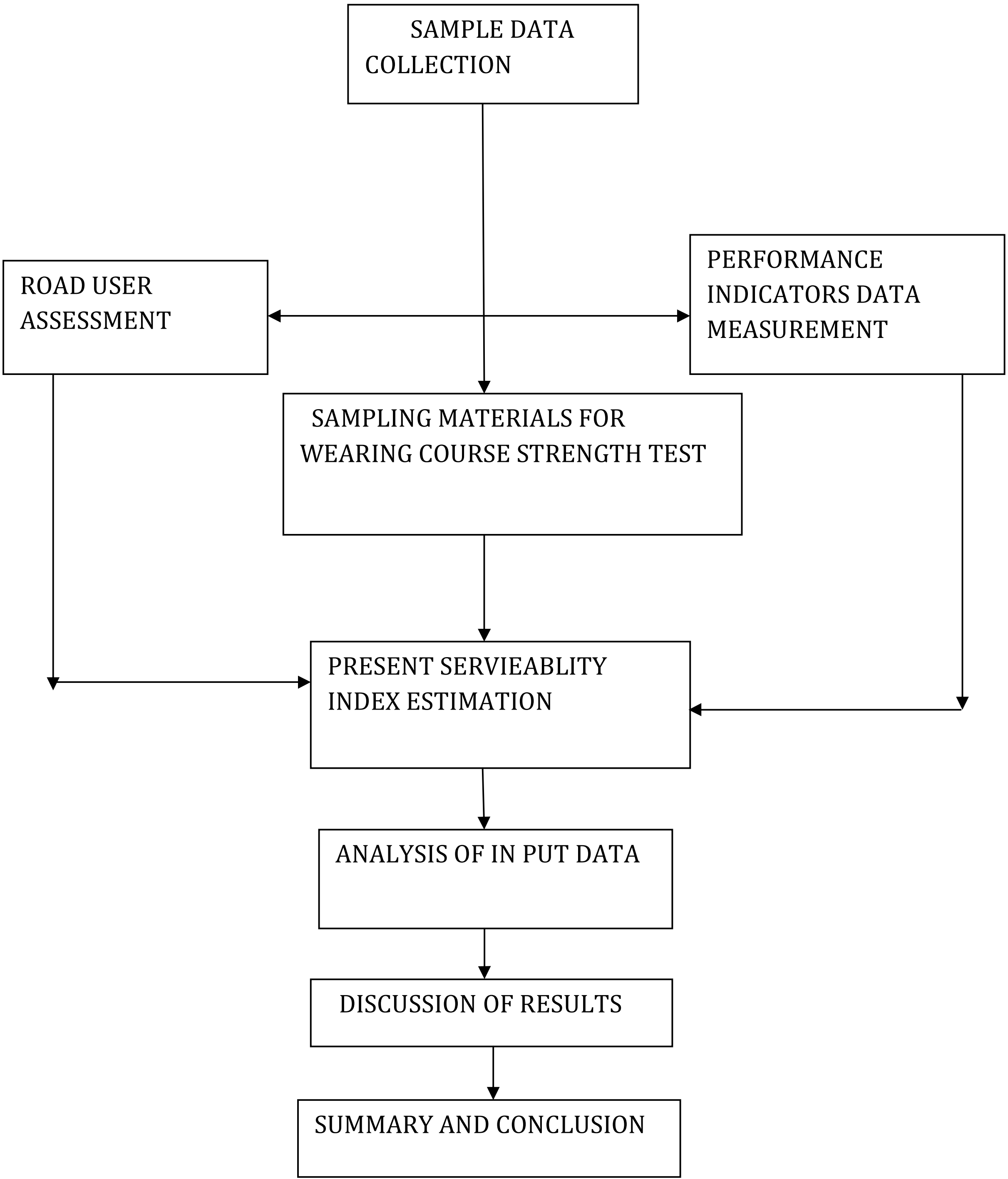


Figure3. 6: Flow chart showing the major activities carried out during the research work

3.2 DATA ANYSLIS

Data collected for the analysis were obtained from design documents and through field measurements for the performance evaluation of sub base material strength.

Before detail analysis of the data for the performance the collected data were road roughness, sample for strength test, performance rating by distributing questionnaire and other distress features on the road surface.

In order to determine serviceability index, analysis and summarize the collected data, multiple regression analysis was used. The regression analysis was examined and the analysis of variance (ANOVA) was performed to determine the significant differences in the observation. All of the statistical analysis were performed using EXCEL and were tested at confidence interval (i.e. significance level of $\alpha= 0.05$), the detail analysis was made in section 4.5.3.

4. EVALUATION OF GRAVEL ROAD WEARING COURSE MATERIAL PERFORMANCE

Based on the data collected from the study site, the performance or the serviceability of the wearing course of gravel road Kamashi – Yaso can be evaluated.

First serviceability can be defined as the ability of specific section of pavement to serve traffic in its existing condition, serviceability can be determined in two ways:-

1. By using present serviceability index (PSI) which is based on both pavement roughnesses measured on the site and distress conditions such as cracking, rutting and patching.

$$PSI= A_0 +A_1F_1+A_2F_2+A_3F_3 \text{---} 4.1$$

A_0---A_3 are regression coefficients

F_1= measure of roughness

F_2= measure of rutting

F_3= measure of cracking

2. By empirical formula derived during by AASHTO road test

$$PSI =5.03-1.91Log\ (1+Sv)-0.01\sqrt{C1 + Pa}\ \ -1.38(RD)^2 \text{--------------------------------------} 4.2$$

The parameters are defined in equation2.9.1.1of section 2.9.1

Apart from pavement roughness measurements, evaluation of pavement distress is important and these terms were included in the original serviceability regression equation used in the AASHTO road test. However distress parameters had a little influence on the value of pavement serviceability and measuring of these parameters is difficult and not perfect as to AASHTO road test they have only less than 5% influence on the value of serviceability, the serviceability can be reliably predicted using roughness only and have discarded the values in this research [50].

In this research, the serviceability of the route kamash – Yaso is evaluated by correlating measured performance with the present serviceability rating that is gathered from the road users. In the research, serviceability is evaluated by measured roughness only due the above mentioned limitations of the other distress values.

Based on the above limitation the research formulation basis on roughness index only:-

$$PSI = X_0 + X_1 \text{ (Log IRI)}$$

X_0 & X_1 are regression coefficients.

IRI = roughness index.

PSI=present serviceability index

Table4. 1: Observable distresses in the gravel road with their structural functional and load associated and non load associated characteristics

Type of distress	structural	functional	load associated	non-load associated	Comment
Loss of gravel		×		×	observed
Potholes	×	×	×		observed
Rutting		×	×		Observed and measured
Erosion		×		×	not observed
Corrugations		×		×	Not observed
Loose material	×		×		Not observed
Stoniness		×	×		observed
Dust		×		×	observed
Cracking	×		×	×	Not observed

4.1Roughness measuring instruments

4.1.1Road roughness

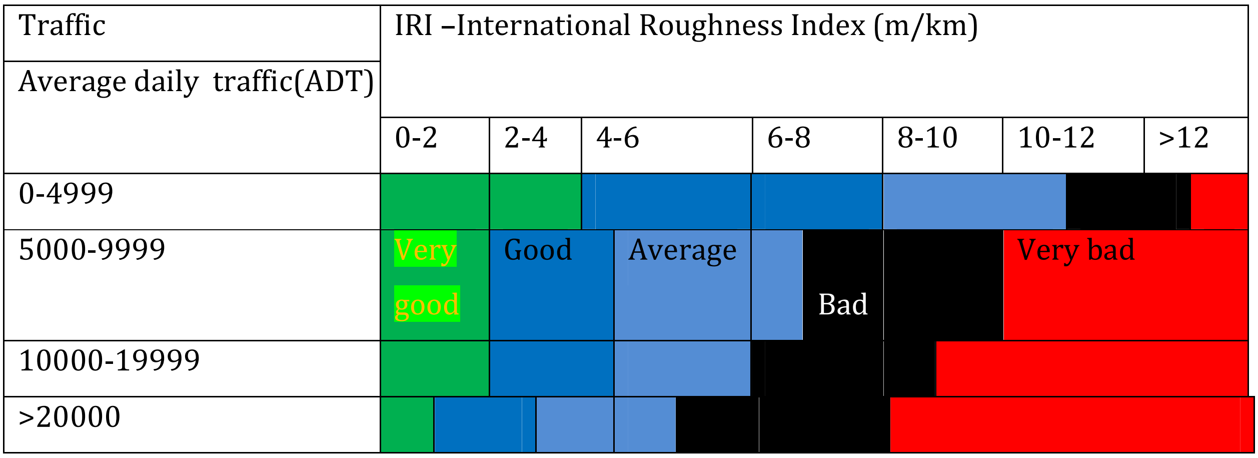
Road surface ride-quality ('Roughness') is the most important condition parameter influencing road user comfort and, more importantly, vehicle operating costs [VOC].

The International Roughness Index (IRI) is a reference measure of the road surface shape that resulted from an international study during AASHTO road test. The IRI is a measure of the impact of the road profile on the ride and dynamic response (vertical movements) of a moving vehicle. The IRI is expressed in m/km. A typical range of IRI values is:

1- Paved roads: 2 to 4 (ideal) - 14 (a failed road)

2- Unpaved roads: 6 to 10 (ideal) - 24 (a failed road) [51].

Due to its wide use throughout the world, the International Roughness Index (IRI) was used as the reference unit of measurement (Figure 4.1.1), Even some performance indicators results had to be converted to the IRI.



Traffic	IRI –International Roughness Index (m/km)						
Average daily traffic(ADT)	0-2	2-4	4-6	6-8	8-10	10-12	>12
0-4999							
5000-9999	Very good	Good	Average	Bad		Very bad	
10000-19999							
>20000							

Figure4.1. 1: IRI threshold matrixes

Source:-Road transport and intermodal research report on IRI; September, 1991

The roughness of the road has its own significant effect on Vehicle Operating Cost; therefore roughness has its own effect on the vehicle operating cost for a vehicle travelling over a section of road. The rougher the section of road the higher the vehicle operating costs. This is due to wear and tear on the vehicle for such components as suspension, tyres, increased fuel consumption.

Therefore, economic benefits to the road user exist if the roughness of the road is reduced. Roughness is the significant component of calculated vehicle operating cost savings, obtained when undertaking benefit cost calculations for pavement smoothing. For smoothing treatments undertaken on a road network, the savings are realized by achieving a lower roughness after, than existed before. The greater the decrease in roughness the larger the saving in vehicle operating costs [52].

There are different types of road Roughness measuring instruments:-

1. Road profile measuring devices such as the rod and level, which measure surface undulations at regular intervals, these devices are very slow in use and there can be a considerable amount of calculation involved in deriving roughness levels from the measurements taken.
2. Modified ‘Dipstick profiler’ (Face Company), this instrument, measures the surface undulations from a static reference and data is fed directly into a microprocessor to do the necessary calculations. They produce high quality results, but they are relatively slow in operation and expensive.
3. Response-type road roughness’s measuring systems (RTRRMS).

These measure the cumulative vertical movements of a wheel or axle with respect to the chassis of a vehicle as it travels along the road. In the case of a standard device such as the towed fifth wheel bump integrator (Bl) (Jordan and Young index).

4. The MERLIN low –cost road roughness measuring machine**.**

In this research the Merlin machine is used for the measuring of the roughness for the case study site of the route kamash-Yaso.

4.2 International roughness index (IRI) measuring instrument, the MERLIN low –cost road roughness measuring machine

The Merlin new instrument which has been developed is a variation of the static profile measuring device. It is a manually operated instrument which is wheeled along the road and measures surface undulations at regular intervals. Readings are easily taken and there is a graphical procedure for data analysis so that road roughness can be measured on a standard roughness scale without the need for complex calculation. Its particular attractions for use in the developing world are that it is

- robust
- inexpensive
- Simple to operate, and easy to make and maintain.

The device is called Merlin, which is an acronym for a Machine for Evaluating Roughness using Low-cost instrumentation. It was designed on the basis of simulation of its operation on road profiles measured in the International Road Roughness Experiment [52].

The longitudinal unevenness of a road's surface (normally termed its roughness) is an important measure of road condition and a key factor in determining vehicle operating costs on poor quality surfaces. A number of instruments have therefore been developed for measuring roughness but many of them are expensive, slow in use or require regular calibration.

This research describes the use of a simple machine which has been designed especially for use in developing countries and used for calibration of other instrument termed as MERLIN it is a machine for Evaluating Roughness using Low-cost Instrumentation. It was designed using a computer simulation of its operation on road profiles measured in the International Road Roughness Experiment in Brazil during AASHTO road test.

The device can be used either for direct measurement or for calibrating other instruments such as the vehicle-mounted Bump Integrator even in ERA vehicle –mounted Bump integrator is calibrated by this instrument practical use.

Merlin's are in use in a number of developing countries.

It consists of metal frame 1.8 meters long with a wheel at the front, a foot at the rear and a probe mid-way between them which rests on the road surface. The probe is attached to a moving arm, at the other end of which is a pointer which moves over a chart. The machine is wheeled along the road and at regular intervals the position of the pointer is recorded on the chart to build up a histogram.

4.3 Principle of operation of Merlin for measuring roughness of the research study site Kamash- Yaso road

The principle of operation is as follows. The device has two feet and a probe which rest on the road surface along the wheel-track whose roughness is to be measured. The feet are 1.8 meters apart and the probe lies mid-way between them (see Figure 4.3.1). The device measures the vertical displacement between the road surface under the probe and the centre point of an imaginary line joining the two points where the road surface is in contact with the two feet. This displacement is known as the 'mid-chord deviation'.

If measurements are taken at successive intervals along a road, then the rougher the road surface, the greater the variability of the displacements. By plotting the displacements as a histogram on a chart mounted on the instrument, it is possible to measure their spread and this has been found to correlate well with road roughness, as measured on standard roughness scales.

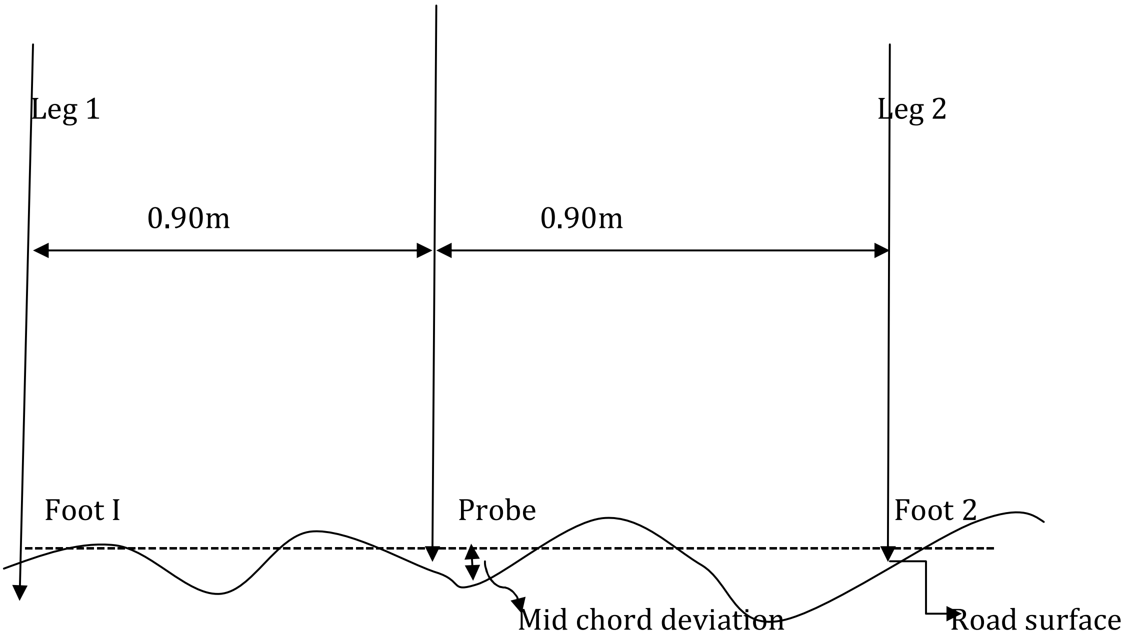


Figure4.3. 1: Measurement of mid chord deviation

The Merlin operates by using just one base length, the machine measures mid-chord deviations without the need for rod and level, the variability of the mid-chord deviations is determined graphically and very little calculation is involved to determine roughness.

The recommended procedure to determine the roughness of a stretch of road is to take 200 measurements at regular intervals, say once every wheel revolution. At each measuring point, the machine is rested on the road with the wheel in its normal position and the rear foot, probe, and stabilizer in contact with the road surface. The operator then records the position of the pointer on the chart with a cross in the appropriate column and, to keep a record of the total number of observations makes a cross in the 'tally box' on the chart.

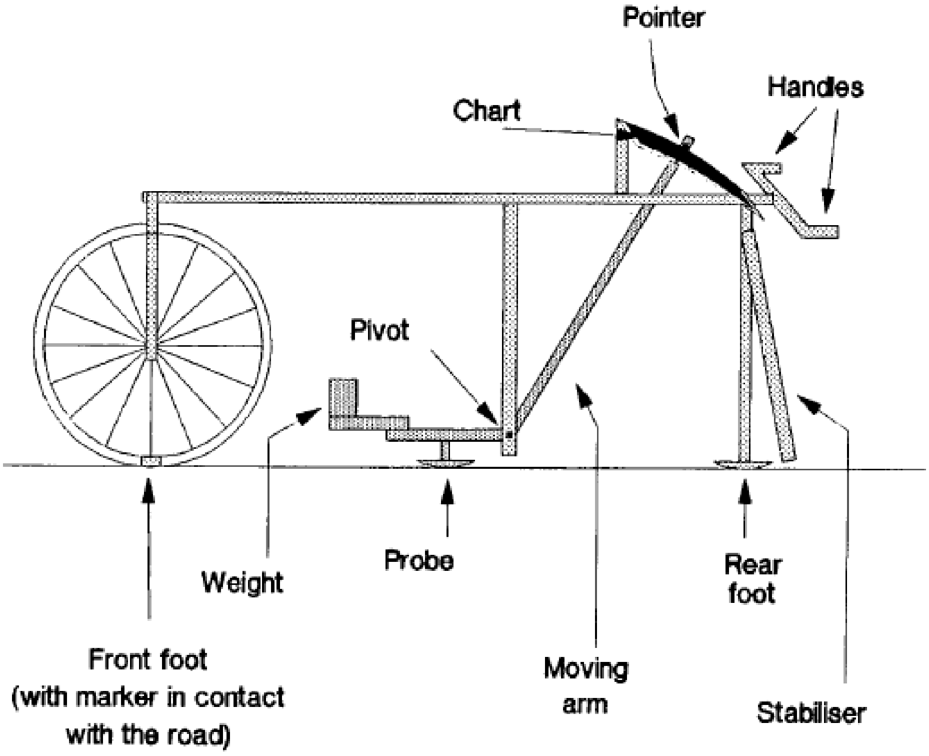


Figure4.3. 2: Sketch of the Merlin instrument for roughness measuring

The handles of the Merlin are then raised so that only the wheel remains in contact with the road and the machine is moved forward to the next measuring point where the process is repeated. The spacing between the measuring points does not matter, as long as the readings are always taken with the wheel in the normal position.

Taking measurements at regular intervals should both produce a good average sample over the whole length of the section and reduce the risk of bias due to the operator tending to avoid particularly bad sections of road. When the 200 observations have been made, the chart is removed from the Merlin.

The positions mid-way between the tenth and the eleventh crosses, counting in from each end of the distribution, are marked on the chart below the columns.

The spacing between the two marks, D, is then measured in millimeters and this is the roughness on the Merlin scale. Road roughness, in terms of the international roughness Index or as measured by a towed fifth wheel bumps integrator, can then be determined using one of the equations given below.

4.4.1. Calibration equations

The relation between Merlin scales and bump integrator (BI) and IRI scales have been given below, according to the data gathered on the site and measured value of depth (D) used for the evaluation of IRI for gravel road as stated formula model of the above parameters can be related as:-

For all road surfaces

$IRI = 0.593 + 0.0471D$---4.4.1.1

$42 > D > 312 (2.4 > IRI > 15.9)$

Where IRI is the roughness in terms of the International Roughness Index and is measured in meters per kilometer and D is the roughness in terms of the Merlin scale and is measured in millimeters.

$BI = -983 + 47.5D$---4.4.1.2

$42 > D > 312 (1,270 > BI > 16,750)$

Where BI is the roughness as measured by a fifth wheel bump integrator towed at 32 km/h and is measured in millimeters per kilometer.

When measuring on the BI scale, greater accuracy can be achieved by using the following relationships for different surface types.

1. Asphalt concrete (AC):

BI=574+29.9D---4.4.1.3

42<D<177(1,270<BI<5,370)

2-Surface treated

Bl= 132+37.8D (4) --4.4.1.4

57 < D <124 (2,250 < BI < 4,920)

3. Gravel

BI =-1,134 +44.0D---4.4.1.5

77< D <290 (2,010< BI < 12,230)

4. Earth

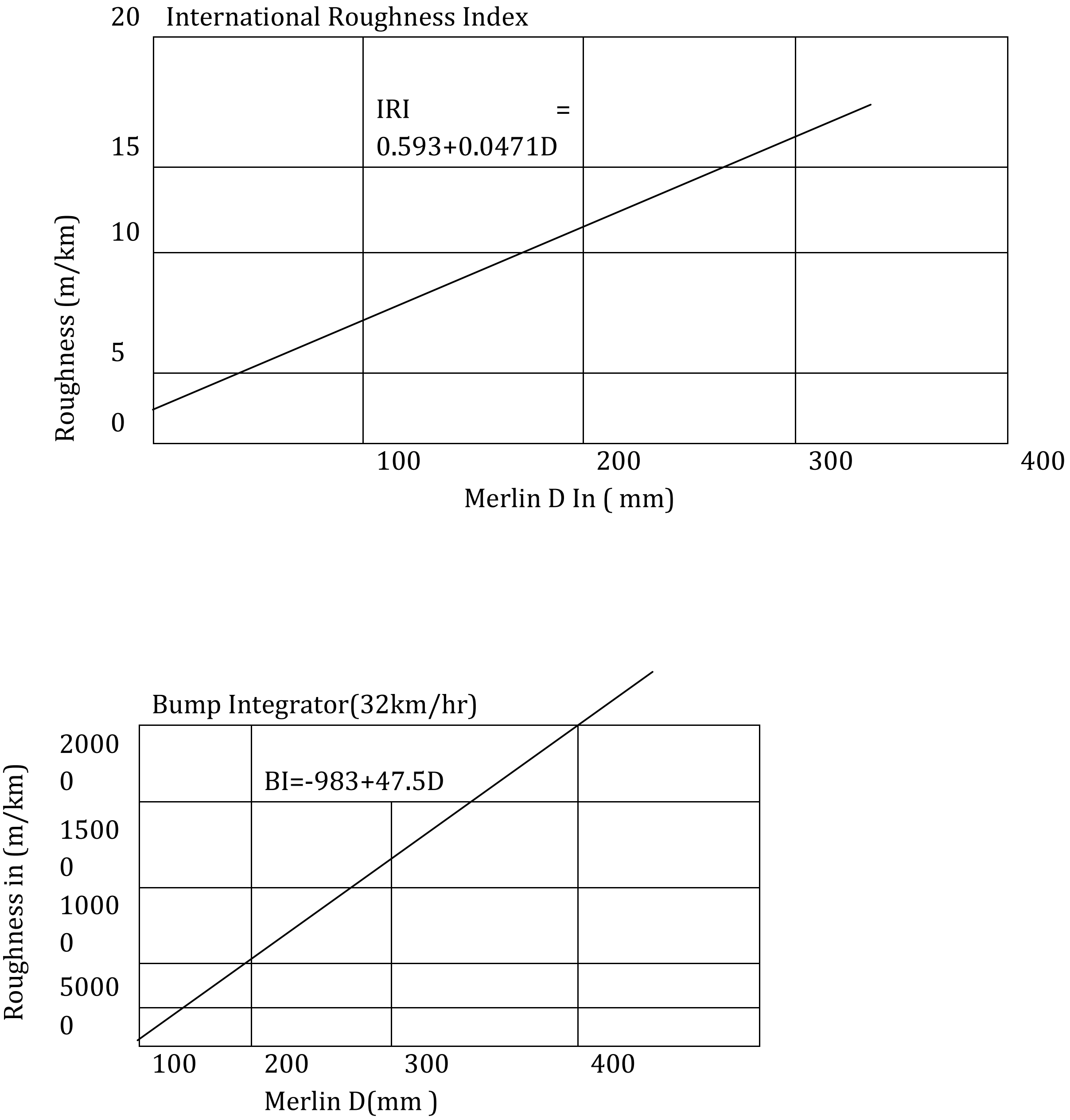
BI = -2,230+ 59.4 D---4.4.1.6

84 < D C<312 (2,940 <BI < 16,750)

These relationships are shown in graphical form in Figures 4.4.1.1below, the equations were derived over the range of roughnesses shown and care should be taken if extrapolating outside these ranges.

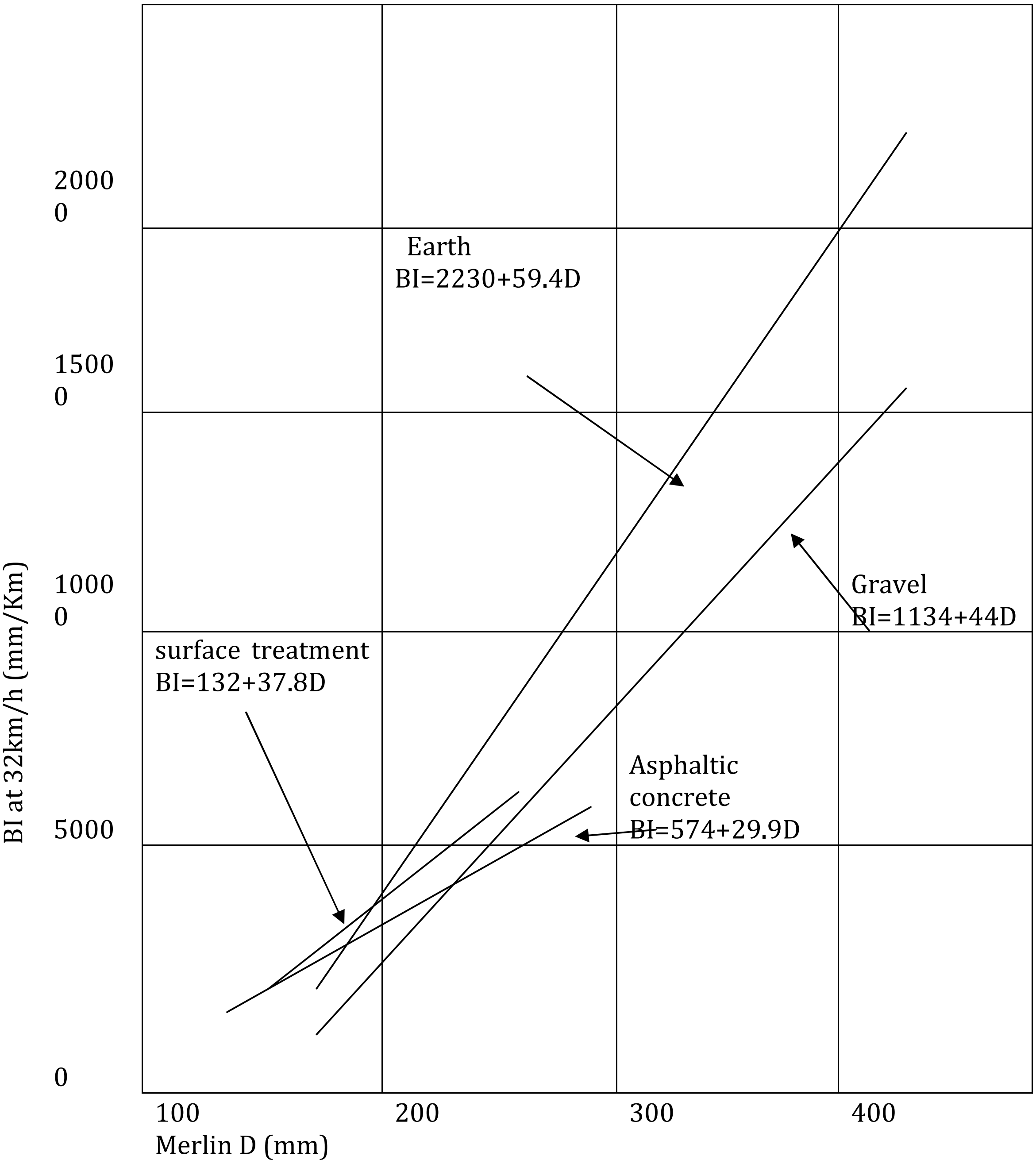
4.4.2 Calibration procedures

Before using the Merlin instrument calibration for its accuracy is necessary, the calibration procedure for Merlin instrument is as follow, its mechanical amplification of the arm should be checked using a small calibration block, typically 6 mm thick. Insertion of the block under the probe should move the pointer by 60 mm and any discrepancy has to be allowed for. For example, if the pointer moved by only 54 mm, then the value of D measured on the chart should be increased by a factor of 60/54.



Source: TRL manual.

Figure4.4.1. 1: Calibration relationships



Source: TRL manual.

Figure4.4.1. 2: Calibration relationship for different BI surface types

4.5 Evaluation of present serviceability index

In order to evaluate present serviceability index of the study site route Kamash –Yaso road, totally roughness index is used, due to the difficulty in measuring of distress like crack in gravel road and their insignificancy in the serviceability evaluation according to AASHTO road test.

The distress condition surveyed value has proportion of 5% value in the whole amount of serviceability measurement so due to the above two core reason in this research the use of roughness index in the determination of present serviceability index (PSI) is taken in to consideration as measured data shows.

The following procedure has been followed in the calculation of PSI:

To correlate the subjective rating of pavement performance with the objective measurements, to calculate the PSI consideration of the following terms should be understood. Present serviceability index (PSI) is the mathematical combination of values obtained from physical field measurement so formulate present serviceability rating (PSR) to the prescribed limit of pavement distress.

4.5.1 Determination of roughness index (IRI)

The analysis and method for the derivation of depth value (D) : from transport research laboratory (TRL),from tally and data marked format depth value (D) is calculated.

The d value is calculated as follow:- each box under TRL tally box is 5mm length, as described above in the Merlin function process when the rim moves 1mm the reading arm moves by 1cm, so 10 is the rim and the arm movement factor i.e. Rim diameter=1mm and the arm diameter=1cm.

During counting to calculate the D value 10 marks neglects from each side and at the 10th the remaining ratio is add to the D value as described in the figure A-1 to A-12 in the appendices A .

As shown in the appendix A the depth “D” value was calculated for each of the six sections both for right and left road way.

For all road surface the international roughness index (IRI) can be calculated by the model.

IRI =0.593+ 0.0471D --4.5.1.1

42>D>312(2.4>IRI>15.9)

Where IRI = is international roughness index

D= depth value measured on the site and multiplied by Merlin calibration constant.

With the measured data and analyzed by the above formula for each of section data and evaluated D value with the formula in the equation 45.1.1

The following tables 4.5.1.1summarize the values.

Table4.5.1. 1: The calculated value of D and IRI for each section

Evaluated Value of IRI					
	IRI=0.593+0.0471D				
Section	D- Value		IRI Value		
	Right	Left	Right	Left	IRI average Value =R+L/2
1	248	337	12.3	16.5	14.4
2	161	332	8.2	16.2	12.2
3	223	213	11	10.6	10.8
4	232	282	11.5	14	12.75
5	235	294	11.67	14.5	13.08
6	242	264	12	13	12.5
					Average=**12.6**

This is the summarized value for depth ‘D’ and IRI.

4.5.2Determination of present serviceability rating (PSR)

Present serviceability rating from very good to very poor as gathered from the field rater or the drivers, guide line used for the drivers are questionnaire requesting road performance form very good to very poor. The scale for the rating is described as:-

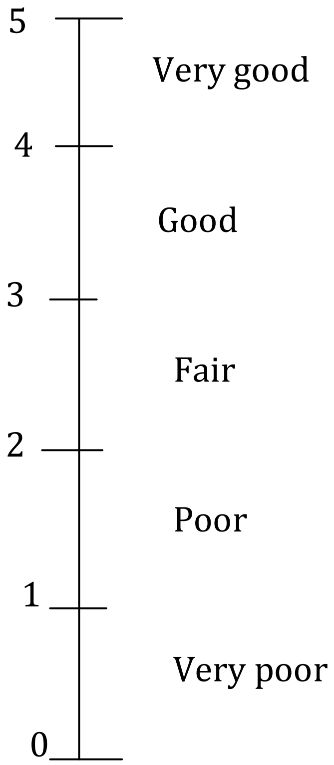


Figure4.5.2. 1: scale for the rating of user assessment

By distributing questionnaire to the drivers on the study site different rating values had been gathered from the selected section of Kamashi –Yaso road project segment. The summarized result from the rater is displayed below table 4.5.3.1.Under the user assessments combined value.

4.5.3 User Assessment and Regression Analysis

User assessment is the road users feed back to the road pavement, in order to evaluate the performance rating of the pavement, experts who drove around the pavement give rate for the pavement, in this research for the study route of kamashi –yaso road segment various sections were rated by road users and the value was assign as shown in the table 4.5.3.1 from very good to very poor and the assigned values of [4-5] and [0-1] respectively.

Experts or drivers who consistently drove around the study route to give a rating for the pavement with their vehicle are rater who give present serviceability rating for the road with the distributed questionnaire.

Table4.5.3. 1: Evaluated result for all selected sections of the user assessment rating

Sections	Very Good (4-5)	Good (3-4)	Fair (2-3)	Poor (1-2)	Very poor (0-1)
Section 1			2.9		
Section 2			2.9		
Section 3			2.9		
Section 4		3.25			
Section 5			2.9		
Section 6		3			

Performance rating value for the road segments as evaluated from the all rater is

Average PSR = [2.9*4+3.25+3]/6=2.98

PSR= **2.98**

The questionnaire is distributed and filled by the drivers which found under each section , in the study route six sections were selected each having 200m length for the roughness measurement by Merlin instrument according to the TRL manual format for Merlin instrument. For each six sections various samples have been taken like rating questionnaire for the drivers at each section, soil sample for CBR strength test for sub base materials used as wearing course and roughness data for each section.

After the PSR rating and measurement summaries have been obtained for all the selected pavements the final step is to combine the measurement summaries into a PSI formula that predicts the PSR to a satisfactory approximation.

In this research technique of multiple linear regression analysis is used to arrive at the formula and to decide which measurements may be neglected based on some parameter that are insignificant in the gravel wearing course performance on the basis of t-statistics value obtained in the regression.

The international roughness index (IRI) value versus user rating evaluation present serviceability rating (PSR) value as tabulated in table 4.5.3.2

Table4.5.3. 2: Serviceability rating (PSR) value for each of the six sections

Section points	Section length (m)	IRI(m/km)	PSR
Section 1	200	14.4	2.9
Section 2	200	12.2	2.9
Section 3	200	10.8	2.9
Section 4	200	12.75	3.25
Section 5	200	13.08	2.9
Section 6	200	12.5	3

Prediction of present serviceability index (PSI) with the measured value of roughness index correlation with PSR in this research, the analysis was shown as annex in the appendix A.

Even though the rut depth data was collected by manually measuring and analyzing physical measurements used for computing PSI includes the distress data of rut depth, cracking and patching, it is the longitudinal profile or roughness that provides the major correlation variables. The correlation coefficient between PSR and PSI is increased by only about 5% after the addition of distress according to [53].

In this research during estimation of PSI distress data is not used due to its relatively small contribution to PSI and the difficulty in the measuring and obtaining the distress data, only roughness was used to determine PSI value with the follow model formula.

$$PSI= X_0+X_1 LogIRI \text{--} 4.5.3.1$$

Where X_0 and X_1 are regression coefficients

IRI= internal roughness index

From table 4.5.3.2 by using the values of each section of the study site IRI and PSR the multiple regressions can be analyzed as shown below.

<u>SUMMARY OUTPUT.</u>

Table4.5.3. 3: Output of regression value

Regression Statistics	
Multiple R	0.039
R Square	0.002
Adjusted R Square	-0.248
Standard Error	0.157
Observations	6

Table4.5.3. 4: summary of output value of regression

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	0.002	0.002	0.006	0.941
Residual	4	0.098	0.025		
Total	5	0.098			

Table4.5.3. 5: Standarad error and t statistical value

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	2.915	0.757	3.850	0.018	0.813	5.017	0.813	5.017
X Variable 1	0.0047	0.059	0.079	0.940	-0.161	0.170	-0.161	0.170

RESIDUAL OUTPUT AND PROPABILITY OUTPUT

Table4.5.3. 6: Residual output and probability output

RESIDUAL OUTPUT					PROBABILITY OUTPUT	
Observation	Predicted Y	Residuals	Standard Residuals		Percentile	Y
1	2.983	-0.083	-0.594		8.333	2.9
2	2.973	-0.073	-0.519		25	2.9
3	2.966	-0.066	-0.472		41.666	2.9
4	2.975	0.274	1.954		58.333	2.9
5	2.977	-0.077	-0.549		75	3
6	2.975	0.026	0.182		91.666	3.25

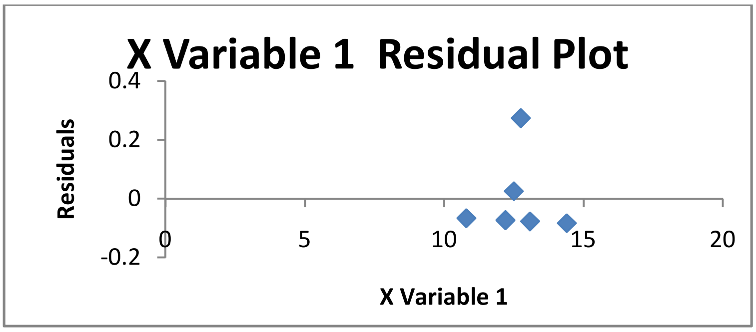


Figure4.5.3. 1: Residual value of regression

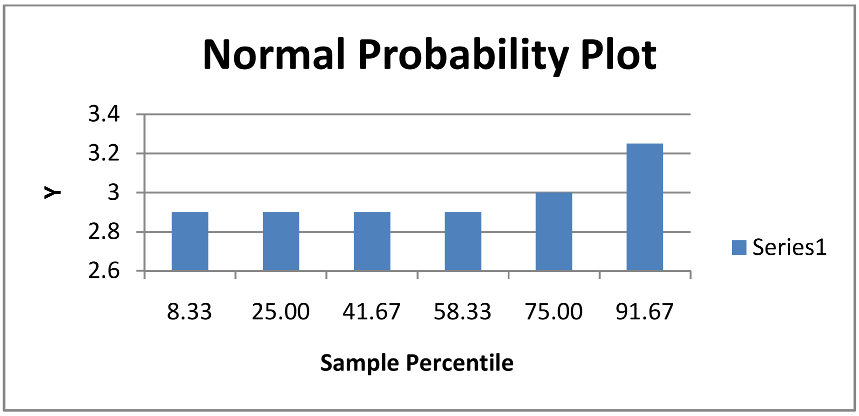


Figure4.5.3. 2: Normal probability plot

The above tables from 4.5.3.3 to 4.5.3.6 explain the correlation between measured performance indicator (roughness) and the user assessment (serviceability rating). Also the tables show the two parameters relationship strength with numerical value of t-statics, correlation coefficient, Standarad error and Residual output and probability output values when analyzed with multiple regression, and the figure 4.5.3.1 and 4.5.3.2 shows probability plot of the two parameters roughness and serviceability rating assuming them as x and y terms on linear axis.

As shown from the regression out put the variables X_0 and X_1 are determined and the value for PSI will be predicted as follow:

From the model PSI= X_0+X_1LogIRI---4.5.3.2

PSI =2.915+0.00475LogIRI X_0=2.915, X1=0.00475

PSI=2.915+0.00475Log12.6

PSI=2.920

This value is the determined value of the road which show the current performance of the route Kamashi-Yaso road project and assuming that the road has fulfilled all the performance requirement standards during its opening time to the traffic with the gravel road requirement the change in serviceability index can be determined keeping variation on each type of the road in mind and taking the initial serviceability index of secondary roads.

4.6 Evaluation of change in serviceability index ΔPSI

Estimate initial and terminal serviceability based on the standard of the study road design data review. Generally, designing gravel road for more than 10 year period is not sound, so according to the new ERA LVR manual of 2011 and ERA design manual of 2002 to the Ethiopia road condition the low volume roads or secondary roads according to hand book of highway engineering are roads with the traffic capacity as defined below:

“Low volume roads in Ethiopia typically carry less than 300 vehicles per day and provide important links from homes, villages and farms to markets and offer the public access to health, education and other essential services. These roads also provide important links between Woreda Centers and the Federal road network.

Vehicle operating costs (VOCs) are high on roads with high roughness and restricted access. VOCs include repairs, maintenance, and fuel and tyre replacement.

The consequence is that transport operators tend to avoid roads with high roughness and other defects forcing people to walk long distances to reach the nearest point where transport services are prepared to operate. Dust is often overlooked as a problem on unpaved roads; it is caused by the action of traffic and wind.

Unpaved roads lose fine material which can travel over 100 meters from the road. The dust affects other road users, pedestrians and school children, houses, shops and crops near the road. Roads in dry areas can lose up to 33 tons of surface fines per kilometer per year. Dust has significant and costly social (cleanliness), health (eye and respiratory hazards), environmental (crop and natural habitat damage) and economic (vehicle and equipment damage, pedestrian and vehicle safety) consequences. Approaches to alleviate dust problems, particularly in populated areas are offered in the Manual.

Gravel for road works is a non-renewable natural resource. On unpaved roads it is used as a sacrificial layer and must be periodically replaced. Optimal materials for gravel surfaced roads are not commonly found in Ethiopia, and it is possible to lose up to 150mm of gravel per year depending on conditions. Gravel roads require a continuous cycle of reshaping and regravelling to maintain the required running surface and the desired level of service. The type of materials prevalent in Ethiopia, the nature of the climate and the terrain presents significant challenges to achieving this type of maintenance.

Screening and blending techniques are available to improve the properties and such techniques are described in the Manual.

The major technical challenges for unpaved roads are to provide durable and functional water crossings, surfacing with materials that provide the desired and necessary level of service and to provide effective maintenance management. These challenges are recognized in the Manual and in many cases options and solutions are offered to mitigate and manage problems.

Innovative construction techniques and methods were identified that optimized the use of local lab our, introduced intermediate equipment techniques and improved opportunities for the local private sector to participate in road construction and maintenance, this is known as an environmentally optimized design (EOD) approach.

Assuming that the research site case study of the road route (Kamashi –Yaso road) was well constructed and fulfilled the initial serviceability index, the two parameter can be calculated for the case study road route, the two parameters are:-

I .The change in the initial and terminal serviceability.

II.The change in the present serviceability and the terminal serviceability

So the present serviceability index calculated in section 4.5.3 of equation 4.5.3.2 is 2.92.

And assuming that initial and terminal serviceability indexes according to AASHTO flexible pavement design manual and hand book of highway engineering, the recommended terminal serviceability index value pt, is 3 for major roads, 2.5 for intermediate roads and 2 for secondary roads. And also a well constructed new pavement has initial serviceability index (PSI_0) 4.2 to4.5.

Therefore the ΔPSI is

$\Delta PSI = P_0 - P_t$ --4.6.1

In this research the standard of the Kamashi –Yaso study road segment fall under secondary road and the terminal serviceability index of 2 were used for the evaluation of change in serviceability.

So change in initial and terminal serviceability index is **2.2** and change in present serviceability index and initial serviceability index is **1.28.**

4.7Evaluation of strength loss of the materials based on the sub base material test result

Generally, for all type of pavement either paved or unpaved wearing course in order to achieve the required bearing capacity and for uniform support to be provided to the upper pavement, limits on soil plasticity and particle size distribution may be required.

The Strength requirement for sub –base materials is a minimum CBR of 30% is required at the highest required moisture content, when compacted to the specified field density, usually a minimum of 95% (preferably 97% where practicable) based on the AASHTO T180 compaction (Pavement design manual of ERA LVR 2011) and ERA pavement design manual of 2002 specification for gravel wearing course roads.

Performance related material specification based on ERA 2002, South African manual and ERA LVR manual of 2011 is divided in various quality zones as shown in the figure4.7.1.and defined in table4.7.1 respectively below.

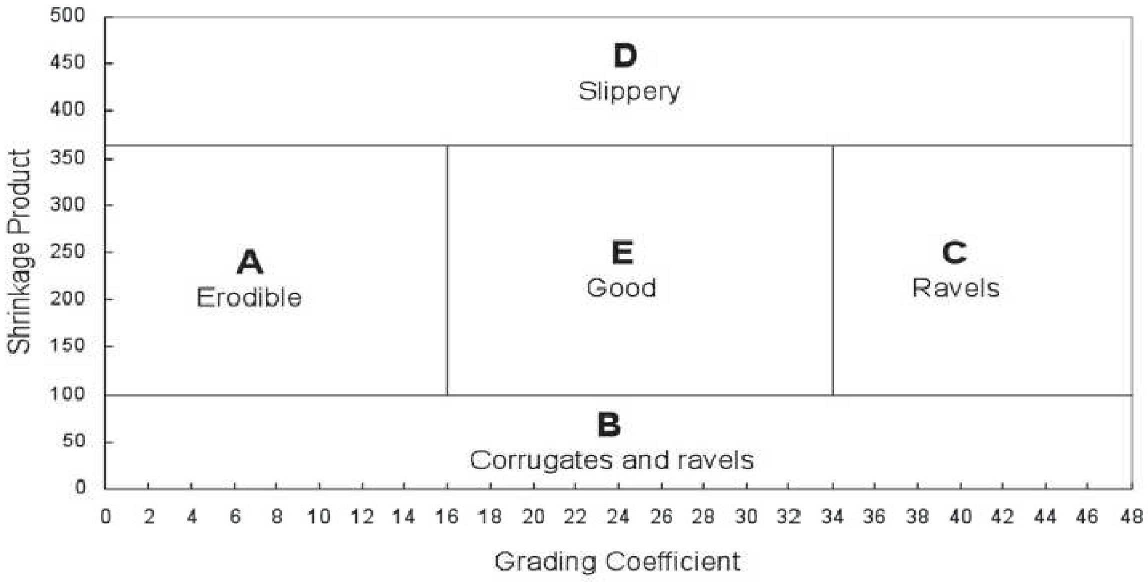


Figure4.7. 1: Material quality zone

Source: - ERA LVR manual 2011

Based on ERA LVR manual the characteristic of the material on each zone can be defined as follow:

A. Materials in this area generally perform satisfactorily but are finely graded and particularly prone to erosion. They should be avoided if possible, especially on steep grades and sections with steep cross-falls and super-elevations. Roads constructed from these materials require frequent periodic lab our intensive maintenance over short lengths and have high gravel losses due to erosion.
B. These materials generally lack cohesion and are highly susceptible to the formation of loose material (raveling) and corrugations. Regular maintenance is necessary if these materials are used and the road roughness is to be restricted to reasonable levels
C. Materials in this zone generally comprise fine, gap-graded gravels lacking adequate cohesion, resulting in raveling and the production of loose material.
D. Materials with a shrinkage product in excess of 365 tend to be slippery when wet.
E. Materials in this zone perform well in general, provided the oversize material is restricted to the recommended limits. According to new ERA LVR manual particle size distribution for sub-bases materials which meet the recommendations of Tables4.7.1 and 4.7.2will usually be found to have adequate bearing capacity.

Table4.7. 1: Particle size distribution for sub –base materials

Sieve size in mm	Percent by mass of total aggregate passing test sieve.
50	100
37.5	80-100
20	60-100
5	30-100
1.18	17-75
0.30	9-50
0.075	5-25

Table4.7. 2: Plasticity characteristics for granular sub –bases materials

Climate	Liquid limit	Plasticity index	Linear shrinkage
Moist tropical and wet tropical(N<4)	<35	<6	<3
Seasonally wet tropical(N<4)	<45	<12	<6
Arid and semi-arid(N>4)	<55	<20	<10

Where N is climatic factor

Source: - ERA LVR manual of 2011

Table4.7. 3: Recommended material specification for unsealed roads

Property	Materials specification limit
Maximum size (mm)	37.5
Maximum over size index $(I_0)(\%)^a$	5
Shrinkage product $(S_P)^D$	100-365(max of 240 preferable)
Grading coefficient ($G_c)^c$	16-34
Minimum CBR(%)^a	15 at 95% mod AASHTO
Treton impact value (%)	20-65
^{a}-I_0 =Percent retained on 37.5 mm sieve b – Sp = Linear shrinkage x percent passing 0.425 mm sieve c – Gc = Percent passing 26.5 mm sieve-per cent passing 2 mm sieve) x per cent passing 4.75 mm sieve d – Conventional soaked CBR unlike the unsoaked CBR originally specified in TRH 20	

Before coming to test result of present sub base materials used as wearing course of the project site sampled and tested for CBR evaluation and its result, let us see the design sub-base material requirement and that it fulfilled during the construction time according to the back history of the project from the data of road owners and the design consultant i.e. the material requirements specification of strength value that it should attain during the construction period.

As progress report of design consultant, Transport Construction Design Share Company (TCDSCO) the minimum CBR value is thirty percent. Based on the design specification of the gravel road standard and according to ERA manual, for the sub-base material of the minimum soaked California Bearing Ratio (CBR) shall be 30%.

when determined in accordance with the requirements of AASHTO T- 193, during the construction time the sub base material source was tested to the CBR strength specification it had fulfilled the minimum requirement of the Ethiopia Roads Authority, "Pavement Design Manual, volume I Flexible pavements and Gravel roads" Addis Ababa, 1998 and the design consultant specification together with the Ethiopian Road Authority Standard Technical Specification. ERA, Addis Ababa, 2002.

The material requirement that the case study site fulfilled according to the laboratory test result of site lab test shows that the sub base material which is the wearing course of the road has CBR value of 32% under highest required moisture content, when compacted to the specified field density, usually a minimum of 95% (preferably 97% where practicable) based on the AASHTO T180 compaction on the field.

This is more than the specification of the design of the road and ERA 2002 manual, as the data from the design supervision consultant progress report for certain stretch of the road that is for the first 20km the specification was fulfilled mechanical stabilization (blending) of the material on two sources. As evaluated in section 5.4.1 the values ,of two samples result, sub –base material for CBR test and tested in highway laboratory shows the CBR result is reduced with some small amount compare to the construction time test result, this shows that the materials is losing its strength through time by traffic and weather condition. As material strength indication of CBR value before the service time i.e. during construction time and during this study time shows that material strength loss of 1.73% CBR value reduction at sation7+300 and 3.32% CBR value reduction at station 19+700 this so much small and shows minimum loss with time of the strength performance.

5. RESULT AND DICUSSION

5.1Performance Indicator measured data and result

Performance indicators data for the physical appearance of the study route Kamashi–Yaso was measured during the site road condition survey by taking check list for each of the sections of road segments, data like roughness was gathered.

Figure5.1. 1: Corrugated, rutting and crack surface of the road

The data measured as shown below in the following figure is annexed in appendix B

Figure5.1. 2: Measuring the longitudinal and lateral depth of rut on the site

The case study site is gravel road, surfaced with natural existing selected material of gravel and the surface friction is measured as roughness of the road.

Roughness (slope variance):- is an important indicator of pavement riding comfort and safety. It is a condition indicator that should be carefully considered when evaluating primary pavements which covers about 95% of performance indicator of any surfaced road. At the same time, the use of roughness measurements plays a critical role in the pavement management system. From an auto driver's point of view, pavement roughness is a phenomenon experienced by the passenger and operator of a vehicle. According to the definition of the American Society of Testing and Materials (ASTM), "roughness is the deviations of a pavement surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic loads, and drainage, for example, longitudinal profile, transverse profile, and cross slope". This definition covers the factors that contribute to road roughness and it is also very broad. However, it does not provide a quantitative definition or standard scale for roughness, so it still requires a measurement and analysis method for quantifying distortions of the pavement surface [54].

Once the measurement and analysis method is selected, in this research work, establishing interpretation scale to determine the severity of the roughness level as measured in the field with the selected instrument. Pavement profiles are frequently used to characterize roughness so in this research work only roughness is considered for evaluation of the serviceability of Kamashi-Yaso road project.

Even though there were several causes of pavement roughness: traffic loading, environmental effects, construction materials and built-in construction irregularities are some of the causes. All pavements have irregularities built into the surface during construction, so even a new pavement that has not been opened to traffic can exhibit roughness. The roughness of a pavement normally increases with exposure to traffic loading and the environment. Short-wavelength roughness is normally caused by localized pavement distress, that is, depression and cracking, at the same time the long-wavelength roughness is normally caused by environmental processes in combination with pavement layer properties.

When examining the performance loss of the study route on the basis of performance indicators as the visualization site survey and the measurement of rutting and roughness of the road it corrugated and raveled requiring maintenance.

The road surface has almost rut depth of 25mm average depth as shown in appendix B of field data measured and shown in figure 5.1.2 of section 5.1 and also the road has roughness index of (IRI=12.6),present serviceability index of (PSI=2.92)as calculated value shows in the data analysis of section4.5.3. On the other side hand the user assessment result gathered from the road user, based on distributed questionnaire rating of 0-5 value output evaluation section 4.5.3 shows the average present serviceability rating(PSR) value is 2.98 as shown in section4.5.3 of data evaluation part.

The rating is valued according to the following nomination.

0-1--------very poor
1-2--------poor
2-3 --------fair
3-4--------good
4-5-----very good

The performance of the road falls under well performing but it needs immediate maintenance requirement according to the user assessment and data evaluation in section four results from the rating of the case study site and the field survey data output result as the analysis of regression result and data evaluation in section 4 output results.

5.2Examination of performance loss based on the performance indicators measured and user assessment result

Performance indicators are measured values indicating the deterioration or loss of strength of the case study road route so in order to obtain the performance of the road various type of field data measurement was done and several sets of data were collected under different conditions using the appropriate instruments.

Data collected for the analysis were obtained from design documents and through field measurements.

The collected data were roughness index data for determination of IRI, measuring of available performance indicator on the surface of the road wearing course that visualizes during the data collection period, performance rate data from road users and sample of wearing course materials for CBR strength test in the laboratory. After the data were measured in the site the necessary implementation work was carried out.

The duties during data collection were done as follow: Measuring performance indicators : Since the standard of the road whose performance is being studied in this research is gravel paved, measuring the crack of gravel road damage and pothole filled is very difficult and impossible so during the field survey except visual assessment to estimate the level of the road status no physical crack measurement is done, But the distress crack depth is measured within the roughness measurement surrounding and around the sample for CBR test sampled to know the cumulative effects on the serviceability of the road with the core parameter which clearly indicate the deterioration level of the road in addition to the rater clue to the level of degree of the performance.

These parameters are measurable characteristics (performance indicators):

- Visible distress (cracking & rutting)
- Surface friction
- Roughness (slope variance).

The visible distress of the road visualized between the time intervals that the road was opened for traffic and site visit time; data gathered and measured during condition survey time is described and shown below.

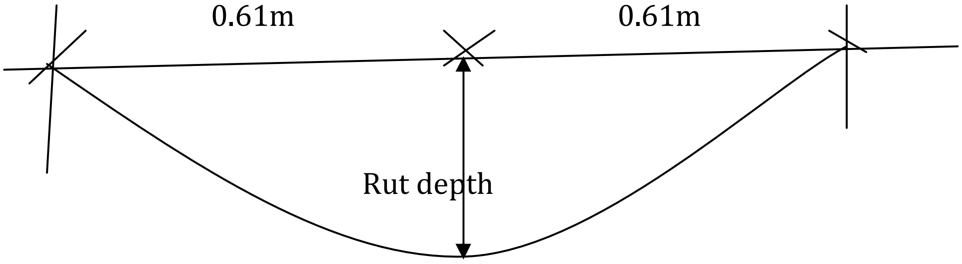


Figure5.2. 1: Rut depth diagram for depth measurement

Figure5.2. 2: Measuring rut depth at field

Traffic can create a surface depression or rut over a portion of a gravel road.

The ruts may be caused by dislodging some of the surface gravel. Loose unstable gravel may be displaced by traffic causing minor surface ruts.

Severe rutting (over 3”) may be caused by weak underlying soils. Poor crown and drainage conditions weaken the base and accelerate rutting the data collected at the site up to 25 km for such distress the maximum rut depth is observed at station which is 64mm.

Slight rutting can be removed by blending and restoring the crown. Severe rutting caused by unstable subsurface soils will require improvements in drainage and addition of aggregate.

Figure5.2. 3: General Picture of rut

Rut in the wheel path needs to be maintained to eliminate pounding and to prevent further road deterioration. Rut measured in the field for various sections were tabulated in the appendix B for each of the selected sections in the study site of this research.

5.3 Correlation between user assessment (ride experience) and performance indicators (measurable characteristic)

To determine whether there was a relationship between the measured characteristics and user assessment (ride experience), a correlation analysis were made between the two elements. The results of the correlation are listed in table4.5.3.3-.4.5.3.6 in the data evaluation part in section 4. From this correlation the t-statics and 95 percent confidence interval (significant level of α = 0.05) shows that the two parameter has true relationship. It is possible to develop a relationship among ride experience (user assessment) and measureable characteristics to assure the two variables relation. In this regard, simple the assessment from the users was made and the measurement and its analysis were made based on the field data gathered along the study road. Furthermore, correlations of the two parameters were analyzed as indicated in the data evaluation and the result was justified with correlation of true t-statistics.

5.4 Analysis of performance indicators, user assessment based on CBR strength test on sub base materials deformation used as wearing course for gravel road

As data obtained from the design consultant of the construction supervision for the road route the design specification based on ERA manual, for the sub-base material used for the wearing course of the road will be according to the minimum soaked California Bearing Ratio (CBR) shall be 30% when determined in accordance with the requirements of AASHTO T- 193.During construction time of the road the wearing course sub base material strength value for the material was above 30 % CBR value as the test result shows in the progress report of the supervision consultant report based on the ERA standard technical specification manual for gravel road. More over as to the CBR test of the investigation shows little bit lower the initial strength requirement, the material strength or CBR value the current sampled shows average 2.5% reduction from the minimum specification CBR strength value requirement of 30%.

Generally methods used to estimate the strength of highway materials are:-

1. Group index (GI)

The group index is an indication of the silt and clay content of the soil and evaluated using the model.

$$GI = [F-35][0.2+0.005(W_L-40)]+0.01(F-15)(Ip-10) \text{-------------------------------------} 5.4.1$$

Where F=the percentage passing the 0.075 mm sieve expressed as a whole number (this percentage is based on the material passing the 75-mm (3 in) sieve.)

W_{Le}= the numerical liquid limit expressed as a whole number; and

Ip = the numerical plasticity index expressed as a whole number.

Generally the group index is usually calculated part of the AASHTO soil classification system. For A-2-6 and A-2-7 soils, only the second term, including the plasticity index is used.

2 -California bearing ratio (CBR)

This test method covers the determination of the CBR of pavement sub-grade, sub-base, and base course materials from laboratory compacted specimens. This test simulates the prospective actual condition at the surface of the sub-base. A surcharge is placed on the surface to represent the mass of pavement material above sub-base. The sample is soaked to simulate its weakest condition in the field. Expansion of the sample is measured during soaking to check for potential swelling.

This method covers the laboratory determination of the California Bearing Ratio (CBR) of a compacted or undisturbed sample of soil. The principle is to determine the relation between force and penetration when a cylindrical plunger with a standard cross-section area is made to penetrate the soil at a given rate. At certain values of penetration the ratio of the applied force to a standard force, expressed as a percentage, is defined as the California Bearing Ratio (CBR).

According to ERA manual, for the sub-base material the minimum soaked California Bearing Ratio (CBR) shall be 30% when determined in accordance with the requirements of AASHTO T- 193. The Californian Bearing Ratio (CBR) shall be determined at a density of 95% of the maximum dry density when determined in accordance with the requirements of AASHTO T-180 method [66, 67] for field determination.

The CBR test consists of the following procedures as key point to arrive the result of the strength value deserved.

A. Compacting a sample at its optimum moisture content.
B. Appling a surcharge to the sample to represent the estimated thickness of pavement over the sub base and sub grade materials.
C. Soaking the sample for four days.
D. Forcing a 19.4cm2 (3in2) plungers into the sample depth of 2.5mm (0.1in).

The force required to obtain this penetration is expressed as percentage of the standard load for crushed road base material (13.3knor 300Lb) to give the CBR value.

CBR-value is used as an index of natural selected materials soil strength and bearing capacity. This value is broadly used and applied in design of the base and the sub-base material for pavement. CBR is one of the most commonly used methods to evaluate the strength of sub base and sub grade materials for pavement thickness design.

In the measuring the strength and the swelling potential of a natural selected soil material and soil is compacted in a mold with the standard comp active effort at its optimum water content (so that it is at about 100% of its maximum density , as determined by the standard compaction test.) This test simulates the prospective actual condition at the surface of the sub grade. In this research sample test of CBR the selected material the surcharge is placed of the surface to represent the mass of pavement material above the sub grade. The sample is soaked to simulate its weakest condition in the field .Expansion of the sample is measured during soaking to check for potential swelling after soaking the strength is measured by recording the force required to show a penetration piston in to the soil.

According to ASTM apply the load on the penetration piston so that the rate of penetration is approximately 0.05 in. (1.27 mm)/min.

Record the load readings at penetrations of 0.025 in. (0.64mm), 0.050 in. (1.27 mm), 0.075 in. (1.91 mm), 0.100 in. (2.54mm), 0.125 in. (3.18 mm), 0.150 in. (3.81 mm), 0.175 in. (4.45 mm), 0.200 in. (5.08 mm), 0.300 in. (7.62 mm), 0.400 in. (10.16 mm) and 0.500 in. (12.70 mm). Note the maximum load and penetration if it occurs for a penetration of less than 0.50in (12.70 mm).

In order to obtain the maximum dry density and optimum water content in this research the following procedures was done.

Compaction: To obtain maximum dry density and obtimum water content for a soil, using the standard compactive effort. This test also known as the moisture density test or proctor test, measure (1) the maximum dry density that a soil can reach under a specified compactive effort, and (2) the moisture content at which maximum dry density is reached. The standard compactive effort is 25 blows of 2.5kg hammer falling 30cm on each of the three layers of material in the mold 10cm in diameter and 943.9 cm3 in volume.

The compaction test with the ASTM and AASHTO test system has standard and modified method in the standard comp active effort 25 blows of with 2.5kg hammer falling at 30cm on each of the three layers of materials in a mold 10cm in diameter and 943.9cm3 volumes in modified comp active effort 25 blows of with 4.5kg hammer falling at 30cm on each of the three layers of materials in a mold 10cm in diameter and 943.9cm3 volumes and used for coarser materials to minimize the number of trials.

In the test sample 1st 4% to 10 % of water is added depending on the natural water content estimation of the sample and the incremental for second trial will be 100ml to

150ml depending on the material if the material is coarser 100ml is enough but if the material is fine use 120ml to 150 as you estimate your sample because of the finer material take more water than the coarser.

In this research the sample used was 4% initial water and 100ml for second in each incremental for the sample at station 7+300 and 4% initial water and 120ml incremental water for the sample at station 19+700 i.e. only 120ml is used after 1st trial and the sample is mixed, in this method the sample of the material is mixed with water and then compacted .The mass of the compacted sample is measured and part of it is taken to dry for the purpose of determining water content.

Table5.4. 1: Compaction Data sheet for sample at station 7+300km

Density	Trial No	1	2	3	4	5	6	7
	Mass sample+mold in gram	6276	6281	6401	6453	6403	6388	6376
	Mass mold in gram	4422	4422	4422	4422	4422	4422	4422
	Volume of the mold in cm3	943.9	943.9	943.9	943.9	943.9	943.9	943.9
	Mass sample in gram	1854	1859	1979	2031	1981	1966	1954
	Density in kilo gram/m3	1964.19	1965.5	2096.25	2151.7	2098.70	2082.84	2070.13
	Dry density in kilo gram/m3	1799.08	1800	1892.25	1906.19	1824.35	1770.04	1737.50
Water content	Container no.	1	2	3	4	5	6	7
	Mass sample + container in gram	165	214	210	154	135	165	173
	Mass dry sample + container in gram	153	196	190	137	118	141	146
	Mass water in gram	12	18	20	17	17	24	27
	Mass container in gram	5	5	5	5	5	5	5
	Mass dry sample in gram	148	191	185	132	113	136	141
	Water contain %	8.1	9.4	10.8	12.88	15.04	17.60	19.14
Natural water content	Mass of sample + container in gram	164						
	Mass of dry sample + container	160						
	Mass of the water in gram	4						
	Mass of container in gram	5						
	Mass of dry sample in grams	155						
	Water content %	2.58						
Optimum water content of sample to be used for CBR compaction is 12.88-2.58=10.3%								

The formula to calculate the above result tabulated in the table is:-

Bulk density of the sample is equal to mass of sample in mold divided by volume of sample

$$\gamma_{\text{bulky}} = M/V \text{---} 5.4.2$$

Dry density of the sample is equal to bulky density divided by one plus water content

$$\gamma_{\text{dry}} = \gamma_{\text{bulky}} / [1+w] \text{---} 5.4.3$$

Where w is water content in %.

Water content is equal to mass of the water divided by dry mass of the sample multiplied by 100.

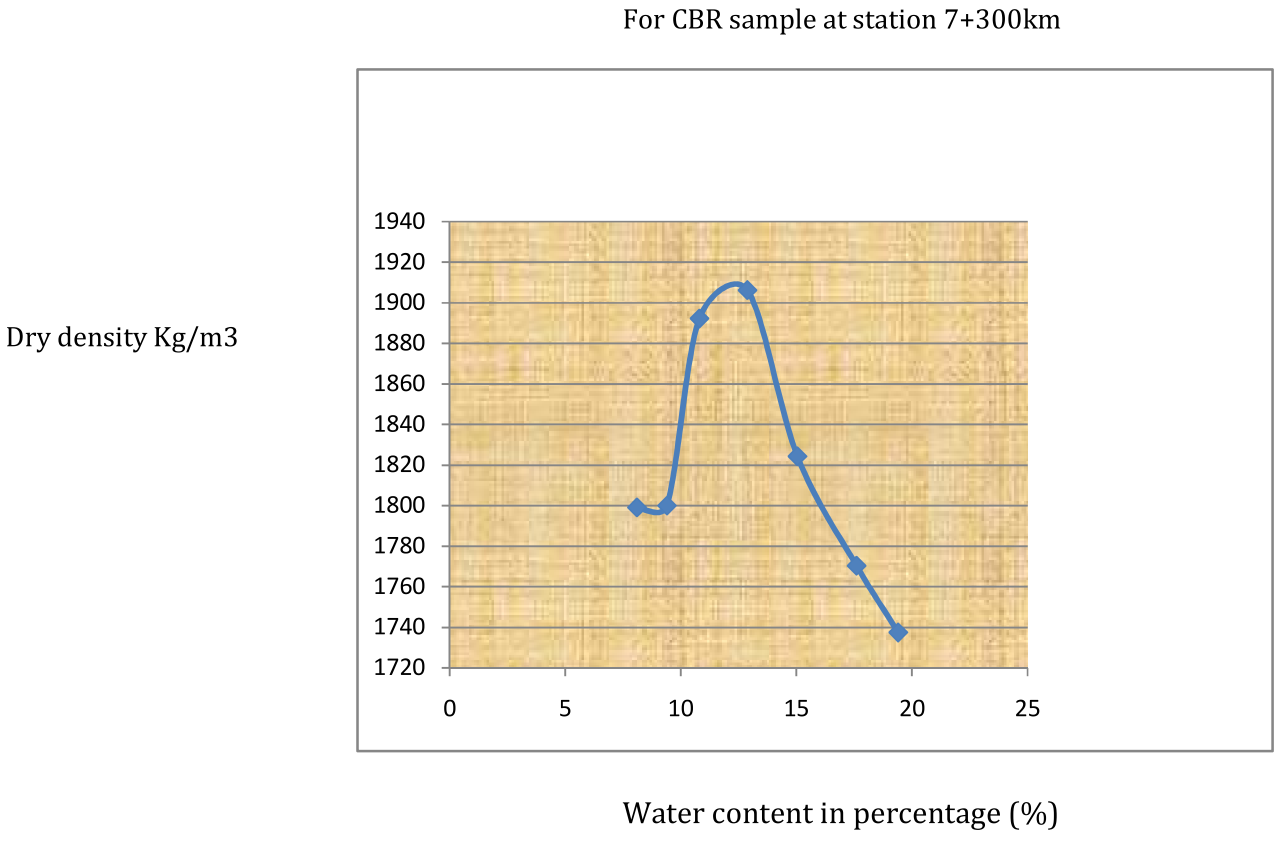
$$W = M_{\text{water}}/M_{\text{dry S}} \text{--} 5.4.4$$

Table5.4. 2: Compaction Data sheet for sample at station 19+700km

Density	Trial No	1	2	3	4	5
	Mass sample+mold in gram	6158	6313	6435	6470	6380
	Mass mold in gram	4422	4422	4422	4422	4422
	Volume of the mold in cm3	943.9	943.9	943.9	943.9	943.9
	Mass sample in gram	1736	1891	2013	2048	1958
	Density in kilo gram/m3	1839.17	2003.39	2132.64	2169.72	2074.37
	Dry density in kilo gram/m3	1645.64	1757.35	1828.08	1830.98	1697.24
Water content	Container no.	1	2	3	4	5
	Mass sample + container in gram	138	119	131	133	170
	Mass dry sample + container in gram	124	105	113	113	140
	Mass water in gram	14	14	18	20	30
	Mass container in gram	5	5	5	5	5
	Mass dry sample in gram	119	100	108	108	135
	Water contain %	11.76	14	16.67	18.50	22.22
Natural water content	Mass of sample + container in gram	125				
	Mass of dry sample + container	118				
	Mass of the water in gram	7				
	Mass of container in gram	5				
	Mass of dry sample in grams	113				
	Water content %	6.19				
Optimum water content to be used for CBR compaction is 22.22-6.19=12.3%						

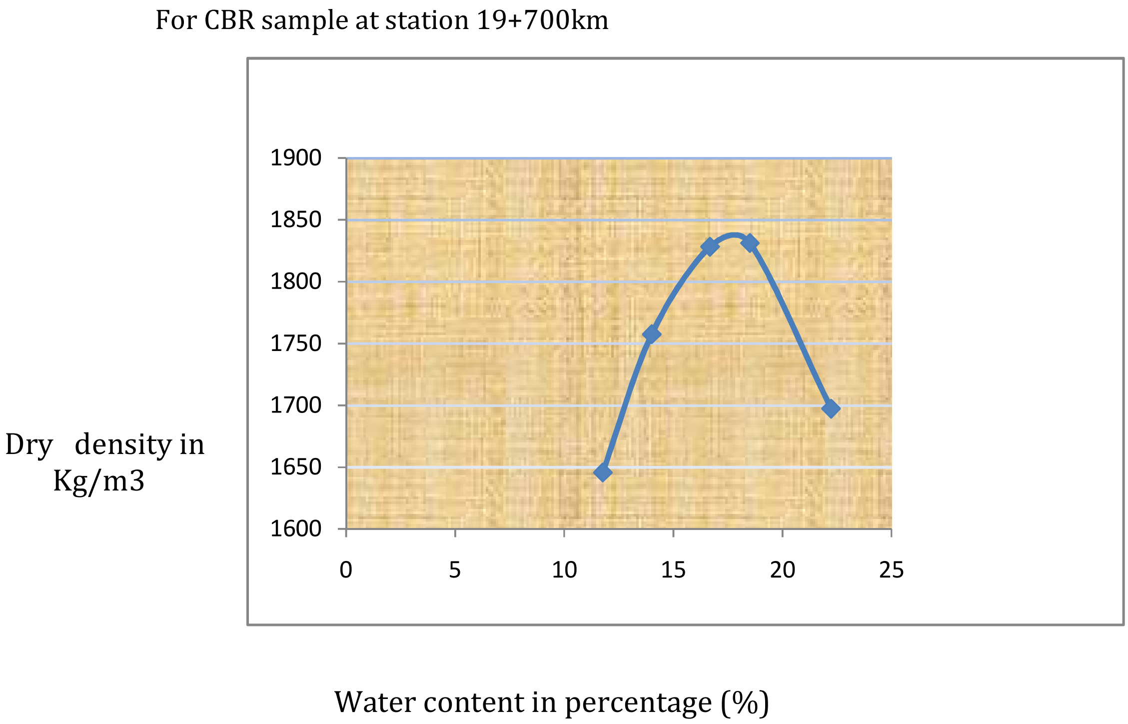
Table5.4. 3: Optimum water content and natural water content evaluation

CBR Sample at station 7+300		CBR Sample at station 19+700	
Dry density	Water content	Dry density	Water content
1799.08	8.1	1645.64	11.76
1800	9.4	1757.35	14
1892.25	10.8	1828.08	16.67
1906.19	12.88	1830.98	18.5
1824.35	15.04	1697.24	22.22
1770.4	17.6		
1737.5	19.4		
Natural water content		**Natural water content**	
mass of water	dry mass of the sample	mass of water	Dry mass of the sample
0.004kg	0.155kg	0.07kg	0.113
Natural water content	2.58%	Natural water content	6.19%
The highlighted row portion is the dry density at which optimum water content is achieved.			



Optimum water content is =12.88-2.58=10.3%,

Figure5.4. 1: Optimum water content graph for CBR test at station 7+300



Optimum water content is 18.5 -6.19 = 12.3%

Figure5.4. 2: Optimum water content graph for CBR test at station 19+700

5.4.1 Determination of CBR and swelling for performance investigation

Table5.4.1. 1: shows determination of CBR &Swell (%) for sub base material used as wearing course of Kamashi – Yaso gravel road

SAMPLED STATION	STRESS(Mpa)		CBR (%)		SWELL (%)
	2.54mm	5.08mm	2.54mm	5.08mm	
7+300	1.9282	2.95653	27.80	28.74	0.128
19+700	1.7996	2.80230	25.90	27.45	0.0515

From the above result it is observed that the selected material used for the wearing course has been lost the initial strength after it has been open to traffic. The reduction in the CBR value is due to the sub base material used for the wearing course is corrugated at certain station and crushed too fine in certain station as it is visualized during condition survey time sampling the project route this is due to traffic, weather and environment condition that the material suffering after it has been open to traffic.

The correlation between lab result and performance is that the loss in material strength is loss in riding quality or comfort to drive, when the material strength is reduced the roughness of the road become higher i.e. the road is fail to perform well.

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusions

In this thesis work of the investigation of performance of unsealed road sub base material used as wearing course of gravel road following general conclusions were made based on the finding of the study:-

- From the analysis result the serviceability index of the road kamashi-Yaso is 2.92 which leads to conclude the road can attain the design period with in the gravel road design period limit.
- The results of the roughness index and measured distress values shows the road running with good condition on the basis of the standard of the road i.e. according to the field gathered data analysis result and the wearing course material strength test result the serviceability of the road is under the bounder value of terminal and initial.
- When compared to the serviceability of existing case study site result with the design standard value, it is almost under design limit but needs maintenance provision.
- According to the result obtained in the six sections of the Merlin roughness index instrument and the analysis obtained IRI value is between the boundary values of gravel road specification limit, therefore the unsealed road wearing roughness is in the good condition.
- Based on the user assessment , the values obtained from the raters indicates that the road is performing fair compared; to the gravel wearing course of the raters experience from this conclusion the road can attain the design period without severe deterioration.
- As the combined regression result of user assessment, measured parameters indication and strength test result of the material used for wearing course of the unsealed road is deteriorating with time regularly which general property of selected natural sub base material used for gravel road wearing course.

- This study has produced significant relationships that can be used to calculate the expected unsealed materials serviceability change with time and low volume road performance which has considerable number and has huge coverage in the country and other developing countries.
- The data Correlation analysis showed that the roughness measuring devices used in this research had good correlations between the instrument and IRI obtained in the analysis of final output.

6.2 Recommendations

The following recommendations are made based on the findings and conclusions of this study:

- It is recommended that more research be conducted in attempt to get more useful pavement data for correlation verification of the performance of unsealed roads by collecting more data in order to improve results for this un sealed roads which exists widely and has high economic value.
- This study has certain limitations like the data for the analysis is taken from only one project route so that it is uncertain to generalize for all type of gravel unsealed roads, because every road project has its own unique condition and environmental situation.

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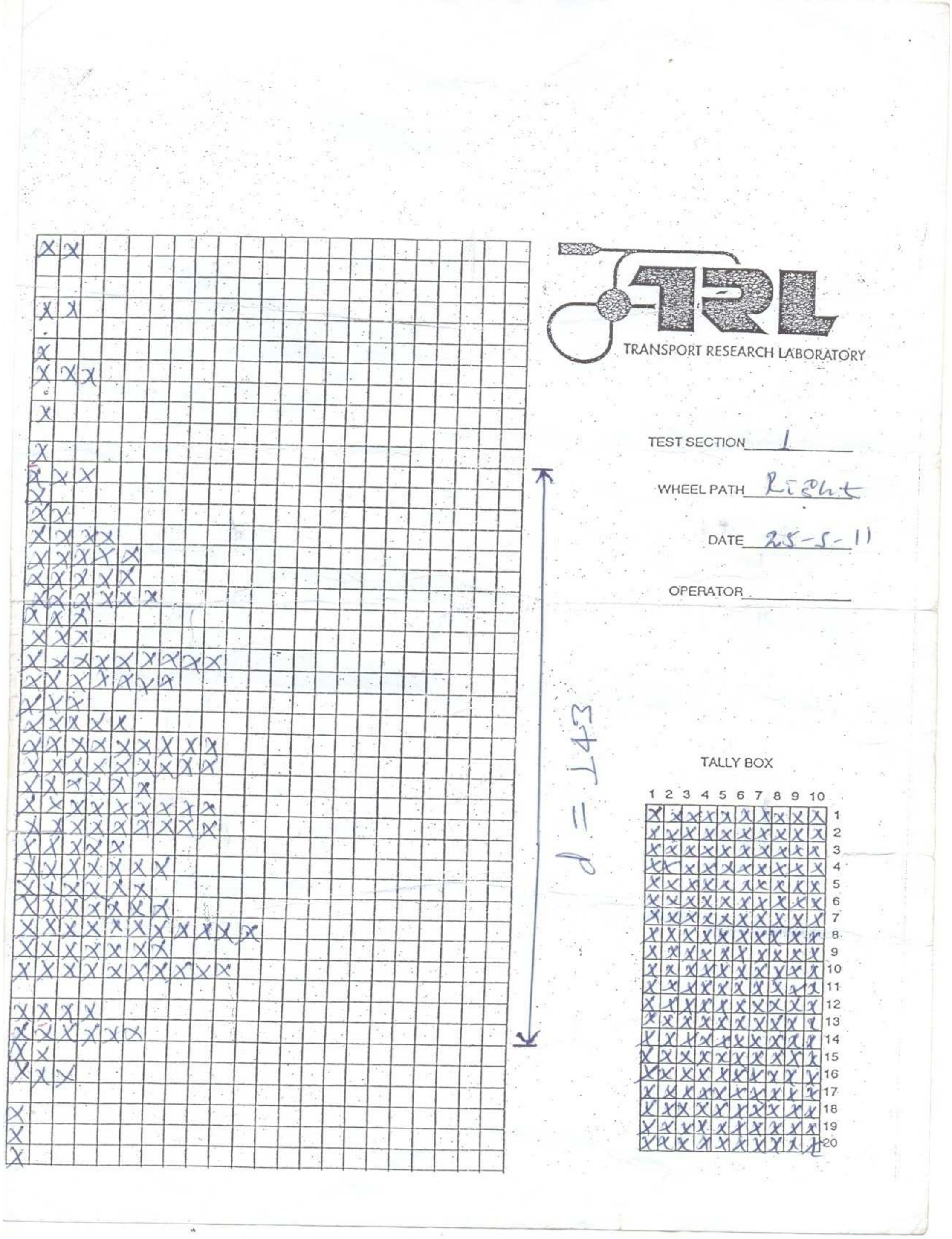
8. APPENDIX

APPENDIX- A: - TRL chart and the depth value “d” calculation for each of the six sections

Section -1 Right



TRL
TRANSPORT RESEARCH LABORATORY

TEST SECTION 1
WHEEL PATH Right
DATE 25-5-11
OPERATOR

TALLY BOX

1	2	3	4	5	6	7	8	9	10	
X	X	X	X	X	X	X	X	X	X	1
X	X	X	X	X	X	X	X	X	X	2
X	X	X	X	X	X	X	X	X	X	3
X	X	X	X	X	X	X	X	X	X	4
X	X	X	X	X	X	X	X	X	X	5
X	X	X	X	X	X	X	X	X	X	6
X	X	X	X	X	X	X	X	X	X	7
X	X	X	X	X	X	X	X	X	X	8
X	X	X	X	X	X	X	X	X	X	9
X	X	X	X	X	X	X	X	X	X	10
X	X	X	X	X	X	X	X	X	X	11
X	X	X	X	X	X	X	X	X	X	12
X	X	X	X	X	X	X	X	X	X	13
X	X	X	X	X	X	X	X	X	X	14
X	X	X	X	X	X	X	X	X	X	15
X	X	X	X	X	X	X	X	X	X	16
X	X	X	X	X	X	X	X	X	X	17
X	X	X	X	X	X	X	X	X	X	18
X	X	X	X	X	X	X	X	X	X	19
X	X	X	X	X	X	X	X	X	X	20

Removing 10 from each side

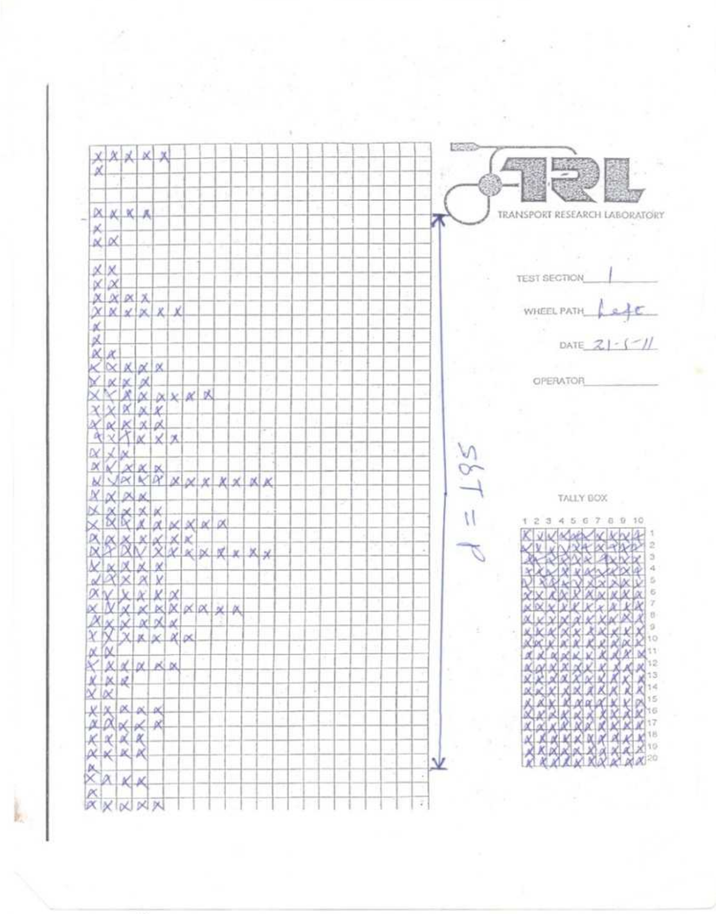
D= [28*5+(4/6)*5]4.92*10/28.4

4.92/28.4 = is the calibration constant for the Merlin

10 = is the rim factor

D= 248mm

Section -1 Left



TRANSPORT RESEARCH LABORATORY

TEST SECTION 1

WHEEL PATH Left

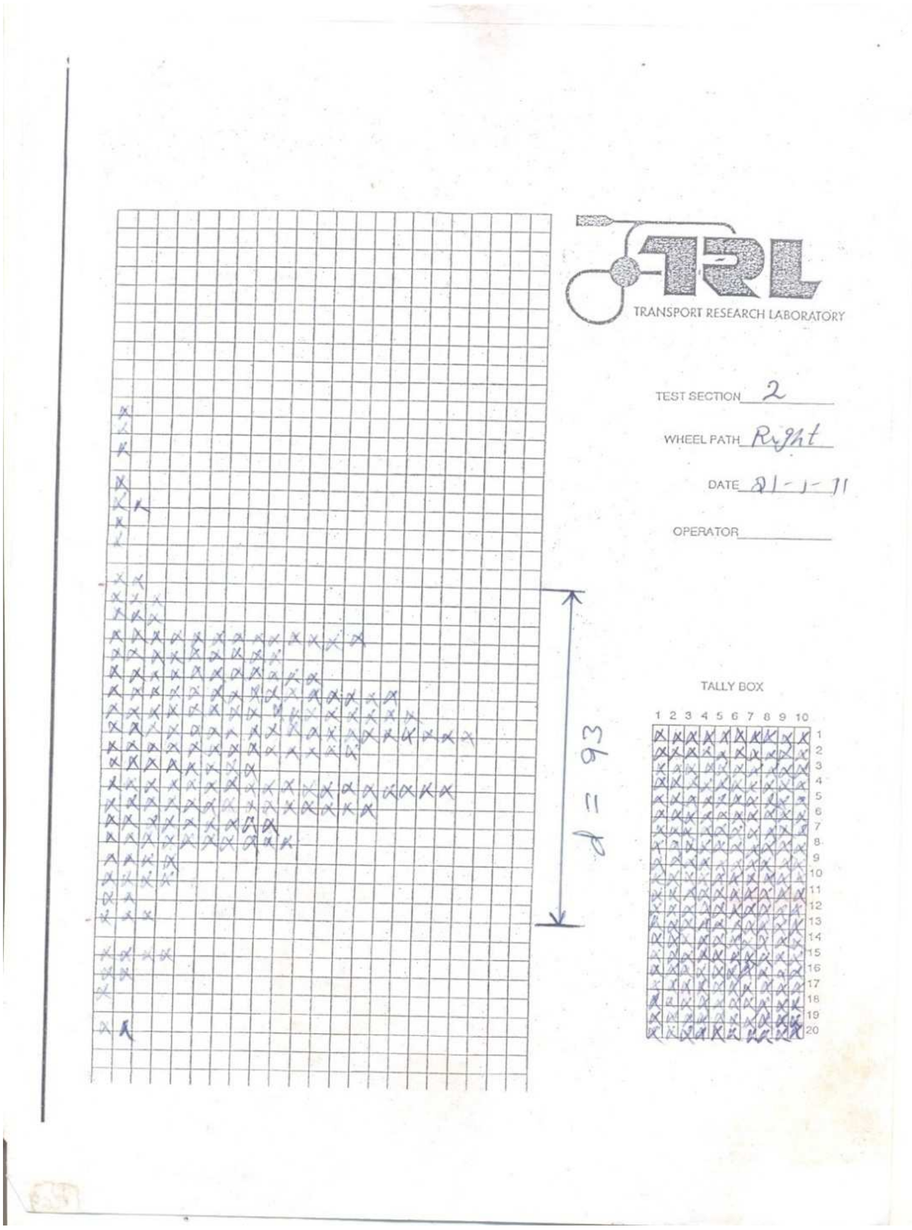
DATE 21-5-11

OPERATOR

D=[39*5+0]4.92*10/28.4

D=337mm

Section- 2 Right



TRANSPORT RESEARCH LABORATORY

TEST SECTION 2

WHEEL PATH Right

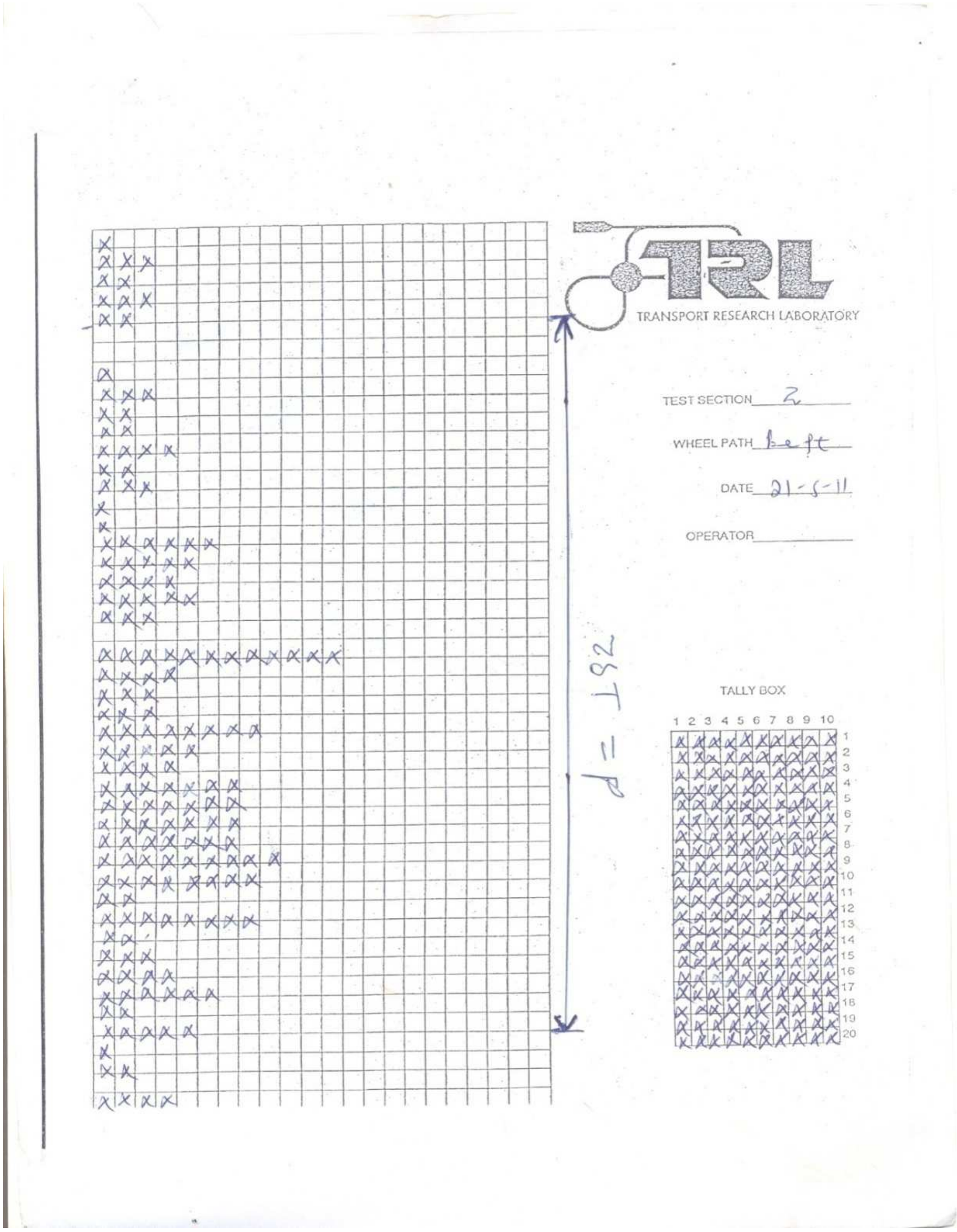
DATE 21-1-11

OPERATOR

D=[18*5+0]4.92*10/28.4

D=161mm

Section-2 Left



TRANSPORT RESEARCH LABORATORY

TEST SECTION 2

WHEEL PATH Left

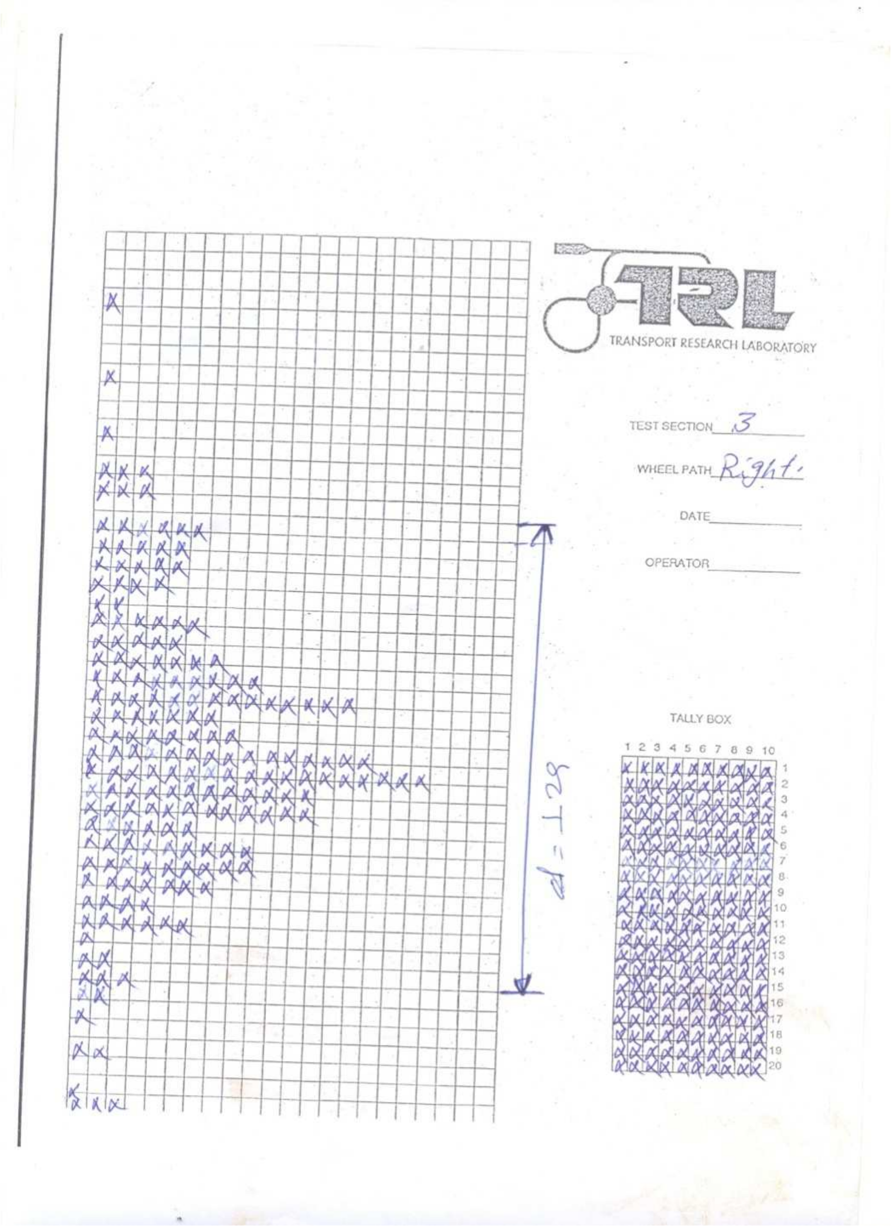
DATE 21-5-11

OPERATOR

D= [38*5+(2/6)*5]4.92*10/28.4

D=332mm

Section -3 Right



TRANSPORT RESEARCH LABORATORY

TEST SECTION 3

WHEEL PATH Right.

DATE

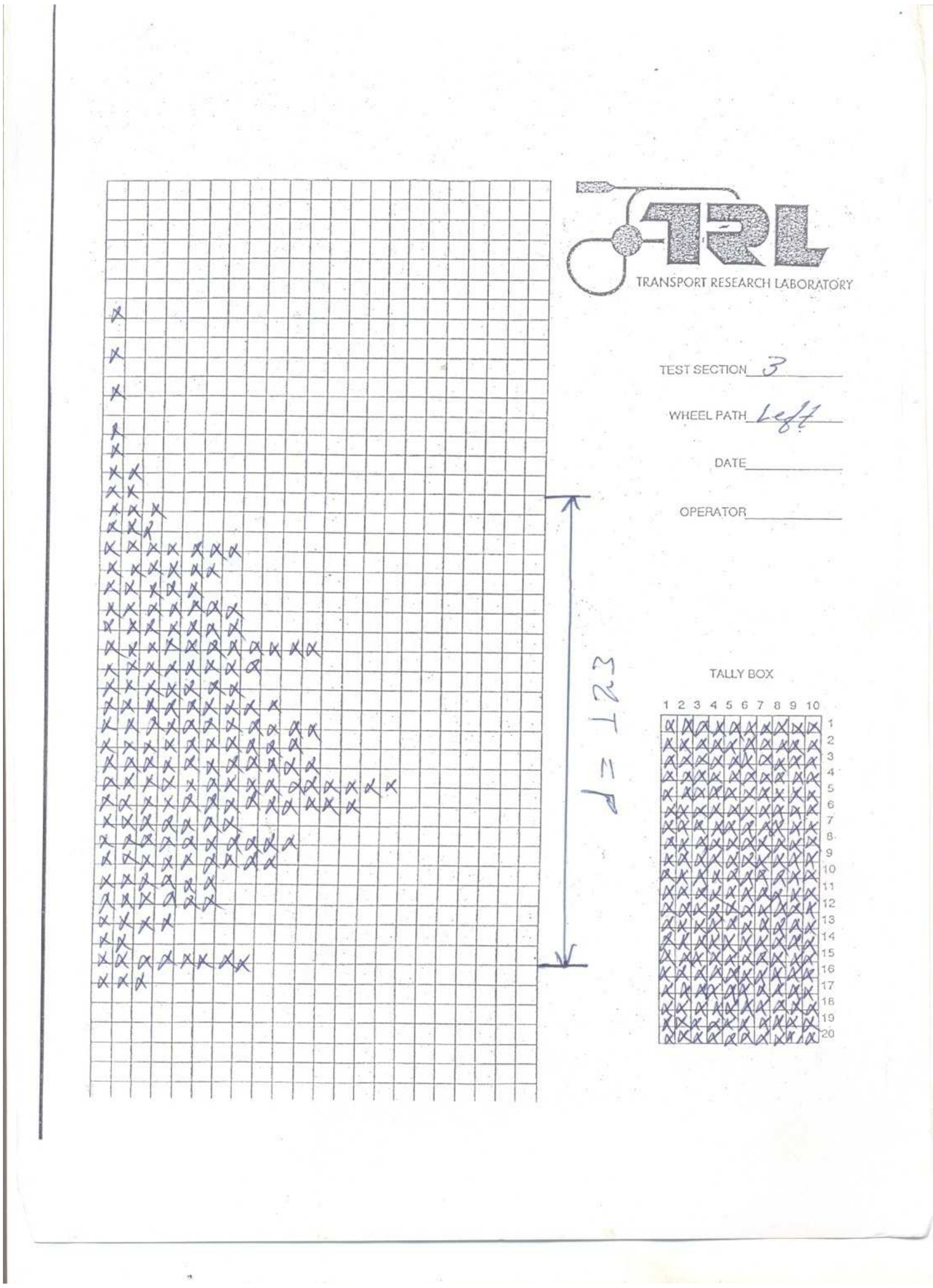
OPERATOR

TALLY BOX

D= [25*5+(5*5/6)]4.92*10/28.4

D=223mm

Section -3 Left



TRANSPORT RESEARCH LABORATORY

TEST SECTION 3

WHEEL PATH Left

DATE

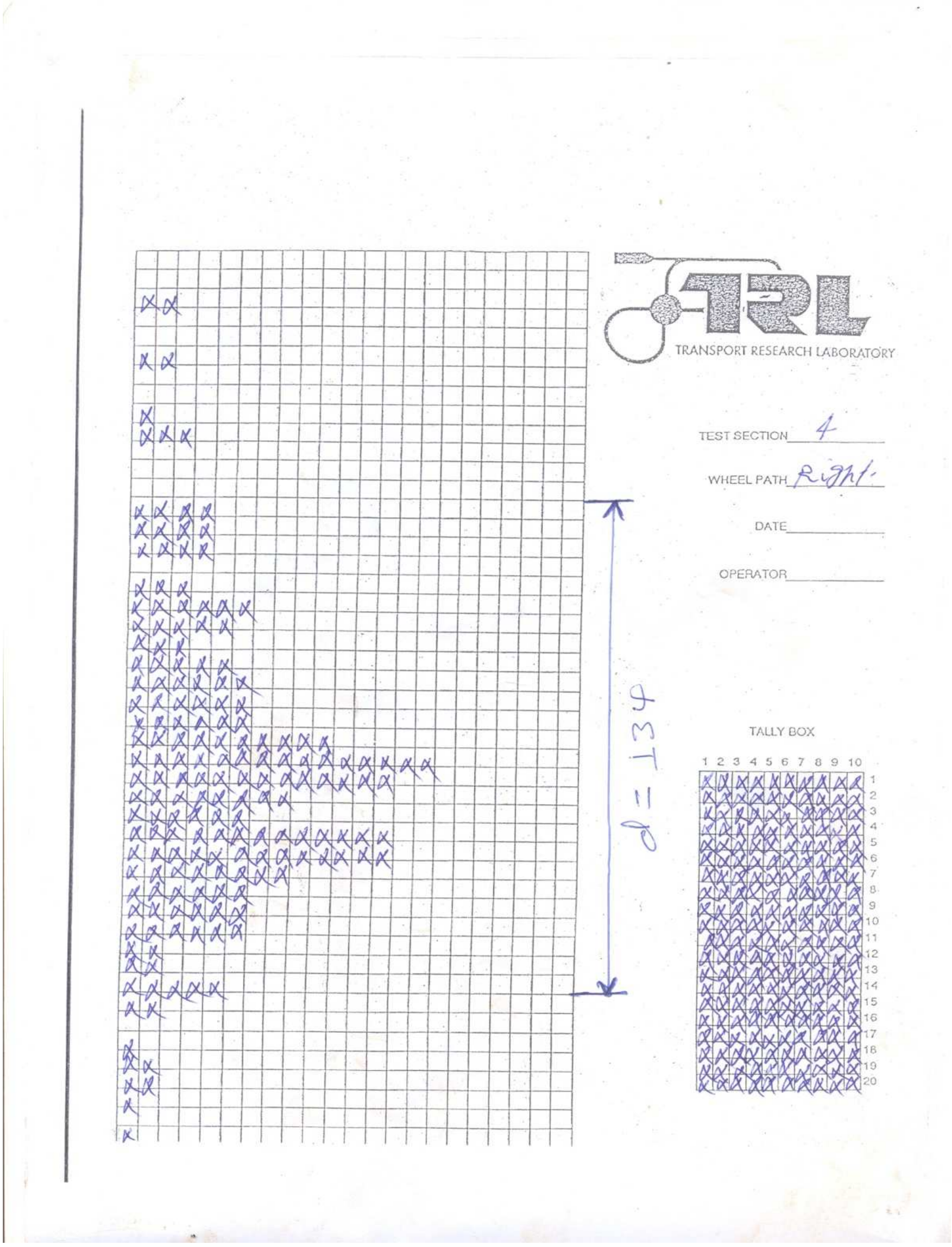
OPERATOR

TALLY BOX

D= [24*5+ (2*5/3)]4.92*10/28.4

D=213mm

Section -4 Right



TRANSPORT RESEARCH LABORATORY

TEST SECTION 4

WHEEL PATH Right

DATE

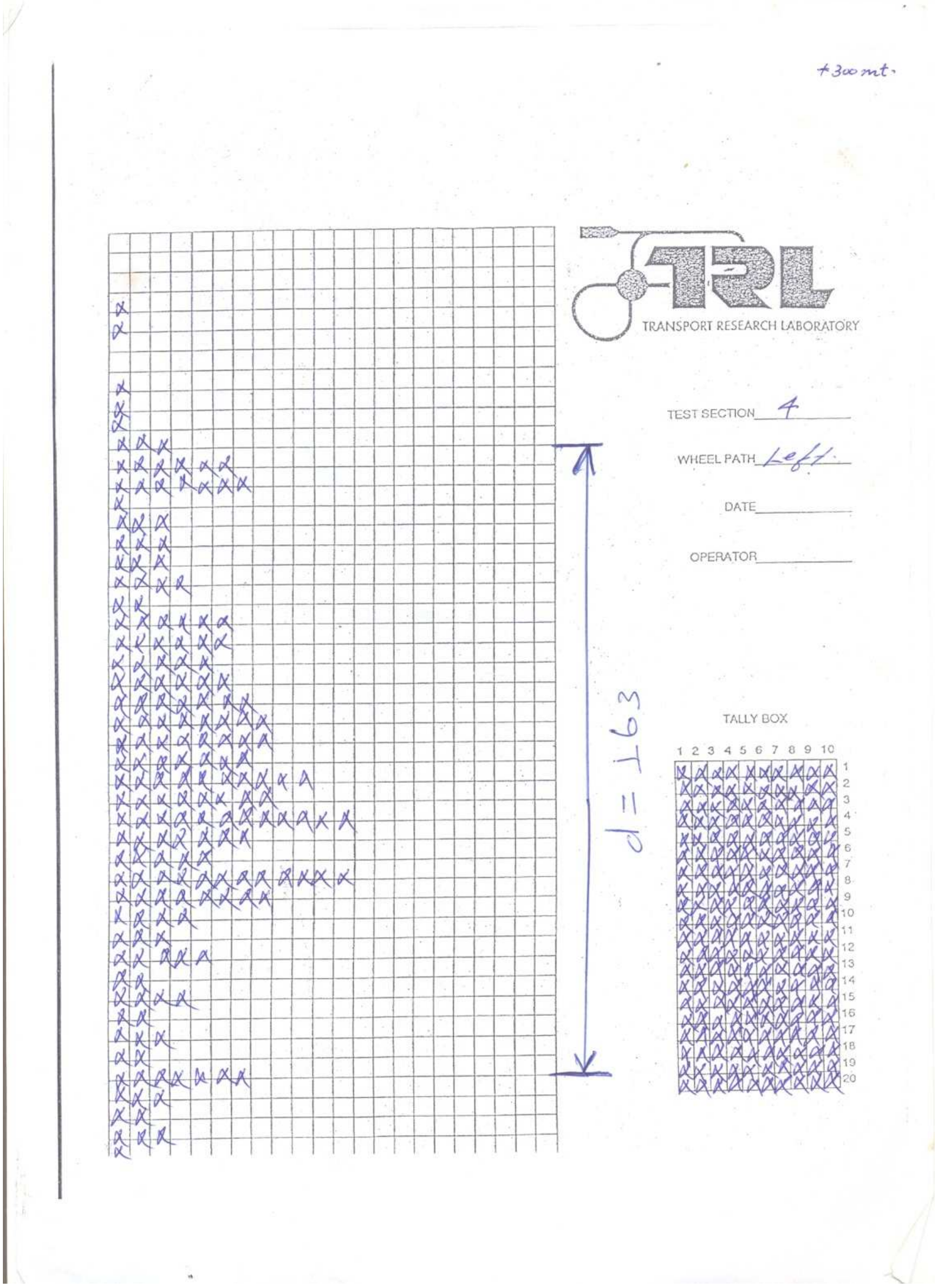
OPERATOR

TALLY BOX

D= [26*5+ (4*5/5)]4.92*10/28.4

D=232mm

Section-4 Left



+300 mt.

TRANSPORT RESEARCH LABORATORY

TEST SECTION 4

WHEEL PATH Left.

DATE

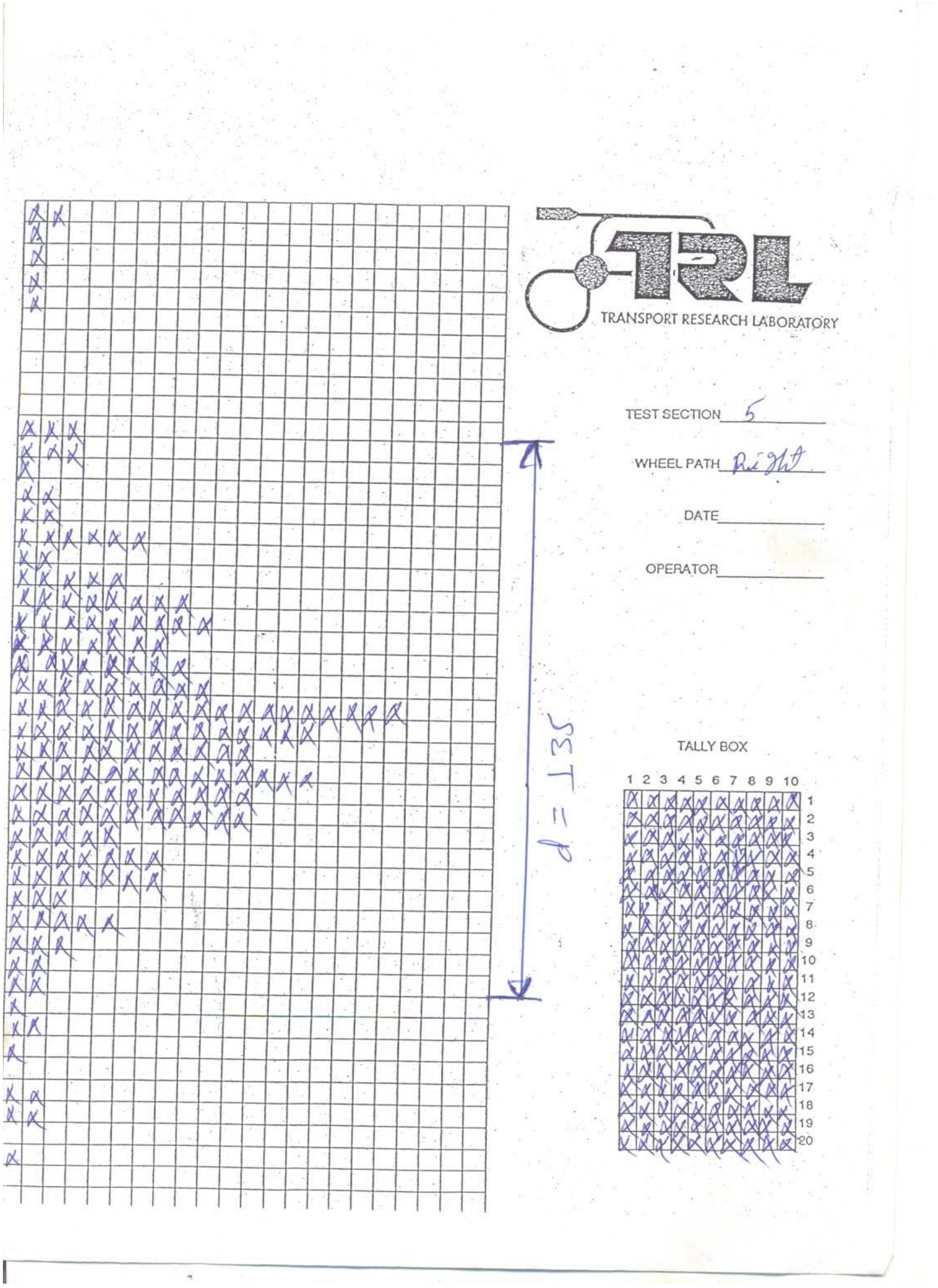
OPERATOR

TALLY BOX

D= [32*5+ (4*5/6)]4.92*10/28.4

D=282mm

Section -5 Right



TEST SECTION 5

WHEEL PATH Right

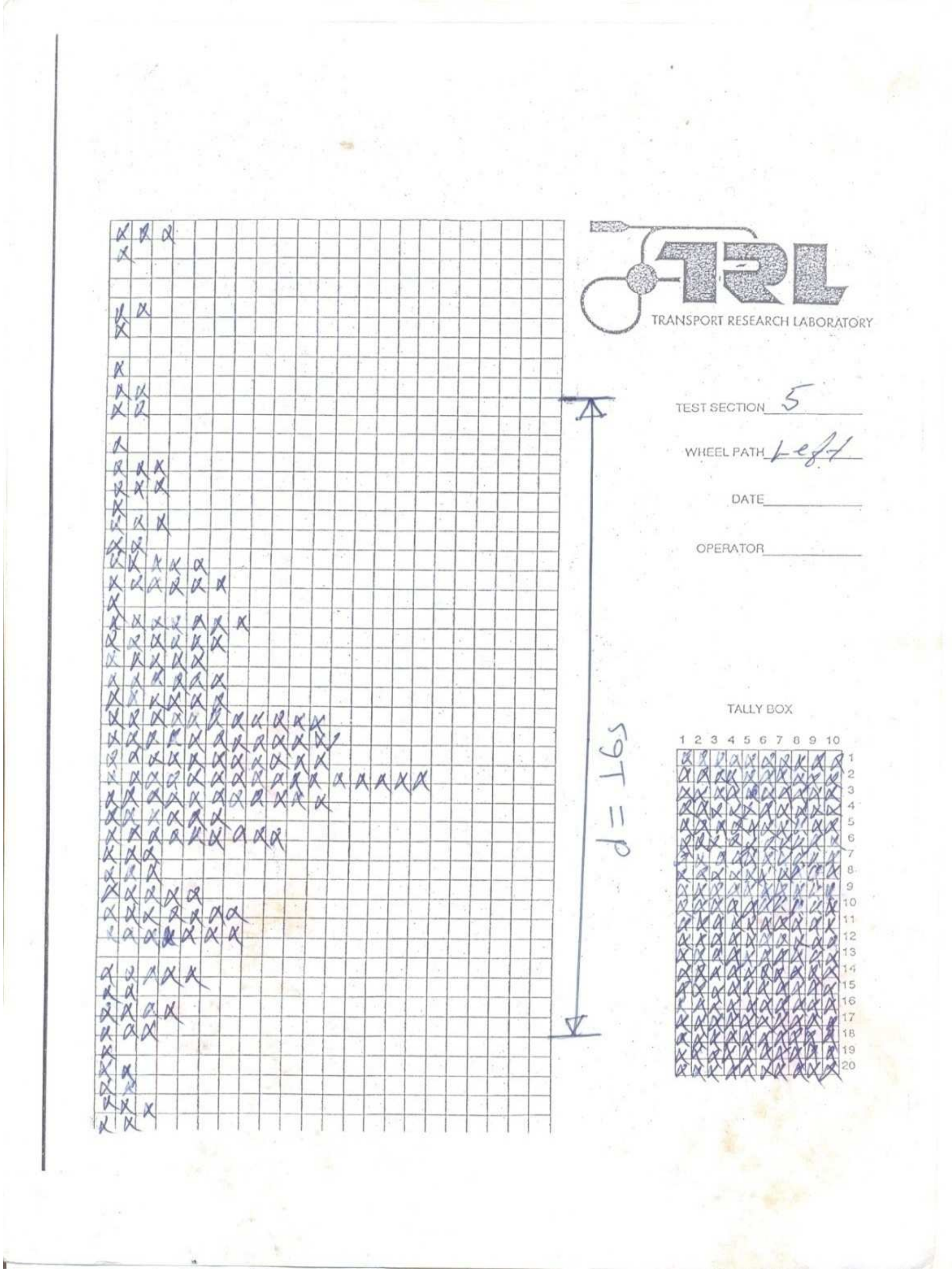
DATE

OPERATOR

D= [26*5+ ((2*5/3) +0.5*5)]4.92*10/28.4

D=235mm

Section-5 Left



TRANSPORT RESEARCH LABORATORY

TEST SECTION 5

WHEEL PATH Left

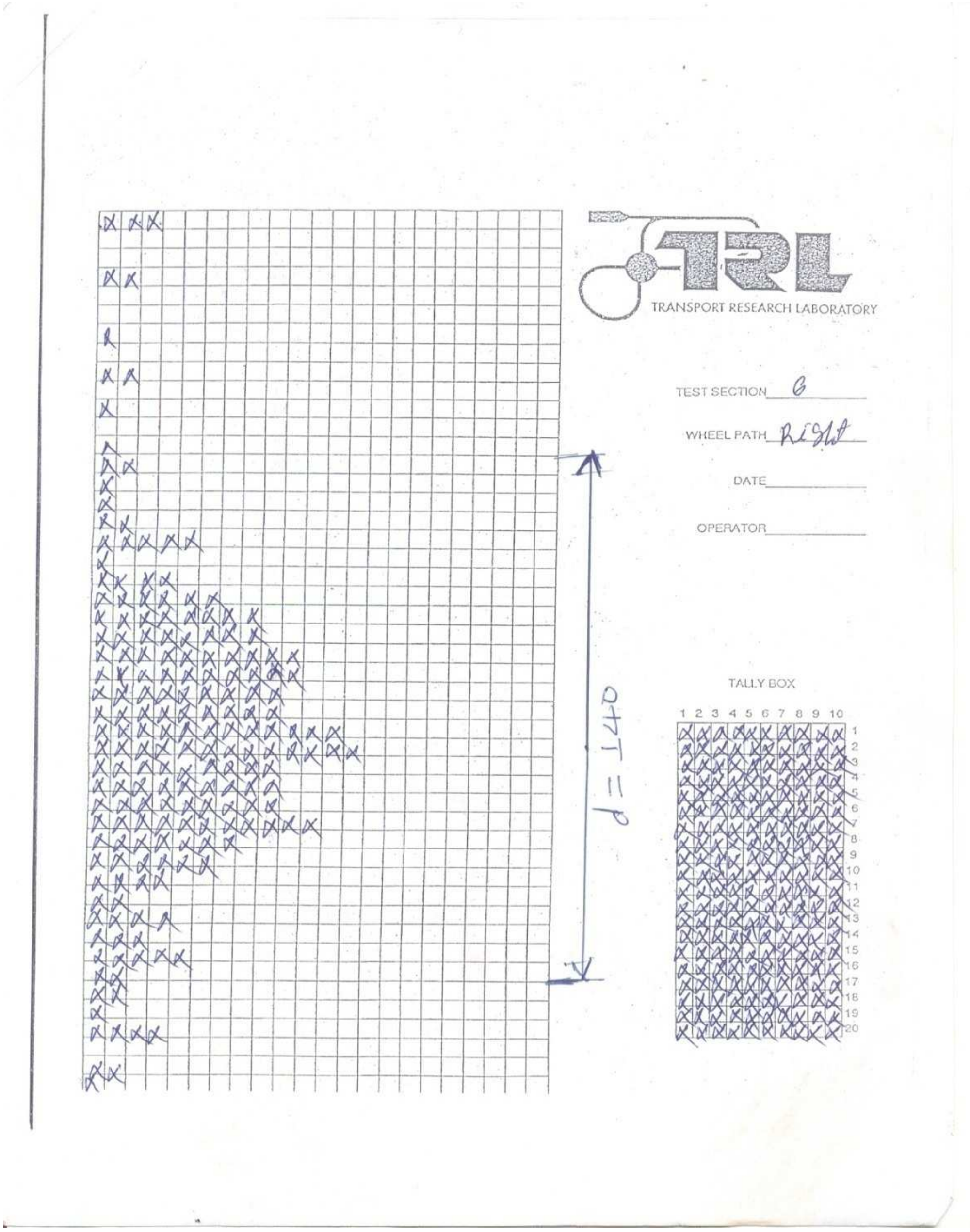
DATE

OPERATOR

D=[33*5]49.28*10/28.4

D=294mm

Section -6 Right



TRANSPORT RESEARCH LABORATORY

TEST SECTION 6

WHEEL PATH Right

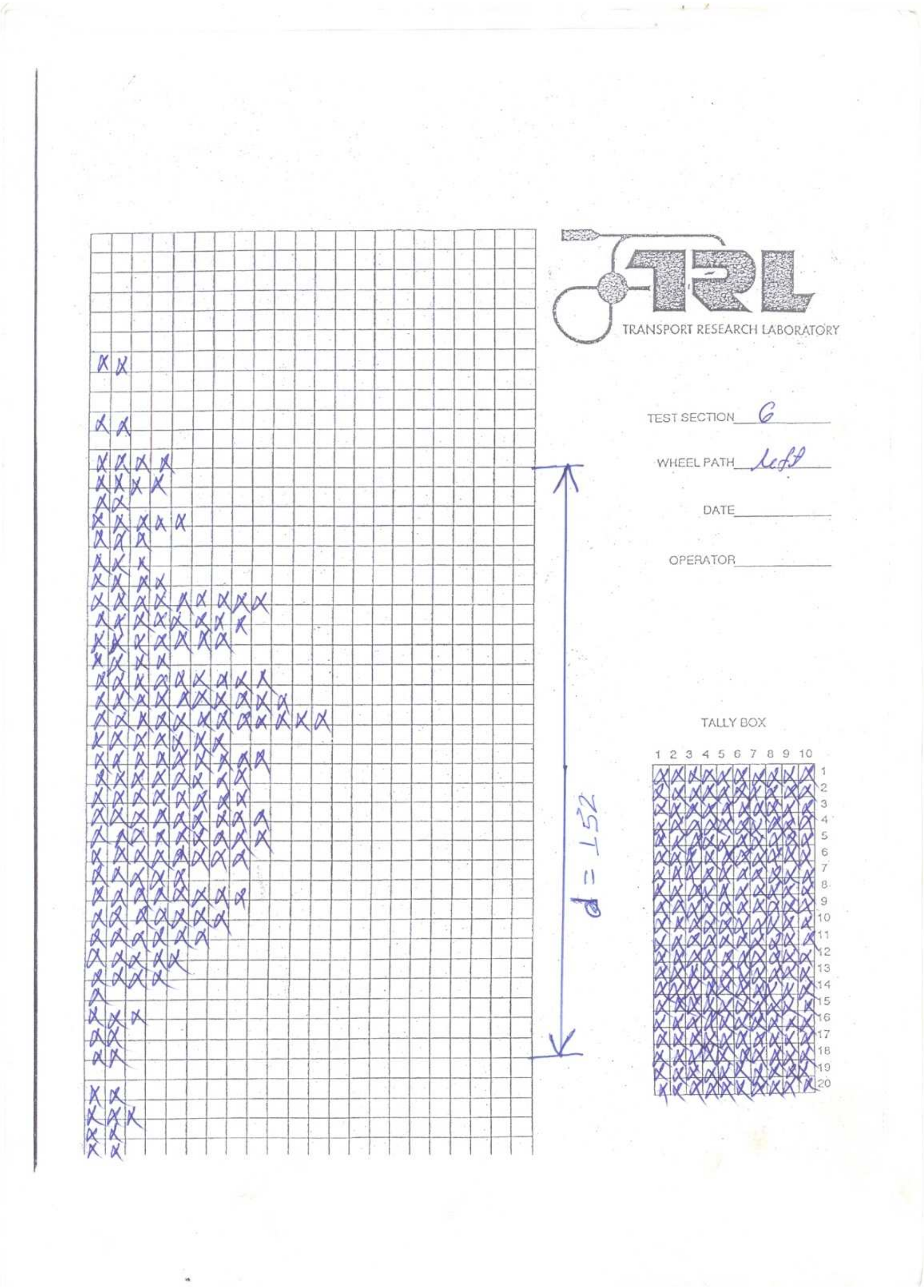
DATE

OPERATOR

D=[28*5]4.92*10/28.4

D=242mm

Section -6 Left


TRANSPORT RESEARCH LABORATORY

TEST SECTION 6

WHEEL PATH left

DATE

OPERATOR

TALLY BOX

D= [30*5+ (2*5/4)]4.92*10/28.4

D=264mm

Appendix B

Appendix-B:-Performance Indicator data measurement

Rutting measurement for each the six section along the study route

Rutting measurement for each section

Section – 1

Check list

No	station	Rut depth		Comment
		Unit	Qty	
		mm/m		
1	2+300	50/30	50mm/30m	
2	2+400	30/30	30mm/30m	
3	2+450	20/30	20mm/30m	

Rut measurement for section 2

Section -2

Check list

No	station	Rut depth		Comment
		Unit	Qty	
		mm/m		
1	4+600	15/30	15mm/30m	
2	4+700	20/30	20mm/30m	
3	4+725	12/30	12mm/30m	
4	4+800	10/30	10mm/30m	

Table B- 1: Rut measuring for section two at various station

Rut measurement for section 3

Section - 3

Check list

No	station	Rut depth		Comment
		Unit	Qty	
		mm/m		
1	7+200	13/30	13mm/30m	
2	7+300	40/30	40mm/30m	
3	7+350	64/30	64mm/30m	

Rut measurement for section 4

Section -4

Check list

No	station	Rut depth		Comment
		Unit	Qty	
		mm/m		
1	9+500	11/30	11mm/30m	
2	9+600	55/30	55mm/30m	
3	9+650	57/30	57mm/30m	
4	9+700	40/30	40mm/30m	

Rut measurement for section 5

Section -5

Check list

No	station	Rut depth		Comment
		Unit	Qty	
		mm/m		
1	15+400	20/30	20mm/30m	
2	15+500	17/30	17mm/30m	
3	15+600	15/30	15mm/30m	

Rut measurement for section 6

Section - 6

Check list

No	station	Rut depth		Comment
		Unit	Qty	
		mm/m		
1	25+000	13/30	13mm/30m	
2	25+100	6/30	6mm/30m	
3	25+150	9/30	9mm/30m	
4	25+200	7/30	7mm/30m	