THE PERFORMANCE OF MARGINAL GRAVEL MATERIALS USED FOR SURFACING GRAVEL ROADS: A CASE STUDY OF IRINGA REGION

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Abstract

This study on the performance of marginal gravel materials employed as surfacing materials for gravel roads was done by monitoring existing gravel roads surfaced with marginal gravel materials in Iringa region. Four gravel roads surfaced with marginal gravel materials in Iringa region were randomly selected in order to obtain empirical results that have general application in Iringa region and those regions experiencing the same climatic (moisture and temperature) seasons. To reduce the cost, the research was linked with existing gravel roads surfaced with marginal gravel materials. A minimum number of six and maximum of eight trial sections of 300 m length on each selected gravel road were established and monitored for a period of three years (2011-2013 inclusive). The performance was measured and quantified in terms of distress noted during condition survey with particular reference to gravel loss. The gravel loss and type of distress prevalent on trial sections were correlated with average daily traffic volume, marginal gravel material's physical characteristics, and climate. The measurement of gravel loss was based on optical levelling, while that of distress was done through visual inspection. Tests on marginal gravel materials comprised of grading and Atterberg limits. The study came out with a gravel loss prediction model. It was noted that, the rate of gravel loss and distress noted on each trial section depended on the quality of construction, maintenance input, daily traffic volume, material's physical characteristics, and the geological type of marginal gravel materials used as the wearing course. Careful selection of marginal gravel materials at the source and appropriate maintenance methodology addressing attributes of distress is necessary to obtain satisfactory performance of the gravel roads networks in Tanzania. Finding of the study can be used with other findings in similar studies conducted in Tanzania to draft appropriate local marginal gravel materials specifications for surfacing gravel roads which should then be subjected to more empirical study for fine tuning.

Keywords: *Marginal materials, gravel loss, prediction model, distress survey, performance, gravel roads*

1.0 INTRODUCTION

Majority of natural gravel materials readily available worldwide, including Tanzania are marginal, which imply they do not comply with the existing specifications adopted for ideal gravel materials for surfacing gravel roads with regard to particle size distribution and Atterberg limits (Taseni 2000:1). Experience from studies conducted in South Africa, Brazil and United States of America to mention just a few countries, have shown that gravel wearing course materials for unsealed roads which conform to existing empirically formulated specification give good performance. Nevertheless, similar studies conducted in South Africa found that gravel materials which were not conforming to those specifications also gave better performance. Therefore, strict adherence in selecting gravel materials which conform to specification derived from one region without correlating with the local performance in the field may results in the rejection of marginal gravel materials which may perform as well as those meeting specifications. Rejection of marginal gravel materials, which are locally available, may lead to expensive pavements. For the sake of sustainability of gravel roads, there is a need of continuous studies to map out appropriate characteristics of marginal materials for local use as wearing course of gravel roads.

1.1 Deterioration Concepts

1.1.1 Serviceability

Serviceability is an indication of the riding quality of a pavement (Visser 2008:16). Serviceability of a pavement usually decreases with time. The rate of deterioration depends on the pavement type, climate (temperature and moisture) and loading conditions. Figure 1 shows typical deterioration cycle of gravel roads. The rate of deterioration can be checked out by appropriate intervention program, derived through performance studies of gravel roads in question.

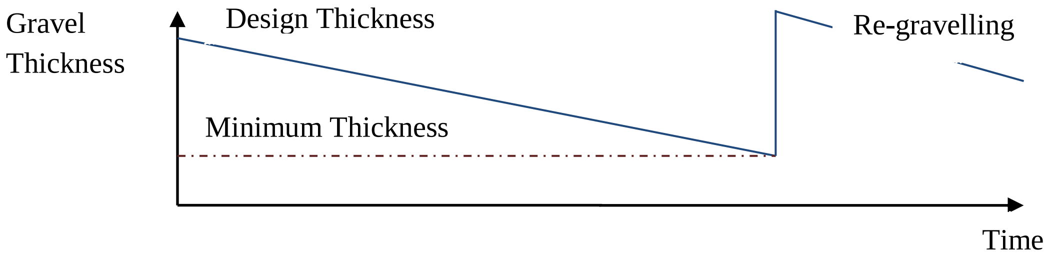

Figure 1: Deterioration cycle of gravel wearing course thickness (Source: Paterson 1991:144)

1.1.2 Pavement performance

Performance of a pavement is measured in part by an indication of user satisfaction. Performance is often also taken as the accumulated serviceability (Visser 2008:19). Pavement performance for gravel roads refers to how well the gravel materials employed as surfacing layers interact with stresses and strains imparted by environment and traffic loads.

1.2 Statement of the Problem

Most gravel materials used in surfacing gravel roads in Tanzania are marginal gravel materials, which mean they do not meet existing gravel wearing course specification. Although Tanzania has in place specifications for these materials but to a large extent these specifications are based on the South African ones, and hence do not reflect reality. In order to address locally available gravel materials according to their appropriateness as wearing course materials for gravel roads there is a need to establish specifications for these materials based on actual quality of construction works, impact of traffic spectrum and environment on finished works, and subsequent maintenance activities. All these can only be captured through performance studies.

1.3 Gravel Materials Employed to Surface Gravel Roads

Gravel roads consist of a single or multiple layers of gravel materials, marginal or standard, depending on the stiffness of subgrade (roadbed). Design requirement of these roads is determination of appropriate thickness of surfacing layer to protect the roadbed from adverse effect of traffic loads and weathering. Pavement of gravel layer thickness must be capable of bearing the direct traffic loads and to spread the load so that the subgrade is not over stressed as shown in Figure 2. The layer should contain enough fines to bind coarse particles together so that the pavement does not deform or abrade in the dry season, while too many fines may make the road surface slippery when wet.

The adequate field performance of gravel materials, marginal or standard, depends on three characteristics which are grading, plasticity, and particles interlocking strength (Taseni 2000:6).

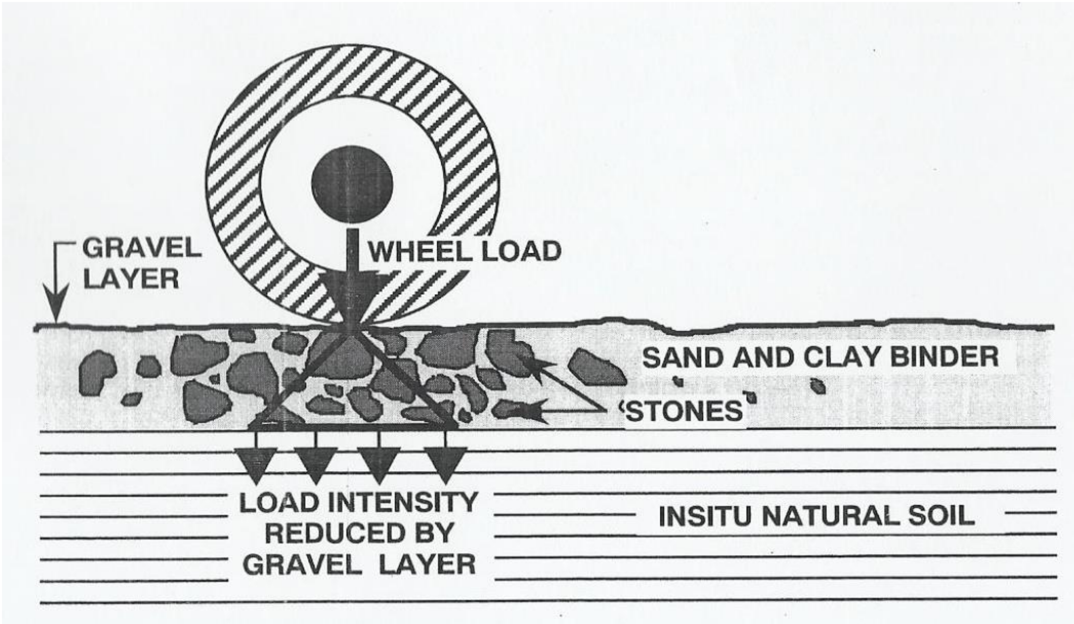

Figure 2: Function of gravel layer pavement (Source: Anderson, Beusch, and Miles 1996:8)

An ideal wearing course for unsealed roads should have the following attributes (Paige-Green and Netterberg, 1987, 1988).

- Ability to provide an acceptable smooth and safe ride without excessive maintenance (i.e. free from corrugation, potholes, ruts and oversize material)
- Stability, in terms of resistance to deformation under both wet and dry conditions (resistance to rutting and shearing).
- Ability to shed water without excessive scouring.
- Ability to resist abrasive action of traffic and erosion by water and wind.
- Ability to resist generation of excessive dust in dry weather.
- Have surface that is not excessively slippery in wet weather.
- Low cost and ease of maintenance.

The performance of gravel roads is evaluated based on the following criteria (Watanatada *et al.,* 1987; Jones, 1984; Beaven *et al.,* 1988; Paige-Green and Netterberg, 1987):

i) Resistance to deformation, ii) Rate of gravel loss (GL), iii) Deterioration of riding quality, and iii) Looseness of the surface material.

The above factors are based on the physical characteristics of gravel material, traffic loading and climate.

Gichaga and Parker (1988) noted that in spite of carrying out materials tests and ensuring that the road is constructed according to specification there are occasions where roads still fail. This implies that parameters tested are not sufficiently comprehensive to yield a satisfactory performed pavement. There is thus a need to monitor road behaviour regularly and address those areas of concerns so as to improve reliability of the expected behaviour of gravel roads based on tests carried out during design stage.

2.0 PERFORMANCE STUDY METHODOLOGY

Two approaches can be used to study performance of existing roads. First, complete deterioration history of samples of gravel road test sections can be obtained by monitoring the sections from the time of initial construction and maintenance to their ultimate failure. The second approach is to sample existing gravel road population at any instant of time, and to include in the sample a representative collection of roads at different states of their design lives. In this study, the combinations of both approaches have been used to take advantage of their merit. The study was done through: Road condition survey, Gravel loss survey, Traffic volume, Laboratory testing of gravel materials, collection of climatic data and modelling gravel loss.

2.1 Road Condition Survey

A detailed description of the visual condition survey of each 300 m long test section, randomly selected from four gravel roads under study was carried out during each site visit unless the section was wet or had recently been graded. For wet sections, which occurred during the rainy season, only drainage, slipperiness and trafficability were recorded. Three gravel roads are under the management of TANROADS Iringa region (Figure 3) and one is under Iringa Municipal Council.

Figure 3: TANROADS Iringa regional three roads selected for the study (Iringa-Kilolo, Iringa-Pawaga and Iringa-Msembe)

2.2 Gravel Loss

Gravel loss was estimated by monitoring changes in the elevation of the cross-section profile of the gravel road carriageway. Monitoring was made between each pair of pegs placed every 20 m along the test sections. At each cross-section, the spot height was measured at 25 cm intervals using the rod and level. The 25 cm intervals were marked around a 2 mm diameter nylon string using masking tape.

The width of the carriageway was determined at each test section. The average reduced level across the defined width was used to estimate the height of the gravel wearing course at each test section. The same defined width of a cross-section was used throughout the monitoring period. The change in the average height of the carriageway between surveys was used as the indicator of change in gravel loss. The changes were monitored after grading.

2.3 Laboratory Tests

Laboratory tests to determine characteristics of gravel materials taken from the borrow pits used for surfacing the unsealed roads under study were conducted according to Tanzania`s Central Materials Laboratory (CML) procedures. These tests are referred to in the TZ-MoW (2000a:2-16). Tests conducted were particle size distribution, and Atterberg limits (BS 1377: Part 2: 1990 cited in TZ-MoW 2000a: 2-16).

2.4 Traffic Volume

In order to evaluate relationship between traffic volume, climate and gravel road performance it is important to know the traffic volume traversing the test sections (Mwaipungu 1999:39). In addition to that, knowledge on the interaction between vehicles and the gravel wearing course is also required to map the gravel materials' performance.

The knowledge of these interactions once acquired and translated into action balances both vehicle and gravel road design. The end result is in minimisation of gravel road deterioration and finally total transport costs.

To establish traffic volume traversing test sections, manual classified traffic counts were carried out near or between or at each test section.

2.5 Rainfall, Temperature and Relative Humidity Data

Data on rainfall, air temperature and relative humidity which cover Iringa region climate were obtained from TMA Iringa regional office. These data covered monitoring period of this study.
For the purpose of pavement design, the climatic condition of Tanzania is grouped into three zones (TZ-MoW1999:2.2), namely wet, moderate and dry. The demarcation is based on the number of months per annum where rainfall is higher than evaporation

2.6 Modelling Approach

The basic framework for analysing determinants of a gravel loss prediction model in this study was a panel data regression model.

According to Cameron and Trivedi (2010:257) the best method to obtain a consistent estimator is to use a population average (PA). Population regression states that the expected value of the distribution of GL (dependent variables) is functionally related to independent variable. In simple terms, it tells how the average response of GL varies with independent variables (Gujarati 2014:666). Thus the final gravel loss prediction model, took the form shown in Equation 1.

3.0 DATA ANALYSIS

3.1 Particle Size Analysis for Coarse and Fine Grained Soils

According to McCarthy (2007:40) particle size and shape are factors that have been found to be related to, or affect the material behaviour of, soil, to a certain degree. Soils with similar particle size distribution curves would, in a general sense, be expected to show similar engineering characteristics. This remark is supported by Scott (1980:9) who asserts that from the shape of grading curve, it is possible to classify coarse-grained soils and to make an estimate of their engineering properties, although predictions of soil behaviour based on particle size distribution curves should be made cautiously. This is due to the fact that laboratory-based particle size distribution curves do not convey the arrangement, particle shape, and packing density of the in-situ soil. According to Paige-Green (1989:6.3-6.4) grading analysis of the same type of gravel materials, marginal or otherwise, but in different locations, will vary considerably depending on the conditions and stage of weathering.

O`Flaherty (2002:100) noted that results of particle size analysis are of most value when used for soil classification purposes; further use of the results should be treated with care unless verification by performance studies permits empirical relationships to be formulated. In this study, the analysis of gravel particle size distributions was used as one of parameters to formulate a gravel loss prediction model, and to assess performance relationship of gravel materials used as gravel wearing course.

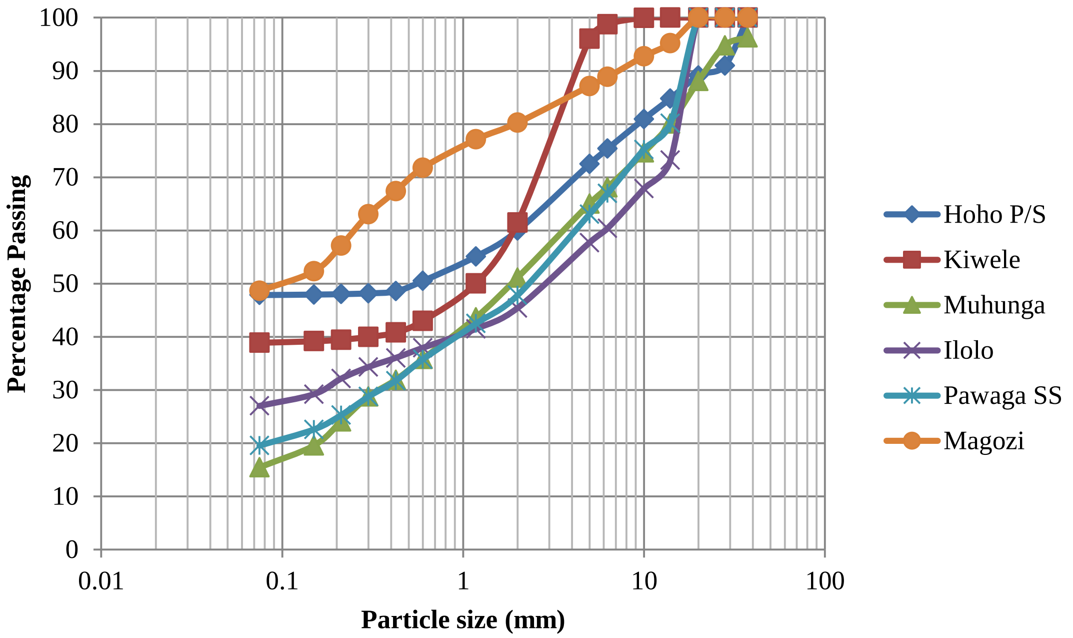

Figure 4: Typical particle size distribution curve for marginal gravel materials

Figure 4 reveals that all six gravel borrow pits materials along the Iringa–Pawaga gravel road pass through a 37.5 mm sieve by 100%. This is above the minimum of 95% given by TZ-MoW (1999:11.3) and TZ-MoW (2000b:3000:24) for marginal materials to be employed for surfacing unsealed roads. It should be taken therefore, that Figure 4 is typical results of particle size distribution for all gravel borrow pits deployed to surface the gravel roads under study, namely Iringa – Msembe, Iringa – Idete, Iringa – Pawaga and Don Bosco road in Iringa municipal council.

From the study of gravel materials samples taken from borrow pits under study it was noted that gravel materials with a high fine fraction will in general have a grading modulus (GM), value of less than 2.0, while gravel materials with a low fine fraction will have a GM value of more than 2.0. According to TZ-MoW (1999:7.4) and TZ-MoW(2000b:3000-23) GM is defined as 300 minus cumulative fractions of materials passing sieves of nominal aperture size of 2.0, 0.425, and 0.075 mm divided by 100.

3.2 Traffic Volume

The estimated 24-hour classified traffic volumes on each site showed that light traffic volume ranged from 30-366 vehicles per day (vpd), with the average of 122 vpd. Heavy traffic volume ranged from 9-47 vpd, with the average of 26 vpd. The total average daily traffic (ADT) volume was 149 vpd

3.3 Atterberg Consistency Tests

Consistency is that property of a soil which is manifested by its resistance to flow (O`Flaherty 2002:101). In about 1910, Swedish soil scientist Albert Atterberg suggested that soil consistency should be described by arbitrarily dividing a soil`s cohesive range into six stages and expressing the limits of each range in terms of moisture content. Amongst these limits, liquid limit (LL), plastic limit (PL) and the shrinkage limit (SL) are the most favourable for highway and soil engineers.

A value, usually used in conjunction with the LL and PL is the plasticity index (PI). The PI of a soil is the arithmetic difference between the LL and PL; in other words, it is the range of moisture content over which the soil is in a plastic state (Garber and Hoel 2014:905). Plasticity would vary considerably for the same type of gravel materials depending on the condition and stage of weathering (Paige-Green 1989:6.3-6.4).

According to Naidoo and Purchase (2001) gravel materials with a PI of less than 6 lack sufficient plasticity to be effective gravel wearing materials. Table 1 shows values for the plasticity characteristics of gravel surfacing materials typically specified for different climatic zones as per Ellis (1979:5).

Table 1: Plasticity characteristics preferred for gravel surfacing materials (Source: Ellis 1979:5)

Climate	LL (Not to exceed a specified value) (%)	PI ranges (%)	Linear shrinkage range (%)
Moist temperate and wet tropic	35	4-9	2.5 -5
Seasonally wet tropical	45	6-20	4-10
Arid or semi-arid	55	15-30	8-15

Summaries of descriptive analysis of Atterberg limits tests of gravel materials from borrow pits used for surfacing gravel road test sections under study are presented in Table 2.

It should be stressed here that, the PI is basically an indication of the moisture susceptibility of the gravel materials; with a high value indicating susceptibility. However, studies on Australian pavement materials have found no correlation between PI and pavement performance (Lay 2009:112). According to the study, it is better to understand general characteristics of a material than to rely on the PI value alone.

Table 2: Summary of descriptive analysis of Atterberg limits data

Parameters	Average	Standard deviation
Liquid Limit (LL) (%)	34	8
Plastic Limit (PL) (%)	22	5
Plasticity Index (PI) (%)	12	3
Shrinkage Limit (SL) (%)	7	2
Shrinkage Product (SP)	247	116

3.3 Derivatives of Atterberg Limits and Particle Size Distribution

3.3.1 Shrinkage product

Shrinkage Product (SP) is the product of shrinkage limit and materials passing through a 0.425 mm sieve. According to TZ-MoW (1999:11.4) , as depicted in Figure 5 , ideal SP for marginal gravel materials to be used for surfacing gravel roads should range between 120 to 270 inclusive, SP between 0 and 120 indicates a material that may ravel and corrugate whereas between 270 and 400 indicates material that may be good but dusty. SP of most of the marginal gravel materials sampled ranged from 120 - 400, with only 4 samples out of 31 outside the range. This implies that 87.1% of sampled marginal gravel materials qualify in terms of SP.

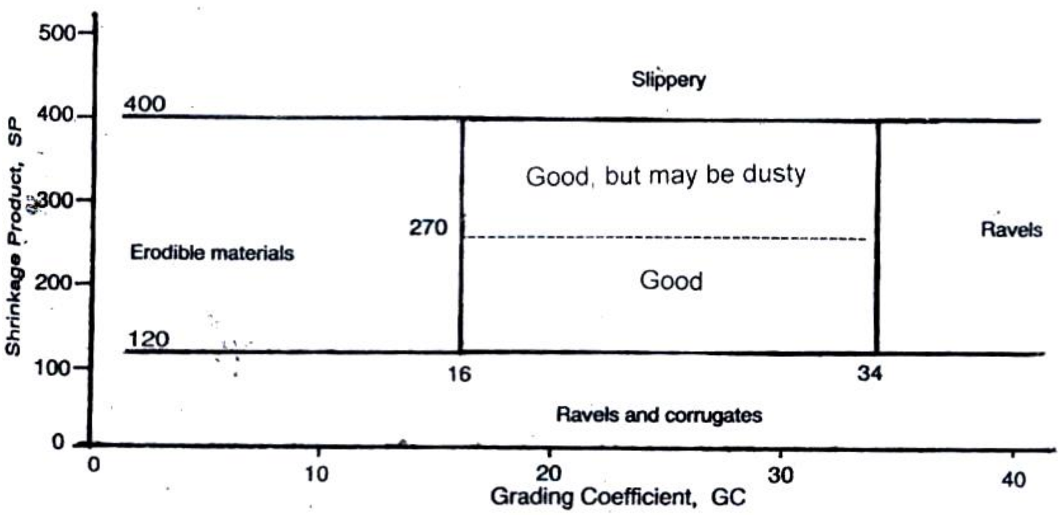

Figure 5: Performance specification for marginal gravel wearing course (Source: TZ-MoW 1999:11.4)

3.4 Visual Condition Survey

Visual assessment is the most applicable method for determining the performance of gravel roads. The survey can be employed to determine re-gravelling requirements, grading frequencies, whether the gravel material on the road is suitable for the prevailing traffic characteristics and environment, and what type of distresses are typical on the gravel road in question (Jones and Paige-Green 2011:1). Following are the attributes of gravel road distress and brief discussion on the results of visual condition survey.

3.4.1 Attributes of gravel road distress

The appearance of gravel road distress is varied and often extremely complex. In this study, the task of describing distress was achieved by recording its main characteristics – the so-called attributes of distress. The attributes referred to are: i) type, ii) degree, and iii) extent.

i) Type of distress: Common types of distress encountered on gravel roads under study included, but not limited to: gravel loss; potholes; rutting; erosion; corrugation; loose materials; stoniness; and dust.

ii) Degree: The degree of a particular type of distress is a measure of its severity. The degree recorded gave the predominant severity of a particular type of distress. The most important categories of degrees are 1, 3, and 5 as noted in Table 3, and

iii) Extent: The extent of distress is a measure of how wide spread the distress is over the length of the road segment.

Table 3: Classification of road condition severity in terms of degree of distress (Source: Jones and Paige-Green 2011:2)

Descriptor	Very good	Good	Fair/ Average	Poor /Bad	Very poor
Degree	1	2	3	4	5

3.4.2 Visual assessment of the condition and performance of gravel roads

The current condition of distress of each test section was assessed by walking along the test section and observing type, severity and extent of distress.

3.4.3 The condition survey results of test sections under performance study

The following is the general state of distress conditions on 22 test sections. Acceptance criteria for distress condition quantifications are as documented by Jones and Paige-Green (2011:6).

(i) **Slipperiness and skid resistance** were at acceptable levels on all 22 test sections.

(ii) **Trafficability** was unacceptable at Ndiwili and Itwanga test sections on the Iringa-Idete road. On the rest of the test sections, the trafficability was acceptable.

(iii) **Drainage from the road** was ranged from poor in those test sections with flat and uneven cross sections to average in those test sections with good cross-section. Only one road, that is Don-Bosco road, had its surface drainage in poor condition.

(iv) **Quality of marginal gravel materials** employed as wearing course ranges from good to average. In this regard, the sections on each road fared as follows: Iringa-Pawaga - six sections had average quality and two had good quality; Iringa-Msembe - three sections had average quality and five sections had good quality; and Iringa-Idete - five sections had good quality, and three sections had average quality. Quantification was bases on extent of cracking, loose materials, particle size distribution, and sizes of stones as being noted on wearing course,

(v) **Gravel quantities** which signify gravel loss were sufficient on all test sections, except at Kidete, Mapinduzi, and Muhunga on the Iringa-Idete road, and Mwika B on the Iringa-Msembe road where the quantities were at isolated exposure levels.

(vi) **The riding quality/safety** during the study was good as the vehicles on almost all test sections could ride at 60 km/h, except on sections with poor trafficability (Ndiwili and Itwanga), the speed ranged from average to poor (50-20 km/h).

(vii) **Tranverse and longitudinal erosions** at Igotikafu along the Iringa-Pawaga road the severity was at 3 degree. The Iringa-Msembe road had three test sections, which fared badly on erosion, namely Mangalali which had transverse erosion severity at 3 degree, while Mwika B and Nyamihuu, had longitudinal erosion severity of 4 and 3 degree respectively. The rest of the test sections on all three roads under study fared well due to being on self-draining terrain.

(viii) **The gravel road's performance**s of all test sections were at 3 degree of severity, which is the border line between good and bad condition.

4.0 DISCUSSION OF MARGINAL MATERIALS SPECIFICATION ADOPTED IN TANZANIA

The specification adopted in Tanzania for marginal gravel materials in terms of grading coefficients and shrinkage product is presented in Figure 5. In general, test results of GC for all the marginal gravel materials borrow pits employed to surface test sections did not meet the requirement set out in Figure 4, as per TZ-MoW (1999:11.4). Despite not meeting the stated specifications, these materials performed relatively well as noted during the condition survey. It should be brought to attention that Figure 4 is based on South African research conducted in the nineteen eighties and reported by Paige-Green (2006:2) with slight changes.

The South African gravel road specifications were developed from roads selected using factorial design, including material types, traffic, and climate and covered a wide range of environmental conditions.

The South Africa specification has an SP range from 100-365, and GC range from 16-34. This proves further the danger of adopting directly the specification employed in other countries without doing adequate local calibration through empirical research.

From the above it is sufficient to mention here that there is a need to adjust the window frame of GC for the marginal materials as none of the distress associated with gravel materials by not meeting the given range as shown in Figure 4 were observed during the condition survey. The range for the Msembe road was 36-72, the Pawaga road was 23-62, and the Idete road 31-49. This study recommends a GC range from 23-72 for marginal materials, as it is more accommodating for all the marginal gravel materials used to surface gravel roads covered by the study.

5.0 GRAVEL LOSS DATA ANALYSIS

Gravel loss constituted by far the largest data set for test sections. Profile heights were taken at 25 cm interval over a 6 m cross-sectional width at an interval of 20 m along a 100 m long site. This equated to 150 readings on one site during each site visit. In total 23,100 profile heights from the 7 surveys conducted at 22 sites were recorded.

5.1 Rate of Gravel Loss

The height of the gravel road wearing surface at each cross-section was estimated by taking the average of the readings over the carriageway width at the cross-section. The average height of the site was then determined by taking the average of the 11 cross sectional heights. The gravel loss on each site was then determined by comparing the average height of the site from each previous survey.

Minimum average gravel loss during the entire period of study was 3 mm and the highest was 73 mm. The mean of this huge variation was 24 mm. This result is somehow similar with the one obtained by Paige-Green (1989:6.13), where predicted annual gravel losses ranged from 4.5 mm for a lightly trafficked , fine grained, low plasticity material in a dry area to about 65 mm for a cohesive, coarsely graded gravels under high traffic in a dry area. The study did not produce consistent range of gravel loss; this might be attributed to either marginal gravel material characteristic or inconsistency in the quality of work output during construction and maintenance activities.

5.2 Gravel Loss Threshold

Annual rate of gravel loss peculiar to study area is a tool to determine a threshold on which to peg the timing of grading or re-gravelling cycles (Patterson 1991:143; Dierk 1992:82). The rate can also be employed as a tool for quality control.

Table 4: Gravel loss thresholds

Rating level		Annual gravel loss (mm)	Severity of distress
1	Very good	27	GL is not noticeable to road user
2	Good	34	GL is slightly noticeable
3	Fair/Regular /Moderate	45	GL is noticeable
4	Poor/Bad	67	Isolated exposures of subgrade
5	Very poor/Very bad	80	Extensive exposures of subgrade

Based on the result of gravel loss survey, the gravel loss threshold proposed by this study as an indicator of the quality of construction, rehabilitation and marginal gravel material characteristics is as shown in Table 4. It should be borne in mind that gravel loss is inevitable, and is one of major characteristic of gravel roads. This is confirmed by Morris (1990:196), who assert that the abrasion of gravel materials from gravel roads is to be expected.

Gravel loss thresholds as proposed in Table 4 is based on a five-year life cycle of properly managed gravel road with initial pavement thickness of 150 mm and residual thickness of 15 mm at the end of design life. Rating levels 1 and 2 are for well-designed and constructed gravel roads, while rating 3 is for fairly-constructed gravel road. Rating levels 4 and 5 are for poor constructed gravel roads. Poorly constructed gravel roads are affected by initial compaction effect. This was noticed on the Muhunga section, along Iringa-Pawaga road, which was re-gravelled and experienced initial rapid gravel loss after being opened to traffic. Similar experience was noted by Paige-Green (1989:6.13), and was attributed to inadequate compaction during construction. It should be stressed here that only gravel roads with gravel loss rating 1 and 2 will attain the five years design life before being rehabilitated.

5.3 Gravel loss modelling

Modelling exercise of gravel loss is based on the methodology as explained in section 2.3. The modelling Equation 1 is as per Cameron and Trivedi (2010:257).

Equation 1: $GL = [0.113 + 0.000000694\,ADT + 0.0000135\,PF - 0.124DR - 0.169PM + 0.000229PP - 0.0144D_1]$ **mm**

Where GL is the annual gravel loss in mm, ADT is average daily traffic in both directions, PF is plasticity factor in percentage, DR is dust ratio, PM is plasticity modulus in percentage, PP is plasticity product in percentage, and D_1 is a dummy variable which represents climatic condition. D_1 = wet climate, and D_0 = dry or moderate climate.

Gravel roads located in wet area experiences a GL of about 0.0144 mm less than the roads located either in moderate or dry areas if all other factors remain constant. The GL is statistically significant at 1% and its coefficient of determination (r^2) is 0.3.

6.0 CONCLUSION AND RECOMMENDATION

1. Climatic data were all collected from one meteorological station, stationed at Nduli airport in Iringa. This station is deemed to represent the climatic pattern of the whole of Iringa region. However, for realistic results climatic data to be reflected in gravel road performance should be collected in the area traversed by the gravel road in question.
2. Specification given by both TZ-MoW (1999:11.3) P&MDM and TZ-MoW (2000b:3000:24) SSRWs for marginal material's particle size distribution to be used for surfacing gravel roads cover a wide range of gravel materials with different performance expectations. This simplifies the selection of gravel materials for surfacing, but it is not realistic. More study is needed to peg the grading limits for the type of marginal gravel materials available in each region in Tanzania.
3. The range of grading coefficient from 16-34 as provided by TZ-MoW (1999:11.3) P&MDM and (2000b:3000:24) SSRWs is too narrow for the tested marginal

materials used for surfacing the gravel roads under study. This range definitely has to be revised, as it is similar to the one employed in South Africa. This study proposes a new GC range for Iringa region, which is 23 – 72 inclusive.

4. Atterberg limits test results showed insignificant variation with specified specification, as issued by TZ-MoW (1999:7.5) in Table 7.3. According to the said Table, the maximum LL range is from 45 to 55; and the PI range from 16 to 24. Liquid Limit and PI results also fall within the climatic range as specified by Ellis (1979:5) in Table 33, and SP results fall within the specified limits of 120-400 (TZ-MoW 1999:11.
5. There is a need to have a long term pavement performance study. The study can be of 5, 10, 15, and 20 years. The goal is to extend the life of pavements through various designs of new and rehabilitated pavement structures, using different materials and under different load, environmental conditions, subgrade soil, and maintenance practices. These studies have been and are still conducted in developed countries, but the difference in maintenance culture, climatic conditions, technology, and gravel materials between these countries and those in sub Saharan Africa make it unrealistic to use the results from their studies. This makes it necessary for sub Saharan African countries to start performing these studies if they want to better their gravel roads.
6. Performance prediction is a critical element in effective pavement design and management. Critics of this method cite lack of accuracy in the models and high degree of variability in the input data used to drive predictions as one of its major setbacks. To address this specific concern, there is a need to develop reliable, good-quality pavement distress measurement. To encourage uniform distress data collection and interpretation methods, to have in place constant revision of distress identification manuals, running rater accreditation workshops annually, and create systematic evaluation principles to quantify the variability (bias and precision) associated with both manual and film-derived pavement distress data.
7. Road building materials, whether natural or manufactured are not perfectly uniform. Values of their physical properties vary. Gravel materials for surfacing unsealed roads, whether standard or marginal, are not perfectly uniform. Values of their physical properties vary as well. While every effort should be made in ensuring testing to be as precise as possible, there are limitations in equipment and in the test methods themselves, which contribute to testing variability. While every effort should be made to ensure uniformity of field compaction, there are limitation in construction equipment, which mean that every location in the road will not be subject to exactly the same process. This material variability, testing variability, and process variability combine to form a total variability. It is this total variability, which is measured when a performance study is conducted through distress survey. Among gravel road distresses is gravel loss.

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