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TITLE A field study on the deterioration of unpaved roads and the effect of different maintenance strategies

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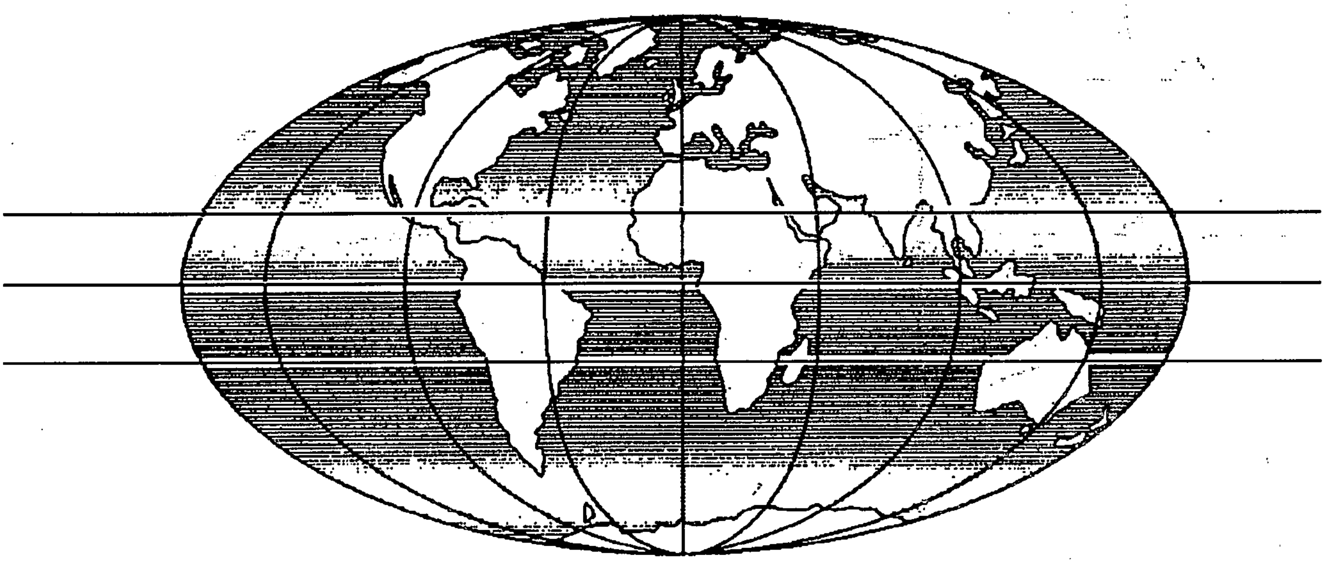

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A field study on the deterioration of unpaved roads and the effect of different maintenance strategies

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SYNOPSIS A recent study carried out by the Transport and Road Research Laboratory has investigated the effect of varying maintenance inputs on the rate of deterioration of unpaved roads. The roads investigated had traffic levels of 50 to 240 vehicles per day with wearing courses that consisted of lateritic, quartzitic, volcanic and sandstone gravels. The deteriorating surface conditions were monitored in relation to the cumulative traffic weights and volumes, and the type of maintenance input. The study also investigated alternative methods of maintaining the roads with motor graders, towed graders and mechanical drags. Results from the investigation showed increased rates of gravel loss compared with previous studies. Other factors, apart from traffic, were found to influence the performance of unpaved roads and these included the material design specifications used in construction, the frequency and quality of the subsequent maintenance and the prevailing climate.

INTRODUCTION

In recent years, unpaved roads in developing countries have been carrying vehicles travelling at higher speeds and carrying heavier payloads. This situation has led to increased rates of road deterioration. The difficulty that this has caused in many countries has been made worse because of the dwindling sources of good regravelling material.

There are three principle modes of deterioration for gravel roads:

Loss of fines. The loss of fines from the surface due to the degradation by vehicle tyres leads initially to a reduction in cohesion of the surface layer and subsequently its disintegration. This also increases the surface irregularity and the permeability of the gravel wearing course. Eventually it starts the process of longitudinal rutting and, in certain soils, precedes the development of corrugations.

Loss of shape. This is the result of the combined action of traffic and climate, and will depend on gravel type and initial road camber. This leads to the development of longitudinal rutting and the loss of the water shedding characteristics of the road. On steep alignments with poor drainage features, there will be additional loss of shape with longitudinal gullies forming as a direct result of the water draining along the road.

Structural damage. This occurs when the maintenance or necessary strengthening of the road has not been done in time, or when the road has been overloaded or underdesigned. It can also occur as a result of damage to structures such as bridges and culverts.

The loss of fines and loss of shape on unpaved roads are common occurrences and, without adequate maintenance, will reduce the effective life of the road and increase the need for regravelling operations. These two factors have considerable influence on vehicle operating costs which is the largest element of the total costs of road transportation.

A recent study carried out by the Transport and Road Research Laboratory (TRRL), T E Jones (1983), investigated the effect of varying maintenance inputs on the rate of deterioration of unpaved roads. The roads investigated had traffic levels of 50 to 240 vehicles per day with wearing courses that consisted of lateritic, quartzitic, volcanic and sandstone gravels. The deteriorating surface conditions were monitored in relation to the cumulative traffic weights and volumes, and the type of maintenance input. The study also investigated alternative methods of maintaining the roads with motor graders, towed graders and mechanical drags.

DESIGN OF THE STUDY

The study was carried out in Kenya in cooperation with the Ministry of Transport and Communications (MOTC). An earlier study, carried out between 1971 and 1974 by a joint World Bank/TRRL/MOTC project investigated the inter-relationships between construction, maintenance and vehicle operating costs for both paved and unpaved roads. This resulted in a computer model designed to aid investment decisions within the road sector and which is known as the TRRL Road Investment Model, S W Abaynayaka et al (1977).

The current study required the determination and quantification of relationships between the following parameters which contribute to the deterioration of unpaved roads:-

(a) Types of equipment used included motorised and towed graders, and dragging implements.

(b) Performance and rate of deterioration of a range of materials generally used as wearing courses for unpaved roads.

(c) The effectiveness of grading at different frequencies.

(d) Use and effectiveness of compaction plant used in the maintenance operation in conjunction with graders.

(e) The effect of the climate in terms of the volume and intensity of rainfall.

(f) Depth of gravel removed by the maintenance operations.

(g) The alignment of the roads with respect to their horizontal curvature and vertical gradients.

Field work started by carrying out an appraisal of the condition of the existing gravel road network in Kenya. Modes of deterioration of the roads were then identified and methods of measuring these were developed. Test sections of road were then selected and the experimental work and monitoring of road performance commenced. Results were collected over a period of two years. These were then analysed and conclusions drawn.

Experimental test sections

The study was concentrated on three geographical areas of Kenya where the MOTC was carrying out rehabilitation works on large networks of unpaved roads. The use of test sections was necessary in order to relate the deterioration rates of unpaved roads to the standard, frequency and type of maintenance, the traffic spectrum, the natural environment and the physical properties of the particular gravel. In addition, the test sections were designed to include variations in geometric design standards in terms of vertical gradient and horizontal curvature. Horizontal curvature varied from less than 30 degrees/km to greater than 90 degrees/km and gradients varied from flat to greater than 3 per cent. The annual rainfall on the test sections varied between 500 and 2000 mm per year, and in each experimental area, test sections were duplicated in order that different levels of maintenance could be carried out. The levels chosen were as follows:-

(a) High: graded every six months,

(b) Normal: graded every nine months,

(c) Nil: not graded during the study.

In addition to these levels, it was found possible to include a small number of test sections with maintenance frequencies of three and twelve months. All test sections were 300 metres in length. In all cases, normal drainage and roadside maintenance were carried out on a routine basis. It was expected that the gravel wearing course properties would make a significant contribution to the rate of deterioration. Test sections were therefore chosen to utilise four basic gravel types which were as follows:-

(a) Lateritic gravels. These are formed by the accretion of nodules of oxide and aluminium. The test sections in the Bungoma area were all lateritic.

(b) Quartzitic gravels. These are rounded gravels derived from the basement rock of the area east of Mount Kenya and formed the wearing course materials used on some of the test sections in the Meru area.

(c) Volcanic gravels. These are angular gravels derived from the volcanic rocks of the Mount Kenya area and were employed as wearing course materials in other test sections in the Meru area.

(d) Sandstone gravels. These are fine grained gravels usually containing quantities of quartz and feldspar found near the Kenya coast. The wearing course materials on test sections at Kaloneni were all derived from sandstone.

Measurement of experimental variables

The principal method of measuring the road condition involved the use of a towed bump integrator to monitor changes in surface irregularity and optical survey techniques to measure the gravel lost from the road through the action of traffic and rainfall. Measurements were also taken of the amounts of surface loose material, depth of ruts, traffic volumes and loading, volume and intensity of rainfall, road geometry and in-situ and laboratory testing of the wearing course and subgrade materials. The measurement techniques used were similar to those used in the original Kenya study, J W Hodges et al (1975).

RESULTS OF THE ROAD DETERIORATION STUDY

Gravel loss from unpaved roads. The loss of gravel from the wearing course is a feature of all unpaved roads and eventually leads to permanent damage of the road structure unless remedial treatment is carried out. To implement routine and recurrent maintenance operations and to plan long term measures such as regravelling, it is important to identify the rate at which the material is lost or eroded for a wide spectrum of roads and gravel types.

The principal variables investigated in the study were, traffic volumes and loading, rainfall volume and intensity, road alignment, gravel type and maintenance input.

The gravel loss data from the study was first plotted as a function of the cumulative traffic volume for each test section. The data which were taken from measurements at approximately three monthly intervals showed no significant differences during wet or dry seasons. A selection of results from each of the four gravel types investigated is shown in Figure 1.

Previous studies of gravel loss on unpaved roads by the TRRL and reported by J W Hodges et al (1975) produced an equation for predicting the annual gravel loss for lateritic, quartzitic, volcanic and coral gravels. The equation was of the following type:-

$$GL_A = f\left(\frac{T_A^2}{T_A^2+50}\right)(4.2+0.092T_A+3.50R_L^2+1.88VC) \quad \text{..... eqn 1}$$

where GL_A is the annual gravel loss in millimetres

T_A is the annual traffic in both directions measured in thousands of vehicles

R_L is the annual rainfall measured in metres

VC is the rise and fall (gradient) expressed as a percentage

f is a constant depending on gravel type.

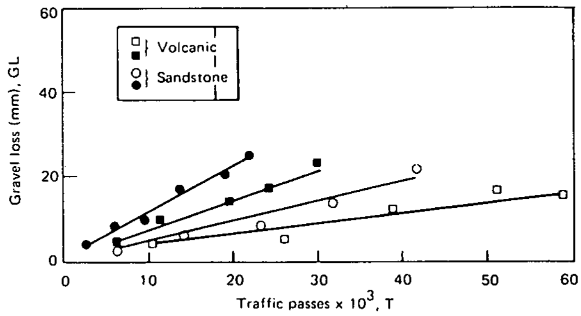

Fig.1 Gravel loss against traffic passes for some volcanic and sandstone gravel roads

Using the relevant values of annual traffic, annual rainfall, vertical gradient and gravel constants in the equation, the annual loss of gravel predicted by this equation was evaluated for each of the current test sections. These values were plotted against the actual values obtained in the study as illustrated in Figure 2. It can be seen

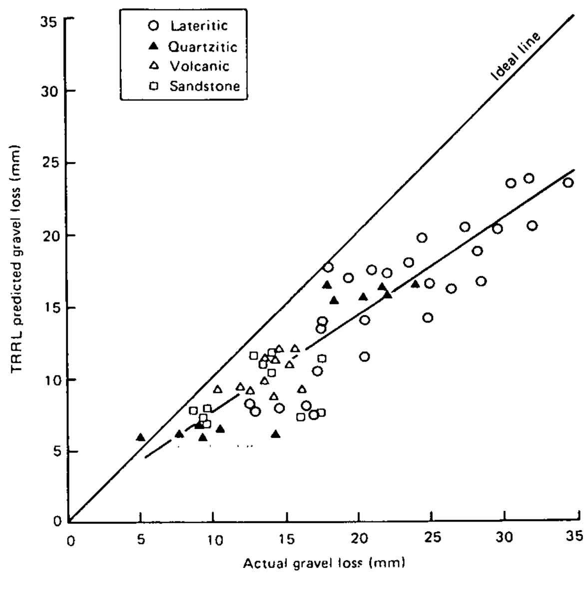

Fig. 2 Predicted annual gravel loss against actual gravel loss for gravel roads found in this study

from this figure that the actual annual loss of gravel is greater than the predicted annual gravel loss by about 37 per cent. To bring the predicted gravel loss into agreement with the actual loss it would be necessary to increase the material constant f as shown below.

TABLE I

Material constants

Material	Old value	New value
lateritic gravels	0.94	1.29
quartzitic gravels	1.10	1.51
volcanic gravels	0.70	0.96
*coral gravels	1.50	
sandstone gravels		1.38

*coral gravels were not investigated in the current study.

The differences between the gravel loss predicted by the original equations and the gravel loss measured in this study can be attributed to the following. In the original analysis, the action of rainfall alone in producing gravel loss was calculated theoretically using the results of agricultural studies by W H Wischmeier et al (1968). An estimated value of soil erodibility was used which gave a predicted maximum annual gravel loss of 2 mm and it was then assumed that there would be negligible gravel loss when the traffic volume was zero. In this study, two experimental lengths of unpaved road were constructed which were not subjected to traffic. Results of optical surveys at these sites gave values of annual gravel loss of 4.3 mm and 7.5 mm respectively. These figures imply that the eroding effect of rainfall is higher than that calculated by Wischmeier or by using the original TRRL analysis. In the TRRL 1971 study, the thickness of wearing courses of the test sections varied between 28 and 223 mm which compared to a range of 121-165 mm in the current study. Any inherent weaknesses or strengths due to the varying thickness of the wearing course would also influence the resistance of the road to deformation. Other contributory factors to the increased rates of gravel loss are the increases in speeds of the traffic resulting from general improvements in gravel road alignment over the network as a whole.

An indication of the range of gravel losses that can occur in practice is illustrated in Figure 3 where the results of studies in a number of different countries are shown. The data from the Kenyan research, both in 1971-74 and in this study, refer to test sections with 3 per cent vertical gradient and 1250 mm of annual rainfall. Roads with steeper gradients in wetter areas will have higher losses, whilst the converse will be true of roads with flatter gradients in drier areas.

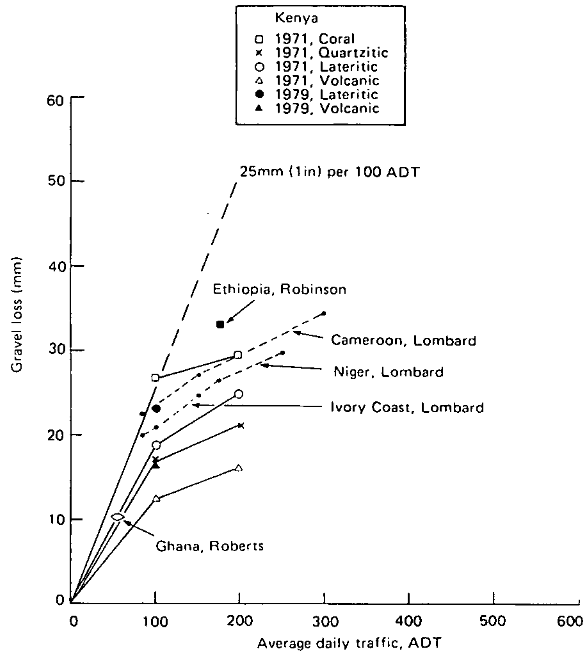

Fig. 3 Gravel loss rates for different countries (T E Jones, 1983)

Figure 3 further illustrates that annual gravel loss on unpaved roads will vary between 10 mm and 30 mm per 100 vehicles per day and will be dependent on climate and road alignment. This means that, annually, 70 to 210 cubic metres of gravel will be lost from each kilometre of road per 100 vehicles per day.

These rates of gravel loss probably only hold for the first phase of the deterioration cycle lasting for two or three years. They should not be considered to hold over a long period of time. As the wearing course is reduced in thickness, other developments such as the formation of ruts will affect the loss of gravel material. However the rates of loss shown in the gravel loss equation are essential requirements as an aid to the planning for regravelling in the future.

Looseness. There are two principle reasons for the presence of loose material on gravel roads. Firstly, it occurs as a direct result of attrition of the road surface by the action of traffic and rainfall. It can also be due to the maintenance technique of grading material lost to the ditches and shoulders back on to the road. If there is sufficient moisture in the material it will be compacted by traffic, but only in the wheelpaths. If there is insufficient moisture, then the loose dry material will be dispersed across the road by traffic and wind. Previous research has shown that loose material on gravel roads influences rates of fuel consumption for a wide range of vehicles.

The results of the looseness measurements for each gravel type have been plotted as a function of cumulative traffic and two of these are illustrated in Figure 4.

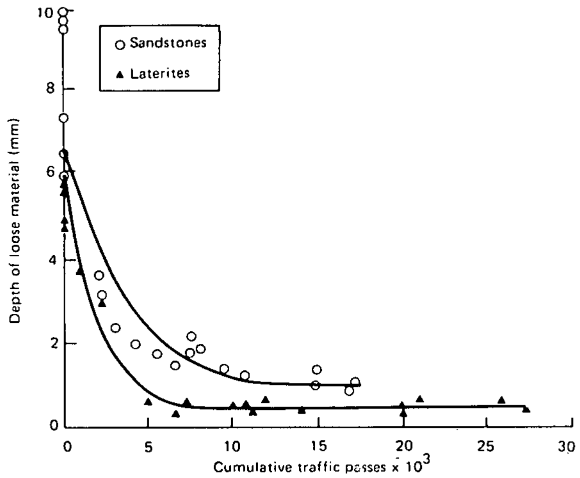

Fig.4 Relationship between depth of loose material and traffic passes for sandstone and lateritic gravels

Although there was a maximum of 10 mm of loose material immediately after grading, the depth reduced rapidly with traffic to a constant level. In the case of the quartzitic gravel, this level was reached after approximately 5000 traffic passes whilst the other gravels took approximately 6000-8000 traffic passes to reach a similar asymptote. When test sections were compacted after grading, looseness was less than 1 mm in all cases. The relationships between depth of loose material (DLM) and cumulative traffic (T) were found to be the following:

Quartzitic gravel

$DLM = 5.895e^{-0.358T} + 1.0$ ..... eqn 2

Volcanic gravel

$DLM = 6.748e^{-0.183T} + 1.0$ ..... eqn 3

Sandstone gravel

$DLM = 6.925e^{-0.187T} + 1.0$ ..... eqn 4

Lateritic gravel

$DLM = 6.011e^{-0.334T} + 0.5$ ..... eqn 5

SURFACE IRREGULARITY

The principal index of unpaved road deterioration which affects vehicle operating costs is roughness (surface irregularity). In turn, traffic is the parameter that has the most significant effect on the rate of change of roughness. In the analysis, the roughness of the sections were plotted as a function of traffic. To obtain the best fit of curve for the measurements, the data were analysed using polynomial regression techniques (the results are illustrated in Figures 5(a) and 5 (b)).

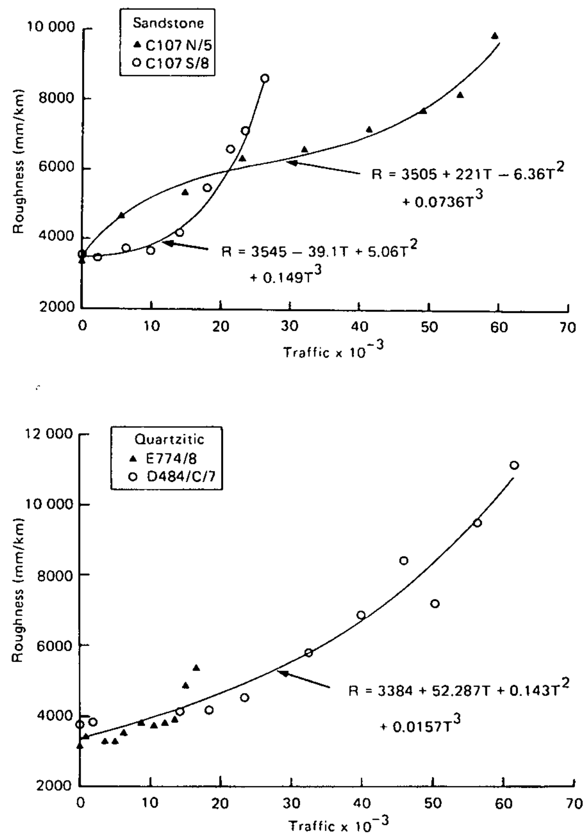

Fig.5a Relationship between roughness and traffic for sandstone and quartzitic gravels

In the majority of cases, the correlation between roughness and traffic is good with regression coefficients higher than 0.93. However, when the results from the individual groups of sections, built with the same gravel type, are plotted together, there are apparent differences in the deterioration cycles, particularly in the cases of the quartzitic and sandstone gravels. The main difference in performance of the quartzitic gravels occurs at a traffic level of 15,000 vehicles where there are two significant increases in surface roughness on the lower trafficked roads. These two high readings

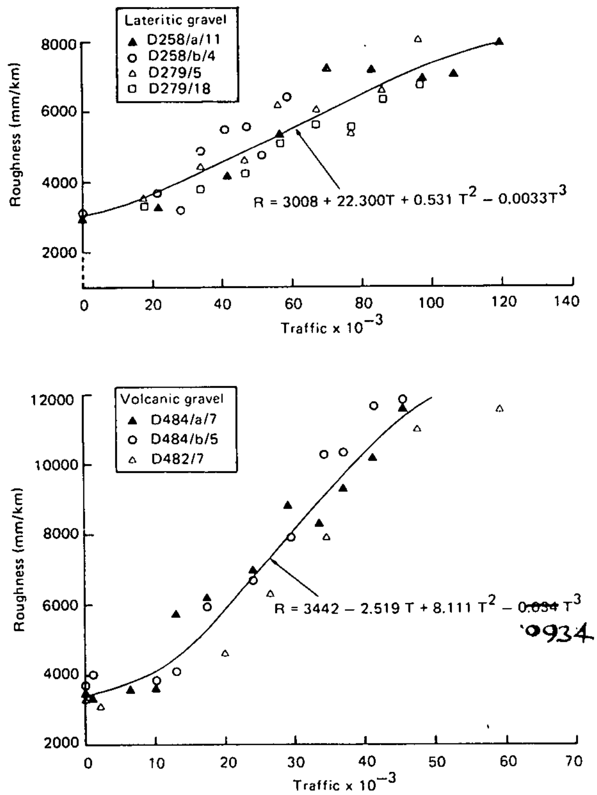

Fig. 5b Relationship between roughness and traffic for lateritic and volcanic gravels

took place after the heaviest and most intensive rain storm recorded during the study had fallen. This particular storm had an intensity of 40 mm/hour over a period of 1½ hours and was probably responsible for the premature deterioration on this road.

The lateritic gravels deteriorated at a slower rate than all the other gravels investigated in the study. After 97,000 traffic passes a roughness of 8000 mm/km was reached which is much lower than the roughness levels obtained with other gravels at lower traffic volumes. Volcanic gravels deteriorated at a faster rate than any of the other gravels, reaching a roughness of 8000 mm/km after only 30,000 traffic passes. The three roads built with volcanic gravel wearing courses were constructed to three distinct levels of geometry, but no direct correlation was found between the roughness of the sections and their particular geometric standards. Although the quartzitic gravels were found to perform better than the volcanic or sandstone gravels, they still deteriorated faster than the lateritic gravelled roads.

In the deterioration cycles, there is some evidence in the equations, particularly in the volcanic and lateritic sections, that the rate of roughness tends to decrease at the high levels. It was observed during the study that there was a change of behaviour by road users at the higher levels of roughness, particularly on the volcanic gravelled roads which had on average the highest level of roughness recorded. Generally vehicles tended to follow a regular well defined line of travel along a road, the positions of which varied according to the numbers of vehicles using the road and the geometry of the road. For example on roads carrying less than 100 vehicles per day most of the traffic straddled the centre of the road forming two concentrated wheel paths. On roads with more than 100 vehicles per day, vehicles tended to use their correct lane more often, and usually four separate wheel paths developed. The pattern of behaviour appeared also to be constrained by the horizontal and vertical alignment of the road, especially on roads with radii of curvature greater than ninety degrees per km. On more heavily trafficked roads, the defined wheel paths became more established and deteriorated to a point where much of the traffic, particularly cars and light goods vehicles, attempted to travel on smoother and relatively untrafficked parts of the road.

The regression equation relating roughness to traffic volume for each of the gravels illustrated in Figures 5(a) and 5(b) are:-

Lateritic gravels

$R=3008+22.300T-0.531T^2-0.0033T^3$ .. eqn 6

Quartzitic gravels

$R=3384+52.281T+0.143T^2+0.0157T^3$ .. eqn 7

Volcanic gravels

$R=3442-2.519T+8.111T^2-0.\sout{084}T^3$ ... eqn 8
·0934

Sandstone gravels

$R=3009+206.382T-3.688T^2+0.0323T^3$ .. eqn 9

where R = mean roughness in the wheel tracks measured in mm/km by a bump integrator towed at 32 km/h.

T = cumulative traffic volume in both directions that has used the road since grading measured in thousands of vehicles.

Development of ruts with cumulative traffic. In the analysis of rut depth the measurements were plotted as a function of traffic and are illustrated in Figures 6(a) and 6 (b).

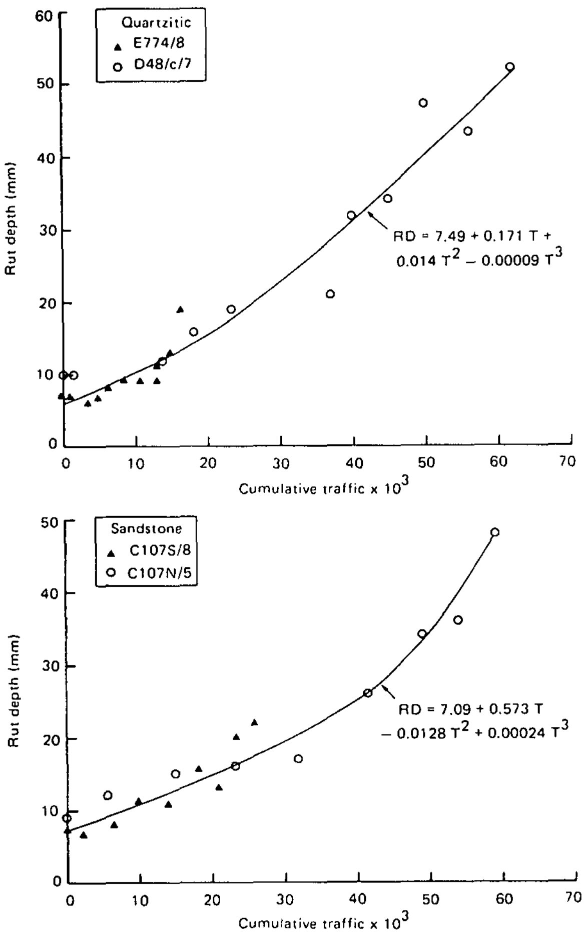

Fig. 6a Relationship between rut depth and traffic for quartzitic and sandstone gravels

On the lateritic gravel sections, the development of rut depths was less pronounced than on sections using other gravel types and there was evidence of a reduction in slope or 'flattening' of the curve similar to that obtained with the roughness measurements. The volcanic gravelled sections did not have high values of rut depth considering the high levels of roughness. This is attributed to the fact that, on these roads, it was observed that extra wheel paths were being developed.

The regression equations which have been fitted to the data obtained from the rut depth measurements are as follows:-

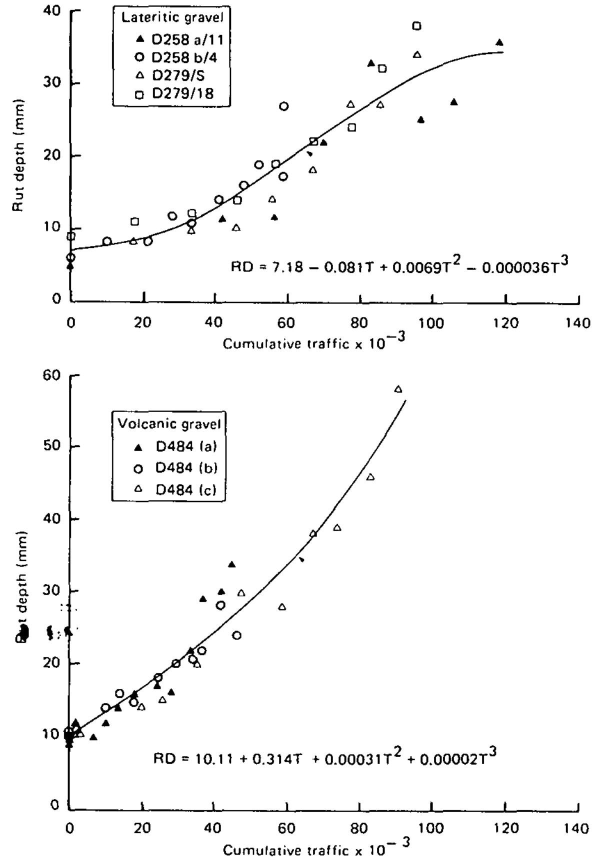

Fig.6b Relationship between rut depth and traffic for lateritic and volcanic gravel

Lateritic gravels

$$RD=7.18+0.081T+0.0069T^2-0.000036T^3 \quad \ldots \text{ eqn } 10$$

Quartzitic gravels

$$RD = 7.49+0.171T+0.014T^2-0.00009T^3 \quad \ldots \text{ eqn } 11$$

Volcanic gravels

$$RD=10.11+0.314T+0.00031T^2+0.00002T^3 \quad \ldots \text{ eqn } 12$$

Sandstone gravels

$$RD=7.09+0.573T-0.0128T^2+0.00024T^3 \quad \ldots \text{ eqn } 13$$

where RD = Rut depth in mm under a 2 metre straight edge

T = Traffic as defined earlier.

Axle load survey measurements. Axle load surveys were carried out at approximately 4 monthly intervals on each group of roads contained within the study. The surveys lasted for 5 days from 6.00 am until 6.00 pm and for one night from 6.00 pm until 6.00 am. The precise timing of the surveys during the year was related as far as possible to expected changes in the type of goods being transported, such as would result from the harvesting of crops. Typical results of the surveys are illustrated in Figure 7 which shows the axle load distribution for one of the experimental roads. It can be seen that the number of axles exceeding the legal limit, which in Kenya is 8 tonnes maximum on a single axle, is minimal. On unpaved roads relatively small numbers of overloaded vehicles can produce permanent damage, T E Jones et al (1979), particularly if the road is in a high rainfall area and has lost some of its shape and water shedding characteristics.

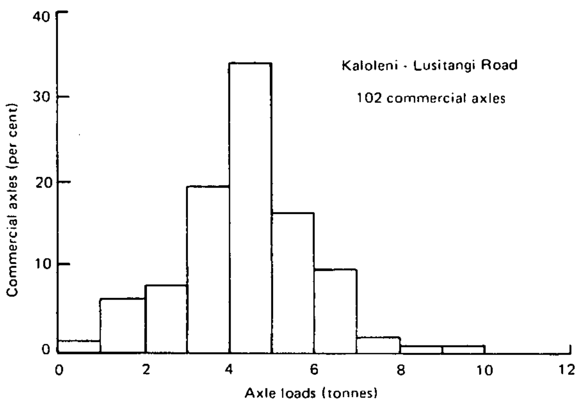

Fig. 7 Distribution of axle loads on Kinango Road and Lusitangi Road in Kaloleni area

Changes in roughness related to cumulative rainfall on untrafficked roads. Parameters other than traffic will affect the deterioration rate of the gravel wearing courses. The principal one of these is rainfall.

Pilot experiments were set up in two areas to establish the effect of rainfall on the road surface in isolation from other parameters. This was achieved by constructing short lengths of road with quartzitic and sandstone gravel wearing courses adjacent to the main test sections utilised in the study. These were left untrafficked except when measurements were taken with the towed bump integrator. Annual rainfall figures derived from the Kenyan Meteorological Department gave average values for these roads of 1250 mm and 630 mm. The actual rainfall recorded at the sites during the twelve month period was 711 and 847 mm respectively.

On the quartzitic road near Meru, there was an annual increase of roughness of 787 mm/km for a cumulative rainfall of 711 mm. In the Kaloneni area, the roughness increased in the same period by 821 mm/km for a higher rainfall of 847 mm. The increase in roughness at the two test sites plotted as a function of cumulative rainfall is illustrated in Figure 8.

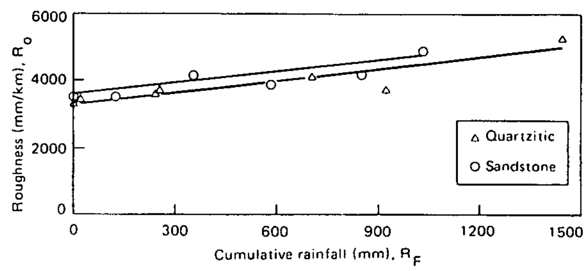

Fig. 8 Roughness against cumulative rainfall for non-trafficked roads

These results mean that, on untrafficked unpaved roads in areas where the annual rainfall is approximately 1 metre, the roughness of the road will increase annually by approximately 970-1100 mm/km. Rainfall records maintained on the two sites showed that the rainfall intensities were low, with the highest storms recorded during the monitoring period of 10 mm per hour. Higher rainfall intensities would have influenced the change in roughness considerably. Therefore, in areas subjected to flash storms, ie near mountains, coastal and lake areas, the annual increases in surface roughness of unpaved roads due to rainfall alone could be much greater. The equations derived from the regression analysis of the data are as follows:-

Quartzitic gravel $R=3303+1.117R_R$ ..... eqn 14

Sandstone gravel $R=3550+1.021R_R$ ..... eqn 15

where R = roughness in mm/km measured by a towed bump integrator

and R_R = rainfall in mm.

For the purposes of predicting roughness in terms of rainfall, it is adequate to combine these equations to give:-

$$R = 3429 + 1.063R_R \quad \text{..... eqn 16}$$

Relative effectiveness of motorised and towed graders on unpaved roads. In Figure 9, the performance of the towed grader is compared with the motor grader in terms of roughness as a function of traffic for two of the gravel types investigated in the study. In each case, the section was graded and then compacted, without water being added, using a vibrating roller. As can be seen from the Figure, there is very little difference in performance between the sections maintained by towed grader and those maintained by motor grader. In each case the curve for the regression analysis for the relevant nil maintenance section is also illustrated for comparison.

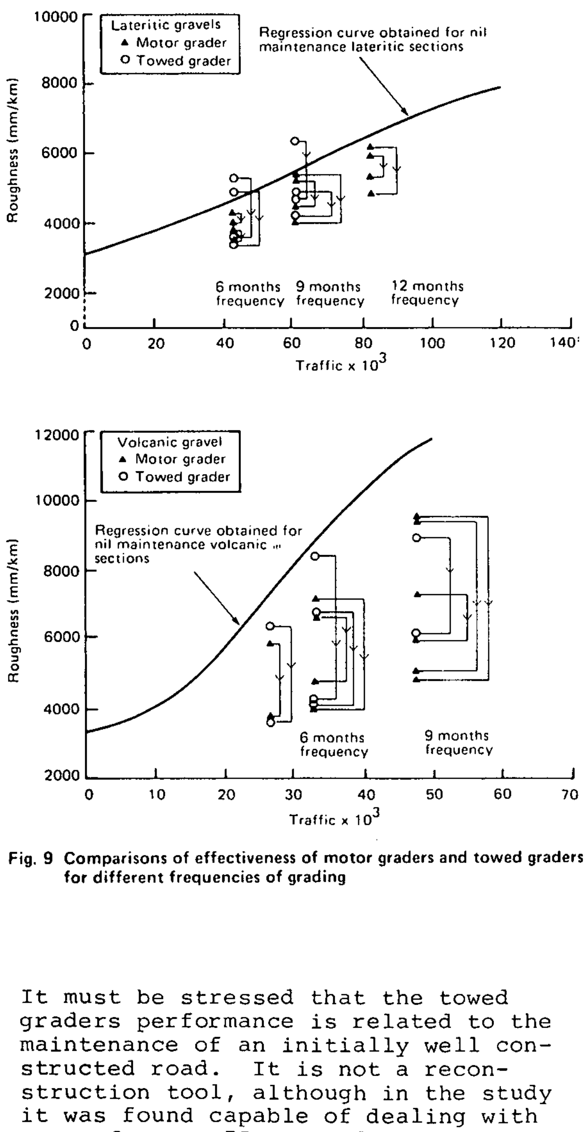

Fig. 9 Comparisons of effectiveness of motor graders and towed graders for different frequencies of grading

It must be stressed that the towed graders performance is related to the maintenance of an initially well constructed road. It is not a reconstruction tool, although in the study it was found capable of dealing with ruts of up to 75 mm in depth. On some volcanic gravelled roads with oversize materials, the towed grader was found to be unsatisfactory.

Deterioration of roads maintained by mechanical drags. The type of equipment planned for use in the drag trials consisted of two brush drags, three cutting drags and a towed grader. Before starting the main investigation, it was decided to carry out some proving trials with these. This was done in order to develop dragging techniques for each design, and also to test the robustness of each drag under road conditions. The sites were located in two dry areas near Isiolo and Meru and one temperate area near Bungoma.

The plant used in the trial was as follows:-

a) Tree broom made from an acacia tree.

b) Tyre sledge made from lorry tyres.

c) Baulk of rectangular timber (designated TRRL A).

d) Timber framed drag with metal leading edges (designated TRRL B).

e) Metal framed drag incorporating used grader blades, the leading one set at 30^{o} to the centre line (designated TRRL E).

f) Towed grader.

Immediately prior to the dragging operation, the roughness of each test section was measured using the towed bump integrator. At the conclusion of the operation, the roughness measurement was taken again. After this, measurements were taken at periods of 7, 21, 35, 49 and 63 days from the day of grading. Results from the dragging trials carried out at Isiolo are shown in Table II.

As can be seen from the table, there is an immediate improvement in road condition after the dragging operation due to the reduction in roughness levels. However, in the case of the tree broom, the roughness quickly started reverting to its old level. Even after a period of 7 days, the roughness had increased by 1000 mm/km. After 21 days it had reached 7600-9000 mm/km, indicative of a road in poor condition. The towed grader achieved both the largest reduction in initial roughness and the least deterioration with time. The performance of the tyre sledge, TRRL "A" and TRRL "B" drags were similar to each other, whilst the TRRL "E" drag achieved results surpassed only by the towed grader.

Table III shows that the effect of the use of rollers was not large. However, with the exception of TRRL "B", rolling reduced the frequency that dragging activities were needed. This improvement cannot be due to the small increase in dry density of the wearing course. Its effect has come from the reduction in the amounts of loose material, the crushing

TABLE II

Summary of drag trials at Isiolo

(Traffic: 108 vpd)

Type of drag	Roughness in mm/km						
		Days after dragging					
	Before	0	7	21	35	49	63
Tree broom	9160	6360	7820	9322	8974	9892	
TRRL "A"	8920	5968	6652	7963	8116	9175	
TRRL "B"	9012	6260	6361	6949	6966	8410	8625
Towed grader	8866	5861	6144	6257	6508	7010	6962
Tyre sledge	9272	6610	7108	7804	8251	8712	8462
TRRL "E"	8762	5816	5864	6551	6562	6861	8123
Nil Maintenance	9068				11027		12861

TABLE III

Results of drag trials with sections compacted with vibrating roller

Type of drag	Roughness in mm/km						
		Days after dragging					
	Before	0	7	21	35	49	63
Tree broom	9510	6130	7162	7560	8642	10812	
TRRL "A"	8904	6284	6563	6324	7078	8606	
TRRL "B"	8750	6068	6561	6654	7153	8666	8210
Towed grader	8560	5622	5923	5911	5861	6302	7514
Tyre sledge	9062	6926	6436	7084	7220	7197	9412
TRRL "E"	9112	5426	5658	5358	5921	6252	7904

of oversize material and the general smoothing of the dragged surface. Similar results were obtained from the other test sites at Meru and Bungoma.

The drag trials carried out on roads containing quartzitic, volcanic and lateritic materials with differing levels of roughness showed that no single drag could provide the complete answer to effective maintenance of low volume rural roads. The results, however, did provide quantified information on the relative merits of various designs of drag from which the following recommendations are made in Table IV.

In order to be effective, drags must be used at intervals frequent enough to ensure that they are used only to smooth the surface of the road. They must not be used on roads which, through neglect or infrequent maintenance, have deteriorated to a level where heavy grading or reshaping is needed rather than recurrent maintenance. Drags should not be towed at speeds above 10 km/h and preferably should be towed at 5 km/h.

CONCLUSIONS

Unpaved roads lose annually between 10 and 30 mm of gravel per 100 vehicles per day. This means that 70 to 210 cubic metres of gravel will be removed from the road surface each year. The total loss of gravel on unpaved roads in developing countries is increasing annually whilst the sources of good road making material are diminishing. These rates of gravel loss can be substantially reduced if greater control is exercised in the construction of

TABLE IV

Recommended drags for varying conditions

Road condition	Recommended drag
Roads with depths of loose material in excess of 20 mm	Tyre sledge Cutting drag using old grader blades (TRRL E) Towed grader
Roads with roughness levels <6000 mm/km with no appreciable loose material	Timber framed drag Towed grader
Roads with roughness levels >6000 mm/km	Cutting drag using old grader blades (TRRL E) Towed grader

gravel roads. More attention must be paid to the particle size distribution of the wearing course material, in particular the removal at source of the oversize gravel.

The study was able to quantify separate deterioration relationships for lateritic, quartzitic, volcanic and sandstone gravels. This was an important improvement on previous studies of gravel roads. The study also showed that there was more scope in the maintenance operation for the use of towed graders and mechanical drags instead of the more expensive motor graders, and recommendations are made for this. On well maintained roads, the amount of loose surface material that remained on the surface was found to be insignificant, and unlikely to influence vehicle operating costs.

The effect of rainfall in isolation from other parameters was found to increase the surface roughness annually by between 970 and 1100 mm/km per metre of rainfall.

Only a small number of vehicles travelling over the test sections were found to be overloaded. Overloaded vehicles did not therefore significantly influence the rate of deterioration.

In many countries the maintenance activities on unpaved roads are scheduled for the period immediately after the end of the wet season. Maintenance organisations should also carry out maintenance at the beginning of the wet season to ensure that the road has the correct profile for effectively shedding water during the rains.

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