Deflections of Lateritic Gravel-Based and Stone-Based Pavements of a Low-Volume Tea Road in Kenya

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Results are described from a testing program of a tea road on the slopes of the Aberdares where tea is the main cash crop. The 5.5-m-wide low-volume road has been carrying the equivalent of about 7,000 standard axles per year. Two experimental sections were identified on the road, one of which contained a lateritic gravel base and the other a stone base. The experimental sections were subjected to a detailed pavement condition survey to identify types and extent of distress features such as potholes, crazing, and edge failure after more than 10 years of service. In situ field tests were carried out on the subgrade, subbase, and base materials to determine in situ field density and moisture. The dynamic cone penetrometer and Clegg impact hammer were used to establish the in situ California Bearing ratio (CBR) values. In addition, pavement deflections and radius of deflected profile were measured using the Benkleman deflection beam. The results of the studies indicate that the experimental sections are still performing well after about 16 years of service. The deflection values obtained were below 100×10^{-2} mm, and the radius of curvature of the deflected profile was greater than 150 m. The pavement condition surveys tended to show that stone-based sections (standard construction) were marginally more distressed than the lateritic gravel-based sections (substandard construction). The study indicates that low-volume roads can be constructed using substandard materials such as lateritic gravels, for which the cost of the road is about two-thirds that of conventional road materials that meet specifications.

Kenya is heavily dependent on agricultural products such as coffee and tea, which are the main foreign exchange earners. The foreign exchange earned through exportation of these agricultural products is used to purchase imported technology in terms of equipment and expertise for faster economic growth of the country. Tea, which is a major cash crop, is grown in the highland areas where climatic conditions are favorable. Results are described of a testing program for a tea road on the slopes of the Aberdare mountains where tea is the main cash crop. Tea roads are constructed to provide all-weather access between the tea factories and the tea collection centers. These tea roads often have poor geometrics, sometimes with grades of 12 percent and more because of the need to provide them cheaply in difficult mountainous terrain. The tea roads are low-volume roads that provide the transportation system necessary for providing farm input service and for allowing agricultural products to reach the markets.

The road for which test results are reported is Gatura-Mataara Road, which is 5.5 m wide at an altitude of about 2040 m located in the Central Province of Kenya. The mean annual rainfall is about 1980 mm; mean monthly maximum temperatures range from 14°C to 21°C and mean monthly minimum temperatures range from 8°C to 10°C. The road is generally on a ridge for which alignment soils are dark red friable clays that are residual soils derived from recent lava and are relatively free draining. The water table is generally greater than 6 m below the ground surface. The objective of the testing program was to find out why some of the tea roads constructed with plastic laterites performed satisfactorily and to compare the performance of stone-based and lateritic-based pavements.

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EXPERIMENTAL SECTIONS

In general, the stone base was used in the Gatura-Mataara road in steeper grades in heavy-cut sections, whereas lateritic gravel base was used on the ridges with flatter grades or in light side hill cut sections. Topography appeared to make little difference in the performance of the two experimental sections except on sharp horizontal curves and on steep grades.

Gatura I Experimental Site ES9

This test section was selected on the Gatura-Mataara Road near Gatura shopping center to the west of a river bridge about 80 km north of Nairobi. The section, which is a 5.5-m-wide carriageway with 1-m-wide shoulders, was completed in 1974 and the pavement is made up of double-surface dressing on 130-mm-thick crushed-rock base on 100-mm-thick gravel subbase that rests on red soil subgrade. The subgrade generally exhibited a soaked CBR value of greater than 9 percent when compacted to 100 percent using a 2.5-kg rammer (light compaction). Most of the crushed stone for base construction was obtained from rock quarries of basalt in the Aberdares. The crushed stone was laid by a paver and compacted by a vibrating roller and a 14-ton three-point flat roller. The surface dressing was carried out using 1,000-gal bitumen distributor, self-propelled chip spreader, pneumatic-tired roller, and tandem roller. The road was carrying about 7,000 equivalent standard axles per year in 1983 and, at a growth rate of about 5 percent per year by 1990, the pavement had received about 0.11×10^6 cumulative standard axles since construction. A standard axle in this case represents 8165 kg (18,000 lb).

Gatura II Experimental Site ES10

This test section, which is also a 5.5-m-wide carriageway with 1-m shoulders, was selected on the same road as Gatura I about 5 km beyond Gatura I (ES9). The section is made up of double surface dressing on 150-mm-thick lateritic gravel base on red-soil subgrade with CBR values of about 5 to 20 percent. The lateritic gravel had a CBR value of 43 percent and was won by ripping and dozing into stockpiles. The gravel was either a weathered tuff or basalt that occurred sporadically in the vicinity of the roads or laterite formed in residual volcanic soils. Front loaders were used to load the gravel into tippers, and spreading was carried out by graders while watering was done by self-propelled bowsers. The lateritic gravel was exposed to 6 months of traffic and weather (i.e., one rainy season) before surface dressing. The gravel base surface was prepared by mechanical brooming and wetting before priming and surfacing. The road section has been subjected to the same traffic loading as Gatura I, i.e., 0.11×10^6 cumulative standard axles, from 1974 to 1990.

The *road design manual* in Kenya (*1,2*) specifies that gravel for use as base should have a minimum CBR value of 50 percent (4 days' soak), whereas the lateritic gravel used in the Gatura II road section had a CBR value of 43 percent. The *Road Design Manual* again requires that the plasticity index (PI) of base gravel for wet areas be a maximum of 15 percent, whereas the lateritic gravel used for the Gatura II road section had a PI of 18 percent. Thus, according to the *Road Design Manual* (*2*), the lateritic gravel used for Gatura II Section is substandard.

With a CBR value of 9 percent, the required stone-based pavement structure is 125 mm of crushed stone base on a 100-mm subbase, according to the *Road Design Manual* (*2*), and thus the design of the section (Gatura I) satisfies the specifications from the *Road Design Manual*. Road Note 31 (*3*) specifies 150 mm of road base on 100 mm of subbase, in which case the base layer is slightly thinner than specified in Road Note 31. Table 1 presents material characteristics for the two experimental road sections (*5*).

EXPERIMENTATION

The following field tests were carried out on the two selected test sections described earlier.

Benkleman Deflection Measurements

Benkleman deflection beams were used to measure elastic deflection of the pavement surface using rebound deflection procedure. In the case of road pavements, deflection tests were carried out on 10 marked test points on a 60-m road section. Test points were marked on the road surface at five cross sections spaced at 15-m intervals. The test truck (a 7-ton tipper) was loaded to give a rear axle load of 6350 kg (14,000 lb), and rear tire pressures were set at 586 kN/m^2 (85 lb/in.^{2}); the tire size used was 900×20D. The standard axle is again taken as 8165 kg (18,000 lb).

Measurements of Radius of Curvature

The radius of curvature of the deflected pavement profile was obtained during the Benkleman deflection measurements. The

TABLE 1 MATERIAL CHARACTERISTICS FOR EXPERIMENTAL ROAD SECTIONS (*5*)

Characteristic	Subgrade	Lateritic Base	Stone Base	Surface Dressing
Optimum moisture content (%)	36–63	16–25		
In situ moisture content (%)	32–52	7–14		
Max. dry density (kg/m^3)	1030–1230	1750–1900		
Relative compaction (%)	100–107	99–105		
Liquid limit (%)	54–82	55		
Plasticity index (%)	13–24	18		
CBR (%)	5–20	43		
Swell (after 4 days' soak) (%)	0.2–0.3	-		
Grading analysis (% passing)				
38mm		100		
19mm		91		
9.5mm		80		
6.4mm		63		
(No. 7) 2.4mm	100	47		
(No. 36) 0.425mm	98	24		
(No. 100) 0.15mm	82			
(No. 200) 0.075mm	76	16		
Surface Dressing				
Prime coat				RCO
First seal				MC5
Chippings				70 m^2/m^3 (20mm)
Second seal				MC5
Chippings				85 m^2/m^3
Aggregate crushing value (%)			32[a]	20
Flakiness index (%)			30[a]	28
Bitumen affinity				Good

[a]Minimum requirements.

load test truck was driven at creep speed and stopped at premarked intervals to enable measurement of rebound deflection using the influence line technique and thereby obtaining the longitudinal deflection profile. The longitudinal profile data were used to compute the radius of curvature and also the equivalent modulus of the pavement structure.

Measurement of Field Moisture and Density

Field moisture and density were also measured. Trenches were excavated across the pavement to enable carrying out in-situ tests. The trenches extended from the road centerline to the verge on either side of the road. The in-situ tests were carried out for the various layers of the low-volume road pavement structure—namely, subgrade, subbase and base layers. The field sand replacement method and the nuclear density meter were used to measure the in-situ density and moisture contents.

Measurement of Field CBR Values

Field CBR values were determined using the dynamic cone penetrometer (DCP) and the Clegg impact hammer (CIH). Trenches were cut across the road pavement as described earlier and the DCP and CIH were used to obtain sounding values that were converted into CBR values. The DCP and CIH soundings had been calibrated against CBR values to enable conversion of DCP and CIH values into CBR values. The DCP and CIH soundings were made in each layer of the pavement structure—namely, base, subbase, and subgrade.

Pavement Condition Survey

A detailed pavement condition survey for the two experimental sections was made in 1989; the objective was to identify potholes, edge failure, crazing, and other forms of pavement distress. The road had received little or no maintenance since completion.

DISCUSSION OF RESULTS

The deflection measurements carried out on the two test sections gave the deflection values presented in Table 2. The corresponding radii of curvature are also presented in Table 2. In order to characterize the bearing capacity of the pavement structure, the parameter equivalent modulus (Eq) was computed for the two test sections for which results are also included in Table 2. Equivalent modulus, which is based on Burmister's two-layer theory, is defined as follows (*4*):

$$\mathrm{Eq} = 10^{r-1}\mathrm{El}(R/D)^{r/2} \quad (1)$$

where

- Eq = equivalent modulus of a pavement structure (kg/cm^2),
- El = elastic modulus of the upper pavement layer (kg/cm^2),
- R = radius of curvature (m),
- D = rebound deflection ($\times 10^{-2}$ mm), and

$$r = 1/[1 + \log(\mathrm{El}/1018)] \quad (2)$$

Wambura (*4*) has also shown that

$$(\mathrm{El})^{B} = (R/0.056)(D/5{,}800)^{A} \quad (3)$$

where

- $A = (1 - X)/(1 - Y)$,
- $X = 0.86 \log h - 0.474$,
- $Y = 0.493 \log h - 0.41$,
- $B = (1 - A)$, and
- h = thickness of the upper pavement layer (mm).

Given the value of h, one can compute X and Y and hence obtain A and B. With A and B and the values of R and D from field measurements, El can be computed and hence r can also be computed. Thus, the value of Eq can be obtained from Equation 1.

Results presented in Table 2 indicate that the pavement structure made with a substandard lateritic gravel base (Gatura II) is marginally weaker than the pavement structure made of crushed stone base (Gatura I) on the basis of deflection and the equivalent modulus.

The results of the pavement condition survey indicated that potholes in the lateritic gravel-based section (Gatura II) were usually shallow and roughly circular. The potholes in the stone-based section (Gatura I) were deeper, much larger, and less regular in shape. The road was not subjected to heavy traffic and little maintenance had been done since completion of the road. In some cases, the verge adjacent to the road had been eroded away, giving a height difference of up to 300 mm between the road pavement level and the verge. On the basis of the pavement condition survey, it appeared that the lateritic gravel-based section (Gatura II) resulted in a stronger pavement than the crushed stone-based section (Gatura I).

TABLE 2 TEST RESULTS OF DEFLECTION AND RADIUS OF CURVATURE MEASUREMENTS FOR GATURA I AND GATURA II

Test Section	Pavement Thickness (mm)	Mean Rebound Deflection (D) $\times 10^{-2}$ (mm)	Radius of Curvature (R) (m)	Equivalent Modulus (Eq) (kg/cm^2)
Gatura I (ES9) (stone base)	130	49	166	2137
Gatura II (ES10) (lateritic gravel base)	150	61	200	1836

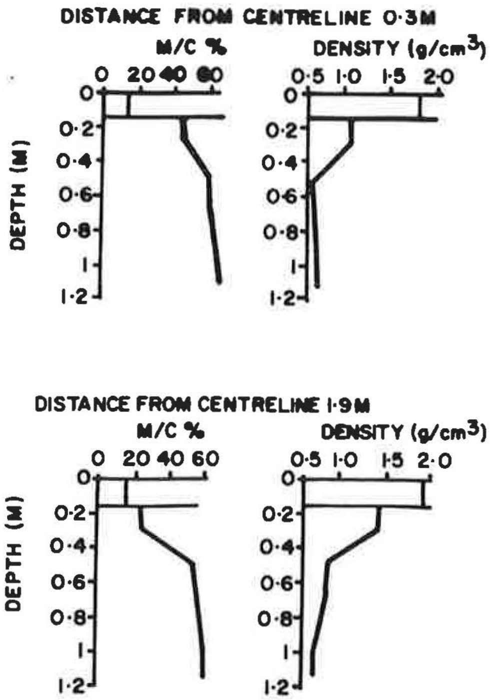

FIGURE 1 Moisture and density variation with depth for ES10 (Gatura II).

An interesting feature of the lateritic gravels was that they were plastic, becoming slippery because of rainfall, but on drying the fines were blown away leaving a densely packed stable gravel in a matrix of fines. This densely packed stable gravel base gave the pavement a strong structure that was difficult for surface water to penetrate. This is believed to be the main reason for the good performance by the lateritic gravel-based pavement structure.

Moisture and density measurements for Gatura II (ES10) gave results shown in Figure 1. The results indicate that moisture is higher in the subgrade than in the pavement, which is as expected.

In situ CBR values at the various depths in the layers of the pavement structure for Gatura II (ES10) with lateritic base were estimated using the DCP and CIH, giving the results shown in Figure 2, from which the CBR value obtained was close to the design CBR using the Road Note 31 (*3*) procedure. The results of the study also indicated that the CBR value of the subgrade immediately beneath the lateritic base in the case of Gatura II (ES10) had increased from values of about 5 to 20 percent to values of 30 to 50 percent. This phenomenon would require further detailed study to establish the cause of substantial increases in CBR value of subgrade.

According to Henry Grace and Partners (*5*), the cost per kilometer of various elements of construction for the two test sections was as follows (1972 prices):

- Cost of preliminaries, earthworks, culverts (excluding bridges), plus surface dressing = Kshs. 169,473 (common for both alternatives);
- Additional cost for crushed stone base alternative = Kshs. 180,744; and
- Additional cost for lateritic gravel base alternative = Kshs. 55,677.

Thus the total costs per kilometer were as follows:

- For crushed stone base construction—Kshs. 350,217
- For lateritic gravel base construction—Kshs. 225,150

The cost of lateritic gravel base construction (substandard construction) that performed reasonably well was about two-thirds that of the crushed stone base construction (standard construction).

CONCLUSIONS

The results of the study on lateritic gravel-based and stone-based pavements of the low-volume tea road led to the following conclusions:

- Rebound deflection values for both test sections were below 100×10^{-2} mm;

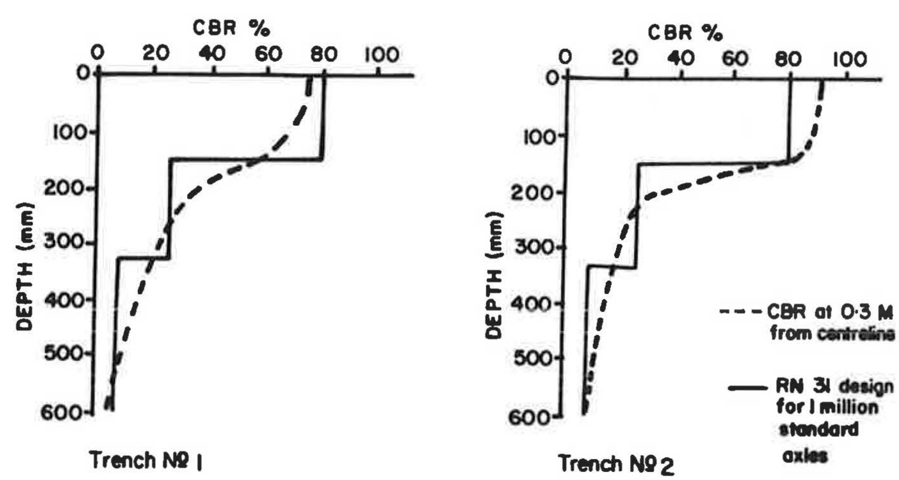

FIGURE 2 Variation of CBR with depth below surface for ES10.

• The radii of curvature of the deflected pavement profiles were above 150 m for both test sections;

• The experimental sections were still performing satisfactorily after 16 years of service during which they had carried about 0.11×10^6 standard axles; and

• Low-volume roads can be constructed using substandard materials such as lateritic gravel; such construction would give reasonable service and would cost must less than the standard pavement structure.

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