Pavement Design and Construction Specifications Developed for Low-Cost, Low-Volume Roads in Kenya

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Appropriate standards have been developed for low-volume roads in Kenya. In the post-independence era, the road network expanded considerably and there was rapid depletion of high-quality materials both for maintenance and for new construction. The network had also expanded into difficult areas, devoid of high-quality road building materials but of high agricultural and economic potentials. Therefore the Low-Cost Pavement Research Program was started in 1982 with the aim of optimizing the use of local materials of marginal quality for pavement layers and thereby reducing total road costs. Particular emphasis was put on using laterites, quartzites, coral gravels, and weathered rock, on subbase, base, and surface layers. Different bituminous binders—straight-run bitumen, short residue, cut backs, and emulsions—were also studied. In order to achieve optimum results, the program was targeted to areas devoid of high-quality materials for pavement and surface layers. Several trial sections were located on various low-volume roads throughout the country.

In 1982, when the Low-Cost Pavement Research Program began, classified roads in Kenya totaled 53 000 km. Only 10 percent were bitumen surfaced; the rest were either gravel or earth surfaced. The network has now expanded to 62 000 km (*1*) but still with similar 1:9 ratio of bitumen to gravel or earth roads. The majority of gravel or earth roads falls within secondary, minor, and special-purpose categories presented in Table 1. Most of these roads have less than 100 average annual daily traffic (AADT).

Because the main objective of the program was to provide specifications for the use of local but marginally substandard construction materials on low-volume roads, investigations concentrated on the following areas (see Figure 1):

1. Kiambu—phonolites and laterites,
2. Kisii/Oyugis—weathered siltstones and laterites,
3. Majengo—quartzites and laterites,
4. Kwale—coral stones and laterites,
5. Lodwar—quartzites and weathered lava,
6. Narok—quartzites, and
7. Garissa—quartzites and kunkar limestones.

CHARACTERISTICS OF TRIAL SECTIONS

Selection and Location of Trial Sections

The trial sections for the program were located in different parts of the country to represent different climatic, geological, and subgrade conditions. Most of the sections were located on level and straight stretches of the road to obtain uniform drainage conditions on both sides of the section. Detailed construction of the trial section was in checkerboard formation. In this manner, the effects of directional traffic volumes could be observed.

A total of seven areas and 30-km length of trial sections selected are presented both in Figure 1 and Table 2. There were also two roads—A1 Marich–Lodwar (195 km) and D348 Lodwar–Kalokol (60 km)—which were constructed between 1978 and 1985 with similar substandard materials.

PAVEMENT LAYER CHARACTERISTICS

Construction Methods

Similar to the normal road construction projects, standard equipment was used to haul, mix, compact, and place pavement layers on the program. This included motor graders, power shovels, dump trucks, pulvimixers, rollers, water bowsers, bitumen distributors, and aggregate spreaders. However, special power screens were used to remove fines from aggregates for the gravel seal.

Compaction requirements for subgrade and subbase or base layers were 95 percent of British Standard (BS) proctor and AASHTO-modified standard, respectively.

Parameters for the cross section varied according to the class of the road. Carriageway and shoulder widths were 5 to 7 m and 0.5 to 2.0 m, respectively, with narrower widths on the earth or gravel roads and wider widths on new alignments and primary or secondary roads. To improve the drainage, side drains were lowered to minimum 0.45 m below the finished road level. Details of The D291 Majengo trial section are shown in Figure 2.

Subgrade Soils

Subgrade soils in the areas covered by the program consisted mainly of friable clays in wet areas and clayey sands in dry areas. The strength of subgrade soils varied between 2 and 15 percent California bearing ratio (CBR). A layer of improved subgrade (lower subbase) was augmented on sections with less than 7 percent CBR. Both subgrade layers were applied on new alignments of Sites 5, 6, and 7—Turkana, Narok, and Garissa, respectively.

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TABLE 1 LENGTH OF CLASSIFIED ROAD NETWORK AS OF 1989 (1)

Class of road		Surface type: Bitumen	Gravel	Earth	TOTAL
Internat. Trunk Rds.	A	2,607.9	644.3	326.7	3,578.9
National Trunk Roads	B	1,171.2	928.3	641.0	2,740.5
Primary Roads	C	2,242.9	3,255.0	2,279.7	7,777.6
Secondary Roads	D	968.6	6,134.6	3,892.9	10,996.1
Minor & Sp. Roads					
Minor Roads	E	512.0	6,119.9	19,142.8	25,774.7
Government Access Rds	G	138.2	191.5	127.5	457.2
Settlement Roads	L	0.0	392.5	549.6	942.1
Rural Access Rds	R	14.7	6,972.7	729.7	7,717.1
Sugar Roads	S	6.7	80.0	858.1	944.8
Tea Roads	T	24.6	321.2	90.8	436.6
Wheat Roads	W	0.0	226.2	95.9	322.1
Total Minor + SP Roads		696.2	14,304.0	21,594.4	36,594.6
ALL CLASSES		7,686.8	25,266.2	28,734.7	61,687.7

Subbase and Base

The materials considered for these layers were laterites, quartzites, coral gravels, and weathered rocks. It was difficult to obtain gravels that met minimum requirements for low-standard bitumen-surfaced roads (2) of CBR 25 and 50 percent for subbase and base, respectively. There are additional requirements for plasticity index and proportion passing 0.075-mm sieve to be less than 15 and 35 percent, respectively.

These specifications, compared with those for high-volume roads, are relaxed. However, in most cases marginal strength properties are obtained even after stabilizing the materials with either lime or cement. It was therefore decided to scarify the existing base and add gravel to increase layer thickness from 150 to 200 mm on all sections with 20 to 30 percent CBR values.

INVESTIGATIONS ON SURFACE DRESSING MATERIALS

Scope of Investigations

Investigations on surface dressing materials were carried out in two main areas—aggregates and bituminous binders. The current specifications (1) do not allow stones with greater than 35 percent Los Angeles abrasion (LAA) and 26 percent aggregate crushing value (ACV) to be used in surface dressing. However, high-quality stones are scarce and not uniformly distributed within the country. Therefore, the use of alternative local materials (weathered stones and gravels) proved a viable option.

Unlike the aggregates, bituminous binders are more affected by the tropical climate. Generally, in a hot and dry climate

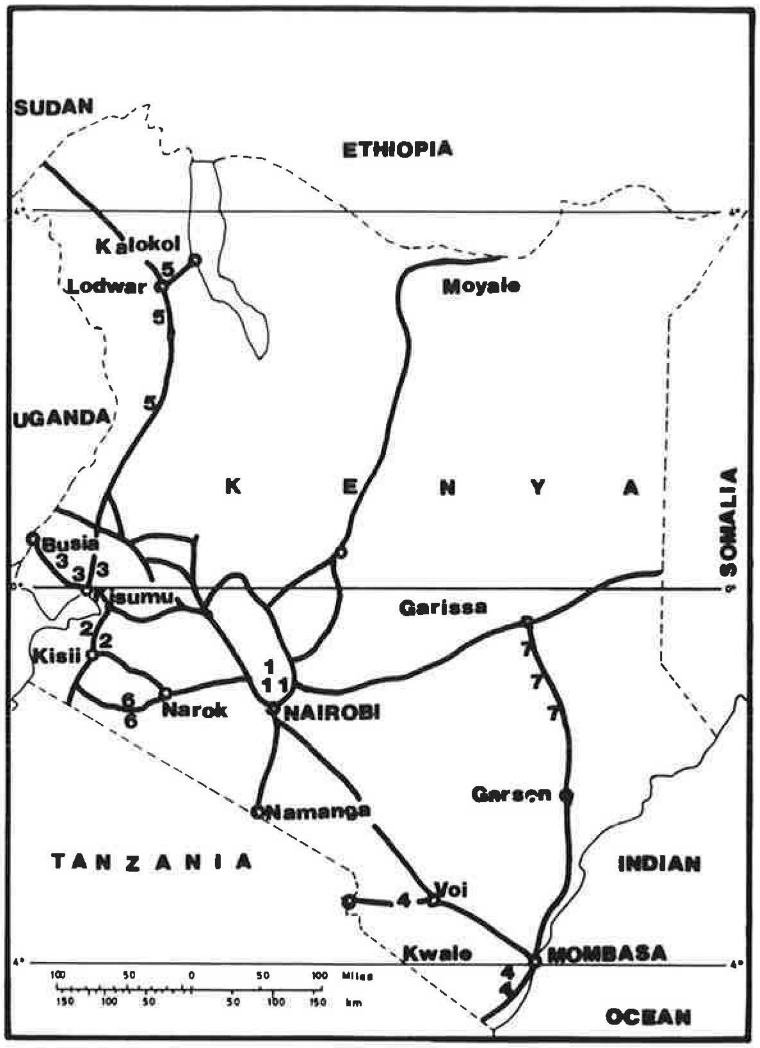

FIGURE 1 Location of low-cost trial sections.

the process of oxidation in binders is accelerated—the binder becomes brittle, then the surface cracks and deteriorates. This phenomenon is considered as one of causes of failures on the thin bituminous surfacings.

With the 80/100-penetration (pen.) bitumen as control, types of bitumen binders studied were as follows:

1. MC 3000 cutback blended from 80/100-pen. bitumen, diesel (fuel oil), and kerosene;
2. K1-60 and K1-70 cationic emulsions;
3. 250/500-pen. short-residue bitumen from Mombasa refinery; and
4. MB 2500 soft bitumen from Norway.

In order to increase adhesion, about 1 percent by weight of the antistripping agent diamin was added to the bitumen in liquid form.

Aggregate Properties

Important aggregate properties considered for the surface dressing trials were LAA, ACV, sodium sulfate soundness (SSS), bitumen affinity tests, and grading. Supplementary tests of water absorption and ACV on wet samples were carried out to determine the effect of water. Aggregate properties are presented in Table 3.

Except for the standard aggregates on the control sections that were applied in single nominal sizes, the weathered rocks and gravels were placed in a continuous graded matrix referred to as "Otta surfacing" (*3,4*) for both first and second seals. The continuous grading has major economic advantage of utilizing most sizes of the aggregates and hence minimizing wastage of gravel except for sizes outside 6 and 20 mm. The sizes of the continuous graded matrix were 6 to 20 mm and 6 to 16 mm for first and second seal, respectively.

In order to remove dust and improve on binder coating of the aggregates, particles finer than 6 mm were removed by use of power screens; wind and water cleaning of aggregates was necessary whenever available.

Spread and Spray Rates

The rate of spread of the aggregates varied between 70 and 100 m^2/m^3 from first to second seal. Because of both the

TABLE 2 CHARACTERISTICS OF TRIAL SECTIONS

Trial Section	Altitude (m)	Rainfall mm	Subgrade	Length km
1.1 C65 Ruiru	1540	1250	red clay	7.100
1.2 E409 Ndumberi	1540	1500	red clay	1.000
1.3 E437 Kiratina	1540	1500	red clay	0.650
1.4 AC Thuita	1540	1500	red clay	0.750
2.1. C21 Kisii	1530	2000	red clay	1.000
2.2. D220 Oyugis	1400	1610	red clay	1.000
3.1. D291 Majengo	1620	1790	red clay	1.000
3.2. E290 Bukuga	1620	1790	red clay	0.560
3.3. D264 Kima	1580	1790	red clay	0.560
4.1. C106 Kwale	90	820	brown sands	0.800
4.2. A23 Voi	650	500	brown sands	0.500
4.3. A14 Waa	20	1250	sandy soil	1.000
5.1. A1 Marich	1100	1000	sandy clay	2.600
5.2. A1 Lodwar	510	170	clayey sands	4.200
5.3 D348 Kalokol	460	170	loamy sands	0.320
6.1. C12 Narok	1900	820	brown clays	1.300
7.1. B8 Garissa	130	300	clayey sands	5.000

continuous grading and the rounded shape of the gravel aggregates, higher bitumen spray rates were necessary. The residual bitumen spray rates ranged from 1.0 to 1.4 L/m^2 depending on the size, shape, and cleanliness of the aggregates. Comparatively, the design manual's (*2*) residual bitumen spray rates for 10- to 14-mm nominal-size high-quality aggregates range from 0.8 to 1.2 L/m^2.

TECHNICAL EVALUATION OF THE TRIAL SECTIONS

Monitoring Program

After the construction of the trial sections was completed in 1985, a monitoring program was set to evaluate the performance of the sections. The monitoring program was carried out between 1985 and 1988, twice annually—after heavy rains from May to July and during the dry season of September to November. This procedure allowed the monitoring of the weakest and strongest states of the pavement. The parameters considered when evaluating the performance of the trial sections were as follows:

- Traffic census;
- Benkelman beam deflection measurements;
- Dynamic cone penetration (DCP) resistance;
- Visual inspections of drainage conditions and pavement defects (crackings, deformations, potholes, and patchings);
- In situ densities, moisture content, and gradings; and
- Roughness measurements from a towed bump integrator.

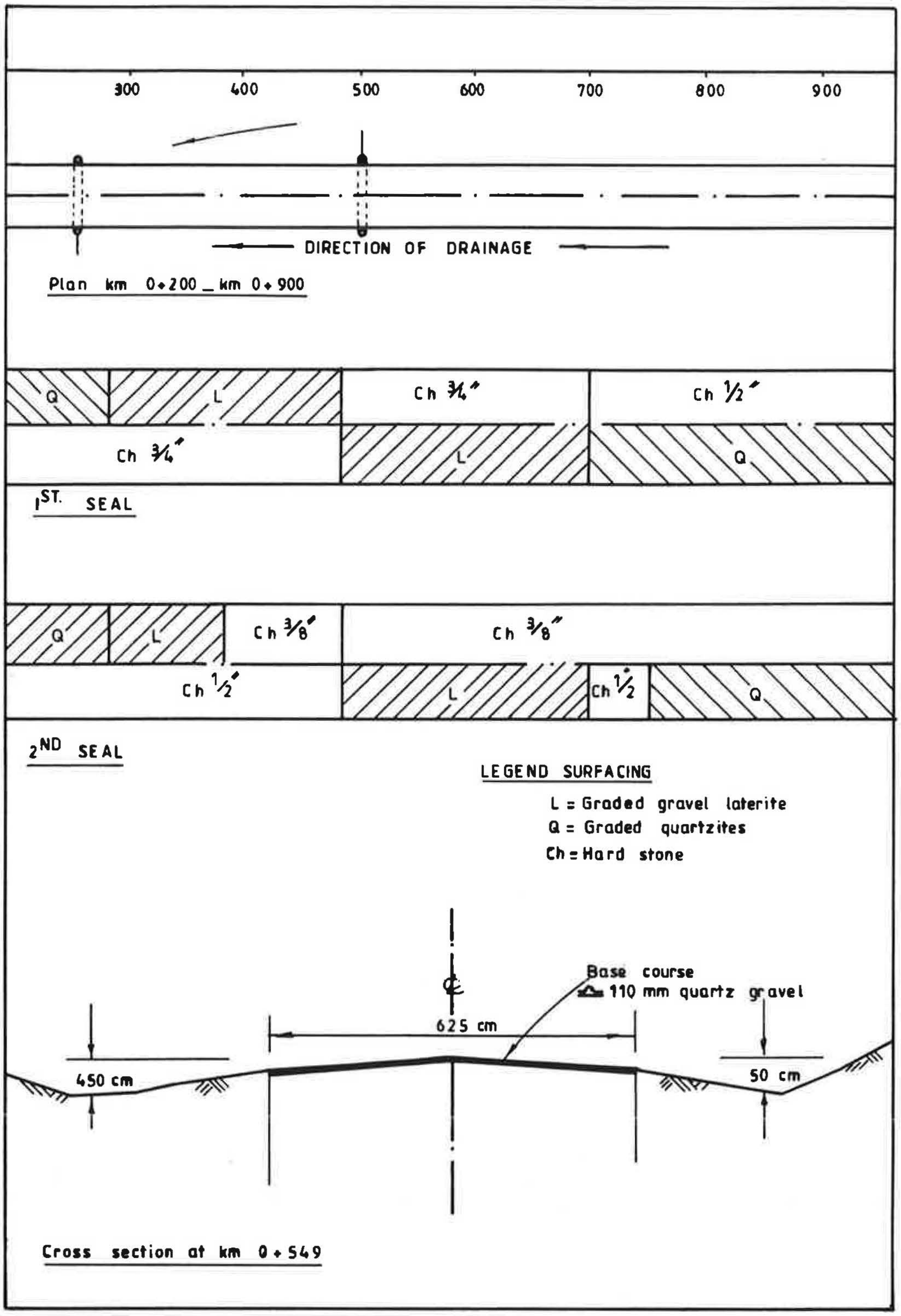

FIGURE 2 Details of D-291 Majengo trial section.

TABLE 3 PROPERTIES OF AGGREGATES ON THE TRIAL SECTIONS

Material	Abrasion test LAA[1] %	Crushing test ACV[2] dry %	Crushing test ACV[2] wet %	Chemical test SSS[3] %	Water absorption %
Ruiru laterites	70-83	48-55	59-62	61	11-13
Oyugis laterites	64	55	62	46	10
Kima laterites	73	48	57	90	9
Kwale laterites	37-67	45	51	9	-
Bukuga quartz	54	29	30	7	4
Lodwar quartz	45-49	26-30	-	-	-
Narok quartz	39	23	-	-	-
Garissa calcrete	29-40	23-30	-	-	-
Kwale/Waa coral	37	37	-	12	-
Ruiru soft tuff	44-51	32-37	48-56	26	16-23
Kisii siltstones	60	36	52	7	-
Voi (Taru grit)	37	28	-	3	-
Lodwar lava	49	32	-	-	-

Note: - indicates test results not available

1 LAA Los Angeles Abrasion

2 ACV Aggregate Crushing Value

3 SSS Sodium Sulphate Soundness

The results and recommendations from the monitoring program were presented in an internal report (*5*). A summary of observations follows:

- Marked increase of traffic AADT was recorded in all trial sections, probably because of the improved nature of the surfacing.
- Good relationship between deflections and DCP resistance was recorded.
- The depth of side ditches and carriage width decreased because of siltation, regraveling, and reshaping of the shoulders.
- The in-situ moisture contents, especially on the shoulders, fluctuated with the seasons. However, the dry density increased corresponding to the fines (<0.075 mm) on the base. This resulted from postcompaction from traffic and breakage of coarser gravel particles.

Performance of Aggregates for Surface Dressing

In general, the performance of the aggregates depended greatly on the hardness resistance (LAA and ACV values). As expected, the control sections constructed of quality aggregates provided the best performances. Next in descending order of performance were quartzites, weathered lava, siltstones, Kunkar limestones, coral stones, and laterites nodules. Apart from the laterites in Kwale, with reasonable LAA and ACV values, presented in Table 3, the laterites proved to be unsuitable as surface dressing aggregate for any traffic volume.

Performance of Bituminous Binders

The cutback MC 3000 exhibited the best performance, by holding the aggregates together and remaining live before becoming brittle and cracking. Next in performance, in the following order, were short residue (250 to 500 pen.), Norwegian MB 2500, K1–70 emulsion, straight run (80/100 pen.), and K1–60 emulsion.

Curing for cutback MC 3000, Norwegian MB 2500, and short residue took a long time (3 to 7 days), rendering them suitable only for new constructions but not for roads requiring immediate opening to traffic.

Antistripping agents are required to increase binder adhesion on the substandard aggregates and particularly on quartzitic gravels.

CONCLUSIONS

Overview

The results both from the Low-Cost Pavement Research Program and the Turkana road trials (*4*) since 1978 have provided valuable information to enable drafting of specifications for low-standard pavement. Further monitoring of the performance of the sections is continuing.

Despite lowered standards to accommodate local gravels for low-volume roads, materials strength, specification for LAA, ACV, and grading are still vital.

It was necessary to separate low traffic [Class T5 in the *Road Design Manual* (*2*)] into two categories, according to AADT and cumulative equivalent standard axles (ESAs), as follows:

- Very light traffic, 0 to 50 AADT and 0 to 100,000 cumulative ESAs; and
- Light traffic, 50 to 100 AADT and 100,000 to 500,000 cumulative ESAs.

Low-Standard Surfacing Aggregates

From the performances of the trial sections, it is recommended that laterites not be used as aggregates in surface dressing. However, quartzites, corals, calcrete, kunkar limestones, weathered lava, and siltstones can be used.

Both LAA and ACV are important strength parameters in the selection of surface dressing materials.

Grading is important in providing a stable interlocking matrix; however, removing aggregates finer than 6 mm by screening is recommended.

In order to enhance binder adhesion on aggregates, cleaning by water or wind is necessary, and for aggregates with poor bitumen affinity the use of antistripping agents is recommended.

TABLE 4 MATERIALS RECOMMENDATIONS FOR BASES

Parameters	very light traffic	light traffic	Requirements in Chapter 12 of the Manual (2)
maximum size mm.	10-40	10-40	10-40
fines 0.075 mm. %	< 40	< 35	< 35
plasticity index max			
dry areas[1]	< 25	< 20	< 20
wet areas	< 20	< 15	< 15
CBR (4day soak)min			
dry areas	25	35	50
wet areas	35	50	50
LAA max	70	60	-[2]
ACV max	45	40	-
thickness min. mm.	200	200	150

note - 1 dry areas have less than 800mm. annual rainfall

2 was not applicable

Guidelines for aggregates specifications for low-standard surfacings are as follows:

	Very Light Traffic	*Light Traffic*
LAA max (%)	60	50
ACV max (%)	40	35

Low-Standard Bases

The materials recommendations for bases are shown in Table 4.

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