



AFCAP/KEN/89 - Research Project for Establishment of Appropriate Design Standards for Low Volume Sealed Roads in Kenya

DESIGN REPORT

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This project was funded by the Africa Community Access Programme (AFCAP) which promotes safe and sustainable access to markets, healthcare, education, employment and social and political networks for rural communities in Africa.

Launched in June 2008 and managed by Crown Agents, the five year-long, UK government (DFID) funded project, supports research and knowledge sharing between participating countries to enhance the uptake of low cost, proven solutions for rural access that maximise the use of local resources.

The programme is currently active in Ethiopia, Kenya, Ghana, Malawi, Mozambique, Tanzania, Zambia, South Africa, Democratic Republic of Congo and South Sudan and is developing relationships with a number of other countries and regional organisations across Africa.

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Executive Summary

A proposal was formulated to research on the application of the DCP Design Method in Kenya with the overall objective to support rural development through establishment of appropriate LVSR pavement design standards which in turn can facilitate the expansion of the paved rural road network.

The project is part of the AFCAP research portfolio and is funded by Kenya Rural Roads Authority, KeRRA, and Crown Agents, UK.

Five test sections are to be designed using the DCP Design method. The five test sections are:

Road	Section length	Region	Annual rainfall
D 379	+/- 400 m	Kiambu	800 – 1200 mm
E 511	+/- 900 m	Muranga	1600 – 2000 mm
D 382	+/- 600 m	Nyandarua	800 – 1200 mm
D 435	+/- 600 m	Nyeri	1200 – 1600 mm
D 462	+/- 700 m	Laikipia	600 – 800 mm

12 hour (6 am to 6 pm) traffic counts were carried out over 7 days in the last half of January 2012. The traffic figures were adjusted upwards by 30% to capture evening and night time traffic and to account for margin of error due to the counting method that was applied.

On this basis the design traffic load were estimated using a 5% and 4% annual increase for buses/medium trucks and heavy/articulated trucks respectively, and the best available data for actual Vehicle Equivalent Factors VEF for commercial vehicles from comparable roads in the project regions.

The traffic counts will be repeated as part of the monitoring programme in the harvesting season August/September 2012 to capture seasonal traffic variations. At the same time axle load surveys on the project roads will be carried out to determine actual VEF for the project roads.

Adjusted Average Daily Ttraffic (ADT) including NMT	D382 Nyandarua	E511 Muranga	D379 Kiambu	D435 Nyeri	D462 Laikipia
Bicycles	277	8	72	54	326
Others (NMT)	18	0	0	13	11
Motor Bikes	302	207	258	196	352
Cars	86	34	302	85	108
Vans/Matatus	177	75	366	43	247
Small trucks	5	11	3	3	32
Buses	1	6	3	2	4
Medium trucks - 2 axles	43	10	14	31	34
Heavy trucks - 3 axles	5	2	2	0	0
Articulated trucks - 4 or more axles	0	0	0	0	1
Total	914	354	1021	430	1114
ADT (excl. NMT and Motorbikes)	317	139	691	166	426
Heavy traffic % of ADT	16 %	13 %	3 %	20 %	9 %
NMT % of ADT	32 %	2 %	7 %	16 %	30 %

Table 1: Estimated ADT 2012

Road	D382	D379	E511	D435	D462
CESA (15 yrs)	294643	85943	53984	157524	187666

Table 2: Design traffic loading (15 years)

Cross-sections based on the current Kenya Minor Roads Standard are proposed for these roads.

- Standard Cross-section 5.4m carriageway plus 0.3 m sealed shoulders;
- Reduced Cross-section 5.4m carriageway for hilly/mountainous terrain;

both with a minimum of 3.5% camber to ensure good runoff from the carriage way and drain inverts 750 mm below the crown.

Due to the narrow road reserve in many areas of Kenya it is felt that both the recommendations in ORN 6 and Ethiopian LVR Design Manual for similar roads will be too costly and will not be conducive to the expansion of the paved rural road network and rural development in general.

The test sections are short and widening may be done later if the roads are upgraded and construction of wider cross-sections is found to be economically justified.

DCP tests were used to determine the pavement design using the WinDCP Software from CSIR, South Africa. The analysis based on the current traffic data shows that the recommended pavement designs have a structural capacity well in excess of the Design Traffic Load for a 15 year design period.

DCP design curves for the Pavement Classes are based on the DCP Design Catalogue from Malawi which is currently the only one of its kind. There is good reason to believe that this is applicable also for Kenya and the monitoring over time will reveal if any adjustments to this catalogue are required.

The recommended surfacing is 15 mm Cold Mix Asphalt similar to the one used on the Demonstration Road D415 in Muranga. For the performance of the asphalt, it is important that the correct aggregate grading is achieved, being as close as possible to the upper limit of the grading envelope to achieve a dense mix.

D462 has recently been repaired and regravelled. Further investigations are required to determine if the road should still be part of the project.

The cost of upgrading the four remaining sections has preliminarily been estimated to KES 20,892,487 or KES 8,356,995/km.

1. Project background

The Africa Community Access Programme (AFCAP) is a regional programme funded by the UK government through the Department for International Development (DFID) which is supporting research, knowledge dissemination and training for improved access for rural communities in Africa.

One of the objectives of AFCAP is to operationalise the SADC Guideline for Low Volume Sealed Roads (LVSR). A significant portfolio of research activities has now been established in the AFCAP participating countries. AFCAP provides technical assistance for these activities and promotes the uptake of the research findings through revised, country specific LVSR design manuals and specifications.

Based on extensive research and performance monitoring of LVSRs constructed with light pavements and non-conventional materials during the last 20-30 years, the Council for Industrial and Scientific Research, South Africa (CSIR) has developed a simplified method for design of LVSRs based on Dynamic Cone Penetrometer (DCP) tests with a DCP Design Catalogue. The method obviates the need for extensive laboratory sub-grade testing at the design stage, yet provides reliable results. Designs based on this catalogue can give substantial cost savings for upgrading of rural gravel and earth roads to LVSR standard.

The recently completed AFCAP Project MAL/016 “Performance Review of Design Standards and Technical Specifications for Low Volume Sealed Roads in Malawi” reviewed the performance of four sections of low cost design LVSRs, some with more than 20 years in service. The roads were constructed using natural gravel bases (average soaked CBR 50% and high PI) on the existing consolidated earth/gravel road formation, with a Cape Seal. All of the roads have performed exceptionally well. The study concluded that the design approach was highly appropriate for LVSRs in Malawi and recommended the adoption of the DCP Design Catalogue for future projects.

On this background a proposal was formulated to research on the application of the DCP Design Method in Kenya with the overall objective to support rural development through establishment of appropriate LVSR pavement design standards which in turn can facilitate the expansion of the paved rural road network.

The project is part of the AFCAP research portfolio and is funded by Kenya Rural Roads Authority, KeRRA, and Crown Agents, UK.

For budgetary and logistical reasons, the project initially aims to design and construct five short test sections located in Central Province. The sections are located in areas with different soils, topography and climatic conditions.

The five test sections are:

Road	Section length	Region	Annual rainfall
D 379	+/- 400 m	Kiambu	800 – 1200 mm
E 511	+/- 900 m	Muranga	1600 – 2000 mm
D 382	+/- 600 m	Nyandarua	800 – 1200 mm
D 435	+/- 600 m	Nyeri	1200 – 1600 mm
D 462	+/- 700 m	Laikipia	600 – 800 mm

Additional test sections with different soils and climatic conditions from those in Central Province may be identified and included in the future, if the necessary budget provisions can be made.

2. Traffic Analysis

Seven day 12 hour (6 am – 6 pm) traffic counts were carried out in the last half of January 2012. The roads had then dried up since the last rains in mid December. The traffic figures are therefore not distorted because of wet conditions on the roads. However, there are likely to be some seasonal variations in the traffic and traffic counts will therefore be repeated during the harvesting season August/September 2012.

Details of the traffic counts and analysis are shown in Annex 1. A summary of the traffic count is shown in Table 1 below.

Average Daily Ttraffic (ADT) including NMT	D382 Nyandarua			E511 Muranga			D379 Kiambu			D435 Nyeri			D462 Laikipia		
	Towards C77	Towards Ngano	Total traffic	Towards Kinjona	From Kinjona	Total traffic	From Wamwangi	Towards Wamwangi	Total traffic	Towards Ihuruu	Towards Kanjora	Total traffic	Towards A2	Towards Luakeli	Total traffic
Bicycles	106	107	213	3	3	6	27	28	55	22	19	42	125	126	250
Others (NMT)	7	7	14	0	0	0	0	0	0	5	5	10	4	4	8
Motor Bikes	115	117	232	82	78	159	108	91	199	81	70	151	122	149	270
Cars	36	30	66	11	15	26	123	110	233	28	38	66	42	42	83
Vans/Matatus	69	67	136	29	28	58	146	135	281	19	14	33	88	102	190
Small trucks	2	2	4	5	4	9	1	1	2	2	1	3	11	13	24
Buses	0	0	1	2	2	4	1	1	3	1	1	2	1	1	3
Medium trucks - 2 axles	17	16	33	5	3	8	5	6	11	12	12	24	12	14	26
Heavy trucks - 3 axles	2	2	4	1	1	2	1	1	2	0	0	0	0	0	0
Articulated trucks - 4 or more axles	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Total	354	349	703	139	133	272	412	373	785	171	160	330	406	451	857
NMT % of ADT			32 %			2 %			7 %			16 %			30 %

Table 3: Summary of traffic counts

The counting station for D382 was at km 6+000 from the junction with C77. The traffic figures for the light traffic (bicycles, motor bikes, cars, vans/matatus) are therefore probably quite a bit higher than at Ngano Village some 15 km from the junction. If the whole road is upgraded in the near future, the ADT figures will probably be more representative.

Based on a study carried out in Kenya on the possible margin of error for various traffic counting methods¹, the ADT has been adjusted by a factor of +30% to account for the uncertainty due to the counting method that was applied. The adjusted ADT is then deemed to include evening and night time traffic that was not counted. The adjusted traffic figures are shown in Table 2.

Adjusted Average Daily Ttraffic (ADT) including NMT	D382 Nyandarua	E511 Muranga	D379 Kiambu	D435 Nyeri	D462 Laikipia
Bicycles	277	8	72	54	326
Others (NMT)	18	0	0	13	11
Motor Bikes	302	207	258	196	352
Cars	86	34	302	85	108
Vans/Matatus	177	75	366	43	247
Small trucks	5	11	3	3	32
Buses	1	6	3	2	4
Medium trucks - 2 axles	43	10	14	31	34
Heavy trucks - 3 axles	5	2	2	0	0
Articulated trucks - 4 or more axles	0	0	0	0	1
Total	914	354	1021	430	1114
ADT (excl. NMT and Motorbikes)	317	139	691	166	426
Heavy traffic % of ADT	16 %	13 %	3 %	20 %	9 %
NMT % of ADT	32 %	2 %	7 %	16 %	30 %

Table 4: Adjusted ADT (+30%) for project roads

¹ "A review of rural traffic counting methods in developing countries", J. Howe, Road Research Laboratory 1972

3. Proposed cross sections

Overseas Road Note 6 “A guide to geometric design” recommends as follows:

ROAD FUNCTION	DESIGN CLASS	TRAFFIC FLOW * (ADT)	SURFACE TYPE	WIDTH (m)		MAXIMUM GRADIENT (%)	TERRAIN/DESIGN SPEED (km/h)		
				CARRIAGE-WAY	SHOULDER		MOUNTAINOUS	ROLLING	LEVEL
Arterial	A	5,000–15,000	Paved	6.5	2.5	8	85	100	120
	B	1,000–5,000	Paved	6.5	1.0	8	70	85	100
Collector	C	400–1,000	Paved	5.5	1.0	10	60	70	85
	D	100–400	Paved/Unpaved	5.0	1.0 ⁺	10	50	60	70
Access	E	20–100	Paved/Unpaved	3.0	1.5 ⁺	15	40	50	60
	F	< 20	Paved/Unpaved	2.5/3.0	Passing Places	15/20	N/A	N/A	N/A

Based on the adjusted ADT in table 2, D379 in Kiambu would fall in Design Class C and all the other roads in Design Class D.

For comparison, table 3 shows the recommended geometric design standards for paved roads with ADT 150-300 as per the Ethiopian LVR Design Manual.

Design Element	Unit	Flat	Rolling	Mountain	Escarpment	Populated areas
Design speed	km/hr	70	60	50	25	50
Width of running surface	m	6.5 ⁽²⁾	6.5 ⁽²⁾	6.5	6.5	6.5 ⁽¹⁾
Width of shoulders	m	1.25 ⁽²⁾	1.25 ⁽²⁾	0.5	0.5	1.25 ⁽²⁾
Total width	m	9.0	9.0	7.5	7.5	9.0
Min stopping sight distance	m	110	90	70	25	65
Min horizontal radius for SE=4%	m	195	135	85	15 ⁽⁴⁾	85
Min horizontal radius for SE=7%	m	170	120	75	17 ⁽⁴⁾	NA
Min horizontal radius for SE=10%	m	150	105	70	22 ⁽⁴⁾	NA
Max desirable gradient	%	4	7	10	12	4
Maximum gradient	%	7	10	12 ⁽²⁾	12 ⁽²⁾	6
Min crest vertical curve	K	21	12	7	4	7
Min sag vertical curve	K	4.8	3.5	2.2	1.3	2.2
Normal cross-fall	%	3	3	3	3	3
Shoulder cross-fall	%	6	6	3	3	6

Table 5: Geometric design standards for ADT 150-300 as per Ethiopian LVR Design Manual

Only E511 Muranga and D435 Nyeri would have ADT 150-300 when taking account of annual increase. The other three roads will exceed this traffic level.

A full economic appraisal for each road would be needed to determine the optimal cross-section. However, it is felt that a total roadway width of 9.0 m as recommended in the Ethiopian LVR Design Manual (7.5 m for E511 which is in hilly/mountainous terrain) for any of these roads would be unrealistic and unwarranted for the following reasons:

- The costs would increase dramatically and probably jeopardise the expansion of the paved rural road network in the foreseeable future;
- In many areas of the country the road reserve is not wide enough to accommodate such widths. Massive expropriation of properties along the roads would have to be done with associated costs and negative impact on the affected households and businesses along the roads;
- The gravelling cycle would continue almost unabated resulting in yet more waste of scarce gravel resources and prolonged negative impact on people’s health due to dust.
- Vehicle operating and transport costs in and out of rural areas would remain higher than if more roads were to be paved.

For much the same reasons, but less so, the recommendations in ORN 6 are also deemed to be unrealistic if the goal is to upgrade a greater portion of the rural road network to paved roads.

The traffic safety aspect must be weighed against the affordability of the chosen geometric design standard and the negative effects of not being able to expand the paved network due to costs and other hindrances. Being too ambitious in the choice of geometric design standards for the lower end of the rural road network (D and E roads) would therefore in all likelihood be less conducive to rural development in the foreseeable future as opposed to choosing a more affordable standard.

Potential traffic safety hazards can be mitigated by installation of speed bumps and signs in and around villages and at danger spots, yet the main benefits of reduced costs of rural transport would be attained.

Based on the above considerations, the cross-sections shown in figures 1 and 2 below are proposed for the test sections. These are just short sections and widening can be done later as and when the entire links are upgraded, if a wider cross-section is found to be justified. A more economical alternative would be to keep the proposed cross-section and only widen the roads through villages.

Standard Cross-section: Total sealed roadway width 6.0 m incl. 0.3 m sealed shoulders

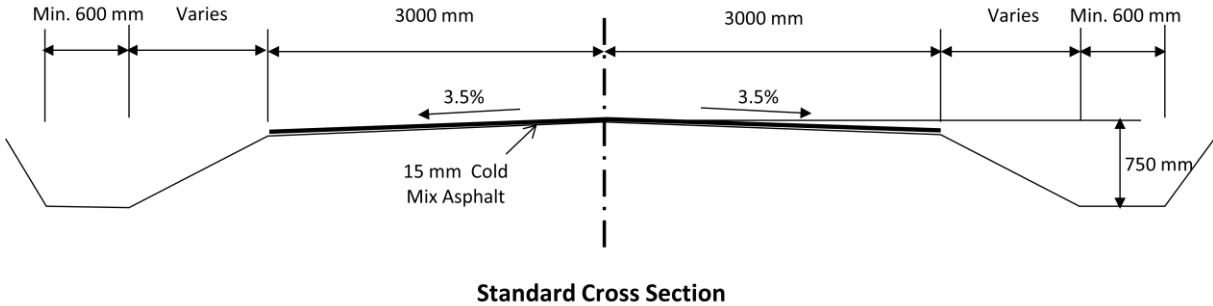


Figure 1: Standard cross section (D382, D379, D435, D462)

Reduced Cross-section: Total sealed roadway width 5.40 m (with local widening in curves if possible)

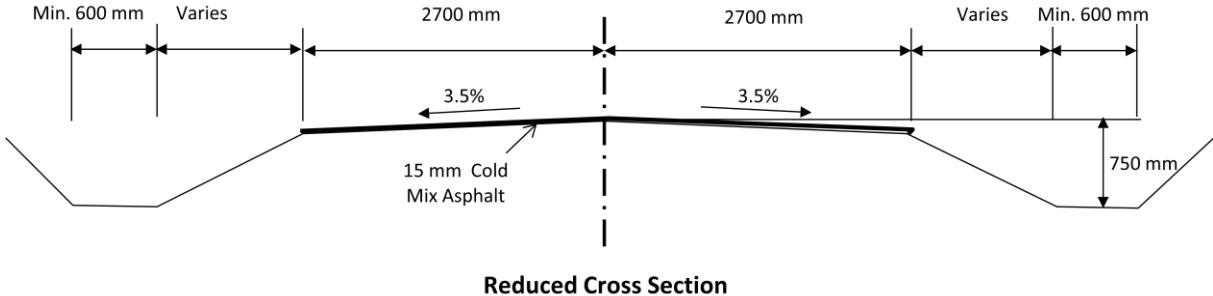


Figure 2: Reduced Cross Section (E511)

The Reduced Cross-section corresponds to the Minor Roads standard for Kenya. The Standard Cross Section is merely an improvement of the Minor Roads standard with inclusion of 0.3 m sealed shoulders where the available space can accommodate this width.

A detailed field survey was carried out by Norken (PTY) Ltd on D379, D382 and E511. The main findings and alignment data are shown in Annex 4. Surveys on D435 and D462 will be carried out at a later stage.

For D382 there is adequate space for the standard cross-section although the current width is only about 5.0m between deep, scoured side drains. Widening, by filling in and compacting the existing side drains and then cutting new side drains will have to be done.

For D379 in Kiambu the reserve is quite narrow and the existing carriageway effective width varies from 4.0 to 5.0 m. Widening by benching in layers and constructing relatively steep side slopes will have to be done to fit the proposed cross section within the width of the reserve.

The ADT on D435 is only slightly higher than on E511 but with a higher proportion of heavy traffic, hence the Standard Cross-section is recommended.

For D435 and D462 widening to accommodate the standard cross section is deemed to be feasible although detailed site investigations are yet to be carried out.

The significantly lower traffic and the nature of the terrain on E511 justify construction of a reduced cross section. It is simply not feasible to construct the wider cross section without incurring major cost for earthworks and potentially destabilizing the steep cut slopes along the road. It could however be possible to do some limited local widening in the curves. The current carriageway has an effective width of approx. 4.75 m which has been observed to be adequate for the current traffic.

4. Pavement design

The Design Traffic Loading has been determined using the following formula:

$$CESA = 365 \times T_b [(1+r)^n - 1]/r , \text{ where}$$

- CESA = Cumulative Equivalent Standard 80 kN axles over the design period
- T_b = Design Equivalent Standard Axles, DESA, at base year 2012
- n = Design period in years
- r = annual growth rate

An annual growth rate of 5% has been used for buses and medium trucks. A slightly lower growth rate of 4% has been assumed for heavy and articulated trucks. Due to the nature and location of the roads, no diverted traffic has been taken into account.

Based on performance reviews of similar low cost pavement designs elsewhere², it has been suggested that the Vehicle Equivalent Factors, VEF, commonly used may be too high. This is confirmed by recent axle load surveys on comparable roads in the respective project areas. The Design Traffic Loading has hence been analyzed using both the VEF as per the Kenya Road Design Manual and reduced values based on these axle load surveys:

- VEF for D379 based on survey on D398 Ruiru-Munduro
- VEF for E511 based on surveys on D416 and D440
- VEF for D382 based on survey on C69
- VEF for D435 and D462 based on survey for C69 due to lack of better data

Vehicle class	VEF (Kenya RDM)	VEF D379	VEF E511	VEF D382, D435, D462
Buses	1	0.08	0.2	0.36
Medium trucks – 2 axles	1	0.6	0.2	0.76
Heavy trucks – 3 axles	4	1.69	2.3	2.92
Articulated trucks – 4+ axles	4	2.76	0.6	1.19

Table 6: Vehicle Equivalent Factors used for the analysis

Axle load surveys on the project roads will be carried out in conjunction with the traffic counts in 2012 after construction of the sections to verify the validity of the reduced VEFs.

For details of the Design Traffic Loading analysis, see Annex 1. A summary of the Cumulative Standard Axles over 5, 10 and 15 year design periods using both the standard and reduced VEF is shown in Tables 5 to 9 below.

D379 Kiambu	Combined both directions ³			From Wamwangi			Towards Wamwangi		
	5	10	15	5	10	15	5	10	15
Design period (years)									
CESA (standard VEF)	43245	97494	165585	30013	67612	114737	26020	58639	99552
CESA (reduced VEF)	22429	50584	85943	13998	31510	53431	13998	31510	53431

Table 7: Design Traffic Loading D379 Kiambu

E511 Muranga	Combined both directions ³			Towards Kinjona			From Kinjona		
	5	10	15	5	10	15	5	10	15
Design period (years)									
CESA (standard VEF)	43213	97328	165131	33967	76376	129354	22026	49665	84368
CESA (reduced VEF)	14330	32053	53984	11942	26711	44987	7988	17946	30370

Table 8: Design Traffic Loading E511 Muranga

D382 Nyandarua	Combined both directions ³			Towards C77			Towards Ngano		
	5	10	15	5	10	15	5	10	15
Design period (years)									
CESA (standard VEF)	102625	231716	394179	66117	149205	253671	62163	140441	239053
CESA (reduced VEF)	76968	173787	295634	50102	113104	192364	44131	99748	169870

Table 9: Design Traffic Loading D382 Nyandarua

² Performance Review of Design Standards and Technical Specifications for Low Volume Sealed Roads in Malawi, Mike Pinard 2011

D435 Nyeri	Combined both directions ³			Towards Ihuru			Towards Kanjora		
Design period (years)	5	10	15	5	10	15	5	10	15
CESA (standard VEF)	53245	121201	207931	34287	78046	133895	32270	73455	126019
CESA (reduced VEF)	40337	91819	157524	24202	55091	94514	26219	59682	102390

Table 10: Design Traffic Loading D435 Nyeri

D462 Laikipia	Combined both directions ³			Towards A2 junction			Towards Juakali		
Design period (years)	5	10	15	5	10	15	5	10	15
CESA (standard VEF)	70802	160599	274517	46188	104548	178314	44291	100583	172141
CESA (reduced VEF)	48309	109681	187666	30173	68447	117008	30213	68655	117575

Table 11: Design Traffic Loading D462 Laikipia

All the roads are narrower than 7.0 m, hence 80% of the combined traffic load has been used for the Design Traffic Load as per the Kenya Road Design Manual.

For research purposes the CESA values computed using the reduced VEF have been used for the pavement analysis with WinDCP software. These are highlighted in red in the tables above. Roads D382, D435 and D462 all fall in the 0.1-0.3 MESA (Million Equivalent Standard Axles) bracket, whereas E511 and D379 both fall in the 0.03 - 0.1 MESA bracket.

Monitoring of the performance of the sections will give an indication of whether use of the reduced VEF is justified.

5. DCP analysis

DCP tests for the D382, D379 and E511 roads were carried out in November in the middle of the rainy season. At the same time material samples were taken of the gravel and subgrade layers for determination of in situ moisture content at the time of testing and the CBR at various compaction efforts and moisture contents as shown in Table 10 below.

It has been found that the moisture content of the pavement layers in a sealed road normally fluctuates between 0.75 of OMC and OMC. Non-standard, in situ materials used for Low Volume Sealed Roads, LVSR, have a significantly higher strength at these moisture contents compared to the 4-day soaked CBR values normally used in the pavement design. These materials have been found to perform well provided that they are adequately compacted and that the bituminous surfacing and drainage system prevents the materials from being soaked during the wet season.

Table 7 clearly shows the inherent strength of the in situ subgrade and high PI laterite gravel at expected in service moisture contents. It is this strength one wants to utilize in low cost pavement design of LVSR.

DCP tests were carried out on D435 and D462 on 17 January 2012. Additional DCP test were carried out on D382, D379 and E511 on January 30 and 31 2012. The rains stopped around mid December 2011, hence the pavements had dried out for about one month when these tests were carried out. On D382 further DCP tests were carried out on 21 March towards the end of the dry season to confirm the design assumptions based on the previous DCP tests.

Sample No	Layer	Ref.	Grading						ATTERBERG LIMITS					Comp. T180		FMC	Moisture condition	CBR at various compaction levels				Increase from 93% to 98%	
			20 mm	10 mm	5 mm	2mm	425 µm	75 µm	LL (%)	PL (%)	PI (%)	LS (%)	PM	MDD (Kg/m ³)	OMC (%)			93 %	95 %	98 %	100 %		
D379 Kiambu	555/S/2011	Gravel	0+000	100	92	75	53	33	24	44	22	22	11	726	1910	14,0	16	4-Dsoak	20	30	40	42	100 %
																		OMC	125	145	165	195	32 %
																		.75 OMC	185	194	197	217	6 %
	557/S/2011	Gravel	0+200	100	94	78	52	34	23	40	22	18	9	612	1910	14,0	11	4-Dsoak	22	27	34	35	55 %
																		OMC	47	56	69	78	47 %
E511 Muranga	560/S/11	Gravel	0+000	100	86	69	48	34	20	37	26	11	6	374	1895	13,4	18	4-Dsoak	15	17	20	22	33 %
																		OMC	67	100	138	144	106 %
																		.75 OMC	128	142	162	174	27 %
	562/S/11	Gravel	0+450	100	88	66	44	25	10	48	25	23	11	575	1880	14,8	17	4-Dsoak	15	18	24	26	60 %
																		OMC	80	116	160	209	100 %
D382 Nyandarua	564/S/11	Subgrade	0+900	100	97	95	90	64	30	53	40	13	7	832	1365	28,0	37	4-Dsoak	15	19	24	25	60 %
																		OMC	90	94	100	105	11 %
																		.75 OMC	134	140	146	155	9 %
	680/S/11	Subgrade	0+000	100	100	93	80	69	50	45	25	20	10	1380	1625	18,8	24,1	4-Dsoak	8,8	9,6	10,8	11	23 %
																		OMC	60	66	75	81	25 %
D435 Nyeri	684/S/11	Subgrade	0+450	100	98	90	82	70	55	45	26	19	10	1330	1495	22,4	29,3	4-Dsoak	24	25	27	28	13 %
																		OMC	60	66	75	81	25 %
																		.75 OMC	80	89	101	108	26 %
	58/S/2012	Subgrade	0+000	100	100	100	98	86	70	64	36	28	14	2408	1355	29,4	26	4-Dsoak	2,3	2,6	2,9	3,2	26 %
																		OMC	62	72	84	94	35 %
D462 Laikipia	59/S/2012	Subgrade	0+200	100	98	97	93	72	52	54	35	19	11	1368	1450	21,6	20	4-Dsoak	3,3	3,6	4	4,2	21 %
																		OMC	55	60	63	65	15 %
																		.75 OMC	65	70	80	85	23 %
	60/S/2012	Subgrade	0+400	100	93	82	75	64	48	48	24	24	13	1536	1720	19,4	20	4-Dsoak	1,8	2,4	3,3	4	83 %
																		OMC	36	38	43	48	19 %
D462 Laikipia	61/S/2012	Subgrade	0+600	100	97	92	88	76	62	54	29	25	14	1900	1475	21,4	20	4-Dsoak	2,9	3	3,2	3,4	10 %
																		OMC	54	64	80	91	48 %
																		.75 OMC	82	94	110	121	34 %
	62/S/2012	Subgrade	0+500	100	94	91	84	67	44	46	26	20	10	1340	1595	16	16,4	4-Dsoak	0,6	1,2	2	2,6	233 %
																		OMC	36	42	50	56	39 %
D462 Laikipia	63/S/2012	Gravel	0+500	100	86	77	74	52	40	39	21	17	9	884	1630	15,4	13,6	4-Dsoak	5	5,3	5,8	6,1	16 %
																		OMC	60	75	90	100	50 %
																		.75 OMC	74	83	96	105	30 %
	64/S/2012	Subgrade	0+600	100	90	84	78	65	48	48	30	18	10	1170	1590	17,0	17,8	4-Dsoak	2,3	2,8	3,5	4,1	52 %
																		OMC	50	53	57	61	14 %
D462 Laikipia	65/S/2012	Subgrade	0+700	100	99	96	92	82	67	47	23	24	11	1968	1600	17,0	19	4-Dsoak	2	2,3	2,8	3,2	40 %
																		OMC	25	28	33	38	32 %
																		.75 OMC	47	49	52	55	11 %
	66/S/2012	Subgrade	0+800	100	100	99	96	90	86	63	26	37	16	3330	1365	25,8	30,4	4-Dsoak	1,1	1,3	1,7	2	55 %
																		OMC	26	29	35	39	35 %
																		.75 OMC	34	39	46	55	35 %

Table 12: CBR at various moisture contents and compactions efforts

Compared to similar tests done in Malawi (see footnote 2) one would have expected a higher increase in CBR values with increased compaction from 93% to 98% Mod AASHTO at 0.75 OMC. The results may have been affected by inadequate moisture equilibration before the CBR tests.

Pavement design catalogue for different LVR categories

Pavement Class E80 x 10 ⁶	LV 0.01 0.003 – 0.010	LV 0.03 0.010 – 0.030	LV 0.1 0.030 – 0.100	LV 0.3 0.100 – 0.300	LV 1.0 0.300 – 1.000
150mm Base ≥ 98% BSH	DN ≤ 8	DN ≤ 5	DN ≤ 4	DN ≤ 3.2	DN ≤ 2.5
150mm Subbase ≥ 95% BSH	DN ≤ 19	DN ≤ 14	DN ≤ 9	DN ≤ 6	DN ≤ 3.5
150mm subgrade 93% BSH	DN ≤ 33	DN ≤ 25	DN ≤ 19	DN ≤ 12	DN ≤ 6

DN = DCP penetration rate in mm/blow

Figure 3: The Malawi Low Volume Road DCP Design Catalogue

The Malawi DCP Design catalogue is used in the following for the pavement analysis. Assumptions have been made for DN values for layers below 450 mm depth.

D382 Nyandarua

The DCP results for D382 were analyzed using the following parameters:

- User defined DCP Design Curve based on LV 0.3 above
 - 0-150 mm DN≤3.2
 - 151-300 mm DN≤6
 - 301-450 mm DN≤12
 - 451-600 mm DN≤36
 - 601-800 mm DN≤50
- 31/01/12 Optimum moisture

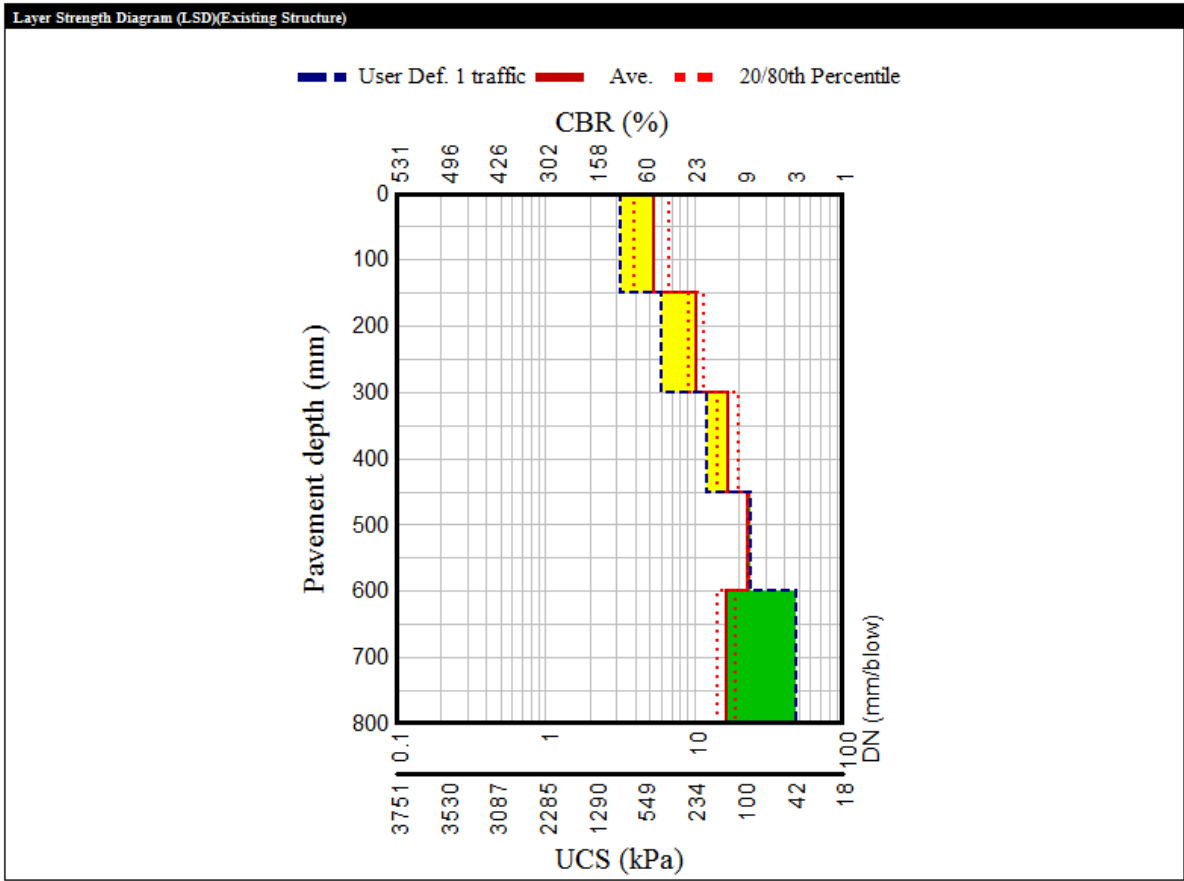


Figure 4: Average all points on D382 from tests on 31/01/12 assumed to be at in-service moisture conditions

The DCP tests done on 23/11/11 showed a high variability in the DSN_{800} (the number of blows to penetrate to a depth of 800mm). From a visual assessment, the subgrade on the whole section is quite uniform consisting of a red coffee soil to a depth of 500-600mm overlying a layer of laterite. The variability is ascribed to the fact that due to the irregular surface, water was ponding in certain spots and effectively soaking the underlying layers. Other high spots on the other hand remained drier and consequently stronger. Some variability was also due to stones in the top layer.

The variability in the DSN_{800} was notably less on 31/01/12 indicating that with time, particularly when the road is sealed, the subgrade will be much more uniform in strength, as expected from the visual assessment. The design is therefore based on these tests when it is assumed that the moisture content was fairly similar to in-service conditions after sealing.

The existing pavement does not show signs of deep structural failure even in unsealed condition. This is a good indication that the in situ subgrade has adequate strength for the existing traffic. The top layer however became very wet and disturbed during the rains and must be reshaped with more material added to form a uniform base layer.

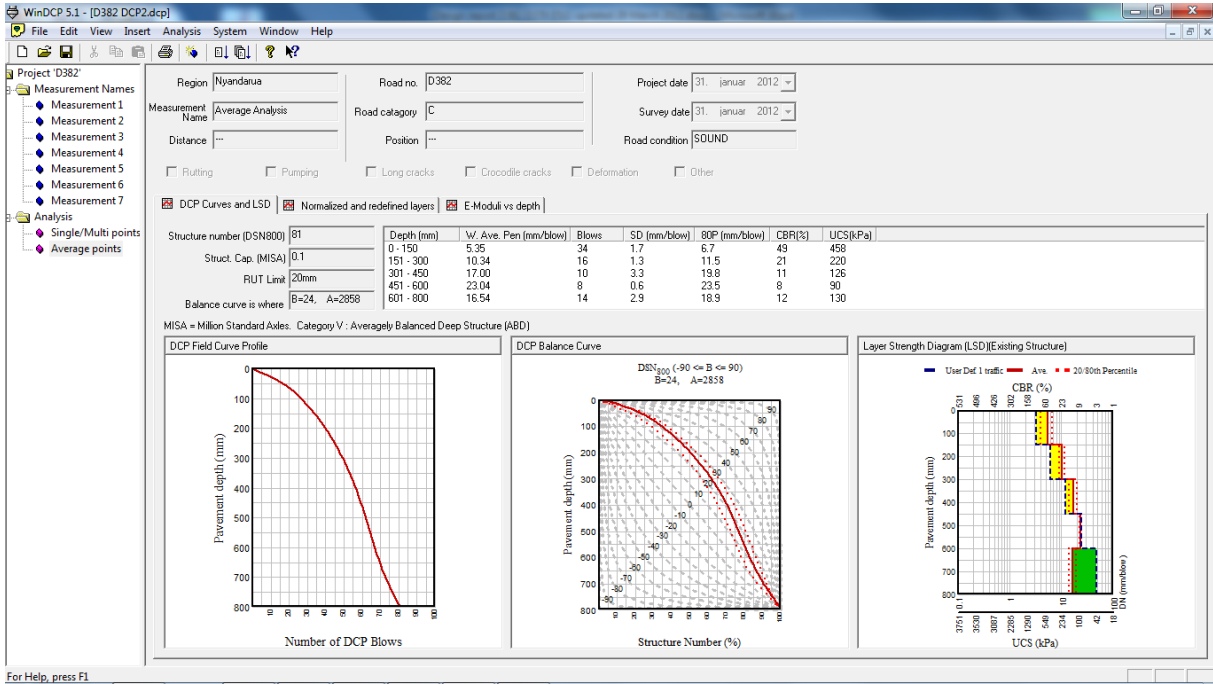


Figure 5: Screenshot of WinDCP Average analysis on D382 31/01/12

By shaping and proof-rolling the existing pavement, then adding a layer of gravel 150 mm thick with a soaked CBR $\geq 45\%$ and compacting to refusal (min. 98% Mod AASHTO), the new pavement structure will be as shown in table 11 below:

Pavement layers	Existing structure		New structure		DCP Catalogue DN mm/blow
	CBR %	DN mm/blow	CBR%	DN mm/blow	
0-150 mm	49%	5.35	$\geq 100\%$	≤ 3.0	≤ 3.2
150-300 mm	21%	10.34	$\geq 49\%$	≤ 5.35	≤ 6
300-450 mm	11%	17.00	21%	10.34	≤ 12
450-600 mm	8%	23.04	11%	17.00	≤ 36
600-800 mm	14%	16.54	8%	23.04	≤ 50

Table 13: Existing and new pavement structure after upgrading showing DCP-CBR and DN values at assumed in-service moisture content \leq OMC

Figure 6 below shows that the pavement structure after upgrading will have a structural capacity of 0.3 MESA, i.e. just above the estimated traffic loading over a 15 year design period.

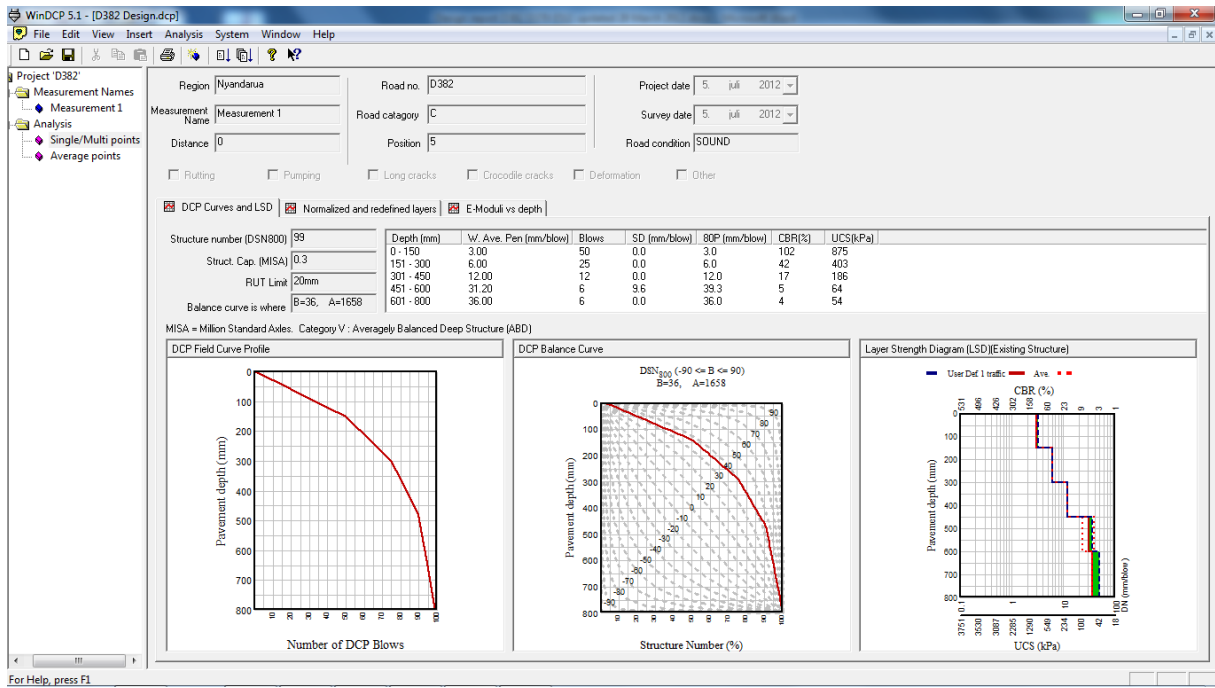


Figure 6: Pavement structure on D382 after upgrading

E511 Muranga

The DCP results for E511 were analyzed using the following parameters:

- User defined DCP Design Curve based on LV 0.1 above
 - 0-150 mm DN≤4
 - 151-300 mm DN≤9
 - 301-450 mm DN≤19
 - 451-800 mm DN≤50
- 30/01/12 Optimum moisture

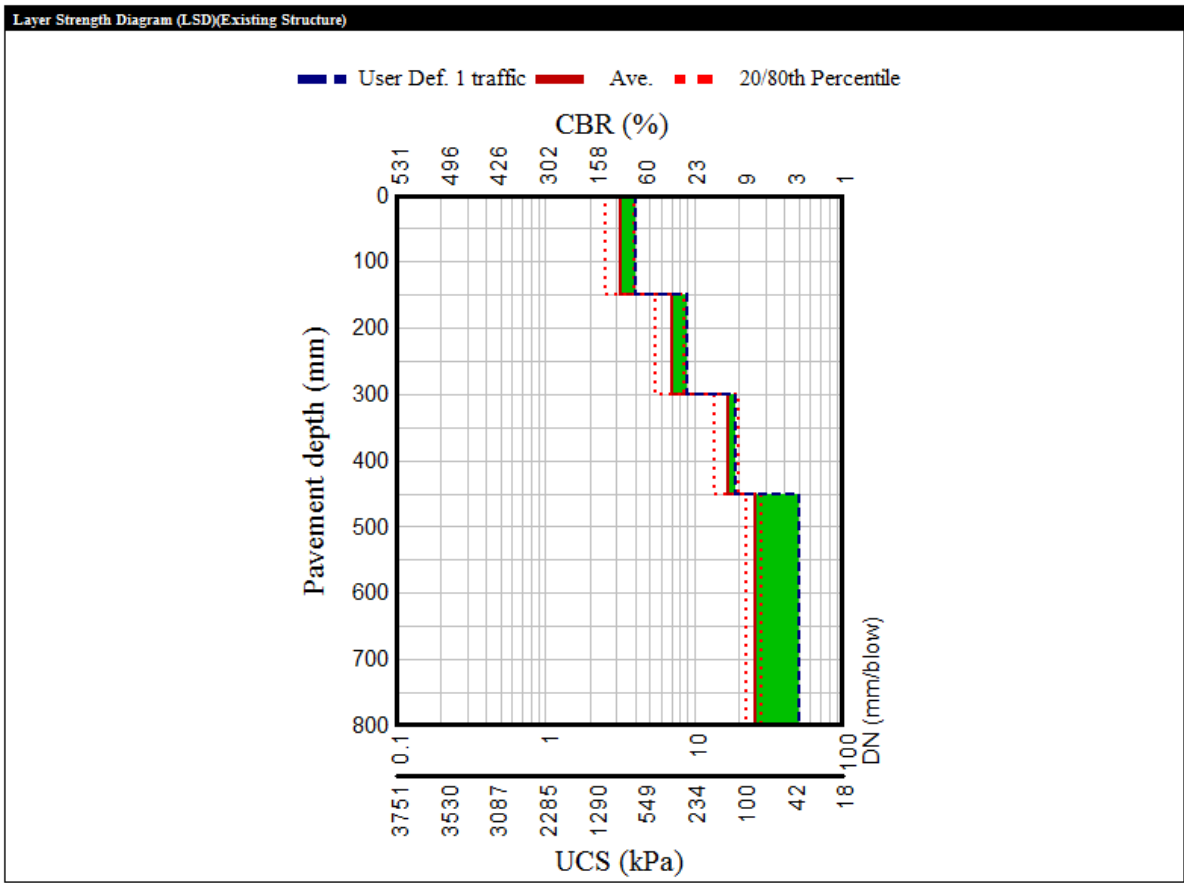


Figure 7: Average all points on E511 from 30/01/12 assumed to be at in-service moisture conditions

From a visual assessment the subgrade is uniform throughout the whole section consisting of dark reddish/brownish clay. It was evident from the DCP tests that the steeper section in particular had been repaired in the past with coarse soft stone gravel containing a lot of oversize material and boulders on sections where vehicles tended to get stuck during the wet season. The road was last graveled during Roads 2000 Phase 1 around 2008/09.

On 30/01/12 the upper 150 mm had dried out and gained strength, whereas the layers from 150 mm down are still more or less at the same moisture content and strength as during the rains. It is assumed that the moisture content is similar to in-service moisture content after sealing.

The existing pavement does not show signs of structural failure even in unsealed condition. This is a good indication that the pavement is adequate for the existing traffic.

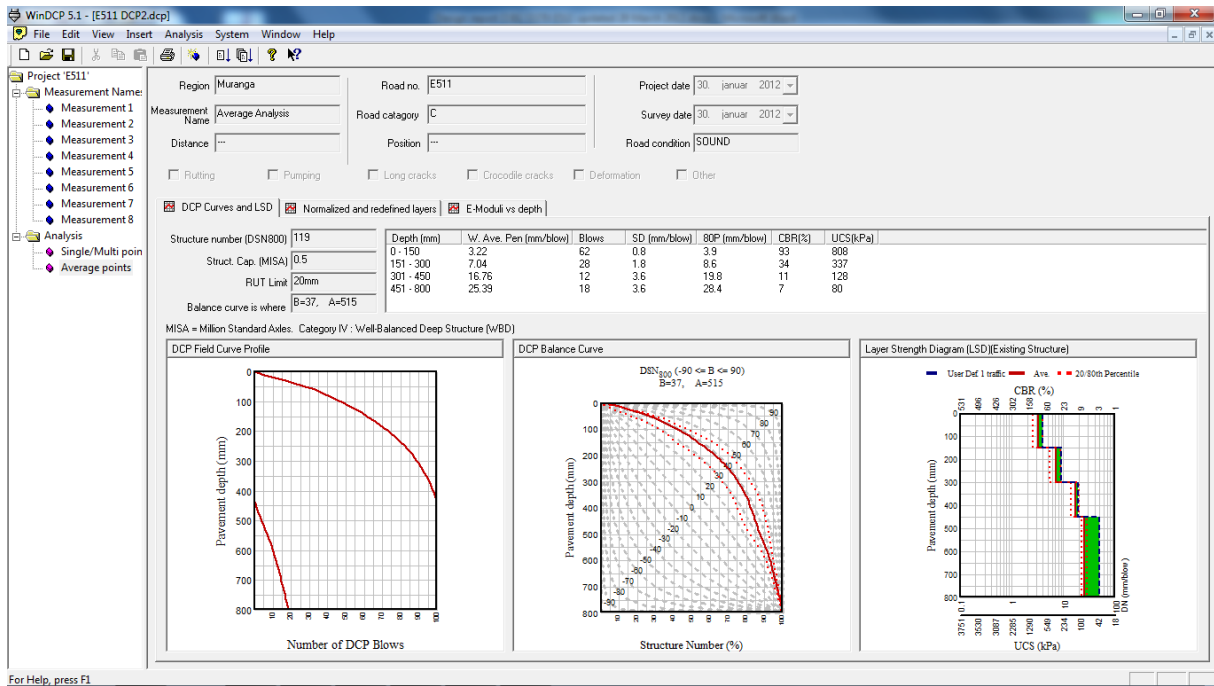


Figure 8: Screenshot of WinDCP for Average analysis on E511 30/01/12

Figure 8 shows that the existing pavement has a structural capacity of 0.5 MESA which is well above the estimated traffic loading for this road over a 15 year design period. Strictly speaking no additional layer is required, but in practice an average layer of 100 mm gravel must be added for the reshaping of the road. After reshaping the upper layer must be compacted to refusal (min. 98% Mod AASHTO) before sealing.

D379 Kiambu

The DCP results for D379 were analyzed using the following parameters:

- User defined DCP Design Curve based on LV 0.1 above
 - 0-150 mm DN≤4
 - 151-300 mm DN≤9
 - 301-450 mm DN≤19
 - 451-800 mm DN≤50
- 30/01/12 – Optimum

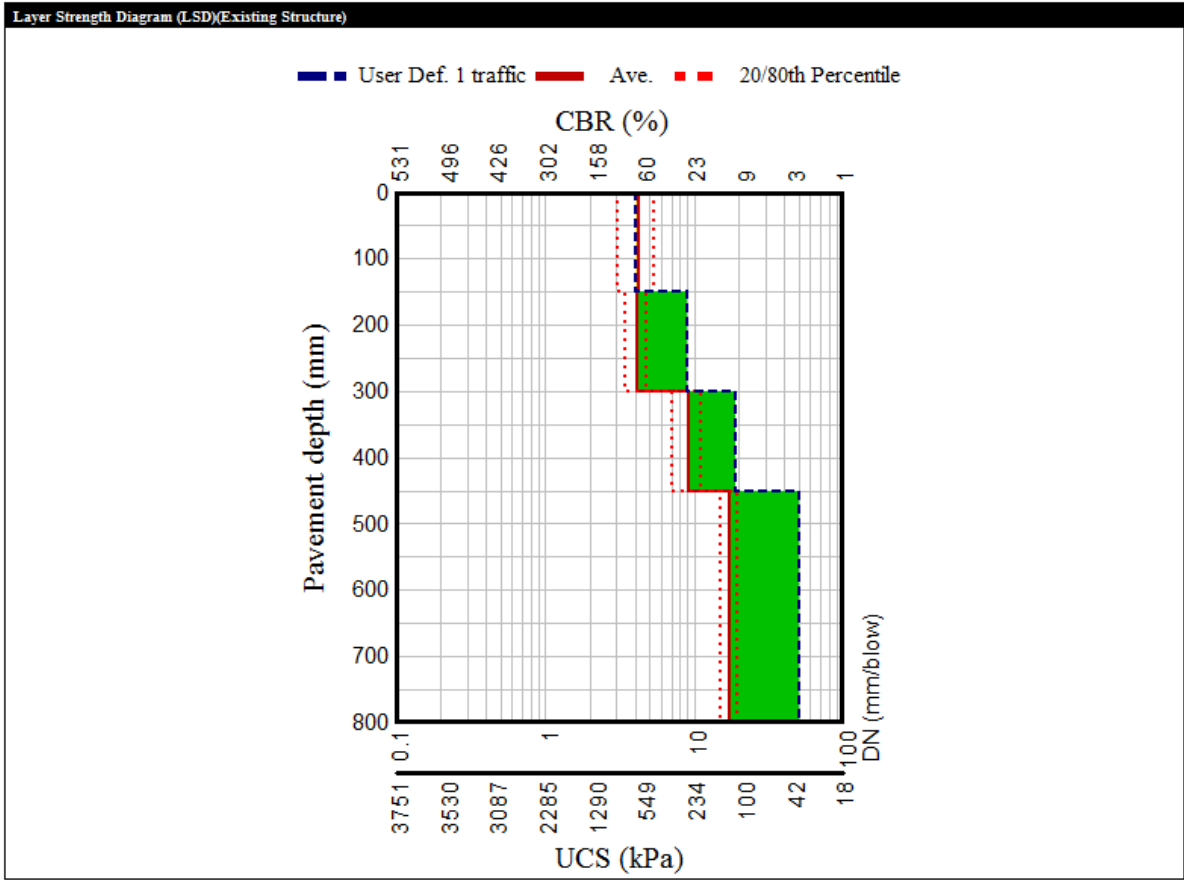


Figure 9: Average all points 01/11/11 (left) and 30/01/12 (right)

By 30/01/12 it is assumed that the moisture content is similar to in-service moisture after sealing.

The results indicate that the pavement has adequate strength. All that is required is reshaping and compacting the top layer to refusal (min 98% Mod AASTHO) before sealing. The existing gravel layer should only be topped up to compensate for gravel loss and to take out the rutting.

Figure 10 below shows that the pavement after upgrading will have a structural capacity of 0.8 MESA, which is well above the estimated traffic loading for this road over a 15 year design period.

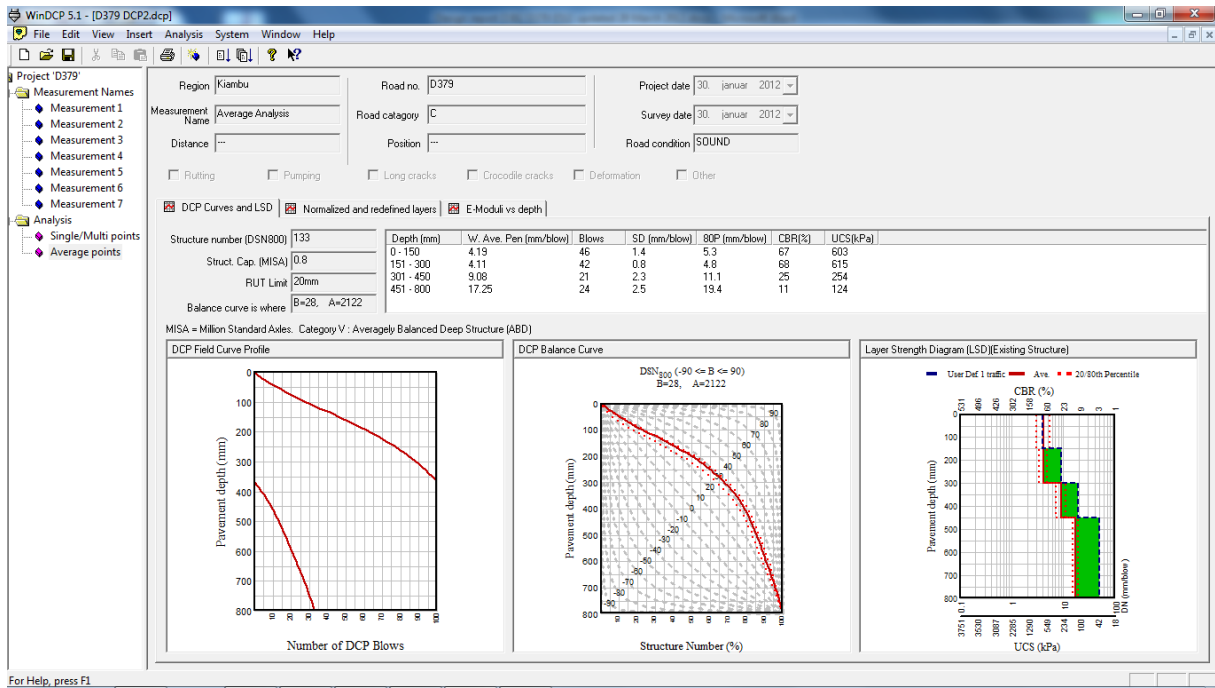


Figure 10: Screenshot of WinDCP for Average analysis on D379 on 30/01/12

D435 Nyeri

The DCP results for D435 were analyzed using the following parameters:

- User defined DCP Design Curve based on LV 0.3 above
 - 0-150 mm DN≤3.2
 - 151-300 mm DN≤6
 - 301-450 mm DN≤12
 - 451-600 mm DN≤36
 - 601-800 mm DN≤50
- 17/01/12 Optimum moisture

A section of the road from about chainage 0+100 to chainage 0+200 has a drainage problem. This section is therefore analysed separately.

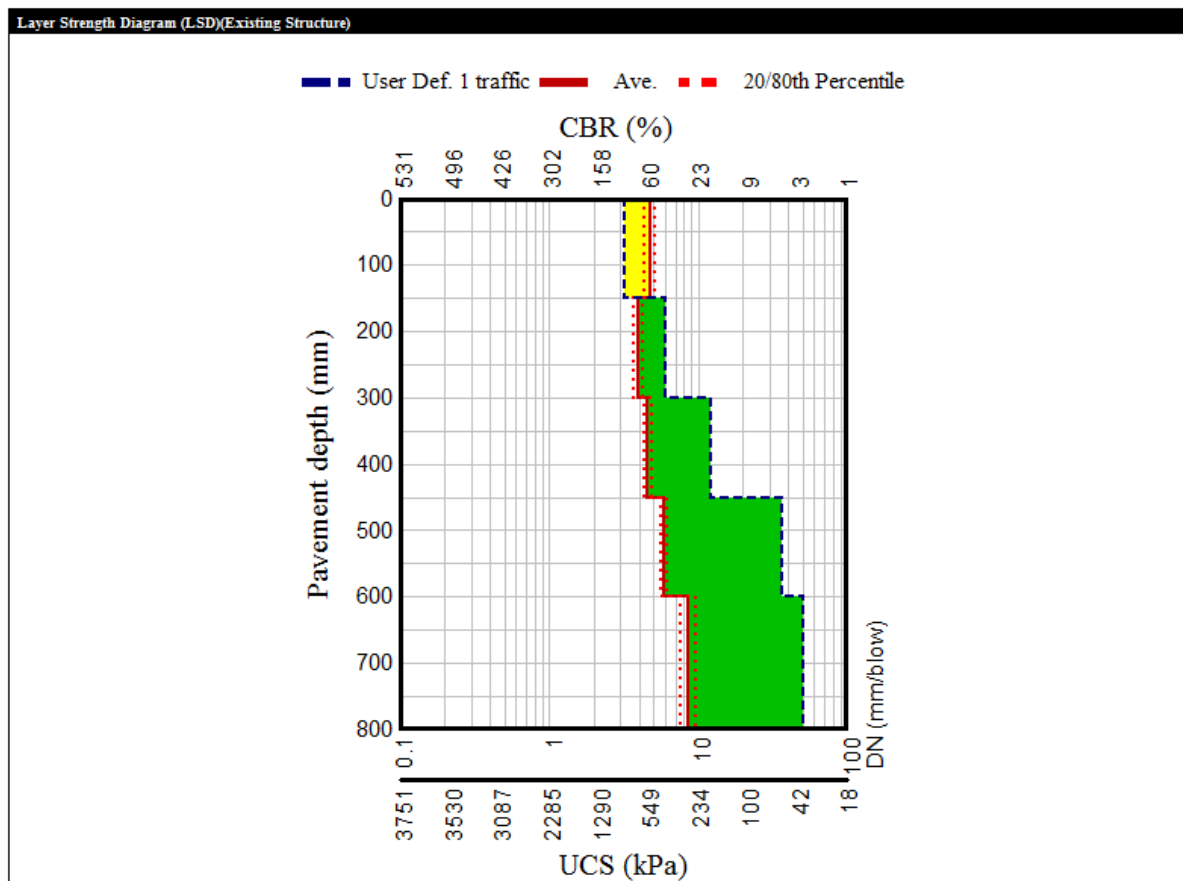


Figure 11: Average of all points with no drainage problem on D435 17/01/12

All that is required on this section is reshaping and compacting the top 150 mm to refusal (min. 98% Mod AASTHO). In practice the existing gravel layer must be topped up to compensate for gravel loss and to take out ruts.

Figure 12 below shows that this section has a structural capacity of 2.6 MESA, which is well above the estimated traffic loading with a 15 year design period for this road.

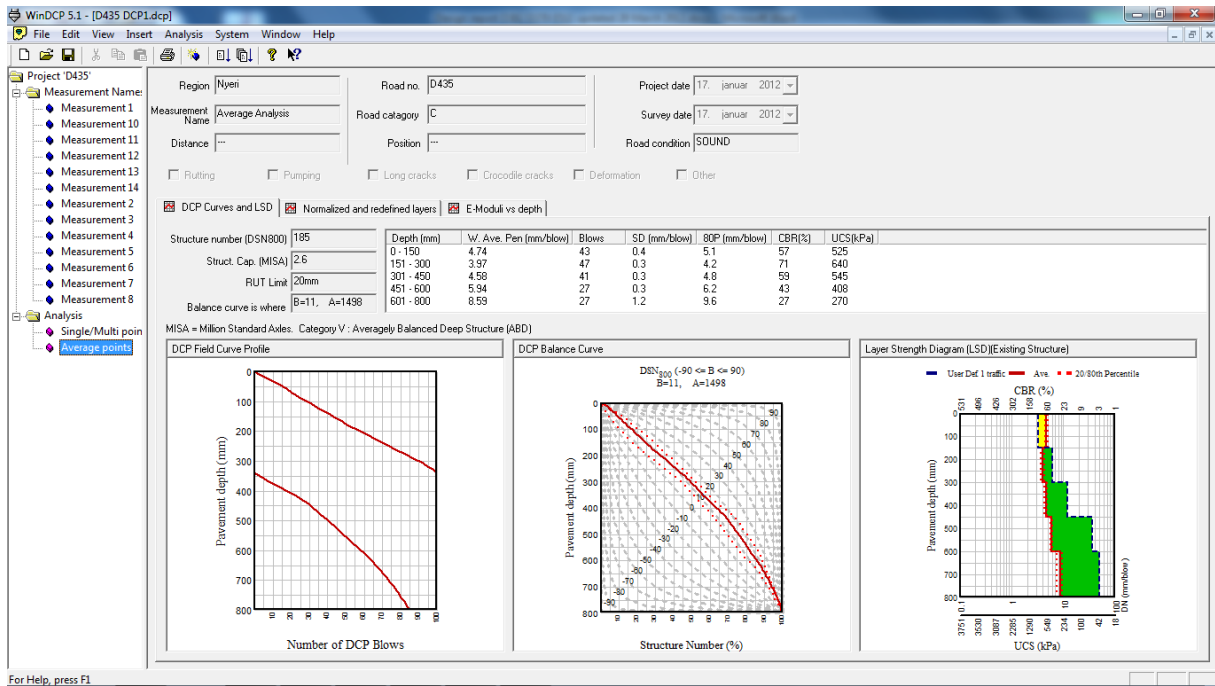


Figure 12: Screenshot of WinDCP for Average analysis on D435 outside section with drainage problems

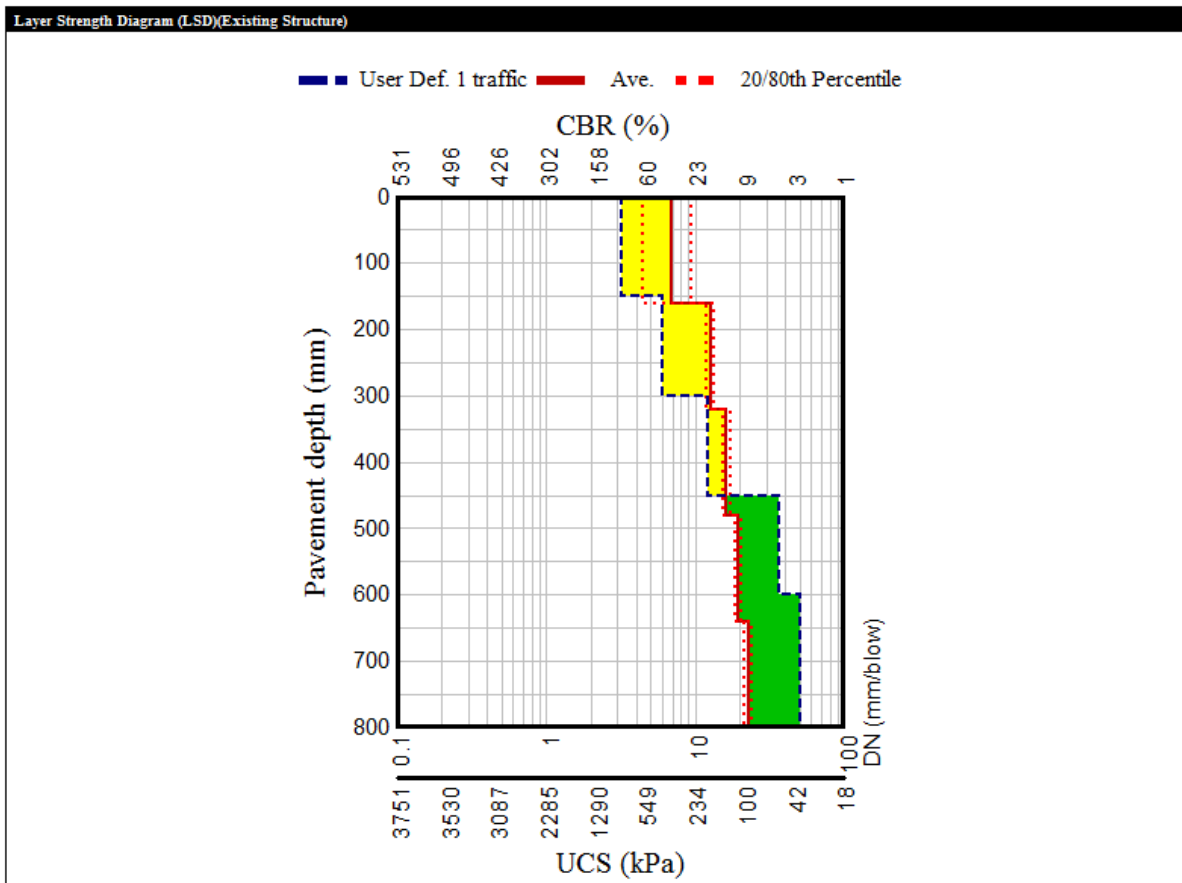
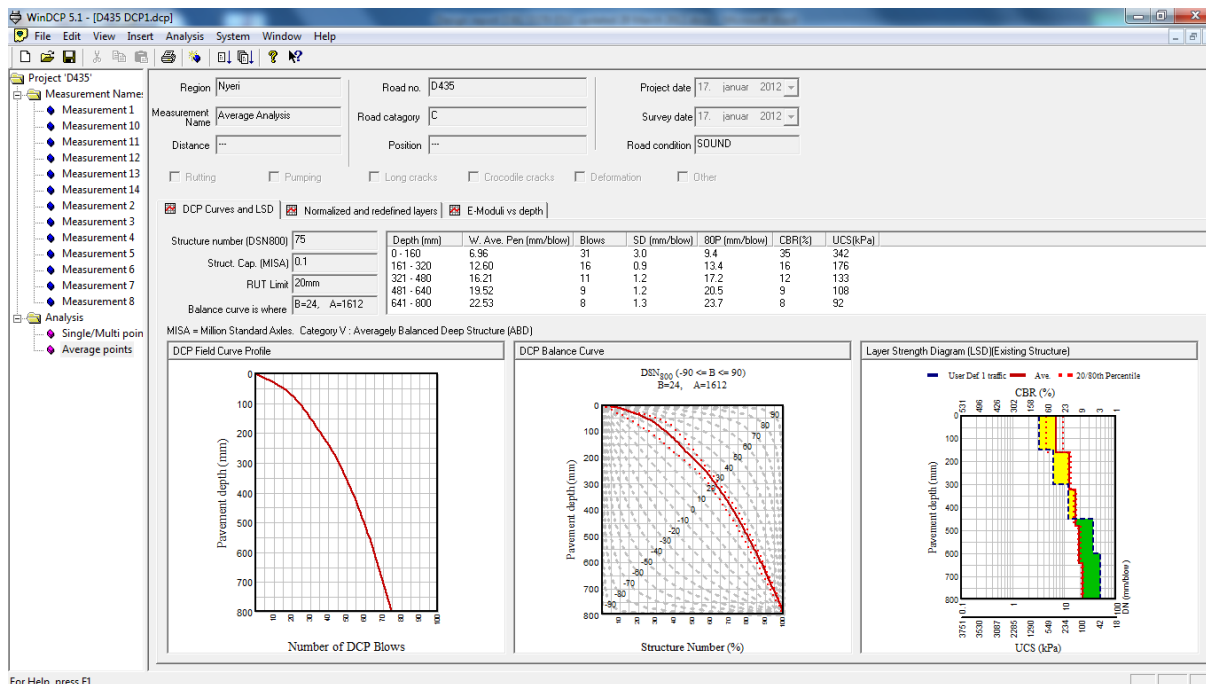


Figure 13: Average 4 points on section with drainage problems



By shaping and proof-rolling the existing pavement, then adding a layer of gravel 150 mm thick with a soaked CBR $\geq 45\%$ and compacting to refusal (min. 98% Mod AASHTO), the new pavement structure on this section will be as shown in table 11 below:

Pavement layers	Existing structure		New structure		DCP Catalogue DN mm/blow
	CBR %	DN mm/blow	CBR%	DN mm/blow	
0-150 mm	35%	6.96	$\geq 100\%$	≤ 3.0	≤ 3.2
150-300 mm	16%	12.6	$\geq 35\%$	≤ 6.0	≤ 6
300-450 mm	12%	16.21	16%	12.0	≤ 12
450-600 mm	9%	19.52	12%	16.21	≤ 36
600-800 mm	8%	22.53	9%	19.52	≤ 50

Table 14: Existing and new pavement structure after upgrading of section with drainage problems showing DCP-CBR and DN values at assumed in-service moisture content \leq OMC

The drainage system will need to be improved on this section. This will reduce the in-service moisture on this section and possibly obviate the need for an additional layer. A decision on this will be taken prior to construction.

Figure 14 below shows that this section after adding a 150 mm gravel layer and compaction to refusal (min 98% Mod AASTHO) will have a structural capacity of 0.4 MESA, which is well above the estimated traffic loading with a 15 year design period for this road.

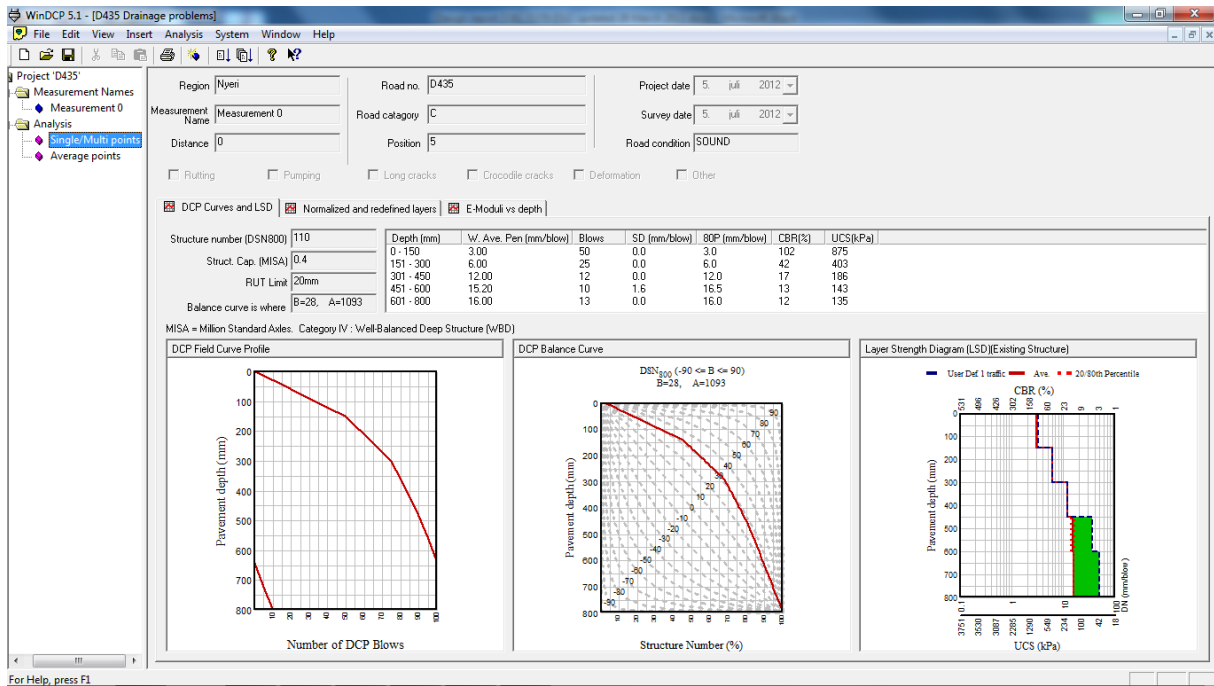


Figure 14: Screenshot from WinDCP for section with drainage problems after adding one 150 mm pavement layer

D462 Laikipia

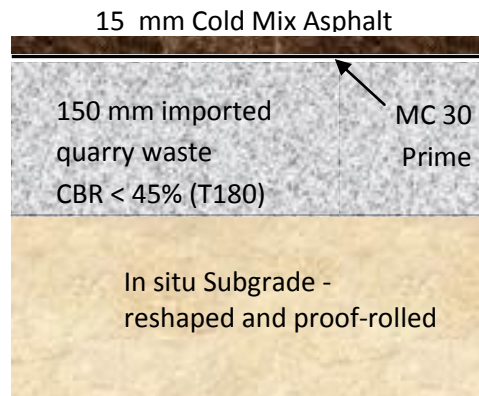
The Regional Manager, Laikipia was as of May/June 2012 undertaking repair and regravelling of this section. A decision on whether the section should be included in the research will have to be taken once the ongoing rehabilitation works have been completed. New DCP tests will then have to be carried out as a basis for the design.

6. Proposed pavement structures

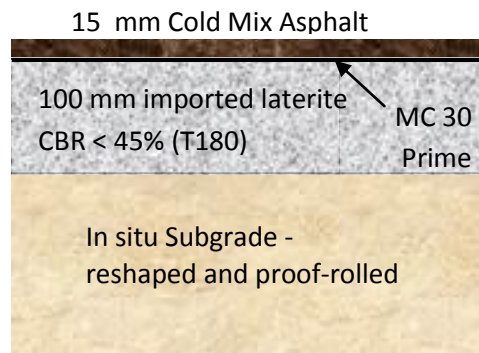
For the construction it is important to bear in mind that the purpose of the research is to determine to what extent one can use the existing pavement structure to successfully construct Low Volume Sealed Roads. The existing structure should therefore be disturbed as little as possible during construction to make best use of the consolidation of the materials that has taken place under traffic. Hence the existing gravel wearing course should only be ripped to the depth required to take out ruts and reshape the road to the specified camber or crossfall.

The proposed pavement structures for the various sections are shown in the following:

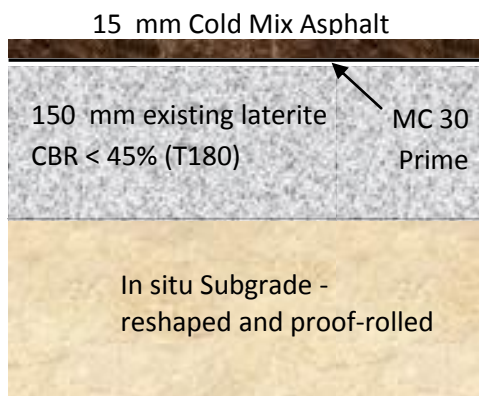
D382 Nyandarua



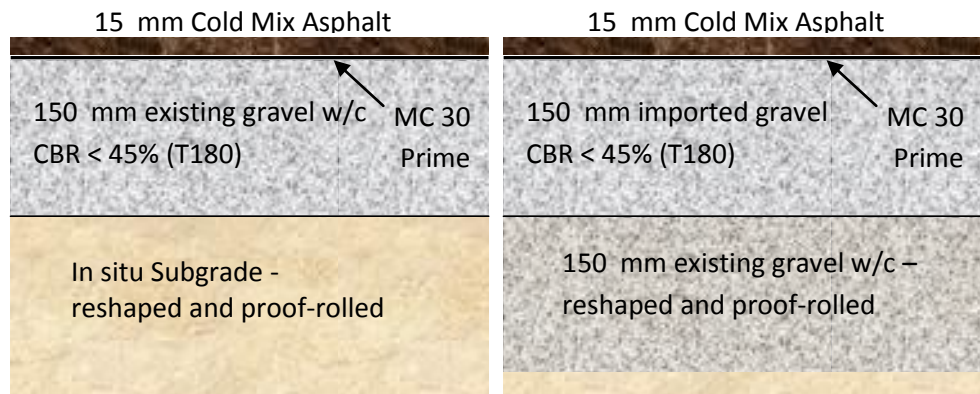
E511 Muranga



D379 Kiambu



D379 Nyeri



Section without drainage problems

Section with drainage problems

7. Cost Estimates

The details of the cost estimates are shown in Annex 2. A summary of the cost estimate is provided in Table 15 below:

Road	Cost estimate	Cost/km
D382 Nyandarua	5,718,720	9,531,200
E511 Muranga	6,112,017	6,792,130
D379 Kiambu	3,624,340	9,060,850
D435 Nyeri	5,436,510	9,060,850
Total	20,892,487	8,356,995

Table 15: Preliminary cost estimates

Annex 1 - Traffic Count and Analysis

Region: Nyandarua	Road: D382		Location: 6+000 from junction at C77				Time: 6 AM to 6 PM			Adjusted
Direction: Towards C77	19.01.2012	20.01.2012	21.01.2012	22.01.2012	23.01.2012	24.01.2012	25.01.2012	Total	ADT	ADT (+30%)
Bicycles	90	61	134	86	173	94	106	744	106	138
Others (NMT)	2	5	9	3	9	8	13	49	7	9
Motor Bikes	91	89	191	121	129	92	94	807	115	150
Cars	56	20	48	51	39	24	12	250	36	46
Vans/Matatus	63	49	97	56	101	68	46	480	69	89
Small trucks	1	5	2	1	3	1	0	13	2	2
Buses	0	1	1	0	0	0	0	2	0	0
Medium trucks - 2 axles	13	16	23	16	20	19	12	119	17	22
Heavy trucks - 3 axles	1	6	4	1	2	1	0	15	2	3
Articulated trucks - 4 or more axles	0	0	0	0	0	0	0	0	0	0
Total	317	252	509	335	476	307	283	2479	354	460

Region: Nyandarua	Road: D382		Location: 0+600 from junction at C77				Time: 6 AM to 6 PM			Adjusted
Direction: Towards Ngano Village	19.01.2012	20.01.2012	21.01.2012	22.01.2012	23.01.2012	24.01.2012	25.01.2012	Total	ADT	ADT (+30%)
Bicycles	86	43	149	82	201	102	85	748	107	139
Others (NMT)	2	8	13	6	6	11	4	50	7	9
Motor Bikes	76	66	185	102	189	90	111	819	117	152
Cars	17	19	49	27	58	24	18	212	30	39
Vans/Matatus	37	39	125	55	113	57	45	471	67	87
Small trucks	1	2	6	1	2	2	1	15	2	3
Buses	0	1	2	0	0	0	0	3	0	1
Medium trucks - 2 axles	10	20	24	12	14	19	15	114	16	21
Heavy trucks - 3 axles	1	3	3	2	2	1	0	12	2	2
Articulated trucks - 4 or more axles	0	0	0	0	0	0	0	0	0	0
Total	230	201	556	287	585	306	279	2444	349	454

Region: Nyandarua	Road: D382		Location: 0+600 from junction at C77				Time: 6 AM to 6 PM			Adjusted
Direction: Combined both directions	19.01.2012	20.01.2012	21.01.2012	22.01.2012	23.01.2012	24.01.2012	25.01.2012	Total	ADT	ADT (+30%)
Bicycles	176	104	283	168	374	196	191	1492	213	277
Others (NMT)	4	13	22	9	15	19	17	99	14	18
Motor Bikes	167	155	376	223	318	182	205	1626	232	302
Cars	73	39	97	78	97	48	30	462	66	86
Vans/Matatus	100	88	222	111	214	125	91	951	136	177
Small trucks	2	7	8	2	5	3	1	28	4	5
Buses	0	2	3	0	0	0	0	5	1	1
Medium trucks - 2 axles	23	36	47	28	34	38	27	233	33	43
Heavy trucks - 3 axles	2	9	7	3	4	2	0	27	4	5
Articulated trucks - 4 or more axles	0	0	0	0	0	0	0	0	0	0
Total	547	453	1065	622	1061	613	562	4923	703	914

Design traffic loading	Combined both directions			Towards C77			Towards Ngano		
Vehicle class	ADT (2012)	VEF ¹	DESA	ADT (2012)	VEF ¹	DESA	ADT (2012)	VEF ¹	DESA
Buses	1	1	1	0	1	0	1	1	1
Medium trucks - 2 axles	43	1	43	22	1	22	21	1	21
Heavy trucks - 3 axles	5	4	20	3	4	11	2	4	9
Articulated trucks - 4 or more axles	0	4	0	0	4	0	0	4	0
Total DESA 2012			64			33			31

Design traffic loading	Combined both directions			Towards C77			Towards Ngano		
Vehicle class	ADT (2012)	VEF ²	DESA	ADT (2012)	VEF ²	DESA	ADT (2012)	VEF ²	DESA
Buses	1	0,36	0	0	0,36	0	1	0,36	0
Medium trucks - 2 axles	43	0,76	33	22	0,76	17	21	0,76	16
Heavy trucks - 3 axles	5	2,92	15	3	2,92	8	2	2,92	6
Articulated trucks - 4 or more axles	0	1,19	0	0	1,19	0	0	1,19	0
Total DESA 2012			48			25			22

1) VEF as per Kenya Roads Design Manual

2) Based on axle load survey on C69 Ol Kalou - Dundori - Njabini.

Cum. Equivalent Standard Axles: $CESA = 365 T_b[(1+r)^n - 1]/r$

T_b = DESA 2012 Bus/Med trucks Heavy/Art. Trucks
r = annual growth rate 5% 4%
n = design period (years)

D382 Nyandarua	Combined both directions ³			Towards C77			Towards Ngano		
Design period (years)	5	10	15	5	10	15	5	10	15
CESA (standard VEF)	102625	231716	394179	66117	149205	253671	62163	140441	239053
CESA (reduced VEF)	76968	173787	295634	50102	113104	192364	44131	99748	169870

3) 80% of the combined traffic loading as per Kenya Roads Design Manual for road narrower than 7.0m

Region: Muranga	Road: E511		Location: At junction with D417				Time: 6 AM to 6 PM			Adjusted
Direction: Towards Kinjona	14.01.2012	15.01.2012	16.01.2012	17.01.2012	18.01.2012	19.01.2012	20.01.2012	Total	ADT	ADT (+30%)
Bicycles	2	6	3	4	1	3	4	23	3	4
Others (NMT)	1	0	0	0	0	0	0	1	0	0
Motor Bikes	97	106	71	65	66	80	86	571	82	106
Cars	19	15	10	5	6	9	16	80	11	15
Vans/Matatus	21	56	29	18	29	33	19	205	29	38
Small trucks	20	2	2	3	2	3	1	33	5	6
Buses	1	1	2	2	4	2	3	15	2	3
Medium trucks - 2 axles	5	1	5	7	5	7	3	33	5	6
Heavy trucks - 3 axles	1	0	0	1	2	3	2	9	1	2
Articulated trucks - 4 or more axles	1	0	0	0	0	0	0	1	0	0
Total	168	187	122	105	115	140	134	971	139	180

Region: Nyandarua	Road: E511		Location: At junction with D417				Time: 6 AM to 6 PM			Adjusted
Direction: From Kinjona	14.01.2012	15.01.2012	16.01.2012	17.01.2012	18.01.2012	19.01.2012	20.01.2012	Total	ADT	ADT (+30%)
Bicycles	3	2	2	6	2	2	1	18	3	3
Others (NMT)	1	0	0	0	0	0	0	1	0	0
Motor Bikes	92	67	78	74	74	77	82	544	78	101
Cars	42	20	5	11	12	6	7	103	15	19
Vans/Matatus	8	39	29	31	26	34	32	199	28	37
Small trucks	14	2	2	2	4	1	2	27	4	5
Buses	0	2	2	3	4	2	3	16	2	3
Medium trucks - 2 axles	4	1	4	5	1	1	5	21	3	4
Heavy trucks - 3 axles	1	0	0	0	2	0	1	4	1	1
Articulated trucks - 4 or more axles	1	0	0	0	0	0	0	1	0	0
Total	166	133	122	132	125	123	133	934	133	173

Region: Muranga	Road: E511		Location: At junction with D417				Time: 6 AM to 6 PM			Adjusted
Direction: Combined both directions	14.01.2012	15.01.2012	16.01.2012	17.01.2012	18.01.2012	19.01.2012	20.01.2012	Total	ADT	ADT (+30%)
Bicycles	5	8	5	10	3	5	5	41	6	8
Others (NMT)	2	0	0	0	0	0	0	2	0	0
Motor Bikes	189	173	149	139	140	157	168	1115	159	207
Cars	61	35	15	16	18	15	23	183	26	34
Vans/Matatus	29	95	58	49	55	67	51	404	58	75
Small trucks	34	4	4	5	6	4	3	60	9	11
Buses	1	3	4	5	8	4	6	31	4	6
Medium trucks - 2 axles	9	2	9	12	6	8	8	54	8	10
Heavy trucks - 3 axles	2	0	0	1	4	3	3	13	2	2
Articulated trucks - 4 or more axles	2	0	0	0	0	0	0	2	0	0
Total	334	320	244	237	240	263	267	1905	272	354

Design traffic loading	Combined both directions			Towards Kinjona			From Kinjona		
Vehicle class	ADT (2012)	VEF ¹	DESA	ADT (2012)	VEF ¹	DESA	ADT (2012)	VEF ¹	DESA
Buses	6	1	6	3	1	3	3	1	3
Medium trucks - 2 axles	10	1	10	6	1	6	4	1	4
Heavy trucks - 3 axles	2	4	10	2	4	7	1	4	3
Articulated trucks - 4 or more axles	0	4	1	0	4	1	0	4	1
Total DESA 2012			27			17			11

	Combined both directions			Towards Kinjona			From Kinjona		
Vehicle class	ADT (2012)	VEF ²	DESA	ADT (2012)	VEF ²	DESA	ADT (2012)	VEF ²	DESA
Buses	6	0,2	1	3	0,2	1	3	0,2	1
Medium trucks - 2 axles	10	0,2	2	6	0,2	1	4	0,2	1
Heavy trucks - 3 axles	2	2,3	6	2	2,3	4	1	2,3	2
Articulated trucks - 4 or more axles	0	0,6	0	0	0,6	0	0	0,6	0
Total DESA 2012			9			6			4

1) VEF as per Kenya Roads Design Manual

2) Based on axle load surveys on D416 and D440.

Cum. Equivalent Standard Axles: $CESA = 365 T_b[(1+r)^n - 1]/r$

T_b = DESA 2012 Bus/Med trucks Heavy/Art. Trucks
r = annual growth rate 5% 4%
n = design period (years)

E511 Muranga	Combined both directions ³			Towards Kinjona			From Kinjona		
Design period (years)	5	10	15	5	10	15	5	10	15
CESA (standard VEF)	43213	97328	165131	33967	76376	129354	22026	49665	84368
CESA (reduced VEF)	14330	32053	53984	11942	26711	44987	7988	17946	30370

3) 80% of the combined traffic loading as per Kenya Roads Design Manual for road narrower than 7.0m

Region: Kiambu	Road: D379		Location: At Wamwangi, junction C64				Time: 6 AM to 6 PM			Adjusted
Direction: From Wamwangi	14.01.2012	15.01.2012	16.01.2012	17.01.2012	18.01.2012	19.01.2012	20.01.2012	Total	ADT	ADT (+30%)
Bicycles	1	30	64	46	30	15	1	187	27	35
Others (NMT)	0	0	0	0	0	0	0	0	0	0
Motor Bikes	47	73	111	141	151	195	37	755	108	140
Cars	36	77	132	165	165	150	133	858	123	159
Vans/Matatus	38	153	178	202	140	166	145	1022	146	190
Small trucks	2	0	1	1	4	0	0	8	1	1
Buses	0	4	2	2	1	0	1	10	1	2
Medium trucks - 2 axles	5	16	9	2	1	1	4	38	5	7
Heavy trucks - 3 axles	0	5	1	1	0	0	0	7	1	1
Articulated trucks - 4 or more axles	0	1	0	0	0	0	0	1	0	0
Total	129	359	498	560	492	527	321	2886	412	536

Region: Kiambu	Road: D379		Location: At Wamwangi, junction C64				Time: 6 AM to 6 PM			Adjusted
Direction: Towards Wamwangi	14.01.2012	15.01.2012	16.01.2012	17.01.2012	18.01.2012	19.01.2012	20.01.2012	Total	ADT	ADT (+30%)
Bicycles	7	31	57	24	61	18	0	198	28	37
Others (NMT)	0	0	0	0	0	0	0	0	0	0
Motor Bikes	31	65	87	128	160	116	48	635	91	118
Cars	48	75	40	128	176	177	126	770	110	143
Vans/Matatus	41	125	175	162	152	157	136	948	135	176
Small trucks	2	0	2	1	0	2	1	8	1	1
Buses	0	7	0	0	0	0	1	8	1	1
Medium trucks - 2 axles	7	21	3	2	1	3	2	39	6	7
Heavy trucks - 3 axles	0	2	2	1	0	0	0	5	1	1
Articulated trucks - 4 or more axles	0	0	0	0	0	1	0	1	0	0
Total	136	326	366	446	550	474	314	2612	373	485

Region: Kiambu	Road: D379		Location: At Wamwangi, junction C64				Time: 6 AM to 6 PM			Adjusted
Direction: Combined both directions	14.01.2012	15.01.2012	16.01.2012	17.01.2012	18.01.2012	19.01.2012	20.01.2012	Total	ADT	ADT (+30%)
Bicycles	8	61	121	70	91	33	1	385	55	72
Others (NMT)	0	0	0	0	0	0	0	0	0	0
Motor Bikes	78	138	198	269	311	311	85	1390	199	258
Cars	84	152	172	293	341	327	259	1628	233	302
Vans/Matatus	79	278	353	364	292	323	281	1970	281	366
Small trucks	4	0	3	2	4	2	1	16	2	3
Buses	0	11	2	2	1	0	2	18	3	3
Medium trucks - 2 axles	12	37	12	4	2	4	6	77	11	14
Heavy trucks - 3 axles	0	7	3	2	0	0	0	12	2	2
Articulated trucks - 4 or more axles	0	1	0	0	0	1	0	2	0	0
Total	265	685	864	1006	1042	1001	635	5498	785	1021

Design traffic loading	Combined both directions			From Wamwangi			Towards Wamwangi		
Vehicle class	ADT (2012)	VEF ¹	DESA	ADT (2012)	VEF ¹	DESA	ADT (2012)	VEF ¹	DESA
Buses	3	1	3	2	1	2	1	1	1
Medium trucks - 2 axles	14	1	14	7	1	7	7	1	7
Heavy trucks - 3 axles	2	4	9	1	4	5	1	4	4
Articulated trucks - 4 or more axles	0	4	1	0	4	1	0	4	1
Total DESA 2012			27			15			13

	Combined both directions			From Wamwangi			Towards Wamwangi		
Vehicle class	ADT (2012)	VEF ²	DESA	ADT (2012)	VEF ²	DESA	ADT (2012)	VEF ²	DESA
Buses	3	0,08	0	2	0,08	0	1	0,08	0
Medium trucks - 2 axles	14	0,6	9	7	0,6	4	7	0,6	4
Heavy trucks - 3 axles	2	1,69	4	1	1,69	2	1	1,69	2
Articulated trucks - 4 or more axles	0	2,76	1	0	2,76	1	0	2,76	1
Total DESA 2012			14			7			7

1) VEF as per Kenya Roads Design Manual

2) Based on axle load survey on D398 Ruiru - Munduro

Cum. Equivalent Standard Axles: $CESA = 365 T_b[(1+r)^n - 1]/r$

T_b = DESA 2012 Bus/Med trucks Heavy/Art. Trucks
r = annual growth rate 5% 4%
n = design period (years)

D379 Kiambu	Combined both directions ³			From Wamwangi			Towards Wamwangi		
Design period (years)	5	10	15	5	10	15	5	10	15
CESA (standard VEF)	43245	97494	165585	30013	67612	114737	26020	58639	99552
CESA (reduced VEF)	22429	50584	85943	13998	31510	53431	13998	31510	53431

3) 80% of the combined traffic loading as per Kenya Roads Design Manual for road narrower than 7.0m

Region: Nyeri	Road: D435		Location: At Ihururu centre				Time: 6 AM to 6 PM			Adjusted
Direction: Towards Ihururu	18.01.2012	19.01.2012	20.01.2012	21.01.2012	22.01.2012	23.01.2012	24.01.2012	Total	ADT	ADT (+30%)
Bicycles	17	19	26	18	18	23	36	157	22	29
Others (NMT)	2	2	7	6	6	8	4	35	5	7
Motor Bikes	79	82	68	86	98	88	64	565	81	105
Cars	22	21	29	40	21	24	39	196	28	36
Vans/Matatus	23	23	19	23	13	20	15	136	19	25
Small trucks	2	3	1	1	0	3	3	13	2	2
Buses	0	0	1	0	0	3	1	5	1	1
Medium trucks - 2 axles	13	11	14	12	5	15	17	87	12	16
Heavy trucks - 3 axles	0	0	0	0	0	0	0	0	0	0
Articulated trucks - 4 or more axles	0	0	0	0	0	0	0	0	0	0
Total	158	161	165	186	161	184	179	1194	171	222

Region: Nyeri	Road: D435		Location: At Ihururu centre				Time: 6 AM to 6 PM			Adjusted
Direction: Towards Kanjora	18.01.2012	19.01.2012	20.01.2012	21.01.2012	22.01.2012	23.01.2012	24.01.2012	Total	ADT	ADT (+30%)
Bicycles	19	20	16	21	18	25	16	135	19	25
Others (NMT)	1	2	5	6	8	7	7	36	5	7
Motor Bikes	66	68	59	65	69	63	101	491	70	91
Cars	21	23	20	47	21	13	119	264	38	49
Vans/Matatus	21	21	8	9	4	18	17	98	14	18
Small trucks	1	2	1	0	0	1	0	5	1	1
Buses	1	2	1	0	0	3	1	8	1	1
Medium trucks - 2 axles	12	10	14	6	1	13	26	82	12	15
Heavy trucks - 3 axles	0	0	0	0	0	0	0	0	0	0
Articulated trucks - 4 or more axles	0	0	0	0	0	0	0	0	0	0
Total	142	148	124	154	121	143	287	1119	160	208

Region: Nyeri	Road: D435		Location: At Ihururu centre				Time: 6 AM to 6 PM			Adjusted
Direction: Combined both directions	18.01.2012	19.01.2012	20.01.2012	21.01.2012	22.01.2012	23.01.2012	24.01.2012	Total	ADT	ADT (+30%)
Bicycles	36	39	42	39	36	48	52	292	42	54
Others (NMT)	3	4	12	12	14	15	11	71	10	13
Motor Bikes	145	150	127	151	167	151	165	1056	151	196
Cars	43	44	49	87	42	37	158	460	66	85
Vans/Matatus	44	44	27	32	17	38	32	234	33	43
Small trucks	3	5	2	1	0	4	3	18	3	3
Buses	1	2	2	0	0	6	2	13	2	2
Medium trucks - 2 axles	25	21	28	18	6	28	43	169	24	31
Heavy trucks - 3 axles	0	0	0	0	0	0	0	0	0	0
Articulated trucks - 4 or more axles	0	0	0	0	0	0	0	0	0	0
Total	300	309	289	340	282	327	466	2313	330	430

Design traffic loading	Combined both directions			Towards Ihururu			Towards Kanjora		
Vehicle class	ADT (2012)	VEF ¹	DESA	ADT (2012)	VEF ¹	DESA	ADT (2012)	VEF ¹	DESA
Buses	2	1	2	1	1	1	1	1	1
Medium trucks - 2 axles	31	1	31	16	1	16	15	1	15
Heavy trucks - 3 axles	0	4	0	0	4	0	0	4	0
Articulated trucks - 4 or more axles	0	4	0	0	4	0	0	4	0
Total DESA 2012			33			17			16

	Combined both directions			Towards Ihururu			Towards Kanjora		
Vehicle class	ADT (2012)	VEF ²	DESA	ADT (2012)	VEF ²	DESA	ADT (2012)	VEF ²	DESA
Buses	2	0,36	1	1	0,36	0	1	0,36	1
Medium trucks - 2 axles	31	0,76	24	16	0,76	12	15	0,76	12
Heavy trucks - 3 axles	0	2,92	0	0	2,92	0	0	2,92	0
Articulated trucks - 4 or more axles	0	1,19	0	0	1,19	0	0	1,19	0
Total DESA 2012			25			12			13

1) VEF as per Kenya Roads Design Manual

2) Based on axle load survey on D398 Ruiru - Munduro

Cumulative Equivalent Standard Axles: $CESA = 365 T_b [(1+r)^n - 1]/r$

T_b = DESA 2012 Bus/Med trucks Heavy/Art. Trucks
r = annual growth rate 5% 4%
n = design period (years)

D435 Nyeri	Combined both directions ³			Towards Ihuru			Towards Kanjora		
Design period (years)	5	10	15	5	10	15	5	10	15
CESA (standard VEF)	53245	121201	207931	34287	78046	133895	32270	73455	126019
CESA (reduced VEF)	40337	91819	157524	24202	55091	94514	26219	59682	102390

3) 80% of the combined traffic loading as per Kenya Roads Design Manual for road narrower than 7.0m

Region: Laikipia	Road: D462		Location: Maili Sita, at junction with A2 Rd				Time: 6 AM to 6 PM			Adjusted
Direction: Towards A2 Junction	18.01.2012	19.01.2012	20.01.2012	21.01.2012	22.01.2012	23.01.2012	24.01.2012	Total	ADT	ADT (+30%)
Bicycles	55	110	209	114	134	158	94	874	125	162
Others (NMT)	0	3	1	1	10	8	7	30	4	6
Motor Bikes	119	136	17	162	194	127	98	853	122	158
Cars	22	21	26	78	41	50	53	291	42	54
Vans/Matatus	58	33	73	146	85	148	71	614	88	114
Small trucks	6	2	14	16	11	23	6	78	11	14
Buses	0	0	0	1	3	3	3	10	1	2
Medium trucks - 2 axles	15	5	12	25	7	12	10	86	12	16
Heavy trucks - 3 axles	0	0	0	1	0	0	0	1	0	0
Articulated trucks - 4 or more axles	0	1	0	3	0	1	0	5	1	1
Total	275	311	352	547	485	530	342	2842	406	528

Region: Laikipia	Road: D462		Location: Maili Sita, at junction with A2 Rd				Time: 6 AM to 6 PM			Adjusted
Direction: Towards Juakali	18.01.2012	19.01.2012	20.01.2012	21.01.2012	22.01.2012	23.01.2012	24.01.2012	Total	ADT	ADT (+30%)
Bicycles	92	123	111	126	143	141	143	879	126	163
Others (NMT)	0	1	2	2	5	9	10	29	4	5
Motor Bikes	133	122	153	187	139	138	168	1040	149	193
Cars	31	17	35	65	46	53	46	293	42	54
Vans/Matatus	73	57	82	153	102	143	106	716	102	133
Small trucks	9	4	22	15	11	16	16	93	13	17
Buses	0	0	0	1	2	3	3	9	1	2
Medium trucks - 2 axles	13	6	7	28	8	21	13	96	14	18
Heavy trucks - 3 axles	0	0	0	0	0	1	0	1	0	0
Articulated trucks - 4 or more axles	0	1	0	0	0	1	0	2	0	0
Total	351	331	412	577	456	526	505	3158	451	586

Region: Laikipia	Road: D462		Location: Maili Sita, at junction with A2 Rd				Time: 6 AM to 6 PM			Adjusted
Direction: Combined both directions	18.01.2012	19.01.2012	20.01.2012	21.01.2012	22.01.2012	23.01.2012	24.01.2012	Total	ADT	ADT (+30%)
Bicycles	147	233	320	240	277	299	237	1753	250	326
Others (NMT)	0	4	3	3	15	17	17	59	8	11
Motor Bikes	252	258	170	349	333	265	266	1893	270	352
Cars	53	38	61	143	87	103	99	584	83	108
Vans/Matatus	131	90	155	299	187	291	177	1330	190	247
Small trucks	15	6	36	31	22	39	22	171	24	32
Buses	0	0	0	2	5	6	6	19	3	4
Medium trucks - 2 axles	28	11	19	53	15	33	23	182	26	34
Heavy trucks - 3 axles	0	0	0	1	0	1	0	2	0	0
Articulated trucks - 4 or more axles	0	2	0	3	0	2	0	7	1	1
Total	626	642	764	1124	941	1056	847	6000	857	1114

Design traffic loading	Combined both directions			Towards A2 Junction			Towards Juakali		
	ADT (2012)	VEF ¹	DESA	ADT (2012)	VEF ¹	DESA	ADT (2012)	VEF ¹	DESA
Buses	4	1	4	2	1	2	2	1	2
Medium trucks - 2 axles	34	1	34	16	1	16	18	1	18
Heavy trucks - 3 axles	0	4	1	0	4	1	0	4	1
Articulated trucks - 4 or more axles	1	4	5	1	4	4	0	4	1
Total DESA 2012			44			23			22

Vehicle class	Combined both directions			Towards A2 Junction			Towards Juakali		
	ADT (2012)	VEF ²	DESA	ADT (2012)	VEF ²	DESA	ADT (2012)	VEF ²	DESA
Buses	4	0,36	1	2	0,36	1	2	0,36	1
Medium trucks - 2 axles	34	0,76	26	16	0,76	12	18	0,76	13
Heavy trucks - 3 axles	0	2,92	1	0	2,92	1	0	2,92	1
Articulated trucks - 4 or more axles	1	1,19	2	1	1,19	1	0	1,19	0
Total DESA 2012			30			15			15

1) VEF as per Kenya Roads Design Manual

2) Based on axle load survey on D398 Ruiru - Munduro

Cumulative Equivalent Standard Axles: $CESA = 365 T_b [(1+r)^n - 1]/r$

T_b = DESA 2012

Bus/Med trucks

Heavy/Art. Trucks

r = annual growth rate

5%

4%

n = design period (years)

D462 Laikipia	Combined both directions ³			Towards A2 junction			Towards Juakali		
Design period (years)	5	10	15	5	10	15	5	10	15
CESA (standard VEF)	70802	160599	274517	46188	104548	178314	44291	100583	172141
CESA (reduced VEF)	48309	109681	187666	30173	68447	117008	30213	68655	117575

3) 80% of the combined traffic loading as per Kenya Roads Design Manual for road narrower than 7.0m

Annex 2 – Cost Estimates

AFCAP/KEN/89				
Preliminary cost estimates D382, E511, D379 and D435				
	Unit	Qty	Unit cost	Amount
Road D382 Nyandarua				
Grub side drains and road reserve	m2	3 600	50	180 000
Cut and backfill side drains with in situ material	m3	600	300	180 000
Import quarry waste for base	m3	756	2 000	1 512 000
Rip, shape and compact to refusal	m3	360	200	72 000
Prime MC30	m2	3 600	88	316 800
Excavate new side drains and cut backslopes	m3	900	200	180 000
Mix and place Cold Mix Asphalt	m2	3 600	650	2 340 000
Provide and lay 600mm access culverts	m	12	9 000	108 000
Provide and lay 900mm cross culvert	m	7	12 000	84 000
Subtotal				4 972 800
Contingencies	15 %			745 920
Total				5 718 720
Cost/km				9 531 200
Road E511 Muranga				
Grub side drains and road reserve	m2	3 600	50	180 000
Import laterite for reshaping/topping up w/c	m3	693	2 000	1 386 000
Rip, shape and compact to refusal	m3	365	200	72 900
Prime MC30	m2	4 860	88	427 680
Reinstate side drains, outlets and mitre drains	m3	450	200	90 000
Mix and place Cold Mix Asphalt	m2	4 860	650	3 159 000
Subtotal				5 315 580
Contingencies	15 %			797 337
Total				6 112 917
Cost/km				6 792 130
Road D379 Kiambu				
Grub side drains and road reserve	m2	1 600	50	80 000
Mix, place and compact side fill for widening	m3	528	250	132 000
Import laterite and fill for base and widening	m3	528	2 000	1 056 000
Rip, shape and compact to refusal	m3	162	200	32 400
Prime MC30	m2	2 400	88	211 200
Excavate new side drains and cut backslopes	m3	400	200	80 000
Mix and place Cold Mix Asphalt	m2	2 400	650	1 560 000
Subtotal				3 151 600
Contingencies	15 %			472 740
Total				3 624 340
Cost/km				9 060 850
Road D435 Nyeri				
Grub side drains and road reserve	m2	2 400	50	120 000
Mix, place and compact side fill for widening	m3	792	250	198 000
Import gravel and fill for base and widening	m3	792	2 000	1 584 000
Rip, shape and compact to refusal	m3	243	200	48 600
Prime MC30	m2	3 600	88	316 800
Excavate new side drains and cut backslopes	m3	600	200	120 000
Mix and place Cold Mix Asphalt	m2	3 600	650	2 340 000
Subtotal				4 727 400
Contingencies	15 %			709 110
Total				5 436 510
Cost/km				9 060 850
Total Cost D382, E511, D379 and D435				20 892 487

Annex 3 – Field survey and alignment data

RESEARCH PROJECT FOR THE ESTABLISHMENT OF APPROPRIATE DESIGN STANDARDS FOR LOW VOLUME SEALED ROADS IN KENYA.

1.0 INTRODUCTION

Norken International Ltd, an Engineering and Management Firm has been requested by African Community Access Programme (AFCAP) for consultancy support for the design of Research sections in Kiambu, Muranga and Nyandarua Regions.

The Research (Test) sections are as follows:

REGION	ROAD	SECTION LENGTH (m)
Muranga	E511	900
Kiambu	D379	400
Nyandarua	D382	600

1.1 Terms of Reference

The scope of works included:

1.1.1 Collection of existing data for the three sections.

This included the existing cross sections including width of the road reserve, horizontal and vertical alignment data and the inventory of culverts.

1.1.2 Production of basic construction drawings.

This included cross sections showing widening, additional culverts (cross and access), drainage works (side drains and mitre drains) and erosion protection (drain lining and scour checks).

2.0 EXECUTION

2.1 Data collection

The assignment started with a reconnaissance visit to Nyandarua with the project consultant on 31/1/2012 to appreciate the expected scope of works. This was followed by a survey study conducted on all the three research section sites and the basic information collected on the three roads. The roads are all existing and were constructed through the government of Kenya R2000 Maintenance road programme.

2.2 E511 Muranga Region

The road was rehabilitated in the FY 2007/08 using the R2000 funding and has since been put on Routine Maintenance by KeRRA Muranga Region. The test section is 900m long and starts at the junction with D417 to a small bridge. It lies within a high rainfall zone (tea growing area) and the traffic is comprising of more than 15 commercial vehicles per day. The drainage is good and the road is still in a fair condition.

2.2.1 Inventory of culverts.

There exists 3No. cross culverts and 1No. access culvert within the research section as shown in the table below.

Chainage	Description	Remarks
0+375	600mm Φ Cross culvert 7m long	Existing and good condition (functioning head/wing walls and aprons). Headwall type 2.
0+542	600mm Φ Cross culvert 7m long	Existing and good condition (functioning head/wing walls and aprons). Headwall type 2
0+725	600mm Φ Cross culvert 7m long	Existing and good condition (functioning head/wing walls and aprons). Headwall type 2.
0+025	600mm Φ access culvert 6m long RHS	Existing and good condition RHS. Headwall type 4.

2.2.2 Cross section

The existing cross section is an average of 5m wide with 6% crossfall. The study recommends a standard cross section from chainage 0+000 to 0+280 and 0+460 to 0+900. For the remainder 180m it is proposed to have a one sided ditch cross section. 18 No. Mitre drains will be placed as shown in the Horizontal Alignment Road profile mainly on the RHS of the road.

2.2.3 Additional Culverts

No additional cross culverts are proposed for the test section. However, one access culvert and access drift are recommended at 0+160 and 0+045 respectively as existing culverts appear to be adequate.

Chainage	Description	Remarks
0+045	Access drift	Proposed RHS
0+160	600m Φ Access culvert, 6.3m long	Proposed LHS. Headwall type 4.

2.2.4 Erosion Protection

The test section has steep gradients ranging from 6-10% hence scour check are recommended to be placed as shown in the Horizontal Alignment profile Of this Road . Concrete Scour checks will be placed along chainage 0+325 to 0+475 (31No.) at 5m intervals and chainage 0+500 to 0+700 (21No.) at 10m intervals on the LHS of the road.

2.3 Nyandarua region

The research section is proposed on D382 and is 600m in length.

The road was improved in the FY 2007/08 with the R2000 funding and has since been under the KeRRA Nyandarua Regions' Routine Maintenance plans. The test section is 15Km from Road C77 near Ngano village. The road is in a fair condition and has little gravel left on the surface. It has traffic of more than 15 commercial vehicles per day and lies within high rainfall zone area with high agricultural production.

2.3.1 Inventory of Culverts

The test section has only one existing 600mm diameter cross culvert that needs improvement of the head/wing walls, inlet and outlet approaches. It has an intact concrete surround.

The existing 450mm diameter access culvert is to be relocated to allow the formation of the junction. Due to maintenance implications, it is recommended to replace it with a 600mm diameter one.

Chainage	Description	Remarks
0+000	450mm Φ Access culvert	Existing LHS, to be relocated and replaced with 600mm diam.
0+660	600mm Cross culvert 7.2m long	Existing need new head/wing walls and apron. Headwall type 2.

2.3.2 Cross Section

The existing carriageway ranges from 5.5-6.0m thus adequate to receive the standard cross section throughout the test section. It is however noted that there exist some amount of ditch scouring and hence need to raise the ditch as indicated in the Road Horizontal Alignment profile.

2.3.3 Additional Culverts

One additional 600mm cross culvert, 8.1m long is recommended at chainage 0+360. It will skew from LHS to RHS and the outlet approach extended.

7 No. access culverts are proposed as shown in the table below.

Chainage	Description	Remarks
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-0+020	600mm Φ Access culvert, 6.3m long	Proposed including concrete surround, head/wing walls and apron. Headwall type 4
0+000	600mm Φ Access culvert, 6.3m long	Proposed including concrete surround, head/wing walls and apron. Headwall type 1
0+100	600mm Φ Access culvert, 6.3m long	Proposed including concrete surround, head/wing walls and apron. Headwall type 4.
0+120	600mm Φ Access culvert, 6.3m long	Proposed including concrete surround, head/wing walls and apron. Headwall type 4
0+235	600mm Φ Access culvert, 6.3m long	Proposed including concrete surround, head/wing walls and apron. Headwall type 4.
0+310	600mm Φ Access culvert, 6.3m long	Proposed including concrete surround, head/wing walls and apron. Headwall type 4.
0+360	600mm Φ Cross culvert,8.1m long	Proposed including concrete surround, head/wing walls and apron. Headwall type 2.

The reason why these accesses are necessary is due to the fact that, the Road is lower than the surrounding area and failure to provide them will lead to the locals blocking the side ditches to gain access to their homesteads.

2.3.4 Drainage works

The side drain is to be improved and then lined in between scour checks as shown in the Road Alignment profile. The gradients range within 6-8% hence scour checks are proposed in chainage 0+010 to 0+380 (35No. LHS and 33 No. RHS) at spacing of 10m.

Mitre drains are proposed at 0+415, 0+610, 0+644 and 0+662 as shown in the Road Horizontal Alignment.

2.3.5 Erosion Protection

Check dams are proposed on the outlet approaches of the culverts in Km 0+360 as shown on the attached road plan.

2.4 D379 Kiambu Region

The road was improved in FY 2009/10 using the R2000 concept. The test section is 400m long and starts at junction with C64 road at Wambugu. It is in good condition and carries traffic comprising more than 15 commercial vehicles per day

2.4.1 Inventory of culverts

There is one existing 600mm Φ cross culvert 7.2m long at chainage 0+020 that is in good condition but only needs improvement at the outlet approach. There is also one existing access culvert at Wambugu Catholic Church at chainage 0+600 that needs replacement. See Table below

Chainage	Description	Remarks
0+020	600mm Φ Cross culvert, 7.2m long.	Existing intact head/ wing walls. Headwall type 2
0+040	600mm Φ Access culvert 6.3m long	Proposed LHS, to be replaced. Headwall type 4

2.4.2 Cross section

The existing carriageway ranges from 4.0-5.0m thus the cross-section will be widened to receive a standard cross-section on the entire test section. There will be improvement on the ditches to receive the design profile as indicated on the cross-Section drawing attached .

The standard cross section of Minor Roads programme will be adopted for the whole of the research section.

2.4.3 Additional culverts

Both access culverts and drifts are proposed as indicated in the table below.

Chainage	Description	Remarks
0+040	600mm Φ Access culvert, 6.3m long	Proposed RHS, headwall type 4
0+070	Access drift	Proposed LHS
0+130	Access drift	Proposed RHS
0+190	Access drift	Proposed RHS
0+195	Access drift	Proposed LHS
0+240	Access drift	Proposed LHS
0+250	600mm Φ Access culvert, 6.3m long	Proposed RHS, headwall type 4
0+370	Access drift	Proposed RHS

As was the case in Nyandarua, if the accesses are not provided the locals will block the side drains to gain access to their homes.

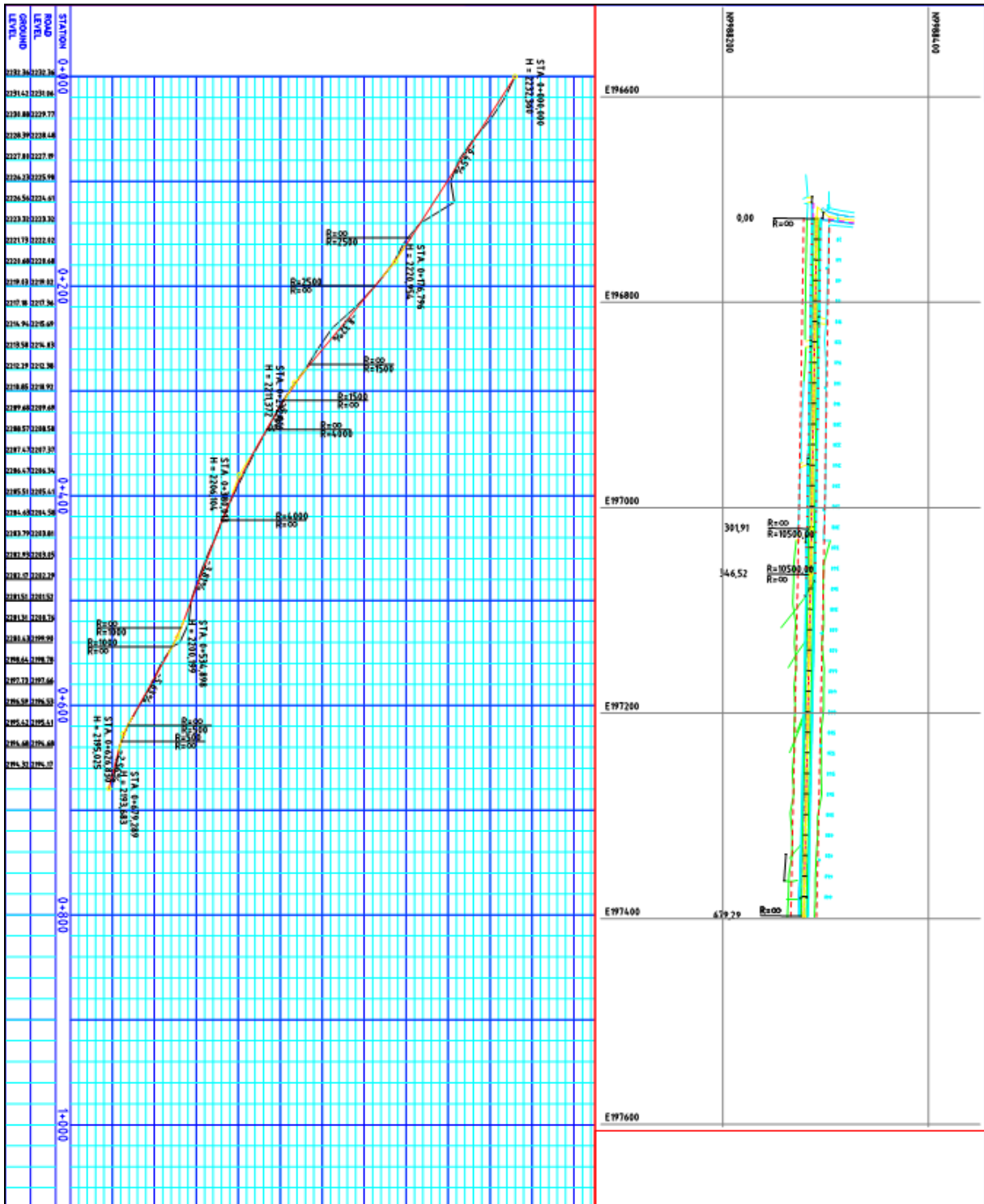


Figure 15: Alignment D382 Nyandarua

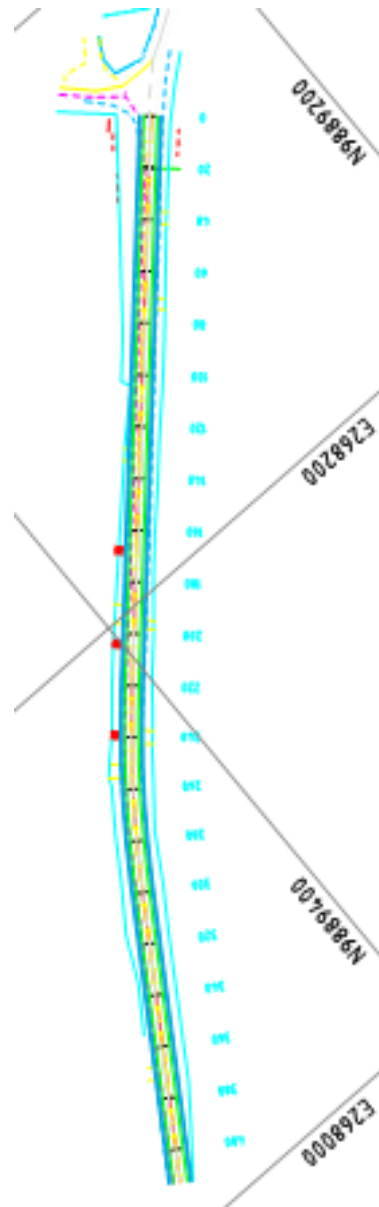
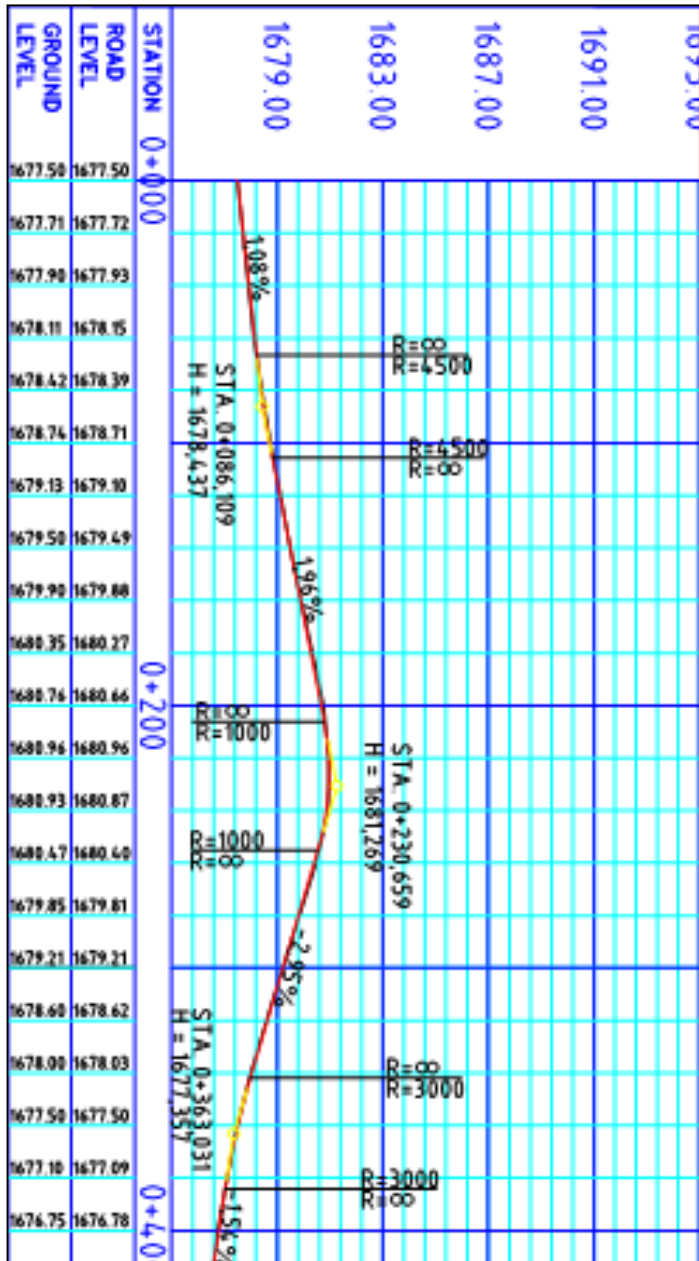


Figure 16: Alignment D379 Kiambu

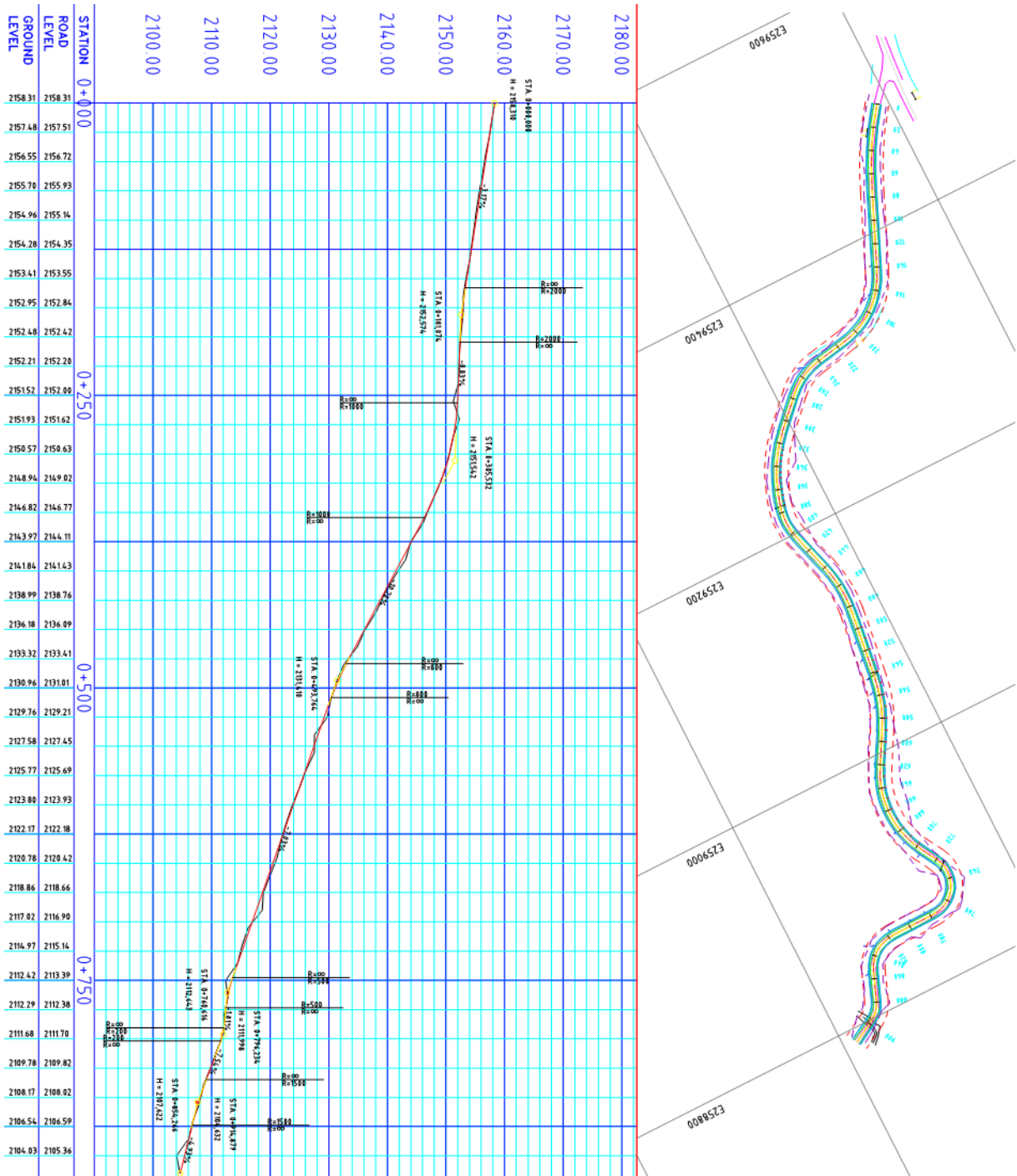


Figure 17: Alignment E511 Muranga

Annex 4 – Cold Mix Asphalt design and construction

Cold Mix Asphalt

The Cold Mix Asphalt was developed as an alternative surfacing option for application on labour-based projects. The advantages are that:

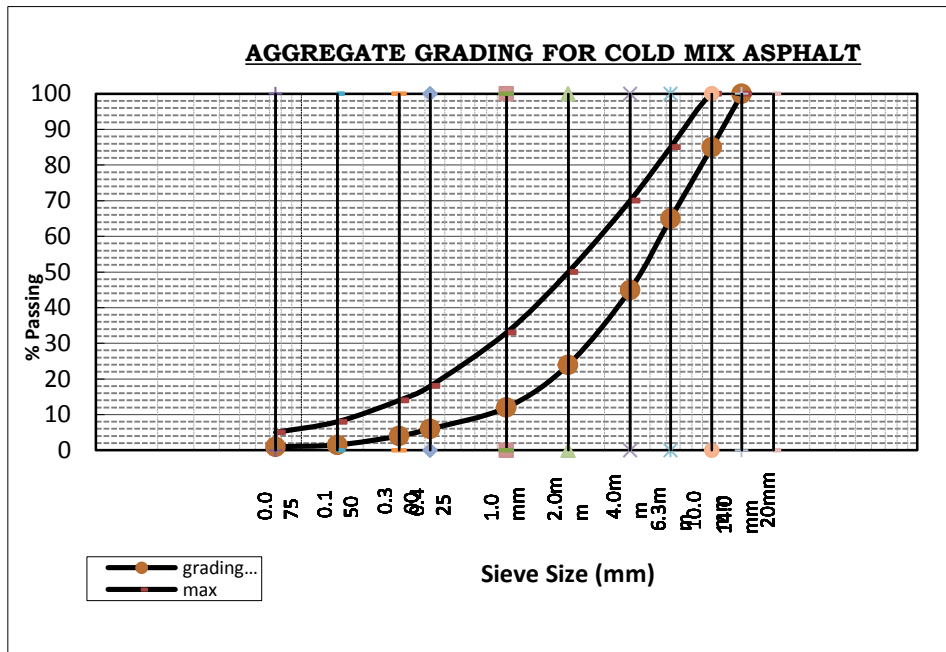
- The potential hazards of working with hot bitumen are avoided;
- It does not rely on heavy and complicated construction plant such as bitumen distributors, bitumen heaters, mechanical chip spreaders and pneumatic tyre rollers. It can be constructed entirely with hand tools, simple equipment and a pedestrian roller for compaction;
- It is therefore suitable for low volume rural roads which are often in remote areas where it may be difficult to mobilize heavy construction plant;
- The speed of the sealing operations can be made to closely match the speed of base construction, hence avoiding damages to the base before it is sealed, particularly where it is impossible or uneconomical to construct by-passes;

The Cold Mix Asphalt can also be a useful supplement to conventional sealing operations (Surface Dressing, Otta Seal) on areas that are difficult to access with heavy machinery (bus stops, parking areas etc.)

Aggregate grading

The aggregates shall be continuously graded and within the specified grading envelope shown below. It is preferable to achieve a grading as close to the upper limit as possible.

Sieve aperture	Percentage passing %	
	Upper limit	Lower limit
14	100	100
10	100	85
6.3	85	65
4	70	45
2	50	24
1	33	12
0.425	18	6
0.3	14	4
0.15	8	1.5
0.075	5	1



Aggregate quality

The Cold Mix Asphalt emulates the Otta Seal, but use emulsion instead of hot bitumen as binder. The performance of the seal is more like an Asphalt Concrete than Surface Dressing and relies on bitumen bonding and particle interlock more than the strength of the aggregates. The aggregates specifications are therefore similar to the ones for the Otta Seal.

The coarse aggregates (6/10 mm stone) shall meet the minimum specification:

Aggregate strength requirements	AADT at time of construction		BS Test designation
	<100	>100	
Min Dry 10% FACT	90kN	110kN	BS 812
Min Wet/Dry strength ratio	0.60	0.75	

Flakiness Index: Maximum 30%

Mix proportions

For tendering purposes the following mix proportions shall be used:

Maximum batch volume:		40 litres
Aggregates:	6/10 stone	12 litres
	0/6 crusher dust	28 litres
	0/2 fine sand	3 litres (as directed by the Engineer, if required to obtain the required grading)
Emulsion:	K3 65% Cathionic Emulsion	6 litres
Water:		1 litre (when aggregates are dry)

Work method

The mixing and laying of the Cold Mix Asphalt surfacing shall be done by labour using only hand tools and purpose made equipment. Compaction shall be done by Double drum steel roller type Bomag 75 or similar.

Preparing the area to be sealed

Before the sealing operation starts, the base must be cleaned of all deleterious material, dust, animal droppings etc.

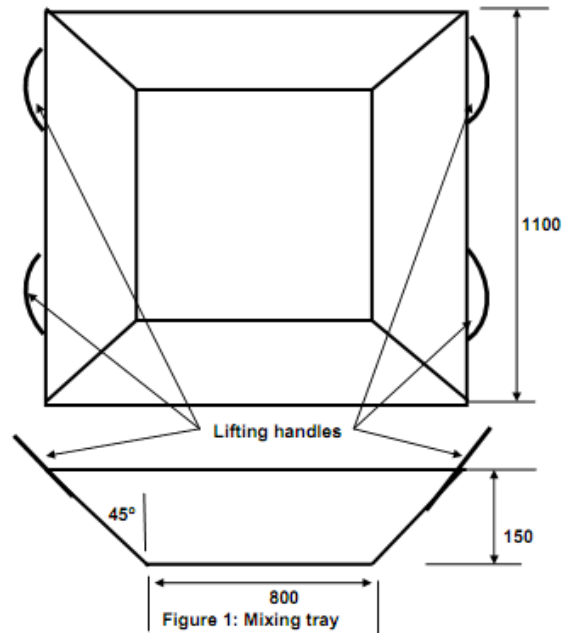
The 20x20mm guide rails are then fixed to the base in a suitably wide strip. It is recommended to limit the width of the strip to max. 1.20m.

A thin tack coat of 1:8 diluted A4 Anionic Stable Grade emulsion is then spread on the area between the guide rails using a watering can and soft brooms and allowed to set and dry before the mixing and placing of the asphalt commences.



Mixing

The mixing shall be done in purpose made mixing trays as shown below:



If the aggregates are dry, a small amount of water must be added and thoroughly mixed in before the emulsion is added.

The mixing must be done

- thoroughly to ensure that all aggregates are coated with emulsion, and;
- swiftly, until the mix has the consistency of a thick soup.

The mixing is best done with square nosed spades to ensure that material in the corners of the tray is properly mixed with the rest.



Placing and levelling

When the mixing is completed, the mix must quickly be placed on the road in between the guide rails and levelled to the top of the guide rails before the emulsion starts to break (turn from brown to black), after which point the mix gets sticky and difficult to spread.



Compaction

Rolling can commence once the guide rails have been removed and the initial breaking of the asphalt has commenced for the full depth of the layer. This period will be affected by the ruling weather conditions, but can normally be done within ½ hour.

The first compaction is done with the roller in static mode. After 2-3 hours the final compaction is done with the roller in vibrating mode.

Rolling is continued until the 20 mm loose layer has been compacted to a thickness of approximately 14-15 mm.

Care must be taken when compacting the asphalt. Rolling of the asphalt should take place in the longitudinal direction of the road and where ever possible at least half the roller should be supported on compacted asphalt. Wrong rolling can result in the building in of undulations in the surface of the asphalt.

Once rolling has been completed and before proceeding with the construction of adjacent asphalt strip the edges of the compacted asphalt must be neatly trimmed and squared and any material resulting from this operation removed from the road surface.

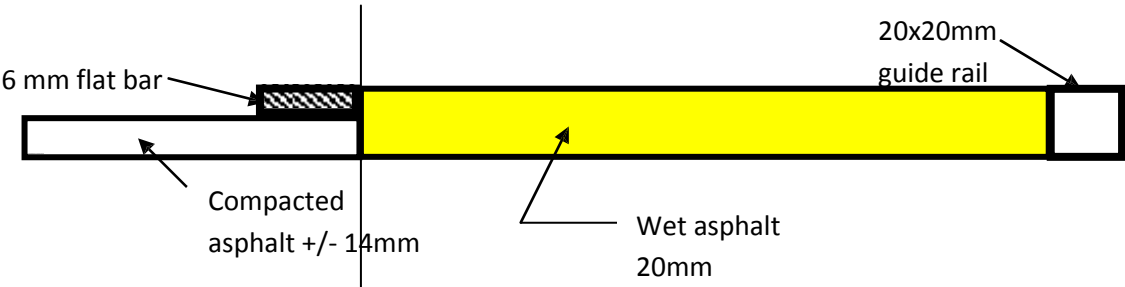
Under normal circumstances, traffic can be allowed onto the newly constructed seal the next day. Care should however be taken with heavy vehicles turning on the fresh asphalt for the next few days.

Construction of the adjacent strip of asphalt

The asphalt on the next adjacent strip can now be constructed as previously described.

In placing the asphalt on the adjacent section of the road allowance must be made for the thickness (+/- 14mm) of the compacted asphalt already placed on the first section of the road.

This is achieved by placing 6mm mild steel flat bar on top of the compacted asphalt and 20mm rails on the other edge of the strip as illustrated below.



Construction joints

Longitudinal and transverse joint are potential weak spots in the asphalt surfacing. Extra care must therefore be taken to ensure tight joints and good bonding between the old and new asphalt.

All joints must be neatly trimmed and any foreign matter (mud, dust, animal droppings etc.) removed before the new asphalt is laid against the joint.

On joints against asphalt that has been constructed a day or more ago, emulsion must be applied on the joint surface with a soft brush.

After construction all joints must be inspected, and where there is a slight “gap” in the joint, a small amount of emulsion must be applied into the gap and crusher dust spread on top to properly seal the joint.



Joint too open,
requires emulsion and
crusher dust to seal



Good joint, hardly
visible