Development of Pavement Design Standards for Low-Volume Roads in Ethiopia
AFCAP/ETH/005/A

Assosa – Kurmuk Laterite Base Trials: Design and Construction Report
CPR 1578

A. Otto
P.A.K. Greening

July 2012

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.

This material has been funded by UKaid from the Department for International Development, however the views expressed do not necessarily reflect the department's or the managing agent's official policies.

For further information visit
https://www.afcap.org

The behaviour of Laterites varies significantly from other natural materials of high plasticity. The plasticity of laterite contributes significantly to strength upon drying back by acting as "cement" to the nodules.

The site on Assosa-Kurmuk road was constructed to demonstrate this principle as well as to investigate the influence of sealed or unsealed shoulders on wheel path moisture and strength both in cut and fill.

The results from long term monitoring should provide information that can update current practice in the use of neat natural bases as well as on the use of sealed and unsealed shoulders.

Contents

List of Figures

List of Tables

1 Background

The Development of Pavement Design Standards for roads in Ethiopia is part of the African Community Access Programme (AFCAP) which has the main goal of providing safe and sustainable access for poor communities in Africa. Revised manuals have been produced under the Ethiopia component of AFCAP which reflect current knowledge and practice and provide practitioners in Ethiopia with a wider choice in the design and construction of rural roads based on results of successful research.

Included in AFCAP are projects primarily aimed at demonstrating the benefits from the application of research-based evidence on pavement design standards for Low Volume Roads that will enable country partners to maximize the use of local resources whilst also assisting the participating road authorities to undertake research projects. These projects are designed to target country-specific problems, the results of which will be used to revise and tailor the manuals and promote the cost-effective provision of roads that facilitate sustainable access and increased mobility, particularly in rural areas. These draft design standards will be disseminated to stakeholders in the federal and regional governments, the private sector and academic institutions.

To this end, four initial demonstration/research projects are being undertaken jointly by the Ethiopia Road Authority (ERA) and TRL. The research objectives have been developed to comply with the overall AFCAP guidelines and include:

(a) Demonstration of approaches that have been used successfully elsewhere and could be applicable to roads in Ethiopia. (These include alternative pavement designs, appropriate use of local materials and various surfacing options).

(b) Research to develop and revise standards and specifications that reflect the prevailing traffic, climatic, terrain and materials characteristics in the country.

Key activities in the selected projects include laboratory testing, construction of demonstration and trial sections, monitoring pavement performance, data collection and analysis and reporting the results with recommendations for any changes to existing pavement design standards and specifications. The parameters to be measured include traffic volume and composition, pavement and materials properties, climatic conditions and construction options for different terrain.

The project described in this report is part demonstration and part research in that it builds on previous research in other countries whilst providing additional information on in-situ moisture sensitivity for some of the lateritic material found in Ethiopia. Analysis of the performance data will enable the Ethiopia Road Authority to confirm or refine the 'Low Volume Roads' design manual.

2 Site selection

Locations for trial sections to be established in Ethiopia were identified from consultations with ERA and various regional representatives as described in the Site Selection Report (Otto, 2010).

Criteria for site selection were agreed as follows:

1. All demonstration and trial test sections to be sealed by way of surface treatment.
2. At least 2 test sections to be an upgrade of what would have been a gravel road to surface treatment.
3. At least 2 test sections to be modified from what would have been asphalt concrete to surface treatment. Control sections can be in the original design for comparison purposes.
4. One test section to be on "black cotton" soil.

5. At least 4 out of 5 test sites to be on ERA roads. This will largely simplify logistics associated with construction of the test sections and allow test sections to carry relatively higher traffic during the short monitoring period.

Some changes in emphasis and priority have subsequently been made due to the change in primary responsibility for the research being transferred from the regions to ERA but the above rational has broadly been retained in the selection of the trial described in this report.

The conceptual matrix used in the site selection criteria is shown in Table 2.1.

Table 2.1 Conceptual Matrix

Variable	Levels
Traffic Volume and Category	<50 to 600vpd
Climate (Rainfall and Temperature)	400-1400mm
Road Gradient	0 – 18%
Materials	Cinders, **Laterites**, Basalts, Limestones, Expansive Clays
Population	Low to High
Existing road surface	Passable / not passable
Existence of socio-economic data	WIDP availability

3 Research on natural gravel road bases

Research carried out by TRL in southern Africa on behalf of the UK Department for International Development (DFID) Gourley & Greening (1999), clearly indicated that existing standards and specifications for sealed roads carrying relatively low levels of traffic (approximately 200vpd) were generally too conservative and impeding rural road provision and development. The research programme included an investigation of existing road pavements with road bases constructed with natural gravel road base. The results showed that these roads had performed far better than expected even though they had often experienced considerable overloading and poor maintenance. The research lead to the development of revised design charts, which are included in the draft Ethiopia Low Volume Road Design Manual.

4 The use of laterites as road base

The research described in section 3 above included roads that had been constructed with lateritic material as base course. These had performed exceptionally well although not meeting a number of the ‘standard’ specifications for road base such as plasticity, strength or grading. Some had also been subjected to overloading and only a few had received maintenance in the form of a reseal. As a consequence of this evidence and using the results of extensive pavement monitoring, revised design charts were developed including one specifically for lateritic material. The charts developed from this research form the basis of the design charts in the draft Ethiopia Low Volume Roads Design Manual (LVRM).

A demonstration section using laterite for base course was also constructed in Malawi in collaboration with the Malawi Road Authority and the European Union.

Most roads in Ethiopia are built using crushed rock for road base. On roads where natural gravels have been used, they are usually surfaced with asphalt rather than a thin bituminous seal. Both these options (crushed rock for base course and asphalt surfacing) are more expensive than using natural gravel for base course plus a surface treatment which is the normal design for the relatively lightly trafficked rural roads in most developing countries.

In 2007, an ERA/DFID research project was started near the town of Awassa, in which rhyolite natural gravel material was used for the base course together with various surfacing options. (It also included sections of blended gravel wearing course). The project was known as the 'Limestone' project in which trial sections of road were constructed using natural gravel base course and surface treatment to demonstrate the potential cost savings and benefits to local users. Whilst it is too early for the performance of this road to be assessed in terms its design life, the expectancy is that of the options used in the trial, the combination of natural gravel base with a double surface dressing is likely to be the recommended approach for sealed rural roads.

The specifications for using natural gravels for road base has also been revised in recent years in a number of countries, with an acceptance that the minimum value of 80 percent soaked California Bearing Ratio (CBR) compacted at 98% mod AASHTO density is unnecessarily high for low-volume roads. Research (including Ref 2) has confirmed these findings. The Ethiopia Low-Volume Roads Design Manual includes categories that allow the use of natural gravels for road base, including laterites.

4.1 Description of the site

The selected site is located 49km along the 96km Assosa – Kurmuk road. This road links the capital of Benshangul Gumuz region to the Sudanese border town of Kurmuk. The road was previously a gravel road, and now being upgraded to a Double Surface Dressing (DBST). The road is expected to function as a major trade link between Ethiopia and Sudan as reflected in the design traffic.

The location of the site is shown in Figure 4-1.

The road is 10m wide comprising 1.5m unsealed laterite shoulders on either side, and 7m carriageway sealed with Double Surface Dressing (DBST). The surfacing aggregate size is 9.5mm second layer aggregate placed on a first layer of 19mm aggregate.

The road comprises many areas of cut and fill on which is placed a laterite sub-base of thickness 150mm. The base material used is crushed stone of thickness 200mm. It is this base that in this project section was replaced with laterite of 200mm thickness on a laterite sub-base of 150mm.

Figure 4-1 Location of the sections on Assosa – Kurmuk road in Western Ethiopia

The trial section was constructed in the middle of the standard road construction so that the performance can be easily compared. The Ethiopian Roads Authority Research and Development Directorate requested authorisation to build a trial section within the main project through the ERA Western Branch office which in turn issued a request to the supervising consultant. A variation order with a full bill of quantities, drawings and standards was then issued to the contractor through the supervising consultant. The construction costs were therefore born within the main contract.

4.2 Objectives of the sections

The project has three main objectives:

(1) To demonstrate that laterite can be used as base course

(2) To research the relative effects of sealed shoulders (in fill and cut) on pavement moisture

(3) To research the benefit of assessing the strength of base course materials at their in-situ moisture content.

5 Moisture-Strength Tests

The standard test for assessing the suitability of base course materials on the basis of strength is the CBR test carried out after 4 days soaking. However, the in-situ moisture content in most sealed roads in Ethiopia, even after the wet season is unlikely to be significantly more than optimum. Therefore, there is clearly a case for assessing base course materials nearer to their in-service moisture condition rather than in the soaked condition. This approach is also gaining support in the design of road bases and is reflected in the current low volume roads manual.

Research carried out by TRL in Botswana in the 1980's indicated that there would be a potential structural benefit from sealing shoulders on roads with natural gravel base course and this has been confirmed in later studies. This moves the region of moisture variation from under the pavement into the shoulders. Sealing shoulders thus ensures a drier pavement environment with higher in-situ strength and greatly improves the opportunities for using materials that have hitherto been deemed unsuitable for road construction on the basis of soaked CBR values. Research in South Africa also showed that there are significant life-time maintenance benefits from sealing shoulders on rural roads.

TRL research indicated that a shoulder width of 1.2 metres was the minimum to ensure that the dry season/wet season moisture variation was retained in the shoulder on the roads studied. In practice, a shoulder width of 1.5 metres is often adopted in the design of sealed rural roads. In the Botswana study, the additional cost of sealing a 1.5m shoulder on both lanes was estimated to be about one tenth of the cost of using crushed rock for base course.

The relationship between Moisture and CBR at a given density will vary for different materials depending on their properties. Therefore, in order to determine their sensitivity to moisture and their likely field strength at the in-situ moisture content, materials should be tested in the laboratory to determine the moisture/density relationship at the expected field density.

Samples of the material to be used as road base in the trials were taken from the borrow pit on the Assosa – Kurmuk road and transported for testing at the ERA laboratory at Alemgena. The maximum dry density (MDD) and Optimum Moisture Content (OMC) values were determined in the usual way. Triplicate samples at OMC were then prepared and compacted in 18 moulds as specified for the California Bearing Ratio (CBR) test.

The variation of CBR with moisture content for the material is shown in Figure 5-1 and the procedure for carrying out the test is described in Appendix A. Although there is some variation in the moisture take up during soaking, the result of approximately 70 per cent for the standard test method used in Ethiopia after 4 day soaking correlates well with the test on borrow pit materials carried out on site by the consultant and the contractor. The CBR values increase significantly to over 150 per cent near OMC and even greater at values just below OMC, which is the overall equilibrium condition of many sealed roads in African countries with natural gravel road base.

The equilibrium moisture content of the base layer in the pavement will not be attained until some time after construction and will depend on factors such as the material properties, pavement environment and climate. The annual variation of the in-situ values of moisture and strength in the pavement layers at different times of the year will be determined in the programme planned to monitor pavement performance. At this early stage after construction, the moisture condition can be expected to remain close to the moisture condition at construction (OMC). When the pavement environment settles to its overall equilibrium state, some seasonal variation in moisture (and strength) can be expected particularly in the region of the interface between the sealed area and the unsealed shoulder. The extent to which this occurs will be an important aspect of subsequent pavement investigation and evaluation. The seasonal variation is expected to be ameliorated or even eliminated on the areas with sealed shoulders in both cut and on embankment. The extent to which this occurs over time is an important aspect of the research.

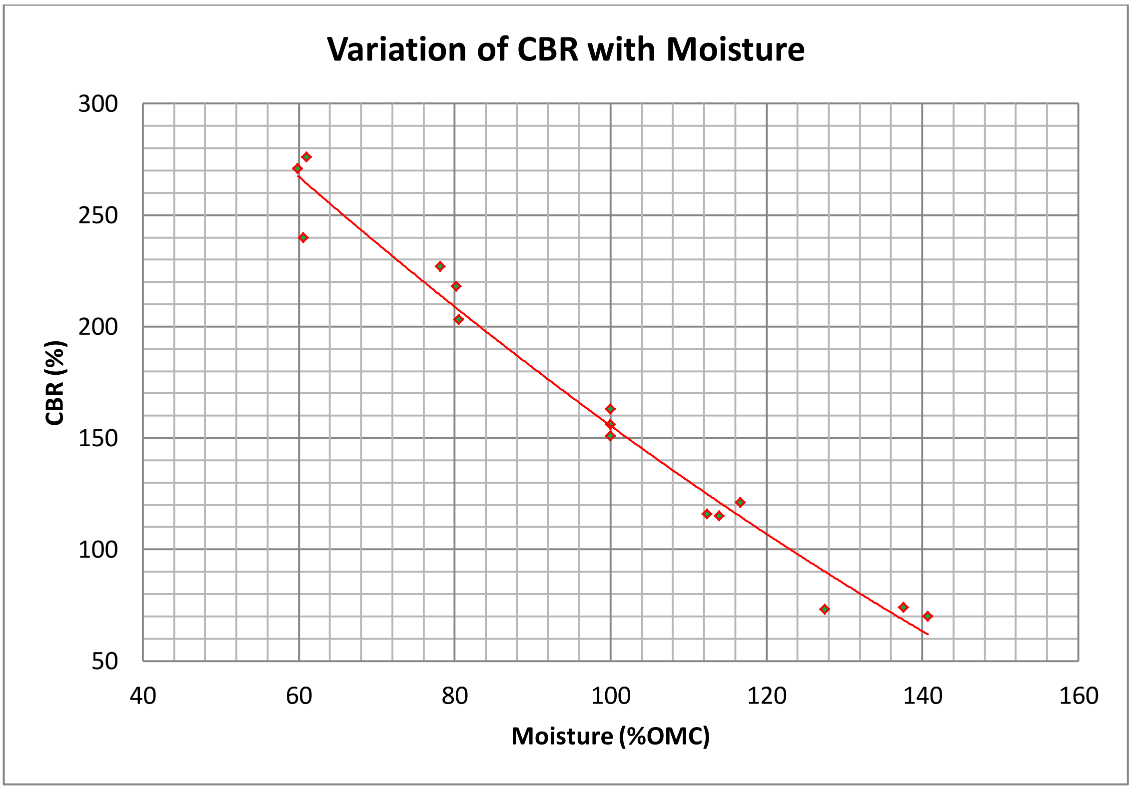


Figure 5-1 Variation of laboratory CBR value with moisture content at 100% MDD

6 Pavement Design

The road pavement design for the project road consists of 150mm of laterite sub-base and 200mm of crushed stone base. The road was designed by the consultant to carry traffic of class LV5 (0.5 - 1.0MESA) on a subgrade of class S5 (CBR=15-29%). The computed design traffic from the consultant's design report was 0.7MESA.

The catalogue in the Ethiopian "Design Standards for Low Volume Roads: Part B: 2011" requires a sub-base of 150mm of G30 and 175mm of G80 for the same traffic and subgrade classes.

Laboratory testing on the laterite showed a 4-day soaked strength of CBR 72% at 100%MDDMod AASHTO. At 2-day soaking the strength is CBR 117% and at 0.8 of 0MC the strength is CBR 216%. It is known from experience that many road bases in Africa remain at between 0.8 of OMC and OMC (and even less in drier areas) for most of their service life.

It was therefore concluded that in the trial section a 200mm laterite base was an appropriate substitute for the crushed stone base as shown in Table 6.1.

Table 6.1 Pavement Structure

Design Chart Requirement (S5, LV5)		**Consultant Design Values**		**Applied on trial section**	
Layer	**Thickness (mm), strength (soaked CBR %)**	**Material type**	**Thickness (mm), Strength (soaked CBR %)**	**Material type**	**Thickness (mm), Strength (soaked CBR %)**
Base Layer	175, 80	Crushed stone	200, 80	Laterite at 100 % MDD	200, 70
Sub-base Layer	150, 30	Laterite	150, 45	Laterite at 95% MDD	150, 45

7 Layout of the sections

The layout of the trial sections is shown in Table 7.1 below and the Bill of Quantities used for construction of the trial section is shown in Appendix B. Sections with sealed and unsealed shoulders both in cut and in fill were included with the objective of determining the relative strength and moisture impacts on the pavement in these situations. It is believed that the moisture and hence the strength in the wheel path will be significantly affected by sealing the shoulders.

The base and sub-base in-situ strength along the wheel path will be assessed in the cut and fill, sealed and unsealed shoulder sections. As a result of the research, the section configuration that does not show significant distress under the loading and environmental conditions can then be adopted as standard practice for low-volume roads in the region.

Table 7.1 Chainages and trial sub-sections

Chainages	Length (m)	Shoulders	Location
49+140 - 49+225	85	Unsealed	Cut
49+225 - 49+330	105	Sealed	Cut
49+330 - 49+460	130	Sealed	Fill
49+460 - 49+580	120	Sealed	Cut
49+580 - 49+700	120	Unsealed	Cut
49+700 - 49+970	270	Unsealed	Fill
Total	830		

8 Construction

When the trial section was selected, the sub-base layer had already been constructed. The base layer was constructed between the periods of 17th April to 27th April. The trial section was constructed as per the drawings shown in Appendix C.

Some of the laterite dumps were contaminated by clay and had to be replaced before they were laid. This was due to the poor technique used by the contractor for extracting the relatively thin laterite seam.

A summary of the properties of the constructed material are as shown in Table 8.1 below. The detailed properties are shown in Appendix D.

Table 8.1 Summary of Laterite properties used

Properties	Average used by Consultant in Compaction approval	Measured in April 2011	Measured in October 2011	Laid on the section
MDD (g/cc)	1.86	1.88		1.83 - 1.85
OMC (%)	14.8	16.3	11.2-12.9	15.90 – 16.80
CBR@65blows (%)		61-71	70-74	60.1 - 69.8
Liquid Limit		44	37	40 – 47
Plastic Limit		34	22	29 – 36
Plasticity Index		10	15	11-12
PM, Envelope(LVR Manual)		300, B	340, B	360, B
% passing 75um sieve (wet analysis)		11.85	14.63-17.52	9.43 – 17.37

DCP tests showed that some sections may not have been adequately compacted after the first round of construction and further compaction was carried out between 14th and 18th May 2012 to improve the density.

The field density tests carried out on the base layer are shown in Table 8.2. All values are at least 98% of maximum dry density. Also DCP tests carried out through to the subgrade are shown in Table 8.3. At this early stage, there is considerable variation in the in-situ strengths but it is expected that these will increase as the base and sub-base layers dry to an equilibrium moisture condition.

Table 8.2 Field Compaction Densities

MDD at 65 blows = 1.86g/cc		**Required Density Ratio = 98%**		
Chainage	**Date of Testing**	**Field Density (g/cc)**	**Relative Density (%)**	**Remarks**
49+140	23/04/2012	1.84	99	
49+140	07/05/2012	1.93	104	Retest
49+240	23/04/2012	1.86	100	
49+240	07/05/2012	1.89	102	Retest
49+340	23/04/2012	1.83	98	
49+480	27/04/2012	1.85	99	
49+510	07/05/2012	1.83	98	Retest
49+540	23/04/2012	1.84	99	
49+640	23/04/2012	1.83	98	
49+740	20/04/2012	1.84	99	
49+840	07/05/2012	1.83	98	Retest

Table 8.3 DCP CBR values measured on the trial section

Chainage	Test Date	*Subgrade CBR*	Sub-Base CBR		Test position
49+170	15/04/2012	50	79		1.5 LHS
49+280	15/04/2012	52	145		1.5 RHS
49+390	15/04/2012	26	62		1.5 LHS
49+485	15/04/2012	37	193		CL
49+650	15/04/2012	149	41		1.5 RHS
49+840	15/04/2012	57	119		1.2 RHS
Chainage	**Test Date**		**Sub-Base CBR**	**Base CBR**	**Test position**
49+220	27/04/2012		63	169	3.25 RHS
49+320	27/04/2012		116	60	5.0 CL
49+420	27/04/2012		127	52	3.25 LHS
49+520	27/04/2012		79	35	0.75 LHS
49+620	27/04/2012		77	41	0.75 RHS
49+720	27/04/2012		34	50	3.25 RHS
49+820	27/04/2012		68	126	5.0 CL
49+920	27/04/2012		60	141	3.25 LHS
Chainage	**Test Date**	***Subgrade CBR***	**Sub-Base CBR**	**Base CBR**	**Test position**
49+140	06/05/2012	31	102	94	2.5 LHS
49+165	06/05/2012	46	104	132	2.5 LHS
49+240	06/05/2012	49	110	31	5.0 CL
49+340	06/05/2012	73	212	102	2.8 RHS
49+440	06/05/2012	17	112	70	2.5 LHS
49+510	06/05/2012	218	137	73	2.6 RHS
49+540	06/05/2012	137	60	75	5.0 CL
49+640	06/05/2012		79	99	2.5 RHS
49+740	06/05/2012	82	39	48	2.8 LHS
49+840	06/05/2012	70	96	212	5.0 CL
49+940	06/05/2012	85	58	46	2.7 RHS

Priming of the section at an application rate of 0.8l/m^2 of MC-30 was done on 28th and 29th May 2012. This was followed by the application of the first surface dressing layer on 7th and 8th June 2012.

The bitumen used for the works was MC-3000 made by cutting back 85/100 Pen grade bitumen with 15% by volume of kerosene. The aggregate used was fresh Basalt of Aggregate Crushing Value (ACV) of 11.6% and Ten Percent Fines Value of 370kN (dry) and 350kN (wet).

During the construction of the surfacing, staff from ERA Research Directorate and TRL were present. Guidance was given on site to the contractor to achieve a good quality surface dressing by adjusting the spray bar height, nozzle angles, checking the temperature and preventing equipment from running on any freshly-laid bitumen. The primed surface was cleaned by compressor and any spots where prime had been removed either by donkey foot marks or by other means were patched with MC-30 before the first layer was placed. Bitumen heated to 130°C was sprayed using a Bitumen Distributor of 10,000 litres. The chippings were applied by a self-propelled chip spreader. On the day of surfacing, rolling was achieved by 4 passes of a pneumatic roller followed by 2 passes of an 8 tonne steel roller. Quality was controlled on site by measuring the spray rate of the bitumen, measuring spread rate of the chippings, constantly checking the spraying temperature, inspecting the and correcting the chippings application. On the following day, rolling was carried out by steel roller to bed down the chippings and the site was closed for 10 days before constructing the second seal.

The application rates of materials for the first layer are shown in Table 8.4 and the grading of the chippings is shown in Appendix E.

Table 8.4 Layer 1 bitumen and chippings spread rate

Chainage	MC3000 Bitumen (kg/m²)			19mm Chippings (kg/m²)			Final Remarks
	Applied	Re-design	Remarks	Applied	Re-design	Remarks	
49+120-49+280 (B/S)	1.48	1.48	√	Missing	17.13		
49+540-49+650 (B/S)	1.51	1.48	√	20.16	17.13	√	
49+760-49+840 (B/S)	1.51	1.48	√	19.78	17.13	√	
49+840-49+940 (B/S)	1.49	1.48	√	18.44	17.13	√	
49+940-49+980 (B/S)	1.42	1.48	–	17.58	17.13	√	
49+980-50+020 (B/S)	*1.25*	*1.48*	––	*20.03*	*17.13*		*Not in section*
49+280-49+540 (L/S)	1.51	1.48	√	20.88	17.13	√	
49+280-49+540 (L/S)	1.50	1.48	√	Missing	17.13		
49+650-49+760 (L/S)	1.49	1.48	√	20.54	17.13	++	
49+280-49+540 (C/S)	1.51	1.48	√	19.72	17.13	√	
49+650-49+760 (C/S)	1.51	1.48	√	21.53	17.13	√	
49+280-49+540 (R/S)	1.45	1.48	–	21.36	17.13	++	
49+650-49+760 (R/S)	1.48	1.48	√	20.28	17.13	++	
Project design values being used for quality control:	1.50kg/m² or 1.55l/m²			17.55kg/m² or 0.013m³/m²			

√ Good, - less than required, -- significantly less than required, + above required, ++ significantly above required

On the 16th June 2012, a meeting was held at Assosa site office with the contractor's representative, the works inspector, engineer from ERA Research Directorate and engineer from TRL to discuss the construction problems which were made in the first seal and to ensure that the same problems do not happen again. The nozzle angles, and spray bar height (25cm) were adjusted again.

The second layer of the surface dressing was done on 18th June 2012. The first seal was cleaned by blowing using a compressor and loose stone was removed by mechanical broom. Spots where diesel from the aggregate trucks had leaked onto the surfacing were removed and patched and then the second layer of the surfacing was placed. Bitumen heated to 130°C was sprayed using a Bitumen Distributor of 10,000 litres. The chippings were applied by a self-propelled chip spreader. On this day, rolling was achieved by 4 passes of a pneumatic roller followed by 2 passes of an 8tonne steel roller. Quality was controlled on site by measuring the spray rate of the bitumen and the spread rate of the chippings, constantly checking the spraying temperature and inspecting and correcting the chippings application. The resulting quality of the work produced appeared to be better than that of the first surfacing layer. On the following day, rolling was carried out by steel roller to bed down the aggregate and the site was closed for 10 days and opened to traffic on the 28th June 2012.

The application rates of materials for the first layer are shown in

Table 8.5 below and the grading of the chippings is shown in Appendix F.

Table 8.5 Layer 2 bitumen and chippings spread rate

Chainage	MC3000 Bitumen (kg/m²)			9.5mm Chippings (kg/m²)			Final Remarks
	Applied	Re-design	Remarks	Applied	Re-design	Remarks	
49+120-49+280 (B/S)	1.24	1.14	√	8.23	9.40	–	
49+540-49+650 (B/S)	1.18	1.14	√	8.14	9.40	–	
49+760-50+020 (B/S)	1.22	1.14	√	7.20	9.40	–	
49+280-49+540 (L/S)	1.20	1.14	√	7.66	9.40	–	
49+650-49+760 (L/S)	1.23	1.14	√	8.24	9.40	–	
49+280-49+540 (C/S)	1.19	1.14	√	8.21	9.40	–	
49+650-49+760 (C/S)	1.18	1.14	√	8.21	9.40	–	
49+280-49+540 (R/S)	1.22	1.14	√	8.21	9.40	–	
49+650-49+760 (R/S)	1.20	1.14	√	6.76	9.40	–	
Project design values being used for quality control:	1.20kg/m² or 1.24l/m²			8.10kg/m² or 0.006m³/m²			

√ Good, - less than required, -- significantly less than required, + above required, ++ significantly above required.

9 Cost considerations

The cost savings of using natural uncrushed material as opposed to crushed rock can be significant. Typical cost ratios quoted in southern Africa are between 4 and 6 and in a recent project in Uganda the ratio was 3.5. However, the relative costs can also vary considerably between projects depending on local circumstances such as the type of available materials and haul distance.

On the Assosa – Kurmuk project the cost ratio in the Bill of Quantities for crushed rock for base course compared with the natural gravel lateritic sub-base, both laid at the required density, is 1.75. Whilst the use of laterite for the base course on this project would still have given a significant cost saving, the saving is surprising low compared with some other projects but illustrates the influence of local factors on costs.

In a research project in Botswana the results indicated that sealed shoulders provide the drier pavement environment that would enable 'weaker' locally available natural gravel to be used as base course in place of crushed rock. In this case, the cost ratio was estimated as being 10:1, predominantly because of the long haul distance to a source of crushed rock that met the prevailing specifications and this example again shows the influence of local circumstances on costs.

10 Pavement monitoring programme

Regular monitoring of the trials sections will begin with the collection of baseline data after the pavement surfacing has settled down after construction. Thereafter, monitoring is expected to take place twice yearly in April/May to coincide with the end of the dry season and in September/October at the end of the wet season when the influence of moisture can be expected to be greatest.

The following procedures are expected to be carried out:

Baseline only

- Bulk samples for laboratory materials testing
- In-situ density tests

The above sampling and testing procedures are aimed at confirming the as-constructed condition of each of the test sections.

Baseline and subsequent monitoring

- Classified traffic counts

  Daily classified traffic counts will be undertaken during monitoring

- Axle loading

  Axle load surveys will be carried out, initially every 6 months, and subsequently at longer intervals when the traffic growth trend has stabilised, so that the actual loading can be related to pavement performance.

- Rut depth

  If there is considerable moisture ingress then one mode of deterioration of gravel road bases is increased rutting, especially in the outer wheel path, which can be susceptible to moisture ingress. Comparison of any rutting that might occur on the sections with sealed and unsealed shoulders will be an important part of the research.

- Strength (DCP/CBR)

  Pavement Strength tests in a vertical pavement profile will be carried out using a Dynamic Cone Penetrometer (DCP) at the offset positions indicated below.

- Moisture content

  Moisture contents at various depths will be measured by taking samples of material for laboratory testing by the specified method and at same position as the DCP at the offsets shown below.

- Deflection Beam/FWD

  Pavement stiffness will be measured by a deflection beam or possibly by using a Falling Weight Deflectometer (FWD).

Cross sectional moisture and strength tests will be carried out at the following positions at selected locations along the road:

-4.5 -4.0 -3.0 -2.5 CL +2.5 +3.0 +4.0 +4.5

The number of cross sectional measurements to be taken on each section of the trials in each monitoring period will be sufficient to provide results with adequate statistical confidence.

Systems will be put in place to enable the time series data to be systematically recorded and analysed.

11 References

Gourley, S. C., & Greening, P. A. K. (1999), *Performance of Low-Volume Sealed Roads: Results and Recommendations from Studies in Southern Africa (PR/OSC/167/99).* Crowthorne: Transport Research Laboratory.

Otto, A. (2010). *Development of Pavement Design Standards for Low Volume Roads in Ethiopia – Site Selection Report (RPN1276).* Crowthorne: Transport Research Laboratory (Report available on direct personal application only).

Appendix A: Guideline Procedure for Tests to Produce a CBR/Moisture Content Relationship

General

(a) Close supervision by one dedicated technician is essential for reliable results.
(b) Take m/c samples from the top half of the mould for CBR tests carried out at the top of the mould and from the bottom half for CBR tests on the bottom.
(c) Moisture contents must be taken IMMEDIATELY after penetration.
(d) A balance capable of weighing moulds to a high accuracy is required.
(e) The values determined in the highlighted procedures below (in bold font) will give the information required to produce plots of CBR v M/C.
(f) The results of tests from the top and bottom of the mould should be plotted separately.
(g) After drying back, the values of CBR may require the use of a higher rated proving ring.
(h) It is recommended that CBR and m/c is determined for one of the 3 moulds BEFORE unsealing and carrying out tests on the 2 remaining moulds selected for supplicate testing.

PROCEDURE

1. Prepare bulk sample by the normal method.
2. Carry out determination of MDD and OMC by the normal MOD AASHTO method.
3. Prepare 15 moulds of material compacted to the agreed compaction (100%MOD AASHO) and at OMC.
4. Select 3 moulds and carry out CBR tests (at nominal OMC) and determination of actual m/c. (12 moulds remain)
5. Place the remaining 12 moulds to one side.
6. Select another 3 moulds and place in water bath as in normal soaked CBR procedure. Follow the usual procedure to determine the soaked CBR and determination of m/c. (9 moulds remain)
7. Place another 3 moulds in the water bath. Remove and weigh each day until the m/c is approximately half way between the omc and soaked values (approx 2 days). Seal the moulds and allow the sample to equilibrate. Carry out determination of CBRs and moisture contents. (6 moulds remain)
8. Allow the remaining 6 moulds to air dry and weigh regularly (every day or so).
9. Calculate the loss in weight required to give a m/c of approximately 0.8 OMC. When the required weight has been achieved, take 3 moulds, seal them with cling film or similar and allow them to equilibrate and then carry out CBR test(s) and determination of m/c. (THIS MAY TAKE SOME DAYS) (3moulds remain)
10. Continue drying the remaining 3 moulds. Calculate the loss in weight for each the moulds to give a moisture content of approximately 0.6 omc. When the required weight has been achieved, take the remaining 3 moulds, seal them and allow them to equilibrate and then carry out CBR test(s) and determination of m/c(s). (THIS MAY TAKE SOME DAYS).
11. Repeat step 10 for any additional moisture contents (e.g. 0.4 omc - requires 18 moulds to be prepared at the start – 3 for each mc/CBR point)
12. Plot the results for CBR and m/c for the top and bottom separately.

The plot should enable an estimate to be made of the expected field CBR's at different moisture contents. Three (3) moulds are normally recommended for each set of values so that if the measured moisture is different to that expected then duplicates remain available for further testing.

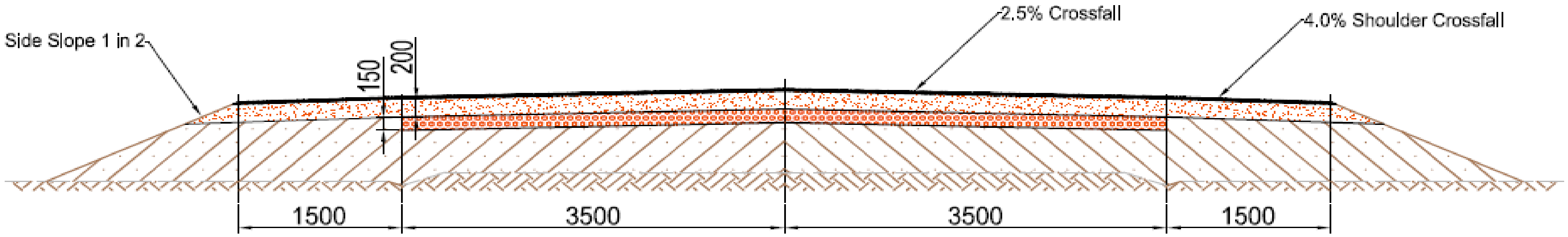
Appendix B: Bill of Quantities

Item	Description	Unit	Quantity.
1	**Gravel Preparation**		
1.1	Stockpile laterite gravel at the borrow pit at chainage 55+700 as directed by consultant.	m³	1,670
1.2	Haul stockpiled laterite gravel from borrow pit at chainage 55+700 to work location between chainages 49+120 to 49+970.	m³km	10,400
2	**Earthworks**		
2.1	Prepare cut to levels and slopes as specified in the original contract documents.		
2.2	Prepare fill to levels, slopes, materials and strengths as specified in the original contract documents.		
3	**Sub-Base Layer**		
3.1	Prepare and construct sub-base layer to thickness, levels, slopes, materials and strengths as specified in the original contract documents.		
3.2	Allow at least 21 days for Sub-Base layer to dry back. Absolutely no traffic is permitted on the compacted layer during this period. Allow sum for traffic control.	Sum	1
4	**Shoulders**		
4.1	Prepare and construct shoulders to thickness, levels, slopes, materials and strengths as specified in the original contract documents.		
4.2	Allow at least 21 days for constructed layer to dry back. Absolutely no traffic is permitted on the compacted layer during this period. Allow sum for traffic control.	Sum	1
5	**Base Layer**		
5.1	Spread the laterite gravel 7m wide in between shoulders previously constructed, water to about 2% less than Optimum Moisture Content, compact to finished thickness of 200mm, transverse slope of 2.5% and density of 98%MDD Mod AASHTO. The contractor shall devise compaction methods and techniques to ensure that the densification is uniform through out the 200mm thickness.	m³	1,190
5.2	Ensure final base surface is truly level and transversely sloped to 2.5%.	Sum	1
5.3	Trim outer edges of pavement layers to achieve designed side drain dimensions and slopes as per original contract.		
5.4	Allow at least 21 days for constructed layer to dry back. Absolutely no traffic is permitted on the compacted layer during this period. Allow sum for traffic control.	Sum	1
6	**Drainage**		
6.1	Construct as specified in the original contract documents.		
7	**Surfacing**		
7.1	Apply priming to the constructed base layer from chainage 49+120 to 49+970; MC30 at 0.8l/m^2.	m^2	5,950
7.2	Additionally apply **priming to shoulders** on both sides of the carriageway from chainage 49+225 to 49+580; MC30 at 0.8l/m^2 .	m^2	1,065
7.3	Construct surface dressing layers to materials, dimensions, methods and quality as specified in original contract documents. Additionally if full width spraying is not used, then the joints of each surface dressing layer must be staggered away from each other.		
7.4	Additionaly construct **surfacing on shoulders** to the same specifications and quality as that applied to the carriageway; as shown in the drawings provided on both shoulders at chainages 49+225 to 49+580.	m^2	1,065

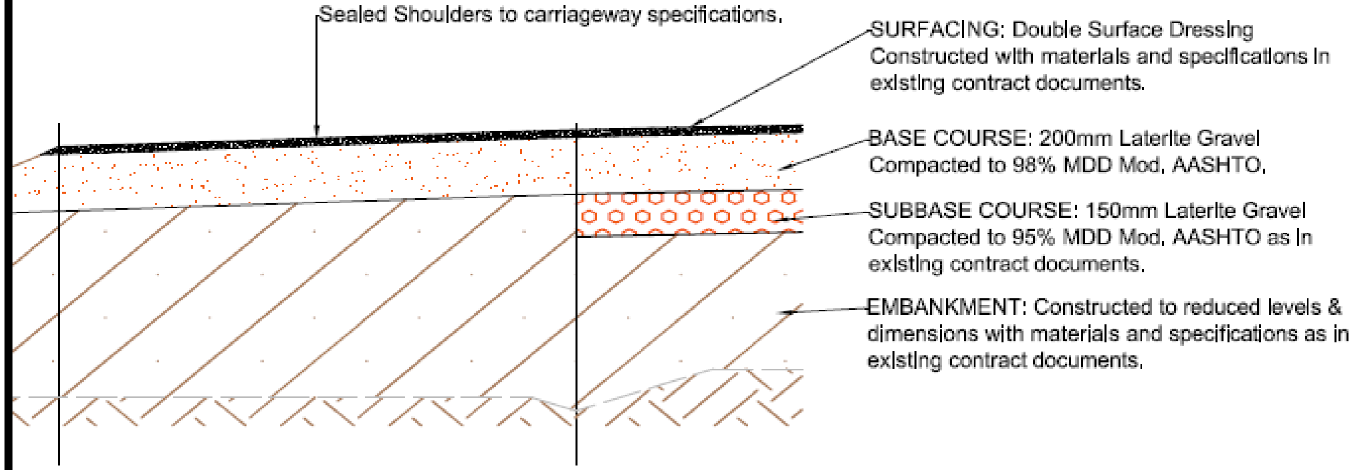
Bill of Quantities (cont)

8	**Road Furniture**		
8.1	Install all signposting required within the sections as specified in the original contract.		
8.2	Fabricate galvanized rectangular plate 1.0m long x 0.8m wide. The plate should be fitted on 2 galvanized steel pipes 4.0m long and 100mm diameter each. Fit the plate by 2 bolts and 2 nuts on each pipe and weld the nut heads to avoid theft. Weld 4 steel hooks at the bottom end of each pipe. Install fabricated signposting at least 1m off the outer edge of the side drain in 2 concrete foundations 0.4mX0.4m X 1.0 m. Chainages 49+120 and 49+970.	No.	2
8.3	Mark lane edges and centreline using Ethiopian standard colour paints and spacings.	m	2,550
8.4	Install marker posts, same design as per original contract, on the outer edge of the shoulder at chainages 49+225, 49+330, 49+460, 49+580, 49+700	No.	5
9	**Laboratory Services**		
9.1	Allow sum for laboratory testing of Gradation, Atterberg limits and MDD.	Samples	6
9.2	Allow for testing in situ compaction and moisture.	Points	5
	Sub-total		
	Add tax		
	Total		

Appendix C: Section Drawings



Section 1-A: Embankment, Laterite Base, Sealed Shoulders.



Edge Detail

ETHIOPIA: AFCAP - Pavement Design Standards

Assosa - Kurmuk Road.

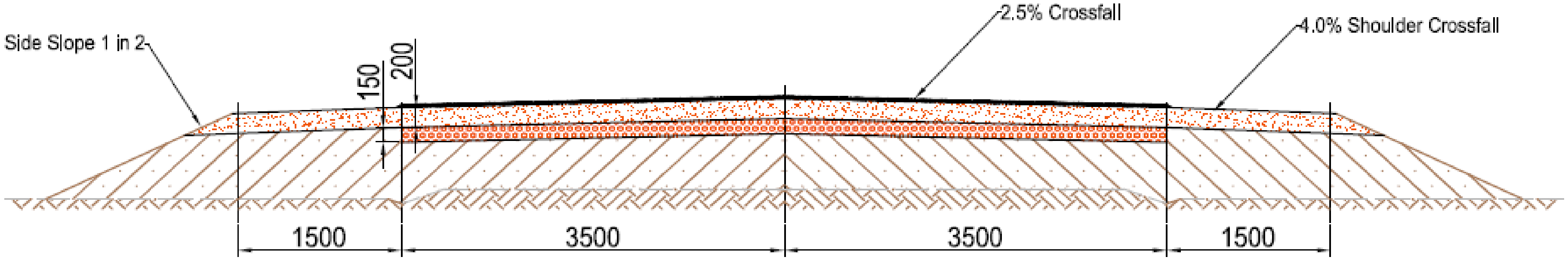
Section 1-A: Embankment, Laterite Base, Sealed Shoulders.

Length: 250m

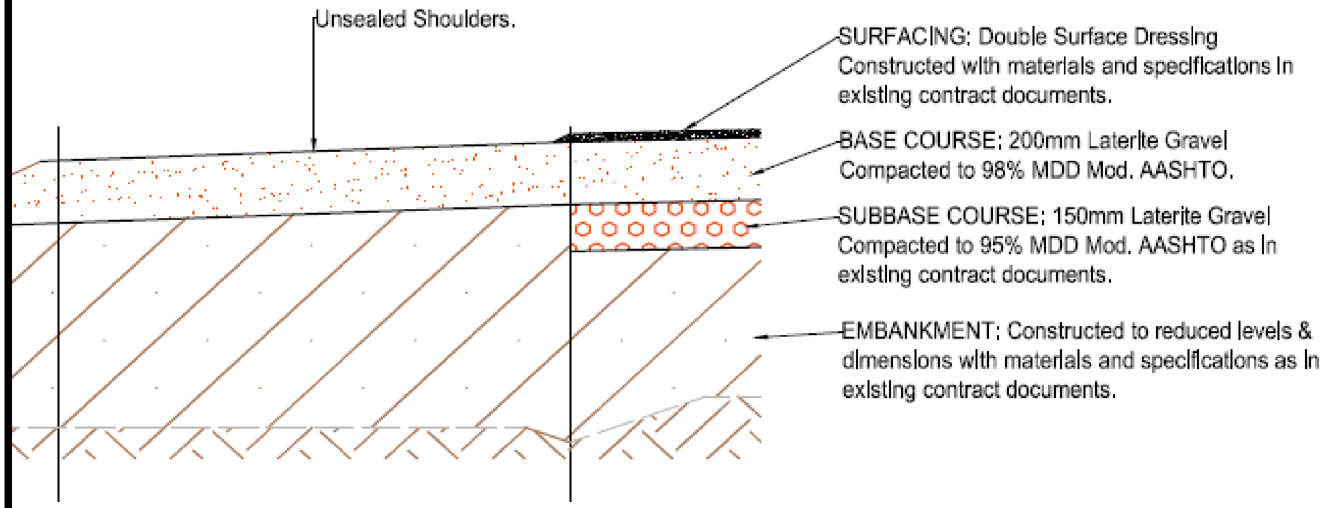
Designed: Tony Greening - TRL

January 2011.

All Dimensions in mm. Do NOT scale from drawing.



Section 1-B: Embankment, Laterite Base, Unsealed Shoulders.



Edge Detail

ETHIOPIA: AFCAP - Pavement Design Standards

Assosa - Kurmuk Road.

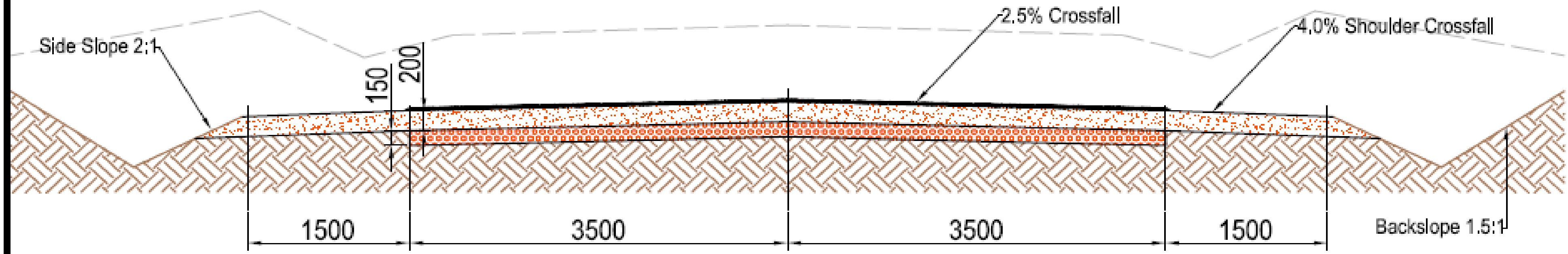
Section 1-B: Embankment, Laterite Base, Unsealed Shoulders.

Length: 250m

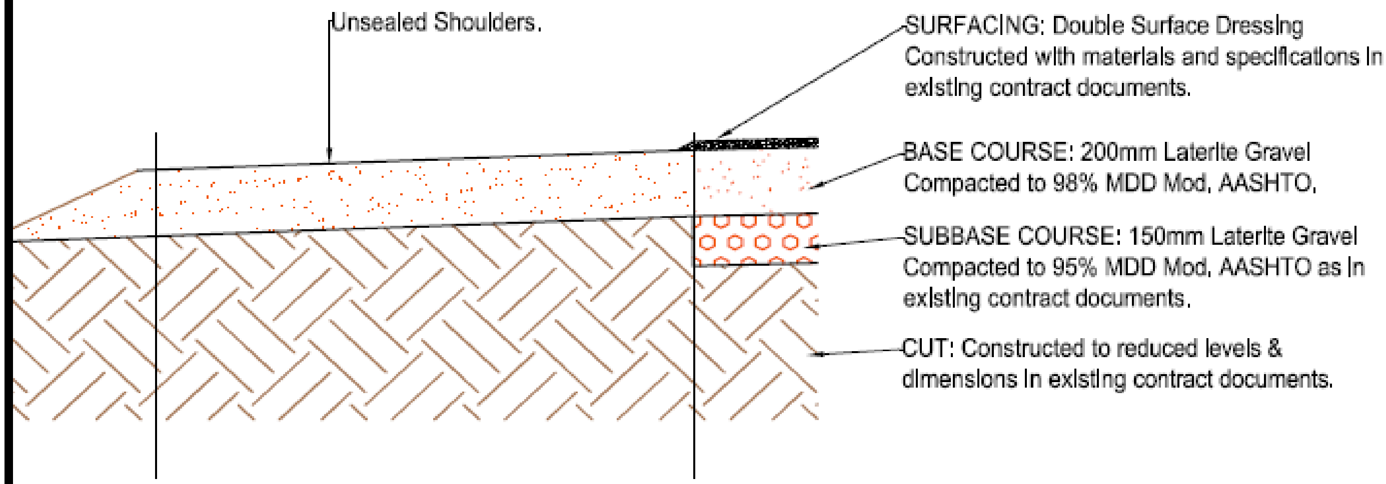
Designed: Tony Greening - TRL

January 2011.

All Dimensions in mm. Do NOT scale from drawing.



Section 2-A: Cut, Laterite Base, Unsealed Shoulders.



Edge Detail

ETHIOPIA: AFCAP - Pavement Design Standards

Assosa - Kurmuk Road.

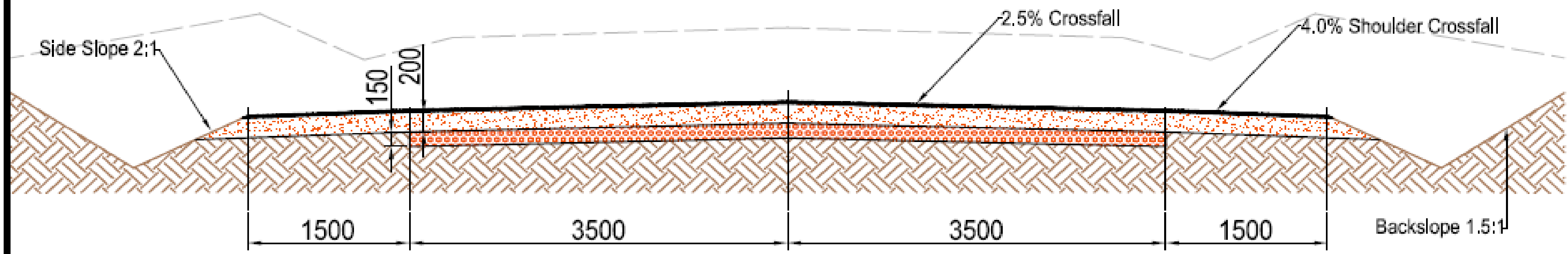
Section 2-A: Cut, Laterite Base, Unsealed Shoulders.

Length: 250m

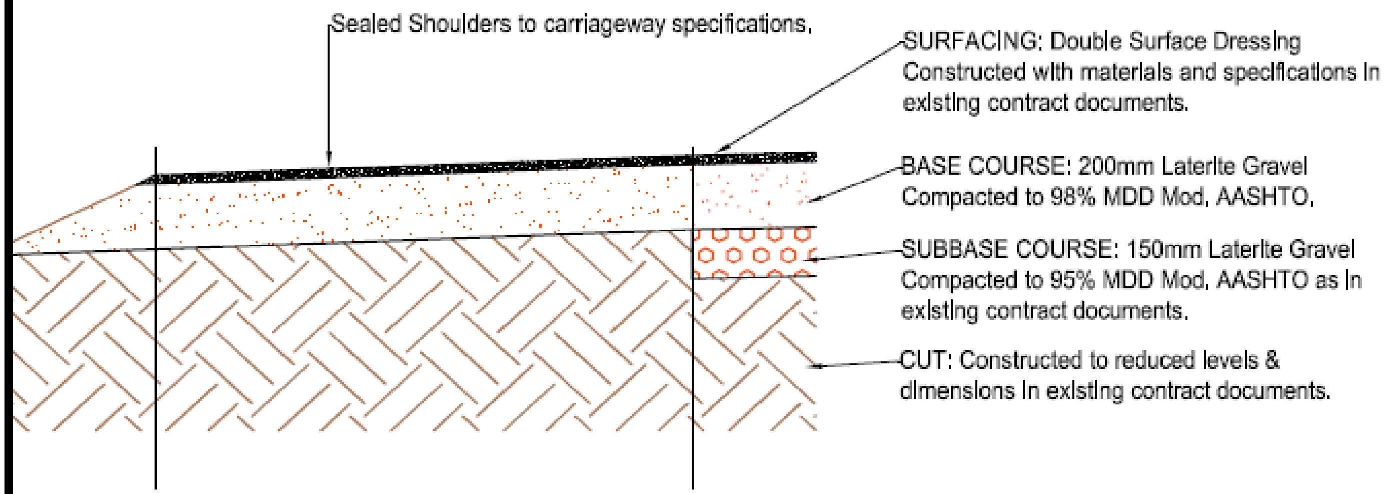
Designed: Tony Greening - TRL

January 2011.

All Dimensions in mm. Do NOT scale from drawing.



Section 2-B: Cut, Laterite Base, Sealed Shoulders.



Edge Detail

ETHIOPIA: AFCAP - Pavement Design Standards

Assosa - Kurmuk Road.

Section 2-B: Cut, Laterite Base, Sealed Shoulders.

Length: 250m

Designed: Tony Greening - TRL

January 2011.

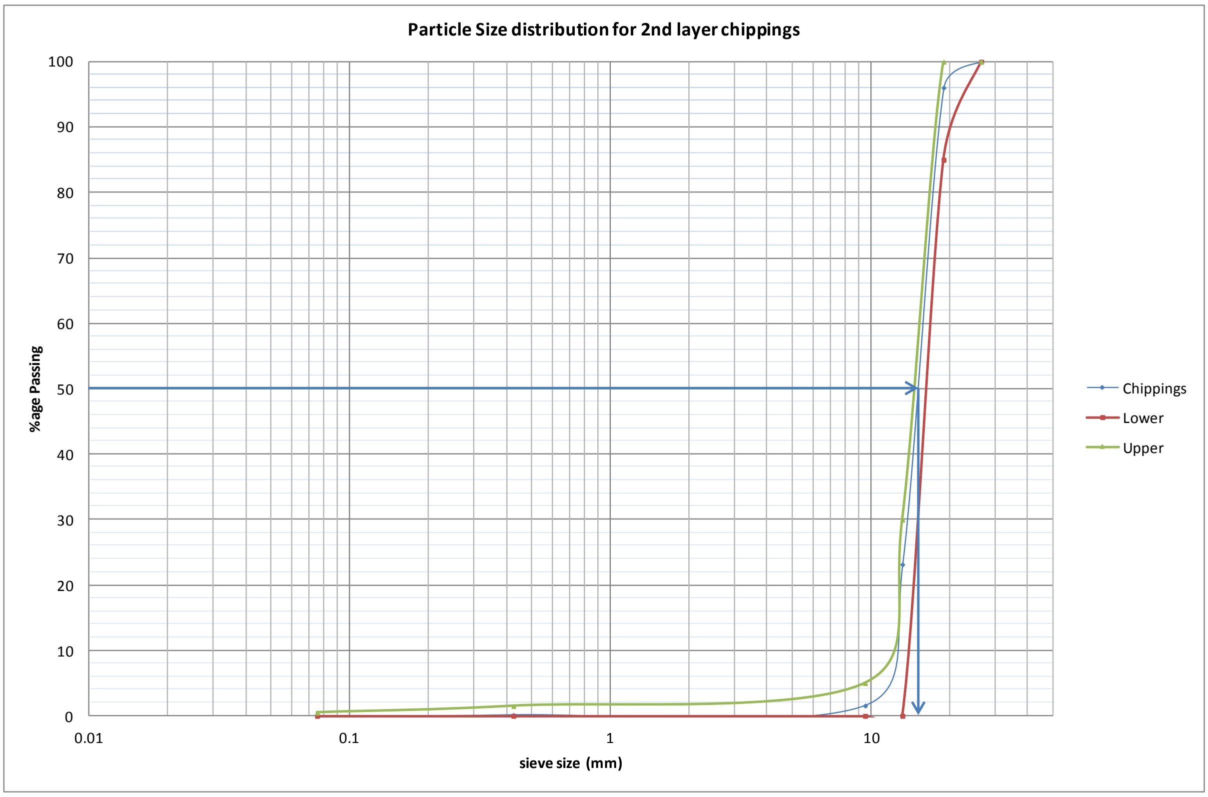
All Dimensions in mm. Do NOT scale from drawing.

Appendix D: Properties of the Laterite Used

Station	Sample Date	Date Tested	Sieve Size	50mm	37.5mm	19mm	4.75mm	1.18mm	0.3mm	0.075mm	LL	PI	PM	Grading Envelope (LVR Manual)	MDD	OMC	4 day Soaked CBR (30blows)	4 day soaked CBR (65blows)	Swell (%)
			% Passing	100	80-100	60-100	30-100	17-75	9-50	5-25									
				100.00	94.70	72.52	51.84	39.85	29.83	16.24									
49+180 (49+140-49+240)	01/05/2012	03/05/2012		100.00	92.21	69.33	49.99	38.58	28.82	14.65	44	11	330	B	1.85	16.0	57.4	66.2	0.05
				100.00	97.32	87.75	45.84	31.39	18.71	12.63									
49+300 (49+240-49+340)	02/05/2012	04/05/2012		100.00	98.36	88.71	41.81	27.47	14.18	11.03	43	11	205	B	1.85	16.2	48.0	69.8	0.03
				100.00	95.35	75.13	54.03	41.17	31.06	17.37									
49+380 (49+340-49+440)	01/05/2012	03/05/2012		100.00	94.69	75.08	53.11	40.82	30.45	16.15	47	11	345	B	1.84	16.3	44.0		0.15
				100.00	95.32	75.51	54.82	42.81	26.81	12.45									
49+500 (49+440-49+540)	01/05/2012	03/05/2012		100.00	95.26	74.05	53.40	37.88	28.96	13.76	40	11	330	B	1.84	15.9	50.0		0.13
				100.00	98.82	75.93	52.87	38.04	28.46	14.34									
49+590 (49+540-49+640)	02/05/2012	04/05/2012		100.00	98.99	76.91	53.62	38.74	29.23	15.38	44	12	360	B	1.84	16.0	61.0		0.29
				100.00	100.00	93.80	51.48	33.49	17.12	9.43									
49+690 (49+640-49+740)	01/05/2012	02/05/2012		100.00	100.00	93.59	50.36	34.26	17.13	10.21	47	12	230	B	1.83	16.8	47.0		0.36
		27/10/2012	A (Compac	100.00	100.00	93.36	54.24	38.00	28.00	11.27									
		27/10/2012	B (Compac	100.00	100.00	96.11	55.23	38.00	25.00	12.48									
				50.00	37.50	19.00	4.75	1.18	0.30	0.08									

TPFV	DRY	Wet
	66kN	39kN

Appendix E: Grading of 1st Layer Chippings



Appendix F: Grading of 2nd Layer Chippings