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Development of Pavement Design Standards for Low Volume Roads in Ethiopia

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Overview of four research projects carried out by the Research and Development Directorate of Ethiopian Roads Authority

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List of Abbreviations

AADT: Annual Average Daily Traffic

AC: Asphaltic Concrete

ADT: Average Daily Traffic

AFCAP: African Community Access Programme

BoQ: Bill of Quantities

CBR: California Bearing Ratio

DfID: Department for International Development

DBST: Double Bituminous Surface Treatment

DCP: Dynamic Cone Penetrometer

ERA: Ethiopian Roads Authority

ERCC: Ethiopian Roads Construction Corporation

ESA: Equivalent Standard Axle

FWD: Falling Weight Deflectometer

HMA: Hot Mix Asphalt

IRI: International Roughness Index

MERLIN: Machine for Evaluating Roughness using Low-cost Instrumentation

LHS: Left Hand Side

LTPP: Long Term Pavement Performance

LVR: Low Volume Roads

NPRA: Norwegian Public Roads Administration

PTR: Pneumatic Tyred Roller

RHS: Right Hand Side

RRC: Road Research Centre

TRL: Transport Research Laboratory

URRAP: Universal Rural Roads Access Programme

VPD: Vehicles per day

VIM: Voids in the mix

VMA: Voids in mineral aggregate

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It should be noted that the BSI Symbol and UKAS Accreditation mark signify that Crown Agents operate a documented Quality Management System registered with the British Standards Institution to the international quality standard BS EN ISO 9001:2008. The provision of consultancy services in revenue enhancement and expenditure and debt management including: customs, taxation and trade, human institutional and organisational development, engineering, procurement management advice and reform, health logistics and procurement services. The management of third party quality assurance and inspection services related to the supply of manufactured and processed products. International freight forwarding services utilising in house sub-contract warehousing. Verification of service as follows: Air Import – Clearance UK airport; Exports – Airport of departure; Sea Imports – Clearance UK port; Sea Exports – Port of loading.

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1. Introduction

1.1 Building local research capacity

DFID and other donors have funded research projects in the transport sector in Africa since around 1950's and the results have provided important beneficial changes in road provision but these projects relied heavily on foreign expertise and funding. Despite many of these projects having components of technology transfer and capacity building, many African countries have, hitherto, shown a lack of interest in building indigenous research capacity. In recent years, however, there have been important changes in attitude to the transport sector by African governments. These changes have included increased awareness of the value of the road network as a national asset and increased recognition that investment in research can yield significant economic benefits.

The UK DFID-funded African Community Access Programme (AFCAP) has also created an increased awareness of the value of research in the countries participating in the programme and has provided some of the tools needed by governments to establish their own research programmes. There are indications that funding for research will also become more available from government budgets and other sources such as road user charges collected by road funds. Nevertheless, the establishment of research institutions with suitably motivated, qualified and experienced staff remains a considerable challenge. Help in building indigenous research capacity in Africa is being provided though the technical assistance component of AFCAP.

In Ethiopia, the World Bank is also supporting the establishment of a Road Research Centre (RRC) in the Research Directorate of the Ethiopia Road Authority (ERA) to undertake research activities. Temporary accommodation for the RRC has been constructed under this programme together with the provision of training courses and technical assistance through AFCAP.

The research projects described in this report are part of the initial programme of research being carried out by the Research and Development Directorate of ERA.

1.2 AFCAP research projects in Ethiopia

Four research projects have been initiated in Ethiopia under AFCAP in collaboration the RRC. These projects are jointly funded with constructions costs funded by ERA and technical support provided by TRL Ltd being funded under AFCAP. Each of the four projects involved the construction of trial sections aimed at demonstrating alternative technology for road provision developed elsewhere. The research components were aimed at increasing the use of locally available materials and solving specific problems related to the performance of some roads constructed with asphaltic concrete.

The overall goal of this research is to reduce costs and help increase cost-effective, safe and sustainable road provision in Ethiopia, which are the core objectives of AFCAP.

The projects were managed by the Research Directorate of ERA.

2. Objectives and content of the report

The main objective of this report is to present an overview of the provision of the demonstration/research trials with particular reference given to the activities undertaken, the likely research outcomes together with outcomes to date. Sections on the constraints and difficulties encountered and recommendations are also included, which should provide guidance for conducting similar research in the future.

Full details of the design and construction and monitoring of the trial sections have been reported previously and readers interested in the detailed technical aspects of the projects should refer to these reports. The reports included in the Reference Section of this report can also be accessed on the AFCAP website.

A brief summary of each of the four projects is presented under the following headings:

- Research objectives
- Location, design and methodology
- Problems/constraints
- Outcomes to date
- Recommendations

A brief section on the additional activities undertaken to support the research programme is also included together with overall conclusions and recommendations.

3. The Research Directorate projects

Following initial discussions and an appraisal of potential projects with ERA, a provisional site selection report was prepared (Otto, 2010), which identified possible locations for research. The final composition of the research programme and the location of project sites were decided by ERA in consultation with TRL staff, who also assisted in the design and construction of the trials which were managed by ERA.

The programme included four projects which were designed to demonstrate approaches developed and used in neighbouring and other African countries and which could benefit rural road provision in Ethiopia. They included research in the use of local materials and initiated possible alternative mix designs for asphaltic concrete roads.

The four demonstration/research projects described in the report are:

- Laterite base trial on the Assosa-Kurmuk road
- Otta sealing in the village of Combel
- Otta sealing in the village of Gerado
- Alternative mix design on the Abbal-Irebti road

Other activities carried out as part of this programme included workshops on the design and construction of the trials, introductory classroom and on-site training on monitoring research trials, workshops and laboratory and site visits.

4. Assosa-Kurmuk laterite base trials

4.1 Background

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. Included in this research were roads that had been constructed with lateritic material as base course. [Whilst the use of lateritic material for sub-base is fairly common, it often fails to meet the required specifications for base course and, when it used, it is usually modified with cement, or more commonly with lime]. The roads with laterite base course included in the research had performed exceptionally well although not meeting a number of the ‘standard’ specifications for road base such as plasticity, strength or grading. Some roads had also been subjected to overloading and some had received no maintenance in the form of a reseal since construction and had still performed well.

On the evidence emanating from the research, a 2 kilometre demonstration section replacing the crushed rock base with lateritic gravel was constructed on the Limbe to Mulanje road in Malawi, which has also continued to perform well.

In Ethiopia, most roads are built using crushed rock for road base. On road bases that have been constructed with natural gravel, 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 lateritic gravel for base course plus a surface treatment which is the normal design for the relatively lightly trafficked rural roads in most developing countries.

The specifications for using natural gravel materials derived from the research described above has been revised, adapted for use in Ethiopia and are included in the Ethiopia Low-Volume Roads Design Manual.

4.2 Research objectives

The project has the following main objectives:

- Demonstrate that laterite can be used for base course
- Research the relative effects of sealed shoulders (in fill and cut) on pavement moisture
- Research the benefit of designing road bases on the strength of materials at their in-situ moisture content.

The demonstration component of the trials is similar to the approach used in Malawi in that the crushed rock base course was replaced with lateritic gravel.

Sealed and unsealed shoulders were incorporated in the trials to research (a) if there is significant seasonal change in moisture and strength in the region of the outer wheel track on sections with sealed and unsealed shoulders in the wet and dry seasons and (b) if these changes differed significantly between areas of cut and fill and (c) the effect on performance.

Recommendations are included in the recently revised design manual for materials to be used in natural gravel base courses to be tested at different moisture contents. This enables the possibility of adopting an environmentally-optimised design approach to road provision in which design can be adjusted to reflect the expected field conditions in the road pavement.

(The research in southern Africa described in Section 4.1 of this report recommended a minimum sealed shoulder width of 1.2 metres and a crown height (crown of road to bottom of drainage ditch) of 0.75metres. However, these figures represent average conditions and are likely to vary considerably for different materials and different environments).

The outputs from the trials will enable practitioners to further modify the recently revised Ethiopian design and specification manuals when using similar lateritic materials on road construction projects, particularly in Benshangul, where laterites occur extensively.

4.3 Location Design and Methodology

A full description of the location, design and construction of the trials are given in the design and construction report (Otto and, Greening, 2012) and the monitoring procedures in the baseline monitoring reports (Otto and Greening, 2012) and only a brief overview of the main design features and methodology are repeated here.

The selected site is located 49km along the 96km Assosa – Kurmuk road, linking Assosa to the Sudanese border town of Kurmuk. The road contract consisted of upgrading the road from gravel to paved. The road is expected to function as a major trade link between Ethiopia and Sudan as reflected in the design traffic.

The 20-year design-life traffic for the road is up to 1.0million esa's. It is 10m wide comprising 1.5m unsealed laterite shoulders on either side, and 7m carriageway sealed with Double Surface Treatment (DBST).

The road terrain comprises rolling countryside and numerous sections of cut and fill. The pavement structure in the main contract consists of a laterite sub-base of thickness 150mm on which is placed a crushed stone base of thickness 200mm.

Construction of the road and trials were carried out by the Chinese contactor (Sinohydro Corporation). The supervising consultant was Arab Consulting Engineering Services in a joint venture with Metaferia.

On the research sections, the crushed rock base course was replaced with 200mm of lateritic gravel with an average 4-day soaked Californian Bearing Ratio (CBR) of 51%.

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

Figure 4-1 Location of trial

An example of one of the cross section of the trials is given in Appendix A.

4.4 Problems and constraints

- The first problem occurred after the initial selection of the locations for the trials when it transpired that the Research Directorate had failed to inform the Contracts Division of the intention to include trials on the road. This was later resolved but resulted in long delays with new (inferior) locations having to be selected and the usual negotiations between the client, consultant and contractor.
- The second major problem that occurred was that some of the base course lateritic material dumped on the road was clearly contaminated with more weathered (weaker) material, This contamination was caused by the excavator operator winning material from below the laterite gravel seam due to poor supervision in the borrow pit. Some dumps on the road had to be replaced with better material (although still inferior to the material originally selected because, by this time, the selected material had been exhausted). The consultant's Resident Engineer on site was extremely cooperative and helpful but no materials engineer was present on the consultant's team at the time of construction of the trials and much of the testing was done by the contractor with the participation of technicians from the consultant.
- The major constraint has been in the timing and execution of the monitoring. The baseline monitoring was carried out under TRL supervision but subsequent monitoring has been done by ERA. Timing of the monitoring is critical in researching the relationship between climate and pavement environment, particularly for determining the strength of the pavement when it is likely to be at its weakest (i.e. in the period immediately following the rains). This is fundamental in fulfilling the objectives of the research. This has been explained to ERA many times. The first scheduled monitoring after baseline monitoring was carried out by ERA but not at the scheduled time, some measurements were not executed and no report has been produced at the time of this report.
- TRL provided intermittent in-country technical support for the project, as specified in its contract. The trials were designed by the TRL staff assigned to the project in collaboration with the ERA Research Directorate and a Bill of Quantities (BoQ) was prepared for the contractor. Most of the items in the BoQ were completed, although signposting of the trial sections has not been done.
- At the end of visits by the TRL experts, a list of ongoing activities was prepared to be carried out in their absence. During these periods, few of the required tasks were undertaken by ERA. This led to missed opportunities for construction and long delays, particularly due to the onset of the rains, despite repeated warnings of the need for key tasks to be completed.

4.5 Outcomes

Despite problems described in Section 4.4 of this report, construction of the trials was completed using lateritic material in the road base, thus achieving the demonstration component of this project. The trials now need to be monitored to measure the performance of the road pavement under traffic.

If timely monitoring is carried out, then useful data will be obtained early in the life of the pavement on factors such as moisture ingress and pavement strength. Analysis of these data will provide information that indicates the need or otherwise for sealed shoulders, in either cut or fill sections or both and also provide information on the width of sealed shoulders, if required, which will enable the research objectives to be achieved.

4.6 Recommendations

There is a lesson to be learned in the need to inform and liaise with stakeholders at an early stage in planning research projects. Where road trials are to be constructed, changes from the existing road construction contract, such as provision for the use of different materials and/or construction techniques, will inevitably result in the need for variation orders with possible disruption to construction programmes and consequential changes in construction costs.

The use of lateritic material for base course represents a significant saving in road construction costs and should be extended to other areas and to other natural gravel materials. Guidelines for their use are given in the revised Ethiopia road design manual.

Funding for research is often difficult to obtain. Credit is due to DFID through the AFCAP for funding the advisory team and to ERA for meeting the costs of the trials. However, without improved commitment to the timing and collection of reliable time series data, the research objectives of these trials will not be achieved.

It is recognised that the Research Directorate has limited resources to undertake monitoring of the trials. However, if the research objectives are to be achieved and benefits of the investment in the research realised, then it is recommended that ERA seek external support for the timely collection of data until such time as they have sufficient skilled resources to undertake the timely monitoring of the trials unaided. A completed section of the trials is shown in **Figure 4-2**.

Figure 4-2 Exampleof one of the trial sections

5. Otta seal surfacing at Combel

5.1 Background

The Otta seal is an alternative to the more commonly used chip seal and other more conventional surface treatments. Its main benefits are:

- The use of graded natural gravel aggregates.
- The use weaker natural gravel aggregates

- More 'forgiving' surfacing construction technique
- High durability

5.2 Objectives

The project provided an opportunity to demonstrate the suitability of an Otta seal for rural road construction in Ethiopia and provide a contractor with experience in using this technology. The trial also provided an opportunity to carry out research.

The project had the following main objectives:

- Demonstrate an Otta seal technique
- Demonstrate the use of locally available natural weathered basalt as surfacing aggregate
- Research the suitability of a local cinder gravel as surfacing aggregate
- Demonstrate the use of fines from crushed rock (crusher dust) as a sand seal.

A further benefit of the trial road was the opportunity to demonstrate the construction of a weathered basalt gravel base with the same material also being used as surfacing aggregate for the construction of sections of the Otta seal surfacing.

5.3 Location Design and Methodology

Full details of the design and construction of the trials are given in the reports by Overby included in the Reference section of this report.

The section of the road network identified for the demonstration project was located in the village of Combel situated to the South of Addis Ababa, 37km from Tulubolo along the Tulubolo-Kela road. The length of the trial is 1900m containing different combinations of materials as shown in the site layout diagram shown in Appendix B.

The village location was selected in order to demonstrate the potential benefits of using the technique to improve rural roads, including roads through rural residential areas. The benefits of sealing these roads include improved all-weather access to facilities within the village as well as the significant environmental benefits compared with the existing gravel road such as reduced dust in the dry season and easier access in the wet season.

Another benefit of this location is that it was sufficiently close to an established plant providing a source of crushed aggregate and crusher sand. Bitumen was hauled from the Tiya heating plant, 69 km along the Alemegena – Butajiri road. The location of the project is shown in **Figure 5-1**

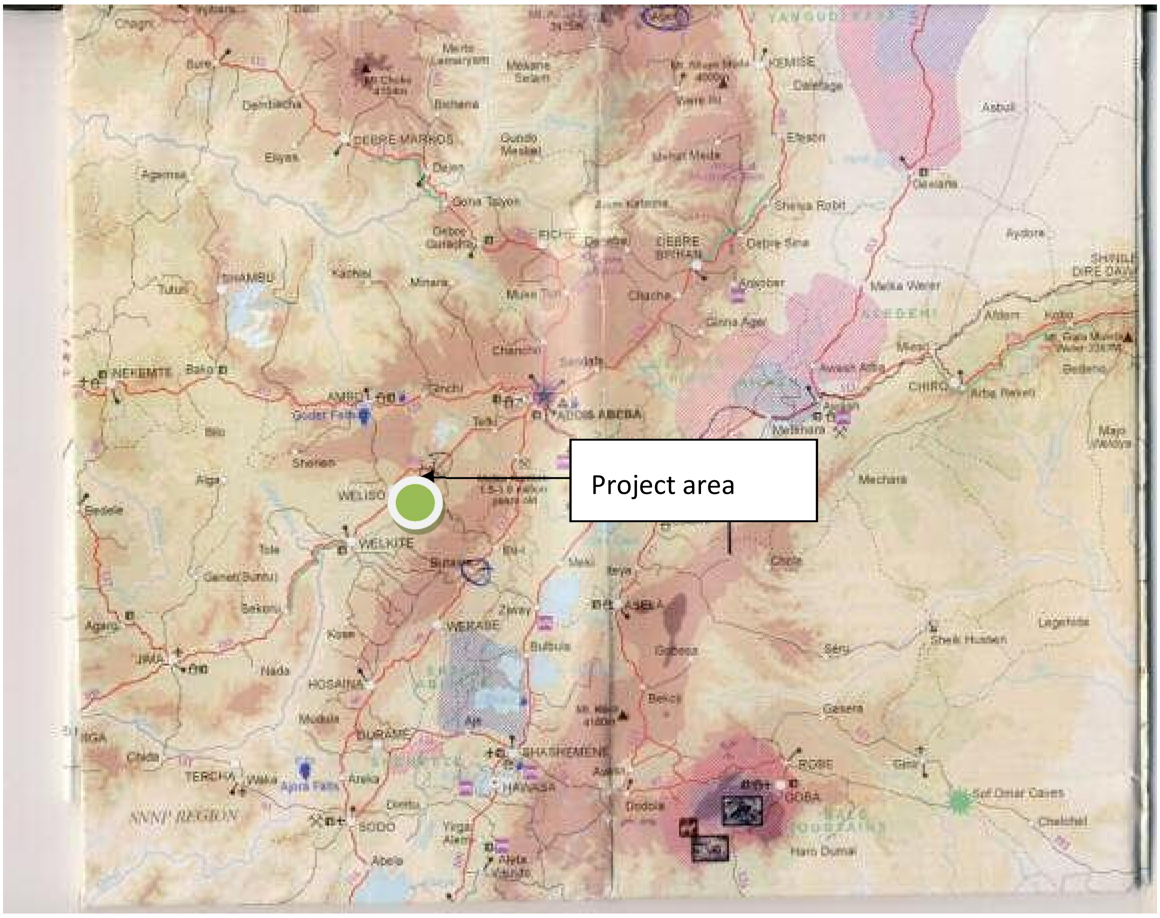


Figure 5-1 Location of project

Transition zones were provided at the start and end of the 1900m trial, which comprised 200 metres of relatively flat terrain at the start, followed by 900 metres with a gradient between 3% and 5% and a relatively flat section through Combel village to the end of the trial.

The road width varied between 5.00 and 7.00 metres. The maximum sealed road width was 6.30 metres. The side drainage was improved throughout the entire section.

The pavement was designed in accordance with ERA's 'Design Standards for Low Volume Roads: Part B 2011' using weathered basalt obtained from a nearby source for base course. However, on the advice of ERA, the road width through the village was less than is specified in the manual, due to problems that would arise from moving existing property boundaries.

Field tests using the Dynamic Cone Penetrometer (DCP) on the existing wearing course showed that the lowest in-situ CBR was 120% and the average thickness of gravel was 170mm. The soaked CBR of the weathered basalt proposed for use as base course was only 45% but its strength at optimum moisture content (OMC) and specified density was 65%.

The risk in using weathered basalt materials, due to their susceptibility to damage from moisture ingress, was managed by using a double seal for the surfacing and sealing the carriageway right up to the side drains. Provision was also made in the design and included in the Bill of Quantities for lining the drains in the flat section through the village, which will reduce the risk to the base from water ponding in them.

The four types of aggregate used in the trials were:

- Plant-crushed hard basalt from the Awash quarry.

- Crusher dust (< 5.0 mm) from Awash quarry.
- Weathered basalt screened by labour (same host material used for base course)
- Volcanic cinder gravel screened by labour.

The source of weathered basalt used for both the base and surfacing was located approximately 5 km south of the demonstration project along the same road as the trial section. The aggregate was screened using labour-based techniques in order to remove oversize (> 19 mm) and fines.

Volcanic Cinder aggregate of various qualities is abundant in some regions of Ethiopia, including the area where the project is located. The aggregate in the selected borrow pit was easily extracted and was screened by labour to remove oversize and fines from the bulk sample. The source was about 46 km west of the demonstration project.

Some minor changes were made to the original design during construction of the 2nd layer The most significant change was the use of an alternative source of cinder gravel due to the poor performance of the cinder used in the 1st layer.

Details of the properties of the materials and construction procedures are given in the construction reports for the 1st and 2nd sealing operations.

5.4 Problems and constraints

The first problem that occurred was in site selection. The first site selected by ERA was near the town of Kela on the Kela-Tulubolo road in a region with deep black-cotton soil, and with part of the section also having a steep gradient. Both of these factors rendered the site unsuitable for the trials because:

- the weak subgrade and absence of good quality base-course materials for construction could affect pavement performance which might incorrectly be attributed to the Otta seal
- It would be difficult for a contractor inexperienced in Otta seal works to construct the surfacing on a steep gradient

The second site selected was at the other end of the same road in the town of Tulubolo where the subgrade was visually assessed as being less expansive but when subjected to laboratory testing also proved to be highly expansive material of the black-cotton type.

The village of Combel, 37 km from Tulubolo, in hilly terrain with good subgrade soils was finally selected for the trials. Site investigations, material sampling and testing was also carried out on materials that could be used for base course and surfacing aggregate within an acceptable haul distance of the trials. The above process, including materials testing, took many months to complete but following completion of the laboratory testing a Bill of Quantities (BOQ) was prepared by TRL personnel for submission to the contractor by the ERA management team.

Despite being informed that a contractor was available to construct the trials, it then transpired that this was not the case. The Emergency Works Unit at ERA with little experience of road construction projects was eventually appointed to carry out the works and the base course was eventually constructed following many months of delays.

It was not possible to provide a deviation for traffic at the site and so the road would continue to be trafficked during construction. Despite frequent warnings given to ERA that the weathered basalt base course needed to be completed, primed and surfaced with the first seal before the onset of the rainy season, construction of the base was not completed in time. All work was suspended during the ensuing rains after which it became apparent that serious damage had occurred to the road base due to trafficking in the wet season. There was no good reason for this to happen. Adequate time was available for construction of the base and the 1st seal between the BoQ being prepared and the onset on the rains.

When it became apparent that construction would be delayed, TRL staff prepared a list of routine activities to be undertaken (including covering any stockpiled material) so that work could start promptly following the rains. Not one of these activities had been done by ERA when the TRL personnel made a return visit after the rains and this occurred on more than one occasion.

Despite an item in the BoQ for scour-checks on the steepest section this work was not carried out before the rains started. Consequently erosion occurred in this section with the eroded soil being deposited in a culvert which then became blocked. Boulder material was later deposited in the side drain as an erosion control measure.

The road base needed repair before the 1st layer Otta seal could be applied. This work was carried out by the Emergency Works Unit and supervised by TRL. It was clear that some sections were beyond patching and required additional material to be laid and compacted but on some of the sections the base course could not be fully restored to its original condition. Further delays occurred due to the lack of availability of essential construction equipment and bitumen, although requests had been made for bitumen to be procured in good time for construction of the surfacing.

The bitumen distributor supplied did not have the correct instrumentation available to accurately control the spray rate.

The Ethiopia Road Construction Corporation (ERCC), a more experienced contractor, was employed for laying the second seal, which helped in the construction process, although completion of the works was also delayed due to equipment failure. Laboratory test results, essential in relation to measuring performance and material selection for future construction, are still outstanding at the time of writing this report, some four months after construction.

5.5 Outcomes to date

The road base was constructed with locally available weathered basalt, which should perform well if adequate measures are taken to limit the ingress of water such as completion of the works according to the BoQ and the execution of timely maintenance

The village of Combel has been provided with a paved road.

The local ERCC has experienced construction of this type of seal and should be able to repeat the technology on other roads in Ethiopia.

The cinder gravel used for one of the sections failed to perform well and a different source of cinder gravel (stronger and non-plastic) was used in the second seal. Unfortunately, some of this material was used on the existing failed section (against TRL advice) and this section should now be considered as a single seal due to the amount of aggregate loss from the 1st seal. The remainder on this cinder was used for the 2nd seal on the final section of the trials on top of the well-performing seal of crushed rock. A completed section of the trials is shown in **Figure 5-2**.

5.6 Recommendations

Material has been dumped at various points in the side drain on the section where erosion is likely but proper scour checks need to be constructed as stipulated in the BoQ.

Unless the drains on the level section through the village are lined (as specified in the BoQ), there is serious risk of moisture entering the bas. If this does occur then rapid failure of the base can be expected.

Figure 5-2 A completed section of the Combel trial

Construction of these trials will provide important information for Ethiopia on the various combinations of the seals and materials used. Collection of data will require regular visual inspection by the research team. Maintenance of the sections is also essential to ensure that factors such as blocked drains and culverts do not adversely impact on performance.

6. Otta seals in the village of Gerado

6.1 Background

The background to the provision of this trial in the village of Gerado is similar to that described in Section 5.1 for Combel, the main difference being that only one type of source material was used for the graded aggregate and crusher dust components of the surfacing.

6.2 Objectives

The objectives of the project were also similar to those described for Combel in Section 5.1 of the report in that it comprised a demonstration of Otta seal surfacing technology constructed on a natural gravel base.

A different ERCC contractor was employed on this project, thus providing a further opportunity for an Ethiopian contractor to gain experience with this technology.

6.3 Location Design and Methodology

The location of the trial is shown in Figure 6-1. The demonstration section is located in the village of Gerado and is 2900 m in length. It includes a transition zone of 100m at the start of the trials. The first 600m has a gradient of about 5%, followed by 900m of gradient about 3%. The next section undulates with a gradient of not more than 2% for 1200m. The last 200m is very steep with a gradient of around 7%. The existing road width varies between 9.4 – 10.0m and the maximum width of the road after sealing was 9.7m on curves. The existing side drainage is generally adequate for most of the trial except for 300m at the beginning that will require scour checks. The main section through the village lies on the side of a hill and lined drains are provided on part of this section.

The pavement was designed on the basis of the ERA's "Design Standards for Low Volume: Part B 2011".

The existing pavement on the road was constructed in 2011 as part of a new gravel road that comprised 275mm of sub-base course, and 150mm of wearing course material according to the construction records. However, field tests carried out one year later showed 330mm of Upper Gravel Wearing Course on top of a 300mm of Lower Gravel Wearing Course.

A simple classified traffic count was carried out and the design traffic was estimated for a period of 15 years. The construction report (Otto and Greening, 2014) gives full details of the design and construction of the trials and the materials' properties obtained from laboratory and field results.

The laboratory results showed that the existing pavement was adequate to carry the design traffic with the field DCP results showing a high mean in-situ value of CBR (120%) between the wet and dry seasons (late September 2011) and a high pavement thickness (up to 600mm).

At the time of investigation, the traffic was about 80 vehicles per day; consisting mainly of light trucks and medium buses. An estimate of the number of heavy vehicles was recorded and used to check the suitability of the pavement design. During the project planning and inception stage, the Universal Rural Roads Access Program (URRAP) began and constructed roads to at least 23 Woredas along the road corridor. This led to an increase of up to 260 vehicles per day, including a large number of mini-buses. The increase in heavy vehicles is still within the estimated design axle loading.

In the coming year the whole length of this road is due to be sealed with a Double Bituminous Surface Treatment (DBST) and will serve as a shorter link between Combolcha and Bahir Dar City which will result in a significant increase in the number of heavy vehicles.

In May 2012, the contractor started work on the base course and approximately 300m of the trial section was scarified, re-shaped and re-compacted. When it was realised that the surfacing works could not start before the onset of the rainy season because of the unavailability of bitumen, work on the base was suspended and was not completed until January 2013. The surfacing works could not start immediately and, with the increased traffic volume, a significant quantity of gravel was lost on some sections. Corrections to the base were done in February and March 2013 but some of the initial smoothness and regularity could not be regained without complete re-construction, which would have impacted on material quality. Surfacing works were carried out on the corrected base in the months of February and March 2013.

Of the 2900m demonstration length, 1500m from 8+000 to 9+500 was primed and the second half of the demonstration from 9+500 to 10+900 was not primed. This section was designed to demonstrate that an Otta seal can be constructed on an un-primed base with the low viscosity cut-back bitumen acting as both binder and prime.

The demonstration project comprises a 100m transition section at the beginning and four sections of 700m length each as shown in Appendix A. The first layer of the whole demonstration section comprised an Otta Seal using a medium graded aggregate of nominal maximum size 16mm. Two sections of 700m length each were constructed on a primed base and the other two were constructed on an un-primed base. The aggregate used for the Otta Seal layer and that which will be used for the second seal (including the crusher sand) is basalt with small amounts of andesite and tuff.

The properties of the aggregate used for the first Otta Seal layer are given in the previously mentioned construction report. In the second seal, the aggregate passing the 16mm screen also included the fines fraction (i.e. not screened on 5mm). The grading for the crusher sand was the fraction fraction passing the 5mm screen.

The crushed aggregate and the crusher sand were stockpiled in a borrow-pit 5km from the sections and the stockpiles were protected with waterproof tarpaulins.

Two types of binders were used, namely MC 3000 and MC 800. The MC800 was produced from MC 3000 cut back with 10% by volume using kerosene. This cutting back was carried out at site but away from the village centre. The MC 3000 was used in the primed base section whereas the MC 800 binder was used in the un-primed base section as previously stated.

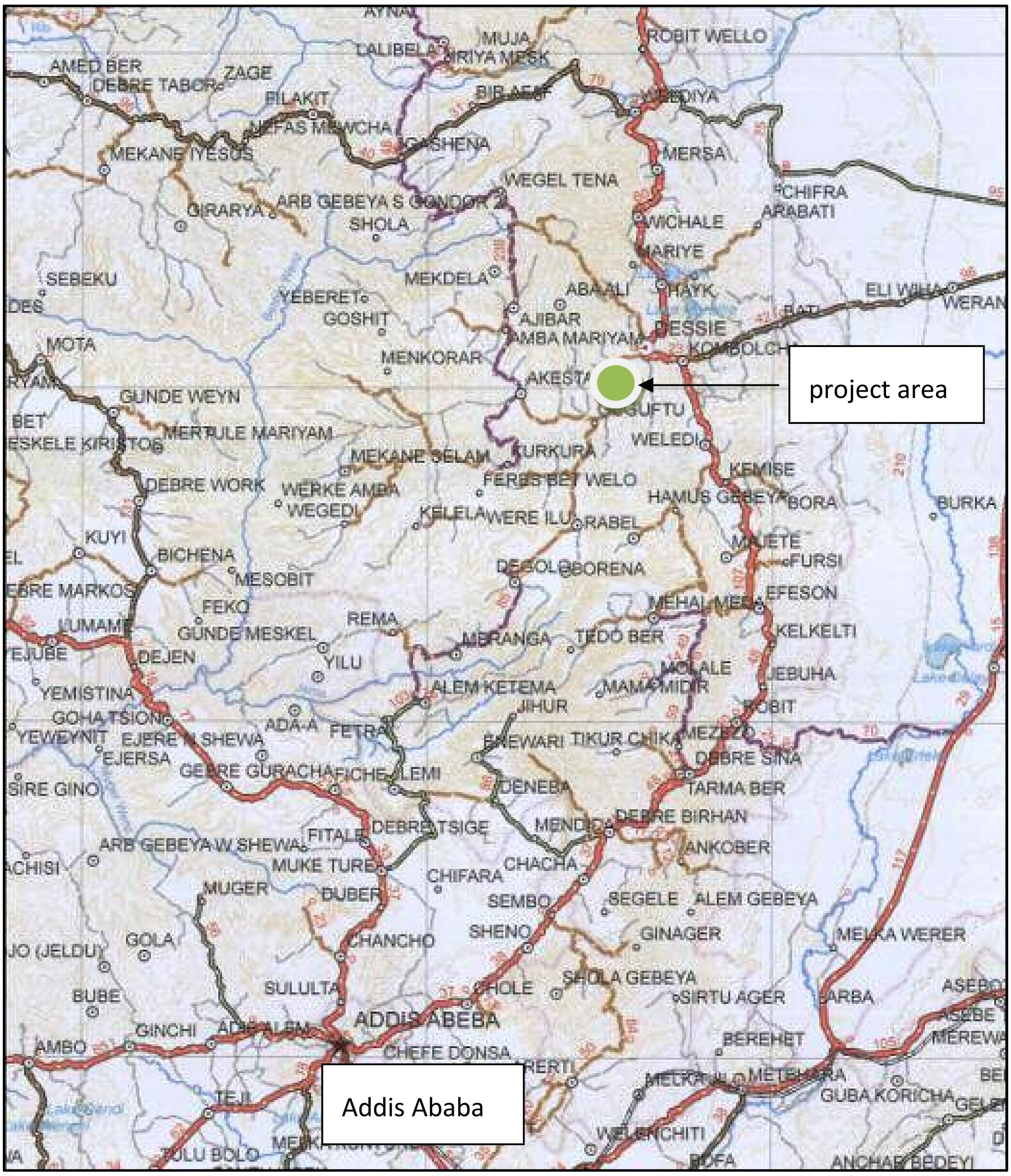


Figure 6-1 Location of the project

The whole trial section was cleaned with a power broom to remove dust and detritus before applying the seal (Figure 6-3). The layout of the trials is shown in Appendix C.

The rolling during construction and afterwards was carried out using a 24-tonne pneumatic roller followed closely behind by a 10-tonne steel roller in non-vibratory mode, as shown in Figure 6-2. The rolling was carefully supervised so that the entire width of the surfacing and all sections received adequate rolling.

After completion of the 2nd sealing operations, the entire section received three days of rolling at slow speed (less than 10km/hr) by the pneumatic roller. The steel roller also stayed on site to roll and flatten out the longitudinal joints.

Figure 6-2 Rolling with pneumatic roller and tipper truck

The second seal was constructed between 29th June and 9th July 2013. This was more than 3 months after the construction of the first seal. The 3 months gap between the first and second seals was deemed sufficient time to allow volatiles (solvents) to evaporate from the first seal. When solvents have evaporated from the first seal, a stable layer allows for better placement of the second seal.

The second seal was constructed just before the onset of the rainy season. This was crucial to avoid or minimise damage to the first seal by the combined damaging effect of rain and heavy traffic. It was especially important for the unprimed section.

Figure 6-3 Close-up of the broomed surfacingapplying the 2nd seal

The crushed aggregate was applied by a self-propelled chip spreader whereas the crusher sand was applied by labourers using shovels from the back of a dump truck. but application was very difficult because a lot of dust was generated hindering visibility and accuracy of application.

After completion of the 2nd seal operations, the entire section received four days of rolling at slow speed (less than 10km/hr) by the pneumatic roller.

A section of road at the beginning of the trial near the school is shown in Figure 6-4.

Figure 6-4 Completed Otta seal surfacing near the schooll

6.4 Problems and constraints

The main problem which delayed construction activities was the availability of bitumen. This led to delays in completing construction of the base with a knock-on impact on construction of the surfacing.

The performance of surfacing sealed roads is highly sensitive to construction practice and on the condition of the equipment used. During construction, there were problems with the bitumen distributors. Three distributors were tried and each distributor suffered at least one problem which caused some delays.

Another problem was traffic management as no diversion of traffic could be provided and vehicles often strayed into the work areas. Vehicles did not obey the speed limits and other signs to control traffic even with the presence of police.

Prior to constructing the first seal, the base course had been re-worked several times due to postponed construction dates and heavy trafficking. Some short sections of the base are not smooth with an incorrect camber caused by the re-working of the base following trafficking. Some attempt to improve this has subsequently been attempted by the contractor although the remedial works have not been well executed.

6.5 Outcomes to date

The material used for the construction of the original gravel road was very dusty. The trial is of significant benefit to the lives of villagers, especially with regard to a reduction in the level of dust and will be of particular benefit to the health of children walking to and from school.

The demonstration of the Otta Seal technology was successfully demonstrated in collaboration with the ERCC based at Combolcha, who are now conversant with the Otta surfacing technology.

Of particular benefit for future projects will be the use of an Otta Seal on an unprimed road base. This technique is advantageous where traffic diversions are difficult. Primed sections require the road to be shut for at least 4 days whereas with an unprimed base, closure of sections of the road is required for only a short period.

The ERCC is undertaking similar projects elsewhere and these show a significant improvement in workmanship, following experience gained in Gerado.

6.6 Recommendations

Timely monitoring of the trial by ERA is required to produce evidence of the performance of the various sections.

It is important that ERA provides guidance and supervision of the construction of future Otta seals by the Research Directorate and/or external consultants. If guidance is not offered to the contractors, there is a risk that the technology may not be well executed leading to failures and a consequential lack of uptake of the technology.

7. Revised asphalt concrete mix design

7.1 Background

Of major concern is plastic deformation which occurs on many Asphaltic Concrete roads in Ethiopia. The problem is particularly evident on steep sections of road manifested as deep ruts in the wheel paths and at junction approaches as "ripples". The slow heavy vehicle speeds in these areas means that the surfacing materials are loaded for longer and hence are more likely to deform. Plastic deformation in HMAC surfacing is the most serious form of failure because the affected material must be removed before the road can be rehabilitated.

Figure 7-1 Deformation of the AC surfacing on the Mekelle - Combolcha road

Figure 7-2 Rutting in the wheel path on the Mekelle-Combolcha road

The problem is more pronounced in areas of high ambient temperature (such as Afar Region and parts of Tigray Region) or areas that experience high temperatures for significant periods of the year. (see Figure 7-1 and **Figure 7-2**).

7.2 Project objectives

The objectives of the project were to:

- Introduce the use of the Refusal Compaction (PRD) design method for Asphalt Concrete to Ethiopia.
- Propose and construct a mix design that will reduce plastic deformation and flow in severe conditions.
- Compare the performance of the proposed mix with that of the mix being used for the project road by the contractor.

7.3 Location design and methodology

The research comprised two components namely, a laboratory testing programme to produce a revised mix and the construction of a trial section.

Plastic deformation is usually associated with an under estimate of the degree of secondary compaction that occurs under heavy traffic which reduces the air voids content (i.e. voids in the mix, VIM) to a critical level at which plastic deformation occurs relatively rapidly. ***It is necessary to ensure that VIM remains greater than 3 per cent if plastic deformation is to be avoided***. When the VIM in an AC layer decreases to less than approximately 3 per cent, stress transfer, which was occurring through stone to stone contact in the coarse aggregate, switches to the bitumen-fines component in the mix. As secondary compaction continues, stone to stone contact is increasingly reduced until plastic deformation occurs. Further details of the processes that cause deformation and the 'Compaction to Refusal' methodology used in the development of different mix designs are given in the Design and Construction Report (Otto, 2014).

The procedure for developing a mix design is quite complex. One of the main problems is replicating what compaction can be expected on the road which depends on traffic loading, road speed and contact area (which is influenced by tyre pressure). It also depends on the amount of bitumen and the type and grading of the material.

The design involves the following iterative process;

- establish candidate mixes with satisfactory volumetric composition;
- testing to confirm that the compacted mix has the required properties for the expected traffic;
- adjust the mix composition and re-test until the design requirements are satisfied.

Different mix designs were prepared using the refusal density technique. The samples were also subjected to the Marshall stability test.

Compaction to refusal provides a ‘reference density’ because the aggregate structure cannot be compacted any further. Particle size distributions can, therefore, be selected to give VMA that will accommodate sufficient bitumen to ensure good workability during construction and retain a minimum of 3 per cent VIM at refusal density. However, it is important that a compromise is reached between high VMA to accommodate enough bitumen to make the mix workable and sufficient fines to provide a strong mix. It is also important that the coarse aggregate is strong enough to withstand vibratory compaction without significant breakdown of the particles.

It is recommended that HMA designed to refusal density is laid to a compacted thickness of 2.5 to 4 times the maximum aggregate particle size to obtain satisfactory workability. The layer thickness can, therefore, range from 70mm to more than 100mm for particle size distributions with maximum particle size 10mm to 25mm.

The gradation of the aggregate mix used in the trial is shown in Table 7.1 which illustrates the relatively small changes in grading that can have a significant impact on road performance.

Table 7.1 Gradation of aggregate used in the trial (TS1)

Sieve (mm)	Percentage Passing				
	Gradation in Use for rest of project	Gradation required for TS1	Produced at Plant	Lower Limit	Upper Limit
37.5	100.0	100.0	100	100	100
26.5	100.0	100.0	100.0	100	100
19.0	97.0	97.5	92.7	85	100
13.2	80.0	80.7	78.2	71	84
9.5	67.0	68.1	65.5	62	76
4.75	53.0	53.5	52.9	42	60
2.36	41.0	40.0	34.9	30	48
1.18	29.0	28.1	24.3	22	38
0.6	16.0	16.4	15.8	16	28
0.3	12.0	11.9	12.6	12	20
0.15	8.0	6.6	8.8	8	15
0.075	5.0	4.6	6.0	4	10

The road chosen for the trial was the Hawusewa – Abala – Irebti road located because it offered a mix of terrain (flat, rolling and mountainous) with relatively cool ambient temperatures on the elevated section of the road near Hawusewa and high temperatures at the low-altitude section of the road near Abala. These conditions occur frequently in Ethiopia because of the large extent of mountainous terrain, the steepness of many of the gradients, some of which occur in areas with high ambient temperature. Under such conditions heavy trucks are slow moving both on the climbing lane and also, under heavy braking, on the downhill lanes.

Completion of the project was constrained due to the time remaining before the end of the first phase of AFCAP and construction delays on the main project. Due to these constraints, only two sections using one design were planned but, to date, only one has been constructed. Also, constraints of available bitumen types and aggregates meant that alternative designs could not easily be changed on site.

Prior to construction of the AC surfacing, the batching plant was set up with the aim of producing the required mix. It was not however possible to attain the exact required mix due to plant constraints. The gradation and strength of aggregate available was such that any slight deviation even within the tolerance limits meant that the properties determined in the laboratory were significantly changed. The Air Voids at refusal compaction for the mix constructed in the test sections will be determined as part of the monitoring process by taking out cores of the surfacing and testing in the laboratory.

A paver was used to lay the AC mat and produced a 50mm thick by 7m wide layer after compaction as shown in **Figure 7-3**. Compaction was carried out by one Tandem Roller plus two PTRs as shown in **Figure 7-4**. After completion of construction, cores were taken out of the AC surfacing to check that the quantity of asphalt and aggregate grading were within tolerance limits. The cores were then subjected to bitumen extraction test and the quantity of bitumen and the grading of the aggregate component were determined.

Figure 7-3 Laying of the asphalt layer by paver

Figure 7-4 Compaction of the asphalt surfacing

7.4 Problems and constraints

The main problems were as follows.

In developing mix design, the various testing equipment used was housed in two laboratories in different locations (Kality and Alemgena). Disruptions to the electricity supply at Kality were frequent and delayed the testing programme.

The construction project was behind schedule and it was difficult to obtain a clear indication from the contractor of when the trial could be constructed.

Communication with the contractor was also difficult as there was no phone signal at the consultant's camp and the RE could only communicate by email by travelling to Mekelle.

The screen sizes in the crusher plant were different from the sizes in the aggregate bins and both of these were different from the sieves used in the consultant's laboratory. This inhibited replication of the laboratory results in the trials.

7.5 Outcomes to date

Alternative mix designs of potential benefit have been developed for the parts of the network considered to be at risk.

A trial section has been constructed on the Hawusewa – Abala – Irebti road

7.6 Recommendations

The following conclusions and recommendations can be made on the research sections at this stage:

- On future projects, sections of the road at risk should be identified and alternative AC mix designs applied.

- It is recommended that AC pavements should incorporate larger sized aggregate and a Binder Course that would provide greater rigidity and rut resistance.
- The choice of binder needs reviewing and harder binders used. The aggregate used in the project is predominantly dolomitic limestone which possesses smooth surfaces that do not offer strong interlock due to low surface friction.
- Consideration should be made in finding good sources of angular sand to be included in AC mixes to improve the interlock hence stability of the mixes
- On the current project, grading of individual aggregate stockpiles needs modification through replacement or introduction of other sieve sizes
- In the selection of aggregate grading, the use of the grading “control points” and the “restricted zones” developed by the SuperPave programme needs to be adopted.
- The refusal density (PRD) approach of determination of air voids needs to be adopted in design and construction of AC surfacings.
- A study of in-service AC roads which have performed well and sections of roads which have failed should be studied to gain additional evidence of the allowable tolerances and the reasons for success and failure.

8. Other activities

Workshops have been conducted on the Otta seals and on the development of the revised asphalt designs. Presentations were made to the ERA researchers on monitoring procedures for research sections together with practical on-site training. A report on the monitoring of the long-term pavement performance (LTPP) has also been produced. (Greening and Otto, 2014)

9. General conclusions and recommendations.

The Research Directorate of ERA was responsible for the management of the four research projects in the research programme described in this report, which was commissioned under AFCAP. TRL was contracted to provide advisory support to ERA on a call-off basis. This restricted TRL’s influence on the timing and execution of essential tasks and assignments.

Two demonstration/research projects using Otta seal technology have been completed in which the performance of various materials is being researched. Contractors have been trained in this surfacing technology and they are already implementing the knowledge on projects elsewhere in Ethiopia. The research results will also facilitate the selection of alternative materials to be used as surfacing aggregate. **However, unless the items for drainage works are completed as specified in the BoQ, especially lining the drains at Combel, there is a high likelihood of base failure occurring.**

The use of lateritic natural gravel for road base has been demonstrated in trials which include a research component on the impact of sealed shoulders in different drainage conditions. If this trial is monitored correctly, the results will provide evidence that will enable greater use to be made in the use of lateritic materials for rural road provision with significant cost savings.

Alternative asphalt concrete mix designs have been developed and the first trial section established to address the poor performance of AC in some areas.

The initiative to establish a well-managed and staffed Road Research Centre in Ethiopia is to be applauded, although the current staffing compliment is significantly less than planned and this has had an adverse impact on the research programme. The Director and his deputy are highly experienced engineers whose full-time jobs are in managing the Directorate. The remaining staff members consist mainly of new graduates, who are relatively inexperienced in research. A hierarchy of experienced engineers and other professionals with research experience, who can mentor graduates recruits and technicians, is an essential component for the effective operation of a RRC.

Lists of routine tasks were prepared by the TRL advisors to be carried out in their absence to limit disruptions and delays in the work programme. On more than one occasion, not one of these tasks had been completed when the advisors returned. This inevitably caused long delays, especially when these activities were key to completing construction activities before the rains or for prompt resumption of activities following the rains.

Monitoring exercises conducted to date have not been undertaken properly or on time, despite the advice that this would impact adversely on the research outputs, especially on road performance indicators linked to the influence of climate. Timely monitoring is needed if the research objectives are to be achieved.

Institutional problems exist which clearly restrict the capacity of the RRC to deliver research outputs in a timely and efficient manner. Some of these problems are undoubtedly due to an insufficient number of qualified and experienced staff who can respond to the challenges of research, which requires greater effort than in carrying out the routine activities of a Roads Department.

The training courses and workshops held as part of this research programme and as part of the establishment of the RRC will help in the development of staff. However, graduate engineers need to spend more time in the field assigned to construction projects so that they gain the practical experience essential to understanding the problems in the sector and to participate in the research activities required to solve them.

The Research Directorate will continue to experience difficulty in conducting research unless staffing levels and research expertise is increased.

Despite the obstacles encountered, four projects were carried out and two villages now have the benefit of a paved road, although it has taken more than twice the time that TRL would normally expect for collaborative projects of this type to be completed.

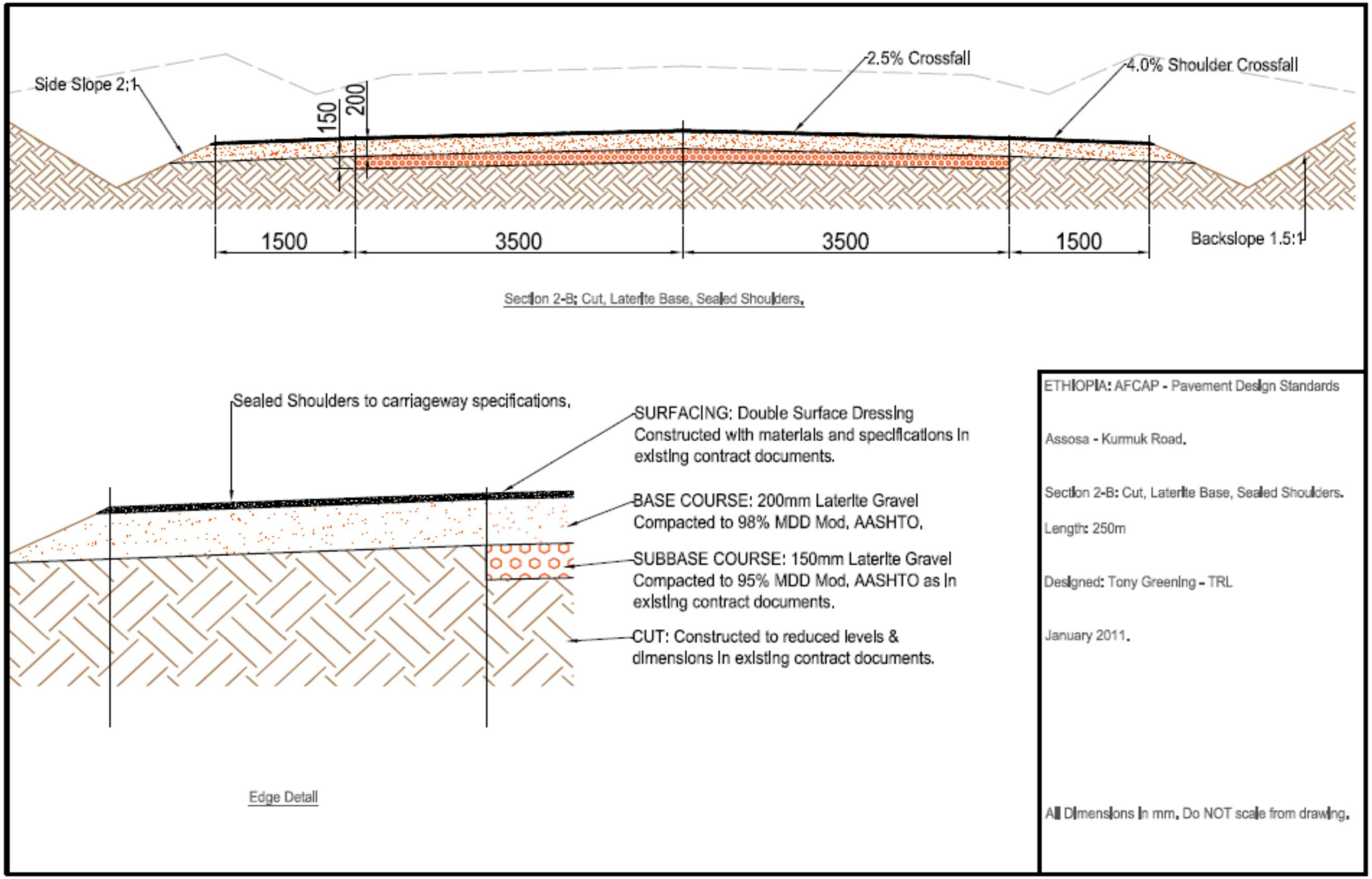
10. References

1. Otto A. (2010) Development of Pavement Design Standards for Low-Volume Roads in Ethiopia – Site Selection Report (RPN 1276). Crowthorne: Transport Research Laboratory.
2. Gourley C S and P A K Greening. (1999). Performance of Low-Volume Sealed Roads: Recommendations from Studies in Southern Africa. (PR/OSC/167/99). Crowthorne: Transport Research Laboratory.
3. Otto A and P A K Greening. (2012). Development of Pavement Design Standards for Low-Volume Roads in Ethiopia: Assosa – Kurmuk Laterite Base Trials: Design and Construction Report. CPR 1578. Crowthorne: Transport Research Laboratory.

4. Otto A and P A K Greening. (2012). Development of Pavement Design Standards for Low-Volume Roads in Ethiopia: Assosa – Kurmuk Laterite Base Trials: Baseline Monitoring Report. CPR 1577. Crowthorne: Transport Research Laboratory.
5. Overby C. (2013) Development of Pavement Design Standards for Low-Volume Roads in Ethiopia: Otta seal Demonstration and Research Project. Combel Village. Tulubolo-Kela Road. Construction Report. Crowthorne: Transport Research Laboratory.
6. Overby C. (2014). Development of Pavement Design Standards for Low-Volume Roads in Ethiopia: Construction of the 2nd layer Otta seal in the village of Combel. (TRL RPN 2973). Crowthorne: Transport Research Laboratory.
7. Otto A and P A K Greening. (2014). Development of Pavement Design Standards for Low-Volume Roads in Ethiopia: Combolcha (Gerado) Otta Seal Demonstration Site: Construction Report. (RPN 2973). Crowthorne: Transport Research Laboratory.
8. Otta A and J Rolt. (2014) Development of Pavement Design Standards for Low-Volume Roads in Ethiopia: Improving the Performance of Hot Mix Asphalt Concrete through Refusal Density Design: Design and Construction Report. (RPN 2974). Crowthorne: Transport Research Laboratory.
9. Otto A and P A K Greening. (2014). A Guideline for the Establishment and Monitoring of Sections on the Road Network to Measure Long Term Pavement Performance (LTPP). (RPN 2945). Crowthorne: Transport Research Laboratory.

Appendices

Appendix A: Cross Section of a Section on Assosa - Kurmuk Trials



Appendix B: Combel sections layout

		37+400			38+000	COMBEL VILLAGE, width 6,30 m			38+800		39+300		
m	-75	0	100	250	300	600	860	990	1400	1700	1850	1900	
	Crusher Dust Seal ON	Crusher Dust Seal ON	Otta Seal Crushed Basalt ON	Otta Cinder Agg ON	Otta Seal Weathered Basalt ON	Crusher Dust Seal ON	Otta Seal Crushed Basalt ON	Crusher Dust Seal ON		Otta Cinder Aggr. ON	Crusher Dust Seal	Crusher Dust Seal	
	Crusher Dust Seal	Crusher Dust Seal	Otta Seal Cinder Aggr.	Otta Cinder Agg	Otta Seal Weathered Basalt	Otta Seal Crushed Basalt	Otta Seal Crushed Basalt	Otta Seal Crushed Basalt		Otta Seal Crushed Basalt	Otta Seal Crushed Basalt	Crusher Dust Seal	
	Prime	Prime	Prime	Prime	Prime	Prime	Prime	Prime		Prime	Prime		
	75m	100m	150m	50m	300m	260m	130m	710m		150m	50m	30m	2005m

Appendix C: Gerado sections layout

8+000				GERADO VILLAGE, width 9.40m - 9.70m					10+900
0	100		800	1100	1500	2000	2200		2900
Double Otta Transition zone bitumen	Double Otta Seal using hard aggregate		Single Otta Seal (hard agg crusher sand cover seal	Double Otta Seal using hard aggregate		Single Otta Seal (hard crusher sand cover s	Double Otta Seal using hard aggregate		
	Double Otta Seal using hard aggregate		Single Otta Seal (hard agg crusher sand cover seal		Single Otta Seal (hard aggregate) with crusher sand cover seal		Double Otta Seal using hard aggregate		
Prime	Prime	Prime	Prime	Prime	No prime	No prime	No prime	No prime	

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