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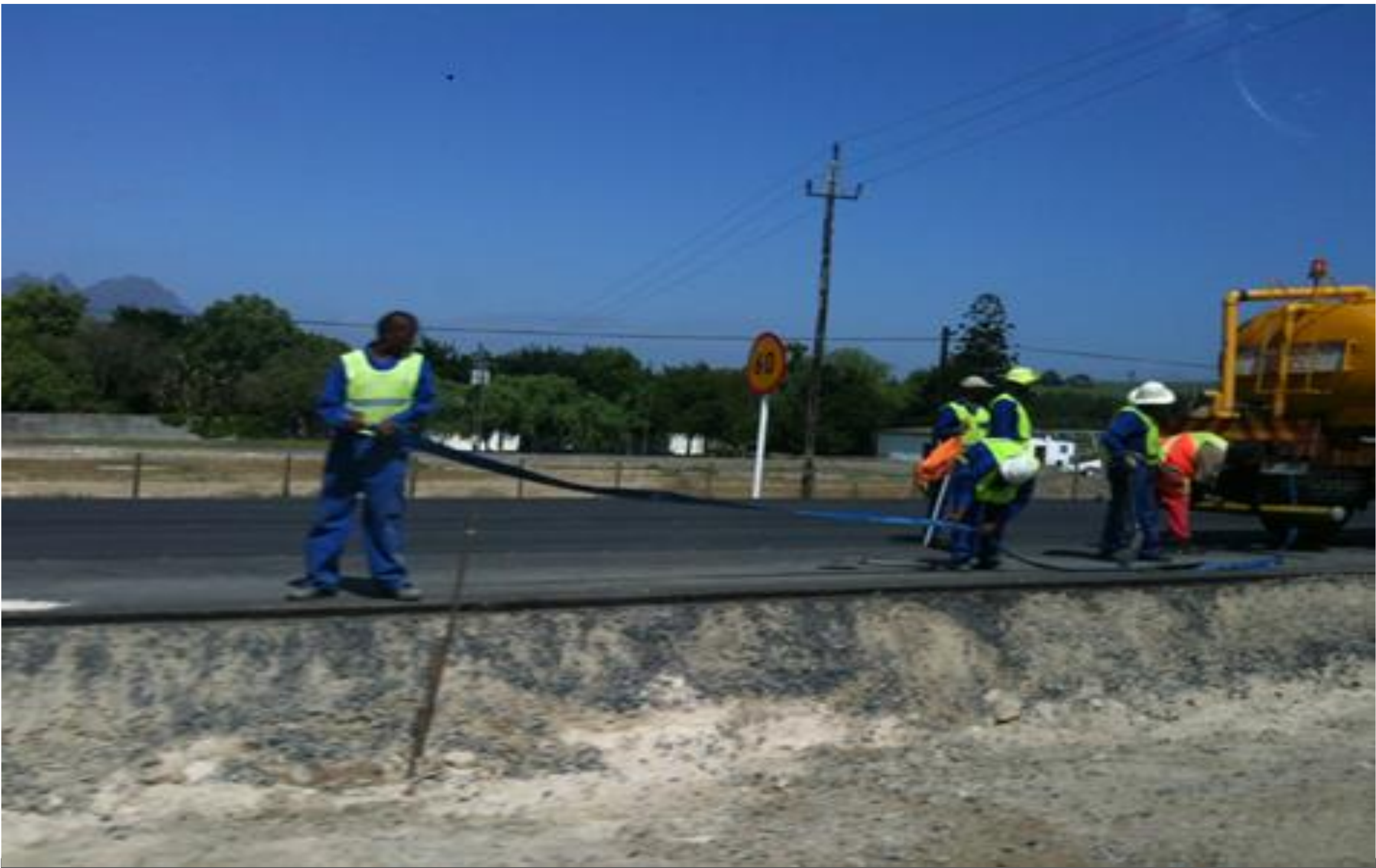

CLIMATE RESILIENT SUSTAINABLE ROAD PAVEMENT SURFACINGS

Trials Constructability report

DT Global

UKaid
from the British people

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Abstract	
One or several simultaneous changes in climate conditions, such as hotter seasons, extreme precipitation events, increasing severe storms and/or sea level rise, could severely affect roads in low-income countries (LICs). Failing to take into account such impacts in future road design, maintenance and operating planning and protocols could result in accelerated road deterioration and increased risk of damage, traffic disruption and accidents, with knock-on effects on economies. The aim of the Climate Resilient Sustainable Road Pavement Surfacings (CRISPS) project is to assess the engineering and economic suitability of three global best practice types of road Surfacings technologies for use in LICs to counter the impacts of climate change. These technologies are modified epoxy chip seals (MECS), modified epoxy asphalt surfaces (MEAS) and Fibre mastic asphalt (FMA).	
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ABBREVIATIONS/ACRONYMS

AA	Addis Ababa
AADT	Annual average daily traffic
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt concrete
ACO	Asphalt concrete overlay
ACV	Aggregate crashing value
Ag. Cr.	Aggregate crushing,
ALD	Average least dimension
A-M	Awash – Meiso road
AM1 - BC	Awash – Meiso (trial pit 1) base course
AM1 - WC	Awash – Meiso (trial pit 1) wearing course
AM2 - BC	Awash – Meiso (trial pit 2) base course
AM2 - WC	Awash – Meiso (trial pit 2) wearing course
AMSL	Above mean sea level
ASTM	American Society for Testing and Materials
AV	Air voids
BBD	Benkelman beam deflection
BC	Base course
BL	Base layer
BS	British Standard
CA	Crushed aggregate
CBR	California bearing ratio
CEN	European Committee for Standardisation
CESA	Cumulative equivalent standard axle
CL	Capping layer

COTO	Committee of Transport Officials
CRISPS	Climate Resilient Sustainable Road Pavement Surfacings
DBST	Double bituminous surface treatment
DCP	Dynamic cone penetrometer
EF	Equivalence factor
ELV	Equivalent light vehicle
EMOGPA	Epoxy modified open graded porous asphalt
ERA	Ethiopia Roads Administration
ESA	Equivalent Standard Axle
FI	Flakiness index
FMA	Fibre mastic asphalt
FWD	Falling Weight Deflectometer
HMA	Hot mix asphalt
HVT	High Volume Transport
HDM-4	Highway development and maintenance
HWCG	Highly Weathered Clayey Gravel
ID	Identification
IRF	International Road Federation (Geneva)
LCA	Life cycle analysis
LHS	Left hand side
LIC	Low-income country
Mat.	Material
M-E	Modjo – Edjere road
MEAS	Modified epoxy asphalt surfaces
MECS	Modified epoxy chip seals
MR	Resilience modulus

MSA	Million standard axles
NA	Natural aggregate
MDD	Maximum dry density
MTD	Mean texture depth
NMA	Ethiopian National Meteorological Agency
NMC	Natural Moisture Content
NZ	New Zealand
NZTA	New Zealand Transport Agency
OMC	Optimum moisture content
ORN	Overseas road note
PSD	Particle size distribution
RCP	Representative concentration pathway
RDD	Representative rebound deflection
RHS	Right hand side
RRC	Road Research Centre
SBL	Subbase layer
SNC	Mean structural number
SNeff	Effective structural number
TMH9	Technical methods for highways (version 9)
TP	Test pit
UoB	University of Birmingham
UK	United Kingdom (of Great Britain and Northern Ireland)
UPM	Universiti Putra Malaysia
VMA	Void in mineral aggregate
VFB	Voids filled with bitumen
WC	Wearing course

WCG	Weathered clayey gravel
WCiG	Weathered cinder gravel
WS	Work stream

EXECUTIVE SUMMARY

The Climate Resilient Sustainable Road Pavement Surfacings (CRISPS) project addresses the High Volume Transport (HVT) research programme's Theme 1 (Strategic Road and Rail) and the principal research area 1. Namely, affordable high-volume roads resilient to climate change and traffic demands. Principally the project addresses the research question: "How could new ways of designing and building roads using new standards and marginal materials deliver low maintenance resilient roads economically?" In this context, resilience is defined as resistance to the primary factors which influence road pavement performance, namely the climate, traffic and the initial construction of the road. To this end, CRISPS assesses whether three global best practice road Surfacings technologies can provide low maintenance, resilient roads economically in low-income countries (LICs). The technologies considered are modified epoxy chip seals (MECS), modified epoxy asphalt surfaces (MEAS) and Fibre mastic asphalt (FMA). The technologies have been developed through many years of research in New Zealand (MECS and MEAS) and Malaysia (FMA) and they are now used in service.

The project aims to demonstrate the engineering and economic suitability of the three technologies for typical traffic and environmental conditions of both high-volume and medium-volume roads typically seen in LICs. This is achieved primarily via a life cycle analysis (LCA) modelling approach of the technologies operating in Ethiopian climates and traffic conditions and through constructability trials using these materials in Ethiopia.

This report is dedicated to the constructability of the three materials in Ethiopia. Constructability, in this case, is defined as the ease of constructing the Surfacings using the plant and equipment typically available to a LIC road agency, or its contractors, such as Ethiopia and many other African and Asian countries. The reasons for the selection of Ethiopia for the constructability trials include (i) its strategic road network is subject to a variety of environments and traffic levels which can be considered to be representative of many LICs. (ii) an assessment of potential partner countries in Part 1 of the HVT programme found that Ethiopia was ranked in the top three LICs in Sub-Saharan Africa and was well placed to support and benefit from Part 2 research, and (iii) the University of Birmingham's (UoB) Roads Group has established close research links with the Ethiopian Roads Administration (ERA) over a number of years, including undertaking a five year research and capacity building programme for ERA to improve the resilience of Ethiopia's roads and, ERA agreed to support the constructability trials in its letter supporting the UoB's project application.

Noting that the purpose of this phase of the research is to demonstrate the constructability of the three technologies (and not in-service performance), a pragmatic approach was taken for the selection of the trial sites, whereby site selection was on the basis of ease of access from ERA's Road Research Centre (RRC), located in Kality, Addis Ababa. For the MEAS and FMA technologies it was necessary to choose sites adjacent to road sections where ERA had planned to undertake major periodic maintenance during the project's time frame as the technologies require the use of a mobile Surfacings batching plant, which is both expensive and time consuming to arrange and move to site. Accordingly, a site on the Awash - Meiso road (A9 - Trunk Road) was chosen for MEAS and FMA surfacings. Trial section for the application of MECS was selected along the B51 Link road connecting the towns Modjo and Edjere. Mean monthly rainfall in both the areas is about 70 mm and maximum temperature in is 37 °C and 28 °C respectively for the Awash-Meiso and Modjo- Edjere sections. In order to assess the performance of the new surfacing materials, control sections designed and built in accordance with the ERA design standard (ERA, 2002) were built adjacent to the trial construction sections. The intention of the project was to compare the economic performance of the MECS section with a thin surfacing used routinely by ERA, i.e., Double Bituminous Surfacing Treatment (DBST) (see Work Stream 2 report). Consequently, the pavement design of the MECS section was based on the design of DBST in terms of chips used as provided in ERA's Pavement design Manual (ERA, 2002a). Similarly, for performance comparison purposes, as a control section comprising dense asphalt was also designed and built in accordance with the ERA's pavement rehabilitation manual (ERA, 2002b) adjacent to the FMA trial section.

The two epoxy modified surfacings (i.e. MEAS and MECS) require epoxy material, in the form of Part A (epoxy resin) and Part B (hardener and accelerator) to be mixed in appropriate ratios before adding the mixture to aggregate. This material is not currently widely available and was obtained from a recognised supplier in the USA, that is ChemCo Systems, and shipped to ERA's RRC in Ethiopia. Since many of the road sections using MEAS technology are constructed using ChemCo's epoxy compounds, it will make it enable comparison of future performance easier. The FMA requires the addition of plant-based fibres and whilst it may be feasible to source fibres of similar characteristics locally, the fibres need to be processed using a precise methodology. Consequently, and given the time frame of the project, it was decided to de-risk the trial and obtain the processed fibre from the Malaysian supplier, that is NOVAPAVE SDN BHD, who manufactures the material on behalf of the Malaysian Ministry of Transport for its use in Malaysian roads.

The constituent materials of all three technologies were obtained, and the trial sites identified and specifications for the design and construction of all three technologies were formulated. However, because of unforeseen, related issues, such as COVID-19, which caused considerable delay to the project and introduced a high degree of risk of completing the project in time, it was decided with the agreement of DT Global, to build only the FMA and MECS trial sections during the funded part of the project. It is hoped ERA will take onboard the pre-trial work undertaken for the MEAS and will incorporate construction of a trial section in a future road maintenance project.

Guidance notes, which include modifications required for the mobile asphalt batching plant used for manufacturing the MEAS and FMA and construction procedures were completed.

Whilst new systems for adding Parts A and B were required for the manufacture of MEAS, a new mesh was required for segregating aggregate into hot into an additional hot bin for the manufacture of FMA, so that proportions of materials added to the pugmill could be adjusted to meet the grading requirements whilst keeping the input into the cold bins unchanged. This ensured that minimal changes were required for the purposes of the construction trial of FMA. A 50 mm thick FMA surfacing was constructed as an overlay over a 80 m long, 3.5 m wide section of the Awash-Meiso road. The mix comprised 0.4% fibre with 5.0% binder. Since the original road was in good condition, only tack coat was applied.

Extensive laboratory work was undertaken on the design of FMA in the ERA - RRC laboratory to ensure that final materials met the draft design standards used in Malaysia (1).

ERA bitumen sprayers too large for using the small quantity of binder required for the construction of the trial section. Therefore, ERA modified an existing towed sprayer. Two spray bars, one for each Part A and Part B of binder, were fitted with 9 nozzles on each bar, both angled to give impingement mixing about ¾ of the distance to the road. An 80m long, 7m wide section (whole width) of the Modjo-Edjere road was surfaced with MECS. Control section of similar length and width, using the single surface chipseal, was constructed using the ERA's conventional procedure on the same day as the MECS trial.

From the research undertaken by the team, the following can be concluded:

1. MEAS Trial Constructability:

    - For MEAS, the critical part of the process is to use correct mix ratios between epoxy and bitumen to ensure strong yet economical binder.
    - Temperature control for epoxy's Part A and Part B, as well as for the aggregate are strongly recommended as this affects reactions between materials.
    - Transport and haulage distances must be checked against temperature losses to ensure that MEAS is laid down at the right temperatures.
    - Placement and compaction of MEAS is as for usual asphalt, ensuring that the latter is at the recommended ranges.
    - Opening the road section to the traffic must not be rushed and is only acceptable when the MEAS surfacing is 50°C or less.

- As the option to buy new asphalt batching plant was excluded for a trial construction, it was important to ensure that the modifications (adding a new heated storage pumping and weighing system for part A) to the existing mobile asphalt batching plant owned by ERA's contractor were such that the plant will remain as useful as before being modified. This should also be done at minimum possible costs.

2. MECS Trial Constructability:

- Temperature control for both epoxy and binder is critical and remains the same for the necessary minimum temperature before allowing traffic to use the road.
- Correct choice of the chips is essential as it has significant impact on the rates of application of the binder and on the costs of the project.

3. FMA Trial Constructability:

- Like for modified epoxy surfacings, FMA requires strictness on temperatures control for the materials during manufacturing, transport to the site and both placement and compaction.
- The FMA was found to be suitable for the existing asphalt batching plant subject to modifications.
- Appropriate and verified proportions of materials must be used

1. Introduction

1.1 About this report

1.1.1 Purpose of this report

This report describes the work undertaken under Work Stream 4 (WS4), 'Constructability'. It describes and discusses the preparation of the constructability trials of the MEAS, MECS and FMA surfacings and the constructability of both the FMA and MEAS surfacings. In particular, the selection of trial construction sites, ground investigations, assessment of the existing drainage of the selected road sections, material specification of the three surfacings, laboratory tests to confirm the mix design recommendations for the trial and control sections, the manufacture of the different surfacings materials, the construction of the FMA and MECS surfacings are described in this report.

The constituent materials of all three technologies were imported to Ethiopia, the trial sites identified, specifications for the design and construction of all three were drawn up. However, only FMA and MECS trial sections were constructed. The MEAS was not constructed due to the lengthy period required to get the component parts required to modify the mobile asphalt batch plant to Ethiopia during the project period and disagreement between the plant supplier and the owner about the capability of the batch plant. Nevertheless, there are a number of important lessons to be learned from the work undertaken in the project concerning the construction of FMA and MEAS and MECS in Ethiopia. Consequently, this report, in addition to describing the work undertaken for the MECS and FMA constructability trials, it also provides information on the work necessary for the trials of the MEAS surfacing and describes the lessons learned.

The purpose of the constructability trials was to demonstrate the constructability of road surfacings using the MEAS, FMA and MECS technologies using the plant and equipment typically available to a LIC road agency, and/or its contractors. The intention was not to monitor the performance of the surfacings over time, and indeed the project did not have the necessary resources so to do. ERA has indicated its willingness to monitor the performance of the sections beyond the end of the CRISPS project, but the assistance of the same and reporting of the on-going performance of the sections does not form part of the research reported herein.

To enable meaningful comparisons between the constructability of the FMA and MECS surfacings and the standard technologies used by ERA, control sections were built adjacent to both the FMA and MECS trial sections. Both sections were designed and built using the same standards specified in ERA's design manual for flexible pavements (2). The function and structural integrity of both constructed sections were assessed using both visual assessment and equipment techniques. These include the South African's TMH9 method for visual assessment (3), Benkelman Beam deflection, Merlin, Pendulum friction meter, straight edge and others at available at ERA's RRC and within the networks on ERA's contractors for road construction and maintenance activities.

1.1.2 Constructability

Constructability was defined using a narrative based on the following:

1. Local availability of the equipment such asphalt batching plant, and both laboratory and field equipment to undertake preliminary laboratory and field tests.
2. Local availability of skills necessary to undertake construction, including capabilities to undertake mix designs.

2. Literature review

In order to develop a better understanding of the surfacings technologies investigated during the CRISPS project and used as part of the constructability of trials, a literature review was undertaken relating to the materials and practices for the surfacings as listed below:

Epoxy modified Surfacings: Modified Epoxy Asphalt Surfacings (MEAS) and Modified Epoxy Chip Seal (MECS)

Fibre Modified Asphalt (FMA)

This section provides brief background to the technologies used.

2.1 Modified Epoxy Asphalt (MEAS) and Modified Epoxy Chipseal (MECS)

The New Zealand Transport Agency (NZTA) has laid over 1,000,000 m^2 of MEAS (4)on roads with up to 100,000 vehicles per day. (5) The Agency's research suggested that using epoxy modified binders had the potential to reduce the life cycle cost of using low noise surfaces to 1/6 of their current value (6; 7). MECS can be used to treat existing low texture chipseal surfaces that tack bitumen down the road in very hot weather. The treatment could be applied in hours instead of weeks to months required for a rebuild. Added benefits are that the technology is relatively insensitive to operator error since it can be applied with simple modifications to existing bitumen sprayers, and it requires little additional maintenance when compared to conventional chipseals. NZTA research also suggests MECS could be optimised to produce long-life chipseals with approximately 60% of the life cycle costs of conventional chipseals (6). Full-scale road trials of MEAS started in late 2019 in New Zealand. The resilience to temperature fluctuations of modified epoxy bitumen binders, as highlighted by previous research studies (8), will mean that their application in appropriate regions in LICs is likely to significantly reduce ongoing maintenance and emergency repair costs and will as a result provide more certainty in road network availability and performance. These benefits will become more apparent in regions where average temperatures and the number of days experiencing extreme heat are expected to rise because of climate change. For example, research suggests that for the middle of the range greenhouse gas concentration scenario (with a Representative Concentration Pathway, RCP 4.5) and the median percentile range of model predictions there is a predicted 2 to 4° C increase in both winter and summer temperatures over the period between 2005 and 2100 for both West and East Africa when compared to the reference period of 1985 to 2054 (9). There is also expected to be a significant increase in the number of days of extreme heat. The possibility of using MECS over localor marginal materials will also provide sustainability (and cost benefits) and it will allow the use of low-quality materials in the construction of roads and thus save scare resources and reduce haulage costs. Further, the easy application of MECS means that better quality roads, requiring less maintenance, compared to conventional chipseal. Thus, reducing further road agency costs.

2.2 Fibre Mastic Asphalt (FMA)

The Universiti Putra Malaysia (UPM), in association with the local authorities in Malaysia, has implemented FMA in Kuantan (East Coast of Malaysia) in 2000 with a total resurfacing of 3,500 m^2 (10). The FMA surfacing is still functioning despite a spike in the traffic volume after almost 20 years. Two more road projects were undertaken in Malacca under the Ministry of Science provision with a total resurfacing of 14,000 m^2 four years ago. And another 7,000 m^2 was resurfaced on UPM public road in 2016. FMA was implemented on the Persiaran Road, Klang Valley Project in 2015 covering approximately 35,000 m^2 (10). Full implementation of FMA is envisioned since the Malaysian Public Works Department (Jabatan Kerja Raya Malaysia) approved the technology and included it in the Malaysian Road construction specification. The recent application of FMA is on the Senai-Desaru Expressway in Johor Baru more than a year ago to test the robustness of FMA that was in fact laid on a heavily tracked truck lane. Previously this stretch had continuously failed badly due to rutting. FMA technology seems to have proven its worth with no failures seen to this date. The technology is based on the use of cellulose fibre extracted from the waste generated from the oil palm tree and formed into pellets for ease of handling and application. The application of this fibre in asphalt has reduced the amount of maintenance intervention lessening the need for road closures and disruption of traffic. Initial findings suggest a life cycle cost savings of 10-15% compared to traditional methods. FMA also performs well in elevated temperatures. Pavement surface temperatures in Malaysia often exceed 60°C with ambient temperatures as high as 39°C during hot spells. The use of fibres is able to retain the asphalt binders in the flexible layer for an extended period ensuring lasting performance and proved its endurance at high temperatures.

3. Ethiopia – Climate and Road Network

3.1 Climate

The Ethiopian road network is covers three main climate types namely the tropical humid, sub-humid and semi-arid climates. The data related to these three climate zones was obtained from the Ethiopian National Meteorological Agency (NMA) by ERA in terms of moisture index, duration of the dry season, mean monthly precipitation, mean temperature, duration of excessive temperature (≥32.5°C) as can be seen in Table 1.

Table 1 Key parameters of the three climate types

Parameter	Tropical Humid	Sub-humid	Semi-arid
Moisture index	60	0	-40
Duration of dry season (month)	3	6	9
Mean monthly precipitation (mm)	175	100	50
Mean temperature (°C)	27	22	26.1
Average temperature range (°C)	5.5	4.5	3.2
Days of Temperature >32.5 (°C)	90	60	90

3.2 Road Network

According to (11; 12) the classified Ethiopian road network is estimated to be about 126,773 km comprising about 17,579 km of paved roads and 109,194 km of unpaved roads. See Table 2. These roads are categorised based on the authority in charge of their management, as detailed in Table 3 below. The ERA is responsible for national roads constructed and maintained by the Federal Government, the regional roads are constructed and managed by the Regional Governments whilst rural roads are essentially constructed and maintained by local communities. In addition to this classification, Ethiopian road network is classified according to the function of the road as Trunk Roads (A), Link Roads (B), Main Access Roads (C), Collector Roads (D) and Feeder Roads (E). ERA category roads comprise road classes A, B and C, and (C) and (D) classifications roads are in Rural and Woreda classification; see Table 3.

Table 2 Classified road network in Ethiopia

Road category	Paved roads (km)	Unpaved roads (km)	Total (km)
ERA	15,886	12,813	28,699
Rural	-	35,985	35,985
Woreda (regional district in Ethiopia)	-	56,732	56,732
Municipality	1,693	3,664	5,357
Total	17,579	109,194	126,773

Table 3 Road classification in Ethiopia (9)

<table>
<tr><th colspan="5" rowspan="2">Functional Classification</th><th colspan="4">Technical Classification</th><th>Political Classification</th></tr>
<tr><th>DS</th><th>Traffic (ADT)</th><th>Width (m)</th><th>Surface type</th><th>Ownership</th></tr>
<tr><td></td><td></td><td></td><td></td><td rowspan="5">Trunk</td><td>1</td><td>10,000 - 15,000</td><td>2 x 7.3</td><td rowspan="4">Asphalt</td><td rowspan="5">ERA
(Federal Road Administration))</td></tr>
<tr><td></td><td></td><td></td><td rowspan="5">Link</td><td>2</td><td>5,000 - 10,000</td><td>7.3</td></tr>
<tr><td></td><td></td><td rowspan="5">Main Access</td><td>3</td><td>1,000 - 5000</td><td>7.0</td></tr>
<tr><td></td><td rowspan="5">Collector</td><td>4</td><td>200 – 1000</td><td>6.7</td></tr>
<tr><td></td><td>5</td><td>100 – 200</td><td>7.0</td><td rowspan="4">Gravel</td></tr>
<tr><td rowspan="5">Feeder</td><td></td><td>6</td><td>50 – 100</td><td>6.0</td><td rowspan="3">RRAs
(Regional Roads)</td></tr>
<tr><td></td><td></td><td>7</td><td>30 – 75</td><td>4.0</td></tr>
<tr><td></td><td></td><td></td><td>8</td><td>25 - 50</td><td>4.0</td></tr>
<tr><td></td><td></td><td></td><td></td><td>9</td><td>0 - 25</td><td>4.0</td><td rowspan="2">Earth</td><td rowspan="2">Woreda Rural Roads Office
(Community Roads)</td></tr>
<tr><td></td><td></td><td></td><td></td><td>10</td><td>0 -15</td><td>3.3</td></tr>
</table>

DS = Design Standard

3.3 Selection of Trial Sections

Two segments along the Awash-Meiso and Modjo – Edjere roads were respectively selected for the MEAS and FMA, and MECS construction trials. The Awash-Meiso road, designated as A10, is a Trunk road and was rehabilitated in 2003. The Modjo-Edjere road, designated as B51, is a Link road and was rehabilitated in 2012. The location of the roads selected sites for the trials are shown in Figure 1.

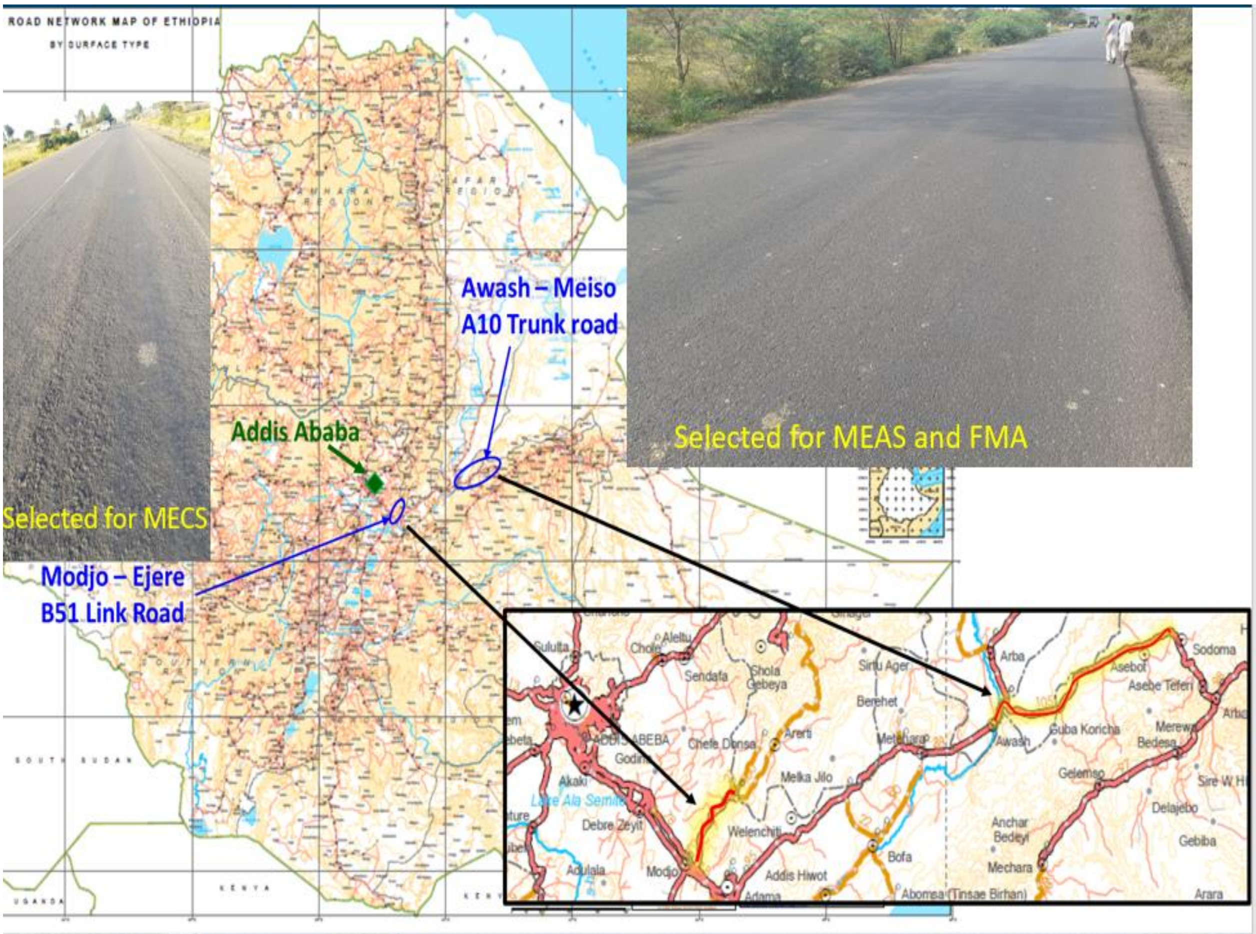

Figure 1 Location of the trial sections

3.3.1 MEAS and FMA Trials

The constructability trial sections were located between Km 31+400 - 32+400 measured from project start at the outskirts of Awash Sebat at 228 Km. The trial section was part of a 71 Km long Awash - Meiso asphalt road surfacings project that started in November 2022. It has two, 3.5m wide lane paved carriageway with 1.5m wide unpaved (subbase) shoulders on both sides. The project road traversed mainly flat and rolling terrain starting at 871 m above mean sea level (AMSL) at Awash ending at 1328 m AMSL at Meiso towns. The road section lies in the Kola (warm semiarid climatic zone) with ESA of 24.0. Table 4 details the location of the Awash – Meiso trial section.

Table 4 Locations of Awash-Meiso - trial section

Road segment	Location of the trial section		Location coordinates	Remark
	from Awash	from Addis Ababa	Eastings (E), Northings (N) and Elevation (Elv)	
Awash - Meiso	31+100 - 31+200	256+100 - 256+200	31+100 - E: 657541 N: 1005931 Elv: 1156	FMA trial section
	31+400 - 31+500	256+400 - 256+500	31+400 - E: 657562 N: 1006084 Elv: 1158	Control section
	31+650 - 31+750	256+650 - 256+750	31+650 - E: 657439 N: 1005190 Elv: 1164	MEAS trial section

3.3.2 MECS Trials

This trial section lies along the 37 Km long road connecting Modjo, in the Oromia region, along B-51 road and Arerti, in the Amhara region. The road starts at an elevation of 1843 m AMSL, traverses mainly on flat and rolling terrains with some mountainous and escarpment areas and passes at an elevation of 1804 m AMSL at Arerti. The proposed trial sections lie from Km 12+050 to 12+150 and from km 12+200 to km 12+300 measured from the out skirts of Modjo at 79 km from Addis Ababa along the A-1 road network which connects Addis Ababa to Semera via Adama. It lies in the Kola climatic zone and the estimated AADT and commercial vehicles per day (CVD/lane) for the year 2022 are 4648 and 1777 respectively. Details of the trial locations along the Modjo – Edjere road are shown in Table 5.

Table 5 Specific location of Modjo-Edjere trial sections

Road segment	Location of the trial section		Location coordinates	Remark
	From Modjo	From Addis Ababa	Eastings (E), Northings (N) and Elevation (Elv)coordinates	
Modjo – Edjere - Arerti	12+050-12+150	87+050 - 87+150	31+400 - E: 0519104 N: 0959193 Elv: 2019	Control section
	12+200-12+300	87+200 - 87+300	31+400 - E: 0519174 N: 0959266 Elv: 2022	Trial section

3.4 Road Condition Survey

Before conducting a ground investigation, a road condition survey in terms of visual condition assessment and rut depth survey for both the Awash-Meiso and the Modjo-Edjere road sections were undertaken. Some surface defects, such as aggregate loss and bleeding, were observed on the Modjo-Edjere road. The Awash- Meiso road section was in very good condition in general. Sections on both the road showed no structural defects. Surface roughness measured in terms of the International Roughness Index (IRI) along the road sections confirmed that they were in good condition, with IRI of 4 or less in general. The results of the rut depth measurements conducted on the control and trial sections along the Awash-Meiso road showed that rut depth was up to 3mm in only one of the wheel paths of the two lanes. In bulk of the areas there was no rutting. For the Modjo-Edjere road section, there were some areas where the rut depth was greater than 5mm (maximum 8.5 mm at one location). In general, there was little rutting. Details of the road condition in terms of rut depth surveys are given in Appendix A.

3.5 Ground Investigation

The Awash – Meiso and Modjo- Edjere roads were last upgraded in 2003 and 2012 respectively. Construction details of the Awash -Meiso road were not fully known so a ground investigation was undertaken along the proposed trial surfacing sections of the both the roads to confirm pavement layer thicknesses and ascertain properties of the materials used. Following the rut depth survey, a ground investigation, which included construction of trial pits and coring of each section of the road and materials recovered were tested in RRC laboratories to ascertain particle size distribution, Atterberg limits, compaction characteristics, CBR specific gravity, absorption tests and before and after tests on asphalt cores. Details of the tests and tests are described in given in Appendix B. Summary of the findings are described in the following sections.

3.5.1 Ground investigation results of the MEAS and FMA sections selected for constructability trials

The pavement layer thicknesses, determined from the trial pit and coring are shown in Table 6 and the in-situ moisture content and densities are shown in Table 7.

Table 6 Existing road construction

Road Segment	Technology application	Pavement layer	Layer material	Thickness (mm)
Awash – Meiso (Trunk road)	MEAS and FMA	Surfacing (AC)	Asphalt concrete	120
		Base course	Crushed aggregate	150
		Subbase	Natural gravel	100 - 150
		Capping	Natural gravel	>250

Table 7 In-situ moisture of pavement layers

No.	Road stretch	Test Pit ID	Layer	In-situ moisture (%)	Optimum moisture content (%)	In-situ dry density (kg/m^3)	In-situ dry density (Mg/m^3)
1	Awash - Meiso	A-M-1	Subbase	14.18	7.1	1.67	2.09
2			Capping layer	13.10	17.39	1.50	1.76
3		A-M-2	Subbase	9.67	13.6	1.77	1.96
4			Capping layer	7.04	13.2	2.06	1.97

Results of laboratory investigation are summarised Table 8.

Table 8 Summary of results of particle size distribution and Atterberg limit tests for samples from the Awash–Meiso Road segment

Location of trial section	Pavement layer	Material type	Particle size distribution	Atterberg limits LL (%)	PI	Linear shrinkage (%)
			AASHTO-T27	AASHTO -T89		BS1377-2:1990
256+100 to 256+750	Base	CA	Material, generally fulfils gradation requirements for base layer (according to Table 5204/1 of ERA specifications 2014)	25 -33	17-18	4.8 - 7.8
	Subbase	CA	Material at one trial pit out of specification and one complies with the gradation requirements for subbase layer (according to Table 5204/1 of ERA specifications 2014)	37 - 51	21-23	7.9 – 14.9
	Capping layer	WCG	Material fulfills minimum requirements of ERA Specifications, 2014)	40 - 51	21-28	9.0 - 11.6
Mat.: Material, CA: Crushed Aggregate, WCG: Weathered Clayey Gravel, NA: Natural Aggregate, ID: Identification, AA: Addis Ababa						

Strength and durability of the materials from the Awash- Meiso road are summarised in Table 9.

Table 9 Summary of strength and durability of materials from the Awash-Meiso road segment

Location of trial section	Pavement layer	Material type	Compaction AASHTO-T180D: MDD (g/cm3)	Compaction AASHTO-T180D: OMC (%)	CBR, AASHTO – 193-93, 96 hours soaked: CBR, @98%MDD,	CBR, AASHTO – 193-93, 96 hours soaked: Swell %	CBR, AASHTO – 193-93, Unsoaked @ NMC/OMC: 10 blows	Unsoaked @ NMC/OMC: 30 blows	Unsoaked @ NMC/OMC: 65 blows	Ag. Cr: BS812:112-1990	FI (%): BS812:1051:1989	Specific gravity and absorption, Coarse Aggregate, ASTMC-127: Specific gravity	Coarse Aggregate, ASTMC-127: Absorption	Fine Aggregate ASTM T-84: Specific gravity	Fine Aggregate ASTM T-84: Absorption
256+100 to 256+750	BL	CA	2.24-2.32	4.9-7.1	87-93	0.0	35 - 41	57 - 83	99-139	8-9	19	2.59-2.81	1.76-2.1	2.59-2.76	3.27-5
	SBL	CA/ NA	1.96-2.35	2.81-3.6	82-85	0.0-0.2	29 - 48	60 - 93	87-176	-	-	2.55-2.70	5.85-9.18	2.28-2.51	9.18-15.31
	CL	WCG	1.76-1.98	13.2-17.4	19-37	0.6-1.3	26 - 30	52 - 68	90-93	-	-	-2.48	-	1.98-2.47	-15.31

CA: Crushed Aggregate, WCG: Weathered Clayey Gravel, NA: Natural Aggregate, ID: Identification, AA: Addis Ababa, Ag. Cr.: Aggregate Crushing, FI: Flakiness Index, BL: Base layer, SBL: Subbase layer, CL: Capping layer

A summary of the before and after bitumen extraction of asphalt cores from Awash- Meiso road segment is given in Table 10.

Table 10 Summary of before and after bitumen extraction of asphalt cores from Awash- Meiso road segment

Location of trial section	Pavement (WC: wearing course, BC:	Thickness, mm	Bulk density cm/cm^3	Maximum specific gravity	Air voids, %	Quantitative extraction AASHTO T-209: Particle size distribution AASHTO-T27	Quantitative extraction AASHTO T-209: Bitumen content (%)	Flakiness index (%): BS812: 106-1-1989
A–M RS, 256+100 to 256+750	WC	50 - 66.3 (56.6)	2.65-2.48 (2.55)	2.64-2.74 (2.69)	2.2-9.1-(5.2)	Except the first two sieves, material fulfils gradation criteria stipulated in Table 6403-3 for NMC of ERA Technical Standards Specifications (TSS)	3.26-5.31 (4.18)	20-35 (29.2)
	BC	60.4-70.6 (66)	2.58-2.69 (2.66)	2.69-2.77 (2.74)	1.6-7 (3.02)	Material fulfils gradation criteria in Table 6403-4 for NMC 25mm	3.69-4.52 (4.15)	20-32 (24)

Mean values are shown in brackets.

3.5.2 Ground investigation results of the Modjo-Edjere road section selected for the constructability of the MECS surfacing

The results of the rut depth measurements conducted on the control and trial sections along the Modjo Edjere road showed that rut depth was negligible except for one short section, where it was 5 and 8.5mm.

The pavement layer thicknesses, determined from the trial pit and coring are shown in Table 9 and the in-situ moisture content and densities are shown in Table 11.

Table 11 Modjo - Edjere pavement layer thicknesses

Road Segment	Technology application	Pavement layer	Layer material	Thickness (mm)
Modjo – Edjere (Link road)	MECS	Surfacing (AC)	Triple surface treatment	25- 30
		Base course	Crushed aggregate	100 - 225
		Subbase	Natural gravel (Cinder)	240 - 80
		Capping	Natural gravel	≥250

Pavement layer thicknesses and material types, determined from the trial pits and cores are summarised in Table 12.

Table 12 Pavement thickness of the section for MECS along the Modjo-Edjere road

Pavement layer	Thickness (mm)	Type of Pavement material used
Surfacing	25-30	Triple surface treatment
Base course	225-240	Crushed aggregate
Subbase	240-280	Natural gravel (Cinder)
Capping layer	≥250	Natural gravel

The in-situ moisture contents and densities determined for each pavement layers and the subgrade along Modjo – Edjere road section selected for the construction of MECS trial section are shown Table 13.

Table 13 In-situ moisture of pavement layers

Layer	In-situ moisture (%)	Optimum moisture content (%)	In-situ dry density (kg/m3)	Maximum dry density (Mg/m3)
Base course	3.72-4.29	6.0-6.6	2.29-2.34	2.33-2.34
Subbase	8.8-9.7	12.5-12.6	1.65-1.74	1.72-1.74
Capping layer	32.3-37.2	20.7-24.3	1.15-1.42	1.4-1.78

Laboratory test results of samples of unbound pavement layers (base course, subbase, and capping layers) HMA and collected for the trial pits located on Modjo - Edjere road section selected for the construction of MECS trial sections are summarized Table 14 and Table 15 respectively.

Table 14 Summarized results of Particle size distribution and Atterberg limit tests for samples from Modjo-Edjere road segment

Location of trial section	Pavement layer	Material type	Particle size distribution	Atterberg limits		Linear shrinkage (%)
				LL (%)	PI	
			AASHTO-T27	AASHTO-T89		BS1377-2:1990
12+050 to 12+300	Base	CA	Partially fulfils gradation requirements for base layer (according to Table 5104/1 of ERA specifications 2014)	Non-plastic	Non-plastic	1.6-1.7
	Subbase	WCG	Material fulfills gradation requirements according to Table 5104/1 of ERA specifications 2014	Non-plastic	Non-plastic	0.18
	Capping layer	HWCG	Outside the ERA specifications 2014 (i.e., LL<60 and PI<30)	51-59	31-34	7-10
Mat.: Material, CA: Crushed Aggregate, WCG: Weathered Cinder Gravel, HWCG: Highly Weathered Clayey Gravel, ID: Identification.						

Table 15 Summarized results of strength and durability tests for samples from test pits along Modjo-Edjere- Arerti

Location of trial section	Pavement layer	Material type	Compaction		CBR, AASHTO – 193-93					Ag. Cr	FI (%)	Specific gravity and absorption			
			AASHTO-T180D		96 hours soaked		Unsoaked @ NMC/OMC					Coarse Aggregate, ASTMC-127		Fine Aggregate ASTM T-84	
			MDD (g/cm^3)	OMC (%)	CBR, @98%MDD %	Swell %	10 blows	30 blows	65 blows	BS812:112-1990	BS812:1051:1989	Specific gravity	Absorption	Specific gravity	Absorption
12+050 -12+300	BL	CA	2.33	6-6.6	135	0.0	48	125	136	20	20	2.80-2.86	2.35-3.19	2.57-2.68	2.35-5
	SBL	WCG	1.47-1.72	12.5-12.6	70-85	0.-0.1	48	92-93	156-176	-	-	1.65-1.69	12.28-13.56	2.66-2.73	9.81-10.06
	CL	HWCG	1.34-1.46	20.7-24.3	7-19	1.2-3.2	4	2-6	5	-	-	-	-	2.54-2.57	-
CA: Crushed Aggregate, WCG: Weathered Clayey Gravel, NA: Natural Aggregate, ID: Identification, AA: Addis Ababa, Ag. Cr.: Aggregate Crushing, FI: Flakiness Index, BL: Base layer, SBL: Subbase layer, CL: Capping layer															

3.6 Traffic

ERA's flexible pavement design manual (2) provides a catalogue of pavement designs specifying materials of different thicknesses and properties, as a function of the strength of the underlying subgrade and the traffic (in ESALs) to be carried by the road section during its service life. ERA's maintenance standards are specified in (9). The FMA trial section design was undertaken according to ERA's current road design standards, using the traffic data for the section as specified by (2). The traffic data was provided by ERA (13) in terms of the annual average daily traffic (AADT) and traffic composition (see Table 16). Using annual changes obtained from historical traffic count data and in consultation with ERA, a traffic growth rate of 5% was assumed. The road section subject to this level of AADT with the given traffic composition would be expected to carry approximately 8.5 MESAs over a 20-year period. According to ERA's flexible pavement design manual (2), a new road section carrying this amount of traffic and built on the subgrade with assumed 7% CBR, should be designed using design chart C1 with subgrade class S3, and traffic class T6. A cross-section of the existing roads and the location of the new asphalt concrete and FMA overlays are shown in Figure 2. From Table 16, the ESALs for a design period of 20 years is predicted to be about 5,168,400 as a result of about 10,950,000 expected total number of vehicles in a two-way traffic scenario. Calculations of the ESALs based on the data provided by ERA (13).

Table 16 Two-way traffic composition data for Awash Meiso Road FMA trial section

Vehicle type	Vehicle equivalence factor	Traffic	
		AADT	ESALs
Four Wheel Drive (4WD)	0.01	44	0.44
Articulated Truck	6.5	19	121
Heavy Truck	5.5	40	22
Light Goods	0.22	312	69
Medium Bus	0.77	267	206
Medium Car	0	582	0
Medium Truck	0.96	58	56
Mini Bus	0.2	178	36
TOTAL (per day)		1, 500	708
TOTAL (annual)		547, 500	258, 420
TOTAL (20 years)		10, 950, 000	5, 168, 400

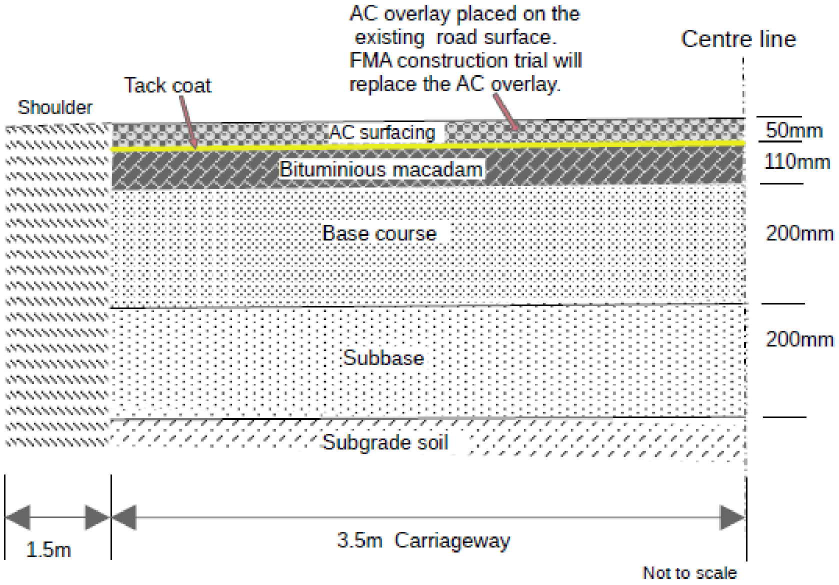

Figure 2 Existing road cross-section

3.7 Drainage Condition Survey

The drainage surveys were undertaken in June 2022 at the end of the dry season and in September 22 at the end of the rainy season. They cover the area of the roads including and adjacent to the test sections along the Modjo - Edjere and Awash - Meiso roads. The surveys include visual observations supported by photographs. The summary of the findings is given described below and all the observations made during the two surveys are described in Appendix C.

3.7.1 MODJO – EDJERE Section

This section was selected for the trial of MECS. The locations of each sub-section (trial and control) are listed in Table 17. The right-hand side (RHS) and the left-hand side (LHS) of the road refer to the direction of driving from Modjo towards Edjere.

The road runs through the rolling countryside and the sections selected for the trials are built on embankment with maximum height of about 3m. Typical cross section is shown in Figure 3.

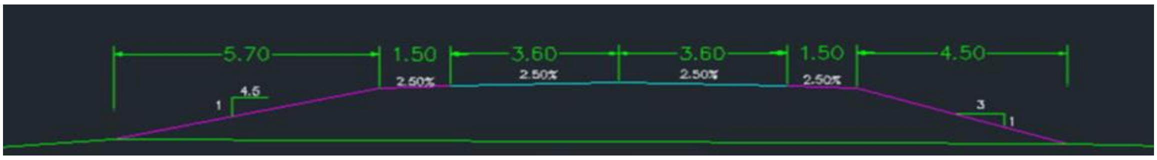

Figure 3 Typical cross section of the Modjo- Edjere trial section

Drainage water is generally carried away from the road via open roadside ditched. Typical example of variation in the June 2022 and September 2022 survey is shown in Figure 4 and Figure 5.

Figure 4 Shoulder, side ditch and adjacent plain at km 12+150 – RHS – June 2022

Figure 5 Shoulder, side ditch and adjacent plain at km 12+200 – RHS – September 2022

Both the surveys showed that the overall condition of the drainage of the Modjo – Edjere road was good during the dry and the wet seasons.

3.7.2 AWASH - MEISO Road Section

This section was selected for MEAS and FMAsurfacings. The report contains the visual survey and photographs. The location of each section and cross drainage structures are listed in Table 17. The right-hand side (RHS) and the left-hand side (LHS) of the road refer to the direction of driving from Awash towards Meiso.

The road runs through rolling countryside and is generally built on shallow embankments, with the exception of a short section which runs through a cutting on one side. Typical cross section is shown in Figure 6.

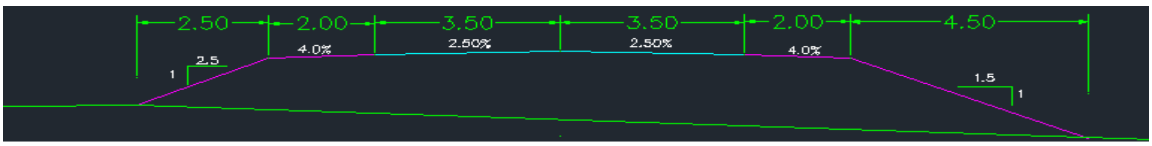

Figure 6 Typical cross section of the Awash- Meiso trial section

Drainage water is generally carried away from the road via open roadside ditched. Typical example of variation in the June 2022 and September 2022 surveys is shown in Figure 7 and Figure 8.

Figure 7 Shoulder, side ditch and adjacent plain at km 31+200 – RHS - June 22

Figure 8 Shoulder, side ditch and adjacent plain at km 31+200 – RHS – September 2022

Both the surveys showed that the overall condition of the drainage of the Awash – Meiso road was good during the dry and the wet seasons. The cross drains did not show any significant issues.

4. Control Sections

4.1 Control sections for MEAS, FMA, and MECS trials

The roads along which trial sections were located were scheduled for planned maintenance which required chipseal and asphalt overlay surfacings. Both these were designed to the ERA specifications as part of the renovation contract.

The locations of the control sections and the relevant trial technologies are shown in Table 17.

Table 17 Locations of Control and Trial Technology Sections

Trial Surfacings	Control section	Road	Chainage
MEAS and FMA	Asphalt concrete overlay	Awash Meiso road (A10)	256+200 to 256+300 measured from Addis Ababa.
MECS	Double Bituminous surface treatment	Modjo – Edjere road (A1 and A7 road segment)	km 12+200 to Km 12+300 measured from Modjo

4.2 Design of Surface Treatment

The design of this chipseal surfacing was conducted in accordance with the ERA Pavement Design Manual for Flexible Pavements (2) and ERA's Best Practice Manual for Thin Bituminous Surfacing (14).

Accordingly, surfacing selection required determination of Traffic. Based on the previous six years traffic count data using average traffic growth rate the estimated AADT and commercial vehicle per day (CVD/lane) for the year 2022 is estimated to be 4648 and 1777. Taking account of the traffic and hardness of the existing road surface, 10 mm size single surface chipseal was deemed suitable. A summary of the surfacing design is presented in Table 18. Design details are given in Appendix D.

Table 18 Summary of single layer chipseal

Nominal chipping size	Chipping application rate	Bitumen grade	Rate of Binder application
10	9 Kg/m^2	80/100 pen	0.81 Kg/m^2

4.3 Control sections for MEAS and FMA trial constructability

Since both the MEAS and FMA are equivalent to asphalt overlay, the control section was designed using the ERA standard procedure for pavement rehabilitation and overlay design manual (15).

Commonly three design methods are used to estimate the required overlay thickness: the effective thickness approach, the deflection approach, and the mechanistic empirical approach. ERA Pavement Rehabilitation and Asphalt Overlay design manual (15) follows the effective thickness procedure adapted from AASHTO and deflection procedure adapted from Asphalt Institute. As per this manual, both methods are to be used so that comparison and choice can be made employing engineering judgments. The 'Effective Thickness' procedure as recommended in ERA (15) (adapted from AASHTO (16)) cannot be used. This design procedure is based on non-destructive test in which the design resilient modulus (M_R)and effective structural number (SNeff) are back calculated from Falling Weight Deflectometer (FWD) measurements. Since FWD was not available, the structural strength of the pavement was estimated from the Benkelman Beam deflection.

A summary of the asphalt overlay is given in the following section. Detailed design is presented in Appendix E.

Various surveys showed that the pavement was in good condition, and does not require any reconstruction, either to partial or full depth over the selected trial section, therefore merely strengthening overlays was considered to be sufficient to cater for the future design traffic loading for a 15-year design life. It was concluded that 50mm thick overlay should be used. Overlay design output is summarised in Table 19 and the recommended grading envelope for the aggregate in given in Table 20.

Table 19 Overlay design summary

Parameter	Value
Overlay thickness	50mm
Marshal Mix Design Requirements for Asphalt Concrete Wearing Course	
Marshall stability, minimum, at 60°C	9 kN
Flow	2 – 3.5 mm
Compaction level, Number of blows on each of the two faces of the specimen	75
Air Voids (AV)	3 – 5 %
Void in Mineral Aggregate, minimum (VMA)	14 %
Voids filled with bitumen (VFB)	65 – 73 %
Loss of stability on immersion in water at 600C, maximum	80 %
Bitumen grade	60/70 Penetration

Table 20 Grading envelope of the asphalt overlay.

Sieve Size [mm]	Wearing Course	Tolerance
19	100	±8
12.5	90-100	±7
4.75	44-74	±7
2.36	28-40	±6
0.300	5-21	±5
0.075	2-10	±3

5. Monitoring

5.1 Monitoring purpose

The aim of WS 4 was only to demonstrate the constructability of the new technology road surfacings. Since the technologies may be adopted by ERA, a monitoring plan was prepared. However, monitoring data is not included in this report as it does not from part of the project brief.

5.2 Proposed Monitoring

Monitoring of various parameters and relevant standards together with monitoring frequencies are shown in Table 21. Since the constructability trials were conducted at the end of the project period it was not possible to include the initial monitoring data, which will be collected within a few weeks of opening the road to traffic. The aim is to assess the immediate impact of traffic and gather baseline information. Temperature and rainfall related data will be obtained from the Ethiopian National Meteorological Agency (NMA). The monitoring plan is for the follow up work undertaken by ERA.

Table 21 Performance Monitoring Schedule

Measurements	Condition parameter	Methods and Equipment	Standard	Frequency	Remark
Visual condition survey	Cracks, raveling, potholes	South Africa (TMH9)	TMH9	Quarterly	Equipment available
Transverse profile	Rutting	1.2 meters straight edge	ASTM-E1703	Quarterly	Equipment available
Longitudinal profile	Roughness	Merlin	ERA	Quarterly	Equipment available
Deflection	Elastic Deformation	Deflection beam	ASTMD4695	Bi-annually	
Density (Surfacings)	Compaction effort	Core sampling	ASTMD2726	Bi-annually	Equipment available
Dynamic cone penetration	In-situ pavement strength	Dynamic Cone Penetrometer	ASTM D6951	Bi-annually	Equipment available
Density and Moisture content	Changes in density and moisture	Oven-drying and sand cone method	ASTM D1556-07 and ASTM D2216-98		Quarterly
Pavement temperature	Pavement stiffness	Converted Air temperature by TRL equation	NMA	Daily	Temperature data (from NMA)
Traffic count	AADT	Manual classified traffic count	ERA	Quarterly	Resource available
Axle load survey	ESAL	Portable weighbridge	ERA	Quarterly	Equipment available
Climatic data	Climatic effects on performance	Awash NMSA weather station	NMA	Monthly	Rainfall data (from NMA)

Measurements	Condition parameter	Methods and Equipment	Standard	Frequency	Remark
Skid resistance	Traffic effect performance	Asphalt road pendulum friction meter	ASTM E303-93	Quarterly	Equipment available from the contractor(s)
Texture	Functional parameter	Volumetric patch method	A STM E965	Quarterly	Equipment available
Permeability		Asphalt pavement seepage meter		Quarterly	Equipment available

6. Guidelines and Specifications for MEAS, FMA and MECS

Draft specifications for MEAS, FMA and MECS are given in this section. Specifications for MEAS and MECS are based on published literature and meetings with experts. Specification for FMA draw on the Draft Fiber Mastic Asphalt developed in Malaysia specifically for using the fibers extracted from the oil palm plant waste (17) and reflects the findings of the trial undertaken in Ethiopia.

6.1 MEAS Construction Trial Guidelines and Specifications

Trial Construction using MEAS in Ethiopia could be achieved through appropriate mix design. This is discussed in the CRISPS project's Anti-Fraud report (18). The other important stages of the constructability, as detailed in the next sections, will include the road's surface preparation, manufacturing of the MEAS, plant modifications and the construction steps including transport of the MEAS and the placement and compaction requirements.

6.1.1 Road surface preparation

The following actions must be undertaken to prepare the road surface for MEAS overlay:

- It is only used where the road is structurally sound.
- The road surface should be levelled by milling if necessary.
- Any surface defects should be repaired in accordance with ERA standard procedure.
- Remove dust from the road surface and apply tack coat prior to application of MEAS.
- Apply RC–70 cut back bitumen tack coat at application rate of 0.12 to 0.2 kg/m^2 (maximum of 0.3kg/m^2) in accordance with ERA standard practice.

6.1.2 Manufacturing MEAS

MEAS is a two-part binder supplied by ChemCo. Part A is the epoxy resin and part B, designated Bv, comprises bitumen, hardener, and accelerator (18).

1. EMAS is a two-part binder supplied by ChemCo. Part A is the epoxy resin and part B comprises bitumen, hardener and accelerator.
2. Part A is a viscous liquid at room temperature. It becomes liquid and easily transferred or pumped at about 45°C. It should be stored at no more than 80°C as it can homopolymerize if the container has any hotspots, where temperatures exceed about 100°C.
3. Part B is solid at room temperature and needs to be heated to 110°C for use.
4. Aggregate should be heated to between 115-125°C before adding to the pugmill.
5. The two parts should be kept separate prior to mixing in the asphalt batching plant.
6. Cross-contamination should be avoided as it may lead to the hardening of the binder.
7. The two parts are mixed in the following proportions - Part A: 14.6% and Part B: 85.4 % (by weight).
8. In New Zealand, it is common practice to blend Parts A and B inline in a continuous mixing plant. There is little experience in using a mobile batching plant such as that used by ERA. In New Zealand it is also common to dilute Parts A and B with normal bitumen (Parts A + B: bitumen in the ratio 1:3) to extend the use of epoxy binder. This is not possible in Ethiopia due to lack of facility to blend bitumen.
9. Batch mixing in a laboratory may be investigated through laboratory tests. Suggested procedure:
    a. manually mixing part B with aggregate and then adding Part A; or
    b. manually mixing parts A and B just prior to adding to aggregate.
10. High temperatures may lead to accelerated curing. The target temperature may not be much higher than 135°C. Need to do laboratory tests with mixes prepared at different temperatures, say 120, 125, 130 and 135°C to check time to harden.
11. Need to maintain a high enough temperature of the mixture for transport to site, placing and compaction. The mixed batch, as it leaves the pugmill (asphalt plant mixing chamber), should be

between 100°C and 120°C. In New Zealand the manufacturing temperature is between 120°C and 125°C. Ensure that suitable viscosity to reduce/prevent drain down during transport.

12. Need to balance MEAS production temperature and transport distance. If the temperature is too high or the haulage distance is too long, then the mixture may not be useable at the delivery point.
13. The best overall solvent (and safest from the point of view of high flash point) is typically available around the world and known as Solvent 200. Esso/Exxon/Mobile supply this as Solvesso 200. Other products are Heavy Aromatic Solvent 200 and Solvent C12. If somehow, the parts A and B cure hard, they will soften (but probably not melt unless diluted) so they can be removed more easily by preheating the part with a weed burner torch which will soften the hardened polymer.

6.1.3 MEAS - Plant Modifications

ERA proposed to use their existing mobile asphalt batching plant, YLB-700 supplied by Sinoroader (based in XuChang, HeNan, China) to produce the MEAS. Figure 9 shows the key parts of the asphalt plant and a summary of its capability are given in Table 22.

The epoxy binder used in MEAS comprises a two-part mix: Part A - resins - and Part B - modified bitumen - in the proportions 14.6% and 85.4% respectively. Initially it was planned to use the existing bitumen supply and monitoring system in the YLB-700asphalt plant for Part B, the larger binder component, without any modifications and it would be necessary to add another storage tank, heating and decanter, heated storage, high viscosity pump, weighing system and an injector pump for Part A. However, further discussion with the ERA's contractor, who owned the plant, revealed that using the existing bitumen supply tank wasnot be possible as it had a large sump. It would also not be possible to use the exiting pumping and weighing system as had been envisaged initially. However, Sinoroader believed the exiting weighing system could be used. Thus, since none of the existing storage, pumping and the weighing facility could be used for Part B, they would have to be purchased. The final flow chart showing the setup of Parts A and B systems for the YLB700 asphalt plant is shown in Figure 10.

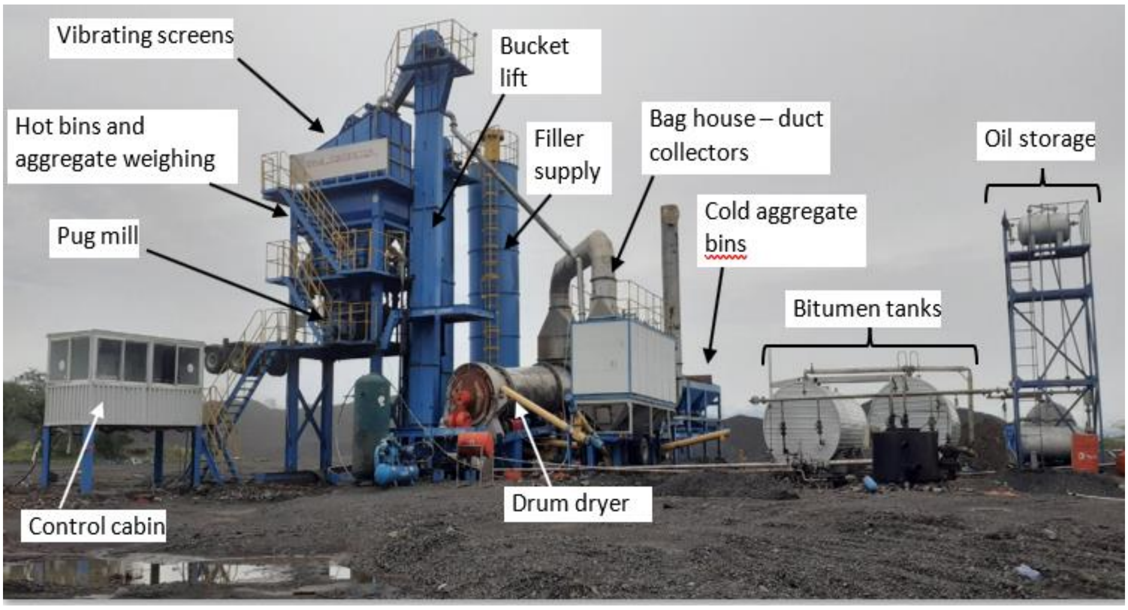

Figure 9 The TLB700 Mobile Asphalt Batching plant

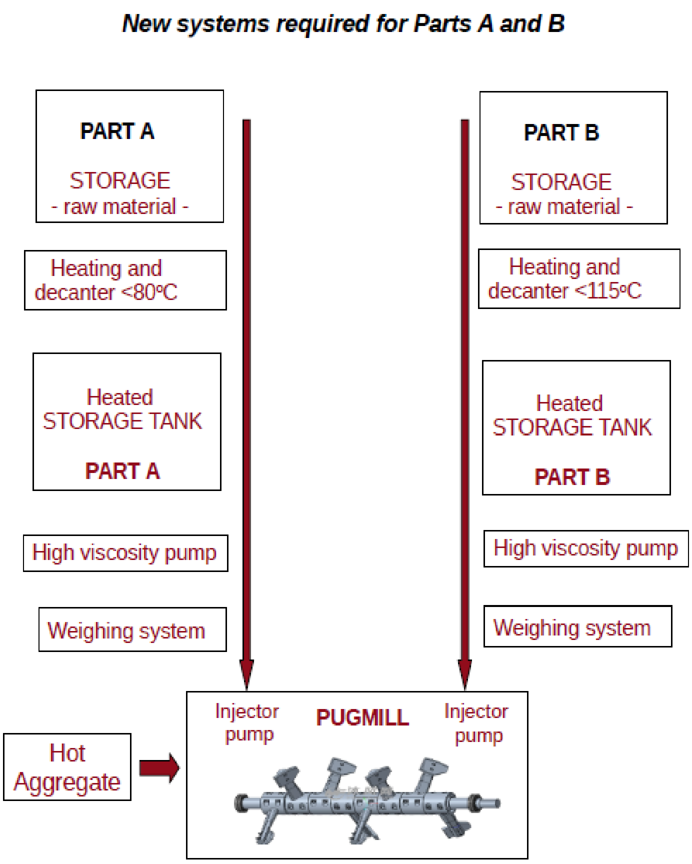

Figure 10 Flow chart showing setup to produce MEAS

Table 22 Capability of the Mobile batching plant – YLB700

Parameter	Property
Output capacity	60t/h
Mixer capacity	700kg/batch
Fuel consumption	≤6.5kg/t
Weighing accuracy	±0.5% hot aggregate, ±0.3% bitumen, ±0.2% filler
Asphalt temperature	130℃-165℃ (adjustable)
Installation power	157kw
Area	35 x 26 x 15m

None of the modification were undertaken as the supplier could not guarantee that the required parts could be delivered to Ethiopia in time for the field trial to be completed before the end of the project and there were contrary views between the plant supplier, Sinoroader and ERA's contractor, who owned the plant, about using the existing weighing system for Part B. This resulted in the MEAS trial not taking place.

6.1.4 MEAS Construction

According to Herrington (7) construction and compaction can be done by a tandem steel-wheel vibratory roller. The total time from the commencement of the manufacture of the first epoxy mixture to the commencement of construction can range from 45 to 60 minutes so careful attention must be paid to the temperature -hardening time relationship and noted in in Section 6.1.2. If there is a possibility that the time for placing the epoxy asphalt is not enough, then it will be necessary to extend the period over which epoxy asphalt mix can be held at elevated temperature to a minimum. However, this can also result in the binder's viscosity being lower than desirable at the time of application.

6.1.5 Transport to site

As noted in section 6.1.2, elevated temperatures may lead to accelerated curing and the target temperature should not be greater than 135°C. There is however a need to maintain high enough temperature of the mixture for transport to site, placing and compaction. The mixed batch, as it leaves the pugmill, should be between 100°C and 120°C. In NZ manufacturing temperature is between 120°C and 125°C. Extract from Waters et al. (19) "The production run went well with mix produced at 120-125°C as used for the 20% EMOGPA voids mix for the CAPTIF trial with no issues, the mix was held in the hot bin for 30 minutes before it was loaded onto the trucks. The mix was transported to site and in the basket of the paver less than 60 minutes after manufacture. The mix paved well and compacted easily with no issues recorded." ERA estimate that there will be, approximately, a 10°C drop in temperature during transport. Therefore, haulage distances must be selected carefully to help control temperatures during transport of MEAS. In other words, there must be strict balance between MEAS production temperature and transport distance. If the temperature is too high or the haulage distance is too long, then the mix may not be usable at the delivery point.

6.1.6 Placing and Compaction

The following requirements should be observed during placing and compaction of MEAS during the constructability trial in Ethiopia.

1. The final compacted surfacing will be 50 mm thick, which is the same as the asphalt overlay used in the control section.
2. Standard compaction equipment such as steel wheel tandem roller of 8 - 10-ton capacity is recommended. Number of passes required to compact may be determined in an off-site trial.
3. The compacted MEAS trial and control sections should be open to traffic when the temperature is lower than 50°C. If required, the surface may need to be cooled down using water bowser or wet blankets.

6.1.7 Monitoring During Batching and Construction

The following aspects of the batching and construction processes of the MEAS should be monitored to achieve good mixture of materials as well as the final constructed trial section:

- Aggregate temperature when input into pugmill
- Time for dry mix
- Time for wet mix
- Temperature of modified epoxy asphalt discharged into truck
- Distance and time to site
- Road surface temperature
- Laydown temperature
- Mat thickness
- Thickness of the compacted MEAS
- Density of the compacted MEAS

- Take samples and compare them with reference strengths (based on laboratory testing at the design stage) .
- Use of FTIR to confirm that the right proportions of epoxy-bitumen were used.

6.2 MECS Construction Trial Guidelines and Specifications

This surfacings course essentially comprises single size aggregate and a two-part epoxy binder. This section aims at providing information about the procedures and methodology required for chip sealing epoxy modified chip seal in Ethiopia.

Details of the plant used for MECS and the control sections are described in Sections 7.1 – Chipseal construction trials.

6.3 Road surface preparation

This will include the following activities, noting that MECS is only to be used where the road structure is sound and does not have any structural defects:

1. Repair any surface defects.
2. Remove dust from the road surface.

6.3.1 Manufacture and construction of MECS

Manufacturing of MECS involves the spraying epoxy Parts A and B. The following guidance and information recommended in the manufacture and construction of the MECS:

1. Part A is the epoxy resin and part B (designated B1f) comprises bitumen, hardener and accelerator.
2. Part B can be stored in the existing tanks in the bitumen spray truck. Part A should be stored in an additional smaller tank attached to the truck. Since bitumen spray trucks have only one spray system it will be necessary to fit a smaller heated tank with temperature control, spay bar, pump and flow control for lower flow rate for Part A.
3. In New Zealand spray jets are at 100 mm spacing the two-spray bar for both Parts A and are arranged to give a triple overlap spray.
4. Both the spray bars have the same fan width and are set at the same height above the road surface.
5. Part A will flow at 40°C. It is recommended that the Part A drum may be heated uniformly to about 45°C to transfer it to the heating tank for chip sealing.
6. Part B1f with lower polymer content is pumpable at about 125°C.
7. Part A temperature should be 75 to 80 ±5°C and Part B to 150 - 160°C to achieve sprayable consistencies before pumping through the spray bars. If the temperature control is poor say ±10°C, then the target upper limit should be reduced to 75°C.
8. Ensure that Part A is heated uniformly, i.e., there are no hot spots of about 100°C, which may lead to a homopolymerization reaction that is both exothermic and expansive and can damage equipment.
9. Part B temperature should be between 150 to 160°C to speed up the reaction and get heat into the mix as during impingement blending, the parts are mixed in fine film/spray (in air) and thus cool off quickly. Do not heat Part A more than the target temperature discussed above.
10. The two parts are mixed in the following proportions - Part A 25.25% and Part B 74.75%.
11. Ensure that correct proportions are used – sprayers may use volumetric control; the ratios of 1 to 3 are weight ratios taking account of temperature.
12. Spray Part B through the existing spray bar "B" and Part A is sprayed through the second spray bar "A" shown in Figure 11. The vertical axis of the Part A and Part B jets are each 15° off vertical so that the A and B spray fans meet about 3/4 of the way to the ground to provide the impingement blending. See Figure 11.
13. The spray bar nozzles shall produce a uniform triple overlap application with the nozzles angled at 15 degrees to the spray bar axis. See Figure 12.

14. In New Zealand Part A jet nozzles are Spraying Systems 80/10 VeeJets that they (Fulton Hogan) operate at 3.41 litres per minute and the Part B jet nozzles are Spraying Systems 80/50 VeeJets that they operate at 11.60 l/min.
15. System should be capable of delivering at a specified rate ±0.08l/m2. Mixing tolerance is ±10% (by weight).
16. Only single layer chip seal is required. This can be constructed on the existing chip sealed surface.
17. Do not use epoxy chip seal direct on the base course.
18. As the epoxy-based binder hardens it does not let any bitumen flush up or down, so can use smaller chips. Suggest using 10 mm and the application rate of binder can range between 1.2 and 1.5 l/m2. For 19 mm chips, may have to use 1.82 l/m2 of binder. Thus, using 10mm chips will be cheaper to construct. Smaller chips will also give a safer running surface (due to dislodged chip impact).
19. Chip surface immediately. Do not over-chip as it may prevent aggregate from bedding-in properly.
20. Adopt standard ERA procedures for compacting chips.
21. For cold temperatures and high-speed traffic there can be chip loss due to slower curing of the binder. Not likely to be an issue in Ethiopia but, need to ensure the road is opened to traffic when chip seal is cured.

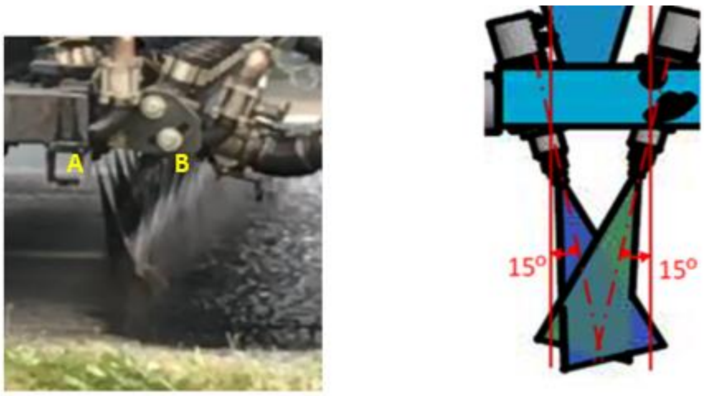

Figure 11 Impingement mixing

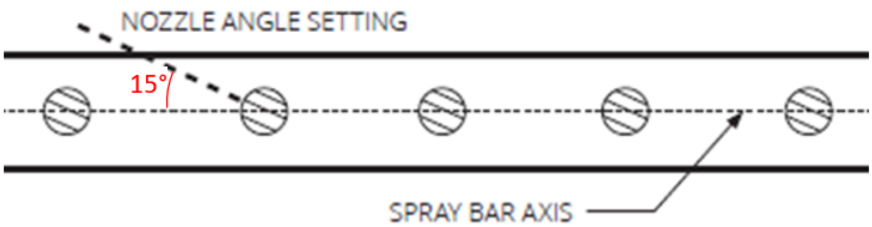

Figure 12 Orientation of spray jets in relation to spray bar axis

7. FMA Construction Trial Guidance and Specifications

7.1 Manufacturing and Placing FMA

Cellulose fibre in the form of pellets was used in this study. It was supplied by Novapave Sdn BHD (Malaysia). It was used in conjunction with bitumen and uniformly graded aggregate. The FMA was manufactured in a mobile asphalt batching plant.

7.1.1 Road surface preparation

Road sections selected road selected should be free of any structural faults and any near surface faults such as potholes must be patched, ruts filled in and cracks are sealed. In addition, the road surface should be free of grit and dust.

7.1.2 Manufacturing FMA

It is proposed to use the YLB700 mobile asphalt plant. The capability of the plant is described in Section 6.1.3. General guidance information on the manufacture of the FMA is given below.

1. The asphalt batching plant has 3 cold aggregate bins, each storing a specific size range of aggregate. Proportions of aggregate used from each bin are shown in Table 23. The project aimed not to change the size of aggregate in the cold but to change the proportions of aggregate used from the hot bins to manufacture aggregate grading that complies with the FMA20 specification material as described in the Malaysian draft standard for FMA.
2. The aggregate should be heated to 180°C and moisture content no greater than 0.5% at the point of entry to the pugmill. The temperature of the aggregate must not exceed 200°C as this may damage the fibre.
3. Bitumen should be heated to between 160 and 163°C when added to the pug mill and the quantity of bitumen should be measured to the accuracy of ±0.3%.
4. The quantity of fibre should be weighed to an accuracy of ±0.2% for each batch.
5. Manually add the pre-weighed quantity of the fibre pellets to the pugmill and mix for 5 to 15 seconds.
6. Add bitumen and mix for about 30 to 40 seconds to achieve a homogeneous mixture.
7. Discharge into truck at suitable temperature (between 130°C and 160°C) such that FMA is delivered at suitable temperature to enable placement and compaction.

Table 23 Aggregate stored in cold bins and proportions used in asphalt

Bin number	1	2	3
Size (mm)	12.5-19	4.75-12.5	0.07-4.75
Proportions (%)	25	43	23

7.1.3 FMA - Plant Modifications

ERA used their existing mobile asphalt batching plant, YLB-700 supplied by Sinoroader to produce the FMA. Figure 9 shows the key components of the asphalt plant, and a summary of its capability is given in Table 22. FMA was produced by adding the required quantity of fibre pellets direct into the pugmill for each batch. The location of the hatch through which the fibre can be added is shown in Figure 13, and a flow chart showing the setup of the asphalt plant for the manufacture of FMA is shown in Figure 14.

Figure 13 Location of hatch through which fibre and Portland cement were added to the pugmill

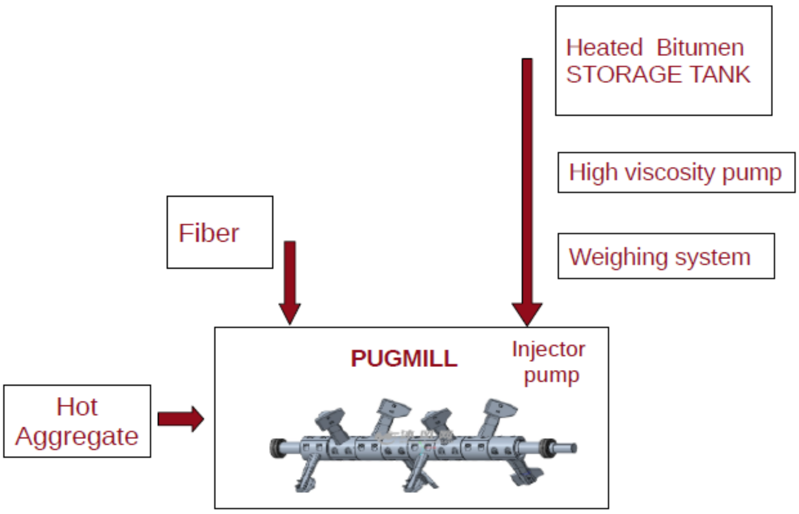

Figure 14 Flow chart showing setup to produce FMA

The YLB 700 batching plant is set up with three hot bins for 19-12.5mm, 12.5 - 4.75mm and 4.75 - 0.075mm aggregate. It was not possible to achieve the required particle size distribution with the existing three screens to comply with the FMA20 grading envelope. So, it was necessary to add a 9.5mm screen to produce the required material. The additional sieve also required separation of materials in four hot bins: 19-12.5mm, 12.5 to 9.5mm, 9.5 to 4.75mm and 4.75 to 0.075mm. This together with fitting a hatch to enable introduction of fibre and Portland cement (active filler) were the only modifications required to the YLB700 asphalt plant for the production of FMA.

7.1.4 Haulage of Asphalt

It was recommended to use ERA's standard procedures for dense asphalt surfacings for transporting FMA to the construction site, which was located about 5 km from the batching plant. Key points about haulage are noted below according to the standard ERA practice of transporting asphalt (20):

1. Prevent heat loss during transport.

2. FMA should be delivered to site at temperature greater than 155°C to fit in with ERA placement and compaction requirements.

7.1.5 Construction of FMA overlay

During the construction, it is recommended that the following guidance should be observed:

1. The final thickness of the compacted FMA overlay was 50mm. This was the same as the thickness of the control section.
2. Adopt standard ERA procedures for constructing the asphalt overlay.
3. The only compaction plant available at the construction site was a 12 ton steel wheel tandem roller. In order ascertain the number of passes, an offsite trial needs to be conducted to determine the number of passes were required to achieve the target density of greater than 95% or in the absence of an offsite trial, roll until there were no more impression marks from the roller.
4. FMA can be rolled at 155°C.
5. All rolling should be completed at FMA temperature of 80°C.
6. The trial section can be opened to traffic when the temperature is equal to or less than 60°C.

7.2 FMA Design

7.2.1 Materials

Whilst much work has been undertaken on FMA in Malaysia leading to its inclusion in their specifications, it was deemed necessary to undertake a laboratory investigation in Ethiopia to confirm the design. Extensive laboratory study was undertaken to firm up the design. Aggregate normally used by ERA in pavement construction was used, however much work needed to be done on improving its particle size distribution, without changing the size of the aggregate input to the cold bins of the asphalt batch plant. An extensive laboratory investigation was undertaken to confirm the final proportions. A summary of findings is presented below.

In order to ensure that the aggregate gradation was suitable for making FMA, it was necessary to add a 9.5mm mesh screen to the hot bins and selecting suitable proportions from each. The final grading of material used for making the aggregate is shown in Figure 15 and the selected mix design properties based on using 5% bitumen is given in Table 24. Portland cement (active filler) and bitumen complying ERA standards were used.

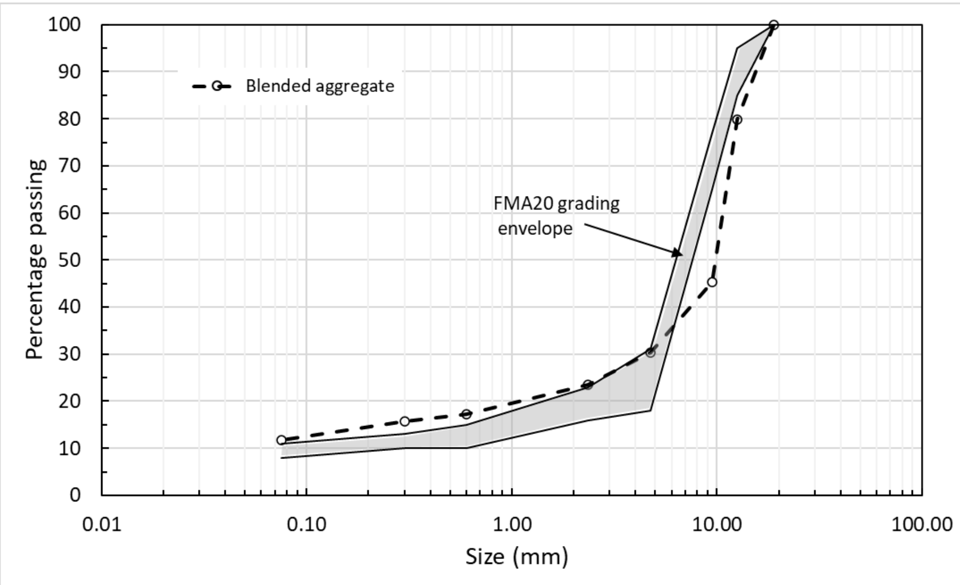

Figure 15 Mix parameters at the design bitumen content

Table 24 Summary of FMA mix design properties based on 5% bitumen content

Mix Parameter	Stability (kN)	Flow (mm)	G_{mb}	VIM (%)	VMA (%)	VFA (%)	G_{mm}
Specification	8.0	2-4	-	3-5	17 (minimum)	65-80	
Measured value	9.0	3.6	2.455	5	16.4	66.6	2.622

Where:

G_{mb} - Bulk specific gravity of the mix
VIM Voids in the mix
VMA - Void in mineral aggregate
VFA- Void filled with asphalt
G_{mm} - Maximum Specific Gravity

8. Construction Trials

8.1 Chipseal Construction Trials

Materials, plant and general methodology used in the construction of both the MECS and the chipseal control sections are described in this section. Both the MECS and the related control sections were 100m in length and were constructed on 6 April 2023.

MECS and the related control sections were built on a section of the Modjo-Edjere Link roads. In order to facilitate flow of traffic, permit safe construction, and allow adequate curing period prior to opening the road to traffic, the relevant section of the Link road was closed and traffic was diverted along an approximately 2 km long temporary diversion which was built for this project. The diversion was unsurfaced and its construction is shown in Figure 16.

Figure 16 Construction of temporary diversion road to facilitate construction of MECS and chipseal control sections.

8.1.1 Materials

The binders used in the MECS are described earlier in this report. Penetration grade, 60/70 Pen bitumen cut back with 12.5% kerosene was used for the control section. Physical properties and gradation of chippings used in the MECS and the control sections are given in Table 25 and Figure 17 respectively.

Table 25 Chipping Aggregate physical Properties

Property	Specification	Test Result	Test Methods
Los Angeles Abrasion Value (%)	<30	7.7	AASHTOT96
Flakiness index	<30	5.7	BS912 Part 105-1990
Soundness (sodium sulphate)	<12	0.7	AASHTOT104
TFV (Dry)	>210	342	BS912 Part 111
TFV (wet)	>130	339	BS912 Part 111
Average Least Dimension	> 5.9	6.5	

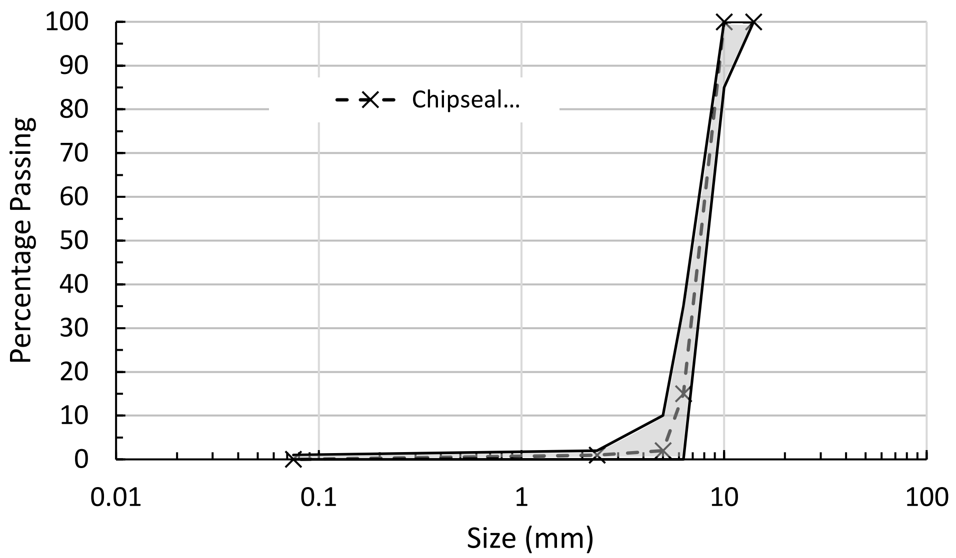

Figure 17 Particle size distribution of aggregate for MECS and chip seal control section - mm nominal size aggregate specifications (18)

8.1.2 Epoxy Binder Sprayer

Two spray bars were fitted to a trailer mounted, towed bitumen sprayer. The main tank, (capacity about 400l) was used for Part B. It was connected to a heating pumping and flow control systems and was connected to a spray bar. A separate bitumen storage tank (capacity about) 215l), heating, temperature control, pumping and flow control system was connected to the second spray bar. The sprayers were made at the Ethiopian Roads Administration, Alemgena Road Maintenance District Workshop.

Each spray bar was fitted with eight nozzles, which were set at 15° off vertical so that parts A and B could mix through impingement about ¾ of the distance to the road surface. The nozzles on each spray bars were spaced at 21cm. The two, 1.75 m long spray bars were set 7 cm apart. The MECS spray system is shown in Figure 18.


Figure 18 Epoxy asphalt binder sprayer

8.1.3 Application of Epoxy

The two-part epoxy binder was applied by means of modified sprayers (see Figure 18) at a rate of 1.2l /m^2 (Part A 0.3l/m^2 and Part B 1.0l/m^2). Part A was heated to a temperature of 78°C and Part B was heated to

160°C. Road surface temperature just before application of the epoxy binder was 37°C and the ambient air temperature was 26°C.

To prevent surging and spluttering, ten per cent of the nominal capacity of the tanks for both Modified Epoxy (Part A and Part B) and asphalt binder were retained in the tanks at the completion of the spraying task. Application of both epoxy and bitumen binder is shown in Figure 19.

Since the length of the spray bars were relatively short the epoxy binder was applied in four strips each 1.75 m wide. Adjacent sprays were overlapped by 150mm. Chippings were not placed on the 150 mm overlap before the adjacent strip has been sprayed. The adjacent strip was not sprayed before the preceding strip, excluding the 150 mm overlap, was covered satisfactorily with chippings. The second and third strip joint was positioned along the centreline of the road.

For the control section, the 60/70 penetration grade bitumen was cut backed with kerosene was applied at an application rate of 0.78l/m^2 at a temperature of 175°C (range 165°C - 190°C). Just before application of the bitumen the pavement surface temperature was noted to be 40°C and the ambient air temperature was 28°C. Binder application for the control section is shown in Figure 20.

Bitumen binder applied at the same application rate as that used for the carriage way was used for the shoulders on both trial and control sections.

The weather during the chipseal operation was clear and dry, but it had been raining for many days prior to the trial.

Figure 19 Epoxy binder application for MECS

Figure 20 Bitumen binder application for the control section

8.1.4 Application of chippings and compaction

Chippings were applied by means of chip spreader at an application rate of 10kg/m^2. The chip spreader was run nearly 3 minutes behind the epoxy sprayer and took 30 minutes to cover the entire length of the trial section. Excess chippings were broomed off the surface. For the control section the chip spreader were approximately 4 minutes behind the bitumen distributor and took 40 minutes to cover the whole length. Application of chippings is shown in Figure 21.

Figure 21 Chipping application

Chippings were compacted with 4 passes of a steel wheel roller followed by at least 8 passes of a pneumatic tyred roller (See Figure 22) until the roller marks are eliminated.

Figure 22 Compaction of the chipseal surface

8.1.5 Opening to Traffic

The section of the road comprising the trial and control sections was closed for 6 days to allow curing of the binder. During this period traffic was routed to the diversion road (see Section 7.1).

9. FMA and asphalt surfacing control section construction

Materials, plant and general methodology used in the construction of both the FMA and asphalt surfacing overlay used in the control sections are described in this section. The FMA section was 75m long due to limited availability of the fibre and the control section was 100m in length. Both were constructed between 8 and 10 April 2023.

The trial site was about a 5.6km (12-minute) journey from the asphalt batching plant.

9.1 Materials

Fibre is described earlier in Section 6.3.1 of this report.

Aggregate used in the manufacture of FMA is described in section 6.2.4.1 and that used in the control section is well graded aggregate with nominal size of 12.5 mm, shown in Table E8 (Appendix E)

Properties of bitumen used in both the FMA and the control section are shown in Table 26

Table 26 Properties of Bitumen used in FMA and asphalt overlay control section

Description	Wearing course
Marshall stability, minimum, at 60^{0}C (kN)	9
Flow (mm)	2 – 3.5
Compaction level, Number of blows on each of the two faces of the specimen	75
Air Voids, AV (%)	3 – 5
Void in Mineral Aggregate, minimum, VMA (%)	14
Voids filled with bitumen, VFB (%)	65 – 73
Loss of stability on immersion in water at 600°C, maximum, (%)	80
Bitumen grade, penetration	60/70

FMA and the related control section were manufactured using the same batching plant YLB 700 and placed and compacted in the same way.

FMA was placed as an overlay on the existing surface for the purposes of the construction trial. It is normal practice in Ethiopia not to mill the roads surface prior to constructing the overlay. Normal practice is to apply a tack coat on the existing surface and then apply the overlay. Thus, only tack coat was used. Rapid curing cutback bitumen, tack coat, RC-70, was applied on the cleaned road surface at an application rate of 0.12 to 0.2 kg/m^2 (maximum 0.3 kg/m^2) in accordance with ERA standard practice.

9.2 FMA and Asphalt overlay construction

The FMA and asphalt for the control sections were located in adjacent sections of the road located about 12-minute journey from the asphalt batching plant. It took about three days to complete the construction; much longer than anticipated due to plant breakdown. Both the materials were placed and compacted using standard equipment with no modifications.

ERA followed their standard procedures for the construction of the control section. FMA was placed in accordance to the guidance notes and summary of the monitoring undertaken during construction is shown Table 27.

Construction of the FMA surfacing and the completed sections are respectively shown in Figure 23 and Figure 24.

Table 27 Summary of the FMA construction trial

Description	Values and Remarks
Aggregate temperature when input into pug mill (°C)	210
Time for dry mix with fibre (sec)	35
Time for wet mix (sec)	40
Temperature of FMA when discharged into truck (°C)	160
Distance and time to site (km)	5.6 (12-minute journey)
Road surface temperature(°C)	45
Laydown temperature(°C)	150
Mat thickness (mm)	65
Thickness of compacted FMA (mm)	50
Density of compacted FMA (Mg/m^3)	2.39
Road surface temperature when opened to traffic	Opened to traffic after 5 days. Pavement temperature at the time was about 43°C.

Figure 23 FMA section construction

Figure 24 Completed FMA trial section.

10. Lessons Learned

The Constructability Trial work stream of the CRISPS project was a complex undertaking requiring the application of new technology in a developing country. It was new to the engineers and operatives at all levels in ERA and required modifications to both plant and their existing practices. A number of the activities undertaken proved more challenging than envisaged. In addition, overseas experts' input could only be provided remotely. Also, the constructability trial for the FMA was undertaken on a trunk road, which made it imperative to ensure that both the mix design and the construction methods adopted would negate the possibility of premature failure of the surface. Key lessons learned from Work Stream 4 of the CRISPS project are described in Table 28.

Table 28 Key lessons learned from WS4

COVID-19	Within a month of the start of the project, many countries imposed COVID-19 lockdowns, which had many impacts on the project, including difficulties in transporting materials (epoxy binder and fibre) into Ethiopia. In both cases, delays were caused by the lack of facility to ship the materials. Input into the project from Malaysia was also delayed due to health-related issues which resulted in the inability to collect data (in Malaysia) when required. COVID-19 also made it difficult for overseas experts to travel to Ethiopia. The level of impact of COVID-19 on the project could not be foreseen at the time of preparing the technical proposal. Key lesson: the need for commitment of in-country collaboration was essential, as was highlighted by ERA's effort to help out with both technical and management challenges of the project. The understanding of the situation from HVT was also helpful, particularly the flexibility to accept changes to both the project's TOR and schedules.
Bureaucracy	Epoxy materials had to be shipped from the USA to Ethiopia via Djibouti. Bureaucracy and administrative requirements at Djibouti caused a significant delay in moving epoxy to Ethiopia. This extent of delay was not foreseen and it was difficult to plan for the level of bureaucracy encountered. Key lesson was that one should not underestimate the effect of bureaucracy on the project; allow for a buffer in the programme, if at all possible. Consultations with professionals in the Ethiopian construction industry ahead of the project could have informed possible challenges likely to be faced during the process of importing materials.
Plant information and modification	Information about the asphalt plant and the chipseal equipment was not readily available for various reasons, including changes in contractors' personnel and lack of expert input from the plant supplier as was the case with the asphalt batch plant. This resulted in a delay in getting the required information to assess the extent of modifications required. The plant supplier and their contractor were slow to respond to ERA's requests for information about the performance and capability of their plant. This was addressed by UoB by contacting the plant supplier direct. Once the direct link was established, good progress was made.

	Some modifications required importing machinery parts into Ethiopia. The cost and lengthy delivery period were major concerns. Particularly the latter as delivery within a certain period could not be guaranteed. In addition to this, there was a conflict in views between the batch plant supplier and the owner about some aspects of plant operation. This resulted in the cancellation of the MEAS trial. Key lesson here was that sound timely cooperation was required among all the project participants.
Laboratory testing and construction practice	Laboratory tests were necessary for the materials to be used, as both the epoxy binder and FMA were new to Ethiopia. Laboratory tests were thus essential to determine and confirm the mix design and help technicians and engineers familiarize with the materials. In the case of FMA delays occurred at times due to impact of COVID-19 in Malaysia and the breakdown of plant in Ethiopia. Once these issues were overcome, testing progressed at pace. Some changes in the construction practices in using unfamiliar materials were also necessary for the manufacture of asphalt and chipseal and the construction of trial surfaces. Key lesson was the need for flexibility in programme and in changing conventional working practices.
Overall	There were a number of issues that, perhaps uniquely and some not so unique, were difficult to plan for, and affected this project resulting in delays. The key lesson, which is perhaps not so novel, is that full cooperation of the partners, good communication and flexibility are needed to deliver a successful project.

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APPENDIX A: Road condition survey: rut depth

Road condition in terms of rut depths were measured before undertaking an intrusive ground investigation. The results of the rut depth measurements along three sections of road (1), (2) and (3) along the Awash-Meiso road selected for MEAS, FMA and control are respectively shown in the Table 29, to Table 31. Rutting was found to be minimal in all the sections. One of the three sections of the road was used for the construction of the control surfacing.

Table 29 A1 Results of rut depth measurement along trial section 1 of Awash-Meiso road segment

Project	**CRISPS**			**Sheet:**	**Survey number:**	
Province	**Afar, Ethiopia**			**Surveyor:**		
Road Name	**Awash - Meiso**			**Date:**	**01 December 2021**	
Section	**Trial section 1**		**Direction of measurement:**		**Awash to Meiso**	
	Location					
Panel	Left lane			Right lane		
	Outer wheel path	Inner wheel path	Distance (m)	Outer wheel path	Inner wheel path	Distance (m)
	Reading (mm)					
1	0	0	0	0	0	0
2	0	3	15	0	0	15
3	0	3	30	3	0	30
4	0	3	45	0	0	45
5	0	3	60	0	0	60
6	0	3	75	3	0	75
7	0	4	90	3	0	90
8	0	3	100	3	0	100
Average (mm)	0	3	-	1.5	0	-

Table 30 A2 Results of rut depth measurement along trial section 2 of Awash-Meiso road segment

Project	**CRISPS**			**Sheet:**	**Survey number:**	
Province	**Afar, Ethiopia**			**Surveyor:**		
Road Name	**Awash - Meiso**			**Date:**	**01 December 2021**	
Section	**Trial section 2**		**Direction of measurement:**		**Awash to Meiso**	
	Location					
Panel	Left lane			Right lane		
	Outer wheel path	Inner wheel path	Distance (m)	Outer wheel path	Inner wheel path	Distance (m)
	Reading (mm)					
1	0	0	0	2	0	0
2	0	2	15	0	0	15
3	0	0	30	0	0	30
4	0	2	45	0	0	45
5	0	2	60	0	0	60
6	0	0	75	0	0	75
7	0	0	90	0	0	90
8	0	0	100	0	0	100
Average (mm)	0	1	-	0	0	-

Table 31 A3 Results of rut depth measurement along trial section 3 of Awash-Meiso road segment

Project	**CRISPS**			**Sheet:**	**Survey number:**	
Province	**Afar, Ethiopia**			**Surveyor:**		
Road Name	**Awash - Meiso**			**Date:**	**01 December 2021**	
Section	**Trial section 3**		**Direction of measurement:**		**Awash to Meiso**	
	Location					
Panel	Left lane			Right lane		
	Outer wheel path	Inner wheel path	Distance (m)	Outer wheel path	Inner wheel path	Distance (m)
	Reading (mm)					
1	0	0	0	1	0	0
2	0	3	15	0	0	15
3	0	2	30	2	0	30
4	0	3	45	0	0	45
5	0	3	60	0	0	60
6	0	2	75	2	0	75
7	0	2	90	2	0	90
8	0	2	100	2	0	100
Average (mm)	0	2	-	1	0	-

Summaries of results of the rut depth measurements along two sections of the Modjo-Edjere road selected for the construction trial using MECS and a control sections are shown in Table 32and

Table 33 respectively.

Table 32 A4 Results of rut depth measurement along trial section 1 of Modjo-Edjere road

Project	CRISPS			Sheet:	Survey number:	
Province	Oromia, Ethiopia			Surveyor:		
Road Name	Modjo - Arerti			Date:	December 2021	
Section	Trial section 1		Direction of measurement:		Modjo to Arerti	
	Location					
Panel	Left lane			Right lane		
	Outer wheel path	Inner wheel path	Distance (m)	Outer wheel path	Inner wheel path	Distance (m)
	Reading (mm)					
1	0	0	0	0	0	0
2	0	0	15	0	0	15
3	0	0	30	3	0	30
4	3	0	45	5	0	45
5	0	0	60	5.5	0	60
6	0	0	75	0	0	75
7	3	3	90	0	0	90
8	0	0	100	0	0	100
Average (mm)	1	0	-	2	0	-

Table 33 A5 Results of rut depth measurement along trial section 2 of Modjo-Edjere road

Project	CRISPS		Sheet:	Survey number:	
Province	Oromia, Ethiopia		Surveyor:		
Road Name	Modjo - Arerti		Date:	December 2021	
Section	Trial section 2	Direction of measurement:		Modjo to Arerti	
	Location					

	Location					
Panel	Left lane			Right lane		
	Outer wheel path	Inner wheel path	Distance (m)	Outer wheel path	Inner wheel path	Distance (m)
	Reading (mm)					
1	0	0	0	3	0	0
2	4	0	15	0	3	15
3	0	0	30	3	0	30
4	0	0	45	3	0	45
5	0	0	60	3.5	0	60
6	0	0	75	0	8.5	75
7	0	0	90	5	2	90
8	0	3	100	0	0	100
Average (mm)	1	0	-	2	2	-

APPENDIX B: Ground investigation

B1 Introduction

A survey of conditions of the materials used in the construction of the roads selected for constructability trial and control sections are described in this appendix. The list of work undertaken include:

- Review of available design, construction, and as built documents.
- Preparation of data collection protocol
- Selection and marking of test pit location.
- Core cutting followed by test pit excavation.
- Pavement thickness measurement
- Sample collection and in-situ density (all layers) determination.
- Transporting sample to Addis Ababa
- Performing laboratory tests

The flow chart for the works is as shown in Figure 25:

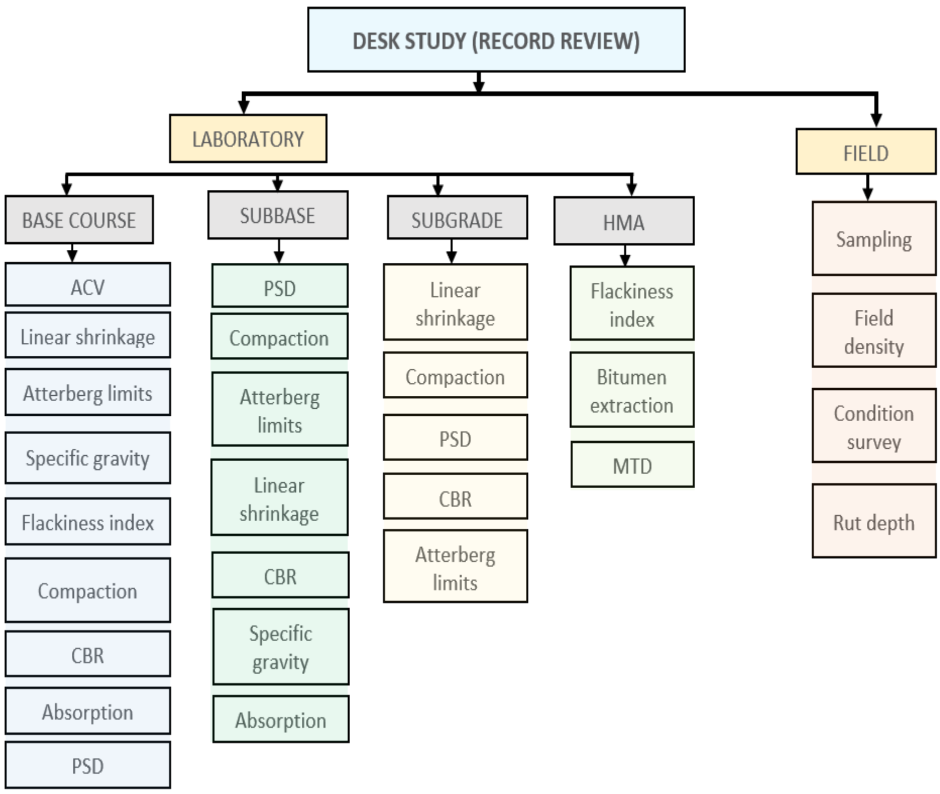


Figure 25 B1 Activities for the materials and road condition surveys

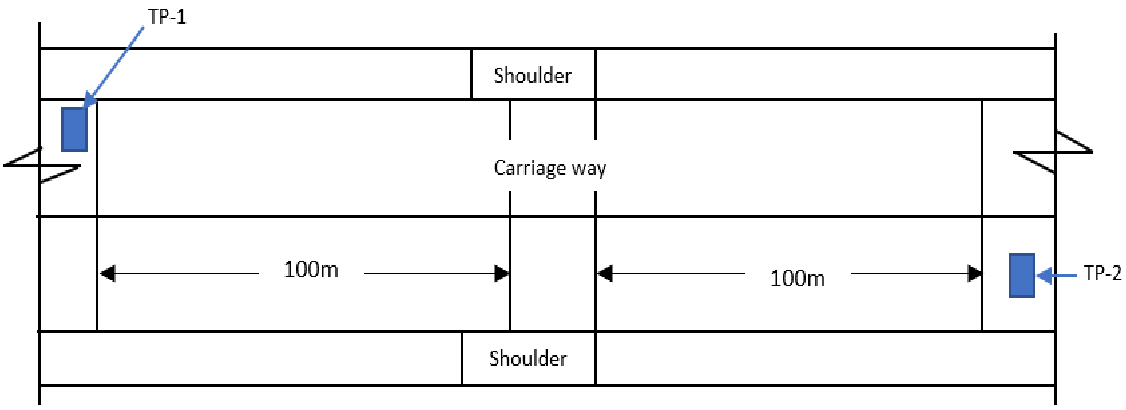
B2 Ground investigation results of the MEAS and FMA sections selected for constructability trials

B2.1 Pavement material sampling

Two test pits were dug on each road segment near to the trial sections to sample the pavement materials for laboratory testing and measure pavement thickness. Table 34 shows the location of each trial sections together with the identification code of each test pit and the layout of the trial pits is shown in Figure 26.

Table 34 B1 Location of test pits

Road segment	Location of trial section (Measured from Addis Ababa)	Test pit location	Test pit code
Modjo-Edjere-Areti Road	87+050 - 87+150	87+040	M-E-1
	87+200 - 87+300	87+312	M-E-2
Awash-Meiso Road	256+100-256+200	256+090	A-M-1
	256+650-256+750	256+760	A-M-2



(*Not to scale, TP= Test Pit*)

Figure 26 B2 Layout of trial pits

B2.2 Pavement thicknesses and composition

Thickness of pavement layers and the corresponding materials properties for the respective road segments are given in

Table 35.

Table 35 B2 Pavement thickness measurement and pavement composition for the selected Awash-Meiso road section for constructability of MEAS and FMA

Road segment	Test pit Code	Pavement layer	Thickness (mm)	Type of Pavement material used
Awash-Meiso Road	A-M-1	Surfacing (AC)	120	Asphalt concrete
		Base course	150	Crushed aggregate
		Subbase	150	Natural gravel
		Capping layer	+250	Natural gravel
	A-M-2	Surfacing (AC)	120	Asphalt concrete
		Base course	150	Crushed aggregate
		Sub-base	100	Natural gravel
		Capping layer	+260	Natural gravel

B2.3 In-situ pavement moisture and density

Table 36shows the in-situ moisture contents determined for each pavement layer and the subgrade at each test pit along Awash - Meiso trial sections.

Table 36 B3 In-situ moisture of pavement layers

Road stretch	Test Pit ID	Layer	In-situ moisture (%)	Optimum moisture content (%)	In-situ dry density (Mg/m^3)	In-situ dry density (Mg/m^3)
Awash - Meiso	A-M-1	Subbase	14.2	7.1	1.67	2.09
		Capping layer	13.1	17.4	1.50	1.76
	A-M-2	Subbase	9.7	13.6	1.77	1.96
		Capping layer	7.0	13.2	2.06	1.97

Laboratory test result

The summary of laboratory test results for the samples collected from the bound (HMA mixture) and unbound pavement layers (base course, subbase, and capping layers) from the test pits located on Modjo-Edjere and Awash - Meiso selected for the construction of trial sections.

Table 37and Table 38 show the laboratory test results of the materials from test pits A-M-1 and A-M-2 along the Awash - Meiso Road segment. Results of tests on asphalt are shown in

Table 39.

Table 37 B4 Summary of results of particle size distribution and Atterberg limit tests for samples from the Awash–Meiso Road segment

Location of trial section	Test pit ID	Test pit chainage	Pavement layer	Mat. type	Particle size distribution	Atterberg limits		Linear shrinkage (%)
						LL (%)	PI	
					AASHTO-T27	AASHTO-T89		BS1377-2:1990
256+100 to 256+750	A-M-1	256+90, from AA	Base	CA	Material, except the first and last sieves, fulfils gradation requirements for base layer - Table 5204/1 of ERA specifications 2014	33	18	7.8
			Subbase	CA	Material, except the top three sieves, does not fulfil gradation requirements for subbase layer - Table 5204/1 of ERA specifications 2014	37	21	7.9
			Capping layer	WCG	Material is classified as A-2-7, fulfills minimum requirements for subgrade - Table 5204/1 of ERA specifications 2014	51	28	11.6
	A-M-2	256+760, from AA	Base	CA	Gradation requirements for base layer - Table 5204/1 of ERA specifications 2014	25	17	4.2
			Subbase	NA	Gradation requirements for base layer - Table 5204/1 of ERA specifications 2014	51	23	14.9
			Capping	WCG	Fulfills subgrade criteria as per ERA specifications 2014 section 4103 (i.e., LL<60 and PI<30)	40	21	9.0
Mat.: Material, CA: Crushed Aggregate, WCG: Weathered Clayey Gravel, NA: Natural Aggregate, ID: Identification, AA: Addis Ababa								

Table 38 B5 Summary of strength and durability of materials from the Awash-Meiso road segment

					Compaction		CBR, AASHTO – 193-93					Ag. Cr	FI (%)	Specific gravity and absorption			
					AASHTO-T180D		96 hours soaked		Unsoaked @ NMC/OMC					Coarse Aggregate, ASTMC-127		Fine Aggregate ASTM T-84	
Location of trial section	Test pit ID	Test pit chainage	Pavement layer	Material type	MDD (g/cm³)	OMC (%)	CBR, @98%MDD, %	Swell %	10 blows	30 blows	65 blows	BS812:112-1990	BS812:1051:1989	Specific gravity	Absorption	Specific gravity	Absorption
256+100 to 256+750	A-M-1	256+90, from AA	BL	CA	2.32	7.1	87	0.0	41	83	139	8	19	2.81	2.1	2.59	5
			SBL	CA	2.35	2.8	82	0.0	48	93	176	-	-	2.70	9.18	2.51	9.18
			CL	WCG	1.76	17.4	19	1.3	26	52	93	-	-	-	-	2.47	-
	A-M-2	256+760, from AA	BL	CA	2.24	4.9	93	0.0	35	57	99	9	19	2.59	1.76	2.76	3.24
			SBL	NA	1.96	13.6	85	0.2	29	60	87	-	-	2.55	5.85	2.28	15.31
			CL	WCG	1.98	13.2	37	0.6	30	68	90	-	-	2.48	5.25	1.98	15.31

CA: Crushed Aggregate, WCG: Weathered Clayey Gravel, NA: Natural Aggregate, ID: Identification, AA: Addis Ababa, Ag. Cr.: Aggregate Crushing, FI: Flakiness Index, BL: Base layer, SBL: Subbase layer, CL: Capping layer

Table 39 B6 Summary of before and after bitumen extraction of asphalt cores from Awash- Meiso road segment

Location of trial section	Test pit ID	Test pit chainage	Pavement (WC: wearing	Specimen ID	Thickness, mm	Bulk density cm/cm³	Maximum specific gravity	Air voids, %	Quantitative extraction AASHTO T-209		Flakiness index (%)
									Particle size distribution AASHTO-T27	Bitumen content (%)	BS812: 106-1- 1989
A–M RS, 256+100 to 256+750	A-M-1	256+90, from AA	WC	AM1-WC-a	66.3	2.57	2.67	3.7	Except the first two sieves, material fulfils gradation criteria stipulated in Table 6403-3 for NMC of ERA Technical Standards Specifications (TSS)	4.09	27
			BC	AM1-BC-a	65.8	2.69	2.75	2.4	Material fulfils gradation criteria in Table 6403-4 for NMC 25mm	3.69	20
			WC	AM1-WC-b	62.1	2.65	2.70	2.2	Material fulfils gradation criteria in Table 6403-3 for NMC 25mm of ERA's TSS	4.58	35
			BC	AM1-BC-b	60.4	2.64	2.69	1.7	Except the bottom sieve, material fulfils gradation criteria as in Table 6403-4 for NMC 25mm of ERA's TSS	4.52	32
			WC	AM1-WC-c	57.2	2.58	2.64	2.5	Except the top sieve, material fulfils gradation criteria stipulated in Table 6403-3 for NMC 9.5mm of ERA's TSS	5.31	20
			BC	AM1-BC-c	68.8	2.69	2.75	2.4	Material fulfils gradation criteria in Table 6403-4 for NMC 25mm	3.73	22
			WC	AM1-WC-d	52.4	2.52	2.67	5.4	Except the last bottom sieve, material fulfils gradation requirements in Table 6403-3 for NMC 9.5mm of ERA's TSS	4.11	35
			BC	AM1-BC-d	70.6	2.69	2.74	1.6	Material fulfils gradation criteria in Table 6403-4 for NMC 25mm	4.52	24
	A-M-2	256+760, from AA	WC	AM2-WC-c	50	2.48	2.73	2.58	Material fulfils gradation criteria in Table 6403-3 for NMC 9.5mm of ERA's TSS	3.73	29
			BC	AM2-BC-c	64.3	2.58	2.77	2.58	Material fulfils gradation criteria in Table 6403-4 for NMC 25mm	4.27	22
			W	AM2-WC-b	51.6	2.51	2.74	2.56	Material fulfils gradation criteria in Table 6403-3 for NMC 9.5mm of ERA's TSS	3.26	29

B3 Ground investigation results on Modjo-Edjere road section selected for the constructability of the MECS surfacing

B3.1 Pavement thicknesses and composition

This subsection shows records of the pavement composition encountered and thicknesses measured while conducting materials sampling from each test pit. Table 40illustrates the thickness of each pavement layers and the corresponding materials properties in each test pit for the respective road segments.

Table 40 B7 Pavement thickness of the section for MECS along the Modjo-Edjere road

No.	Road segment	Test pit Code	Pavement layer	Thickness (mm)	Type of Pavement material used
1	Modjo – Edjere – Arerti Road	M-E-1	Surfacing	25	Triple surface treatment
2			Base course	225	Crushed aggregate
3			Subbase	280	Natural gravel (Cider)
4			Capping layer	≥250	Natural gravel
5		M-E-2	Surfacing	30	Triple surface treatment
6			Base course	100	Crushed aggregate
7			Subbase	240	Natural gravel (Cinder)
8			Capping layer	+300	Natural gravel

B3.2 In situ pavement moisture and density measurement

Table 41 shows the in-situ moisture contents determined for each pavement layers and the subgrade at each test pit along Modjo-Edjere road section selected for the construction of MECS trial section.

Table 41 B8 In-situ moisture of pavement layers

No.	Road stretch	Test Pit ID	Layer	In-situ moisture (%)	Optimum moisture content (%)	In-situ dry density (Mg/m3)	Maximum dry density (Mg/m3)
1	Modjo – Edjere	M-E-1	Base course	3.72	6.0	2.29	2.33
2			Subbase	8.8	12.6	1.74	1.75
3			Capping layer	37.2	24.3	1.15	1.4
4		M-E-2	Base course	4.3	6.6	2.34	2.34
5			Subbase	9.7	12.5	1.65	1.72
6			Capping layer	32.3	20.7	1.42	1.78

B3.3 Laboratory test results

The summary of laboratory test results for the samples collected from the bound (HMA mixture) and unbound pavement layers (base course, subbase, and capping layers) at the test pits located on Modjo-Edjere selected for the construction of MECS trial sections.

Table 42and Table 43show the laboratory test results of the materials sampled from test pits M-E-1 and M-E-2. Each Table contains the location of the test pit with its corresponding ID, the pavement layers where the samples were collected, the standard test procedure used for testing and the test results.

Table 42 B9 Summarized results of Particle size distribution and Atterberg limit tests for samples from Modjo-Edjere road segment

Location of trial section	Test pit ID	Test pit chainage	Pavement layer	Mat. Type	Particle size distribution	Atterberg limits		Linear shrinkage (%)
						LL (%)	PI	
					AASHTO-T27	AASHTO-T89		BS1377-2:1990
12+050 to 12+300	M-E-1	12+040, from M-E junction	Base	CA	Material, except the last sieve, fulfils gradation requirements for base layer (according to Table 5104/1 of ERA specifications 2014)	Non plastic	Non plastic	1.7
			Subbase	WCG	Material fulfills gradation requirements for subbase layer according to Table 5104/1 of ERA specifications 2014	Non plastic	Non plastic	0.1
			Capping layer	HWCG	Outside the plasticity requirements for suitable subgrade as per Table 4103/1 of ERA specifications 2014 (i.e., LL<60 and PI<30)	59	34	10
	M-E-2	12+312, from M-E junction	Base	CA	Material except the last sieve fulfills gradation requirements for base layer according to Table 5104/1 of ERA specifications 2014	Non plastic	Non plastic	1.6
			Subbase	WCG	Gradation requirements for base layer fulfilled according to Table 5104/1 of ERA specifications 2014	Non plastic	Non plastic	1.8
			Capping	HWCG	Outside the plasticity requirements for subgrade as per ERA specifications 2014 section 4103 (i.e., LL<60 and PI<30)	51	31	7
Mat.: Material, CA: Crushed Aggregate, WCG: Weathered Cinder Gravel, HWCG: Highly Weathered Clayey Gravel, ID: Identification.								

Table 43 B10 Summarized results of strength and durability tests for samples from test pits along Modjo-Edjere- Arerti

Location of trial section	Test pit ID	Test pit chainage (from M-E junction)	Pavement layer	Material type	Compaction		CBR, AASHTO – 193-93					Ag. Cr	FI (%)	Specific gravity and absorption			
					AASHTO-T180D		96 hours soaked		Unsoaked @ NMC/OMC					Coarse Aggregate, ASTMC-		Fine Aggregate ASTM T-	
					MDD (g/cm³)	OMC (%)	CBR,	Swell %	10 blows	30 blows	65 blows	BS812:112-1990	BS812:1051:1989	Specific gravity	Absorption	Specific gravity	Absorption
12+050 -12+300	M-E-1	12+040	BL	CA	2.33	6	135	0.0	48	125	136	20	20	2.80	3.19	2.68	2.35
			SBL	WCG	1.47	12.6	85	0.0	48	93	176	-	-	1.69	12.28	2.66	10.06
			CL	HWCG	1.34	24.3	7	3.2	4	6	5	-	-	-	-	2.57	-
	M-E-2	12+312 j	BL	CA	2.33	6.6	135	0.0	-	-	-	20	20	2.86	2.35	2.73	5
			SBL	WCG	1.72	12.5	70	0.1	48	92	156	-	-	1.65	13.56	2.04	9.81
			CL	HWCG	1.46	20.7	19	1.2	4	2	3	-	-	-	-	2.54	-

CA: Crushed Aggregate, WCG: Weathered Clayey Gravel, NA: Natural Aggregate, ID: Identification, AA: Addis Ababa, Ag. Cr.: Aggregate Crushing, FI: Flakiness Index, BL: Base layer, SBL: Subbase layer, CL: Capping layer

APPENDIX C: Drainage Survey

C1 Introduction

The drainage surveys were undertaken in June 2022 at the end of the dry season and September 2022 at the end of the rainy season. They cover the area of the trial areas and the adjacent sections along the Modjo - Edjere and Awash - Meiso roads. The surveys include visual observations supported by photographs.

C2 MODJO – EDJERE Section

This section was selected for the constructability trial of MECS. The locations of each sub-section (trial and control) of the trial section are listed in Table 44. The right-hand side (RHS) and the left-hand side (LHS) of the road refer to the direction of driving from Modjo towards Edjere.

Table 44 C1 Location of trial subsections along the Modjo-Edjere road

No	Description	Name of the sub section	Chainage
1	Trial section-1	M-E-1	12 + 100 – 12 + 200
2	Trial section-2	M-E-2	12+250 - 12 + 350

C2.1 M-E -1: Km 12+000 - 12+100

- The pavement lies on a fill section as shown in Figure 27.
- The section traverses on a flat to rolling terrain, slopes from the left to the right of the road way, no side ditch exists on both sides of the road. See Figure 28to Figure 31.
- The catchment drains away from the road side.
- The shoulders are paved with shingle.

Figure 27 C1 Cross section at km 12+050

Figure 28 C2 Shoulder, side ditch and adjacent plain at km 12 + 100 – RHS – June 2022

Figure 29 C3 Shoulder, side ditch and adjacent plain at km 12 + 100 – RHS – September 22

Figure 30 C4 Shoulder, side ditch and adjacent plain at km 12 + 100 – LHS – June 2022

Figure 31 C5 Shoulder, side ditch and adjacent plain at km 12 + 100 – LHS – September 22

C2.2 M-E-2: km 12+200 - 12+300

- The pavement lies on a fill section as shown in Figure 32.
- This section traverses flat to rolling terrain, with side ditches as shown in Figure 33to Figure 40.
- The catchment drains away from the roadside.
- The shoulders on either side of the road are paved with single surface treatment.

Figure 32 C6 Cross section at km 12+300

Figure 33 C7 Shoulder, side ditch and adjacent plain at km 12+150 – RHS – June 2022

Figure 34 C8 Shoulder, side ditch and adjacent plain at km 12+200 – RHS – February 2022

Figure 35 C9 Shoulder, side ditch and adjacent plain at km 12 + 150 – LHS - June 2022

Figure 36 C10 Shoulder, side ditch and adjacent plain at km 12 + 200 – LHS – September 22

Figure 37 C11 Shoulder, side ditch and adjacent plain at k12 + 250 – RHS - June 2022

Figure 38 C12 Shoulder, side ditch and adjacent plain at km 12 + 250 – RHS - September 22

Figure 39 C13 Shoulder, side ditch and adjacent plain at km 12 + 250 – LHS – June 2022

Figure 40 C14 Shoulder, side ditch and adjacent plain at km 12 + 250 – LHS – September 22

C3 AWASH - MEISO Road Section

This section was selected for epoxy and fibre modified asphalt surfacings. The report contains the visual survey and photographs. The location of each section and cross drainage structures are listed in Table 45. The right-hand side (RHS) and the left-hand side (LHS) of the road refer to the direction of driving from Awash towards Meiso.

Table 45 C2 Location of the trial sections along the Awash- Meiso road

No.	Description	Location	Remarks
1	The first part of the trial section (A-M-1)	31+200 - 31+300	
2	Cross drainage	31+747	Single pipe 60 cm
3	The second part of the trial section (A-M-2)	31+853 - 31+953	
4	The third part of the trial section (A-M-3)	32+100 - 32+200	
5	Cross drainage	32+500	Small bridge 6 m span

C3.1 Awash-Meiso - 1: km 31+200 TO km 32+300

- The section traverses on a flat to rolling terrain starting from km 31+200 to km 31+300 (from Awash Sebat to Meiso), slopes from the left to the right of the road way and no side ditch exists on either side of the road way.
- The pavement lies on a fill section as shown in Figure 41 and Figure 42.
- Although no defined side ditch exists on the left side, the runoff coming from the vicinity at the left side of this section is expected to join the embankment toe and flow forward towards the cross drainage at km 31+747. See Figure 43to Figure 48.
- The shoulders on either side of the roadway are not paved.

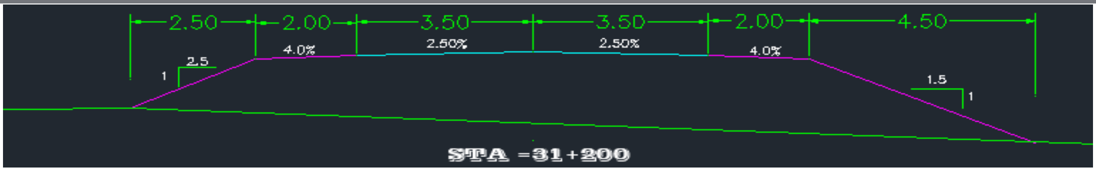


Figure 41 C15 Cross section km 31+200

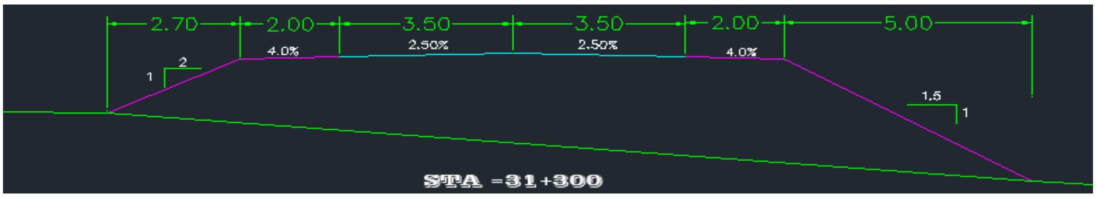


Figure 42 C16 Cross section km 31+300

Figure 43 C17 Shoulder, side ditch and adjacent plain at km 31+200 – RHS - June 22

Figure 44 C18 Shoulder, side ditch and adjacent plain at km 31+200 – RHS – September 22

Figure 45 C19 Side ditch and adjacent plain at km 31+200 – RHS – June 2022

Figure 46 C20 Side ditch and adjacent plain at km 31+200 – RHS – September 22

Figure 47 C21 Shoulder, side ditch and adjacent plain at Km 31+200 – LHS June 2022

Figure 48 C22 Shoulder, side ditch and adjacent area at km 31+200 – LHS – September 22

C3.2 Cross Drainage: Pile Culvert at km 31+747

The cross drainage, located between the sections A-M-1 and A-M-2 at km 31+747, consists of a single pipe of diameter 60 cm, as shown in Figure 49.

There was sign of silting up, but there was a small amount of vegetation at the inlet and outlet of the cross drainage in June 22, but there was much vegetation in September 22 as can be seen in Figure 50.

Figure 49 C23 Inlet of the culvert on the left side of the road at km 31+747 – June 2022

Figure 50 C24 Vegetation in the area of the inlet of the culvert on the left side of the road at km 31+747 – September 22.

C3.3 Awash-Meiso -2: km 31+853 to km 31+ 953

The section extends from km 31+853 to km 31+953 with slopes from the left to the right of the road and no side ditch exists on the right side of the road.

The pavement lies on a fill section as shown in Figure 51and Figure 52. Although no defined side ditch exists on the left side, the runoff coming from the vicinity at the left side of this section is expected to join the embankment toe and flow back towards the cross drainage at km 31+747 mentioned above.

The shoulders on both sides of the roadway were not paved. See Figure 53 to Figure 56.

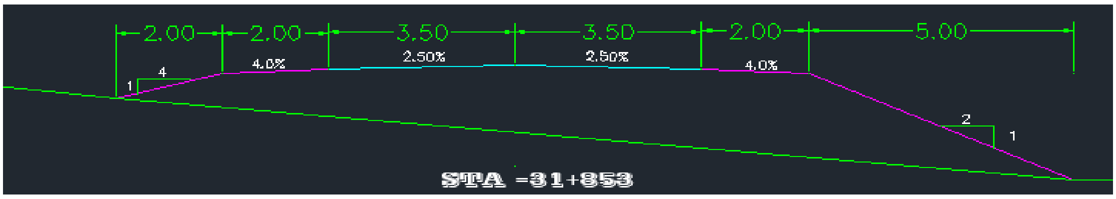


Figure 51 C25 Cross section 31+853

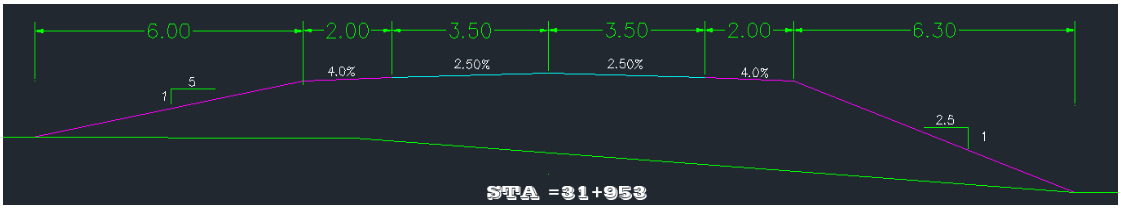


Figure 52 C26 Cross section 31+953

Figure 53 C27 Right side of the road at Km 31+853-RHS – June 2022

Figure 54 C28 Right side of the road at Km 31+853-RHS – September 22

Figure 55 C29 Left side of the road from km 31+853 to km 31+953 – June 2022

Figure 56 C30 Left side of the road from km 31+853 to km 31+953 – September 22

C3.4 Awash-Meiso-3: km32+100 to 32+200

The section traverses rolling to mountainous terrain from km 32+100 to km 32+200, slopes from the left to the right of the road way and the drainage of this section is expected to flow towards the cross drainage back at km 31+747 (described in section 3.6.2.2).

About 75 % of the pavement lies on fill section and the remaining is in cut. Typical sections are shown in Figure 57 and Figure 58.

Except at the part of the road closer to 32+200 where an earthen ditch exists, no side ditch exists on the right side of the road way as the terrain drains way further to the right. See Figure 59 to Figure 62.

The left side has a side ditch which suffers from silting up and requires clearing.

The pavement has unpaved shoulder on both sides.

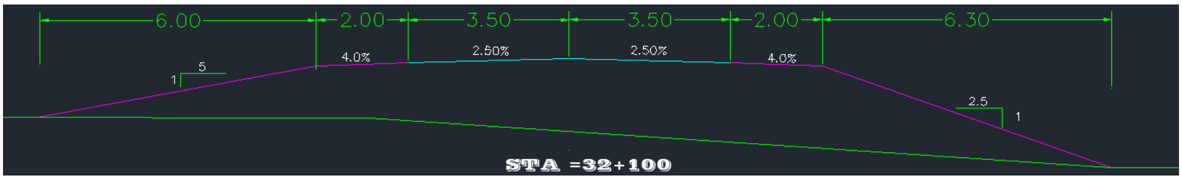


Figure 57 C31 Cross section at 32+100

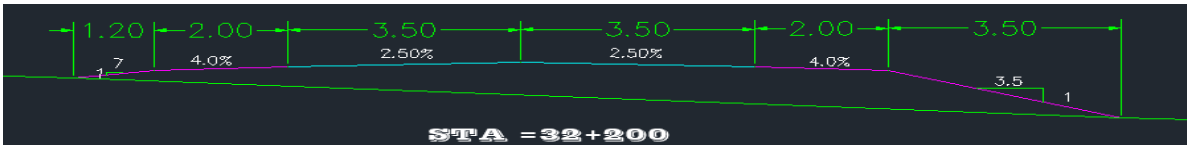


Figure 58 C32 Cross section at 32+200

Figure 59 C33 Shoulder, side ditch and adjacent plain at km 32+200 – RHS – June 2022

Figure 60 C34 Shoulder, side ditch and adjacent plain at km 32+200 – RHS – September 22

Figure 61 C35 Shoulder, side ditch and adjacent plain at km 32+200 – LHS- June 2022

Figure 62 C36 Shoulder, side ditch and adjacent plain at km 32+200 – LHS- September 22

C3.5 Cross Drainage: Small Bridge at km32 + 500

The river is located at km 32+500 from Awash Sebat to Semera Junction. The river is dry most of the year and at the time of the survey, in June, it was dry. See Figure 63. There was some flow during and for some period after the rainy season as can be seen in Figure 64.

The bridge has a span of 60m and clearance of 6.8 m measured from the river bed.

Figure 63 C37 River bed at the bridge at km 32+500 in June 2022

Figure 64 C38 River bed at the bridge at km 32+500 in September 22

APPENDIX D: Design of chipseal control section

D1 Design of Surface Treatment

According to the existing triple surface treatment (TST) surfacing, which was verified during the pavement material sampling, the pavement (at the trial section) has an overall thickness of about 490 mm and comprises capping layer, sub base, base course and TST surfacing as shown in Table 46.

Table 46 D1 Summary of existing pavement construction

Section	Pavement layer	Pavement thickness (mm)
km 12+050 – km 12+150	Surfacing (Triple surface treatment)	35
	Base course	200
	Subbase	250
	Capping layer	600

D2 Design procedure

The design of the chipseal surfacing was conducted in accordance with the procedures and recommendations of ERA, 2013(1) and ERA, 2013 (2). Outline of the design process followed in given in Figure 65.

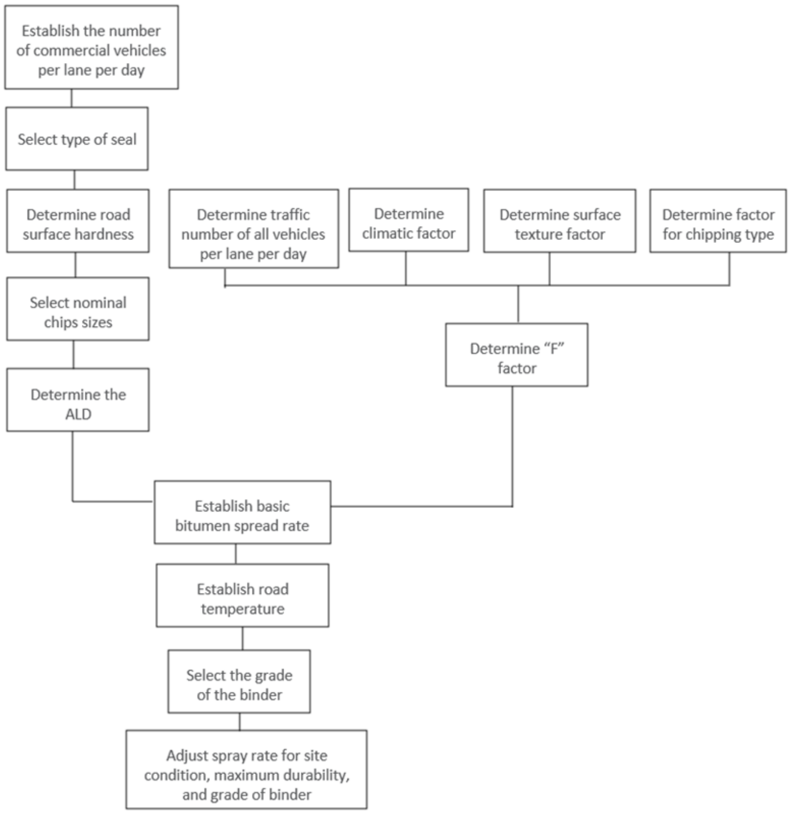


Figure 65 D1 Outline procedure for the design of the surface treatment

D2.1 Traffic volume and composition

The design of chip seals starts with determination of the number of commercial vehicles from traffic count for the design year (2022). Table 47shows six years traffic count data belonging to Mojo-Edjere Road segment collected from ERA traffic count and axle load survey team (2016 to 2021) and an extrapolated data for the year 2022, which is the design year, based on the previous six years traffic count data using average traffic growth rate.

Table 47 D2 Traffic volume and composition

Year	Cars	Land Rover	Small buses	Large bus	Small truck	Medium track	Heavy truck	Truck trailer	AADT	CVD per Lane
2016	613	678	950	564	756	833	758	914	6066	2388
2017	619	652	947	564	751	760	714	786	5796	2261
2018	859	870	947	756	898	987	1056	961	7336	2791
2019	904	861	1013	613	861	953	990	1072	7267	2751
2020	688	589	875	398	676	825	728	740	5519	2121
2021	641	532	886	418	706	635	618	561	4997	1912
2022	610	483	875	377	675	566	564	497	4648	1777

As shown in Table D2, the estimated AADT and commercial vehicle per day (CVD/lane) for the year 2022 is estimated to be 4648 and 1777 respectively.

D2.2 Nominal size of Aggregate

Accordingly, to ERA Pavement Design Manual (2) selection of the nominal size of chippings is based on the daily volume of commercial vehicles using each lane of the road (see Table 48) and the hardness of the existing pavement surface according to categories shown in

Table 49.

Ideally, chippings aggregate should be single sized, cubical in shape, clean and free from dust, strong, durable, and not susceptible to polishing under the action of traffic. ERA Pavement Design Manual (1) recommends grading size of chipping aggregate and Flakiness index that comply with the requirements, see

Table 50.

Table 48 D3 Recommended nominal size of chippings (mm)(1).

Type of Surface	Approximate number of commercial vehicles with an unladen weight greater than 1.5 tonnes currently carried in the design lane				
	2000 - 4000	1000-2000	200-1000	20-200	Less than 20
Very Hard	10	10	6	6	6
Hard	4	14	10	6	6
Normal	20[1]	14	10	10	6
Soft	*	20[1]	14	14	10
Very Soft	*	*	20[1]	14	10

Notes:

1. *The size of chipping specified is related to the mid-point of each lane traffic category. Lighter traffic conditions may make the next smaller size of stone more appropriate.*
2. *Very particular care should be taken when using 20mm chippings to ensure that no loose chippings remain on the surface when the road is opened to unrestricted traffic as there is a high risk of windscreen breakage.*

** Unsuitable for surface treatment.*

Table 49 D4 Categories of Road Surface Hardness (1)

Category of Surface	Penetration at 30°C[1]	Definition
Very Hard	0 - 2	Concrete or very lean bituminous structures with dry stony surfaces. There would be negligible penetration of chippings under the heaviest traffic
Hard	2 - 5	Likely to be an asphalt surfacing which has aged for several years and is showing some cracking. Chippings will penetrate only slightly under heavy traffic
Normal	5 - 8	Typically, an existing surface treatment which has aged but retains a dark and slightly bitumen-rich appearance. Chippings will penetrate moderately under medium and heavy traffic.
Soft	8 - 12	New asphalt surfacing or surface treatments which look bitumen rich and have only slight surface texture. Surfaces into which chippings will penetrate considerable under medium and heavy traffic.
Very soft	>12	Surfaces, usually a surface treatment which is very rich in binder and has virtually no surface texture. Even large chippings will be submerged under heavy traffic

Table 50 D5 Grading Limits, Specified Size and Maximum Flakiness Index for Chipping Aggregates (1)

Sieve size (mm)	Nominal Size of Aggregates (mm)			
	20	14	10	6.3
28	100	-	-	-
20	85-100	100	-	-
14	0-35	85-100	100	-
10	0-7	0-35	85-100	100
6.3	-	0-7	0-35	85-100
5.9	-	-	0-10	-
3.35	-	-	-	0-35
2.36	0-2	0-2	0-2	0-10
0.600	-	-	-	0-2
0.075	0-1	0-1	0-1	0-1
Specified size	Minimum percentage by mass retained on BS test sieve			
	65	65	65	65
Maximum Flakiness index	25	25	25	-

The specified retained for the nominal sizes of 20, 14, 10 and 6.3mm ares 14, 10, 6.3 and 3.35mm respectively. Furthermore, according to ERA, 2013 (3) the chipping aggregate shall have a Los Angeles Abrasion value of not more than 30, Sodium Sulphate Soundness value of 12 or less, and the strength of surfacing aggregate as determined by the Ten Percent Fines Value (TFV) shall be a minimum of 210 kN and 160kN respectively for Dry and Wet condition. It also specifies the Average Least Dimension (ALD) to be higher than 5.9.

As shown in Table 47, the commercial vehicle within unladen weight greater than 1.5 tones/ day count in the design lane is 1777 (category 2: 1000 -2000) and the hardness of the existing triple surface which served for 11 years is categorized as normal where the penetration of chips at a temperature of 30°C is between 5 and 8mm. Accordingly as specified in

Table 50the recommended nominal chipping size for normal type of surface hardness and under the application of traffic category 2 is 14mm. However, considering that the majority of the traffic on the trial section is light vehicles, it is recommended to use 10mm chipping aggregate.

D2.3 Determination of average least dimension of chipping

ALD is used to determine the optimum application rate of both binder and chippings for surface dressing. It is the arithmetic mean of all the measured least dimensions of the measured aggregate particles. The least dimension of an aggregate particle is the smallest perpendicular distance between two parallel plates through which the particle will just pass.

The ALD is a function of both the average size of the chippings as determined by normal square mesh sieves, and the degree of flakiness. According to ERA Pavement Design Manual (1) the ALD may be determined in two ways:

1. A grading analysis is performed on a representative sample of the chippings in accordance with ASTM C136 (4). The sieve size through which 50 per cent of the chippings pass is determined (i.e., the 'median size'). The flakiness index is then also then derived from the nomograph shown in Figure 66.
2. A representative sample of the chipping is carefully subdivided in accordance with British Standard 812: 1990 (5) to give approximately 200 chippings. The least dimension of each chipping is measured manually and the mean value, or ALD, is calculated.

For the aggregate used in chipseals in the CRIPS project, the flakiness index is tested according to BS812 Part 105-1990 (5) was 5.5 and the particle size distribution was showed a uniformly graded aggregate with particles ranging between 6 and 10 mm, as shown in Figure 2, with mean aggregate size of 7.8 mm.

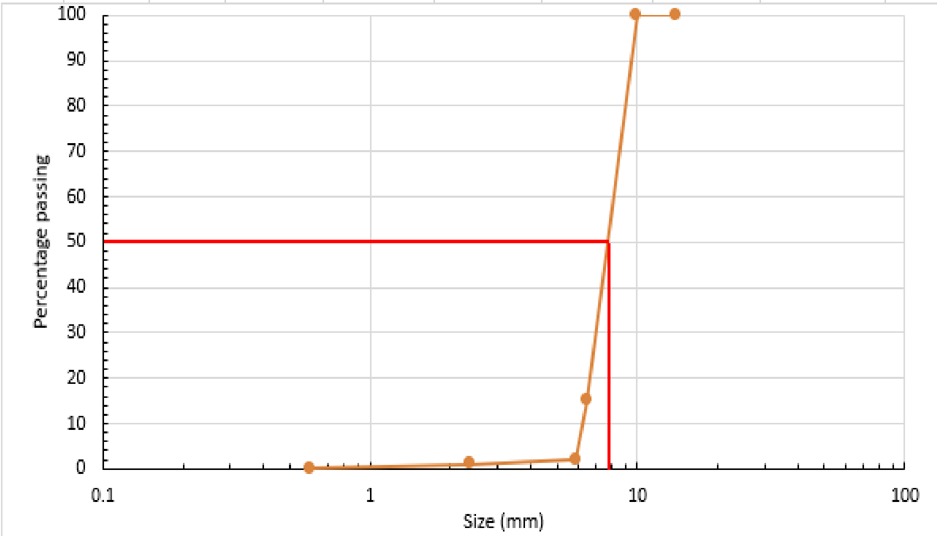


Figure 66 D2 Mean aggregate size determination chart

Based on an FI of 5.5 and median size of 7.8mm the ALD was estimated from the nomograph in Figure 67 was estimated as 6.5mm.

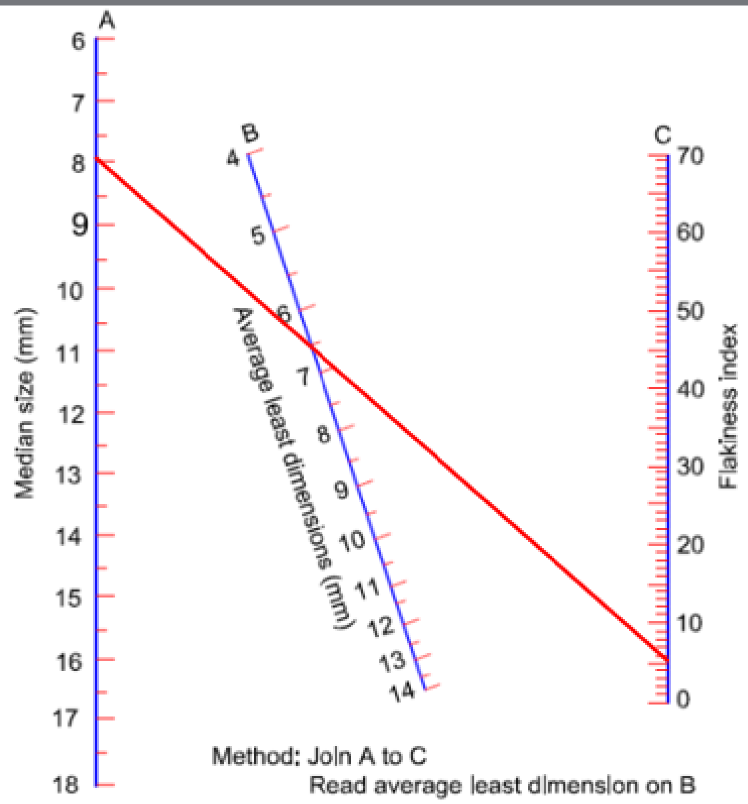


Figure 67 D3 Determination of Average Least Dimension

D2.4 Determination of overall weighting factor

According to section 9.5 of ERA, 2013(1) the overall weighing factor (F) was determined based on traffic class, existing surface, climatic condition and type of chipping to be applied to determine the basic rate of spray of bitumen. As shown in Table 51, the overall factor (F) is -2.

Table 51 D6 Determination of overall weighing factor (F), ERA,2013a (19)

Description	Category	Factor
Traffic class	Very heavy (3000+)	-5
Existing surface	Very lean bituminous	+4
Climatic condition	Tropical climate	+1
Type of chipping	Flaky	-2
	Overall factor (F)	-2

D2.5 Binder Type and Application Rates

D2.5.1 Binder Type

The performance of surface dressing depends on several factors including the binder type. The binder selection, whether cutback grade or penetration grade bitumen, is largely controlled by road temperatures at and shortly after the time of construction. ORN 3, 2000 (6) suggests that in the tropics, the daytime road temperatures pavement surfacing typically lie between about 25°C and 50 °C, normally being in the upper half of this range unless heavy rain is falling. For these temperatures the viscosity of the binder should lie between approximately 1 x l04 and 7 x l05 centistokes. At the lower road temperatures cutback grades of bitumen are most appropriate whilst at higher road temperatures penetration grade bitumen is the preferred option.

Based on six years temperature data from Ethiopian Metrological Agency, the daily minimum and maximum temperatures of the area where the trial section is going to be built are 11.7 °C and 27.7°C respectively. The mean of the daily maximum (27.7 °C) and minimum (11.7°C) temperature is 19.7 °C. Therefore, according to ORN 3, 2000 (21) and considering the linear relationship between air and road temperature, Hitch,1981 (22) the working temperature lies between 19.7 °C and 27.7 °C. Using the chart, see Figure 68, developed by Hitch,1981 (7) or East Africa the corresponding surface temperature is read as 22.5 °C and 40.5 °C, the suitable bitumen type is MC 3000.

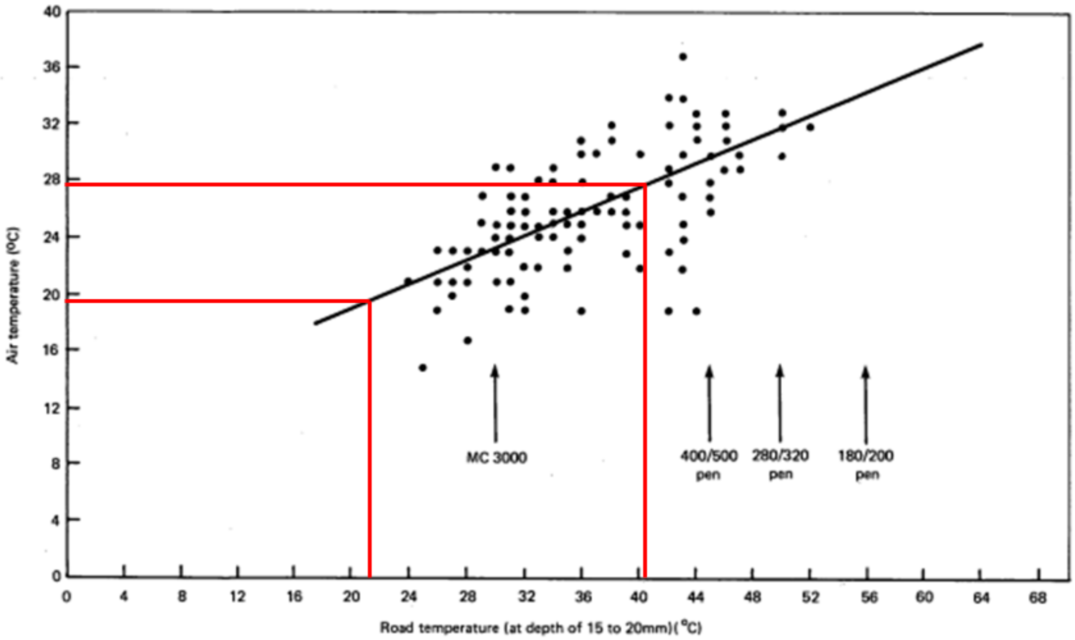


Figure 68 D4 Bitumen type and Air/road temperature relationship

D2.5.2 Determination of binder application rate

After selecting the nominal size of chipping and the type of binder to be used, the next step for chipseal design is to determine the rate of spread of the binder.

According to ERA (2) the overall factor (F) and average least dimension was used to determine the basic binder spray rate from Figure 69. Therefore, for F value of -2 and ALD 6.5mm the basic binder application rate was estimated to be 0.81kg/m^2.

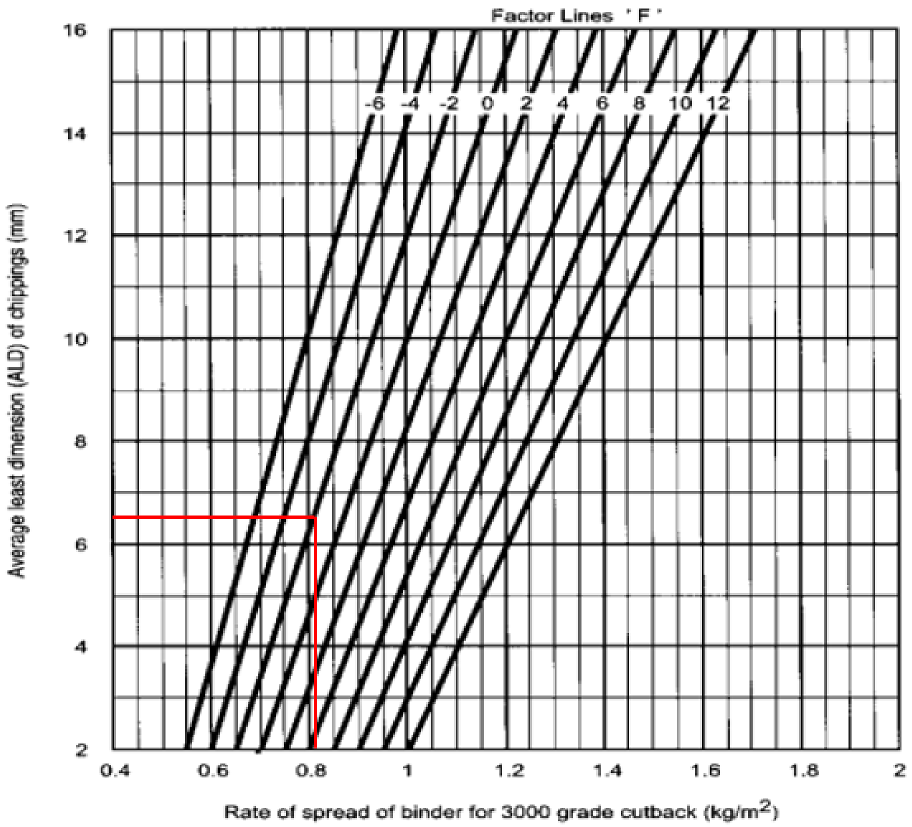


Figure 69 D5 Surface dressing chart

Section 9.5.8 of ERA (2) provides adjustment factors on the basic spray rate of bitumen requires to consider bitumen type, traffic speed and road gradient. The adjustment factors are indicated in Table 52.

Table 52 D7 Bitumen spray rate adjustment factor (1), ERA,2013b (31)

Factors to be considered	Description	Spray rate adjustment factor
Type of binder	80/100 pen	-10%
Traffic speed	Fast traffic (80 km/hr)	+10%
Road gradient	< 3%	No modification

The adjusted binder application rate therefore was computed as follows:

R_{adj} = (R) X (adjustment factor)

Where:

R= basic bitumen application rate (kg/m^2)

R_{adj} = adjusted bitumen application rate (kg/m^2)

The overall adjustment factor is the sum of the individual factors and equals to zero.

Thus,

R_{adj} = R= 0.81kg/m^2

D2.6 Chipping application rate

The rate of application of the chipping, assuming that the chipping has a loose density of 1.35 Mg/m^3, can be computed from the following equation (ERA, (1))

Chipping application rate (kg/m^2) = 1.364*ALD

Where ALD is average aggregate least dimension

Therefore, chipping application rate = 1.364*6.5= 8.87kg/m^2, say 9kg/m^2

D3 Summary of the application rates

The proposed chipping and asphalt binder application rates are summarized in Table 53.

Table 53 D6 Application summary

Nominal chipping size	Chipping application rate	Bitumen grade	Rate of Binder application
10 mm	9 kg/m^2	80/100 pen	0.81 kg/m^2

The actual application rate should be adjusted based on the nature of chippings at the time of construction.

D4 Surfacing of the shoulder

Shoulders provide lateral support for the pavement layers. If they are sealed, shoulders play a great roll in stabilizing the internal moisture of the pavement and consequently maintain its strength. Therefore, it is recommended to seal the shoulders.

D5 References

(1) ERA, 2013a, Pavement Design Manual - Volume 1: Flexible Pavements, Ethiopian Roads Authority, Addis Ababa, Ethiopia.

(2) ERA, 2013b, Best Practice Manual for Thin Surfacing, Ethiopian Roads Authority, Addis Ababa, Ethiopia.

(3) ERA (2013) Standard Technical Specifications and Method of Measurement for Road Works, Ethiopian Roads Authority, Addis Ababa, Ethiopia.

(4 ASTM C136-06 Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates, ASTM International.

(5) BS812-1990 Testing aggregates - Part 105: Methods for determination of determination of particle shape- section 105.2: Elongation index of coarse aggregate. British Standard, United Kingdom.

(6) Overseas Road Note 3 (2nd Edition) A guide to surface dressing in tropical and sub-tropical countries, TRL, United Kingdom.

(7) Hitch L S (1981). Surface dressing in developing countries: research in Kenya. Laboratory Report, LR 1019. TRL Limited, Crowthorne, United Kingdom.

APPENDIX E: Asphalt Overlay Design of the Control Section

E1 Introduction

Since both the MEAS and FMA are equivalent to conventional asphalt overlay, the control section was designed using the ERA standard procedure for pavement rehabilitation and overlay design manual (1). The rest of this Section is based on ERA's Awash - Kulubi - Dire Dawa/Harrar Asphalt Overlay Design Summary report (2).

Commonly three design methods are used to estimate the required overlay thickness: the effective thickness approach, the deflection approach, and the mechanistic empirical approach. ERA Pavement Rehabilitation and Asphalt Overlay design manual (15) follows the effective thickness procedure adapted from AASHTO and deflection procedure adapted from Asphalt Institute. As per this manual, both methods are to be used so that comparison and choice can be made employing engineering judgments. The 'Effective Thickness' procedure as recommended by ERA (1) (adapted from AASHTO (3)) cannot be used. This design procedure is based on non-destructive test in which the design resilient modulus (M_R) and effective structural number (SNeff) are back calculated from Falling Weight Deflectometer (FWD) measurements. Since FWD was not available, the structural strength of the pavement was estimated from the Benkelman Beam deflection.

E2 Inputs required and Considerations

E2.1 Observations on Pavement Condition

Since the various surveys showed that the pavement was in good condition, and does not require any reconstruction, either to partial or full depth over the selected trial section, merely strengthening overlays would be sufficient to cater for future design traffic loading, apart from minor pre-overlay treatments. Since the deflection approaches of Asphalt Institute will provide the thickness of the overlay directly, no additional assessment required to select the rehabilitation option. Alternatively, the rehabilitation and overlay option can be assessed based on structural deficiency concept. The required structural number (SNnew) shall be an adequate new pavement structure for the specific combinations of design traffic and subgrade CBR. Besides, the existing pavement's strength deficiency (SNdif) is the difference between the required structural number (SNnew) and structural number of the existing pavement (SNeff). Hence, SNdif for the overlay design can accommodate the prevailing traffic on the road subgrade considering the salvage value of the existing pavement. Depending on the mean structural deficiency, the intervention type can be proposed as shown in Table 54.

Table 54 E1 Structural Deficiency Criteria

Mean Structural Deficiency	Action	Notes
Zero or negative	Maintain with a surface treatment (e.g., surface dressing)	A thin overlay can be used to correct other road defects
0.-0.6	Thin overlay	Remedial works possible
0.6-2.5	Design thick overlay (45-180mm)	Remedial works probable
>2.5	Partial reconstruction probable	

E2.2 Design period

Design Manual for Flexible Pavements recommends that pavements for trunk road should be designed for a life of 20 years (2). The accompanied rehabilitation manual doesn't explicitly state the design period for the overlay design. The current version of the manual state that the pavement design life for overlay work should be like that of new pavement design. However, designing rehabilitation work for such a long design period would incur additional economic burden. It is recommended by IRC:81 (4) that the design life for strengthening of major roads should be at least 10 years (4). The American State Highways Pavement Design Guideline (3) states, The Following Design Periods Will Be Used For Flexible Pavement Designs: New Construction or Reconstruction 20 Years; Pavement Overlay Without Milling 8 to 20 Years; Pavement Overlay with Milling Limited Access 12 to 20 Years*; Non-Limited Access 14 to 20 Years*;and Pavement Overlay of Rigid Pavement 8 to 12 Years" (* Shorter design periods can be used if there are constraints such as curb and gutter or scheduled future capacity projects that justify limiting overlay thickness).

The most common design periods used for this scope of work is from 10 to 15 years depending on specific factors prevailing in the specific project at hand. Accordingly, a design life of 15 years was adopted for the design of the bituminous overlays of existing pavements.

E2.3 Design CBR Value

For calculation of design CBR value the standard test procedure as per AASHTO T193 (5) for laboratory determination of CBR was allowed. The design CBR required for use in effective strength approach requires average CBR over homogenous section as an input data. Accordingly, the CBR values of soils that were obtained at 95% of MDD were used for the analysis. The adopted values are presented in next section. Soil investigation data confirmed that soil with CBR value of 8% (at 95% MDD) was available at most of the places along the existing road alignment. The borrow material investigation also confirms availability of such materials for use in fill sections. Hence a subgrade CBR value of 8% was considered for the design of new flexible pavement.

E2.4 Design Traffic Considerations

The projected traffic was based on 12 years data for each category of vehicle as shown in

Table 55.

Table 55 E2 Historical Traffic count data of Awash-Mieso Section

Year	Car	L/ Rover	S/ Bus	L/ Bus	S/ Truck	M/ Truck	H/ Truck	T/ Trailer	Total	Growth rate (%)
2010	24	128	162	75	88	191	104	95	867	
2011	22	131	195	87	105	128	169	112	949	9.458
2012	31	148	186	90	120	145	64	140	924	-2.634
2013	17	141	181	67	107	148	125	155	941	1.840
2014	20	135	193	79	94	153	118	112	904	-3.932
2015	29	157	186	68	116	163	94	89	902	-0.221
2016	36	113	180	106	120	137	51	97	840	-6.874
2017	32	159	250	123	179	157	125	157	1372	63.333
2018	43	142	172	71	165	146	90	773	1602	16.764
2019	52	205	362	173	305	406	538	924	2965	85.081
2020	58	226	259	108	251	348	268	474	1992	-32.98
2021	35	110	159	85	120	117	109	278	1012	-46.19
Average growth rate (%)										7.6

The entire corridor has been divided into nine homogeneous traffic sections for the purpose of pavement design. Design traffic loading (CESA) has been estimated using the estimated traffic data, and calculating for each direction using equation 1:

$$CESA = 365 * AADT * EF * \frac{[(1+i)^{n+1} - 1]}{i} \qquad (Eq.1)$$

Where:

CESA: Cumulative equivalent standard axle, n: Design period, i: Growth rate, AADT: Annual average daily traffic in both directions, and EF: Mean equivalence factor from axle load survey.

The summary of the estimated design traffic loading for each section has been given in Table E4.

E3 Asphalt Concrete Overlay Design

E3.1 Using Asphalt Institute Method

As per ERA 2002 Pavement Rehabilitation and Asphalt Concrete Overlay Design Manual, the thickness of the bituminous shall be determined based on Asphalt Institute (6) Benkelman Beam Deflection Technique, which requires the following input parameters:

- Benkelman beam (static) deflection measurements
- Representative rebound deflection
- Projected overlay traffic
- Temperature adjustment factor
- Critical period adjustment factor

These parameters listed above are used to determine the design overlay thickness by using a design chart that has a unique relationship established among the overlay thickness, the projected overlay traffic, and a corrected elastic deflection referred to as the representative rebound deflection. As discussed previously, all parameters have been derived except the Representative rebound deflection. The mean and standard deviation of the adjusted individual deflection readings were used to calculate the Representative rebound deflection, RRD, as:

$$RRD = (X + fs) * c \qquad (Eq. 2)$$

Where:

x is the arithmetic mean of the individual deflection measurements adjusted for temperature

f is the average reliability required for the rehabilitation treatment (As per this manual value of 2 is recommended which corresponds to 98% reliability (% of all deflections which will be covered by representative rebound deflection. The corresponding value for 90% reliability is 1.3)

s is the standard deviation of the adjusted individual measurements

c is a critical period adjustment factor

The representative rebound deflections are given in the Table 56.

Table 56 E3 Representative Rebound Deflection for the Awash – Meiso road section.

Section	From	To	Length (km)	Mean	S. Dev	Seas. Cor	RRD (mm)
1	0+000	53+000	53	0.28	0.09	1.05	0.48
2	53+000	67+500	14.5	0.39	0.07	1.05	0.56
3	67+500	79+000	11.5	0.33	0.08	1.05	0.51

The estimated CESA for the Awash-Meiso section was 24 million.

The RRD and design traffic data was input in the design chart given in Figure 70 to obtain the overlay thickness. Table 57gives the overlay thicknesses per surveyed sections of the road from Awash to Meiso. Equivalent Standard Axle of 24.0

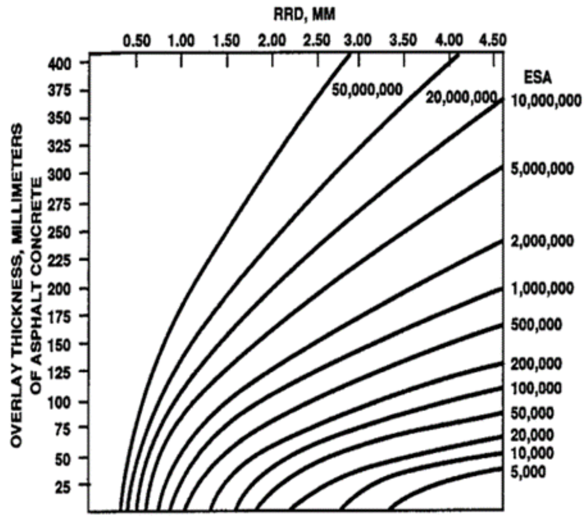


Figure 70 E1 Adopted overlay design chat (3)

Table 57 E4 Overlay Thickness for the Awash- Meiso section based on Asphalt Institute Deflection

Section	From	To	Length (m)	RRD	ESA	Overlay, (mm)	Recommended overlay (mm)
1	0+000	53+000	53	0.48	24.0	45	50
2	53+000	67+500	14.5	0.56	24.0	65	65
3	67+500	71+000	3.5	0.51	24.0	50	50

The thicknesses derived were adjusted to fulfil lift thickness criteria are shown as recommended overlay in Table 57.

E3.2 Using AASHTO Pavement Design 1993 Method

The overlay thicknesses derived using Benkelman Beam deflection techniques was cross checked by AASHTO method (6) The AASHO Road Test was constructed on a single subgrade, therefore the effect of different subgrades could not be estimated, and the structural number could not include a subgrade contribution. To overcome this problem and to extend the concept to all subgrades, a subgrade contribution was derived, and a modified structural number defined as follows:

$$SNC = SN + 3.51(log_{10}CBRs) - 0.85(log_{10}CBRs)^2 - 1.43 \qquad (Eq. 3)$$

Where:

SNC = Modified structural number of the pavement

SN = Structural number of the pavement

CBR = in-situ CBR of the subgrade

This modified structural number (SNC) has been used extensively and forms the basis for defining pavement strength in many pavement performance models including HDM 3. When evaluating the existing pavement to design rehabilitation measures, it was found that in most instances the existing pavements cannot be divided easily into distinct roadbase and subbase layers with a well-defined and uniform subgrade. Hence, when calculating the structural number according to the equation above, it is required to judge which layers to define as road base, which as subbase, and where to define the top of the subgrade. There are often several layers that could be considered either as subbases or part of the subgrade, especially where capping layers or selected fill have been used. To overcome this problem the total depth of all layers that were considered to be road pavement is limited to 700mm and Paterson's equation (7) was used to derive the SNC.

$$SNC = 3.2 * BBD^{-0.63} \qquad (Eq. 4)$$

Where:

BBD is Benkelman Deflection reading in millimetres

Paterson's test data were limited to pavements with deflections generally less than 2 mm. It was found that Paterson's equation for SNC over predicted the capacity of pavements with thicknesses over 700 mm. This has been found valid for the project case as learned from the pavement composition survey and deflection test.

To be consistent, the future structural number was calculated using AASHTO flexible pavement design equation shown below (3):

$$log_{10}W_{18} = Z_R * S_0 + 9.36 * log_{10}(SN_f + 1) - 0.20 + \frac{log_{10}\left[\frac{\Delta PSI}{4.2 - 1.5}\right]}{0.40 + \frac{1094}{(SN_f + 1)^{5.19}}} + 2.32 * log_{10}M_R - 8.07 \qquad (Eq. 5)$$

Where:

W_{18}: estimated future traffic, 18-kip ESALs

Z_R: standard normal deviate (based on reliability factor)

SN_f: future design structural number

ΔPSI: design present serviceability index (PSI) loss

M_R: design resilient modulus value, psi. The design $M_R = 1500\ CBR$

The required thickness of the AC overly is the function of the structural capacity required to meet future traffic demands and the structural capacity of the existing pavement, as determined from the following equation:

$$h_{ol} = \frac{SN_f - SN}{a_{ol}} \qquad (Eq. 6)$$

Where:

$SN_f\ and\ SN_{eff}$= future structural number

SN =as defined before

h_{ol} = required overlay thickness, inches

a_{ol} = Structural layer coefficient of asphalt overlay

Using SN_f and SN_{eff}, values as obtained above from both approaches, the overlay thicknesses were then computed as summarized in Table 58for 95% reliability level.

The range of thicknesses obtained using the AASHTO Pavement Design 1993 Method (3), was much higher than that obtained using the Asphalt Institute method. It is likely that the in-situ CBRs are greater than those deducted from laboratory tests. CBR deduced from DCP tests were very high probably because the subgrade soil may contain a lot of pebbles making the bearing capacity higher than that achieved in laboratory. However, it is believed that the deflection procedure was by far the most accurate overall and hence recommended for the project. See Table 59for final recommendations.

Table 58 E5 Overlay Thickness based on AASHTO 1993 for the Awash- Meiso road section

Section	From	To	Length, m	RRD	ESAL	Design CBR	SNSG	SNC	SN	SNf	Overlay (mm)
1	0+000	53+000	53	0.48	24.0	13.68	1.5	5.1	3.7	4.5	51
2	53+000	67+500	14.5	0.56	24.0	12	1.4.	4.6	3.3	4.42	70
3	67+500	71+000	3.5	0.51	24.0	12	1.4	4.9	3.5	4.42	54

Table 59 E6 Recommended overlay for the Awash-Meiso road section

Section	From	To	Length (km)	Overlay (mm)
1	0+000	53+000	53.0	50
2	53+000	67+500	14.5	65
3	67+500	71+000	3.5	50

Overlay thickness of 50mm was used for the construction of the control section located between 31+200 and 32+200.

E4 Shoulder

The existing shoulders are 1.5m wide each and constructed with granular subbase material quality. In most instances, they are generally in good condition, and require receiving fill to match the new level of the overlay design.

E5 Pre-overlay Treatment

Since the sections chosen for the constructability trials did not show signs of distress, no pre-treatment was required.

E6 Asphalt Overlay Material Requirements

Selection of binder and mix type for the HMA overlay material was made on the basis of traffic and environmental conditions expected. Some of the project conditions valuable in the selection process were:

- Climatically the first 80km of Awash - Hirna section and last 10km of Dengego - Dire Dawa can be grouped under one category, hot climate. The mean monthly maximum and minimum temperatures are 37ºC and 12ºC, respectively. Road surface temperature is estimated to be around 60ºC. Any material selected for this section will perform well for remaining sections.
- The 15 years ESAL is greater than 30million in the majority of sections
- Heavy truck percentage is not as such a concern. Very heavy axle loads, stopping or slow-moving heavy vehicles are not the characteristics of the project road.

E7 Binder Selection

According to MS2, for hot climatic condition 60/70 penetration grade bitumen is preferable. As per Super pave asphalt binder specification., PG graded binders are selected based on the climate in which the pavement will serve, and then additional shift in the selected high temperature binder grade can be made to account for slow transient and standing load application, based on the recommendation of AASHTO MP-2, Standard Specification for Super pave Volumetric Mix Design. Statistical analysis to determine the pavement design temperatures was not possible as daily maximum temperature of 20 years data couldn't be obtained. However, estimate can be made based on the daily maximum and minimum temperature data obtained from the meteorology. Based on this, asphalt grade between PG 64-10 and PG 70-10 is suitable which roughly corresponds to 60/70 penetration grade asphalt. Thus, 60/70 is recommended for the overlay work. Available information revealed that the same grade was used in the previous rehabilitation/upgrading of the project.

E8 Asphalt Mix Selection

E8.1 Marshall Criteria

It is a good practice, and also the only feasible alternate, to conduct the mix design based on Marshall Test procedure and recommendations given in the Asphalt Institute Manual Series, (MS-2). This is the applicable practice in the country and also recommended to avoid difficulties in obtaining the necessary laboratory equipment for more complex test methods (such as Super pave), and the associated initial cost of establishing suitable site laboratory, maintenance and calibration of equipment, if intended. In consistent with this, it is to be prudent to follow Marshall criteria stipulated by the same together with recent revisions as presented in Overseas Road Note 19 (8) to suit the project prevailing condition and advancement as to knowledge on the subject. As per ORN 19, the project Design ESALs lie in Heavy traffic category (>5 million ESA), and the recommended Marshall criteria also adopted for the CRISPS project. Marshall mix design requirements are shown in Table 60.

Table 60 E7 Marshal Mix Design Requirements for Asphalt Concrete Wearing Course

S/N	Description	Wearing course
1	Marshall stability, minimum, at 60^{0}C (kN)	9
2	Flow (mm)	2 – 3.5
3	Compaction level, Number of blows on each of the two faces of the specimen	75
4	Air Voids, AV (%)	3 – 5
5	Void in Mineral Aggregate, minimum, VMA (%)	14
6	Voids filled with bitumen, VFB (%)	65 – 73
7	Loss of stability on immersion in water at 600C, maximum, (%)	80
8	Bitumen grade, penetration	60/70

E8.2 Asphalt Aggregate Gradation

Asphalt concrete mixtures include aggregate which have particle size distribution that in general follows the Fuller's Curve. There are numerous types of asphalt concrete mixtures produced worldwide, including those presented in ERA Technical Specification 2002 (9), with Fuller Curve indices between 0.35 and 0.6. Mix with more coarse aggregate (far on the lower side of Fuller curve) will produce harsh mix, inclined to segregation, while mix with high content of fine (far on the upper side of Fuller curve) will become readily unstable with slight excess of asphalt. To this end, ASTM provides equal gaps to either side of the maximum dense curve to suit various requirements. Therefore, the choice is normally based on the level of traffic (e.g., sever sites or not), and climatic/project feature (where either durability/appearance or stability is a concern for examination). Since there is moderate proportion of heavy vehicle and the seasonally wet climate (dominantly), durability and stability need to be balanced on the project road. In this respect, therefore, fine grading with nominal size of 12.5mm grading of wearing course is recommended in ERA, ASTM, BS and many other standards. However, ASTM grading has been recommended for the following reasons:

- Many standards and specifications are based on the concept that the best way to ensure that the client gets what he/she requires is to specify materials and methods that have been found to have acceptable properties in the past. ASTM standard is generally accepted and internationally recognized standard grading envelope with many years of proven performance.
- We have chosen that the mix design is to be made in accordance with Asphalt Institute Mix Design Manual (MS2). This mix design manual refers to ASTM standards for grading envelopes.
- Its relatively wide grading tolerances will allow the use of locally available materials sources. Please note that the use of locally available materials, which do not impair optimal performance, will save cost and time.

Grading limits are presented in Table 61, but percentage passing 2.36mm sieve is recommended to be maximum of 40% to assure that the mixture is coarse graded.

Table 61 E8 Grading limits for combined aggregate and mix proportions for Asphalt Wearing Surfacing

Sieve Size [mm]	Wearing Course	Tolerance from Job Mix
19	100	±8
12.5	90-100	±7
4.75	44-74	±7
2.36	28-40	±6
0.300	5-21	±5
0.075	2-10	±3

The applicable lift thickness for the above mix is 37.5 to 75mm. It is envisaged that this mix is also suitable for the levelling course unless the required fill is less than 37.5mm. In the latter case ASTM mix with nominal size of 9.5mm (maximum percentage on 2.36mm sieve must be 45%) can be used.

E9 References

(1) **ERA.** *Pavement Rehabilitation And Asphalt Overlay Manual .* Addis Ababa: ERA, 2002.

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(3) **AASHTO.** *Flexible Pavement Structural Design.* Pennsylvania: AASHTO, 1993.

(4) **Indian Roads Congress.** *Guidelines for strengthening of flexible road pavements using Benkelman beam deflection technique, IRC-81.* New Delhi: IRC, 1991.

5) **AASHTO.** *The California Bearing Ratio, T193-99.* s.l.: AASHTO, 2003.

6) **The Asphalt Institute** *Asphalt Overlays for Highway and Street Pavement Rehabilitation, Third Edition. Manual Series No. 17.* 2000. Benkelman Beam Deflection Technique

(7) The World Bank, *Road deterioration and maintenance effects : models for planning and management, W D O Paterson, The JohnsHopkinsUniversity Press, Baltimore, June 1990*

(8) **TRL.***Overseas Road Note 19, A guide to the design of hot mix asphalt in tropical and sub-tropical, countries. Transport REseacrh Laboratory,* Crowthorne, United Kingdom, 2002.

(9) ERA. *Pavement Design Manual* – Volume 1 Flexible Pavements and Gravel Roads, Ethiopian Roads Authority, Ethiopia, 2002.