


TARGETED INTERVENTIONS UNDER THE RURAL ROAD INVESTMENT PROGRAMME IN MOZAMBIQUE (PHASE 1)

Construction/Progress Report

by the AFCAP Research Consultant

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CLIENT PROJECT REPORT CPR 470

Transport Research Laboratory

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TARGETED INTERVENTIONS UNDER THE RURAL ROAD INVESTMENT PROGRAMME IN MOZAMBIQUE (PHASE 1)

Construction and Progress Report

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Table of Contents

Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ACV	Aggregate Crushing Value
AFCAP	Africa Community Access Programme
ANE	Administração Nacional de Estradas
BoQ	Bill of Quantities
CBR	California Bearing Ratio
DCP	Dynamic Cone Penetrometer
DfID	Department for International Development
DIMAN	Department of Maintenance (ANE)
ETB	Emulsion Treated Base
LL	Liquid Limit
MDD	Maximum Dry Density
Mt	Metical
PI	Plasticity Index
PL	Plastic Limit
QA	Quality Assurance
RRIP	Rural Road Investment Programme
TRL	Transport Research Laboratory
vpd	vehicles per day
WC	Wearing Course
4WD	4 wheel drive

Executive Summary

This report concerns the construction stage of the first phase of targeted interventions on low volume rural roads in Mozambique (2008-2009) under the Rural Road Investment Programme. Inputs provided by the Research Consultant under this phase consist of:

1. A series of site visits to observe and review construction practices on the ten sites selected by ANE. There is at least one project in each province except Niassa.
2. Providing immediate practical advice to the supervising consultants, contractors on the job and provincial ANE staff aimed at improving site practices.
3. Reviewing the road designs that were already in place at the start of the AFCAP/TRL contract.
4. Supervising construction as far as is possible by means of intermittent site visits.
5. Developing a series of works procedures (work norms) for the various site activities.
6. Developing quality control procedures for site work.
7. Identifying sites that are suitable for research, principally for constructing trial sections of road to develop improved methods and designs.
8. Designing suitable research trials.
9. Visiting additional RRIP sites that have been selected for the second phase of AFCAP and carrying out preparatory work.
10. Disseminating the findings of Phase 1 by means of a stakeholder workshop.

The report incorporates information on progress and technical aspects of the construction processes that is correct up to July 2009. The report deals with each site in turn and provides a comprehensive record of the engineering problems encountered, the advice provided, the research trials that have been designed and the work procedures (work norms) that have been developed.

Summarising all the issues identified in this project is not practicable, indeed, the report as it stands is, itself, essentially a summary, albeit a detailed one. However there are some common issues that apply to many sites and some recommendations that follow from these.

1. Because many sites are very remote and difficult to visit adequately in one day, it is recommended that ANE include the hire of caravans under 'Preliminaries and General' or 'Site Establishment' items in the BoQ for rural road projects.
2. On most sites there appeared to be no Programme of Works. It is recommended that a Programme of Works is produced and approved before the start of any project. This is absolutely necessary to manage the resources, time and outputs successfully.
3. There was almost a complete lack of project documents for most sites. Construction drawings (plan/elevations etc), general project outline diagrams, line drawings showing chainages, cross-sectional drawings, even simple sketches of the engineering works, were rarely available. It is recommended that adequate documents are produced and that site personnel are provided with them and with detailed work procedures/norms including step by step operational instructions.

4. There was almost a complete lack of approval processes and an enforcement mechanism. It is recommended that approval forms should be developed for the different operations on site and used in such a way that no further works can be carried out on sections where the work has not been approved. For example, control of compaction has been a major issue and this has a very strong effect on the performance of the roads in terms of durability and maintenance demand. It is recommended that all earthworks requiring compaction be tested and approved using standard procedures.
5. There was lack of appropriate and suitable equipment and other resources for the operations. Any compromises on the resources can lead to costly consequences. It is recommended that an approval system is put in place to review and approve the equipment and other resources provided by the contractor, also taking into account availability in the country. Standards can be written which the evaluator can follow and some exceptions can be made in the light of available resources.
6. It is not clear how knowledgeable the provincial staff, consultants and contractors actually are about the design and construction of rural roads. The lack of basic design information such as material strengths, hydrological survey information and so on may be caused by a lack of appreciation of the need for such data or simply an acknowledgement that there are little or no resources to collect such data let alone use it in the design process. It is recommended that during the workshop and training phase of AFCAP a survey is conducted to determine the nature of the main constraints preventing provincial consultants from carrying out higher quality road engineering.
7. There is a serious lack of quality control and quality assurance documentation, especially on site. It is recommended that this information should be detailed in a QA manual which should be available on sites at all times. This should be an appropriate document written with full appreciation of the difficulties of constructing roads in remote areas with limited resources, but should provide a first step in a programme of continuous improvement.
8. The quality checks on construction materials should be a continuous process on a construction project. This is necessary because materials continue to vary as construction proceeds. It is recommended that a laboratory assistant be present during construction to carry out standard tests (or at least basic indicator tests) for approval of materials.
9. The progress of construction has been very slow and the remoteness of the sites is the major contributing factor. Consequently the unit costs will most certainly be very high. There is a need for an early evaluation of the basic principles of the approach and the processes involved in light of the observations made in this report.

1 Introduction

1.1 The situation in Mozambique

Mozambique is a vast country with a relatively small population in comparison to its size. Thus, although the density of roads is low, and therefore many communities have very poor access, the rural road network is large. More than 80% of it is unpaved.

Good road building materials are scarce and therefore the materials that are used in the construction of roads are generally of poor quality. For example, in some places the only available materials are the coastal sands that cover large areas along the entire eastern coastline of the country and conventional materials are available only at very high and unaffordable costs. Road deterioration is rapid and there are many roads that are impassable for large parts of the year. Maintenance demand is high and the situation is exacerbated by its high cost and low capacity within the road sector - there is a limited number of experienced contractors and consultants to design, supervise and construct the roads. This lack of capacity is a serious concern for ANE, hence capacity building in terms of the technical knowledge and operational resources is high on the agenda.

Because good road-building materials are scarce, the engineering options and the best solutions must, necessarily, be different, possibly unconventional, biased towards innovation rather than standard practice. This, in a situation of limited capacity, poses a great challenge.

1.2 The Rural Road Investment Programme

To help solve the problem of rural access, in 2008 ANE commissioned the Rural Road Investment Programme (RRIP) whose main objective is to provide all-weather access to rural communities through spot improvement interventions. The proper implementation of the RRIP is key to the success of the programme and therefore a management structure was set up which includes the Department of Maintenance (DIMAN) and the Provincial Delegations as well as the provincial consultants who are primarily responsible for the maintenance programmes in the provinces.

The programme is concerned with rural roads that carry relatively low volumes of traffic. In favourable situations such roads can be built for a relatively low cost compared with more heavily trafficked roads. However, at some sites where the passability of the road is severely affected, the only viable engineering solutions for all-year access can be almost as expensive as for more heavily trafficked roads; for example, an embankment to raise a road above a flood plain or a high level bridge to cross a fast flowing river. Thus the nature of many spot improvements to achieve all-weather access on rural roads is such that they are often expensive. In such cases it is advisable to apply similar standards of engineering practice that would be applied for any major structure. This is always very difficult in the rural environment but is a goal that should be striven for.

1.3 The Africa Community Access Programme (AFCAP)

Added support was provided for the RRIP as part of the Africa Community Access Programme (AFCAP) of the UK's Department for International Development (DfID) through which TRL was engaged to provide technical assistance to the RRIP. TRL's assistance began in October 2008 and consists of providing technical advice, supervision and training together with an important research component aimed at improving key aspects of the provision of rural roads.

The absence of supporting technical specifications and work norms that are appropriate for the materials that are available in Mozambique and suitable for an acceptable standard for low volume roads calls for new approaches. Specifications which will be developed in this project must take into account the capital costs and the life-cycle costs. To achieve this, research should take centre stage. This research should be founded on the knowledge obtained from the review of the design standards, the construction methods and the maintenance approaches that are currently used in Mozambique.

The AFCAP programme is currently divided into two phases.

Phase 1

Phase 1 consists of the following activities on a number of sites preselected by ANE.

1. A series of site visits to observe and review construction practices.
2. Providing immediate practical advice to the supervising consultants, contractors on the job and provincial ANE staff aimed at improving site practices.
3. Reviewing the road designs that were already in place at the start of the AFCAP/TRL contract.
4. Supervising construction as far as is possible by means of intermittent site visits.
5. Developing a series of works procedures (work norms) for the various site activities.
6. Developing quality control procedures for site work.
7. Identifying sites that are suitable for research, principally for constructing trial sections of road to develop improved methods and designs.
8. Designing suitable research trials.
9. Visiting additional RRIP sites that have been selected for the second phase of AFCAP and carrying out preparatory work.
10. Disseminating the findings of Phase 1 by means of a stakeholder workshop.

Phase 2

The planned inputs under Phase 2 of the AFCAP/TRL contract consist of:

1. Assisting ANE in selecting suitable sites for spot improvement interventions in all provinces.
2. Providing guidance to the provincial delegations on preparations for Phase 2 designs and works.
3. Preparations of draft designs for Phase 2 interventions.
4. Identifying sites that are suitable for research, principally for constructing trial sections of road to develop improved methods and designs.
5. Designing suitable research trials.
6. Providing immediate practical advice to the supervising consultants, contractors on the job and provincial ANE staff aimed at improving site practices.
7. Supervision of works.

8. Comprehensive training for ANE staff, their consultants and their contractors.
9. Monitoring of all 'research' sites to assess performance.
10. Analysis of performance data from the research sites.
11. Preparation of documentation on specifications, work norms, quality control procedures for low-volume roads with particular emphasis on low-cost surfacing options.

This report covers the work that was carried out in the first phase of AFCAP but also, and inevitably, includes recommendations which will be useful in the execution of Phase 2.

The AFCAP support began after the RRIP had been underway for several months, hence the work on some of the sites was well advanced when TRL staff made their first site visit. Designs had been completed and construction work was well established. On other sites very little had been done. Furthermore, during Phase 1 of the AFCAP support, the progress of the works on some sites was quite rapid whereas on others it was slow. As a result of these two effects, TRL's role on each site was somewhat different. On the more advanced sites it was possible to prepare sets of draft work norms based on extensive site experience whereas on other sites TRL's role was simply to provide advice based on the current stage of the work.

The main part of this report deals with each site in turn and provides a comprehensive record of the engineering problems encountered, the advice provided, the research trials that have been designed and the work norms that have been developed to date.

Whilst this report deals with all the main issues arising in this project, more detailed information about each site can be obtained from the project Inception Report and various site visit reports that have been produced throughout the project.

It will be seen that the road sites for Phase 1 are to be found in all of the provinces except Niassa and most of them serve rural populations that are a very long way from main towns or provincial capitals.

2 Summary of the Phase 1 sites

Table 1 provides a brief summary of the Phase 1 sites. Table 2 shows a summary of the Phase 2 sites. Some Phase 2 sites are continuations of those in Phase 1, where the original Phase 1 work was not completed by the end of the Phase 1 period, whilst others are based on the initial site visits that were made for site selection purposes.

2.1 Progress of the works

Work output varied from site to site. There was a clear distinction between the work output of the established contractors and the small scale and upcoming contractors in terms of quality and productivity. The level of TRL's assistance therefore also varied depending on the experience, knowledge and skills of the contractors.

Details of each site, their principal engineering problems, designed solutions, construction problems, advice provided, constraints on good engineering practice, proposed research trials, work norms developed, etc. are all described in detail in Chapter 3.

Chapter 4 attempts to summarise problems common to many of the sites that need to be addressed in Phase 2 of the RRIP, or in future programmes if engineering practice is to be continuously improved in Mozambique.

Table 1 Summary of the current AFCAP sites

Site Number	Province and Road Name	Passability Issues	Length (Km)	Improvement
CD1	Cabo Delgado Xitaxi-Mueda	A steep hill with very weak, slippery and erodible soils	1.3	Construction of concrete slabs, and bituminous seal on cement-stabilised sand base
NP1	Nampula Gracio-Milhana	Mecuburi bridge and approaches over-topped during floods	0.5	Additional flow capacity. Surfacing of approaches.
NP2		Milhana crossing flooded for long periods	0.5	Construction of embankment and causeway to provide all-weather crossing
TE1	Tete Bene-Fingue-Cachombo	Long steep hill, dangerous when wet and difficult to ascend. Weak soil.	1	A roadbase of large stones to be 'grouted' with concrete and covered with a further 50mm of concrete screed.
TE2		Causeway with inadequate capacity	0.5	Increase waterway area and reduce times of impassability
ZA1	Zambezia Zero-Mopeia	Low sections which flood	44	ANE designs for raised embankments, water crossing structures and regravelling.
MN1	Manica Nhacufera-Machaze	Very coarse gravel causing very high roughness	5	Process wearing course, compact as base and surface with Otta seal. A research section
SF1	Sofala Beira-Savane	Sandy soil impassable during floods.	45	Construction of water crossing structures and sealed embankments

IN1	Inhambane Panda-Urene	Passability and problems; absence of good gravels. Inadequacy of the Cudingene crossing	-	Gravel wearing course and an embankment Increased flow capacity of river crossing.
GZ1	Gaza Macaritane-Chicualacuala	High gravel loss. Weak and slippery soil	2	Construction of cement stabilised sand base surfaced with block paving
MP1	Maputo Magude-Motaze	Loose sand	0.3	Construction of pavement using chemical stabiliser (Romix) and surfaced with cold mix, surface dressing and sand seal
MP2	Maputo Calanga-Checua	Loose sand; weak soil; swamps which are flooded and impassable for much of the year;absence of good materials	40	Construction of culverts

Table 2 Summary of the Phase II sites to date

Site Number	Province and Road Name	Passability Issues	Length Km	Improvement
NS1	Niassa Mavago-Msawize	Approximately 10 km of road in rocky ground Approximately 20 km of road in plastic red clay	c. 30	Most of the road must be improved to provide year round access.
NS2	Niassa Nova Madeira-Cz. Lupiliche	Loose sand and weak swampy soil	4	Possibly blend soils to provide a tighter, less erodible pavement.
NP2	Nampula Gracio-Milhana	Milhana crossing - flooding for long periods	0.5	Continuation of Phase 1. Construction of embankment and causeway to provide all-weather crossing
NP3	Nampula Mecane-Pilivili	Sandy soil, floods Two large structures vulnerable to collapse Long lengths of degraded gravel surface	33	Exact plans not known. Expected to improve 2 structures and raise road level
NP4	Nampula Naguema-Chocas Mar	Sandy – floods	8-10	Raise level across flood plain (c. 1km), improve cross drainage and surfacing.
TE3	Tete Matema-Furancungu-Daca	1) Maintenance /construction errors. 2) Deep flows across submersible structures	c. 5	Various spot improvements. The road is over 200km long

		3) Steep eroded hill near Furancungu that is impassable		
ZA2	Zambezia Zero-Mopeia	Low sections which flood	44	Continuation of Phase 1 Application of various seals to sections of the Phase 1 gravel wearing course. A research site
MN2	Manica Nhacufera-Machaze	Very coarse gravel; very high roughness	Not known	Continuation of Phase 1 Additional research of appropriate surfacings, primarily Otta seals
SF1	Sofala Beira-Savane	Road floods and is impassable	45	Continuation of Phase 1 Experimental road designs using emulsion treated sand roadbases and application of various surfacings. This is a key research site.
IN1	Inhambane Panda-Urene	Passability and problems; absence of good gravels. Inadequacy of the Cudingene crossing	5	Completion of Phase 1
IN2	Inhambane Cumbana-Chacane	Very loose fine sand soil		Research site – Otta seals
GZ1	Gaza Macaritane-Chicualacuala	High gravel loss. Weak and slippery subgrade	Not known	Replacing the unsuccessful block paving of Phase 1. Five demonstration/research sections proposed with different surfacings.
MP2	Maputo Calanga-Checua	Loose sand, weak soil, swamps which are flooded and impassable for much of the year. Absence of good materials	40	Continuation from Phase 1. Construction of embankments using sand blended with clay from the swamps
MP3	Maputo Marracuene Macaneta	Road liable to flooding. Expansive soils Absence of good materials	10.7	Raising the level across the flood plain. A research site

3 Progress of the AFCAP programme on each site

This section provides detailed accounts of the issues on each site. This includes

(i). A brief description of each site
(ii). The problems of passability
(iii). The RRIP solution and proposed works
(iv). Where appropriate, suitable research trials to improve methods and specifications
(v). The problems encountered in executing the construction work
(vi). Identification of major constraints preventing good engineering from being achieved
(vii). TRL's advice for solving problems and achieving a better engineering result
(viii). Where progress has been sufficient, TRL's recommended site practices (work norms) and quality procedures

The sites are described in the order shown in Table 1.

3.1 Xitaxi-Mueda road, Cabo Delgado (CD1)

3.1.1 Description of road and history

The Xitaxi Mueda road branches off the main north-south road in Cabo Delgado and passes north westerly through a populated and agricultural area to Mueda. Mueda can also be accessed on a west-east road further north. The site is 200km from the provincial capital Pemba.

The first few kilometres of the road comprise a series of short hills which are badly eroded and slippery when wet. The short hills are followed by a long ascent from the coastal plain up to a raised plateau. Beyond the top of the ascent, the road to Mueda is reported to pass through gentle terrain and be passable. Current traffic levels are very low.

The road is being improved under Phases 1 and 2 of RRIP.

3.1.2 The key problem

This escarpment has some sections that are very steep indeed and is impassable to most vehicles in the rainy season and to many vehicles all year round.

This road is a good case study for spot improvements whereby a total constructed length of around 3 kilometres on localised passability problems will provide year-round access along an entire road of around 100 kilometres

3.1.3 RRIP work on the road

The main escarpment is being improved under RRIP Phase 1; the steeper sections with a concrete surface and the less steep sections with a bituminous surfacing.

Improvements to the road before the escarpment are proposed for Phase 2; the hills with a bituminous seal and the flatter sections with gravel.

A guiding principle of the planning was the use of concrete on gradients typically steeper than 12%, a surface dressing or Cape seal on gradients between 6% and 12% and gravel on gradients less than 6%, although the degree of compliance with this principle is not yet known, partly because the gradients appeared to be simply estimated rather than measured.

In addition to the road construction, general drainage improvements are proposed along the road.

3.1.4 TRL's role

Advice on numerous aspects of the works (see Visit Reports and Inception Report) including:

(i). Prospecting for materials, testing and stockpiling.

(ii). Constructing Cape seals and surface dressings.

(iii). Testing concrete.

(iv). Compaction.

(v). Problems on steep hills.

Recommendations for some research variations to provide improved designs for the future, in particular:

- 100 mm and 150 mm thick slabs versus 200 mm thick slabs with and without reinforcement
- Placement of reinforcement within the slab

Topographic survey results, materials test data, concrete cube test results and DCP test results have been requested.

3.1.5 Observations during site visits

The unimproved road is a degraded road with loss of shape and crown height and an eroded and slippery surface.

On the first site visit, sections of concrete surface were already complete. The concrete slabs are approximately 5 metres long and 200 mm thick. A form of wire rather than 'rebar' reinforcement was being used. The slabs are cast alternately, with missing slabs infilled after the first slabs have cured.

During the last site visit (March 2009) some of the proposed trial sections had also been constructed using 150 mm thick slabs and slabs with no reinforcement. A trial section with a bituminous surface dressing seal had also been constructed at the top of the escarpment onto a base formed by scarifying and shaping the gravel which was previously on the surface. Details of test results from the trial sections have been requested

Labour-based methods are being used for most of the construction activities. The preparation of aggregate, the transportation and placement of concrete, including the excavations and other earthworks, were all carried out using labour-based techniques. The labour was supported by machines on activities which could not have been executed efficiently by labour. Such equipment included the concrete mixer, a poker vibrator and a tractor-trailer combination for on-site transportation.

This construction site required the most stringent of quality control measures. Rigid pavements are very expensive and good value for money is a major issue. The construction of a bituminous surfacing conventionally requires specialised equipment. Carrying it out using labour-based methods requires both skill and a high level of supervision

Materials

1. The work was being constructed using cement stabilised bases, despite it being apparent that there might be materials of base quality in the vicinity. It is important to search widely for materials well in advance of the construction work. This enables local materials to be used and costs to be reduced. Material prospecting demands expert knowledge of indicators such as terrain, surface soil and vegetation.
2. It is important that all used materials are correctly tested to ensure that they meet specifications and are therefore suitable for use.
3. Cement had to be procured and transported a considerable distance from Pemba. The situation was made worse by a rise in prices beyond that which might be normally expected - at some point during construction the price was double the cost at the time of tendering and this became a contractual issue in the management of the contract. This is likely to distort the unit costs of the construction of the concrete slabs.

Base construction

The surface of the base upon which the Cape seal was to be constructed was non-uniform, with many small depressions in which bitumen can collect, and soft in places, as shown by indentations from tractor tyres. The quality of the base should be improved.

Concrete pavement construction

1. Concrete construction was variable, with potentially inaccurate batching by volume and with a high slump. High slump concrete can leave voids when hydrating and can also deform when being compacted on a steep gradient. It is not clear whether the concrete slabs are being kept moist for long enough to allow curing to complete.
2. The materials used for the construction of the concrete slabs included weak, very coarse and non-standard aggregate produced by labour-based methods (hand crushing). This is a variation from conventional standards which may be adequate for such a road and will become a parameter for investigation in the research component of the project.
3. The road foundation on which the slabs were constructed was not properly compacted and was evident when it rained. The compacted foundation softened so badly that it was not possible to walk on it.
4. The method of joint filling was unsuccessful. The material did not fit tightly and it was necessary to seal immediately the top of the slab joints with bitumen to prevent water from percolating into the base under the slabs. The base is sensitive to moisture ingress and this may eventually affect the foundation of the slabs and then the slabs themselves.

5. The batching was not carried out properly and this could affect the quality of concrete. The batching was carried out using small plastic containers. At times, they were filled flush with the top and at others they had the aggregate heaped and hence overfilled. The application of water was also not controlled and this is where the slump test would have been useful. The slump test specifications for a particular type of concrete ensure that the concrete produced has a consistent level of workability. In this manner the water cement ratio is controlled, enhancing the quality of the concrete. It was evident that, at times, the concrete mix was too lean i.e. the workability was too high, because there was too much water in the mix. During vibration of the concrete a lot of water flowed out of the mix with cement paste and this affects the quality of concrete.
6. No cube strength tests have been availed to the team to date. The results are essential for the assessment of the concrete strength as built.
7. The grooving of the concrete slabs was clearly inadequate and the surfaces of the slabs were not rough enough for long-lasting traction. This was later improved on subsequent slabs.
8. Despite the issues raised in (1) to (4) above the output and the quality was reasonable considering the contractor's lack of experience, substandard materials available for the construction and the remoteness of the site.
9. The stone pitching of the drains was carried out properly.

Surface dressing/Cape seal construction

1. The preparation of base course made out of cement stabilised red sand had a very rough and uneven surface. This is not good for surface dressing because the bitumen will flow from the bumps to the depressions during application causing uneven distribution of the binder and this will, in turn, affect the performance of the surfacing. This could have been caused by over application of compaction water. Strict controls should be applied to construction of this nature.
2. The handling of bitumen was not appropriate. Heating of bitumen is a crucial operation and any overheating can affect the quality of the bitumen. There was some indication that the heating process was not properly controlled, for example, through temperature checks with thermometers. Overheating boils off the volatiles and the bitumen will age much quicker than is normally anticipated.
3. The application rates were initially not controlled. When machines are used for the application of bitumen and chippings, prior calibration ensures accurate application. For labour-based application there are techniques that can be used to ensure accurate application. These include predetermined volumes of stone and binder for clearly demarcated areas on the road. This makes it easier for the labourers. For the application of binder, selected labourers should be trained using water before allowing them to spray bitumen.
4. Rolling was carried out with a 1.7 ton 'sit-on' steel roller and the chippings were crushing under its weight. The aggregate was weak, most likely with a very high ACV. It is better practice to roll with a pneumatic roller. For these small scale works, a loaded truck can be used if a pneumatic roller is unavailable.
5. The ANE provincial consultant raised the concern that the surfacing stone was stripping. This could have been caused by one or more of the following reasons:

- The application rate for the bitumen was inadequate, perhaps due to lack of control during application.
- The binder was over heated and lost some of its binding properties.
- The chippings were dirty and the binder could not hold on to the binder.

The solution provided was to apply a fog spray to the stripping sections. For new sections the application of bitumen was split, applying two thirds of the required rate of binder before and one third after the application of chippings. This is good practice for labour-based surfacing. This change has resolved the problem.

3.1.6 Available information

The following information had been requested during previous site visits:

(i). Topographic survey results.

(ii). Materials test data.

(iii). Concrete cube test results.

(iv). DCP test results.

This information has not been provided although some details of concrete strengths have been reviewed on site.

The following documents were available.

(i). Bill of Quantities of the 3.1 km of proposed Phase 2 improvements from chainage 1+100 to 6+800. Most of the improvements are the provision of a cement-stabilised red sand base, a Cape seal and lined side drains. Also included are some sections of fill, a short section of mechanically stabilised soil, assumed to be gravel, and one section of scour checks. Most of the sections are assigned a priority level P code of P1 or P2. One short section, to be gravelled, is P3, i.e. easily passable.

(ii). A standard cross section showing the methodology for improving an eroded surface with scarification, formation, compacted base, prime, 13.2 mm Cape seal and improved drains.

3.1.7 Advice and recommendations

Site practice

Improvements to the following aspects of site practices were recommended.

1. When re-using gravel from the surface of the road as base material it is necessary to remove it from the road and carefully stockpile it to avoid contamination. The subgrade must then be shaped and compacted, and then the gravel must be brought back, shaped and compacted.
2. All pavement layers should be properly compacted. At the very least, if compaction cannot be measured, all surfaces should be compacted to refusal.
3. Concrete aggregate should be sieved to remove fines and dirt.
4. Primed surfaces should be kept clean before the bitumen layer is sprayed. Dirt can reduce adhesion of the bitumen.

5. Bitumen spraying should be improved. The area which should be covered by a known volume of bitumen at the specified spray rate should be marked out and the operator should ensure that the bitumen is sprayed uniformly over this area. It is often useful for the operator to practice in advance using water on a separate area of ground. A rose should be used for spraying when possible. When calculating spray rates, it is important to take into account the water content of emulsion.
6. On steep hills, and particularly with less viscous emulsions, bitumen can flow before the aggregate is placed. If this happens, it is possible to spray half the bitumen first, spread and compact the chippings and then spray the remainder of the bitumen. A cationic emulsion is often more suitable on steep gradients.
7. Pneumatic-tyred rollers should be used for compaction. Steel-wheeled rollers tend to crush and crack the aggregate and are not so good at orientating the stones into a tight mosaic. If pneumatic-tyred rollers are not available, only relatively light steel-wheeled rollers should be used (<8 tonnes) and then only if the aggregate is strong enough.
8. A search should be carried out for natural gravels in the vicinity of the road to be used as base material. Test pits should be used to estimate the area, depth and thickness of any material source and to obtain samples. All apparently suitable material should be tested. Non standard material may be useable but its properties need to be known, as indicated below.
9. The concrete surface on the main hill should be extended down the slope by approximately 50 metres to where the gradient is less.
10. The sections listed in the Bill or Quantities are all multiples of 50 or 100 metres. Construction information should be more accurate than this. A more accurate BoQ would be useful.
11. The Provincial Consultant should prepare a line diagram of all completed and planned work along the road.

Surveys, tests and analyses

The following surveys, tests and analyses were requested.

1. The need for a topographic survey was repeated. The results will enable surface construction to be correlated with gradient and surface suitability to be assessed.
2. Non-stabilised base materials, including prospected gravels and red sand, should be tested for the following:
   (i). Grading.
   (ii). Atterberg limits (PL, LL, PI, linear shrinkage).
   (iii). Soaked CBR strength at 95% MDD, Mod. AASHTO compaction.
3. Cement stabilised materials should be tested for:
   (i). Soaked CBR strength at 95% MDD under modified compaction
   (ii). Unconfined Compressive Strength.
4. Two samples of in situ subgrade material should be taken from every section and tested for the following:
   (i). Grading.

   (ii). Atterberg limits (PL, LL, PI, linear shrinkage).
   (iii). Soaked CBR strength at MDD under modified compaction.
5. Stone being used for chippings should be tested for the following:
   (i). Grading
   (ii). Flakiness
   (iii). An appropriate strength test, such as ACV, Los Angeles or 10% Fines.
6. A DCP survey of the in situ materials should be carried out at 50-metre spacing.
7. Batched concrete should be tested using slump tests and cube tests.
8. Field density tests of compacted base material should be carried out on sections that are to be surfaced.

Design work

No additional design assistance by TRL is currently planned.

3.1.8 Recommendations on work-norms

While the works have proceeded reasonably well, the following recommendation should be considered in order to improve the workmanship.

Concrete pavement*:*

1. The base for the rigid pavement should be processed and well compacted because a weak base may lead to rocking slabs at some stage in the life of the pavement.
2. Quality tests should take centre stage in the management of the construction contract and copies of the test results should be kept on site to ensure improvement of workmanship. The concrete cube testing for both the 7 and 28 days strength should be carried out and made available in the office and on site. The same applies to the compaction field density tests and compaction moisture.
3. There should be a programme of works on site. A programme of works helps to improve the performance and efficiency of the works.
4. The slump test apparatus should be used every time that concrete works are undertaken.
5. Roughening of the surface of the slabs should be carried out through ramming with a straight edged plank. Merely scratching the smoothened surface does not provide adequate and durable roughness and the shallow grooves thus formed can fill up with sand and silt thereby losing the necessary traction.
6. The curing process must be carefully monitored and lengthened to 14 days because rapid loss of moisture on the surface could lead to weak concrete on the surface of the slabs which would not be resistant to abrasion and crushing under traffic.

Surface dressing

1. The subgrade should be scarified and re-compacted to a lower limit density of at least 91%. The approval process should be based on the test results and the engineer's inspection report.

2. The cement stabilised base should be processed within 6 hours for maximum material modification and strength gain from the stabilisation. When a vibratory smooth wheeled steel roller is used, final cutting with the towed grader should be thorough to avoid poor compaction resulting from the bridging effect.
3. Bituminous emulsion is recommended for labour-based surfacing for safety reasons. The application should be split so that less bitumen is applied before the chipping and more bitumen after the chipping to prevent the bitumen from flowing off the carriageway.
4. Application of the surfacing should properly be organised and training of the contractor and labourers is essential. A spotting process where premeasured quantities of chippings are dumped at regular intervals on the road side for demarcated areas on the primed carriageway should be done at least a day before the surfacing activity begins.

3.1.9 Photos

Eroded section of road prior to the main ramp

Toe of the concrete surface on the main ramp

View across a steep section of the ramp

Concreting a slab

Section of prime (L) and Cape seal (R)

Crushing of Cape seal chippings

Non-uniform base prior to applying the surfacing

Tractor tyre indentations in the poorly compacted base

3.2 Gracio-Milhana road, Mecuburi bridge and Milhana crossing, Nampula (NP1 & NP2)

3.2.1 Description of road and history

Gracio is located approximately 80 kilometres north of road N1 between Nampula and Nacala, along an unpaved road which is currently being improved from a very poor condition. Milhana is approximately 43 kilometres further north. The road between Gracio and Milhana passes through gentle terrain and is crossed by several water courses and liable to flooding in places. A high level bridge crosses the Mecuburi river. The road ends on the far side of a wide basin which can flood to a depth of up to about 2 metres. Traffic along the road is very low.

3.2.2 Key problems

The key problems to providing reliable access along the road are:

1) Long lengths of road and water crossings structures in poor condition and in need of repair.
2) The Mecuburi bridge is sometimes overtopped and one of the approach embankments suffers severe erosion.
3) Wide basin crossing at Milhana that is impassable for several months.

3.2.3 RRIP work on the road

Some work is underway on the road under RRIP Phase 1, including construction of several culverts and regravelling. The height of the approach embankment to the Mecuburi bridge has been raised.

Further work, including crossing the wide basin, is proposed for Phase II.

3.2.4 TRL's role

General advice on;

(i). Gravel sources.
(ii). Construction problems.
(iii). Possible solutions to the overtopping problem at the Mecuburi bridge.
(iv). Possible solutions for crossing the flood basin near to Milhane.

TRL will also provide designs for the Milhana crossing during Phase II and designs of possible surfacing research trials for Phase II.

3.2.5 Observations during site visits

1. Most of the road is in poor condition with many areas of eroded and degraded formation, loss of gravel and some collapsed structures. Re-gravelling has begun in some places.

2. Unfortunately, in many places, recently constructed formation has already started to collapse and erode into the side drains and will need repair before being gravelled again.
3. The wing walls of the recently constructed culverts were observed to be low, connecting to the headwalls at the level of the underside of the culvert slab rather than at the level of the top of the gravel surface. This low level is likely to lead to rapid erosion of the gravel.
4. The estimated cost of a large culvert approximately 19 kilometres from Gracio is higher than would be expected for such a structure. Reasons for this high cost are unknown. It also appeared that the required cross-drainage capacity of the culvert has been estimated without supporting information concerning likely peak flows and therefore the culvert is at risk of being overtopped with subsequent damage to the road and to the culvert itself. It seems that, typically, culverts which overtop are replaced with larger culverts without any attempt to estimate the required size.
5. During the last site visit in March 2009 the wide basin at Milhana was covered in water to a depth of around 1.5 metres. Pedestrians were walking through the water holding their possessions in the air or they were crossing using a local canoe. Water flow was estimated at approximately 20-30 cubic metres and 1-2 linear metres per second. Recently placed fill material had already been washed away. A substantial crossing is required comprising a long embankment with adequate height above flood water (typically 500 mm), protection against erosion and cross drainage structures.
6. Good gravel sources – granite, quartz and laterite – were identified alongside most sections of the road. Some had already been prepared and stockpiled.
7. It is probable that sources of surfacing aggregate can be found locally.
8. It was explained that when work began on site there were few people living alongside the road. These numbers have increased significantly, demonstrating the attractive effect of a rural road as well as warning of the potential harm if the road subsequently deteriorates or is isolated by damage to the section before Gracio.

3.2.6 Available information

The following information had been requested during previous site visits:

(i). Information on the overtopping frequency and water depth at the bridge approach.

(ii). Test results of the subgrade along the road.

(iii). Test results of gravels and base materials found alongside the road.

(iv). DCP tests through the basin at Milhana at 40 metre spacing.

(v). Hydrological survey of the catchment and basin at Milhana to estimate required cross drainage requirement.

(vi). Topographical survey of the basin at Milhana to identify suitable embankment sites.

None of this information has been made available.

A drawing of the culvert at 19 kilometres from Gracio was provided on site although this drawing did not include some recent design modifications such as the removal of intermediate pillars.

3.2.7 Recommendations

Site practice

1. It was recommended that new formation work is covered with gravel as soon as possible to prevent it being damaged by rain.
2. The basin at Milhana should be surveyed in detail to look for the most suitable place to locate the embankment crossing (a stable site, reduced volume of required fill, etc) and to determine if an outlet blockage is preventing the basin draining and thereby raising flood water levels.
3. Source of good construction materials should be identified and assessed for quality (grading, Atterberg and CBR tests) and quantity.
4. Alternative designs for the Milhana crossing should be considered.
5. A breakdown of concrete costs should be prepared.

Surveys, tests and analyses

The following surveys, tests and analyses were requested.

1. Topographic survey of the Milhana basin
2. Hydrological analysis of the catchment and basin at Milhana
3. Hydrological survey of the required cross drainage capacity of the large concrete bridge

Design work

1 The Provincial Consultant should obtain topographic maps of the region in order to estimate the required cross drainage capacity of the Milhana basin crossing.

2 The Provincial Consultant should prepare a line diagram of the site showing the planned works.

3.2.8 *Photos*

Section of road in need of repair and a new structure

Low wing walls which lead to the erosion of surfacing materials

Section, beyond Mecuburi bridge, which is said to overtop

Culvert approximately 19 km from Gracio under construction

Basin at Milhana showing people wading across

Section of formation degrading without the protection of a gravel surface

3.3 Bene-Fingue-Cachombo road, Tete (TE1 and TE2)

3.3.1 Description of road

Bene is located approximately 100 kilometres north of Tete town on the road to the Zambian border. Fingue is approximately 110 kilometres along a Provincial road heading west from Bene around the north of Lake Cahora Bassa. Cachombo is another 25 kilometres beyond Fingue. The road is in hilly terrain. The road is unsealed and in reasonable condition with very little erosion or soft areas, although the surface is mostly very rough with many large protruding stones. The road is currently under contracted maintenance. Most water crossings along the road are either drifts or vented causeways.

3.3.2 Key problems

The key problems to providing reliable access along the road are:

1) Short term closures when drifts flow too full for safe passage.
2) The steep, slippery and erodible ascent beyond Fingue.

3.3.3 RRIP work on the road

There are two completed or ongoing RRIP improvements on the road. Approximately 87 kilometres from Bene a series of piers and a deck have been constructed onto the upper surface of a vented causeway across the Rio Nhimbe, which flows very deep when in flood, thereby increasing the cross drainage capacity of the structure.

Approximately 10 kilometres beyond Fingue, a very steep hill ascent which is said to be very slippery when wet and loose when dry is being provided with a stone masonry surface and concrete screed.

A further improvement is proposed under Phase 2 just before Cachombo. A drift, which currently flows very deep when in flood, is to be replaced with a vented causeway with, apparently, 13 large diameter pipes.

It is a stated objective of the ANE Delegate to eliminate all submersible crossings by raising the level of all submersible structures in the Province with piers and a raised deck. Submersible structures are considered to be uncomfortable and dangerous and subject to short term loss of access.

3.3.4 TRL's role

TRL had no role in the design of the piers and deck on the Rio Nhimbe drift.

TRL provided advice regarding the improvements to Fingue hill, including recommendations on:

(i). The use of locally available materials and labour based methods.
(ii). Subgrade preparation and the suitability of the existing material.
(iii). Stone selection and the rejection of stones liable to laminate.
(iv). The need to fill gaps between large stones with smaller stones.

(v). Screed construction, including the possible inclusion of reinforcement, although during the most recent visit, this inclusion was not being planned

When the recommendations have been shown to produce a sustainable solution to the accessibility problems on Fingue hill, a work norm will be produced. A draft of this work norm is given later in this section.

3.3.5 Details of the trials

The performance of the surfacing improvements to Fingue hill should be monitored.

3.3.6 Observations during site visits.

Rio Nhimbe causeway

1. The original causeway at the Rio Nhimbe had five openings below a submersible deck. It was reported to overtop to a depth of at least 1 metre during and for around 24 hours after rainfall. 15-20 masonry pillars have been constructed on top of the original deck and a raised deck has been added. It was stated that the masonry of the pillars was keyed into the original deck and that reinforcing steel was embedded into the original deck and tied into the raised deck. It is not known by how much the reinforcement was embedded, nor how many bars were used. Water courses in the area are seen to carry huge trees and stumps when in flood, which would exert large forces on submersible structures.
2. The structure was almost complete in March 2009 with only a protective concrete leading edge to be added to the upstream face of several pillars. However, the improved structure was recently overtopped causing significant erosion on the downstream side. Additional wing walls are being built on this same side.
3. It was stated that the improvement was designed by simply raising the deck by approximately the same height by which the original structure was said to flood. It is not believed that any topographical or hydrological analysis was carried out.
4. The approach ramps are inadequate. They should be extended away from the structure with a non-erodible surface and protected side slopes. Erosion protection is also needed on both sides of the downstream channel. The deck surface is flat. A slight cross-fall would have been preferable.
5. There were some problems with concrete quality on the Rio Nhimbe structure, with exposed reinforcement and reduced cover.

Fingue hill

1. Fingue hill is a steep slope almost 1 kilometre long in red silty soil. It was stated that there are many accidents on the hill. By March 2009 approximately 30 metres of half carriageway width had been surfaced by excavating to a depth of 200 mm, compacting the soil surface and filling with large rocks collected nearby to a camber of 5% (although this section is curved and appears to be super-elevated). Concrete will be used to infill the stones and cover them to a thickness of around 50 mm. The carriageway surface will connect with mortared stone pitching in the side drains.

2. It was understood that the original plan was to place thin reinforcement in the layer of concrete but, on site, it was explained that this was only a suggestion and that the Provincial Consultant chose not to do this.
3. Earlier site visit reports refer to the use of imported base material underneath the stones. However, this was not being done.
4. During a previous site visit, alternatives such as wheel track strips were discussed. These have not been trialled on the site.
5. The soil in the completed section was poorly compacted, but apparently no compaction equipment had been available. It is important that all future surfacing is constructed onto a well compacted base. The stones do not appear to have been tightly packed together. A tightly packed surface with a reasonably fine aggregate concrete would have been preferable.
6. Compaction of the soil before stones are placed should be checked against a defined standard.
7. Some stones are being rejected, notionally because they are laminar and weak and unacceptable but, on observation, some laminar stones are being included and some non-laminar stones are being rejected. The current rationale for rejecting stones is unclear. An alternative description was that laminar stones would have been unacceptable if they had formed the exposed surface of the carriageway, but since all stones are to be covered by concrete, it was acceptable to use laminar stones in the construction.
8. Construction joints are not currently being formed in the surface. Some short lengths of stone pitched side drains are being constructed.
9. Although the entire hill should be improved with surfacing, funding constraints have led to a decision to improve 150 metres near the top and 100 metres near the bottom. Gravel is to be used on the intermediate sections.
10. Further down the hill a short section of trial surfacing has been completed, with a mortared stone pitched side drain and a similarly protected mitre drain. A deep lateral surface texture has been provided on the carriageway.
11. The road crosses a hillside. Some relief culverts have been provided to carry water from the uphill side for disposal on the downhill side.
12. Still further down the hill is a short detour which has been opened up by road users to locally reduce the gradient and give vehicles an opportunity to accelerate before the main ascent. The Provincial Consultants are considering retaining this detour in the final alignment.

Cacombo drift

1. The third site is just before Cachombo. It is a drift which flows to a depth of at least 1 metre for at least 24 hours after rainfall and whose deck appears to be damaged part way across.
2. Many of the other drifts along the road were submerged in non-flowing water, in most cases because outfalls are blocked with vegetation. All water courses should be maintained and vegetation cleared. Some drifts have well designed outlets. Advance warning signs were seen before one of these drifts. It is felt that a single drift on a road can surprise a driver and cause an accident, but when there are

many drifts, as on this road, drivers become used to them and the accident risk is lower.

3. Good gravel is reported to be widely available in the area of the road.
4. The passabilities of the selected sites on this road are very different. Water crossings which flow full are impassable and dangerous to pass during and after rainfall – the selected sites are typically impassable for around 24 hours after rainfall – but when dry they are passable and safe. Fingue hill, however, is impassable and dangerous when wet but also very difficult to pass at all times of the year. Clearly the water crossings are less of a long term problem than Fingue hill. It is important that acceptable periods of lost access are included in definitions of impassability. Despite this, the three selected sites are probably the highest priority sites along the road and therefore a good selection.

3.3.7 Information.

The following information had been requested during previous site visits:

(i). A topographic survey of Fingue hill.

(ii). Material tests of suitable base material for Fingue hill.

(iii). DCP survey of the in situ material on Fingue hill.

The Provincial Consultant said that a topographic survey had been done and that the results had been sent to DIMAN. Other information was not available.

The following activities were requested during the visit on the 15th of March.

(i). Preparation of a Bill of Quantities for the proposed structure near Cachombo.

(ii). Discussion with appropriate Provincial and District authorities to confirm priorities of improvements.

(iii). Submission of a list of proposed improvements with costs to DIMAN.

(iv). Hydrological analysis of the required cross-drainage capacity of the Rio Nhimbe crossing. Topographical and hydrological analyses are required to correctly estimate the required cross drainage capacity of a structure. It was stated by the ANE Delegate that Provincial Consultants tend to under-design water crossing structures.

None of this information has yet been received.

No design, construction or costing information was available on site. However, discussion after the visit with the ANE Delegate, gave the following figures.

- The cost of the Rio Nhimbe structure was quoted as almost Mt 3 m, this being around $120,000 – this seems a high price for such a structure
- The cost of Fingue hill improvements was quoted as over Mt 4.75 m, this being around $190,000, although this is said to include an additional 6 kilometres of general road improvements, although the details of this are unknown

3.3.8 Advice and recommendations.

There is no information available regarding quality control measures that were used on Fingue hill but the construction of this nature should take into account the following:

1. Structural strength of the stone/concrete composite must be adequate for any loading that is not abnormal but, for long sections, thermal stresses caused by summer heat and rapid cooling when it rains can take a toll on the concrete screed causing cracking and exfoliation.
2. Crack inducing grooves should be formed in the concrete surface every 4 metres.
3. The concrete mix should be rich (minimum 1:2:3) to ensure that the corrugations do not wear out too quickly and reduce traction.
4. Severe undercutting can cause partial or extensive collapse of the stone paving and the screed above it. Ingress of water under the stone paving should be prevented.
5. Construction of the surface should be improved to achieve the correct camber, adequate compaction of the soil and tight placement of the stones.
6. All reasonably strong stones can be used – it is not necessary to exclude laminar stones.

3.3.9 Draft recommended work norms for stone masonry and concrete screed

The construction procedures should be as follows:

1. Clear section of all debris.
2. Mark and excavate carriageway area for laying stones.
3. Compact road base.
4. Lay stone packed in stable position.
5. Poor concrete of high workability to fill the gaps.
6. Lay mesh wire or fencing net wire.
7. Prepare and place concrete screed of low workability.
8. Compact by ramming and in the process impress fine corrugations for traction.
9. When concrete has set, place a blanket of sand on top and wet it for curing for 7 days.

3.3.10 Photos

Improved structure on Rio Nhimbe with water flowing at both levels

Downstream erosion of improved Rio Nhimbe structure

First section of stones on Fingue hill

Stone placement – uncompacted soil and loose packing

Rejected stones – some laminar, some non-laminar

Preparation of mortared stone pitched side drain

Short trial section of surfacing

Short detour to reduce gradient

Deep drift near to Cachombo

Rough road surface

Well designed drift outlet

3.4 Zero-Mopeia road, Zambezia (ZA1)

3.4.1 Description of road and history.

The Zero-Mopeia road branches off from the National Road, N1, about 60km from the Zambezi Bridge Construction Project, a 3km bridge that is the third longest in Africa. The road is about 44km long. The area is generally flat to undulating and a substantial section of the road traverses a natural forest.

3.4.2 Key problems

Some sections of the road were lower than the surrounding ground and subject to flooding during the rainy seasons. Passability was limited and enhanced maintenance was necessary for all-weather access. (Beyond Mopeia the road is subject to flooding from the Zambezi river and passability problems are more severe).

3.4.3 RRIP work on the road

The project was planned for stage construction, the first stage being to raise the road level where necessary and to re-gravel. At the time of the first site visit the construction works had been completed up to Mopeia. The second stage of the work is to provide a surfacing.

3.4.4 TRL's role

(i). To assess the quality of the construction work and to assess long term performance .

(ii). To identify sites for potential surfacing research trials

3.4.5 Observations during site visits

Materials

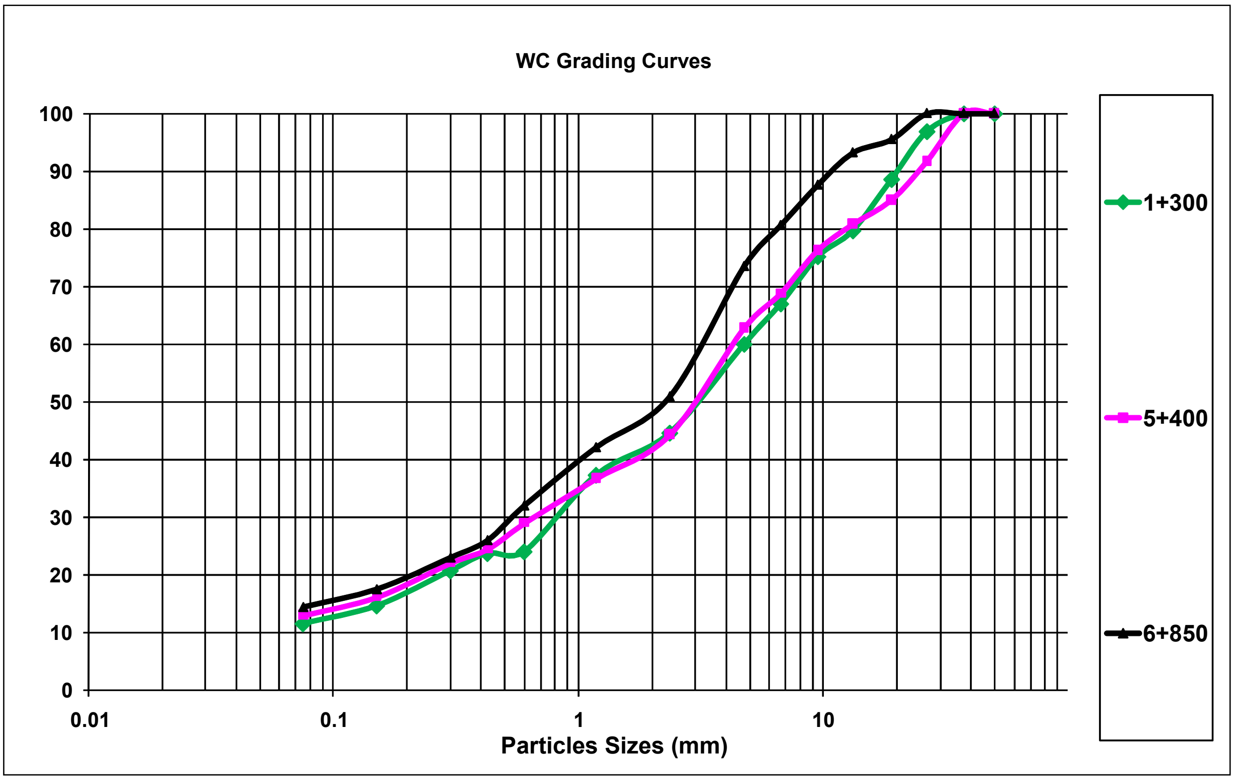
1. The area is unusual in that good gravel is available at economic haul distances, unlike most other projects under RRIP. In-situ sandy subgrade material was used for the formation. The wearing course was constructed of fine quartzitic gravel with a proportional content of fine red silt. This makes the material perfect for use as wearing course. The graphs below show the grading of the gravel in comparison with internationally accepted standards (TRL report '*Increased application of labour based methods through appropriate engineering standards)*.
2. This material will also be used as roadbase material in the second stage of the construction. The wearing course will become the subbase and the roadbase will be constructed with similar gravel. It is therefore necessary to assess the quality of the gravel against specifications for natural gravel roadbases for sealed roads. The graph below shows that it is a little fine.

Construction

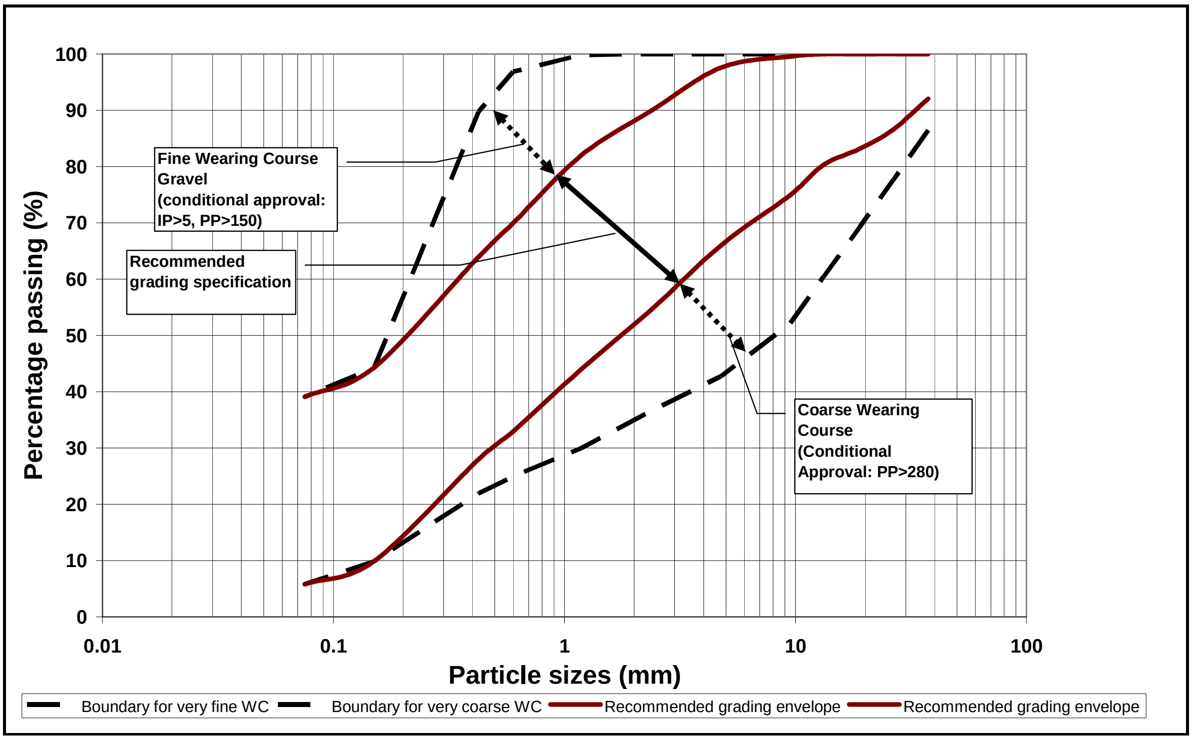
1. The quality of the completed road looked good based on the visual assessment carried out during site visits. However, there was no quality control data given to

the team and it is difficult to ascertain the quality of the compaction. However, it is possible to obtain the level of compaction through DCP tests on the completed section on the edges of the road at least 0.5m from the shoulders.

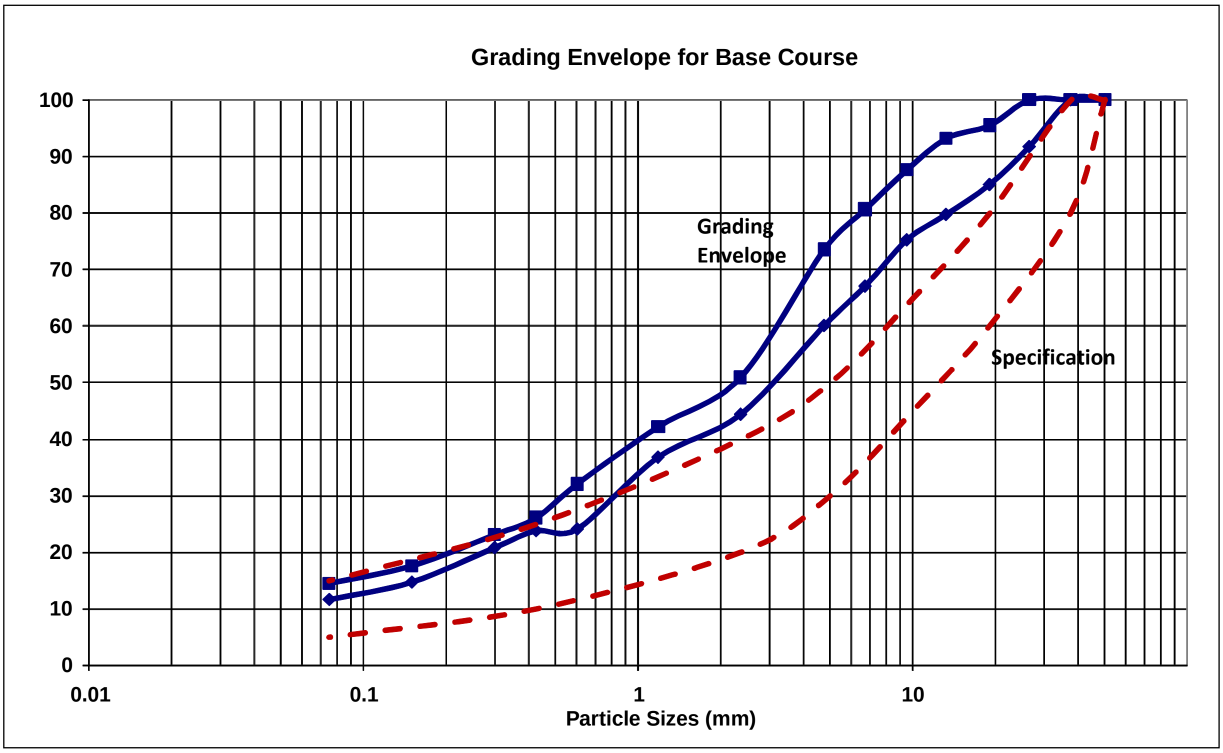
2. It is also not clear whether the embankments that were built will be sufficient because part of the road falls within the Zambezi flood plain. It is difficult to properly design for this sort of flooding so mostly the heights of embankments are determined from local knowledge. This method of assessing flood heights often works but not always. On some sections, the road is lower than the surrounding ground but the slope of the side drains is probably adequate (0.3%).
3. The camber was quite low at approximately 3%.
4. Appropriate work procedures and specifications are often not properly followed when works involve the construction of gravel roads because the standard is considered to be low. This could be the reason why quality test results were not immediately available.
5. Higher compaction gives substantial benefits because the wear resistance of the wearing course is enhanced and uneven settlement in the lower layers is prevented. Thus it is important to test compaction achieved during the construction of gravel roads. This applies to both the subgrade and the wearing course. For remote projects where laboratory facilities are unavailable it may be necessary to use a 'method specification' type of quality assurance.



Grading curves of the gravel on the Zero Mopeia Road



Recommended grading curve for gravel surfacings.



Comparison with TRL specifications for natural gravel roadbases

3.4.6 Recommendations for work-norms

For roads that have a high likelihood of being upgraded to sealed roads at some stage in future, the construction procedures should be as follows:

1. All loose sands and materials should be removed until harder ground is reached.
2. If the loose sand is deep, heavy compactors should be used to collapse any loose pockets or collapsible soils; super-compactors can be used for this purpose. If super compactors are not available normal pneumatic or vibratory compactors can be used though their effectiveness is not as good as that of super compactors. After a few passes water should be applied and further compaction should be carried out ensuring that, at the point of compaction, the soil is wet of optimum.
3. Embankments should be compacted in layers (not more than 200mm thickness) and quality test should be carried out on each layer unless the method specification type of quality assurance is used.
4. The top of the subgrade should be formed into the required camber so that the gravel layer can be constructed with uniform thickness.
5. The surface of each layer should be checked for flaws which should be corrected before subsequent layers are constructed.
6. Final clearing is a very important because it enhances stability of the side and back slopes and helps rapid vegetative growth.
7. It is important to set up a proper approval process to avoid flaws in the construction process because poor construction has a significant influence on the in-service performance of unpaved roads and even greater impact on low cost sealed roads.

3.4.7 Photographs

Section of the completed Zero Mopeia road

3.5 Nhacufera-Machaze road, Manica (MN1)

3.5.1 Description of road

A Provincial road which leads west from the N1 towards the border with Zimbabwe, about 100 kilometres south of the junction with N6. The road passes through gently rolling terrain and its surface is very rough, with large stones protruding from the gravel surface. Traffic is very low, perhaps due to the poor road surface. Approximately 150 kilometres along this road is the town of Machaze and further along, the town of Nhacufera, close to Inhambane Province and the Zimbabwe border.

The remoteness of the site from the provincial centre Chimoio, approximately 300 kilometres away, has had a significant effect on project operations and cost. Mobilisation, procurement, transportation and supervision over this distance are time consuming and costly.

3.5.2 Key problems

The key problem that makes the road relatively impassable is the extremely rough surface caused by the large stones in the gravel. The ride is extremely uncomfortable and although the road is stable and free of erosion, there are very few vehicles which are able to travel along it.

3.5.3 RRIP work on the road

Five kilometres of this road have been improved under RRIP funding. A further five kilometre section of the road is proposed for improvement under further RRIP funding.

The completed work on the road involved scarification, processing and reshaping of the gravel, provision of a single Otta seal and improved drainage. Similar improvements are proposed for the next phase of funding.

3.5.4 TRL's role

TRL provided advice concerning all stages of the construction of the first five kilometres including several variations as pilot trials. In future TRL will,

(i). monitor the performance this section.

(ii). propose designs for future improvements along the road.

(iii). propose and design research trials to improve the design methods for Otta seals.

(iv). provide guidance during construction.

(v). produce work norms for the construction methods.

3.5.5 Observations during site visits.

Materials

1. Very coarse quartz gravel on the existing gravel carriageway which was used for the construction of base course. The materials was poorly graded consisting of fine silt and quartz boulders and very little of other particle sizes in between. This is the

reason why the existing wearing course was so rough and caused passability problems.

2. The surfacing aggregate was a graded quartzite with nominal maximum and minimum sizes of 20 mm and 5 mm respectively. The quartz gravel was quarried and processed using labour-based methods. This involved excavation, stockpiling, sieving through 20 mm and 5 mm sieves and stockpiling the processed materials appropriately to avoid contamination. The fines content was less than 1% and the ACV was 18%, hence the aggregate met conventional specifications.
3. Prime (MC30) and bitumen (MC3000) were procured from South Africa and delivered to site. This occurred during an international 'price bubble' and it is likely to distort the cost of construction.
4. Water was difficult to obtain. The project is located in a dry area and water is very scarce especially during the dry season. The contractor stated that this was one of the biggest challenges during construction because water had to be obtained and hauled over a long distance, approximately 30km.

Construction

The construction process involved:

(i). Site clearing and preparation.

(ii). Scarification of the existing carriageway, mixing, watering and compaction with a grid roller and a pneumatic roller. The use of the grid roller was meant to break the quartz boulders which were present in large quantities in the existing wearing course.

(iii). Application of prime at 1.0 l/m^2 with a conventional binder distributor followed by curing.

(iv). Application of MC3000 bitumen at 2.0 $l/m^{2.}$

(v). Laying the processed gravel or graded aggregate. A small amount of excess gravel is usually unavoidable but too much was applied in this case because the contractor was apparently worried about the possibility of bleeding.

(vi). Rolling with an 18-ton pneumatic roller during the hottest part of the day for seven days.

(vii). Construction of a double Otta seal and also a sand seal over a single Otta seal.

1. Quality control is an important and integral part of the construction process. Quality assurance for the construction works depends on the appropriateness of the quality control methods used and how well they are adhered to in practice. For this remote site it is quite a challenge to carry out all necessary quality control measures unless a site laboratory is put in place.
2. There were quality checks on the processed aggregate in terms of the grading and fines contents and the grading envelope was within the grading specification envelope based of the Otta seal manual (Norwegian Public Roads Administration, Publication No. 93, '*A guide to the use of Otta seals*').
3. The intended processing of the base course was not successfully carried out because the grid roller failed to crush the hard quartz boulders adequately; hence the base layer had a large quantity of oversize stones. The grid roller mainly pressed the

stones down, lower into the base rather than crush them. There was concern that the Otta seal might not stick well to the shiny surfaces of any protruding stones.

4. Base compaction was not controlled adequately. No field density test results have been provided and it is not clear whether such tests were carried out at all. Such quality control measures are very necessary because the combination of substandard/marginal material and poor quality control can result in poor in-service performance even at low traffic volumes.
5. The single Otta seal along the road was almost completed at the time of the last site visit in March 2009. Rolling with a pneumatic-tyred roller was underway. This is the most critical component of Otta seal construction. Prolonged rolling in hot weather causes the bitumen to migrate up into the aggregate layer and is an essential part of the Otta seal process. Road traffic itself is often used to provide this kneading and compactive effort but this has to be carefully controlled because traffic is equally able to dislodge aggregate when travelling too quickly. When traffic is too low to provide adequate compactive effort, as in this case, a reasonable solution is to use a pneumatic roller to start the process until all aggregate is bound and then to open the road to traffic. This is likely to take about a week. In the absence of a pneumatic roller or road traffic, a loaded truck can be used, although the width coverage of a truck is much less and more time is needed). It is important that rolling starts promptly after construction.
6. The aggregate for the surfacing was over-applied. As a result the contractor had to produce more aggregate as the stocks ran short of the required amount.
7. The Otta seal appeared to have been reasonably well constructed and the aggregate appeared to be reasonably coarse and with a low fines content. However the section with the double Otta seal showed signs of stripping and may have been caused by one or more of the following:
   a) The application rate of the bitumen was inadequate and there was not enough bitumen to hold the aggregate
   b) The bitumen had not migrated adequately into the interspaces in the first layer and bitumen sprayed for the seal coat could have flowed into these interspaces leaving a lean film of bitumen on the surface that was inadequate to hold the stone. This is the most likely reason for the stripping problem.
8. One section of road has been raised with an embankment and a series of six culverts. It is believed that a sand seal or a second Otta seal is to be constructed along this section.
9. The final 1 kilometre or so of the road is a hill where the option of a second seal had already been considered. On site the possibility of trialling a variety of second seals on the hill was discussed, including a second Otta seal, a sand seal, a grit seal (coarser than a sand seal) and a control with no second seal.
10. Some drainage improvements had been carried out with, for example, a length of masonry scour checks, although it was pointed out that additional mitre drains are effective and cheap and should be provided wherever possible.
11. It was proposed that a hill a short distance beyond the end of the site be left unimproved in order to slow vehicles down on the approach to a vented drift where fatal accidents are said to be common, in part due to high approach speeds. However, it was stated that a better solution would be to improve the hill to reduce

traction problems and also implement road safety measures on the approach to the drift.

12. It was noted that various activities that are often referred to as 'final clearing', such as spreading soil arisings (i.e. unwanted soil spoil) are often omitted from a contract and that such activities should be included.
13. The site was considered as a possible case study that could be visited by those from other Provinces under the AFCAP project, although site accessibility is a disadvantage.
14. The drainage system was not improved as part of the construction works and, at some locations, the crown height was not adequate (at least 750 mm above the invert level of the side drains is recommended based on extensive research in southern Africa; SADC *Guidelines for Low Volume Sealed Roads*, 2003).
15. There was no allocation for final clearing, an activity which could have involves opening of mitre drains and deepening and reshaping of side drains

3.5.6 Information

The following information had been requested during previous site visits:

(i). DCP tests along the entire road, at a suggested spacing of 100 or 500 metres

(ii). The grading and fineness index of the aggregate used for the Otta seal

(iii). A topographic survey, although it was noted that this was not essential

This information was not available on site.

During a previous site visit, alternatives such as sealed shoulders and a narrow mat were discussed. These have not been trialled on the site.

No design, construction or costing information was available on site.

The following were requested:

(i). Propose trials of second seals for the hill at the end of the road

(ii). Assess the remaining quantity of Otta seal aggregate at the current source; if insufficient for the Phase 2 work, prospect for more suitable Otta seal aggregate

(iii). Search for more convenient sources of water

(iv). Final clearing activities should be included in contract BoQs

(v). Sieve any identified new sources of Otta seal aggregate and test for grading and ACV

No responses to these requests have yet been received.

The contractor agreed to provide a line diagram showing the completed work and the planned Phase 2 work.

3.5.7 Recommendations for work norms

The works procedures, the quality and appropriateness of the equipment used and the competence of the site staff were satisfactory. However, for low-volume sealed roads certain measures should be put in place in order to enhance the in-service performance.

Regarding this site in particular the following recommendations need to be considered to improve on the quality and performance of the intervention:

1. The pan test and trialling on short sections should be carried out so that the application rates of the bitumen and the aggregate are matched. This will reduce the amount of aggregate that is lost and help to reduce the cost of construction.
2. The crushing of aggregate can be improved through minor changes in the processing:
    a. Scarify the existing wearing course gravel, mix and windrow.
    b. Spread in layers no more than 50mm and roll with grid roller while the material is dry and windrow the crushed material
    c. Repeat the process 2 or 3 times
    d. Mix with water and compact normally
3. Quality tests for the construction activities should be carried out for approval of works. If laboratory test are not feasible because of the remoteness of the sites or lack of a site laboratory the Method Specification Type of QA can be used effectively. This includes compaction to refusal which can be determined on site through trialling.
4. For very low volume roads, the period of rolling the Otta seal should be increased so that the bitumen is worked adequately into the aggregate layer. Usually the action of traffic aids this but with traffic as low as 15 vehicles per day much of the effort will need to be applied at the construction stage, therefore an Otta seal may not be the best option for such roads. A few passes of the pneumatic-tyred roller during the hot period of the day for about 2-3 weeks is appropriate.
5. Funds need to be made available for minimal formation, final clearing and improvement of drainage including mitre drains. This will substantially improve the in-service performance of the road at relatively very low costs.

3.5.8 Photos

Newly constructed Otta seal

Newly constructed Otta seal – detail


Pneumatic-tyred roller


Otta seal after initial rolling


Scour checks


Down hill at the end of the road


Rough surface of the original road


Rough surface of the original road – detail

3.6 Beira-Savane, Sofala (SF1)

3.6.1 Description of road and history

Beira Savane Road branches north-eastwards from N6 in the western outskirts of Beira. After 2 kilometres through an urban residential area, the road crosses a 30 km flat coastal flood plain before arriving at Savane, from where a short boat trip connects to a small beach resort. About half way between Beira and Savane, the road passes through a small village on slightly raised ground.

The road has been selected for a trial of Emulsion Treated Base (ETB). The trial will also include a range of bituminous surfacings. The road is also proposed as a possible training site for the AFCAP project.

3.6.2 Key problems

The road is regularly flooded hence the key problems to be solved to provide reliable access along the road are:

(i). Raising the level of the road across the flood plain.

(ii). Finding adequate construction materials.

(iii). Ensuring adequate cross drainage through the embankments.

3.6.3 RRIP work on the road

The section through the village close to the main road is a high priority together with the lowest and most flood prone areas of the road as a whole. Some culverts have been constructed and some embankment work has been carried out on the flood plain but most of the work will be carried out during Phase II.

3.6.4 TRL's role.

Advice on all aspects of the works including,

(i). Embankment construction.

(ii). Finding suitable materials for roadbase and surfacings.

(iii). Testing of materials

(iv). Design of stabilised roadbase and surfacings

(v). Design of the research sections

3.6.5 Observations during site visits.

1. Large culverts are currently being installed in the unsealed urban section of the road, with soffit levels approximately 500 mm above the current road level and short ramps on either side.
2. The remainder of the road, approximately 30 km, is an unsealed low embankment across the flood plain, formed from a good compactable graded sand.

3. Some culverts have been constructed on the flood plain, again to a raised level and with short ramps. It is not known how, if at all, the required cross drainage capacity of the culverts were estimated.
4. A length of embankment approximately 2 km long had been built at the time of the last site visit (March) approximately 25 km from the start of the road, with an additional 300 mm(approximately) of material. The shoulders are already eroding and forming sediment in the drains.
5. It was stated that the completed embankment was designed to be 50 mm above the maximum flood level. This is insufficient if the pavement and surfacing are to remain dry and strong. A height of 600 mm above the highest expected flood level is normally recommended in order to prevent the upper pavement layers becoming saturated and weakened.
6. Raising the road level by 500 mm with side slopes of 1:3 will reduce the width of the carriageway by 3 metres. In most places the current road has adequate width, but this may not be the case for the 2 km embankment which has already been constructed to a designed width hence this may result in a carriageway with inadequate width.
7. Armouring could be used to improve adhesion between the sandy material and a bituminous seal. Geocells could also be used on the sandy material.
8. Two sources of sandy gravel have been assessed close to the road near to Savane, one of red material which was nearly exhausted, and another of yellow material which had supplies remaining. The yellow material was used in the 2 km embankment described above. Another gravel source was reported at 14 km from the start of the road, but has not been visited.
9. TRL carried out two DCP tests at locations that looked prone to flooding. At both places the material appeared well compacted to a depth of at least 900 mm, with a typical penetration rate of only 5-15 mm per blow. It is possible that the road has been formed over many years by simply spreading layer after layer of sandy gravel as it slowly settled down into the soft in situ material.

3.6.6 Information.

The following information had been requested during previous site visits:

(i). Material properties of the yellow sandy gravel.

(ii). Material properties of the sandy in situ material.

(iii). DCP tests along the entire road.

(iv). Material properties of available surfacing stone (grading, flakiness and ACV)

(v). Mix design tests for ETB.

(vi). Topographic and flood survey to determine the appropriate height for the embankment.

Data relating to the gravel sources and surfacing stone was made available. Soaked CBRs for the yellow sandy gravel were reported to be around 100%, rather higher than would be expected for the material. The automatic CBR laboratory equipment was not operational and the manual device that was used had not been calibrated recently and was well past the date limit for re-calibration. Unfortunately the flakiness of the stone was too high for surface dressing stone.

Other requested information (DCP tests, ETB mix design, topographic survey) was not available.

Retesting of the sandy gravel was requested.

The materials available from three quarries alongside the main road (N6) were assessed for surfacings. The basalt at Xiluvo quarry was of good quality and a sample of 19 mm stone was found to have adequate flakiness for surface dressing.

3.6.7 Available information

A list of works was available, showing the sections where improvement works were planned namely an embankment with surfacing from kilometre 10.5 to 12.9 where the road floods, and from kilometre 14.0 to 16.0 km to reduce dust problems in the village about half way between Beira and Savane.

3.6.8 Recommendations

Site practice

1. Completed earth works should be covered with an erosion resistant material before it can be damaged by rainfall.
2. Maintenance is required to keep side drains clear – they are filling up with sediment.

Activities

The following activities were requested.

1. Prospecting for more suitable base materials, and stockpiling and testing of any suitable materials

Surveys, tests and analyses

The following surveys, tests and analyses were requested.

1. Topographic survey along all sections of the road where embankments are planned and correlation with maximum flood levels in order to determine where embankments are required and what height they should be. This survey should also include cross sections every 100 metres.

   Since the flood plain is flat, the entire length of the road is a priority and should be improved, rather than selecting specific sites which are currently slightly lower than other places. If the funds are insufficient for the entire road, improvements should start at the end of the urban section and continue until funds are exhausted and restarted when more funding is available.

   Both these alternatives were considered. It is not yet known which sections the ANE delegation will decide to improve.
2. A DCP survey of the in situ materials along all sections of the road that are to be improved should be carried out at a spacing of 200 metres.

3. Material properties of the 19 mm and 6.5 mm stone obtained from Xiluvo quarry were requested.

Design work

1. The ANE Delegation should arrange with DIMAN and the laboratory in Maputo for testing and mix design of the ETB. A guidance note had been commissioned from a South African engineer with extensive experience of ETB but this may need to be modified to suit the testing equipment that is likely to be available in provincial laboratories. In particular, the design method relies on the Indirect Tensile Strength Test and this is not usually available in provincial laboratories. Alternative 'strength' tests could, perhaps, be provided.
2. The Provincial Consultant should prepare a line diagram of the problematic sections and possible improvements.
3. TRL are to produce a series of designs for the different trial sections, allowing variations in surfacing seal to be trialled and ETB to be trialled with compacted natural gravel as the control.

3.6.9 Photos

The junction of N6 and Beira Savane Road

Raised culvert construction in the urban area

Flat coastal flood plain

Site of ponding water on the coastal flood plain

Lateral erosion of the constructed embankment

Side drain erosion of the constructed embankment

Stockpile of sandy gravel

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3.7 Panda-Urene, Inhambane (IN1)

3.7.1 Description of road

Panda Urene Road is a 30 kilometre road located west of Maxixe. It passes through flat terrain on a plateau slightly raised above the coastal plain. The in situ soil is fine sand. Traffic is very low.

3.7.2 Key problems

The key problems that need to be solved to provide reliable access along the road are:

(i). Passability and instability problems of the in situ soil when dry.

(ii). Unavailability of good natural gravel in the area.

(iii). Inadequacy of the Rio Cudingene crossing.

3.7.3 RRIP work on the road

RRIP Phase 1 funding is being used to improve the first 5 kilometres. The following 10 kilometres are being improved in a similar manner under separate funding and the final 15 kilometres to Urene are planned for improvement under RRIP Phase 2. Urene is an Administrative Post and the road is said to be required for agricultural and social needs.

The RRIP works along the first 5 kilometres include formation and gravel wearing course along the entire length and an embankment across Rio Cudingene.

3.7.4 TRL's role

TRL had no role in the design of the improvements. During the site visit on the 21st of March, TRL provided advice on:

i). The need to base the design of the water crossing structures on the expected flood water flow. Topographical and hydrological analyses are required to correctly estimate the required cross drainage capacity of a structure.

ii). The likely performance of the poor quality material being used on the road as gravel and the difficulty in obtaining good quality gravel

Beyond observation of the performance of the surfacing material and the adequacy of the improved embankment across Rio Cedingene, no research trials are appropriate for this road.

3.7.5 Observations during the site visits

1. The first section of the road from Panda is being formed from a flat unformed track. However, the in situ sandy soil is very weak and unstable and the formation appears to collapse rapidly to a flat loose section under the action of traffic and rainfall. The soil is weak and unstable partly because fines have been washed away by rain and traffic. This section is almost impassable in the dry in a 4WD vehicle.
2. At the time of the last site visit in March 2009 gravelling work was beginning but the gravel, currently being sourced alongside the road 1.4 km from Panda, is a non-

plastic red sand and is likely to erode or degrade very quickly. Good gravel does not appear to be available within a cost effective haul distance.

3. The gentle descent to Rio Cudingene has been prepared for formation but is in fine loose sand that can be impassable when dry.
4. It is not expected that the road construction will last long and is therefore an inappropriate solution for this combination of climate, terrain, soil and available materials. The Head of the Technical Department stated that he would expect the road to last for a few years under current traffic levels but that as traffic increases, its life expectancy will decrease.
5. The Rio Cudingene crossing is an embankment with a series of small structures. The earthworks are to be repaired and widened. Five original culverts are to be cleaned and repaired. Two new culverts are being constructed and a large corrugated steel culvert is being replaced with a small and well constructed two span concrete deck and masonry abutment bridge.
6. The improvements to the Rio Cudingene crossing have not been based on a hydrological analysis. The cross drainage capacity is clearly inadequate for the huge catchment. The new bridge is unlikely to have significantly greater capacity than the culvert which it is replacing. The entire embankment should be protected against inevitable overtopping. It was also reported anecdotally that when the embankment floods, it does so with high depth and with rapid flow.
7. The wing walls of the small bridge connect to the main structure approximately 300 mm below the top surface of the deck. To prevent surfacing eroding over the top of the wing walls, they should connect at the same level as the top of the deck (see photograph).
8. The remaining 1.6 km of road gently ascends from the river and has been prepared for formation, revealing a wide expanse of fine silty dusty sand. One short section has become waterlogged.
9. The first portion of the road beyond, under a separate contract, comprises red sand gravel on a loose sandy formation. Camber there is low and the road is unlikely to last long.

3.7.6 Information requests

The visit in March 2009 was the first TRL visit to this road. There has therefore been no previous opportunity to request any information.

The following surveys, tests and analyses were requested during the visit in March.

(i). Topographical and hydrological analysis of the required cross drainage capacity of the Rio Cudingene crossing

(ii). Materials tests of the red sand gravel being used on site

None of this information has yet been received.

No design, construction or costing information was available on site.

3.7.7 Recommendations

There are no recommendations to be made at this stage.

3.7.8 Photos

Completed formation which is rapidly collapsing

Source of red sand gravel alongside road

Looking back up the sandy descent to Rio Cudingene

The Rio Cudingene crossing with the bridge in the foreground and the replaced culvert pipes to the right

Rio Cudingene bridge

One of several original culverts to be cleaned and repaired

Gentle ascent from Rio Cudingene

Completed red sand gravel beyond the RRIP funded improvements

3.8 Macaritane-Chicualcuala, Gaza (GZ1)

3.8.1 Description of the road and history

This road leads to the border with Zimbabwe in the south-western part of Mozambique. The test section is remote, being 110km from Macaritane, in excess of 300km from Maputo City and more than 250km from the provincial capital Xai Xai. The traffic is about 180vpd with 30% classed as heavy hence it is not classed as a low volume rural road.

3.8.2 Key problems

The gravel wears quickly and is slippery and dangerous in the wet season leading to problems of passability.

However, and unusually, gravel is available for road construction in this area but solutions are needed for the majority of the province where gravel is not available.

3.8.3 RRIP work on the road

The trial involved the construction of road base of cement stabilised sand and surfacing with concrete block paving. The section designated for the trial is 2km long and is situated in flat terrain alongside the railway line.

3.8.4 TRL's role

The trial was part of the original RRIP proposals for this site and the design was carried out before AFCAP began. TRL's role was to provide advice on all aspects of the construction of the trial.

If the trial was successful, TRL's role was to compile a set of work procedures (work norms) to ensure that, if followed, future similar works will be carried out in the best way to minimise the risk of errors, poor construction and, subsequently, poor performance.

3.8.5 Observations during site visits.

Materials.

The existing gravel on the carriageway is of good quality, well graded, slightly plastic quartzite. At the quarry the gravel seam is sandwiched between two layers, an overburden of black silty clay and an underlying clay. Red sand is also available in the area within 20km from the construction site and this was to be used for the construction of part of the base course, stabilised with 4-7% cement. The blocks were imported from Maputo City and the quality was good though strength tests results have not been provided.

Site operations

The construction activities included the following:

(i). Scarification, regularisation and compaction of the existing material on the road carriageway.

(ii). Excavation, loading and placement of the gravel on the road section.

(iii). Compaction of the gravel layer to meet compaction specification of 95% MDD Mod. AASHTO.

(iv). Construction of the kerbing on either side of the carriageway.

(v). Placement of 50mm of sand bedding

(vi). Placement of the concrete pavers to produce an interlocking mosaic structure

1. Some failures in the base layer and consequently the surfacing were experienced at the start of construction in the first 50m of the section (see photos). The base layer was built with gravel which was much higher in plasticity than previously designed and the compaction achieved was too low.
2. The gravel material in the pit was extracted through an excavate-and-load process which is very common on construction sites in Mozambique but highly discouraged. This process leads to the mixing of overburden and the underlying clay with an already plastic quartz gravel seam and this resulted in the highly plastic gravel layer (PI>18).
3. Compaction was carried out with little control of the compaction moisture. The information available is that the gravel was compacted almost dry. Laboratory tests showed that a maximum field density of about 65% MDD (Mod. AASHTO compaction level) was achieved which is well below the required minimum of 95% MDD. Hence, in addition to its poor quality, the base was very weak. The compaction was rejected on the basis of these results but works were allowed to proceed without correction and the pavers were laid on top of the failed base.
4. There was also heavy rain which caused flooding and soaked the base. The pavers simply sunk into the soft base resulting in failure of the section.

The pavers were removed and this option for paving has been abandoned.

3.8.6 Recommendations for work-norms.

The failure of the construction highlighted the need for contractors to follow suitable working instructions (work norms) for all activities and for the introduction of an enforceable QA procedure to guarantee this. The recommendations are;

1. Excavate-and-load approach should be discouraged and the work norms should specify:
    a. Removal of overburden followed by inspection by the supervising engineer
    b. Stockpiling the gravel within the approved seam avoiding contamination with the underlying layer
    c. Sampling of the stockpiled gravel for quality test in the laboratory before using the gravel on the road. An approval report and any recommendations should be supplied from the laboratory for any kind of treatment that may be required
    d. Once approved the gravel can then be hauled from the pit to the road also without contamination and used appropriately.
2. The approval system should ensure that failed sections are corrected before works can proceed. This is good practice in road construction which should be followed strictly.
3. There should be good control of the compaction moisture during construction and the hand squeeze method is a proven moisture control measure for compaction moisture

which gives immediate results and a low margin of error, even though it appears very approximate.

4. The mixing of materials should be thorough to create homogeneity in the gravel material matrix and the compacted layer.

3.8.7 Photos

Block paving failures on Macaritane Chicualacuala Road

3.9 Magude-Motaze road, Maputo (MP1)

3.9.1 Description of road and history

The Magude-Motaze Road passes from a District centre to an Administrative Post in an agricultural area approximately 150 km north of Maputo and west of the N1.

In September and October 2008, prior to TRL's involvement, a series of trials of bituminous road products from South Africa (Romix and Tarfix) was begun on the section of road leaving Magude using technicians and foremen from the supplying companies and locally recruited labour. These trials are nearly completed and a similar series is to be constructed close to Motaze in March 2009.

3.9.2 Key problems

The site does not have particularly severe access problems although the surfacing comprises loose sand which can pose passability problems if no maintenance is carried out. The site was chosen specifically for the trials rather than to solve a passability problem.

3.9.3 RRIP work on the road

The trials are additional to work carried out under RRIP.

3.9.4 TRL's role

TRL had no role in the design of these trials but will monitor performance and analyse performance data. Following initial site visits, TRL provided advice on:

(i). The inadequacies in the construction of some of the sections and improved methods were proposed.

(ii). Monitoring methodology for assessment of performance including recommended laboratory tests.

Full details of proposals, advice and recommendations can be found in the Inception Report.

The following information had been requested during previous site visits:

(i). Results of aggregate testing, including strength tests, grading, flakiness and rock type.

(ii). DCP tests of the in situ material.

(iii). Application rates of the Romix and Tarfix products.

None of this information has been made available. The reasons are unknown.

3.9.5 Details of the trials and observations during site visits.

Section referencing of the trials in this report may differ from the official section referencing because documents pertaining to the trials were not available. The trials are new and so any observed deterioration is likely to be the result of poor construction practice rather than the subsequent effects of traffic and climate.

Section 1. This section is a short trial (30 m long) of clay brick surfacing on a sand bedding and gravel base on the approach to a railway bridge. It is separate from the Romix/Tarfix trial. At the last site visit (27 February 2009) it was only partly completed, awaiting delivery of more bricks from the approved local kilns. Section 1 is constructed on a gradient of approximately 5%; the other sections on gradients of 1-2%.

The surface is rough but covered with a large quantity of blinding sand. Some bricks are loose, often where incomplete areas of bricks do not give lateral support to completed areas. Where the bricks are tight, the surface feels strong and durable. No cracked bricks were seen.

Section 2. This 50-metre section comprises a Romix stabilised gravel base with no surfacing.

Section 3. This 50-metre section comprises a Tarfix surface dressing on a Romix stabilised base. There is severe damage on the left hand side, apparently caused by a low loader loading construction equipment. The surface is of variable appearance, although there are no cracks or potholes and only a small quantity of small patches. The section has a good cross section shape. The left hand drain has been locally filled to provide vehicle side access. Other parts of the side drain are eroded, reducing the lateral support to the base and surfacing.

Section 4. This 10-metre section comprises a Tarfix surface, supplied pre-mixed in bags, on a Romix stabilised base.It has a very uniform appearance with no cracking, bleeding, potholes, patching or damage to the cross section shape. There is minor edge damage in one location.

Section 5. This 30-metre section comprises a Romix surface, mixed on site in a concrete mixer, on a Romix stabilised base. There is localised surface damage at one location, apparently caused by the ramp of a low loader. The surface is of variable appearance, with some surface bleeding, a very small amount of surface cracking and longitudinal cracking near one edge, small shallow potholes (up to 100 mm across), no patching and no damage to the cross section shape.

Section 6. This 20-metre section is the same as Section 5 but without the surface which is scheduled for completion when furtther trials are constructed in Motaze. The cross section shape appears undamaged but large stones are protruding from the surface. The removal of over-sized stone had been requested during an earlier visit.

Section 7. This 20-metre section comprises a 3 mm sand seal on a Romix stabilised base. Bleeding has given a smooth micro-texture but the surface is of variable appearance with small shallow potholes (up to 100 mm across).

General observations relating to all sections include:

1. All Romix and Tarfix products are emulsions and were applied cold.
2. Since all sections have been recently constructed, any observed defects are more likely to be due to construction problems rather than poor performance.
3. There is no significant difference in condition between shoulders, wheel-tracks and the centre line.
4. The left hand third (looking away from Magude) of most sections is covered in sand.
5. Although the cross section shape does not appear damaged, the camber of all sections is low.
6. It has been noted that much of the trial construction was not measured or checked for aspects such as compaction, bitumen spray rate, layer thicknesses, etc..

3.9.6 Available information.

No trial documents, including a line diagram of the section, have been made available to date.

3.9.7 Results of the trials.

Monitoring of the performance is required before conclusions about the cost effectiveness of the designs can be determined. For monitoring and performance analysis to be meaningful, a considerable amount of information about the properties of both the basic and processed materials and the properties of the constructed pavement are required. It is not known whether all this information was collected by the consultants or contractors during construction. Although requests have been made, no information has been provided.

To ensure that the proprietary materials are used properly in accordance with the manufacturer's recommendations, work norms are required. If they have not been provided, they need to be obtained from the suppliers of the materials who supervised the construction.

3.9.8 Photos

Section 1: General view

Section 1: Surface detail

Section 2: General view

This is blank

Section 3: General view

Section 3: Patching and surface detail

Section 3: Left hand side edge damage

Section 3: Erosion and reduced lateral support

Section 4: General view

Section 4: Surface detail

Section 5: General view

Section 5: Potholes and surface detail

Section 5: Cracking, bleeding and surface detail

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Section 6: General view

Section 6: Large stones and surface detail

Section 7: General view

Section 7: Potholes, bleeding and surface detail

3.10 Calanga-Checua, Maputo (MP2)

3.10.1 Description of road

Calanga Checua is located approximately an hour north by car from Maputo, east of N1 and is reached from N1 by passing through a large sugar cane plantation. The road is approximately 40 km long and comprises a repeating sequence of hilly tracks in loose sandy soil and wide swamps which are liable to flooding. Current traffic levels are very low, due to the condition of the road and, probably, the low economic activity along the road.

3.10.2 RRIP work on the road

The work under the first Phase of RRIP is to construct water crossings and embankments across the swamps but only the water crossings are likely to be constructed during Phase 1 of this AFCAP project. The sandy tracks between the swamps are to be improved subsequently under separate funding.

3.10.3 Key problems

The key problems that prevent reliable access along the road are:

(i). Loose sand on hilly tracks that are often impassable even for 4-wheel drive vehicles.

(ii). Weak soil across the swamps.

(iii). Flooding of the swamps which are then impassable for much of the year.

(iv). Absence of good quality road construction materials.

3.10.4 TRL's role

The importance of good embankment construction with good quality materials and adequate compaction was emphasised and the importance of hydrological analysis to assess the required cross drainage.

Advice was provided about,

(i). improving the embankments by mixing materials.

(ii). the design of the water crossings.

(iii). the design of road surfacing.

(iv). methods to allow the suitability of the culverts and embankments to be assessed.

Data and materials testing was requested. Full details can be found in the Inception Report

No research trials were appropriate for this road.

3.10.5 Observations during site visits

On the last site visit (February 2009) only the first 10km (approximately) of the road were travelled.

1. Five single aperture culverts with an estimated diameter of 800 mm were observed in the first four swamp crossings. Construction quality was reasonable. It is not known how far culvert construction had progressed along the road.
2. Short access ramps up to soffit level of each culvert have been constructed but it is not known what material was used for this or how well it was compacted. Some organic material was seen in these ramps. It was stated that gravel from a source 15 km away will be used to complete the embankments, although this differs from the proposal reported during the previous site visit.
3. The cross drainage capacity of each swamp appears to have been estimated rather than calculated using standard hydrological analysis.
4. The intended cover over the culverts is 700-800 mm, up to just below the top of the headwalls.
5. The sandy tracks between the swamps are extremely difficult to pass, even with 4WD, particularly where traffic and rain have washed the fines from the coarser material, and will require adequate solution if the road is to be passable.
6. Good quality road construction materials do not appear to be available close to the road.
7. As suggested initially, it may be possible to mix weak soil from the swamps (‘matope’) with sand to give a material with adequate plasticity and strength which can be used as an embankment or general fill material.
8. Road levels should be approximately 600 mm above the highest expected flood level in order to prevent the upper pavement layers becoming saturated and weakened.

3.10.6 Available information

During previous site visits the following information had been requested.

(i). Material properties of the matope (clay material) in the swamps and the sand along the hilly sections to allow a matope and sand mix to be designed for the embankments.

(ii). DCP survey along the road to assess the strength of the in situ material.

(iii). Hydrological analysis to allow required cross drainage capacity to be assessed.

(iv). Topographic survey to allow embankment levels to be designed.

(v). Designs to allow the suitability of the culverts and embankments to be assessed.

None of this information has been made available. Also no design, construction or costing information was available on site.

3.10.7 Recommendations

1. It is essential that all parts of the embankments, including what may be temporary ramps over each culvert, should be properly constructed with good quality materials and adequate compaction.
2. It was recommended that embankments are constructed as soon as culverts are complete while culvert construction continues further along the road.

3. Although the swamps are critical, the sections of sandy track are also critical. Their improvement is necessary if the road is to provide reliable access.

3.10.8 Photos

Swamp crossing with two culverts

Short access ramps up to soffit level

4 General recommendations.

Mozambique is a large country with a variety of technical problems that need to be solved if all-weather access is to be provided for the majority of communities. Summarising all the issues identified in this project is not practicable, indeed, the report as it stands is essentially a summary, albeit a detailed one. However there are some common issues that apply to many sites. Most will not come as a surprise to the reader.

4.1 Site organisation

1. Most of the sites are remote. One aspect of this is that there is often nowhere to stay overnight within reasonable distance of the site. The consequence of this is that most qualified personnel shun these projects or visit them rarely or for a short time, hence this is one contributory reason for the low technical capacity that has been observed on most of the construction sites. *It is recommended that ANE include the hire of caravans under 'Preliminaries and General' or 'Site Establishment' items in the BoQ for rural road projects.*
2. On most sites there was no Programme of Works. *It is recommended that a Programme of Works is produced and approved before the start of any project. This is absolutely necessary to manage the resources, time and outputs successfully*.

4.2 Site operations and quality control

There are a number of basic documents and drawings that are normally associated with civil engineering projects and a variety of material testing and quality testing that are required. For rural road projects where labour based methods are used and funds are always insufficient to meet the needs, some simplifications are acceptable. A review of the basic minimum requirements has not been carried out but the following observations illustrate the deficiencies.

1. There was almost a complete lack of project documents for most sites. Construction drawings (plan/elevations etc), general project outline diagrams, line drawings showing chainages, cross-sectional drawings, even simple sketches of the engineering works, were rarely available. *It is recommended that adequate documents are produced and that site personnel are provided with them and with detailed work procedures/norms including step by step operational instructions.*
2. There was almost a complete lack of approval processes and an enforcement mechanism. *It is recommended that approval forms should be developed for the different operations on site and used in such a way that no further works can be carried out on sections where the work has not been approved.*
3. There was lack of appropriate and suitable equipment and other resources for the operations. Any compromises on the resources can lead to costly consequences. *It is recommended that an approval system is put in place to review and approve the equipment and other resources provided by the contractor, also taking into account availability in the country. Standards can be written which the evaluator can follow and some exceptions can be made in the light of available resources.*
4. It is not clear how knowledgeable the provincial staff, consultants and contractors actually are about the design and construction of rural roads. The lack of basic

design information such as material strengths, hydrological survey information and so on may be caused by a lack of appreciation of the need for such data or simply an acknowledgement that there are little or no resources to collect such data let alone use it in the design process. *It is recommended that during the workshop and training phase of AFCAP a survey is conducted to determine the nature of the main constraints preventing provincial consultants from carrying out higher quality road engineering.*

5. There is a serious lack of quality control and quality assurance documentation, especially on site. It is recommended that this information should be detailed in a QA manual which should be available on sites at all times. This should be an appropriate document written with full appreciation of the difficulties of constructing roads in remote areas with limited resources, but should provide a first step in a programme of continuous improvement
6. The quality checks on construction materials were lacking yet this should be a continuous process on a construction project. This is necessary because materials continue to vary as construction proceeds. *It is recommended that a laboratory assistant be present during construction to carry out standard tests (or at least basic indicator tests) for approval of materials.*
7. Control of compaction has been a major issue and this has a very strong effect on the performance of the roads in terms of durability and maintenance demand*. It is recommended that all earthworks requiring compaction be tested and approved using standard procedures.*
8. The progress of construction has been very slow and the remoteness of the sites is the major contributing factor. Consequently the unit costs will most certainly be very high. There is a need for an early evaluation of the basic principles of the approach and the processes involved in light of the observations made in this report.

Acknowledgements

This report was produced as part of the AFCAP project entitled *Rural Road Investment Programme in Mozambique* contracted to TRL Ltd. The drafting of this report was undertaken by Kenneth Mukura, Simon Done and Dr John Rolt. The final quality assurance and technical review was undertaken by Dr John Rolt. The project team acknowledges the invaluable assistance provided by ANE staff based in Maputo who have been assisting with the project at all times and also the staff in all the provincial offices whose assistance and support during the site visits was essential. Appendix A lists the names of everyone involved. Comment and support from members of DfID's AFCAP team is also acknowledged with special thanks for his technical inputs to Robert Geddes.

Appendix A

February/March 2009 site visit itinerary

The itinerary of the site visits is given in the following table. A number of the sites which were visited are being considered for improvement under RRIP Phase 2 funding and, if selected, will be reported in later reports.

Province	Road	Staff who accompanied the site visits	TRL Team members [1]	Date
Gaza	Macaritane Chicualacuala	Eng Fernandes, Head of Maintenance, DIMAN	KM	21st Feb
Maputo	Marracuene Macaneta	• Eng Muonima, DIMAN and RRIP Coordinator for Southern Region • Eng Monroy, Team Leader, Consultec, Provincial Consultants for ANE Maputo	KM, SD	25th
	Calanga Checua	• Eng Muonima • Eng Monroy • Eng Philippe, Inspector, Consultec	KM, SD	25th
	Magude Motaze	• Eng Muonima • Eng Philippe	SD	27th
Cabo Delgado	Xitaxi Mueda	• Eng Kaunda, Team Leader, Scott Wilson, Provincial Consultants for ANE, Cabo Delado • Eng Branco, DIMAN and RRIP Coordinator for Northern Region • Eng Letha, Unpaved Road TA to DIMAN	KM, SD	2nd March
Nampula	Mecane Pilivili	• Eng Rashid, Head of Technical Department, ANE Delegation, Nampula • Eng Andrade, Inspector, Scott Wilson, Provincial Consultants for ANE Nampula • Eng Branco • Eng Letha	KM, SD	4th
	Naguema Chocas Mar	• Eng Rashid • Eng Shadrack, Inspector, Scott Wilson • Eng Branco • Eng Letha	KM, SD	5th
	Gracio Milhana	• Eng Rashid • Eng Gerard Kabwibwi, Team Leader, Scott Wilson • Eng Branco • Eng Letha	KM, SD	6th
Niassa	Maniamba Metangula [2]	• Eng Arnado, Head of Technical Department, ANE Delegation, Niassa	KM, SD	7th

		• Eng Apolinário, Inspector, Stange, Provincial Consultants for ANE, Niassa • Eng Branco		
	Mavago Msawize	• Eng Arnado • Eng Apolinário • Eng Branco	KM, SD	8th
	Nova Madeira Cz. Lupiliche	• Eng Arnado • Eng Apolinário • Eng Branco	KM, SD	9th
Sofala	Beira Savane	• Eng Agapito Cruz, Head of Technical Department, ANE Delegation, Sofala • Eng Baulane, Head of Laboratory, ANE Delegation, Sofala • Foreman of TCO Contractor • Inspector, Técnica, Provincial Consultants for ANE, Sofala • Eng Fernandes, Head of Maintenance, DIMAN and RRIP Coordinator for Central Region (on the 19th of March)	KM, JR, SD	11th
	3 quarries [3]	• Eng Baulane	KM, JR, SD	12th
Manica	Machaze Inhacufera	• Eng Luis, Inspector, COTOP, Provincial Consultants for ANE, Manica • Enga Yvonne, ANE Delegation, Manica • Eng Ramus Gwatidzo, Site Manager for TARCON contractor	KM, JR, SD	13th
Tete	Bene Fingue Cachombo	• Eng Muonima • Eng Cigarette, Head of Laboratory, ANE Delegation, Tete • Eng Lubrino, Inspector, Técnica, Provincial Consultants for ANE, Tete • 2 Fiscais, Técnica	SD	15th
	Matema Furancungu Daca	• Eng Muonima • Eng Cigarette • Eng Bento, Inspector, Técnica	SD	16th
Zambézia	Zero Mopeia	Eng Fernandes, Head of Maintenance, DIMAN	KM, JR	16th
Sofala	Beira Savane	[4]	KM, JR, SD	19th
Inhambane	Panda Urene	• Eng Muonima • Eng Fernando Dabo, ANE Delegate, Inhambane • Eng Mariano, Head of Technical Department, ANE Delegation, Inhambane	KM, SD	21st
	Cumbana Chacane	• Eng Muonima • Eng Fernando Dabo • Eng Mariano	KM, SD	22nd

1 – KM: Kenneth Mukura; JR: John Rolt; SD: Simon Done

2 – additional visit to a road with Otta seal surface and drainage problems at the request of the request of Eng Sylvestre, the ANE Delegate in Niassa

3 – visit to assess aggregate sources when travelling from Sofala to Manica

4 – participants are listed for the first visit to the site on the 11th of March

In addition to the staff who accompanied the site visits, those in the following table were also met.

Name	**Title/function**
Eng Nelson Nunes	Director General of ANE
Eng Jackisson	Director of DIMAN
	ANE Delegate, Cabo Delgado
Eng Nota	Head of Technical Department, ANE Delegation, Cabo Delgado
Eng Crisanto	ANE Delegation, Cabo Delgado
Eng Mavila	ANE Delegate, Nampula
Eng Sylvestre	ANE Delegate, Niassa
Eng Belmiro	ANE Delegate, Sofala
Eng Nunes	Technical Department, ANE Delegation, Sofala
Eng Chau	ANE Delegate, Tete
Eng Dadi Mendes	Deputy ANE Delegate, Tete