

USE OF LOCALLY-PRODUCED MATERIALS FOR LOW-VOLUME ROAD PAVING

Authors' names:

Eng. Nkululeko V. Leta, Technical Assistant, Mozambique National Roads Administration (ANE)

Raquel Langa, Researcher, Monitoring Department, ANE

First Author's address: **Administração Nacional de Estradas, Avenida de Moçambique, 1225, Maputo, Mozambique**

Abstract

The purpose of this paper is to provide details of the experimental sections constructed on low-volume rural roads in Mozambique using locally available or produced materials for paving. These materials are fired clay brick, cobble stone and concrete slabs constructed by small scale local contractors with active participation of the local communities. The details include technical specifications, construction procedures employed, preliminary findings after a number of years in use and some conclusions.

The construction procedures and specifications for subgrade and base construction do not vary much for these low-volume roads. Regarding paving with fired clay bricks and cobble stone, the construction processes are similar as they both involve construction of restraining kerbing on the sides, sand bedding layer and infilling of joints in between the bricks or stones, and compaction with vibratory roller to line and level to ensure stability. Even the key maintenance activity of removing and replacing damaged pavers applies to both materials.

We believe the fired clay bricks section has performed reasonably well considering that the bricks, produced specifically for building construction, were not modified for appropriateness as pavers, and that the traffic levels are very high. As expected, the concrete slabs have not shown any signs of distress two years after construction. The cobble stone sections are relatively new and no conclusions can be drawn from their performance yet.

1. INTRODUCTION

Subject: Locally-produced materials such as fired clay bricks, cobblestone and unreinforced concrete slabs are not commonly used for road paving in Mozambique. Wherever they have been used, this has taken the form of individual application such as in factory or office yards, private residences and others. Needless to say the construction procedures and results of these experiences have not been well documented, hence not much is known of the performance of these solutions under different types of loading.

The Government of Mozambique has commissioned the Rural Roads Investment Programme (RRIP), where experimental sections are being designed and executed by the Mozambique National Roads Administration (ANE), with a view to provide a more scientific assessment of the performance of these paving options, including a monitoring period of at least three years to collect sufficient data for analysis.

Scope and Purpose: The purpose of this paper is to provide details of these experimental sections, focusing mainly on the application of locally-available and produced materials mentioned above, and to share some of the preliminary results from some of these pilot projects. It is important to note that use of these materials is not a new innovation, as these have been used for road paving in many countries for decades with varying degrees of success and challenges depending on the conditions peculiar to each one of them. The objective is to take advantage of the abundance of these materials in Mozambique's different geographic regions to investigate their viability and sustainability for paving low-volume rural roads, with a view to providing decent and durable access to the rural population living there at an affordable cost.

The Government of Mozambique, in its fight against poverty in the countryside, has declared Districts as principal poles of development, and as a first step, priority has been given to provision of guaranteed all-year accessibility to the District Centres. Consequently, the first pilot projects are located on roads providing direct access to these District Centres, if not within the confines of the Centres themselves.

Under the current RRIP, the strategy has been through implementation of durable targeted interventions on the most problematic sections, i.e. those that render these rural roads impassable on a yearly basis with repeated injection of funds for repairs.

Plan for development of the subject matter in the paper: The paper will define the problem, the challenges and opportunities, as well as the implementation strategy towards overcoming the challenges and solving the problem. Finally, the specific projects detailing the technical aspects of the paving solutions will be discussed, including methodologies used, preliminary results obtained as well as the respective conclusions and recommendations for sustainable maintenance of these sections.

Value to the reader: The reader will be able, after reading the paper, to have an understanding of the specific challenges confronting the Mozambique Rural Roads sector, assess the viability and sustainability of the technical measures/solutions taken, and have the opportunity to contribute ideas for improvements during the discussion sessions at the Conference. Hopefully, the reader will also benefit from some of the approaches to solving the challenges of rural road paving using locally-available materials in their respective environments.

2. ROAD PAVING SELECTION FACTORS

What is the problem? In a paper on Rural Road Paving Options, gTKP summed up the challenge as follows, "Rural roads can be expensive to construct and difficult to maintain. Bad roads constrain the impact of all rural initiatives and can cause community isolation from services and markets, high transport costs, spoilt crops, retarded development, deprivation and poverty.

It is therefore vitally important to provide sustainable low volume rural roads (LVRR) with affordable surfaces, compatible both with their transport tasks and their physical environment"

There is a wide range of durable surface/paving options for Low Volume Rural Roads. Selection should be based on consideration of the factors shown below. Local guidelines need to be prepared based on Whole Life-costing of the various feasible paving options, including realistic maintenance assessment of each solution.

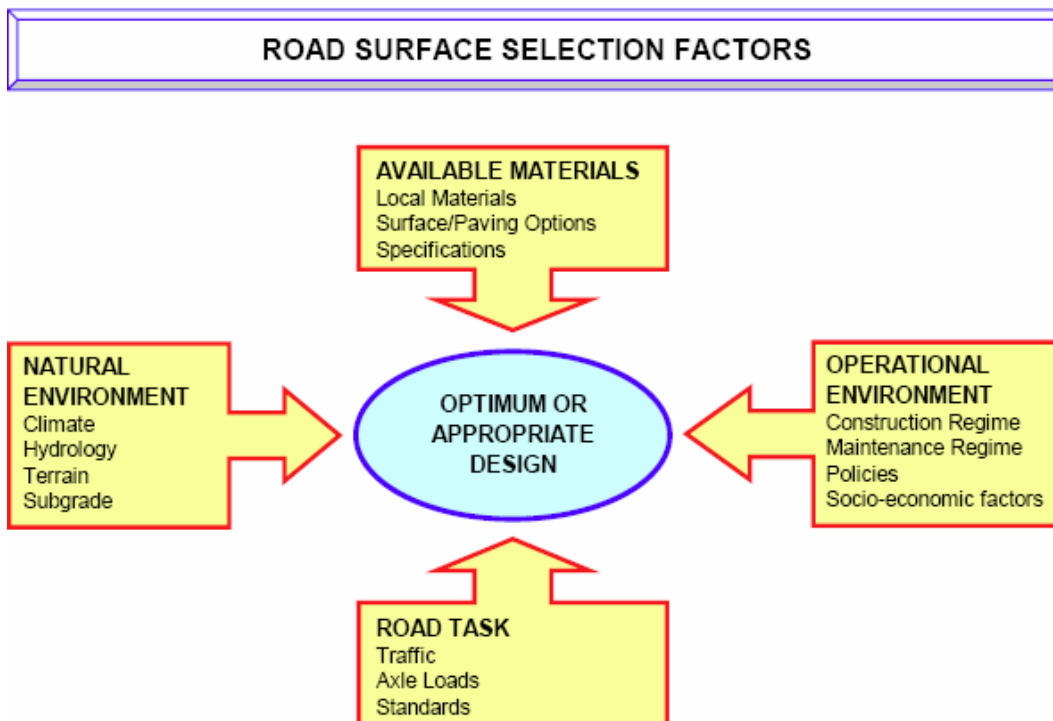


Illustration: Reprinted from: gTKP Rural Road Surfacing Options Paper

3. IMPLEMENTATION STRATEGY

The pilot projects aim to introduce a 'targeted improvement' approach for the unpaved road network. Problematic roads or sections are prioritised and durable solutions identified for the most critical sections. These solutions aim to gradually bring guaranteed all-year round accessibility by making the most effective use of the limited funds available, easing the maintenance burden for the client and reducing vehicle-operating costs for the users. Special focus of the programme is to optimize the use of locally available materials to provide durable low cost surface treatments using labour based technology, in combination with improved (sub) base layers where natural materials do not possess the desired properties.

During the initial phase, more emphasis has been put in providing access to the District Centres, as well as bridge approaches and steep and slippery slopes on rural roads.

3.1 Strategy Objectives

The implementation strategy aims to achieve the following objectives:

- To guarantee sustainable access to the District Centres through provision of durable paving solutions;
- To harness the natural resources available locally to provide decent and durable access to the rural population at an affordable cost;
- To test the applicability of various technologies vis-à-vis local materials and costs;
- To maximise the creation of local employment through recruitment of casual labour from the respective districts;
- To build capacity at district level in design, construction, supervision and maintenance of the applied paving solutions;
- To build capacity of local labour in construction and maintenance of the types of paving applied, through direct involvement in the execution of the construction projects.

3.2 Implementation Phases

3.2.1 Phase I – Mapping of locally-available materials in each District

The key activities to be carried out during this phase are as follows:

- Survey of locally-available materials for identification and characterization;
- Geographic location of the materials;
- Assessment of the quantity and quality of the existing materials;
- Collection of samples for testing;
- Conducting laboratory tests to determine applicability;
- Creation of data base per District;
- Training of personnel in management and use of the data base.

3.2.2 Phase II – Investigation and Analysis of various paving/surfacing options

The key activities are as follows:

- Identification of the local material (characterization and classification);
- Determination of the quality, durability of the material through laboratory testing,
- Determination of costs, availability of casual labour in the area, etc
- Identification of alternative solutions for low-cost surfacing appropriate for use of labour-based technology;
- Definition of the construction and maintenance methodologies for these solutions;
- Mapping of the District road network, including Access to the District Centres;
- Classification of the District roads in accordance with their importance and functionality;

3.2.3 Phase III – Design and Execution of Pilot Projects

The following main activities are envisaged during this phase:

- Preparation of designs for each type of paving solution proposed;
- Preparation of technical guidelines for construction procedures;
- Implementation of these paving solutions in the selected Districts;
- In-service training of District engineers and local supervisory personnel;
- Close monitoring of the construction process, recording all construction data including taking BEFORE, DURING and AFTER photographs;

- Post-construction monitoring of performance of experimental sections;

3.2.4 Phase IV – Preparation of Technical Guidelines and Specifications

The final phase of this process will be the preparation of “homegrown” technical specifications for the different paving options to be used nationwide.

4. Paving Options for Rural Roads

In accordance with the specific circumstances in each District, in terms of availability of materials, cost-effectiveness of extraction and application, the following options for paving materials were considered for the pilot projects:

- Fired clay brick using clay in its natural form;
- Fired clay brick using clay with low cement content;
- Cement-Mortared stone;
- Cobble Stone;
- Concrete slabs reinforced with wire mesh placed at half-depth
- Unreinforced concrete strips

5. USE OF FIRED CLAY BRICKS FOR PAVING LVRR

Background

Fired clay bricks are the product of firing moulded blocks of sandy, silty clay. These clays occur naturally in all the Provinces in the country, mainly in humid areas close to rivers, lakes and deltas.

In Mozambique, the bricks are produced through private enterprise, village associations and others mainly for building construction. There is some measure of standardization of processes in terms of identification of appropriate types of clay, moulds for different sizes of bricks and production processes. The clay is then fired to reasonably high quality bricks using small kilns and firewood as the most common source of energy. There are, however, no standard quality control measures specified as each producer determines the firing period and acceptability of the final product.

It is important to note that the bricks used are generally not of adequate engineering quality appropriate for use in the construction of road paving, as the desirable crushing strength of at least 15MPa is rarely achieved.

5.1 Characteristics of the Experimental Section

Site Description

The experimental section is deliberately located on bridge approaches, along one of only two routes into and out of the Magude District Centre, has a longitudinal slope of 6% and is also located at an intersection with a local access road. This is intended to maximize the negative factors contributing to deterioration of the paving through higher traffic levels, abrupt braking and acceleration (bridge is single lane), as well as sharp turning by local traffic. Dragging of poles and firewood are some of the observed abnormal uses of that section of road!

- Road Name: Magude-Motaze, Maputo Province

- Position of section: Bridge approach and intersection for local traffic
- Type of Traffic: Light to heavy (tractors, <2t trucks, buses, 5-10 trucks, <30t trucks)
- Length of Section: 50 metres
- Average Rainfall: 800mm/year
- Width: 6 metres (two lanes)
- Camber: 4.8%
- Longitudinal slope:6%
- Base of mechanically stabilised natural gravel, 150mm thick
- Number of bricks used: 14,000
- Number of bricks per m2: 46
- Unit Cost of brick: \$0.10
- Cost per m2 of paving: \$16.00
- Date of construction: April / May 2009

Table 1: Specifications and Results attained

Description	Specification	Result achieved
Brick		
Brick dimensions	200x110x70mm	200x110x70mm
Crushing strength, dry	15MPa, min	Dry 8-11 MPa
Ditto, after 24h immersed in water		Wet 5-7MPa
Water absorption, % of their weight of water after 1hr soaking	<16%	18%
Clay		
Plasticity Index (PI)	Not defined	7%
Shrinkage limit	Not defined	8%

5.2 Construction Procedures

- Existing natural gravel base was used as it was considered well consolidated due to trafficking over a period of a year after construction. A few eroded sections along wheel paths were repaired and compacted, and the whole section evenly graded to give uniform surface.
- Excavation and placement of restraining kerbing in concrete, in advance of the main paving,
- Placing and spreading 50mm sand bedding layer of coarse river sand,
- Laying bricks in interlocking pattern,
- Spreading fine sand for joint filling,
- Light compaction with vibratory roller to tightly pack the spaces between bricks,
- Removal of excess sand with brooms.
- Bricks laid on the longer edge, within the kerbing on each side of the pavement.

5.3 Preliminary Findings

Monitoring visits were conducted as follows:

- 1st six month period after construction, May to October 2009, (dry season) – monthly;
- 2nd six month period, November 2009 to April 2010 (wet season) – every 3 months;
- 3rd six month period, (dry season) – every 3 months

The monitoring includes the following aspects:

- **Visual Inspection.** Visual assessment of paved surface relating to onset and progression of surface defects such as cracking, breaking and crushing, settlement and wearing off of the bricks; (Results are shown in Table 1....)

In the first six months after construction, cracking was observed mainly in the middle third of the section. Curiously, no cracking was observed along the wheel paths. A possible explanation could be that the steep camber induced flexural stresses around that area resulting in cracking of the paving.

Gradually the cracking spread to the entire width after another year in use.

Appearance of poorly burnt clay at the surface of the brick was observed after 18 months. The firing was also not uniform as the size of the “black core” varied from brick to brick.

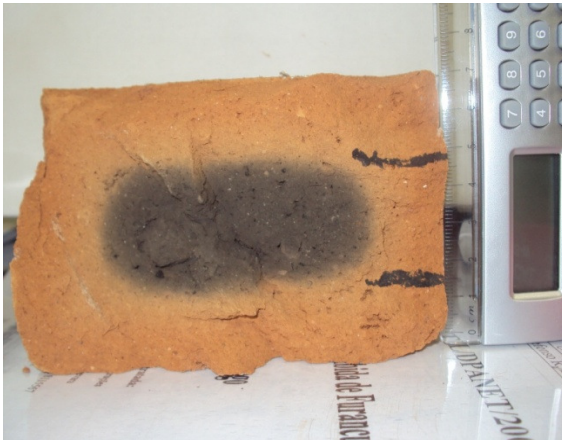
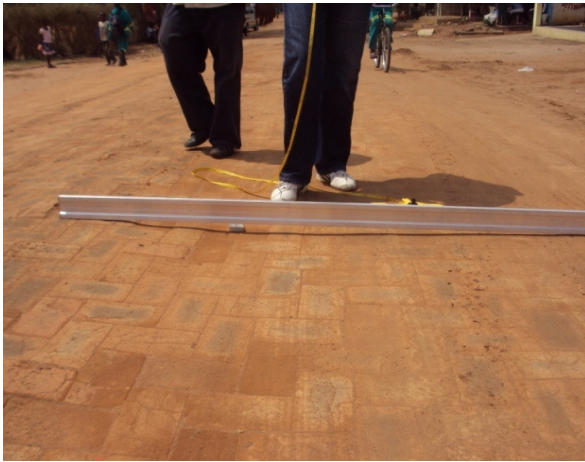


Photo nº 1: Poorly-fired clay brick



Photo nº 2: Visual signs of bricks wearing off

- **Traffic Counting.** Assessment of type and volume of traffic using the section is done during these monitoring visits. Formal traffic counts are conducted over a one-week period, starting at 05.00Hrs up to 1800Hrs. Table 2 shows sample results for 13 July 2009 and 26 June 2010.
- **Measurement of rutting deformation.** As expected, deeper ruts were observed along the wheel paths, and especially on the sections that were repaired prior to laying of bricks. This would suggest settlement, rather than wearing off of the bricks, as the main cause of the rutting.



Photos n° 3 & 4: Use of straight edge and wedge

to measure rut depth

- **Drainage Assessment.** To date no adverse drainage problems have been observed on the section. This could be attributed to tight packing of the bricks and adequate camber (2-4.5%), as well as a steep longitudinal slope (6%) which facilitates efficient drainage away from the surface.
- **Measurement of Brick Wear-off.** Level control of identified points along 5 cross-sections, drawn at 10m intervals along the length of the section is conducted during each visit. These sections are identified as PT I up to PT V. Thirty points, at 20cm intervals along each cross-section are marked with paint for position control purposes. Two steel reference pegs were concreted *in-situ* at a distance of 3m and 2m from the edge of the kerbing on either side. These pegs function both for level control and for ensuring the same points are surveyed each time. (See Figure 1-5 below)

Cross-sections at 5 locations along the experimental section (see Plan Diagram)

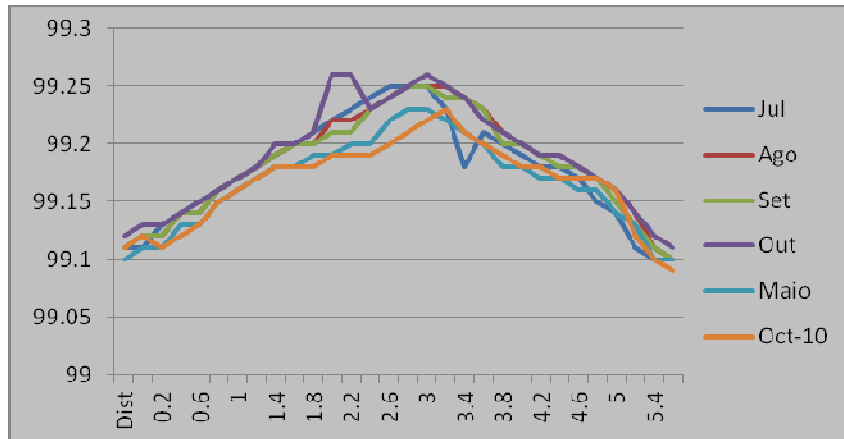


Figure 1: PTI - Cross-section nº 1

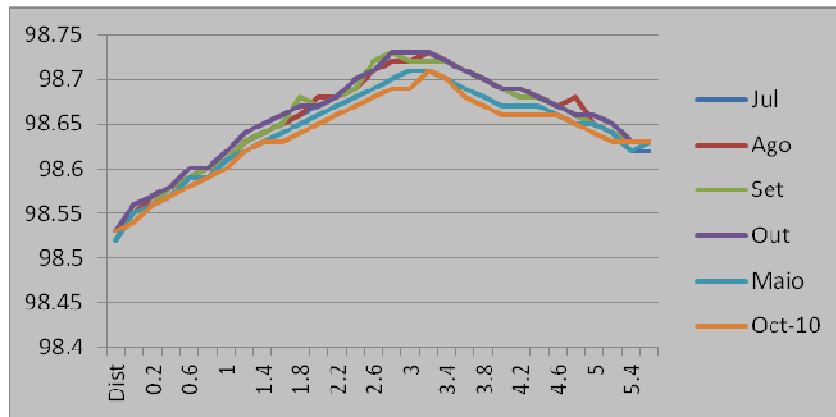


Figure 2: PTII - Cross-section nº 2

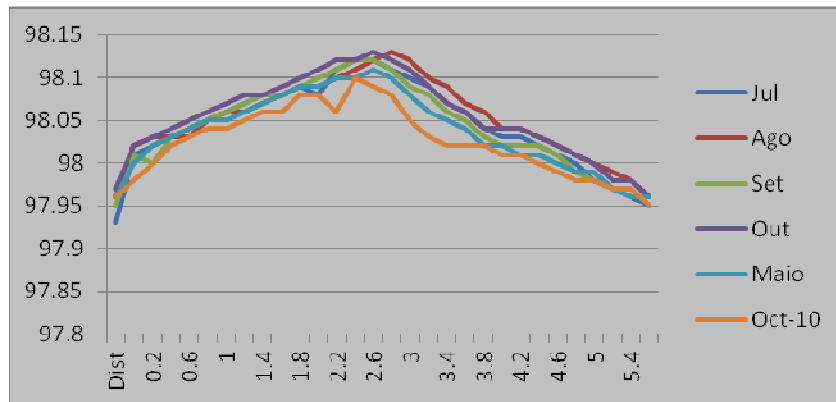


Figure 3: PTIII - Cross-section nº 3

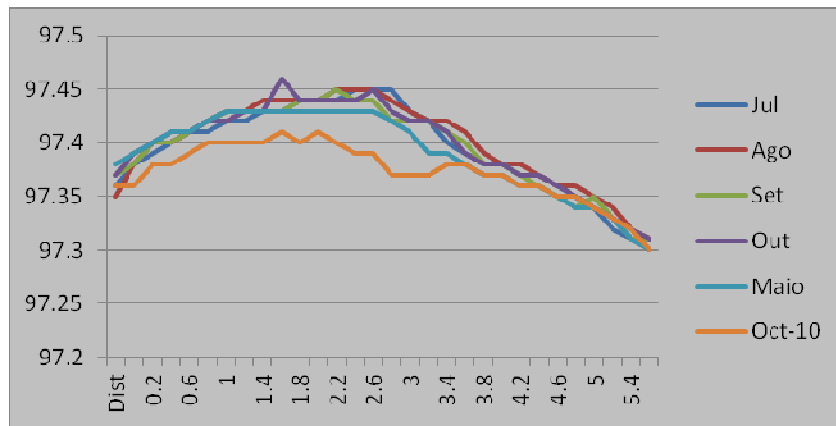


Figure 4: PTIV – Cross-section nº 4

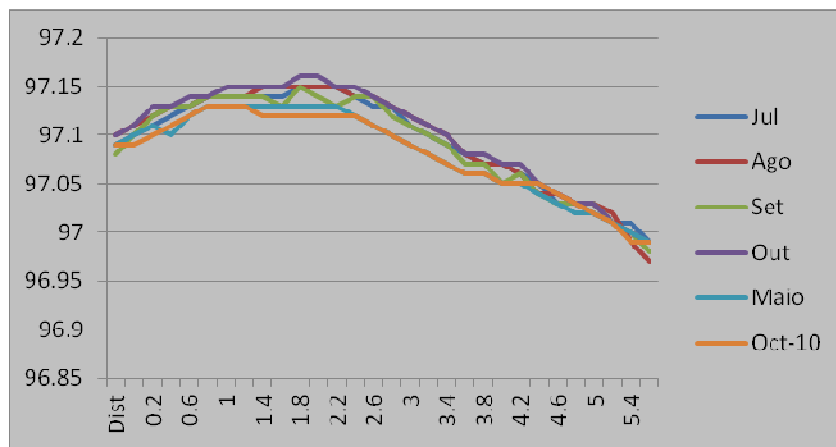


Figure 5: PTV – Cross-section nº 5

5.4 Challenges

The main challenges to producing better and appropriate bricks for low-volume road paving, and in larger quantities in Mozambique, are as follows:

- i) to identify viable and sustainable alternative sources of energy (1km requires about 300,000 bricks). With firewood as the main source of energy, the impact on the environment would be catastrophic;
- ii) to improve kiln design, and the production processes, particularly the firing temperature and the time the bricks are subjected to that temperature, as well as the curing part;
- iii) to establish “homegrown” technical specifications and standard testing methods for the paving brick;
- iv) to source funding for establishment of improved and standardized kilns; and,
- v) to incentivize local communities to produce more and better bricks for road paving.

5.5 Conclusions

- Appearance of black colour in the central area of the brick indicates poor firing of bricks. It should also be noted that the bricks were not improved in any way for use as road pavers, but were provided by the local suppliers of bricks for building construction;
- It was also noted that once bricks were broken and not immediately replaced, deterioration accelerated leading to pulverization of damaged brick. In time, this also exposed the surrounding bricks to the same deterioration processes. **Rapid replacement of broken bricks is therefore a key maintenance activity;**
- Need for better facilities and processes for improving the quality of bricks. The firing must be such that the black core of the brick turns to a reddish brown colour;
- Low-quality bricks can last a bit longer as long as there is no lateral movement and/or settlement i.e. base to be constructed to specifications; restraining side kerbing to be intact and bricks tightly-packed, levelled (protruding bricks break easily) and well jointed; good drainage through provision of adequate camber (2 – 4%).
- Cost reductions can be achieved through use of bricks as side kerbing rather than concrete as was done on this project. However, the kerbing must be robust enough to prevent lateral movement of the bricks resulting in dislocation and the consequences thereof. This can be achieved through grouting the exposed part with cement.



Photos nº 5 & 6: Paved section just after construction (May 2009)



Photo nº 7 & 8: Section as at 28 October 2010 - marked areas show crushed bricks to be replaced

6. COBBLE STONE

6.1 Background

Cobble stone surfacing is a historically well established technique that has been adopted successfully as a robust low-maintenance alternative to gravel on low volume rural roads where there is good supply of suitable stone. Cobble stone surfaces have good load spreading properties and the surfacing material is reusable if road foundation failure occurs.

This technique is suitable for small scale community-based quarrying and production, especially where local skills in stone excavation and production are established in the locality. The pilot projects under discussion are located in areas where suitable stone is found in abundance and skilled local artisans are encouraged to set up small companies and carry out this work. The legislative framework for this is already in place.

6.2 Characteristics of Experimental Section

Site Description

Location: Fingoe District Centre, Tete Province

Length of section: 200m

Name of Road: off R603 Bene – Fingoe

Construction dates: June 2005 (100m) and July 2010 (100m)

6.3 Construction Procedures

Suitable stones were collected by hand by the local population from the surrounding area, with the direction of local artisans who were responsible for quality control of the stone. Specifications and procedures for construction of subgrade and base were as follows:

- Preparation of base and placing restraining kerbing. Kerbing was constructed using cement-grouted stone masonry;
- Selection and preparation of stone, including machine cutting to improve the shape for stability and smoother surface.
- Placing the stone and infilling the spaces between the stones with well graded coarse sand;
- Rolling was carried out with a pedestrian vibratory roller;
- Three different approaches to cobble stone paving were implemented:
 - a) Injoint filling with fine sand, on relatively flat surfaces
 - b) jointing with cement mortar, and,
 - c) jointing with cement mortar plus application of 50-75mm concrete screed on top, especially on steep slopes to avoid “uprooting” of exposed stone by heavy vehicles going up the hill,

In all cases, the key is in the selection, shaping and placing of cobblestones to provide a stable and non-bumpy surface.



Photo n° 9: Hand-laid stones before spreading sand;

Photo n° 10 Completed section (July 2010)



n° 11: Cement-grouted stone on LHS

Cement-grouted stone+cement mortar screed

Photo

6.4 Preliminary Findings

The section with cement-grouted stone + 50mm cement mortar screed was constructed 5 years ago (2005), and is still holding up reasonably well with no major cracking or deformation observed. This could be also due to low traffic levels on that section which is located just off the main road, and passing through the District Administration offices.

The other sections are still relatively new and are being monitored regularly.

6.5 Conclusions

The quality of the end-product is satisfactory, but performance monitoring of the different sections is an on-going activity.

7 CONCRETE SLAB

Background

Concrete possesses little tensile strength hence the success of a concrete slab is dependent on preventing tensile cracking. The key to this is to ensure that the underlying support for the concrete is always adequate and is not damaged through erosion. A sand layer underneath the slab is not ideal and therefore the drainage measures have to be very carefully designed if the slabs are to be durable.

The intervention includes the design and construction of concrete slabs only for the steep sections and other cheaper solutions for the less steep sections. Concrete is a high initial cost paving solution, but this can be more than offset by whole-life cost benefits to make it a more cost-effective solution. If constructed properly, concrete paving is durable, with high traffic carrying capacity and very low maintenance using simple local building skills.

7.1 Characteristics of Experimental Section

Site Description

Cabo Delgado has a long coastline and the problems of vast expanses of sandy materials affect this province as in the southern part of Mozambique. The project site is remote, about 240km from the provincial capital Pemba. The site constitutes a ramp with some very steep sections, >15%, which get eroded annually and are very difficult to navigate during the rains. The soil is very fine sand and sandy clay and, normally, the road is cut off during the rainy season.

The road itself is potentially important economically because the other side of the ramp has a huge potential for timber harvesting, as well as the added benefit of cutting the travelling distance from the Provincial Capital to the District Centre by 120km!. Previously, heavily laden traffic simply could not traverse this section, which resulted in higher transport costs for that part of the province. There is very little choice in terms of paving solutions as the most available material is sandy soil.

- Road Name: N381 Xitaxi - Muidumbe, Cabo Delgado Province
- Position of section: Steep ramp, 10km off the main N380 North-South Highway
- Type of Traffic: Light to medium (tractors, <2t trucks, 5-10 trucks)
- Length of Section: 800 metres
- Average Rainfall: 300mm/year
- Width: 6 metres (two lanes)
- Camber: 2%
- Longitudinal slope:>15%
- Base of mechanically stabilised natural gravel, 150mm thick
- Construction date: July 2008

7.2 Construction Procedures

The concrete slabs were constructed using locally available materials such as hand-crushed concrete stone and local sand. The application was carried out using labour-based methods, thus maximising local employment.

The reinforcement mesh was placed at half depth of a 200mm thick concrete slab and placed using concrete spacer blocks. Steel reinforcement meshes were also procured consisting of 6mm steel re-bars at 200mm spacing. A 150mm thick concrete slab with reinforcement placed at one-third depth could have been adequate and cheaper but it was decided to use the thicker slab as partial safety factor for poor materials and for an ill-equipped and inexperienced local contractor.

- Concrete was mixed in a concrete mixer on site and transported and placed by labourers with wheelbarrows.
- Compaction of the concrete was carried out using a poker vibrator.
- After placement and compaction, ribs were impressed on the surface for skid resistance purposes.
- The slabs were left to set and wetted sand cover was used for curing purposes.
- The side drains were stone pitched to prevent erosion of the in-situ sandy soils.

7.3 Preliminary Findings

Two years after completion, no tensile cracking has been observed on this section. A few sections that were not adequately ribbed during construction have smoothed out creating a few slippery sections along the slope.



Photos n° 13: Before intervention, Feb 2008



Photo n° 14: After intervention, July 2009



Photos n° 15: Section as at October 2010 - no tensile cracking observed



7.4 Conclusions

Access has been restored on this important link, and, reports of increased traffic using the road are testimony of the effectiveness of the solutions.

8 Cost Effectiveness Issues

It is important to note that under the pilot project phase, implementation costs were rather high as the primary objective was to test the technical viability of the various options in the different environments. The secondary objective of ensuring cost-effectiveness and sustainability will be achieved through improved technical designs and implementation strategies involving more local community participation, as well as dissemination of new technologies and methods of carrying out the works.

References:

- 1) Intech Associates – TRL, 2007. **RRST Construction Guidelines**
- 2) TRL – 2009. **AFCAP Project Rural Road Investment Programme in Mozambique, Inception Report**

KEY WORDS

Fired clay brick; Cobble stone; Tensile cracking; Cost-effectiveness; rutting