SEMINAR: SUSTAINABLE ACCESS AND LOCAL RESOURCE SOLUTIONS
Date : 28 – 30 November 2005

TITLE:
Labour-Based Surfacing Trials on the Mozambique Feeder Road Project

AUTHORS: W G Ford, TRL Limited, United Kingdom
S Done, TRL Limited, United Kingdom

1 Introduction

The focus on road provision in rural areas is moving away from the conventional concept of benefits from reduced vehicle operating costs to that of providing all weather access. When access (to schools, clinics, markets etc) is treated as a priority, it is likely that there will be an increased focus on localised improvement options. If these 'spot improvement' works are to be carried out, the conventional equipment based approach becomes prohibitively expensive and cumbersome for the small sections of road to be tackled. However, this can create opportunities for locally based small contractors using labour-based technologies.

Earth and gravel roads are particularly susceptible to environmental damage. Often, just short sections of road are affected but these can have a serious impact on passability, especially during the wet season, thus reducing the benefits for the rural communities who the roads were intended to assist. Conversely, spot improvements targeted at problem sections of rural road networks can give large benefit/cost ratios.

These spot improvements can take many forms, including the surfacing of sections of road that are likely to require recurrent maintenance. Low-cost sealing as an option for spot improvement works can be carried out by labour-based techniques. Much of the equipment required for the bituminous surfacing is part of the standard plant used by small contractors in the construction of rural roads. Any additional equipment that may be required is relatively cheap and within the range of the capital investment expected by small-scale contractors.

In recent years, labour-based methods have also been seen as an important route to allow the entry of emerging contractors into the road sector. The main reason for the success of this approach is that a much lower level of investment is required by labour-based contractors than for more equipment intensive operations. This has enabled contractors to enter the roads sector at different levels ranging from petty contracting for routine maintenance to periodic maintenance, rehabilitation and even larger construction projects. With the thrust towards decentralisation, it is also important that the urban and rural authorities have a contracting capacity that can operate at the local level without incurring large mobilisation costs for relatively small road works. This is particularly relevant to the construction and maintenance of the relatively short lengths of surfaced roads for which many of these local authorities are now responsible.

As unemployment continues to grow within the region and the developing world generally, the use of local resources becomes increasingly attractive not only in financial terms but also in social terms. By adopting labour-based methods, temporary employment can be offered to people in rural areas that are generally far from other work opportunities. The development of locally based (district and province level) contractors can assist in spreading the employment opportunities into all areas of a country, and provide capacity at the local level for the implementation of road maintenance and improvement works. This is particularly

important as the emphasis shifts away from road construction towards maintaining existing road investments. This inevitably results in less new construction work being undertaken and an increase in the need for maintenance and repair works.

2 Background to the surfacing trials

The traffic carrying capability and sustainability of earth and gravel roads, in a tropical or sub-tropical country, will be affected by the seasonal occurrence of severe wet weather conditions. This causes erosion of the surface and results in reduced pedestrian and vehicular accessibility between the local villages and towns, particularly where gradients occur.

Often it is only short sections that cause access restriction and one of the alternatives for provision of a more durable surfacing would be a bituminous seal. The mobilisation of plant and equipment to construct a conventional bituminous seal on short sections makes the surfacing process technically and economically non-viable. However, there is potential to construct a range of bituminous seals using labour based methods and a modicum of equipment.

In 2000 TRL were commissioned by the Department for International Development (DFID) to provide technical assistance to the Mozambique Feeder Roads Project in the Zambézia province of Mozambique. The project was carried out on behalf of the Provincial Directorate of Public Works and Housing (DPOPH) and the Provincial Roads Department (DEP) and was funded by DFID.

The purpose of the technical assistance was to develop and test a range of bituminous surfacings, which can be applied to gravel roads, using labour-based construction techniques.

To test the feasibility of this type of construction a series of demonstration trials were carried out in Mozambique in September 2001 by TRL personnel in the province of Zambézia.

3 Surfacings

The bituminous surfacings constructed were:

Single and double sand seals
Gravel-bitumen seals
Single and double surface dressings
Pre-mixed bitumen and gravel
Penetration macadam

4 Aggregates

Three sources of aggregates were available locally for use in the bituminous surfacings. These were:

- A natural gravel having a low fines content and containing particles that tended to be rounded. This gravel was screened to remove particles larger than 12mm in size.
- Selected sizes of hand-knapped rock were used for penetration macadam and screened rock was used for surface dressings.
- A fine sand.

4.1 Bituminous binders

The labour force employed for constructing the trials had no experience of using hot bitumen and for reasons of safety and to minimise environmental damage only bitumen emulsions and MC30 primer were used in the construction of the trials.

Anionic and cationic bitumen emulsions were supplied to the site in 200 litre drums. Anionic bitumen emulsion has no chemical reaction with quartzite, granite, sandstone, tillite, rhyolite or amphibolite and adhesion is only obtained through evaporation of the water. However, anionic emulsion will react with dolerites and basalts and can be used for the stabilisation of roadbase materials. They can also be used in high fines content mixes where the benefit of extended good workability can be helpful for labour intensive work. However, cationic emulsion is generally preferred partly because of the improved adhesion that this type of binder gives with quartzite and granite and also because of reduced cost.

The maximum and recommended spraying temperature for bitumen emulsions containing between 60 and 75 per cent bitumen is 60°C. However, the bitumen emulsions used on site contained 60 per cent bitumen and could be readily sprayed by hand lance or applied by manual methods at ambient temperature.

Details of the binders used are given in Table 1.

Table 1 Bituminous binders used on the trial sections

Binder	Description
MC30	High solvent content, cut-back. For priming
Invert emulsion	Suspension of water in bitumen. For priming
Anionic emulsion	Stable grade, 60% bitumen
Cationic emulsion	Rapid break, spray grade, 60% bitumen
Cationic emulsion	Stable grade, 60% bitumen

4.2 Binder application

The binders were applied using a hand lance and by manual methods. It was found that the hand lance could not be used to apply the emulsions at high rates of spread. During construction of penetration macadam the first application of emulsion to the crushed rock layer had to be limited to about 2 litres per square metre to prevent run-off. The total quantity of emulsion required for surface dressings had to be applied using ‘split applications’ to allow aggregate to be spread before run-off occurred. In this technique approximately half of the emulsion and all of the aggregate is applied to the road surface. A second spray is applied which must be ‘blinded’ with crusher dust or sand to allow rolling and trafficking. The alternative method was to manually apply the emulsion to minimise run-off.

5 Construction of trial sections

5.1 Priming of the gravel roadbase

Both MC30 and an invert bitumen emulsion were used for priming the roadbase to allow comparison of ease of application and long term performance to be assessed. In both cases the bitumen could be applied by hand lance at ambient temperature. Before spraying primer the roadbase was lightly watered to allow the primer to spread more easily. However, the depth of penetration of both primers into the dense roadbase was minimal and much less than the ideal of about 6mm.

The invert bitumen emulsion, which is a suspension of water droplets in bitumen, was easy to use and dried more quickly than MC30. A major drawback of MC30 is that it contains approximately 40 per cent of solvent that has implications for environmental damage.

The application rates were 1.0 l/m^2 for MC30 and 1.2 l/m^2 for the invert emulsion. The section, which was surfaced with penetration macadam, did not require priming.

5.2 Sand seals

These seals are normally constructed in a similar manner to surface dressings but are cheaper, if sand is readily available, and may be more tolerant of variations in materials and application rates. Sand seals are usually less durable than surface dressings and the restrictions regarding choice of bitumen are the same as for surface dressings. Both single and double sand seals were constructed using anionic and cationic bitumen emulsions.

The only economically available sand was much finer than is normally recommended for sand seals but it was considered appropriate to investigate the long term performance of this material.

5.3 Gravel-Bitumen seals

It had been intended to try to construct surfacings similar to Otta seals which have been constructed on a number of roads in Southern Africa and elsewhere. Construction requires the spreading of a film of hot bitumen on a prepared roadbase followed by the application of a thin layer of gravel. The gravel is rolled extensively by pneumatic tyred rollers or, if necessary, a laden truck so that the bitumen is 'worked up' through the gravel until the layer has the appearance of a dense bituminous surfacing.

The advantage of this type of surfacing is that adjustments can be more easily made to apply more gravel or more bitumen to adjust for variations in material properties or application rates. However, some screening of the gravel may be needed to remove large particles or to limit the fines content. More importantly, it is necessary to use a bitumen viscosity range suitable for the available gravel used in the Otta seal. This may be MC 3000 cutback bitumen, or a 150/200 penetration bitumen that must have adequate mobility within the gravel during the rolling and early trafficking. Hard penetration grade bitumens and emulsions are not suitable for Otta seals.

The bitumen must be heated to allow proper spreading of the bitumen which is normally done with a distributor with MC3000 cut-back raised to a temperature of approximately 135ºC. This has an important implication for labour based work for which safe working methods would have to be put in place for heating and applying bitumen with simple applicators.

For the trials it was intended that multiple application of emulsion and gravel would avoid the need for heating the binder whilst ensuring that bitumen was distributed through the depth of the gravel. In practice the available gravel proved to have too high a fines content and

control of the rate of application of gravel was very difficult. Only two short sections were constructed.

5.4 Surface Dressing

Normally, surface dressing requires a high quality of workmanship and materials. Binder is heated in and applied by a distributor. Good quality chippings, in terms of grading, shape, cleanliness and hardness, are applied by a purpose made spreading device. However, surface dressing can be done by labour based methods but it is usually not of high quality. It can be relatively expensive unless suitable gravel, which can be easily screened, is available locally. For the trials, locally available hand-crushed rock could be easily screened to give two nominal sizes of aggregate. Dust in the smaller sized chippings was removed by manual segregation. Washing with river water could have been carried out had this been necessary.

New prepared roadbases must be primed and it is normal to apply a double dressing on new construction. For the trials a cationic, rapid break spray grade bitumen emulsion containing 60 per cent bitumen was applied at ambient temperature. Single and double dressings were constructed and the bitumen emulsion was applied by three methods;

- for single seals and the first layer of double seals the correct quantity of bitumen emulsion was spread by brooming and brushing over 1 metre wide strips in each lane;
- for a single seal, the hand lance was used to apply bitumen emulsion before and after spreading chippings, i.e. a ‘split application’. Crusher dust was applied to allow rolling and trafficking; and
- application by watering can of pre-determined quantities of emulsion required for the second layer of the double seals.

The design of the surface dressings was based on the recommendations given in Overseas Road Note 3. Representative samples containing about 200 chippings were obtained and the average least dimension of each sample was measured.

5.5 Pre-mixed bitumen and gravel

Mixing gravel, crusher dust, Portland cement and stable grade cationic bitumen emulsion in a concrete mixer produced this surfacing. After mixing, the material was placed by wheelbarrow on a primed roadbase and levelled to a depth of approximately 37mm by using suitable wooden battens placed on the road surface. The gravel was given one pass of the non-vibrating roller and allowed to ‘cure’ until the next afternoon when it was back-rolled at the hottest time of day.

The finished surface was porous and rapid break cationic bitumen emulsion was applied at a rate of 1.2 l/m^2 and blinded with crusher dust to produce a more durable surface.

5.6 Penetration macadam

This material is described in BS434 and the recommended procedures given in the British Standard were applied as far as possible in the construction of a 50mm thick surfacing. This type of surfacing is normally very robust and is likely to be the best solution for sites where traffic and road geometrics are severe. The cost of this surfacing is relatively high because a source of screened crushed rock aggregate and a high rate of application of binder are required. However, the method lends itself to intensive labour based construction.

Crushed aggregate is normally used because this material helps to generate a stable, interlocking layer after it has been compacted. Suitable locally available hand-knapped aggregates were available for the trials.

The proportions of aggregate of different nominal sizes used were;

60% of 40mm nominal single sized stone.
30% of 28mm nominal single sized stone.
10% of 14 to 20mm nominal single sized stone.

It is normal to use a 3 point dead weight roller of 8 tonnes mass and a vibrating roller to produce a dense inter-locked aggregate structure. However, only a small pedestrian roller, without vibration, was available for the trials. This may have been the best method of construction for the site because vibratory compaction would probably have caused the aggregate to be pushed down into the gravel roadbase. The only way that a tight surface finish could be obtained under the relatively light rolling was to apply bitumen emulsion and fine aggregate in increments.

Rapid break cationic bitumen emulsion was applied by watering can at an initial rate of 2 l/m^2. Aggregate of 10 to 14mm size was then spread at a rate to just fill large surface voids and to allow further rolling. Three more applications of bitumen emulsion, at a rate of approximately 1.2 l/m^2, were made with smaller sized aggregate, fine sand and finally crusher dust. A total of approximately 5.5 to 6 litres of bitumen emulsion were applied per square metre. A very light application of water was made to the existing aggregate surface before applying emulsion to help the binder penetrate and to spread more easily.

6 Visual condition survey

The performance of each of the surfacing applications was evaluated by a visual condition survey in March 2005, three and a half years after construction.

6.1 Single sand seal

Of all the applications on the site the single sand seal sections have suffered the most. Many large potholes have formed over the entire width of the road and the surfacing can now be considered as failed and in need of reconstruction with an alternative surface treatment. Where the sand seal remains, the surface has little texture and is very smooth in places.

6.2 Double sand seal

Except for an area where the near side edge of the surface has eroded, both surfaces were found to be in quite good condition. The texture of the surface was better than the single sand seal. The use of a cationic as opposed to an anionic bitumen emulsion in the construction has not shown any obvious differences.

6.3 Single surface dressing

The two sections constructed were found to be in good condition with a well textured surface. The application of the different types of prime coats used during construction does not seem to have affected the performance.

6.4 Gravel-bitumen seal

The two sections tended to have a smooth rich appearance. There were several elongated potholes close to a transverse joint between the MC30 primed gravel seal section and the single surface dressing section. A complete transverse joint failure was observed between the invert emulsion primed section and the double surface dressing section. These failures are likely to be constructional rather than material.

6.5 Double surface dressing

Apart from a transverse joint failure with the gravel seal application, both sections were in good condition. Although textured, the surface on both sections was not as good as the single surface dressing application. The application of the different types of prime coats used during construction does not seem to have affected the performance at this stage.

6.6 Pre-mixed bitumen and gravel

These sections were in good condition.

6.7 Penetration Macadam

The surface was heavily textured and in good condition with no signs of deterioration. It is the most robust of all the surface applications.

7 Performance ranking

The potholes and joint failures on the site were considered to be a construction rather than a material problem and were not considered during the ranking. On the basis of the visual inspection the following performance ranking was allocated.

1 Penetration macadam
2 Pre-mixed bitumen and gravel
3 Single surface dressing
4 Double sand seal
5 Double surface dressing
6 Gravel-bitumen seal
7 Single sand seal

8 Construction costs

Recommending the use of one application as opposed to another does not only depend on performance but on construction costs also. During the construction of the trials a study was carried out to estimate the labour costs for each application. Together with the costs of materials (aggregate, primer and emulsion) the cost per square metre for each application was calculated in US$ and are shown in Table 2.

Application	US$/m^2
Penetration macadam	3.80
Pre-mixed bitumen and gravel	2.28
Double sand seal	1.86
Double surface dressing	1.53
Gravel-bitumen seal	1.19
Single sand seal	1.16
Single surface dressing	1.06

Table 2 Estimated application costs

The stated costs are only estimates and can not be used for contract pricing as the availability of local aggregates and bitumen emulsions will reflect in the price per square metre of each application. The bitumen primer and emulsions were the most expensive components used in the construction of the surfacings. They accounted for between 80-95% of the unit costs.

9 Conclusions

- The condition of the different surfacing applications after 3½ years is generally good.
- The single sand seal sections quickly deteriorated and can not be considered to be more than a temporary measure.
- Performance ranking of the applications has shown that the penetration macadam treatment is the best.
- The cationic and anionic emulsions have so far performed equally well. There seems to be no advantage in using one as opposed to the other in the construction of a particular surfacing treatment.
- There appears to be no advantage in using MC30 as opposed to invert emulsion as a prime coat.
- Estimates of the unit costs of construction for each application show that the penetration macadam is the most expensive with the single sand seal the least expensive.
- By considering performance ranking and construction costs, the single surface dressing, was considered the most economical application.