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Labour-based bitumen roads as cost-effective alternatives to conventional gravel wearing courses

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Abstract

As part of the Gundo Lashu Programme for Labour Intensive Rural Roads Maintenance that is currently being implemented in Limpopo Province, South Africa, the training of 24 emerging contractors in rehabilitation of rural gravel roads was carried out. All 24 contractors went through an extensive practical and theoretical training programme and have completed their first Trial Contracts, which formed the second step in their development programme. They are currently executing larger Standard Contracts after which they will emerge into the open market.

South African rural roads generally carry much more traffic than the rural road network in the rest of sub Saharan Africa with many gravel roads carrying up to 1000 vpd. At the lower end, there is a vast network of district and community access roads carrying less than 100 vpd, which is largely unimproved and maintained only as bladed tracks. In addition, there are probably hundreds of thousands of kilometres of unimproved village roads and streets. The potential for large-scale application of labour-based road works is therefore enormous.

Delivery of a quality product is seen as key to the acceptance of labour-based road works. In Gundo Lashu it was realised early on that finding good quality wearing course gravel in itself constituted a major problem in many areas of the province, thus bringing the costs for a fully rehabilitated and gravelled 5.5m wide road to about R230 000 in some instances. Aside from depleting an increasingly scarce resource, construction and maintenance of conventional gravel roads would be very costly.

An assessment of different options for the provision and maintenance of a good gravel wearing course, in financial and economic terms as well as suitability for labour-based operations was carried out. This indicated that better use and/or improvement of in situ material by emulsion or chemical stabilisation in combination with provision of various low cost bituminous seals results in lower predicted life-cycle costs than the gravelling option for the roads in question. Aside from the potential financial/economic benefit, the alternative solutions would have considerable intangible or non-quantifiable benefits such as reduction of dust pollution, reduced negative environmental impact and conservation of valuable resources in the form of gravel deposits.

Labour-based contractors can use the techniques assessed successfully on roads carrying up to 200-300 vpd and thus cover a large proportion of the rural road network. Aside from retaining the employment benefit, the potential savings in construction and maintenance costs may be used to construct more roads and thus provide a larger proportion of the rural population with good quality all-weather access roads of an appropriate standard and contribute to economic development of previously

disadvantaged communities. The implementation of sustainable community-based maintenance programmes is an essential part of the works programme.

INTRODUCTION

Gundo Lashu, the 'Labour Intensive Rural Roads Maintenance Programme', which is currently being implemented in Limpopo Province, South Africa set out, *inter alia*, to train 24 emerging contractors in rehabilitation of rural gravel roads. All 24 contractors went through an extensive practical and theoretical training programme and have completed their first Trial Contracts, which forms the second step in their development programme. The contractors are currently executing Standard Contracts designed to be completed within a 12-month period, after which they will exit from the training programme and be exposed to the competitive contracting environment.

South African rural roads generally carry much more traffic than the rural road network in the rest of Sub Saharan Africa with many gravel roads carrying up to 1000 vpd. A significant portion of the provincial roads carries traffic from 100 to 400 vpd. At the lower end, there is a vast network (nobody really knows the exact extent) of district and community access roads carrying less than 100 vpd, which are largely unimproved and maintained only as bladed tracks. In addition, there are hundreds of thousands of kilometres of unimproved village roads and streets. The potential for large-scale application labour-based road works is therefore enormous and only limited by the funding available for the sector.

Delivery of a quality product is seen as key to the acceptance of labour-based road works. In Gundo Lashu it was realised early on that finding good quality wearing course gravel in itself constituted a major problem in many areas of the province, thus bringing the costs for a fully rehabilitated and gravelled 5.5m wide road to about R230 000 in some instances. Aside from depleting a scarce resource of potential material for sealed roads the cost of construction and maintenance of conventional gravel roads that will provide a generally poor quality wearing gravel course material is high.

A continuation of the (re)gravelling approach was therefore seen as a threat to the general acceptance of LBT even if the technology in itself could not be blamed for not producing roads that would stand up well over time and provide a reasonably safe and comfortable drive for the motorised road users. It should be noted in this regard that concern about the quality of the wearing course gravel seemed to a large extent to be minimal among consulting engineers and project managers in the maintenance of the gravel road network. Finding alternative solutions hence became a necessity for a successful continuation of the programme and key to the broad acceptance and establishment of the technology in the road sector.

The Roads Agency of Limpopo, which implemented the Gundo Lashu programme, therefore engaged CSIR to carry out a case study based on the second batch of Trial Contracts, which were to be executed in areas where good wearing course gravel was scarce or non-existent. In one of the areas, the in situ material consists predominantly of Kalahari-type sands whilst in the other area the in situ material is mostly low- or non-plastic weathered granite.

The primary objective of the study discussed in this paper was to assess different alternatives to the provision and maintenance of a good gravel wearing course, in financial and economic terms as well as suitability for labour-based operations.

Preliminary results of the study (Table 1) showed that better use and/or improvement of in situ material by emulsion or chemical stabilisation in combination with low cost bituminous seals would in fact be cheaper than the gravelling option for the roads in question. Sand-cushioning could also be a more favourable alternative where the gravel specifications could not be met. Aside from the potential financial/economic benefit, the alternative solutions would have considerable intangible or non-quantifiable benefits such as the reduction of dust pollution, reduced negative environmental impact and reduced use of valuable resources in form of gravel deposits.

Road	Action	Estimated Construction costs (R/km)	Total Life Cycle Costs (R/km)[a]	Recommended action	Trial sections
D3342 and D3348 Bochum	TRH 20 Non TRH20 + additional maint Sand cushion Paved TRH 20 Pave in situ Pave local import Pave treated in situ Paved imported and treated	173 546 92 600 210 000 228 000 110 000 147 600 195 000 235 000	440 603 409 858 408 000 460 201 352 928 387 110 411 090 447 454	Pave in situ with double seal[b] Non TRH20 & extra maintenance	Chemical treatment Bitumen emulsion
D4263 and D4262 Km 12-24 Jane Furse (30 vpd)	TRH 20 Non TRH20 + additional maint Sand cushion Paved TRH 20 Pave in situ Pave local import Pave treated in situ Paved imported and treated	196 333 92 600 216 000 247 000 107 000 139 600 167 600 191 600	436 583 389 194 413 455 427 946 300 673 330 310 386 181 407 999	Pave in situ with double seal[b] Non TRH20 & extra maintenance Sand cushioning	Chemical treatment Bitumen emulsion
D4263 and D4262 Km 0 - 12 Jane Furse (78 vpd)	TRH 20 Non TRH20 + additional maint Sand cushion Paved TRH 20 Pave in situ Pave local import Pave treated in situ Paved imported and treated	221 222 92 600 231 222 276 222 107 000 139 600 177 600 221 600	847 400 815 576 772 795 765 645 611 807 641 444 747 975 787 975	Pave in situ with double seal[b]	Chemical treatment Bitumen emulsion Non TRH20 & extra maintenance
D4263 and D4262 Km 24 - 32 Jane Furse (145 vpd)	TRH 20 Non TRH20 + additional maint Sand cushion Paved TRH 20 Pave in situ Pave local import Pave treated in situ Paved imported and treated	180 000 92 600 231 222 247 000 107 000 139 600 195 000 221 600	1 265 611 Not practical Not practical 1 122 461 995 198 1 024 825 1 187 713 1 211 895	Pave in situ with double seal[b]	Chemical treatment Bitumen emulsion

a) Economic costs over a 20 year analysis period

b) The use of in situ base and a double seal should be the first choice in all cases. Where the in situ materials do not allow this (ie CBR< 45 per cent), locally imported material (haul < 2 km) should be assessed prior to treatment of local or imported material. For the low traffic roads, the use of Non-TRH 20 materials with extra maintenance or sand cushioning is the second choice.

All options under consideration were eminently suitable for labour-based techniques. Thus, if chosen, they would retain more or less the same employment potential but shift costs away from plant (tippers, tractor/trailers) over to materials (bitumen, chemical stabiliser).

It was envisaged that labour-based contractors can use the techniques successfully on roads carrying up to, say, 200-300 vpd and thus cover a large proportion of the rural road network. Aside from retaining the employment benefit, the potential savings in construction and maintenance costs may be used to construct more roads and thus reach a larger proportion of the rural population with good quality access roads of an appropriate standard and contribute to economic development of previously disadvantaged communities.

Constructing sealed roads, no matter the type of seal to be applied, required a slight review of the construction techniques traditionally applied for labour-based gravel roads and a more selective choice of in situ materials to be used for the layer works. By simple means, it is thus possible to construct high quality sealed roads to a lower overall cost than a dusty, corrugating gravel road.

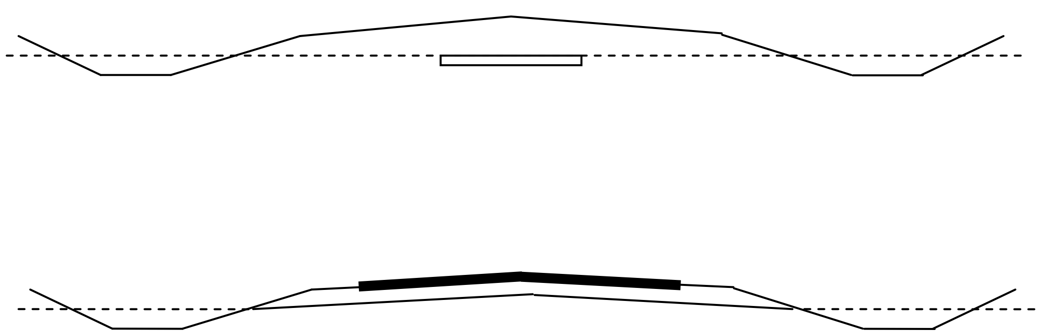

Figure 1: The old method (top) results in weak spots and biscuit layers in construction of the formation (subbase). The revised method (bottom) ensures controlled moisture content, optimum compaction of the layers and a uniform thickness of the base

Thus by broadening the scope for application of labour-based technology on a large scale and producing durable high quality assets which are seen to be an engineered product, embracement of the technology by a conservative engineering community should be forthcoming. Perhaps the LBT community has been trapped in the “gravel road syndrome” too long? It is well known that rehabilitation of gravel roads is not regarded by many engineers as proper engineering, but merely as a maintenance function. Moving a step up to low cost sealing could therefore be the trick to finally ensure acceptance of the technology and the sustainability of labour-based road programmes beyond the ever-recurring pilot phase.

PREVIOUS EXPERIENCE WITH LOW-COST SURFACING

Significant experience has been built up in South Africa[1,2] and elsewhere[3] regarding the application of surface seals to existing gravel roads to provide appropriate low volume sealed roads. Provided that the existing wearing course materials have an adequate strength (a soaked CBR of 45 per cent is adequate for most roads carrying less than about 50 vehicles per day and 60 per cent will suffice for roads carrying up to about 100 vpd), application of a suitable seal will provide a significantly better road than any unsealed equivalent.

Appropriate seals include double sand[4,5] and grit seals and the Otta seal[6], all of which are highly tolerant to low experience contractors and have significant benefits in that they make use of local materials (of substandard strength compared with normal requirements) requiring minimal processing. The majority of the material source is used, unlike conventional chip seals that make use of only a small proportion of the total source.

The successful use of this type of pavement design depends on attention to a number of construction practices:

- Drainage – It is essential that effective side-drains be constructed with invert levels at least 300 and preferably 450 mm below the pavement crown level.
- Materials – The materials must be as uniform as possible and meet the design requirements.
- Compaction – All gravel layers should be compacted to refusal for the plant available and not a specified density. It is necessary, however, that a minimum density is achieved in all cases, preferably 98 per cent of the modified AASHTO maximum dry density. It is thus essential that adequate compaction water is available and this is uniformly distributed through the material at as close to optimum moisture content as possible.
- Maintenance – A good maintenance capability, which is regularly implemented, is necessary. This must ensure that cracking, potholes and vehicle or animal damage to the surfacing are timeously repaired and all drainage structures are clean and effective. This should ensure a sustained community labour involvement.

DISCUSSION OF THE FINANCIAL/ECONOMIC ANALYSIS OF THE CASE STUDY

A summary of the economic analyses of the options was provided in Table 1. Details regarding specific aspects of the project are provided in Tables 2 and 3.

Table 2: Cost per kilometre of individual treatments for Bochum cluster roads

Alternative	Present Worth of Costs (R)		Net Present Value (R)	
	Financial	Economic	Financial	Economic
TRH20	186 945	440 603		
Non TRH20 + extra maintenance	139 479	409 858	47 466	30 745
Chemical/bitumen treatment & seal				
In situ	245 956	411 090	-59 011	29 513
Imported < 2 km	282 320	447 454	-95 375	-6 851
Sand Cushioning	194 233	408 000	- 7 288	32 603
Paved TRH20 material	275 956	460 201	- 89 011	-19 598
Paved local material				
In situ	168 683	352 928	18 262	87 675
Haul < 2 km	202 865	387 103	-15 920	53 500

Table 3: Cost comparisons per kilometer for Road D4264 (traffic 145 vpd)

Alternative	Present Worth of Costs (R)		Net Present Value (R)	
	Financial	Economic	Financial	Economic
TRH20	237 022	1 265 611		
Non TRH20 + extra maintenance	223 162	1 319 424	Not practical	
Chemical/bitumen treatment & seal				
In situ	423 596	1 187 713	-186 594	77 898
Imported < 2 km	447 778	1 211 895	-210 756	53 716
Sand Cushioning	214 763	1 174 191	Not practical	
Paved TRH20 material	369 524	1 122 461	-132 502	91 420
Paved local material				
In situ	242 301	995 198	-5 279	270 413
Haul < 2 km	271 938	1 024 825	-34 916	240 786

Table 2 summarises the Present Worth of Costs (PWoC) and Net Present Values (NPV) of a typical section of road carrying about 30 vehicles per day. The analyses are presented as both financial costs (ie, the cost to the road authority) and economic costs (the cost to the road authority and the road user) and shadow costs were used for all input costs. All analyses were carried out over a 20-year analysis period using a discount rate of 10 per cent. Construction and maintenance costs were based on the best available estimates at the time (these were reassessed at the end of the projects and close agreement was found).

Six basic alternatives were analysed:

- TRH 20[7] – Conventional regravelling with materials complying with the South African gravel wearing course material standard.
- Non TRH 20 material with extra maintenance - This option would make use of the local materials, generally with inadequate plasticity. To avoid corrugation and ravelling, additional maintenance would be necessary but the overall riding quality would generally be poorer than the other options.
- Chemical/bitumen treatment with a seal – This option assessed the costs of treating the in situ material with either bitumen emulsion or a proprietary soil chemical stabilizer. Included in this option was that of importing local material from adjacent to the road, where the in situ material could not be suitably treated.
- Sand cushioning – This is an option that makes use of a thin layer of sand to protect the gravel wearing course from vehicle wear. It requires good conventional gravel wearing course material and regular low-cost maintenance (sand replacement and dragging), but minimises the loss of the imported gravel wearing course.
- Paved TRH 20 material - The option of paving material imported for a conventional gravel wearing course was assessed. This is typically a poor alternative, as the gravel wearing course necessarily requires cohesion and is thus often excessively water sensitive to perform as a good base course under a bituminous seal.
- Paved local material – Inspection of the local materials indicated that many of them would probably perform successfully as a base course. The options of sealing them directly as well as importing local materials from adjacent to the road were analysed.

It was clear from the results that:

- In financial terms, only the use of non-TRH20 materials with additional maintenance and the sealing of in situ local materials have direct cost advantages.
- Sand cushioning has slight cost disadvantages in financial terms.
- The economic analyses indicate that all options except the sealing of TRH20 materials and the treatment and paving of imported materials are beneficial. Where the in situ materials are not suitable for sealing directly, the sealing of imported materials (< 2km haul) without treatment is the most cost-effective solution in all cases.

- The total savings (economic) generally exceed the difference between construction costs on any sections of the roads: the results thus indicate that for the roads analysed, the TRH 20 option is mostly the least cost effective.

For the low traffic prevailing on these roads, sand cushioning and the use of non TRH20 gravels with additional maintenance would result in the need and necessary development of sustainable local maintenance capabilities.

However, the options of sealing local materials (with or without treatment) are significantly more beneficial than the non-sustainable practice of replacing gravel lost through traffic and erosion associated with the unsealed road options (other than the sand-cushioning to a significant extent). The maintenance cost of the paved options was selected to be high, providing sustainable employment for a number of teams for the service life of the road, although it is anticipated that maintenance will be less and a higher proportion of the maintenance costs will be directed to materials. Other benefits such as dust reduction and an overall improved riding quality of the road (with a reduction in vehicle operating costs of about 23 per cent) would be obtained with the paved options. This type of saving in vehicle operating costs can be significant to a rural community such as this, where transportation is an important cost.

Similar findings were generally determined for Road 2464 (Table 3). The expected traffic on this section of the cluster, however, would make the use of non-TRH 20 type materials and sand cushioning impractical. The maintenance required would present a severe traffic disruption and safety hazard.

The expected cumulative E80s for this road will exceed the design E80s after about 8 years, whereafter rehabilitation will be required. A reseal and second rehabilitation would be required within the 20-year analysis period. The TRH20 design, on the other hand would require regravelling three times in this period necessitating the use of about 33 000 m^3 of gravel and would require grading about once a month initially and more frequently for the last 7 years.

The financial net present values of the paved options are slightly worse than the TRH20 option, only marginally worse when the in situ material can be used. All options are economically beneficial, primarily as a result of the large savings in road user costs related to the better road surface provided by paving the road. Road user cost savings of up to 25 per cent would accrue to the community.

It is interesting to note that the use of chemical stabilizers or bitumen emulsion treatment is the least cost-effective of all options in financial terms but has significant benefits in economic terms. Where suitable base course quality materials cannot be sourced locally, improvement using chemical or bitumen emulsion stabilization should thus be considered. The use of these products generally has high construction costs but low overall life-cycle costs, provided they perform as expected. The maintenance needs and techniques for these are currently unknown.

THE PRACTICAL TRIALS

Various technical solutions have been discussed in the previous section. The final proposals, however, included a number of innovations.

In the granitic terrain of Jane Furse, the in situ material has a CBR value well in excess of 80 per cent and can thus be used directly as a base course with a bituminous seal. It was proposed that the local sand would provide an appropriate sand seal (a double seal was recommended to minimise animal hoof damage). It was also proposed that the top 50 mm of the base be enriched with a dilute emulsion to both permit traffic movement prior to sealing and to avoid the necessity for a prime. Assessment of the slope of the CBR density curve[8] indicated that the strengths of the materials are density sensitive and a high degree of compaction would be essential.

In the sand terrain of Bochum, the in situ material had a CBR of about 30 per cent while the cleaner Kalahari type sands had strengths in excess of 45 per cent. The proposal was to treat the in situ materials and sand with a diluted emulsion and a nominal cement application (to assist with breaking of the emulsion) and surface the road with an Otta seal. The aggregate for the Otta seal could be obtained form an existing borrow pit some 10 km from the project, by ripping, gridding and scalping the plus 16 mm to provide a suitable aggregate for the Otta seal.

It was found that the labour-based technique being implemented had some shortfalls, resulting in poor densities being achieved and a thin feather wedge at the outer extremes of the formation (subbase). The formation, which in the gravelling option would form the subbase, but with the redesign would form the base course for the sealing options, was therefore corrected to ensure uniform and sufficient compaction in order to proceed with the sealing trials. In order to ensure that the project remained on schedule, this was done under a separate contract using mechanical plant.

The construction process would make use of premixing and shuttering[10] to ensure uniformity of the material and to directly control the density and compaction. Instruction of the Contractors and their supervisors in the use of shuttering to prepare the base (ensuring the correct compaction and pavement structure) was then carried out. Labour-based application of the prime and construction of the sand seal was demonstrated and a trial/demonstration section of Otta seal was constructed. The local contractors then continued with Sand and Otta sealing.

Base Course

The base course at Jane Furse was 100 mm thick and was constructed primarily of the in situ decomposed granite, with a short section including a bitumen emulsion enriched upper 50 mm. Construction used shuttering as described in LICT 7[10] and was successfully carried out. The emulsion enriched upper portion was constructed by placing 75 mm of untreated material (at OMC within the shuttering and then placing 75 mm of bitumen emulsion treated material on this before compaction. The treated material was prepared in a concrete mixer by mixing a fixed quantity of the local material with 2 per cent stable grade 60 % anionic emulsion and 1.0 per cent cement with the required volume of water to achieve optimum fluid content for compaction. The layer was then compacted until it was 100 mm thick.

Sections using the weaker sandy materials at Bochum were constructed in a similar manner. As a control section, a short section was constructed using 100 mm of the natural material. A longer section using full depth bitumen emulsion treatment, prepared in the same way as the Jane Furse enrichment and with the same emulsion and cement contents was constructed.

Prime

On the sections that were not treated with emulsion, a prime consisting of 0.7 ℓ/m^2 of MC-30 was used at a temperature of about 40℃ (tested by hand – not hot enough to burn a finger). This was applied according to LICT 7[10] by demarcating selected areas and applying a known quantity based on the time of spraying. Larger areas of the road constructed using plant were primed conventionally using an MC 30 applied at 0.7 ℓ/m^2.

Surfacing

A short section of sand seal was carried out using local sands. The original intention was to use selected surficial material removed from the existing unsealed road and obtained form local stream beds, from which the fines had been removed during trafficking or by water. A typical grading analysis of these materials is shown in Table 4. However, during construction of the demonstration section, material stockpiled next to the road that was removed from the pre-existing gravel road was used. This had a significantly higher fines content than that proposed and considerably higher than is suggested even after relaxation for sand seals for low volume roads in the literature[11]. Significant dust was generated during construction and despite fears that the section would be a failure, the end result was very good. Cationic 65 emulsion was used as a binder for the sand seal and applied at a rate of 1.6 ℓ/m^2 at a temperature of about 55℃.

Table 4: Grading of sands for sand seal

	Percentage passing sieve size (%)		
Sieve size (mm)	**Proposed sand**	**Actual sand**	**Relaxed Specification[11]**
6.7	100	100	100
4.75	98	96	85 – 100
2.00	74	78	-
0.60	33	-	20 – 50
0.425	25	46	-
0.075	4	19	0 - 2

The Otta seal was constructed initially as a demonstration/trial section of about 300 m and subsequently over a length of about 7.5 km by the local contractors. The material was obtained locally and was placed on about 2.2 ℓ/m^2 of 150/200 pen bitumen cut back with about 12 per cent power paraffin and sprayed by tanker at 135℃. Three sands were tested initially and were found to be too fine (Figure 2). A source of residual granite material with some coarse aggregate was then located close to the road and was manually screened through a 19 mm grizzly screen. The grading of this was somewhat better although the 10%FACT strength of the coarser fraction was less than the recommended 100 kN. Despite this the material was successfully used.

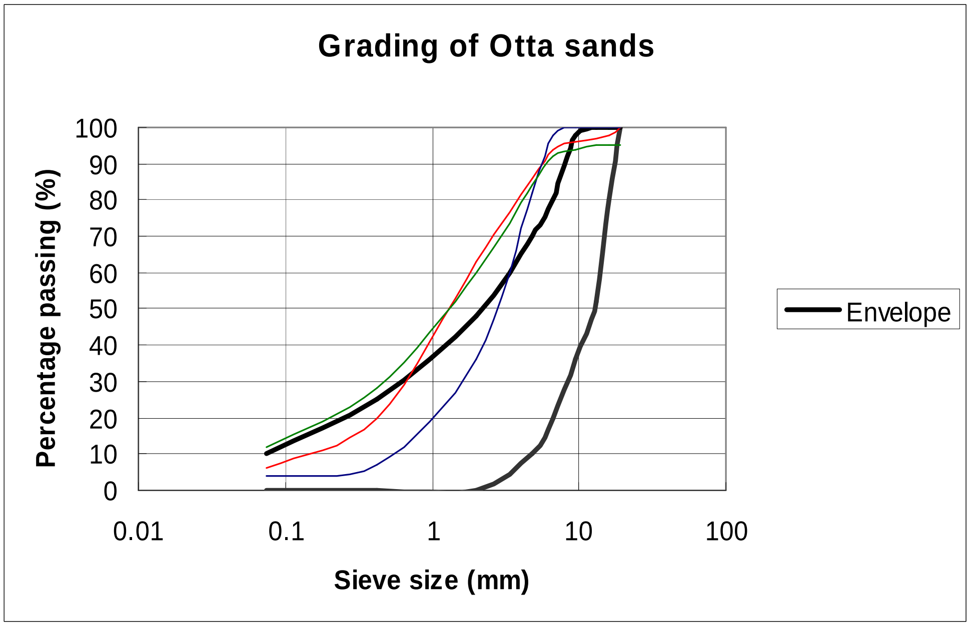

Figure 2: Grading of local sands

CONCLUSIONS

The Gundo Lashu programme in the Limpopo Province of South Africa is a labour-based training programme involving the regravelling of a network of unsealed roads. Suitable wearing course gravels are, however, scarce in the area and in order to provide adequate wearing courses, blending or the haulage of material would be necessary. Economic analyses showed that it would be more cost-effective to pave the existing (in situ) materials with a low cost seal than to acquire materials for unsealed roads, which would need to be repeatedly regravelled in an unsustainable programme.

Sections of emulsion treated and emulsion-enriched base were cost-effectively constructed and various surfacing trials using sand and Otta seals were successfully constructed using local materials, deviating from conventional specifications. It was thus clearly demonstrated that sealed roads using local materials can cost-effectively replace unsealed roads in the correct circumstances.

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