Appropriate Standards and Specifications for Surfacing of Low-volume Rural Roads

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ABSTRACT: In many developing countries, a substantial proportion of the road network consists of earth and gravel roads (typically 75%) that carry relatively low traffic. Natural gravel materials are used for providing, maintaining such roads in spite of increasing scarcity of suitable materials. The inherent problems of maintaining unpaved roads can be overcome by paving them when economically justifiable. However, due to limited funds this is often not possible in most developing countries. One type of surfacing that can provide an economic and practical alternative to traditional surfacings is the graded aggregate surfacing, the Otta seal. This paper presents the background to the Otta Seal and outlines its design, construction and maintenance. The paper concludes that, in appropriate circumstances, the Otta Seal can be a practical, cost-effective alternative to the more traditional types of surface treatments.

1 Introduction

In many developing countries, a substantial proportion of the road network, typically more than 75%, consists of gravel and earth roads. These unpaved roads generally carry relatively light (generally less than 200 vpd) but nationally important traffic and provide access to rural areas where the majority of the population lives. Rural communities depend on reliable, year-round road access without which their basic social and economic needs cannot be met.

The inherent problems of maintaining unpaved roads can be overcome by paving them. However, even when this solution is economically justifiable, it is often not possible to adopt it in most developing countries because of very limited funds. This has prompted road engineers to search for and develop innovative methods of surfacing unpaved roads in order to reduce costs, improve their economic attractiveness and at the same time not impair the quality of the end product.

One type of surfacing that can provide an economic and practical alternative to traditional surfacings is the graded aggregate or Otta seal (Pinard, M. I. et al 1999). This type of surfacing allows the use of relatively inferior, naturally occurring, unscreened gravels in circumstances where the use of traditional bituminous sprayed surfacings using relatively expensive crushed rock would be unaffordable or simply not possible due to the unavailability of such materials.

2 Need for low-cost sealed roads

2.1 Sustainability of gravel roads

A gravel road surface can be appropriate and cost effective in certain specific circumstances. These include situations where: sufficient quantities of gravel are available that meet the required surfacing specifications; haul distances are relatively short; longitudinal road gradients are less than about 6%; rainfall is low or moderate; traffic is relatively low; dry season dust generation is not severe; finance and resources are going to be available for the necessary on-going periodic re-gravelling and routine maintenance.

However, increasingly, the above suitability criteria are often not met and the practice of managing more than 75% of a national road network as gravel roads is being seriously questioned. The major concerns to national
governments, development agencies and rural roads agencies over the efficacy of rural road gravel roads may be summarised as follows: Gravel is a sacrificial, the cost of periodic (regravelling) and routine maintenance of gravel roads can be very high. Dust generation in dry weather causes adverse impacts in terms of being a health hazard for communities living adjacent to the road.

2.2 The case for low - cost sealed road

Conventional design and construction methods coupled with conventional cost-benefit analysis result in thresholds for sealing roads at about 200 vpd. Developments in technology, research and knowledge have created a new platform for a more rational and up-to-date approach to the economics of rural road provision. By adopting appraisal methods that are able to capture the non-economic benefits of low - volume road provision (e.g. the Roads Economic Decision (RED) model (Archondo-Calliao, R. 1999) and by promoting the use of local materials and using labour-based approaches and technologies coupled with design approaches that work with the environment has shown that in some circumstances bitumen sealing of gravel roads is economically justified at traffic levels as low as 40 to 70 vpd (Morusulk, G, et al, 1999). crushed rock would be unaffordable or simply not possible due to the unavailability of such materials.

3 Bituminous surfacings

3.1 Types and mechanism of performance

Various types of bituminous surfacings have been developed for application to specific situations relating to a variety of circumstances. The challenge is to match the surfacing type to the prevailing circumstances in the most cost-effective and sustainable manner. These types of surfacing are illustrated schematically in Figure 1. (Overby, C. 1999). In many developing countries, a substantial proportion of the road network, typically more than 75%, consists of gravel and earth roads. These unpaved roads generally carry relatively light (generally less than 200 vpd) but nationally important traffic and provide access to rural areas where the majority of the population lives. Rural communities depend on reliable, year-round road access without which their basic social and economic needs cannot be met.

The various types of bituminous surfacings (excluding asphalt concrete) illustrated in Figure 1 may be placed in one of two categories as regards their mechanism of performance under traffic which is illustrated in Figure 2 and summarised below:

Category A Surfacings: (Sand seal, Slurry seal, Otta seal): These seal types rely to varying extents on a combination of mechanical particle interlock and the binding effect of bitumen for their strength, similar to a bituminous premix. Under trafficking, the seal acts as a stress-dispersing mat comprised of a bitumen/aggregate admixture - a mechanism of performance which is quite different to that of Category B surfacings.

Category B Surfacings: (Chip seal): This seal type relies on the binder to “glue” the aggregate particles to the base, this being the primary objective of the binder. Where shoulder-to-shoulder contact between the stones occurs, some mechanical interlock is mobilized. Should the bitumen/aggregate bond be broken by traffic or poor adhesion, insufficient material strength, water ingress or numerous other causes, “whip off” of the aggregate by traffic is almost inevitable. Under trafficking, the aggregate is in direct contact with the tire and requires relatively high resistance to crushing and abrasion to disperse the stresses without distress.

Figure 1. Schematic of common types of bituminous surfacings.
3.2 Service life

The service life of a bituminous surfacing depends on a number of factors including: type of surfacing; quality of surfacing (aggregate strength, binder durability, construction quality, etc.); Table 1 presents typical service lives of the various types of bituminous surfacing as illustrated in Figure 1.

<table>
<thead>
<tr>
<th>Type of seal</th>
<th>Typical range of service life (years)</th>
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<tbody>
<tr>
<td>Sand seal, single and double</td>
<td>2 - 4 and 6 - 9</td>
</tr>
<tr>
<td>Chip seal, single and double</td>
<td>4 - 6 and 7 - 10</td>
</tr>
<tr>
<td>Cape seal (13mm + single slurry)</td>
<td>8 - 10</td>
</tr>
<tr>
<td>Single Otta seal + sand cover</td>
<td>8 - 12</td>
</tr>
<tr>
<td>Double Otta seal</td>
<td>12 - 16 In a semi-dry climate the Otta seal has performed well after more than 20 years in service</td>
</tr>
</tbody>
</table>

Table 1. Typical range of service lives of bituminous surface treatments.

![Figure 2. Mechanism of performance of surfacing types](image)

4 The Otta seal surfacing

4.1 Origin and initial use

In 1963 the Norwegian Road Research Laboratory (NRRL) was commissioned to develop a method of bituminising gravel roads to improve their quality at a relatively low cost. Based on economic and technical considerations, the following two main goals had to be achieved: the investments should be recovered in a few years through maintenance cost savings only; the road user should find the quality and performance of the surfaces similar to conventional bituminous surfacings. The trials were carried out in the Otta Valley in Norway between 1963 - 65. The performance of the Otta seal exceeded all expectations (Thurman - Moe, 1966). As a result, a type of surfacing that was initially intended for use as a temporary "bituminous maintenance seal" was subsequently also adopted for use on existing and newly constructed bituminous roads carrying both low and medium volumes of traffic.

4.2 Description and types

The Otta seal is essentially a 16 - 32 mm thick bituminous surfacing consisting of an admixture of graded aggregates, ranging from natural gravel to crushed rock, in combination with relatively soft (low viscosity) binders with or without a sand seal cover. After rolling and trafficking, the binder works its way upwards through the aggregate interstices which results in a dense, durable matrix that relies on both mechanical interlock and bitumen binding for its strength - similar to a bituminous premix. This is in contrast to the one or two layers of single-size crushed aggregate that are placed on a relatively thin film of a comparatively hard binder to produce
the more traditional single or double Chip seals (Pinard and Obika, 1997) as illustrated in Figure 3.

![Figure 3. Difference in make-up of a single Otta seal and Chip seal](image)

There are various types of Otta seal in terms of number of layers, type of aggregate grading and whether or not a cover sand seal is used. These various types may, in general, be summarised as follows:

- **Single Otta seal** - open/medium/dense graded – sand seal/no sand seal
- **Double Otta seal** - open/medium/dense graded – sand seal/no sand seal

The dense, closed texture of an Otta seal, which is further enhanced with the use of a cover sand seal, is particularly advantageous in the hot temperature conditions that occur in many countries. In such conditions, high solar radiation significantly increases the rate of oxidation of the surfacing binder which, due to the protective sand seal cover, occurs less quickly with Otta seals as compared with the more conventional Chip seals. The choice of a particular type of Otta seal in relation to traffic is indicated in Table 2. These recommendations are flexible and will be project dependent.

One of the main advantages of an Otta seal is the flexibility it offers in terms of the variety of materials that can be used for producing the graded aggregate. Accordingly, the approach to producing the graded aggregate should be to devise the best way of using whatever source of materials is available in combination with a judicious choice of binder (Overby, 1982; Overby, 1983; Roads Department, Botswana, 1999). Both crushed or uncrushed material as well as a mixture of both can be used for Otta seals.

<table>
<thead>
<tr>
<th>Traffic levels and type of work</th>
<th>Type of Otta seal</th>
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</thead>
<tbody>
<tr>
<td>Temporary seal (diversions, haul, temp. access etc.)</td>
<td>Single Otta seal</td>
</tr>
<tr>
<td>Maintenance resealing</td>
<td>Single Otta seal</td>
</tr>
<tr>
<td>AADT less than 500</td>
<td>Single Otta seal + sand cover seal</td>
</tr>
<tr>
<td>AADT more than 500</td>
<td>Double Otta seal</td>
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</table>

The grading of the aggregate should fall within, and should desirably be parallel to, the envelope shown in Figure 4. Although the grading envelope is relatively wide, the preferred maximum size is 16mm (19mm can be tolerated for the double Otta seal) and the maximum amount of fines (material passing the 0.075 mm sieve) should preferably not exceed 10%, although fines in excess of 20% have often performed well. The grading of naturally occurring gravel generally falls within the specified envelope, but where there is oversize material it has to be removed by screening. The recommended grading and aggregate strength in relation to traffic level is given in various guidelines (Overby, 1999) and illustrated in Figure 4.

The type of binder used in an Otta seal can significantly affect its constructability, durability and ultimate performance. It is therefore critically important that a correct choice of binder is made to ensure that the critical function of a complete coating of the aggregate particles including the fines is achieved during construction. The range of binders related to viscosities that have been found to be most appropriate for this purpose are as follows: MC 800 cut back bitumen (softest), MC 3000 cut back bitumen (medium) and 250/200 penetration grade bitumen (hardest). The above types of binders are generally manufactured at refineries from where they can be readily supplied. However, one may also cut back the 150/200 penetration grade bitumen using power paraffin to the required viscosity range.
4.3 Design

Compared to other types of bituminous surface treatments, the design of an Otta seal is relatively simple. It relies on an empirical approach that is based on experience in terms of the selection of both an appropriate type of binder and an aggregate application rate. The factors that influence such a selection include: aggregate type and grading; binder type (viscosity) and curing time; traffic volume and proportion of heavy vehicles; porosity of base or condition of old surfacing; rolling equipment, capacity and procedure; weather conditions during construction.

The typical hot spray rates that apply for Otta seals varies between 1.6 - 2.2 l/m² depending on traffic. It should be noted that prime is not required on an unstabilised base course if not being calcareous. Aggregate application rates vary between 0.013 - 0.020 m³/m² and for sand cover seal between 0.010 - 0.012 m³/m². However, in practice the aggregate and sand application rates will very often be increased in order to reduce the risk of bleeding.

4.4 Construction

The construction operations for an Otta seal are similar to those of a conventional bituminous surface treatment and involve the spraying of the bituminous binder on the surface of prepared base followed by the spreading of aggregate. However, in contrast to the procedure adopted in the construction of the more traditional surface treatments, priming of the base course is generally not required prior to the application of the binder for the first layer of an Otta seal, except in the case of stabilised and calcareous bases. In order to bind the dust on the surface of the base it is essential to dampen the base with water prior to spraying the binder.

The use of pneumatic tired rollers (minimum weight 12 tons) is essential in view of their ability to knead the binder upwards through the aggregate particle interstices. The more intensive the rolling that is applied to the aggregate the better will be the quality of the Otta seal. In the absence of pneumatic rollers, compaction can be successfully carried out by the use of loaded trucks following a set rolling pattern covering the entire surfaced area. The road should be opened to traffic immediately after rolling is completed as this will assist in the further compaction of the seal. A minimum period of 8 - 12 weeks should elapse between the construction of the first and the second layers. The immediate post-construction care of an Otta seal is important to its longer-term performance and requires careful attention. Such after-care includes additional rolling and brooming back the aggregate that has been dislodged by traffic into the wheel tracks.

Otta seals provide wide scope for their construction utilising labour based methods (LBM) and, in so doing, create much needed employment. Although a few activities, such as the rolling of the surfacing aggregate, will require the use of mechanical plant, the majority of activities can be carried out using labour-based methods (Pinard and Overby, 1999).

4.5 Cost - effectiveness

The A life - cycle cost comparison between a single Otta seal with a sand cover seal and a commonly used double Chip seal reveals a significant cost benefit in favour of the Otta seal in the order of 0.6 cost ratio over a 20 year period. This advantage is derived largely as a result of the following factors such as: - lower initial
construction cost due largely to greater utilisation of the crushed aggregate or screened gravel (typically 20% less than for a conventional double Chip seal); - longer service life (typically 10-12 years for a single Otta seal with a crusher dust or river sand seal versus 6-10 years for a double Chip seal); - lower maintenance costs (omission of fog spray; longer reseal and road marking cycles).

5 Conclusions

The global use of the Otta seal as per 2007 has been used by 14 countries worldwide. In Botswana more than 2300 km have been surfaced using the Otta seal which count for about 1/3 of the paved road network).

The adoption of new ideas often requires a paradigm shift in thinking with regard to the old, tried and proven way of doing things. Until this bold shift occurs, there is often a tendency to suppress the introduction of new technology. In this context, the future direction for the more widespread use of Otta seals will depend largely on the implementers of policy - the Road Authorities, the Donor community and Consultants/Contractors.

Although, the merits of the Otta seal are fairly well known in eastern and southern Africa there is still a resistance to change from the more conventional and, in many cases, less cost-effective surfacing types. The reasons for this may be many but the main constraints are probably the change of specifications which places some of the responsibility and perceived risk on the Client as both the Consultant and the Contractor may be instructed to adopt the Otta seal approach. However, the effective dissemination of previously published documents and the holding of workshops involving all the stakeholders in the road construction industry is gradually leading to a more widespread acceptance and use of the Otta seal surfacing.

6 References


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