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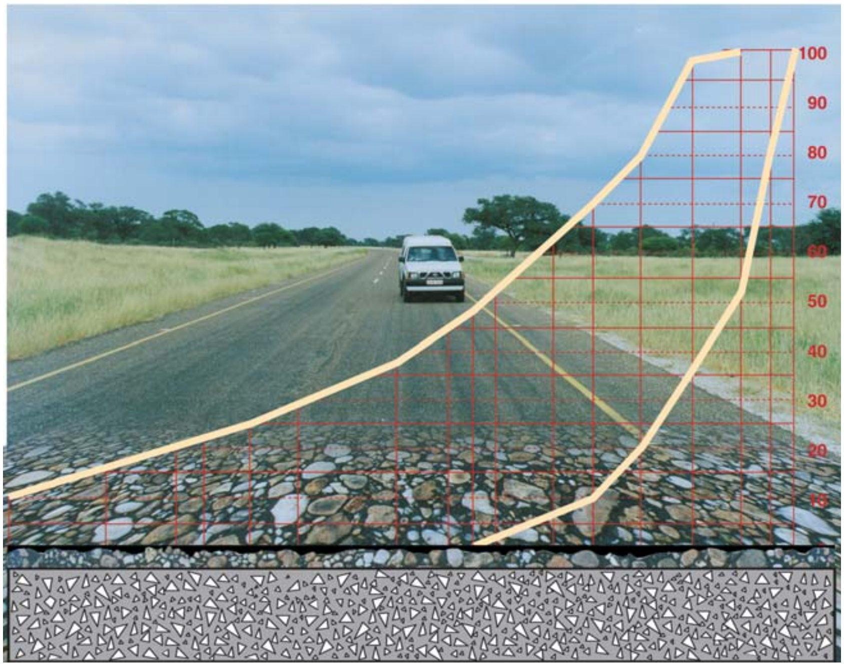
Publication

A Guide to the Use of Otta Seals



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A Guide to the Use of Otta Seals

Directorate of Public Roads
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PREFACE

The first Otta Seal surfacing was constructed in Norway during the years 1963 - 1965 based on an innovative and experimental approach. The main objective was to develop a method that could effectively improve the quality of the gravel roads to a cost equal to the gravel road maintenance. In 1965 the Norwegian Road Research Laboratory had successfully developed a sprayed bituminous seal using graded gravel and soft binder at a relatively high binder content. During the next 20 years, more than 12000 km of unpaved roads were surfaced by the Otta Seal method, comprising about 20% of the total paved road network in Norway. The Otta Seal rapidly proved to be very cost-effective and durable, and its performance much better than originally expected.

During the next 25 years Norwegian engineers has been promoting this type of sprayed bituminous seal at various parts of the world, adopting appropriate specification, matching the local environment. The reported experiences have without doubt been very successful ranging from areas of freezing cold to hot/wet and dry/very hot climate. In many cases, strict adherence to the more conventional standards for bituminous surfacings would either prohibit the project or made it unnecessarily costly. However, the lack of information regarding the Otta Seal, properties, design (previously the design of Otta Seals was based on empirical methods, rather than the more rational methods used for Chip Seals), construction and performance and the reluctance from the construction industry to embrace new technology, has so far limited the use of this type of sprayed bituminous surfacing.

The two main objectives of this Publication is to provide the following:

- Provide a ready, practical reference for the engineers and technicians who design and execute the sprayed bituminous work.
- Summing up 25 years experiences with the global use of the Otta Seals providing technical evidence and economical justifications that the Otta Seals have no other limitations than other types of sprayed bituminous seals.

It is my sincerely hope that this Publication will provide the required confidence in using this type of innovative type of sprayed bituminous surfacing, as well as to be a guidance to the practitioners, governmental engineers and technicians, contractors and consultants in situations that will favour this type of sprayed bituminous surfacing.

Oslo, 10th of August 1999

Olav Søfteland

Director General of Public Roads

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The number of persons that contributed to that Guideline is also highly credited for their inputs to this Publication.

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INTRODUCTION

1.1 Background

Budgetary constraints for the provision of sealed low volume roads both in the industrialised and developing countries have for many years forced the road engineers to search and develop innovative methods of road design, construction and maintenance in order to maximise the utilisation of the available funds. In this effort, very often consideration has to be given to the use of local materials, although the material may be non-standard or marginal to the more rigid specifications. Strict adherence to the more conventional standard specifications would either prohibit the project or make it unnecessarily costly.

One area where cost savings can be made in road construction is with the judicious choice of bituminous surfacing. Normally, the selection of the most cost-effective surfacing would be based on a life cycle analysis of appropriate surfacing types in which the influence of a range of factors is investigated. One type of surfacing which has proven to be eminently cost-effective in appropriate situations is the Otta Seal using graded aggregate. For more than three decades has this type of bituminous surfacing proved to be very cost effective both in Scandinavia, Iceland, East and Southern Africa and partly also in Bangladesh.

Unsealed roads very often provide an unsatisfactory driving comfort and associated high maintenance and operational costs. Dust pullotion is also a problem in urban areas. (South Africa).

A bituminous surfacing protects the base course layer and provides good riding quality. Hence, low operational costs. (Zimbabwe).

1.2 The Guideline, purpose and scope

The main purpose of this Guideline is to provide practical guidance on the design, construction and maintenance of Otta Seals. The Guideline also summarises the experience that has been gained in the use of the Otta Seal for the last three decades in a global perspective. In so doing, the intention is to improve the understanding of this type of road surfacing and to promote its use under similar environments where optimum use has to be made from limited funds available for road construction and maintenance.

It is emphasised that this Guideline should be used for the purpose intended, i.e. as a guideline and not as a prescriptive approach or standardised way of designing, constructing or maintaining Otta Seals. Some judgement will always have to be exercised in arriving at decisions regarding the parameters that are incorporated in particular designs.

The Guideline is intended for use by the various organisations associated with the design, construction and maintenance of Otta Seals. These organisations include employers, consultants, contractors and materials suppliers.

1.3 Structure of the Guideline

The Guideline contains twelve main chapters, following the general introduction, which is given in this Chapter, Chapter 2 gives an overview of the role and function of bituminous surfacings. The origin and the innovated approach for the Otta Seal is given in Chapter 3. Chapter 4 provides details of the Otta Seal, description and performance characteristics. This is followed by the Chapters 5 and 6 which describe the materials constituents of the Otta Seal. Chapter 7 then outlines the various selection criteria affecting the choice of surfacing followed by the Chapters 8, 9 and 10 which deal with the design, construction and maintenance of Otta Seals respectively. The various contractual issues associated with the use of Otta Seals is described in Chapter 11. Finally, Chapter 12 describes the global use of the Otta Seals as case histories, followed by a historical summary.

Two Appendices are provided, Appendix A and B gives Mass/Volume conversion tables and Abbreviations, respectively.

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BITUMINOUS SURFACINGS

2.1 Role and function

Bituminous surfacings are an integral component of paved roads and perform a number of functions that offer many advantages over unsealed roads. These include:

- Provision of a durable, impervious surfacing which seals and protects the pavement layers from moisture ingress and consequent loss of pavement strength and degradation;
- Provision of a skid-resistant surface which can resist the abrasive and disruptive forces of traffic and the environment;
- Prevention of the formation of corrugations, dust and mud which generally permits relatively safe travel at higher speeds and lower vehicle operating and maintenance costs.

As for all bituminised roads, the pavement strength must be adequate to carry the anticipated traffic loading.

2.2 Surfacing types

Various types of bituminous surfacing have been and are used on the global Public Highway Network. These included:

- Sand Seals
- Surface Dressings (Chip Seal)
- Cape Seals
- Otta Seals
- Asphaltic Concrete (varying thickness)

The above seal types are illustrated in Figure 2.1.

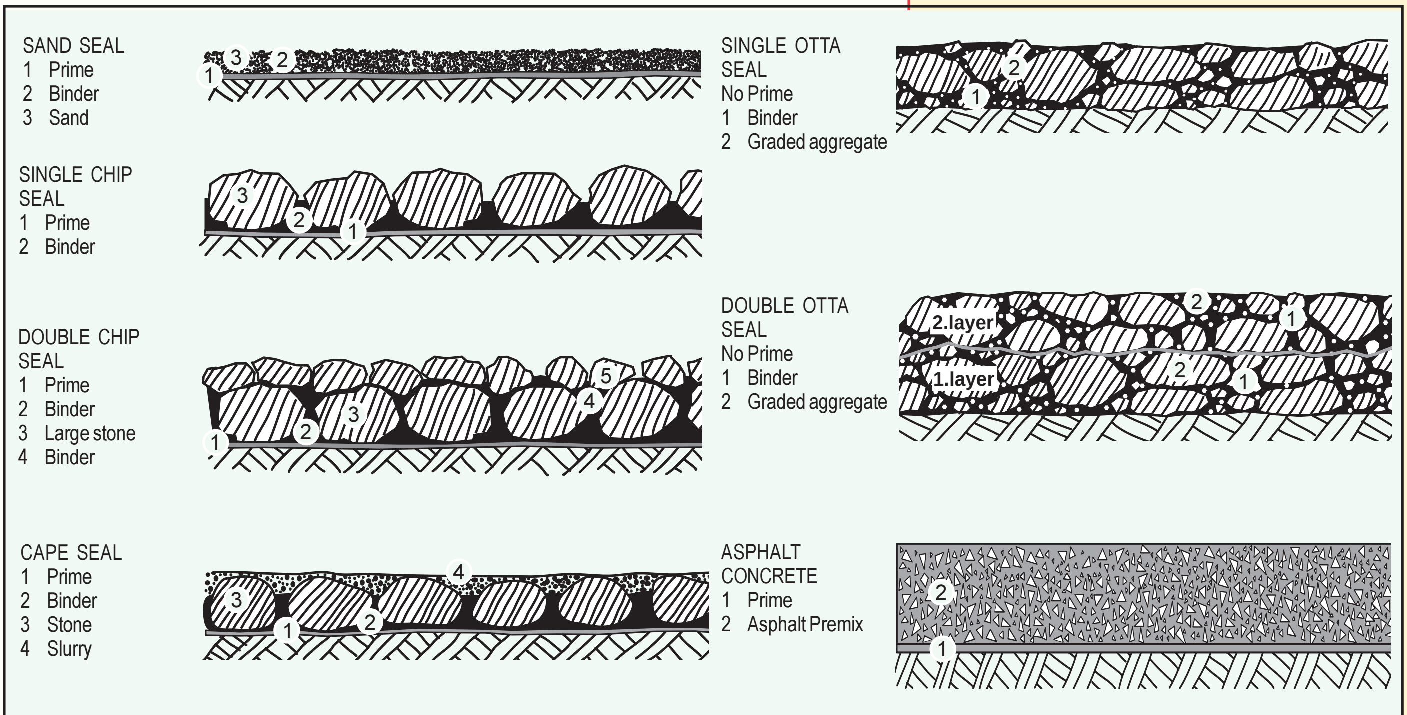


Figure 2.1 Schematic illustration of various types of bituminous surfacings.

2

2.3 Factors affecting choice

The choice of bituminous surfacing in any given situation will depend on a number of factors which include the following:

- Type of pavement (strength, flexural properties, etc);
- Economic and financial factors (funds available, life cycle costs, etc.);
- Riding quality required;
- Operational factors (traffic, surface stresses, geometry, etc.);
- Safety (surface texture, interference with traffic, etc.);
- Environmental considerations (climate, noise, etc.);
- Construction and maintenance strategies;
- Characteristics of available materials (aggregate, binder, etc).

Subject to the surfacing meeting various technical and environmental requirements, a life cycle cost comparison of alternative surfacing types should be carried out as a basis for determining the most cost-effective solution. Such a comparison would normally consider not only initial construction costs, but also maintenance and vehicle operating costs.

ORIGIN OF OTTA SEALS

3

3.1 Background

In the early sixties about 50% or 40 000 km of the total public roads in Norway were unpaved gravel roads with low bearing capacity, carrying an AADT between 50 - 500 vehicles. During the spring thaw period many road sections were unpassable for both light and heavy vehicles. These roads, at that time, according to the current practise were considered to be completely reconstructed prior to applying bituminous surfacing. However, the progress of the rehabilitation programme was slow due to budgetary and heavy construction plant constraints. In 1963 the Norwegian Road Authorities had identified a need to develop a method or treatment that could effectively improve the quality of the gravel roads to a cost equal to the gravel road maintenance. The two main goals, based on economical and technical aspects that had to be achieved were as follows:

- The investments should be earned back in a few years through reduced maintenance cost only;
- The road user should find the quality and performance of the surface close to other conventional bituminous surfacing.

In order to satisfy these two overruling main goals the surfacing should preferably comply with the following requirements:

- Be cheap and easy to carry out anywhere in the country;
- Utilise locally available screened natural aggregates;
- Be impervious to prevent water into the water susceptible base material;
- Be very flexible, durable and easy to maintain;

In 1963 the Norwegian Road Research Laboratory (NRRL) was commissioned to develop a bituminous surface treatment that applied to a situation the before mentioned economical and technical requirements. During the years 1963 - 65 trials were carried out in the Otta Valley where its name derives from.

Initially intended for use as a temporary "bituminous maintenance seal" for gravel roads its good performance led to its adoption also for newly constructed and existing bituminous roads for both low and medium traffic situations. Since its inception, the method has had an extended use, from being an economical maintenance seal on gravel roads, to a fully fledged bituminous surfacing. This surfacing type is today considered to have no other limitations regarding traffic volumes than one would apply to any sprayed bituminous surfacing.

The unpaved road network was in a poor condition in Norway in the early sixties. During the thaw period often un-passable for both light and heavy vehicles. (Norway).

The Otta Seal originates from the Otta Vally in Norway where it was first used. (Norway).

The lack of information regarding the Otta Seal, properties, design, construction and performance and the reluctance of the construction industry to embrace new technology has so far limited the use of this type of bituminous surfacing.

4

PERFORMANCE CHARACTERISTICS

4.1 Description and types

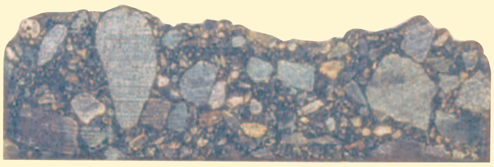
Otta Seals consist essentially of a 16 - 32 mm thick bituminous surfacing constituted of an admixture of graded aggregates ranging from natural gravel to crushed rock in combination with relatively soft (low viscosity) binders, with or without a sand seal cover. This type of surfacing contrasts with the single sized crushed aggregate and relatively hard (high viscosity) binders used in conventional surface dressings e.g. Chip Seals.

There are various types of Otta Seals 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:

1. Single Otta Seal
   aggregate grading “open”, “medium” or “dense”
   - with sand cover seal
   - without sand cover seal
2. *Double Otta Seal*
   aggregate grading “open”, “medium” or “dense”
   - with sand cover seal
   - without sand cover seal

The choice of type of Otta Seal is dependent on a number of factors which are described in Chapter 7.

All types single surfacing seals demand very high standards of workmanship to perform well and therefore carry higher risks of performing unsatisfactorily.



The mechanical interlocking, and bitumen binding of the Otta Seal is "a bit like" bituminous premix. A Double Otta seal.

4.2 Mechanism of performance

The mechanism of performance of Otta Seals is quite different to that of the more conventional Chip Seals. These differences may be summarised as follows:

Otta Seal: Graded aggregate is placed on a relatively thick film of comparatively soft binder which, on rolling and trafficking, can work its way upwards through the aggregate interstices. In this manner, the graded aggregate relies both on mechanical interlocking and bitumen binding for its strength - "a bit like" a bituminous premix.

Trafficking of the seal immediately after rolling is desirable and its final appearance is formed after 4 - 8 weeks giving a “premix” like appearance in the wheel paths. Priming of the base is normally not required.

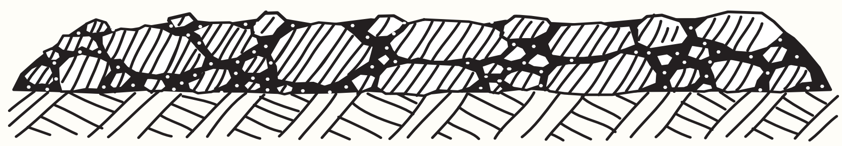
Chip Seal: In the case of the conventional Chip Seal surfacing, aggregate is placed on a film of comparatively hard binder with the objective of “gluing” the former to the latter. Thus, the Chip Seal relies very much on the bond between the binder and the aggregate for its strength. If this bond is insufficient (e.g. due to the use of a too thin binder film or the occurrence of in-service embrittlement due to binder oxidation) then ravelling will occur. Moreover, the selection of the respective aggregate sizes is critical to ensure interlocking between the first and second layers. Traffic on the surfacing needs to be carefully controlled until the binder is finally set. Priming of the base is normally required.

The concept of bleeding should also be viewed quite differently between Otta Seals and the more conventional Chip Seals. In the former, if excess bitumen works its way to the surface during rolling or trafficking, it can simply be blinded with fine aggregate or coarse to fine sand. The fine aggregate (or sand) tends to be fairly readily coated by the comparatively soft binder and work its way into the interstices of the graded aggregate to produce a tight, closely knit surface which looks very much like a conventional premix. In contrast, bleeding of Chip Seals can be more problematic due to the difficulty of coating the fine blinding aggregate (or sand) with a relatively harder binder.

Due to the differences in the mechanism of performance between Otta Seals and Chip Seals, it is important to recognise that their respective methods of design and construction should not be assumed to be similar.

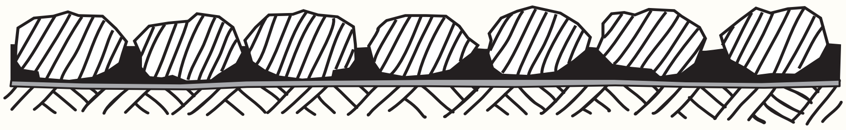
Figure 4.1 illustrates the difference in make-up and mechanism of performance of a Single Otta Seal in comparison to a Single Chip Seal.

The dense, closed texture of Otta Seals generally promotes impermeability and protects the binder from direct solar radiation and associated oxidation and embrittlement.



Single Otta Seal (0-16 mm). Thickness: minimum 16 mm

If the procedure for design and construction of a Chip Seal is adopted for an Otta Seal, the result will be disastrous!



Single Chip Seal (13,2 mm). Thickness = ALD (8 to 10 mm)

Figure 4.1 Mechanism of performance, a single Otta Seal compared to a single Chip Seal.

4.3 Performance characteristics

General

The performance of Otta Seals depends (as for all other types of surfacing) on a number of factors such as:

- type of Otta Seal, (texture, durability etc.)
- bearing capacity of the pavement
- traffic using the road

Close-up of the graded aggregate used in the Otta Seal. Note the dense matrix and interlocking.

Durability - texture

The dense, closed texture of an Otta Seal, which is further enhanced with the use of a cover sand seal, is particularly advantages in the hot temperature conditions that occur in the country. In such conditions, high solar radiation significantly increases the rate of oxidation of the surfacing binder which occurs less quickly with Otta Seals as compared with the more conventional Chip Seals.

Otta Seal with sand cover seal, where the dense matrix is further enhanced. (Botswana).

The influence of aggregate shape, strength and grading is of moderate importance due to the mechanism of behaviour of Otta Seals in contrast to the significance of these properties in conventional Chip Seals.

Visual evidence of the performance of Otta Seals under varying levels of traffic indicates that traffic volumes higher than 500 vpd are, in fact, advantageous to the performance of the seal.

The possible use of natural occurring gravel, including the fines, are some of the factors that favoure the use of Otta Seals. (Kenya).

A newly laid Otta Seal (with a high fines content) will for the first 2 - 4 weeks give dust pollution. (South Africa).

An Otta Seal will for the first few months after opening to traffic exhibit a rich bitumen appearance, which initially appears non-uniform and inferior compared to the conventional Chip Seal. (Botswana).

After some months in service the Otta Seal "beds down" and provide an uniform appearance. (Botswana).

Flexibility

Long service lives experienced in Norway and Kenya with Otta Seals placed on pavements with relatively high Benkelman Beam deflections (in excess of 1.25 mm) indicate that this type of seal exhibits excellent flexibility.

Traffic

The Otta Seal concept is not considered to have any limitations regarding traffic volumes than would not also apply to any other type of sprayed bituminous surfacing.

4.4 Relative advantages and disadvantages

Otta Seals differ in many respects from conventional sprayed bituminous surfacings such as Chip Seals.

One of the major advantages offered by Otta Seals is their ability to perform well with aggregates of relatively low quality in terms of strength, shape, texture and dust content, giving rise to cost savings which can be considerable depending on project location, availability of aggregates and bitumen price. However, as with other types of bituminous surfacings, Otta Seals possess both advantages and disadvantages that are described below.

Advantages

Some of the factors favouring the use of Otta Seals include situations were:

Road construction is taking place in remote areas where, for example, only natural gravels occur, and where it may be prohibitively expensive to set up crushing facilities;

- Workmanship may be of indifferent quality;
- Flexibility and durability of the surfacing are required to tolerate, for example, comparatively low quality, low bearing capacity pavements with high deflections;
- There is a low maintenance capability;
- High solar radiation levels prevail.

Disadvantages

One of the main disadvantages of Otta Seals is their initial, inconsistent and somewhat patchy appearance during the first 4 - 6 months of their service life. During this stage, the surface may appear rich in bitumen or may even "bleed", necessitating the spreading of sand or crusher dust over the affected area to absorb the excess of bitumen. This tends to give the erroneous impression to the lay person that something is wrong with the surfacing or that it is of inferior quality to the more traditional Chip Seal. However, this is certainly NOT the case. After some 8 - 12 weeks of trafficking the surfacing will start to "bed down" and will provide a more uniform and consistent appearance which looks somewhat like the more expensive Asphaltic Concrete that is generally used on very heavily trafficked roads.

Another disadvantage with the use of Otta Seals is with regard to the need to consider a number of additional contractual issues that need to be specially dealt with in the Contract Documents. These issues are discussed in Chapter 11.

Table 4.1 describes the relative differences between Otta Seals and conventional Chip Seals and indicates the qualitative differences between the two types of surfacing.

Parameter	Otta Seal	Conventional Chip Seal
Aggregate quality	Relaxed requirements for: - strength - grading - particle shape - binder adhesion - dust content Maximises use of locally available natural gravel or of the crushed product.	Stringent requirements for: - strength - grading - particle shape - binder adhesion - dust content Maximised use of the crushed product is difficult, use of natural gravel is in practice inappropriate
Binder	Relatively soft binders (low viscosity) are required: 150/200 penetration grade or MC3000 or MC800 cutback bitumen.	Relatively hard binders are required for necessary stone retention: (80/100 pen. grade under hot conditions).
Design	Empirical approach to design. Relied earlier to a large extent on experience and site trials.	Empirically based rational design methods.
Construction technique	Relatively little sensitivity to standards of workmanship. Labour intensive methods easy to apply if desired.	Sensitive to standards of workmanship. Labour intensive methods difficult to apply.
Constrution costs	In most instances costs are lower than Chip Seals, up to 40% depending on the availability of aggregate.	Cost competitive only where good quarries are located nearby; the bitumen price is high and the traffic volumes are high (> 500 vpd).
Contractual matters	Additional contractual issues need to be resolved.	Contractual issues well-known
Aesthetics	An appealing, uniform appearance can be difficult to achieve. However, such an achievement is not necessarily an indicator of a good result for Otta Seals.	Ranges between a very appealing and a poor appearance depending on quality of construction workmanship.
Skid resistance in wet weather	Poorer than a Chip Seal that is well designed and constructed using large chipping. However better than Slurry Seals and Asphalt Concrete.	Ranges between the extremes of excellent and very poor depending on quality of construction workmanship.
Use on fresh bituminous base layers	Not suitable due to the need for high bitumen contents required for quick rise of the binder through the aggregate interstices.	Suitable, but requires careful design and construction if excessive bleeding is to be avoided.
Periodic maintenance between reseals	Generally little need for periodic maintenance between reseals.	Rejuvenation with emulsion fog spray between reseals is normally required for maintaining stone retention.
Durability of the seal	The use of relatively soft binders and a dense matrix enhances durability of seal.	The use of relatively hard binders reduces the durability of the seal.
Typical service life	Typical service life: - Double Otta Seal: 12 - 15 years - Single Otta Seal with a sand cover seal: - 9 - 11 years	Typical service life : - Double Chip Seal: 8 - 10 years - Single Chip Seal: 5 - 6 years Adequately workmanship is essential

Table 4.1 Relative differences between Otta Seals and conventional Chip Seals.

5

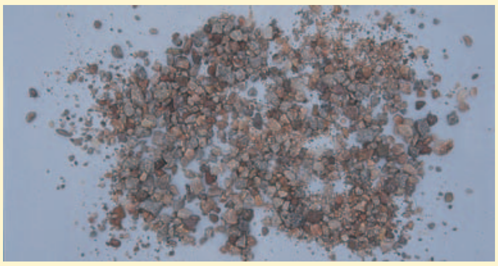
The general approach is to select the appropriate binder viscosity type and binder application rates to suit the available aggregate. Although the aggregate strength requirements are relaxed, it is always good practice to select the best quality of materials that are economically available in the project area.

Experience has shown that the best performance of an Otta Seal may be obtained when 30% of the aggregate is crushed. However, this should not be considered as “a rule of thumb”.

“As dug material” which in many cases only requires screening of oversize materials, can successfully be used in Otta Seals. (Kenya).

Labour based methods can effectively be used in producing aggregate for use in Otta Seals. (Bangladesh).

Sophisticated and expensive crushing plant is normally required to produce aggregate for Chip Seals. (Norway).



The aggregate used in an Otta Seal make allowances for a wide range of particle sizes, from 16 mm and down.

AGGREGATES

5.1 Key properties

A large variety of material sources can be used for the production of graded aggregate for use in Otta Seals. The following typical materials have been used as aggregate for Otta Seals with excellent performance:

- screened natural gravel from weathered granitic rocks;
- crushed and screened gravel from sandstone and lake deposits;
- screened river/lake gravel and sand;
- crushed, screened rock from a variety of rock types such as igneous rocks and pedogenic deposits of calcrete, silcrete and ferricrete.
- moraine, screened only and/or crushed;
- laterite and decomposed granite, screened to remove oversize;
- coral stone

Aggregate strength

Aggregates of relatively lower strength may be used for Otta Seals, compared to those typically specified for conventional Chip Seals (See Table 5.2).

Grading

The aggregate grading for Otta Seals is relatively relaxed and allows for a rather wide grading envelope. However, the grading curve of the aggregate should fall within the designated area and should be as “smooth” and parallel to the envelopes as possible. Table 5.1 gives the general grading requirements for Otta Seals.

5.2 Screened and crushed aggregates

‘As-dug’ gravel should be screened to remove oversize particles and excessive fines. A low moisture content in the material is desirable to avoid clogging of the finer mesh of the sieve. If moist material cannot be avoided, it may be necessary to increase the mesh size of the sieve. The presence of fines in the screened material is acceptable provided appropriate compensation is made for the binder viscosity, binder application rate and construction methodology.

Crushed gravel

The wide grading envelope requirement of Otta Seals allows a relatively higher proportion of the crushed product to be used compared to Chip Seals. Crushing allows a better utilisation of the gravel sources and generally improves the quality of the aggregate. The bulk of the crushed gravel product is normally utilised in Otta Seals resulting in little or no wastage. However, high establishment costs may prohibit crushing of gravel on smaller projects.

Crushed rock

Crushed rock is usually the most widely used type of aggregate for any surfacing in the country, including Otta Seals. A general rule of thumb is that any crushed material acceptable in the base course layer can be used to produce aggregate for an Otta Seal surfacing.

5.3 Aggregate for sand cover seals

A sand cover seal is normally recommended to apply over a single Otta Seal instead of using a double Otta Seal for low volume roads (< 500 AADT). The aggregate for the sand cover seal will normally consist of crusher dust or screened river sand or alternatively, fine pit sand can be used if no better material is available within an economical haulage distance.

Where fine pit sand is used for the sand cover seal, this often results in a fatty appearance during the early life of the surfacing. However, the appearance improves with time and traffic to a good, coarse textured surface. The fine sand cover seal continues to protect and enhance retention of the aggregates in the underlying Single Otta Seal throughout its service life. Sand cover seals made of crusher dust or river sand are considerably more durable than the fine pit sand seal and provide an excellent finish.

5.4 Aggregate requirements

General

The preferred aggregate grading will, to some extent, depend on the traffic volume at the time of construction, as well as during the two months immediately following the sealing operation, as this contributes significantly in forming the Otta Seal.

Maximum particle size

The preferred maximum particle size is 16 mm, but 19 mm can be accepted in the first seal where a double seal is to be constructed.

The use of aggregate with a maximum size larger than 16 mm should preferably be avoided where possible as this may lead to loss of stones during service. This is specifically relevant when a Single Otta Seal is considered with only a sand cover seal on top.

Fines content

The amount of fines (<0.075 mm) should preferably not exceed 10%. A higher fines content may result in construction problems, as the binder tends to coat the finer particles before the larger ones, and may lead to a less durable surfacing with inferior surfacing characteristics. However, aggregate with fines contents up to 15% have performed well on some projects, and no surfacing defects have yet been recorded due to excessive fines contents on any of these projects.

The fines content should ideally not exceed 10%. However, aggregate with fines content up to 15% has performed well in Otta Seals. (Botswana).

Soft binders (e.g. MC800) are preferable where the fines content is relatively high.

General grading envelopes and aggregate strength

Table 5.1 shows the general material requirements for an Otta Seal and Figure 5.1 the general grading envelope. The aggregate strength requirements are shown in Table 5.2

Material properties	Requirements	AASHTO or BS Test Designation
Plasticity Index	max 10	T 90-61
Flakiness Index	max 30 (applies only for crushed material)	BS 812
Sieve sizes [mm]	**Overall grading requirements [% passing]**	
19 16	100 80 - 100	T 146-49
13,2 9,5	52 - 100 36 - 98	
6,7 4,75	20 - 80 10 - 70	
2,00 1,18	0 - 48 0 - 38	
0,425 0,075	0 - 25 0 - 10	

Table 5.1 Material requirements for Otta Seals.

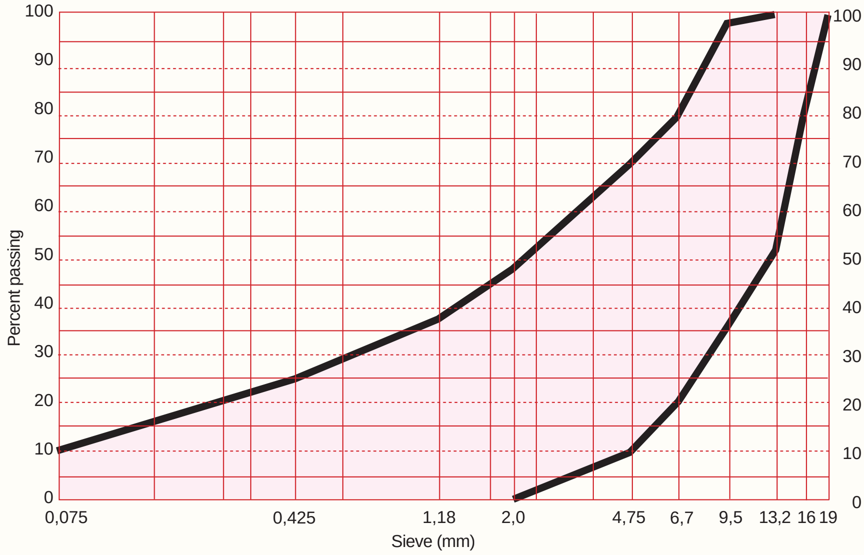


Figure 5.1 General garding envelope for Otta Seal aggregates

The required aggregate strength for Otta Seals is lower than that of a Chip Seal. Lower strengths can be tolerated because the graded particle matrix results in less internal pressure caused by stone to stone contact. The soft binders used in Otta Seals are, in addition, able to surround, coat and hold in place any particle that may break during rolling.

Aggregate strength requirements	Vehicles per day at the time of construction		BS Test Designation
	< 100	>100	
Min. Dry 10% FACT	90 k N	110 k N	BS 812
Min. Wet/Dry strength ratio	0.60	0.75	

Table 5.2 Aggregate strength requirements for Otta Seals.

Flakiness

No requirement for flakiness is specified for natural gravel or a mixture of crushed and natural gravel in Otta Seals. For crushed rock, it is preferable that the weighted Flakiness Index does not exceed 30. The weighted Flakiness Index is determined on the following fractions:

9,5 - 13,2 mm, 6,7 - 9,5 mm and 4,75 - 6,7 mm

Sand cover seals

Material for a sand cover seal used in Otta Seals can be crusher dust, river sand or fine pit sand or a combination of these materials. The material should be free from organic matter and lumps of clay and should be non-plastic. All material should preferably pass the 6,7 mm sieve.

6

BINDERS

6.1 Desirable characteristics

The correct choice of binder for Otta Seals is critical for its performance and a good result requires that both the binder type and application rate are tailored to the aggregate properties. Binders used for Otta Seals should:

1. be soft enough to initially coat the fines in the aggregate;
2. be soft enough to rapidly move up through the matrix of aggregate voids by the action of rolling and traffic;
3. remain soft long enough to continue moving up through the matrix of aggregate voids over a period of 4 to 8 weeks;
4. be able to be applied in a large enough quantity in one spray operation.

In addition to the above, the following binder properties are desirable in any bituminous seal. The binder must:

- be viscous enough to provide sufficient stability after the initial curing of the seal;
- be durable enough to give the expected service life;
- be able to be used with available equipment and skills;
- be environmentally friendly to the greater possible extent;
- be economical in use.

The selection of the binder type will depend on the aggregate properties, as well as the prevailing temperature conditions, rolling capacity and traffic volumes.

The graded aggregate used in Otta Seals possesses inherent stability making it easy to achieve the necessary stability of the seal without having to resort to the use of hard binders.

Type of binders of paramount importance.

Correct viscosity range:
Normally MC 3000 or MC 800
but also pen. bitumen grade 150/200

80/100 pen. bitumen grade *shall NEVER* be used.

6.2 Types

A general description of selected binder types and their potential use in Otta Seals is given below.

Penetration grade bitumen

80/100 or 150/200 penetration grade bitumen is normally used with conventional Chip Seals does not meet the requirements for Otta Seals and should NEVER be used for such surfacings. The hardest type of bitumen that can be used for Otta Seals is the 150/200 penetration grade which can be used under hot climate conditions (similar to summer periods on the African continent).

Cutback bitumen

Cutback bitumen in the MC 3000 and MC 800 viscosity range are the most commen binder used in the Otta Seals. MC 800 more often in northern Europe.

Bitumen emulsion

Emulsions have never been used for Otta Seals on the African continent, although it has been used in the Scandinavian countries with limited success. Emulsions are generally difficult to apply in a large enough quantity without run-off along the road's cross fall or gradient, and do not remain soft for long enough unless produced especially for this purpose. Specially made emulsions from suppliers are, however, unlikely to be economical. Moreover, production of any type of emulsion on site is a specialised operation that entails quality control problems, hence this process is not recommended.

6

Recent reports from South Africa (Louw & Jacobs, 1999) suggest that a semi-priming modified binder (SPMB) may be suitable for use with Otta Seals and could offer some advantages over conventional binders.

Tar

Tar has not been used in Otta Seals because it tends to harden much more rapidly than bitumen, thus compromising the service life of the seal. Furthermore, tars have serious environmental disadvantages and their use in road surfacings is not recommended.

Modified bitumen

Binders modified with rubber, SBS, SBR, PVA or other constituents have not been tried in Otta Seals. Any modified binders that are known on the market have too high a viscosity for use in Otta Seals and are therefore generally not suitable. In theory, however, there is no reason why a modified binder cannot be specially tailored to provide the properties that Otta Seals require, but such applications can only be recommended for trials.

6.3 Properties

Applicable binders for Otta Seals

The range of acceptable binder viscosities for Otta Seals is provided by the following standard types:

- MC 800 cut back bitumen (softest)
- MC 3000 cut back bitumen (medium)
- 150/200 penetration grade bitumen (hardest)

These binders are very often available and are supplied directly from the refineries. The process of manufacture at the refineries varies. The 150/200 is often a softened (fluxed) 80/100 straight run bitumen. The cutbacks are frequently produced from a blown stock harder than 80/100 which has been cut back with a type of kerosene known locally as power paraffin to give the required viscosity.

Durability of cutback bitumen

The long-term durability of manufactured cut back bitumen (MC 3000 and MC 800) that is available locally is not always acceptable. This is due to the production process which entails blending from a hard base bitumen.

Improved durability is achieved by producing cut back bitumen on site from a softer base bitumen such as 150/200 or 80/100 penetration grades, rather than using cutbacks supplied directly from the manufacturers.

6.4 Blending on site

General

Blending of bitumen on site may be desirable for one or more of the following reasons:

- to obtain the required viscosity of cutback bitumen (by cutting back with an appropriate cutter);
- to enable use of a preferred type of base bitumen;
- to 'permanently' soften a penetration grade bitumen that is too hard (by fluxing);

Cutting back to improve the viscosity and binder properties is possible, even under «primitive» conditions. (Bangladesh).

- to improve the durability of a bitumen (by fluxing);
- to simplify handling and storage where a number of binder types are required on the same site (by cutting back or fluxing).

Cutters

Cutting back is the addition of volatile oils to produce a temporary reduction of the binder's viscosity. The volatility of the cutter used will influence the type of cut back bitumen that will be produced in terms of whether it is rapid, medium or slow curing.

Table 6.1 shows the cutters that produce the respective types of cutback bitumen.

Grade of the produced cutback	Cutter	Notes
RC (Rapid Curing)	Petrol	Hazardous, should not be used
MC (Medium Curing)	Kerosene (Power paraffin Illuminating paraffin, JetA1 aviation turbine fuel)	Suitable for Otta Seals
SC (Slow Curing)	Diesel or heavy fuel oils	Curing process too slow for Otta Seals

Table 6.1 Cutters.

An Otta Seal will in most cases require a cutter that produces a medium curing (MC) cutback bitumen. Power paraffin is normally preferred among the cutting oils producing a MC cutback bitumen. Illuminating paraffin and JET A1 may also be used depending on the prevailing price.

Flux oil

Fluxing is the addition of heavy oil that affects the long-term viscosity and durability of the binder. Fluxing slows down the hardening process of the bitumen and, within certain limits will produce a more durable seal. Engine oil, unused or used, is suitable for this purpose. Fluxing should be carried out in moderation, as there is a risk of disintegration of the seal if the binder is excessively fluxed.

Blending proportions

The cutter proportions presented in Table 6.2 are indicative for blending with the penetration grades 80/100 or 150/200 respectively.

Safety precautions

Blending of cutback bitumen on site may be hazardous. Correct procedures should be followed during blending and appropriate safety precautions against fire and hot bituminous spray should be taken to safeguard personnel involved in the operations. Precautions are also necessary to ensure that the public is kept at a safe distance from the blending site.

The viscosity of the medium curing (MC) cutback bitumen (e.g. MC 3000, MC 800, MC 70, MC 30) is determined by the amount of cutter used, not the type of cutter.

The type of cutter used determines the length of time (Rapid, Medium or Slow) required for evaporation of the volatiles to take place, producing RC, MC or SC grades.

Under normal circumstances MC cutters will evaporate from the seal within 8 - 12 weeks.

Diesel as a cutter will produce a slow curing (SC) cutback bitumen that remains soft over a long period. Evaporation may take in excess of six months to occur and will cause unnecessarily prolonged bleeding and, at worst, instability of the seal.

Required product	Cutter (power paraffin) in percent of total mixture	
	80/100 base bitumen	150/200 base bitumen
150/200	3-5% (flux oil is used instead of cutter)	-
MC 3000	8 - 10 % *)	5 - 8 %
MC 800	18 - 20 % *)	15 - 18 %
*) The durability of the binder can be improved by replacing 3% - points of the cutter with flux oil where the 80/100 penetration grade is used as base bitumen.		

Table 6.2 Typical blending proportions to produce medium curing cutback bitumen.

Correct procedures must always be followed when cutting back on site as such operations may be hazardous. Otherwise, fire may be the result. (Bangladesh).

The following safety precautions should be adhered to:

- The blending site shall be located at a minimum distance of 100 metres from installations, homes or places that people occupy
- No open fire or smoking shall be allowed during the blending operation within a radius of 100 metres. This includes heaters in bitumen tanks;
- The blending site should be at least 100 metres away from cutter and fuel storage tanks.

It is emphasised that the blending process shall be kept fully under the responsibility of qualified personnel.

Blending operations

Cutter or flux oil should not be mixed with bitumen having a higher temperature than 140°C. This is due to the hazards of flammable gas emission from the tank. The correct procedure is to pre-heat the bitumen to 140°C and either pump the cold cutter or flux oil into the bottom of the tank through the designed hose and valve, or to pump the hot bitumen over in a new, cold tank already containing the cutter or flux oil. The following precautions should be strictly adhered to as the blending operation is a hazardous one and causes considerable risk of explosion and fire.

The manhole should NEVER be used for adding cutter or flux oil to hot bitumen;

- Cutter or flux oil should NEVER be pumped into an empty tank that is still hot after having contained bitumen;
- The bitumen level in the tank should NEVER be allowed to fall below that specified by the manufacturer while the heaters are in operation. This is normally a minimum of 150 mm above the highest point of the heater pipes.

After combining bitumen with cutter or flux oil the mixture shall immediately be circulated for 1 hour in order to ensure a homogenous product.

Flux oil is less flammable than cutters, nonetheless, for safety reasons on site, it is good practice to always handle both flux oils and cutters with similar precautions.

Some re-heating may be necessary to reach spraying temperature after blending of the bitumen. However, if prime is the desired product then re-heating is normally not necessary.

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6.5 Temperatures for storage and spraying

Recommended temperatures for storage and spraying of binders are shown in *Table 6.3.*

Bitumen product	Storage temp. °C		Spraying temp. °C
	< 24 hours	> 24 hours	
150/200	165	115	165 - 180
MC 3000	155	100	135 - 155
MC 800	120	75	110 - 135

Table 6.3 Recommended storage and spraying temperatures.

Cutback bitumen should not be held at spraying temperature for periods exceeding 12 hours. This will cause loss of light oil fractions and an undesirable change in binder properties.

6.6 Anti-stripping agent

General

The adhesion between bitumen and aggregate depends on close contact between the two materials. Stripping is the breaking of the adhesive bond between the aggregate surface and the bitumen, normally by water displacing the bitumen because water has greater surface tension than bitumen. By adding a comparatively small quantity of anti-stripping agent to the bitumen, the surface tension of the water is reduced and the bitumen is able to wet aggregate surfaces. In general, adhesion agents are intended to:

- promote adhesion of binder to wet aggregate;
- prevent loss of adhesion under influence of immediate rain after construction;
- provide satisfactory adhesion during construction.

The use of anti-stripping agent is always recommended when using natural gravel with a high fines content. However, good performance has been reported without the use of additives. When crushed material is used, appropriate laboratory testing should be carried out to identify the need for anti-stripping agent.

Anti-stripping agents are expensive products and should only be used when absolutely necessary.

Anti-stripping agents are sold under a variety of brand names.

Handling and dosage of anti-stripping agents

Anti-stripping agents are usually corrosive and require the use of protective gloves and eye goggles during handling. Liquid agents can easily cause splashing and require special care. Some 'solid' agents may appear in a liquid form, depending on ambient temperature, and should be treated with equal caution.

Normal dosage of anti-stripping agent is 0,5% to 0,8% by weight of bitumen. Appendix A gives the Mass/Volume conversion tables.

The most common method of achieving the admixture is to pour the calculated amount of additive into the bitumen distributor immediately before the spraying operation is to start and to allow 30 minutes of circulation to ensure a homogenous mix.

A wire basket suspended inside the bitumen distributor will ease the dissolving problem if a solid anti-stripping agent is used.

Anti-stripping agents that have been kept hot in the bitumen distributor for more than five hours should be considered stale. An additional dosage would then be required, amounting to half of the originally specified percentage.

There are a variety of anti-stripping agents on the market, of which some are less adversely affected by high temperatures than others

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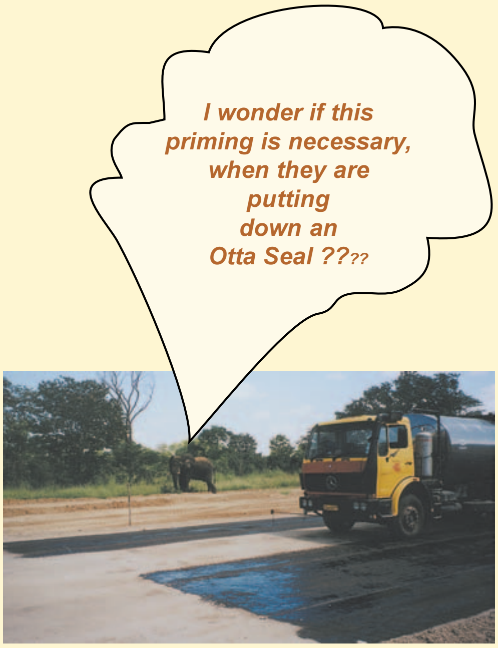


Priming can, in some instances, provide practical benefits for reasons such as wet weather conditions, problems with traffic control or as a preferred construction procedure for operational reasons. However, Otta Seals do not require priming of the base course to function well.

6.7 Prime

General

Priming of base courses made of non-calcareous material is normally not required when using Otta Seals. However, when using calcrete of any type in the base course, priming is warranted due to the high amount of bitumen absorption.

Types of prime

Cutback bitumen with a viscosity in the range 30 - 140 cSt (MC 30 or MC 70) is normally used for priming. Tar primes have serious environmental disadvantages and are not recommended for use as primes.

Application rate

A prime is normally applied at an application rate of between 0.8 and 1.2 l/m^2. Calcareous base courses require application rates in the high range and a lower viscosity of the prime than other types of base course material. High soluble salts content in the base course require high application rates or the use of an emulsion tack coat.

SURFACING SELECTION CRITERIA

7

7.1 Factors influencing choice of surfacing

There are a number of factors that need to be taken into account when selecting the most appropriate type of bituminous seal. This will always be the case whether it is new construction, rehabilitation or reseal work. The initial construction cost for various types of bituminous surfacings depends on a variety of factors including the cost of prospecting for aggregate and the construction methodology adopted. In addition to initial construction costs, maintenance and vehicle operating costs should be considered as well (e.g. life-cycle cost) as a basis for selecting the most cost-effective surfacing type.

7.2 Life expectancy

Different types of surfacings will provide different service lives for given site conditions. Table 7.1 shows the life expectancy for the various types of Otta Seal and a Double Chip Seal. These have been derived from experience gained in Norway, Kenya and Botswana.

Type of Otta Seals		**Expected service life [years]**
Single Otta Seal	No cover seal	5-6 *, but may variy depending on type of surfacing and quality of workman-ship
Single Otta Seal with a sand cover seal	Fine sand in the sand cover seal	9 -11
	Crusher dust or river sand in the sand cover seal	10 - 12
Double Otta Seal		12 - 15
Double Chip Seal Frequency of rejuvenation (fog spray)		6 -10 2 - 3
* As experienced in Norway		

Table 7.1 Life Expectancy for various types of Otta Seals and a Double Chip Seal.

A single Otta Seal with a sand cover seal. After more than 9 years in service and without any surfacing maintenance the surfacing performs excellently. (Botswana).

Otta Seals have proved to be more durable than other conventional surface treatments in appropriate circumstances.

7

This Guideline does not describe in detail the procedures required to calculate total life-cycle costs, but such calculation models are readily available in handbooks for pavement management and rehabilitation.

7.3 Economic assessment of Otta Seals versus Chip Seals

An economic assessment of the alternative surfacing seals should always be carried out in order to select the most cost-effective solution.

As different seals vary in construction cost, and give varying maintenance-free lives, an economical comparison between a Double Chip Seal and the various type of Otta Seals should not only consider the initial construction costs, but also include the cost of required future maintenance such as rejuvenation (fog spray) reseals and road markings over an appropriate analysis period.

In order to obtain life-cycle costs for alternative surfacing types the following are required for the calculations:

- Initial construction cost;
- Fog sprays (number required and cost);
- Reseals (number required and cost);
- New road markings after each intervention (number required and cost);
- Discount and inflation rates.

The relative construction cost of a Double Otta Seal with a cover sand seal compared with a Double Chip Seal (cost factor 1.0) may in general be described as presented in Table 7.2. However, this relative construction cost comparison may differ considerably from country to country, as well as between projects. The figures in Table 7.2 is based on data from Botswana.

Project Features	High traffic AADT > 500	Low traffic AADT < 500
Long haulage of acceptable chipping (> 100 km)	0,8	0,7
Quarry sites for chipping are close to project (< 25 km)	1,1	1,0

Note: The cost of a Chip Seal = 1,0

Table 7.2 Relative construction costs of a Double Otta Seal and a Double Chip Seal .

All types of surfacing seals will normally lend themselves to simple, although different maintenance techniques such as fog spraying, resealing or slurry sealing. Fog sprays with diluted emulsion have been found to be cost-effective for Chip Seals where the seal is beginning to ravel. If this is done before the seal starts to disintegrate, the service life of the seal can be prolonged.

The life-cycle maintenance strategy for Otta Seals and Chip Seals have been compared and may in general be described as is in Table 7.3. Again, this may differ considerably between the different countries. The figures in Table 7.3 is based on maintenance intervention adopted in Southern Africa.

Life expectancy, activities and construction costs	Otta Seals		Double Chip Seal
	Single + sand cover	Double	
Life expectancy (years)	11	15	7
Maintenance activities (years)	None	None	Fog sprays after 3 and 10 years. Reseal after 8 years. Road marking after each intervention (4 times).
Initial relative cost of construction	1.0	1.2	1.2
Chipping size used for 11 and 15 years analysis period 13.2 mm + 6.7 mm and 19.0 mm + 13.2 mm respectively. To simplify the life-cycle cost analysis it has been assumed that no other type of maintenance will take place during the analysis period and that vehicle operation costs are the same for both Otta Seals and Double Chip Seal.			

Table 7.3 Maintenance intervention for lifetime cost comparison of different type of seals.

A life cycle cost analysis over a 20 years period from Botswana (August 1999) based on maintenance interventions as seen in Table 7.3 using discounted cash flow techniques, and employing the Present Worth Method of economic analysis. This method involves the conversion of all costs incurred in the construction and subsequent maintenance of the seal, including the provision of road marking to common 1999 base year of Net Present Value (NPV) costs. It is assumed vehicle operation costs are similar for both seals.

This calculation gave a life cycle cost of the conventional Double Chip Seal that was approximately 80% higher than for the Single Otta Seal plus a sand cover seal. As is apparent, the cost advantage of the latter over the former is derived mainly as result of lower initial costs, longer seal life and less maintenance interventions. The differences would be even greater if any haulage of aggregate is involved or if screened natural gravel within the project area were used for the Otta Seal rather than crushed aggregate.

8

DESIGN

8.1 Factors influencing the design

The design of Otta Seals is based on empirical methods, rather than the more rational methods used for Chip Seals.

The principles governing the design of Otta Seals are based closely on the inter-relationship between the aggregate used and the binder viscosity and spray rates adopted, which means that the binders used will always be tailored to the type of aggregate produced.

Otta Seals may be constructed as a single or double layer, with or without a sand cover seal, and the choice of a particular type of Otta Seal is normally based on the following considerations:

- properties of available aggregate
- traffic volume
- construction cost
- required service life

Otta Seals allow for the use of a variety of aggregate gradings. The binder viscosity and spray rate are selected to suit the aggregate grading, traffic conditions and temperature at the time of construction. Decisions taken at that time of construction largely determine the performance of the Otta Seal during its service-life.

In the design of Otta Seals, the type of bitumen and the bitumen spray rates are initially established based on typical values of the main parameters determining the design. Variations in the site conditions or aggregate grading at the time of construction may require adjustments of spray rates on site. Changes in binder viscosity may also be necessary where the variations in site conditions or materials are significant.

The procedures to be followed in the design of Otta Seals are shown as a flow chart in Figure 8.1

8.2 Selection of Otta Seal type

Double Otta Seal

The Double Otta Seal is the most durable, but also the most expensive and is recommended for main roads carrying high volumes of traffic. Double Otta Seals with a cover sand seal are seldom specified due to their high costs and marginal benefits.

Single Otta Seal with sand cover seal

The combination of a Single Otta Seal followed by a sand cover seal is a cheaper option than a Double Otta Seal. The service-life will however, be shorter, but the former provides a very cost- effective solution for roads with AADT generally less than 500. The benefits of using a sand cover seal are the following:

- improved stone retention in the underlying seal;
- enhanced durability due to increased binder thickness and the forming of a dense surface texture;
- protection of the aggregate in the underlying seal in the case of marginal quality of materials;
- reduced risk of damage in the case of imperfections in the underlying seal.

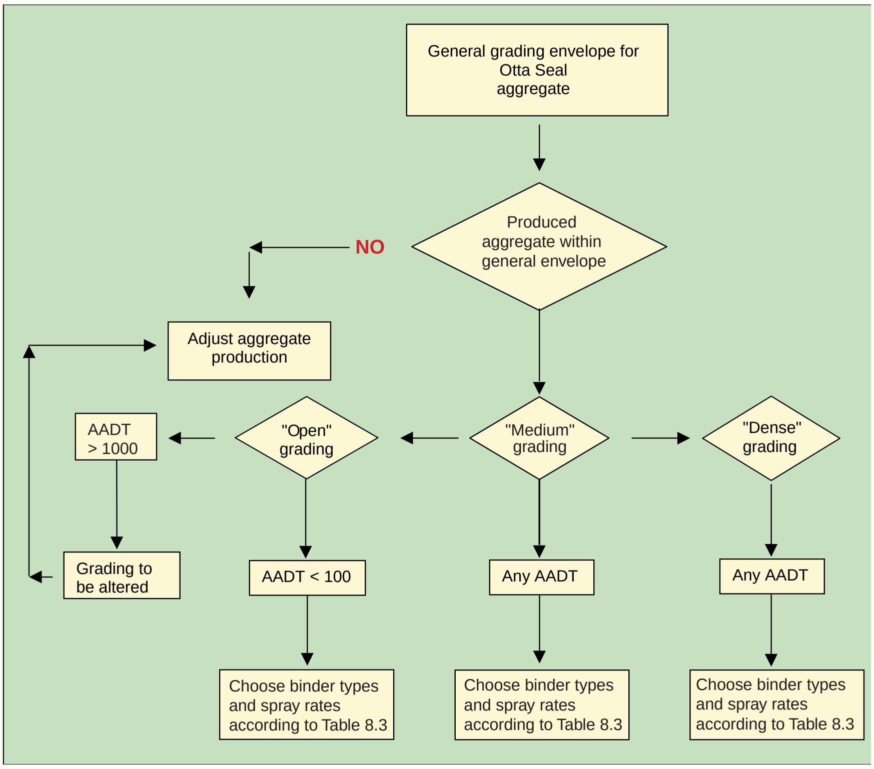


Figure 8.1 Flow chart for the design procedures of Otta Seals.

Single Otta Seals

Single Otta Seals are not commonly used on the African continent. However, in north Europe and in Bangladesh single Otta Seal is used.

Table 8.1 shows recommended Otta Seal types in relation to traffic level and the type of sealing work to be carried out. However, the given recommendations are flexible and will be project dependent.

Traffic levels and type of work	Type Otta Seal
Temporary seal (diversions, haul roads, temporary accesses, etc.).	Single Otta Seal
Maintenance resealing (all traffic classes to which sprayed surfacings are applicable.	Single Otta Seal
AADT less than 500	Single Otta Seal + sand cover seal
AADT more than 500	Double Otta Seal

Table 8.1 Recommended type of Otta Seal in relation to traffic levels.

8.3 Preferred aggregate grading

The design of Otta Seals allows for a variety of aggregate gradings to be used as long as the grading curve falls within the designated area of the general grading envelope (ref. Figure 5.1) and runs as "smoothly" and parallel to the envelope as possible.

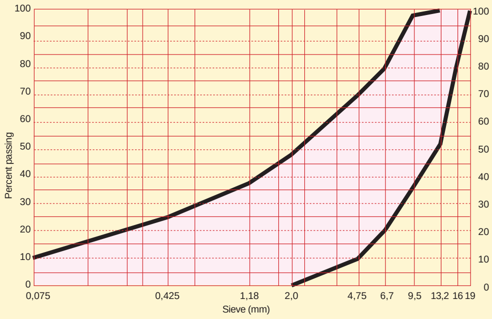
As guidance for the designer of Otta Seals, three grading envelopes, depending on traffic, have been produced to allow for a more rational design. However,

For the coarser aggregate type used in the Otta Seal it may be beneficial to water the aggregate stockpile 3-4 days before use.

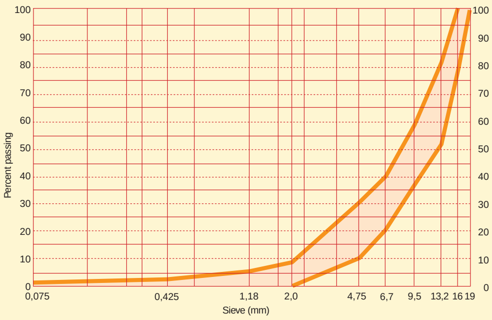
The aggregate application rates for an Otta Seal will appear excessive in comparison with that for a conventional Chip Seal

8

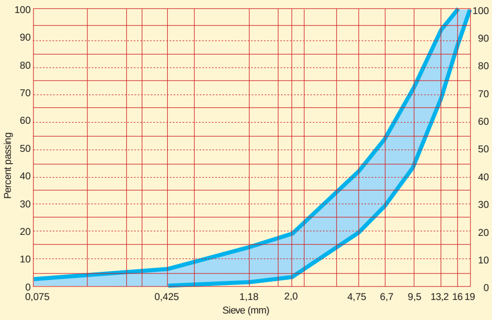
General aggregate grading requirements



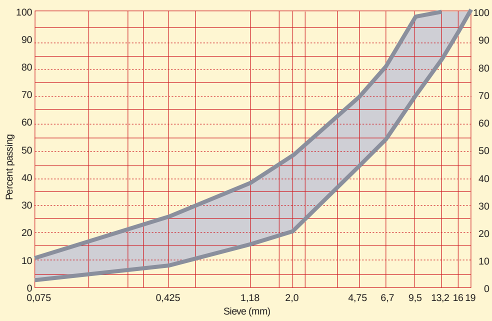
Open grading



Medium grading



Dense grading



The binder application rates are relatively higher for Otta Seals than for conventional Chip Seals. The hot spray rates of binder normally fall within the range of 1,6 - 2,0 l/m². (Kenya).

the designer should always bear in mind that generally all types of aggregate which fall within the general specified envelope can be used, provided the binder viscosity and spray rates are tailored accordingly.

The only limitation regarding the aggregate grading used in an Otta Seal is with regard to the "Open" grading which should not be used for traffic volumes above AADT 1000.

Table 8.2 indicates the preferred aggregate grading for design purposes according to traffic volume.

AADT	Best suited grading
Less than 100	"Open"
100 - 1000	"Medium"
More than 1000	"Dense"

Table 8.2 Preferred aggregate grading for Otta Seals

The grading envelopes for "Open", "Medium" and "Dense" grading are given Table 8.3a, the design procedure for Otta Seals.

8.4 Type of binder

Table 8.3 shows the recommended type of binder for Otta Seals made with the three respective aggregate gradings under typical site conditions on the African continent, as described in the table. Under normal Scandinavian site conditions 150/200 penetration grade bitumen is not used for Otta Seals.

Where "weak" natural gravel containing a fairly high proportion of fines is used the correct binder type will be MC 3000 or even

MC 800 viscosity range, depending on weather conditions.

It should be noted that in Table 8.3a MC 3000 viscosity grade bitumen is recommended for use with "Medium" grading aggregates under cold conditions (temperatures below 15°C).

8.5 Binder spray rates

The required binder spray rates for Otta Seals varies according to the following parameters:

- traffic (AADT)
- aggregate grading (open / medium / dense)
- the absorbency of the aggregate particles
- whether the base course is primed or not

Hot spray rates lower than 1,5 l/m² should not be allowed.

For aggregates with a water absorbency of more than 2%, the hot spray rate should be increased by 0,3 l/m².

In the case where the base has been primed the hot spray rate should be decreased by 0,2 l/m² for the first layer.

Table 8.3b gives the nominal hot spray rates for Otta Seals.

1. ALTERNATIVE GRADING ENVELOPES

Sieve sizes (mm)	Open grading (% passing)	Medium grading (% passing)	Dense grading (% passing)	AASHTO or BS Test designation
19	100	100	100	T 146-49
16	80 – 100	84 – 100	93 – 100	BS 1377
13,2	52 – 82	68 – 94	84 – 100	
9,5	36 – 58	44 – 73	70 – 98	
6,7	20 – 40	29 – 54	54 – 80	
4,75	10 – 30	19 – 42	44 – 70	
2,00	0 – 8	3 – 18	20 – 48	
1,18	0 – 5	1 – 14	15 – 38	
0,425	0 – 2	0 – 6	7 – 25	
0,075	0 – 1	0 – 2	3 – 10	

Any material falling within the Open, Medium and Dense grading envelopes may be used as aggregate in an Otta Seal. However, for a traffic level AADT > 1000 vpd. at the time of construction material within the Open grading envelope shall NOT be used.

2. CHOICE OF BITUMEN IN RELATION TO TRAFFIC AND GRADING

AADT at the time of construction	Type of bitumen			
	Open grading	Medium grading	Dense grading	
More than 1000	Not applicable	150/200 pen. grade	MC 3000 MC 800 in cold weather	
100 - 1000	150/200 pen. grade	150/200 pen. grade in cold weather	MC 3000 MC 800 in cold weather	
Less than 100	150/200 pen. grade	MC 3000	MC 800	

80/100 pen. grade bitumen shall NEVER be used in Otta Seals unless softened or cut back to meet the above viscosity requirements.

The cut back bitumen grades can be made by blending 80/100 pen. grade on site using the following proportions:

To make 150/200 pen. grade:	3 - 5% softener mixed with 95 - 97 % 80/100 pen. grade. Softener can be a purpose-made petroleum distillate, alternatively engine oil, old or new. In addition 3% points of power paraffin shall be used.

The cut back bitumen grades can be made by blending 150 /200 pen. grade on site using the following proportions:

To make MC 3000:	5 - 8% power paraffin mixed with 92 - 95% 150/200 pen. grade.
To make MC 800:	15 - 18 power paraffin mixed with 82 - 85% 150/200 pen. grade.

Circulation in the tank shall be carried out for at least 1 hour after mixing.

Table 8.3 a Design procedures for Otta Seals.

8

3. BITUMEN SPRAY RATES

Hot bitumen spray rates for un-primed base course (l/m²)

Type of Otta Seal	Grading	Open	Medium	Dense AADT <100	Dense AADT >100
Double	1 st layer	1,6	1,7	1,8	1,7
	2 nd layer (*)	1,5	1,6	2,0	1,9
Single, with a sand cover seal	Fine sand	0,7	0,7		0,6
	Crusher dust or coarse river sand	0,9	0,8		0,7
	1 st layer (*)	1,6	1,7	2,0	1,9
Single (*)		1,7	1,8	2,0	1,9
Maintenance reseal (single)		1,5	1,6	1,8	1,7

(*) On a primed base course the spray rate shall be reduced by 0,2 l/m² in the first layer.

Notes:
- Where the aggregate has a water absorbency of more than 2%, the bitumen spray rate shall be increased by 0,3 l/m².
- Binder for sand cover seal shall be MC 3000 for crusher dust or coarse river sand, MC 800 for fine sand

4. AGGREGATE APPLICATION RATES

Type of seal	Aggregate spread rates (m³ /m²)		
	Open grading	Medium grading	Dense grading
Otta Seals	0,013 – 0,016	0,013 – 0,016	0,016 – 0,020
Sand cover seals	0,010 – 0,012		

In practice, the aggregate application rates will very often be increased in order to reduce the risk of bleeding.

Table 8.3 b Design procedures for Otta Seals.

A too excessive aggregate application. (Botswana).

Correct aggregate appliction rate. (Botswana).

8.6 Aggregate application rates

It is important to apply sufficient amounts of aggregate to ensure that there is some surplus material during rolling and through the initial curing period of the seal. This aggregate embedment will normally take about 2-3 weeks to be achieved where crushed aggregate is used, after which any excess aggregate can be swept off. Where natural gravel is used the initial curing period will be considerably longer.

The aggregate application rates should fall within the ranges given in table 8.3b

Table 8.3b gives the criteria for selection of bitumen type and spray rates for the design of Otta Seals. No correction of bitumen spray rates should be made in the design to compensate for the solvent used in the cutback bitumen

In contrast to the procedures adopted for the design of Chip Seals on shoulders, no special design procedure is required for Otta Seals on shoulders.

CONSTRUCTION

9.1 General

The construction of Otta Seals is generally similar to the conventional Chip Seal. The binder is sprayed onto the surface followed by the spreading and rolling of the aggregate. However, the use of prime is not essential for Otta Seals.

9.2 Preparation of base course

General

A good bond between the base course and the surfacing is as important for Otta Seals as for any bituminous seal.

Un-primed base course

The base course should be broomed free of all dust or any other foreign matter before commencing the surfacing operations. In order to suppress any dust, and to promote some penetration into the base course, it is necessary to carry out light watering prior to spraying the binder. After watering, the base course should be allowed to dry to a dampened state before the binder is sprayed.

Primed base course

The preparation of a primed surface for construction of Otta Seals is similar to good practice procedures adopted for placing any bituminous seal.

9.3 Sealing operations

General

In the construction of Otta Seals the following factors should be given particular attention:

On the day of construction

A rule of a thumb is to assume that a good result would have been achieved when one can see bitumen being pressed up in-between the aggregate particles, sparsely distributed in the wheel tracks of the chip spreader or truck wheels.

Sufficient rolling of the Otta Seal cannot be over-emphasised. A minimum of two pneumatic tyred rollers at a minimum weight of 12 tonnes or more are essential at the day of construction, as they have a superior ability to knead the binder upwards into the aggregate particles, and to apply pressure over the entire area. A minimum of 15 passes with a pneumatic tyred roller is required over the entire surface area, shoulders included, on the day of construction.

After the initial rolling is completed (on the day of construction) it may be an advantage to apply one pass with a 10-12 tonnes static tandem steel roller to improve the embedment of the larger aggregate. During this process any weak aggregate will be broken down and will contribute to the production of a dense matrix texture.

Like all other surface treatments, an Otta Seal will not contribute directly to the structural strength of the pavement. The pavement must therefore be properly designed and constructed to withstand the expected traffic loading throughout its design life.

The preparatory work for construction of the first Otta Seal layer when prime is not used is similar to the preparatory work before construction of a prime on a conventional Chip Seal. On a dry or dusty base course the binder will contract ("ball up") and leave spots un-covered by bitumen thus causing potholes to develop.

Preparatory work prior to sealing operation, cleaning loose material from the base. (South Africa).

Light watering of the broomed base before spraying the binder will enhance the bond between the base and the Otta Seal. (South Africa).

Surplus cover material is always needed in the con-struction of an Otta Seal, and it is important to ensure that the aggregate application rate is sufficient to accommodate this requirement (ref. Chapter 8.6).

Otta sealing operations. Enough aggregate is essential in order to allow the binder to work its way upwards to coat all the particles. (Botswana).

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Extensive rolling with pneumatic rollers is essential to achieve a good result. (South Africa).

One pass with a static tandem steel roller will improve the embedment of the larger aggregate.

In the absence or in addition to pneumatic rollers, compaction can be successfully carried out by the use of loaded trucks following a pre-determined rolling pattern covering the entire surfaced area. (Botswana).

Otta Seal surfacing, 2 - 3 days after construction, and where traffic has been allowed using the surfacing immediately after construction. (Botswana).

Aggregate that has been dislodged by traffic should be broomed back into the wheel paths. This to ensure maximum embedment of the aggregate into the soft binder. (Botswana).

Rolling after treatment	**Minimum requirements**
On the day of construction	15 passes with pneumatic roller (weight > 12 tonnes) + 1 pass with a static steel roller
For each of the next two days after construction	15 passes with pneumatic roller (weight > 12 tonnes)
2-3 weeks after construction	Sweep off any excess aggregate
Note: During construction a minimum of two pneumatic tyred rollers are required. One pneumatic tyred roller will either delay the surfacing operations or worse, not be able to roll the newly laid surfacing sufficient.	

Table 9.1 Minimum rolling requirements.

Commercial traffic should be allowed on the surfaced area immediately following completion of the initial rolling with the pneumatic roller(s). This will assist further in the kneading of the binder/aggregate admixture.

A maximum speed limit of 40 - 50 km/hour should be enforced immediately after construction and sustained for 2 - 3 weeks when any excess aggregate should be swept off.

9.4 Follow-up inspections

It is essential that follow-up inspections of the Otta Seal surfacing are carried out to ensure that any defects that may have occurred during the sealing operation are corrected.

An inspection must be made during the first 6 - 7 days following sealing, particularly if there is a major change in the weather conditions e.g. rainfall or an extreme change of temperature. A sudden change in traffic loading may also affect the newly constructed surfacing.

9.5 Immediate post-construction care

To successfully construct an Otta Seal, immediate post-construction care is important and should not be neglected. This includes additional rolling and brooming back of the aggregate that has been dislodged by traffic.

The initial two days after construction

During the first two days after sealing, extensive rolling by pneumatic rollers shall take place in order to ensure that all particles embedded in the binder are properly coated. A minimum of 15 passes with the pneumatic tyred roller shall be applied daily, covering the entire surfaced area.

Subsequent 2 - 3 weeks after construction

Aggregate that has been dislodged by traffic during the immediate post-construction period should be broomed back into the wheel tracks as required during the first 2 - 3 weeks. This ensures that maximum amounts of aggregate particles are embedded into the soft binder. A newly constructed Otta Seal may be dusty and could produce "flying stones" for the first few weeks after construction.

2 - 3 weeks after construction, any excess aggregate can be swept off and the traffic speed limitations can be lifted. If natural gravel with a fairly high content of fines is used the period should be prolonged.

The period up to 12 weeks after construction

A minimum period of 8 - 12 weeks should elapse between the construction of the first and the second layers. This is to allow as much traffic as possible to traverse the surfacing as well as to allow evaporation of the solvent. During this period, the surfacing becomes more settled and in the wheel paths, where the aggregate has become embedded by traffic, a “premix” like appearance should start to appear.

The initial occurrence of bleeding and isolated fatty spots should not be any cause of concern, and can be blinded off with aggregate and preferably rolled into the surfacing. Signs of slight bleeding confirm that the aggregate/binder ratio has been optimal.

If natural gravel having a fairly high fines content is used, the period before sweeping off the excess gravel should be prolonged as long as possible, and not less than 6 - 8 weeks.

Bleeding

Some bleeding in localised areas and in the wheel paths is a normal part of the curing process for Otta Seals. Any available fine aggregate can be used for blinding off, such as crusher dust, river sand or fine pit sand. Where bleeding is extensive, a coarse aggregate may be used. It is advisable to apply rolling when blinding off the surface and to choose the hot time of the day for this work.

9.6 Traffic management

Traffic control is an important aspect that should not be overlooked as the early trafficking is a valuable contribution to the curing of the seal, leading to its enhanced performance.

The traffic management should be carried out in such a manner that the entire surfaced area, including shoulders, is equally exposed to traffic. This can be achieved by forcing the traffic into designated artificial lanes marked by traffic cones or similar.

9.7 Additional considerations for Double Otta Seal and combination seals

General

Special attention to certain details is required during construction of Double Otta Seal and combination seals using a sand cover seal.

Curing

It is important that the curing of the 1st seal is allowed to continue for a minimum of 8 - 12 weeks, depending on curing conditions and binder type, before applying the following seal. This is required to minimise prolonged fatting up due to cutter oil from the binder.

After a period of 8 - 10 weeks (traffic dependent), the Otta Seal beds down to produce the appearance of an asphaltic concrete premix. (Botswana).

Close-up, after 8 - 10 weeks the aggregate beds down. (Botswana).

Some bleeding in localised areas and in the wheel paths form a normal part of the curing process. Severe bleeding can be rectified by sand or additional aggregate rolled into the bleeding areas. (Botswana).

The surplus aggregate is valuable material that should be collected and recycled for use in subsequent sealing operations.

The Otta Seal should preferably be equally exposed to traffic over the entire sealed area as this will enhance an uniform appearance. This can be achived by the use of traffic cones to direct the traffic in to areas that need trafficking.(Botswana).

Over application of sand is essential when applying a sand cover seal on top of a single Otta Seal. (Botswana).

The sand blown off by traffic should be broomed back into the exposed areas until full embedment is achieved. (Botswana).

An Otta Seal will apparently show a significant difference visually between the shoulders and the carriageway. The traffic in the carriageway area works the binder upwards to the surfacing and hence, making difference in colour. This difference in colour will improve the traffic safety aspect. (Botswana).

After some months the Otta Seal with a sand cover seal are fully settled and shows excellent appearance. (Botswana).

Sand cover seal

The most important factors to be observed in constructing a sand cover seal are to ensure that enough cover aggregate is applied, and that aggregate dislodged by traffic is broomed back into the exposed areas as required. The back brooming should be repeated regularly until the sand is fully embedded in the first layer of the surfacing. This normally takes place after 4 weeks.

9.8 Important construction details

General

In addition to normal good construction practice certain construction details require particular attention when constructing sprayed bituminous surfacings, including Otta Seals.

Joints

Extra care is needed at all joints, both horizontal and longitudinal, to ensure that sufficient bitumen is sprayed and sufficient rolling and trafficking is applied. It is necessary to ensure that a minimum longitudinal joint overlap of 150 mm is attained and that additional heavy rolling is applied to even out the joints and the built up ridge caused by bitumen over-spray.

To avoid longitudinal joints it is preferable to spray the full width of the road in one pass if at all possible with the available equipment.

If longitudinal joints are necessary, they should be positioned outside the wheel tracks, i.e. along lane boundaries or the centre line.

Transverse joints should be constructed by normal good sealing techniques whereby start and finishing sheets are used, and the end of the previous section is blinded off to make an accurate starting line for the new section. Any over or under application will cause either a bump, or aggregate stripping respectively. Transverse joints should never be placed on top of each other. These joints should be staggered by approximately 50 metres.

Intersections with yield sign, roundabouts and steep gradients

Due to the relatively soft binder and high binder application rate, heavy trucks may push the seal across the carriageway during the early life of the seal. This can cause ridges of bitumen to be formed, exposing the base in the bottom of the "ruts".

In steep gradients, similar, as for Chip Seal design, the Otta Seal will need adjustment in the binder application rates in steep climbing gradients to prevent excessive bleeding and instability during the early stage of the seal. The same applies at down hill gradients in combination with sharp curves where the vehicles tends to break heavily.

In areas where this may be a problem, one should reduce the binder content by 0,3 l/m^2 and utilise a coarse aggregate grading. In cases where this is regarded to be a major problem, the binder should be 150/200 penetration grade, or if possible a penetration grade slightly harder than 150/200. This can be achieved by adding 2-3 % kerosene (power paraffin or illuminating paraffin) to 80/100 penetration grade bitumen.

MAINTENANCE

10

10.1 General

As a result of the enhanced durability characteristics of Otta Seals, maintenance intervention is not required to the extent necessary with conventional seals. Thus, such interventions as fog spraying, which is required every 3 - 4 years with Chip Seals, are unnecessary with the Otta Seals. Further, the resealing frequency for the Otta Seal varies between 9 - 15 years, depending on type of seal, whereof for Chip Seals the frequency is in the order of 7 years.

The repair and resealing of any localised surface defects are similar for the Otta Seal as for any other sprayed type of surfacing.

10.2 Use of Otta Seals as reseals

The use of Otta Seals as reseals do not differ from other sprayed types of bituminous reseals that are commonly used. The preparatory work necessary for a reseal using a conventional Chip Seal is also required for Otta Seals. However, in contrast to conventional Chip Seals where aggregate size requirements are an important factor depending on the existing seal aggregate, this meshing aggregate requirement does not apply for Otta Seals. Any aggregate size within the general grading envelope can be used.

The Otta Seals are well suited as a reseal for roads that is extensively cracked /patched, but which is still fairly structurally sound. This because of the use of low viscosity binders, high binder content and good interlock between the many particles thick aggregate layer, making the Otta Seal relatively flexible.

The recommended spray rates for Otta reseals are given in Table 8.3b.

On pavements that have deteriorated badly, an Otta Seal, because of its durability (high bitumen content and low viscosity binders which make the Otta Seal very flexible) is well suited as a reseal. (Malawi).

11

CONTRACTUAL ISSUES

11.1 General

This Chapter deals with some of the important contractual issues which should be considered when specifying Otta Seals, particularly where it contrasts with a conventional Chip Seal. The approach to certain contractual issues differs from normal Chip Seal contracts and the following are considered to be important:

- The need to specify a minimum number of passes with the rolling equipment;
- The requirement for the Otta Seal to be trafficked for a minimum period of 8 - 12 weeks before the second or cover sand seal is applied;
- The back-brooming of dislodged crusher dust/sand to the exposed areas;
- The requirement that road marking cannot be applied until the second seal has settled down, usually several months after the first seal has been applied. There will be a need for temporary road markings in such situations;
- "Bleeding" and blinding of localised areas which may required that a small team must be available to undertake such operations, which may take place during the first hot season after the contract is completed;
- An allowance should be made in the Bill of Quantities for an additional item to clean off blinding sand, in case of extreme bleeding for the first seal, prior to the laying of second or cover seal.

The items listed above may present contractual problems unless they are unambiguously dealt with in the Contract Documents. The following section deals with measures that will cater for these items, which differ from contracts where a conventional Chip Seal is used.

11.2 Contractual issues

Rolling using pneumatic equipment

The "Special Technical Provisions" which form a part of the Contract Documents should include the following text:

- Any part of the surfaced area, shoulders included, shall receive not less than 15 passes with a pneumatic tyred roller with a gross weight of not less than 12 tonnes on the day of the sealing operations, and one pass with a static steel roller after the initial roller with the pneumatic roller is completed. In the following two days, further 15 passes with a pneumatic roller will be required on each day.

The Contractor must have sufficient roller capacity on site to achieve the above requirements. In practice, at least 2 pneumatic tyred rollers will be required in addition to the steel roller.

Any other additional rolling will be in accordance with the "payment item for additional passes".

The Otta Seal requires to be trafficked for a minimum period of 8 - 12 weeks before the second seal or cover seal is applied.

This item can cause problems contractually, and may be dealt with as follows:

"Substantial Completion" could be given when the Otta Seal is opened to traffic, provided there are no surface defects or other outstanding works which may violate the "Road Traffic Act" (stop signs, speed limit signs, etc.). It may be necessary to employ temporary road markings for road safety purposes (project dependant).

After a further one month (i.e. approximately 4 months after "Substantial Completion" for the whole contract) the permanent road markings will be painted onto the road surface by the Contractor and the payment for permanent road marking made only at this stage.

The back-brooming of dislodged aggregates

A separate pay item for back-brooming of dislodged aggregate should be included in the Contract Documents, possibly as a rate per km.

Road marking

The road marking could be undertaken as a separate contract, since a good result is difficult to achieve until a great time after construction (this also applies to a lesser

extent for ordinary Chip Seals). Such practice could be extended to capital as well as maintenance resealing projects.

If it is decided to include road marking in the main contract, then the contractor should be informed of this delay requirement in the contract documents. For safety reasons, some pre-marking or temporary lines may be painted on the road during the interim period.

Bleeding and blinding off

Experience within the country has shown that in some cases, especially where the binder application rate is on the high side, some blinding of fatty surface spots may be required during the first hot season after the contract has been completed and the contractor has moved off site. Allowance should be made in the contract for establishment of a team for blinding of the seal, if and when required, for a duration of 4 to 8 weeks.

This item must be included in the Bill of Quantities as a separate item, otherwise, payment may be under Day Works, which will be much more costly. The payment should be specified per km (not per sq. metre).

Cleaning off blinding sand on the first and second seal

This should be catered for as an additional pay item in the Contract Documents.

The payment should preferably also be per km.

12

THE GLOBAL USE

12.1 General

The reported use of Otta Seals can be summarised nine countries: three from northern Europe (Norway, Sweden and Iceland), four in East and Southern Africa (Kenya, Botswana, Zimbabwe and recently also in South Africa) one country in Asia (Bangladesh), and a trial at Victoria State/ Territory, Australia.

Figure 12.1 shows the global use of Otta Seals.

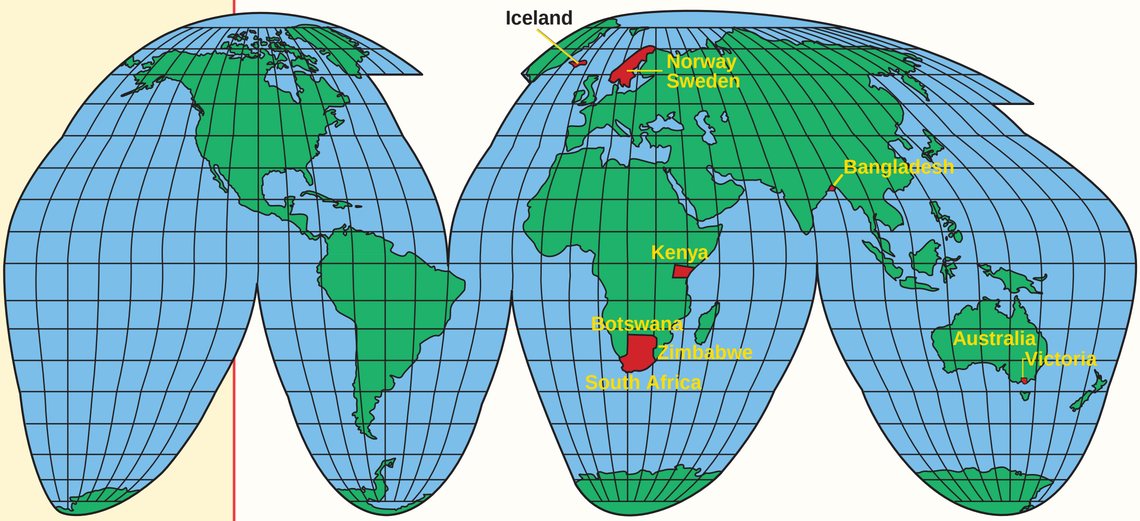

Figure 12.1 The global use of Otta Seals

Country	Length	Comments
Norway	4000 km	In 1985 the figure was 12 000 km
Sweden	4000 km	
Iceland	2000 km +	
Kenya	500 km	
Botswana	1000 km +	
Zimbabwe	80 km	Inclusive several trials
South Africa	One trial, 2 km.	About 100km to be Otta Sealed in1999-2000
Bangladesh	20 km +	Only labour based methods used
Australia (Victoria)	Two trial 2,2 km.	2.2 km in Victoria State/Territory

Table 12.1 shows the length of Otta Seals in the various countries, per 1999.

Table 12.1 The global use of Otta Seals.

The use of the Otta Seals have not been as widespread as it could be. The reason for this may be several, but the following may have been the general constraints:

Firstly - No rational design procedure has been readily available;

Secondly - The consultants and contractors do not know the Otta Seals application, hence they are both reluctant to specify and tender, and if tendering, they very often use conventional Chip Seal prices;

Thirdly - Most of the work as per today, although not all, has been done by in-house construction units.

Nevertheless, in Botswana this is changing as the Roads Department put pressure in both the consultants and the contractors to make reliable cost comparisons.

12.2 Norway

Background

Service-life and performance depends heavily on local conditions as always, not specifically for the Otta Seal. It is experienced in Norway that on a road with an AADT of about 1000 and a Benkelman beam deflection (80 kN) of 1,25mm a Double Otta Seal will give excellent performance for 10 years or more. For a Single Otta Seal a service life of 5 - 6 years is common.

In total 4000 km are today surfaced by Otta Seals, this counts for about 7% of the total bituminised road network of 52 000 km, whereof 26 000 km comprises of main roads and 26 000 km of secondary roads.

Table 12.2 shows the total length of Single and Double Otta Seals in Norway at the end of 1998.

Otta Seal type	Type of roads		
	Primary	Secondary	Ratio
Single Otta	500 km	1500 km	25/75
Double Otta	1000 km	1000 km	50/50

Table 12.2 Total length of Single and Double Otta Seals in Norway at the end of 1998.

In Norway today there are 65 km of Single Otta Seals and 120 km of Double Otta Seals that have been in service for more than 20 years and these roads are still performing satisfactorily. The majority of these roads are part of the secondary road network.

Norwegian specifications

The general specifications used for Otta Seals in Norway are as follows:

Traffic : AADT< 2000

Aggregates : Moraine gravel, both screened and crushed or in combination are used. Gabbro is a common rock type used. Experience has shown that a mixture of crushed/uncrushed aggregate ratio of 30/70, respectively, gives the best performance.

Aggregate class - 1 - 3

Flakiness/friability - < 1,5

Grading - Requirements in the lower part of the envelope as shown in Table 5.1. Material passing the 4,00mm sieve shall not be less than 35%. Material passing the 0,075mm sieve shall not exceed 10%.

- Application rate 1st. seal 0-16 mm 22-30 kg/m^2. 2nd. seal 0-11 mm 18-20 kg/m^2 (often preferred as second seal).

Otta Seals have been and is still extensively used in Norway. (Norway).

Otta Seal using crushed aggregate on a primary road after 6 years in service. (Norway).

Close-up of the Otta Seal surfacing. (Norway).

Bitumen	:	Medium curing bitumen, BL 1500M - BL 4500 Emulsion BE 70M, of the following bitumen types MB 3000 - 10 000 General application rates, BL between 1,7 - 1,9 l/m^2. BE between 1,9 - 2,1 l/m^2
Adhesion agents	:	Always used, 0,8% by weight of bitumen.

12.3 Sweden

General

The Otta Seal was introduced in Sweden around 1985. The term for the Otta Seal in Sweden is Y1G and in general their experiences are similar to those from Norway. As per today about 4000 km of roads have been bituminised using Otta Seals. A large proportion of these roads were originally secondary gravel roads in the northern and eastern (forest counties) parts of Sweden that were upgraded to a bituminous standard. The Swedish Road Authority has also used Single Otta Seal as dust binding precautions on gravel roads without any pavement strengthening (life expectancy 3 - 5 years). As quoted from the Swedish Road Authorities (Overby 1997), the general experience by using the Otta Seals has been, and is still, good. However, the reorganisation of the Swedish Road Authorities and younger engineers have led to the fact that this type of surfacing has decreased over the recent years. In many cases, the Otta Seal has been placed on poorly drained gravel roads with insufficient bearing capacity with the result that the seal has failed much earlier than anticipated.

Swedish specifications

The general specifications used for Otta Seals (Y1G) are very similar as for those that applies in Norway. However, the maximum AADT is limited to AADT < 500.

12.4 Iceland

General

A newly laid Otta Seal using crushed basaltic gravel. (Iceland).

In 1978 the Otta Seal was introduced in Iceland as an alternative to plant mixed oil-gravel on low traffic roads. Because of large distances and a rather limited market, stationary or even mobile asphaltic mixing plants have not been feasible, and hence the Otta Seal has been manifested as a cost- effective and technically appropriate solution for low traffic roads particularly in remote areas.

Per today more than 2000 km have been covered with a double Otta Seal, and the performance is rated to be very good (Overby 1997).

Iceland specifications

The most common aggregate used is basaltic gravel with a crushed surface fracture of minimum 40% for a traffic volume of AADT > 1000, and minimum 20% for AADT < 1000. The grading requirement is similar to what is given in Tabel 5.1. The strength of the aggregate refers to the LAA value, where the following are adopted in the specifications:

AADT < 200	LLA < 30%.
AADT 200 – 1000	LLA < 25%
AADT >1000	LLA < 20%

The most common bitumen used is BL 1500R at an application rate of 2,0 l/m^2.

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12.5 Kenya

General

In the middle of the 1970's the Governments of Kenya and Norway agreed to construct a 290 km long gravel road on a 50/50 share basis. The project was linked to the new Turkana road in the arid/semi-arid North western part of Kenya. Following the completion of the road, maintenance problems arose in this climate. A bituminous surfacing was discussed, and it was decided to apply a Double Otta Seal. During the period 1978 - 1984 the entire road length was surfaced using MC 3000 as binder, and alluvial quartzitic gravel screened only (uncrushed) as surfacing aggregate. Aggregate strength was ACV/LAA of 32/49, respectively. The base course thickness was min. 130 mm with the following materials requirements:

- CBR $_{soaked}$ nominally min. 50, but single values of 30 were in places accepted.
- PI max. 20.

Benkelman Beam deflection (80 kN) of less than 1,25 mm was regarded as acceptable prior to surfacing (Hansen 1983). No prime was applied on any of the road sections, but an adhesive agent was always admixed in the binder.

Performance of Otta Seals

A study team (Mariki et al 1995) that visited several of roads in 1995 quoted the following:

Turkana Road at Marich Pass

The road was completed in 1978 and had in 1995 carried cumulated E 80 loading equal to 4,0 mill. Close to 1 million vehicles had been using the road. Annual mean rainfall is 1000mm.

Part of the section had been resealed (third seal) using Otta Seal with quartzitic gravel similar to what was used for more than 15 years back. Apart from some stone loss the performance was good.

Turkwell Gorge - Lodwar

This section was completed in 1980. and had in 1995 carried cumulated E 80 loading equal to 2,1 mill. About 700 000 vehicles had been using the road. Annual mean rainfall between 300 - 400 mm.

About half of the road had been resealed using Otta Seal, and its performance was good. Those section that had not been resealed (being in service for more than 17 years without any kind of maintenance) had reached the end of it's service-life as extensive potholing prevailed. The section completed in 1984 with an annual mean rainfall of 170 mm was still performing excellent (after 17 years in service) without any sign of potholes or other surfacing defects.

Kalokol – Ferguson's Gulf

Completed in 1985 and had in 1995 carried cumulated E 80 loading equal to 0,16 million, and about 200 000 vehicles had been using the road. Annual mean rainfall about 170 mm.

Base layer thickness of 70 mm with CBR soaked of 50. Aggregate (0 - 18mm) used for the double Otta Seal was natural occurring uncrushed quarts gravel with an ACV/LAA of 26/45. Being in service for 10 years with no maintenance the surfacing was performing extremely well, without any signs of surfacing defects.

Turkana road, about 20 km north of Marich Pass. Screened quartzitic gravel were used as aggregate for the Otta Seal. After a number of years in service the performance was good. (Kenya).

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Close-up of an Otta Seal where natural occurring laterite was used as Otta Seal aggregate. (Kenya).

A section where coral stone was used as Otta Seal aggregate. The first section has been in service for some months and the aggregate has "bed down" making an appealing and uniform appearance. The second section has newly been constructed and the coral aggregate still need some time to "bed down". After more than 14 years in service these sections are performing excellently. (Kenya).

Under the Rural Roads Programme Otta Seals were extensively used, and in combination with labour based work. Natural decomposed granite used as aggregate for Otta Seal was hand screened and applied by hand. (Botswana).

Overview of the same road (Single Otta Seal) after being in service for more than 8 years. (Botswana).

Mombasa, Road trial at Kwale

The two road sections were constructed in the early 1985. The trial consists of two different types of base material, laterite unstabilised and laterite stabilised with 6% coral fines. Two types of aggregate were used for the Double Otta Seal. Natural occurring laterite with an aggregate strength (ACV/ LAA) of 42/54, and where 10% passed the 0,075mm sieve. Oversize material where screened out and crushed.

The crushed coral stone aggregate, where 4% passed the 0,075mm sieve had an aggregate strength (ACV/LAA) of 32/38.

For the conventional Chip Seal a fairly hard crushed sand stone aggregate were used with an aggregate strength of 22/36.

The bitumen used was a MC 3000 viscosity grade, being cut back on site from 80/100 penetration grade bitumen using diesel and kerosine. Application rates 1,8 - 1,9 l/m^2 for both layers of the Otta Seal. For the Chip Seal 80/100 bitumen was used with an application rate of 1,7 and 1,3 l/m^2, first and second layer, respectively. After 10 years in service the road had carried a cumulated

E 80 loading equal to 0,14 million, and about 900 000 vehicles had been using the road. Annual mean rainfall is 820 mm. All the sections performed excellently. It was however noticed that the Otta Seal had a denser waterproof surface texture than the Chip Seal. The Chip Seal had a more open surface texture and looked "hungry" for bitumen.

Road C106, Kwale

This section was also constructed in 1985 and the traffic loading and rainfall were similar to the previous section. Aggregate for the Double Otta Seal was a mixture of both uncrushed and crushed coral stone aggregate. After 10 years in service the appearance of the surfacing looks more like an asphalt concrete surfacing with a very dense waterproof matrix. A slight "fatty up" was noticed in the wheel paths.

Kenyan experience

The Otta Seals constructed in Kenya since 1978, have been in service between 10 and 17 years under different climatic and traffic conditions. In conclusion, their performance have been excellent, this in despite of the use of inferior aggregates such as uncrushed quartz and laterite gravel, as well as uncrushed/ crushed coral stone.

The use of Otta Seals is included in the Kenyan Road Design Manual of 1987.

12.6 Botswana

Rural Roads programme

In 1974/75 Botswana Roads department started the Rural Roads Programme for construction of gravel roads into the rural areas under the funding by the Norwegian Agency for development Co-operation (NORAD). However, in 1977 it became evident that in the arid and hot climate as prevailing in Botswana, gravel roads became difficult to maintain.

In 1978 the first 10 km of both single and double Otta Seals were constructed at the Oodi road (Overby 1982 and 1990). The aggregate used was uncrushed but screened (removal of oversize) decomposed granite with an ACV of 40. Binders were MC3000 and MC800 applied at a rate between 1,5 and 2,0 l/m^2.

Application of the binder was carried out by a bitumen distributor while the aggregate was applied by hand.

The Otta Seals showed very satisfying early performance, which triggered off bituminous sealing of several other Rural Roads projects. The variety of aggregate being used were lake gravel deposits consisting of silcrete, quartz and hard nodular calcrete mixed with a small amount of calcareous silt stone, with an ACV of 33 (Overby 1990) crushed soft silcrete and sand stone of very varying quality. These single Otta Seals were always covered by a light spray of binder, MC3000 or MC 800 at an application rate between 0,7 - 0,9 l/m^2, and covered with Kalahari sand which is easily available over most parts of the country.

Botswana experience

The Otta Seals have been successfully used in Botswana for the past 20 years. Surfacings using inferior aggregates have performed well for more than 15 years carrying 250-300 vehicles per day. Per today more than 1000 km of roads have been surfaced using a single Otta Seal with a Kalahari sand cover seal on top. This accounts for about 20% of the bituminised road network.

Experience with Otta Seals in Botswana confirms that for low traffic roads (AADT <100) the more "open area" of the grading curve should be adhered to. While for AADT > 100 a more medium to dense grading is preferred.

In the Botswana Road Design Manual of 1994 the use of Otta Seals is included as an alternative surfacing for Low Volume Roads AADT < 500. However, recently Roads Department has been constructing Otta Seals on roads with much higher traffic volumes. The life expectancy for a Single Otta seal with a sand cover seal on top is 9 - 12 years, and for a Double Otta Seal 12 - 15 years.

12.7 Zimbabwe

Secondary and Feeder Road Development Programme (SFRDP) (Sida and Sweroad 1995)

Between 1990 and 1993 a number of test sections were constructed using Otta Seals. Traffic levels varied from about 30 to nearly 300 vehicles per day and the rainfall from less than 300 to more than 1200 mm annually. Materials used were both crushed and uncrushed quarts/granite where materials less than 2,0 mm were screened out. After 4 - 6 years in service the Otta Seals had performed in an excellent manner, although some cracks were evident in some of the sections, but their origin has not been determined conclusively.

12.8 Bangladesh

Environmental Trial Road at Faridpur

Through the Local Government Engineering Department (LGED) Otta Seals were in 1992 constructed as a part of the Environmental Trial Road at Faridpur that aimed at finding a more flexible and durable bituminous surfacing than currently used for Feeder Roads. Common procedure typically consisted of a 25 mm thick bituminous carpeting. Aggregate for the Otta Seal was screened river gravel 0 - 16mm (quartz and basalt) that was placed

Close-up of the previous photo showing a Single Otta Seal. Note that some of the weak aggregate has been crushed down by traffic, but during the early stage after construction the binder has absorbed the crushed aggregate and a dense waterproof surfacing has been formed. (Botswana).

The final product, after 8 months in service of a Single Otta Seal (crushed aggregate) with a sand cover seal on top using fine Kalahari sand. (Botswana).

The same road in a "bird view". Note the appealing uniform appearance, more like an asphaltic concrete. (Botswana).

At the Environmental trial Road at Faridpur, the bitumen was both cutback and fluxed in order to give the correct binder consistence. This was successfully carried out by simple but appropriate methods. (Bangladesh).

The Otta Seal aggregate was applied by labour based methods, by pre-stockpiling the hand crushed aggregate. A 100 metre long section, 3,7 metres wide was covered by aggregate after 7 minutes time, and the section was opened to traffic. (Bangladesh).

In the absence of pneumatic tired rollers, rolling of the Otta Seal can be done by loaded trucks following a pre-determined pattern of rolling. (Bangladesh).

The final product, a Single Otta Seal after 2 years in service. (Bangladesh).

Otta Seals trial, using crushed quartize with a high amount of fines. The aggregate was applied by a self-propelled chip spreader. (South Africa).

along the road side in small stockpiles and applied immediately by hand after the binder was sprayed. The binder, 80/100 pen. grade, arrived in drums that were pre-heated and emptied into a tractor-pulled distributor.

By addition of cutters (paraffin) the binder was altered to satisfy the requirements for viscosity during construction. Flux (engine oil) was added to improve the long term durability of the binder.

The binder application rates varied between 1,9 - 2,1 l/m^2. Half-loaded trucks carried out the rolling by trafficking in a predetermined rolling pattern. Neither prime nor adhesion additives were used.

Bangladesh experience

After 6 years in service the Otta Seals have performed well under a traffic loading between 50 - 80 commercial vehicles per day (mostly buses and trucks). These feeder roads are built by labour intensive methods on top of 4 - 5 metres high embankments with a crone width of about 6,0 metres. For most of the year the embankments is surrounded by water, sometimes flush with the surfacing and pavement movements are inevitable. A very flexible surfacing is therefore required for satisfactory performance.

Also from a construction point of view the Otta Seal has advantages under conditions as in a country as Bangladesh. On feeder roads detours are difficult, or in many cases impossible, to construct due to narrow crone and high embankments. It is important that the road is not closed to traffic over a long period, normally maximum one hour. The Otta Seal construction allows for trafficking immediately after spreading the aggregate, while Chip Seals or asphalt carpets need a primed base to perform satisfactorily. Priming under these conditions would require closing of the road for several hours, and in addition blinding off the prime with sand would in most cases be required.

The Labour Based methods extensively used in Bangladesh have also proved to favour the use of Otta Seals, as a large proportion of the work can be done by labours.

Per today, about 20 km of roads have been surfaced using labour intensive methods and Otta Seals. A Sprayed Sealing Guideline for Otta Seals in Bangladesh has been prepared and its specifications form a part of the LGED Standard Specifications.

12.9 South Africa

Trial sections

In KwaZulu Natal province in South Africa the first Otta Seal surfacing trial took place in June 1999. Two types of aggregate were used:

- decomposed granite with low aggregate strength
- crushed quartize with high aggregate strength (10% FACT = 200), but with high fines content (more than 10% passing the 0,075 mm sieve)

The binder was 150/200 penetration grade bitumen, cut back on site by power paraffin to the required viscosity range. The hot bitumen spray rates varied between 1,7 - 2,2 l/m^2 depending on the aggregate grading and whether the base was primed or un-primed. The traffic volume was between 300 - 500 vehicles per day.

During the trial the Road Authorities stated that the aggregate used in the Otta Seal would under no circumstances considered used in a bituminous surfacing in the province. The early performance of the Otta Seals is very promising and would imply a considerable user cost saving in upgrading the gravel road to a bituminous standard.

The KwaZulu, Natal Road Authorities plans to embark on a full scale project in October 1999 to uppgrade about 100 km of gravel roads to bituminous standard using Otta Seals.

12.10 Australia

In early 1999 a small trial using Otta Seala were constructed at Victoria State/Territory, using crushed aggregates with fines content passing the 0.075 mm sieve restricted to 10%. The base was not primed and a Single Otta Seal was applied. After 7 months in service the surface show no sign of premature deterioration. The traffic level on the access road is low but used by heavy load trucks moving in and out from a quarry side.

A full scale Otta Seal trial at the length of 2 km was undertaken in June 1999 using cutback bitumen and aggregate confirming the recommended grading curve. The AADT on this rural road is about 100. The Victoria State/Territory plan to construct more Otta Seal in the near future.

12.11 Historical summary

Since the time of its inception in the Otta valley in Norway, the Otta Seal method has had an extended use, from being an economical "maintenance seal" to a fully fledged bituminous surface treatment with no other limitations regarding traffic than one would apply to any other sprayed bituminous surfacing.

The Otta Seal method is an example of the innovative use of local, often marginal quality materials, in combination with appropriate bituminous binders to produce durably surfacing under a variety of environmental conditions. Ranging from cold - freezing climates in northern Europe to tropical hot/wet climate as experienced in Asia and desert dry and very hot climatic conditions prevailing on the east and southern part of the African continent.

The Otta Seal has proved to be a durable and a very cost-effective surfacing. Its use has in many circumstances made allowances to construct roads under very unfavourable prevailing conditions, where conventional surfacing approaches would have been too expensive or not possible at all. It is therefore recommended to make life-cost comparisons to other sprayed bituminous surfacing, assessing the availability of local materials and their use in an Otta Seal when considering appropriate surfacing for roads (low volume roads) carrying traffic volumes of less than 1000 vpd This exercise may in many cases conclude that Otta Seals is the most economical and appropriate surfacing type.

The Otta Seal has repeatedly proven to be a very forgiving type of sprayed seal under quite different environments. Poor workmanship etc. during construction, that would have been disastrous in the case of a Chip Seal, will in many incidents give satisfactory performance in the case of Otta Seals.

Immediately after the Otta Seal aggregate has been applied. The seal looks like a gravel road at this stage. But with time, the single Otta Seal will "bed down" and a bit premix type appearance will appear. (South Africa).

The same road as above, bu after 3 months in service. (South Africa).

Close up of the Single Otta Seal above. Note the close surface texture, making an impermable surfacing. (South Africa).

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APPENDIX A

Mass/Volume conversion Tables

MEXPHALTE 80/100

MASS (kg)	VOLUME (litres) at TEMPERATURE (°C)																			
	20	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190
10	10	10	10	10	10	10	10	10	11	11	11	11	11	11	11	11	11	11	11	11
20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	22	22	22	22	22
30	29	31	31	31	31	31	31	31	32	32	32	32	32	32	32	32	32	33	33	33
40	39	41	41	41	42	42	42	42	42	42	42	43	43	43	43	43	43	43	43	44
50	49	51	52	52	52	52	52	52	53	53	53	53	53	53	54	54	54	54	54	55
60	59	62	62	62	62	63	63	63	63	63	64	64	64	64	64	65	65	65	65	66
70	68	72	72	73	73	73	73	73	74	74	74	74	75	75	75	75	76	76	76	77
80	78	82	83	83	83	83	84	84	84	84	85	85	85	86	86	86	86	87	87	88
90	88	93	93	93	94	94	94	94	95	95	95	96	96	96	97	97	97	98	98	99
100	98	103	103	104	104	104	105	105	105	106	106	106	107	107	107	108	108	108	109	109
200	196	206	207	207	208	209	209	210	211	211	212	213	213	214	215	215	216	217	217	219
300	294	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	328
400	391	412	413	414	416	417	418	420	421	422	424	425	426	428	429	431	432	433	435	438
500	489	515	516	518	520	521	523	525	526	528	530	531	533	535	537	538	540	542	543	547
600	587	618	620	622	623	626	627	630	632	634	636	638	640	642	644	646	648	650	652	657
700	685	721	723	725	727	730	732	734	737	739	742	744	746	749	751	754	756	758	761	766
800	783	823	826	829	831	834	837	839	842	845	848	850	853	856	858	861	864	867	870	876
900	881	926	929	932	935	938	941	944	947	950	953	956	960	963	966	969	972	975	978	985
1 000	978	1 029	1 033	1 036	1 039	1 043	1 046	1 049	1 053	1 056	1 059	1 063	1 066	1 070	1 073	1 077	1 080	1 083	1 087	1 095
2 000	1 957	2 059	2 065	2 072	2 078	2 085	2 092	2 098	2 105	2 112	2 119	2 125	2 132	2 139	2 146	2 153	2 160	2 167	2 174	2 190
3 000	2 935	3 088	3 098	3 108	3 117	3 128	3 137	3 148	3 158	3 168	3 178	3 188	3 199	3 209	3 219	3 230	3 240	3 250	3 261	3 285
4 000	3 914	4 117	4 130	4 143	4 157	4 170	4 183	4 197	4 210	4 224	4 238	4 251	4 265	4 278	4 292	4 306	4 320	4 334	4 348	4 379
5 000	4 892	5 147	5 163	5 179	5 196	5 213	5 229	5 246	5 263	5 280	5 297	5 314	5 331	5 348	5 366	5 383	5 400	5 417	5 435	5 474

MEXPHALTE 80/100

MASS (kg)	VOLUME (litres) at TEMPERATURE (°C)																			
	20	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190
6 000	5 871	6 176	6 195	6 215	6 235	6 256	6 275	6 295	6 315	6 336	6 356	6 376	6 397	6 418	6 439	6 459	6 480	6 501	6 522	6 569
7 000	6 849	7 205	7 228	7 251	7 274	7 298	7 321	7 344	7 368	7 392	7 416	7 439	7 464	7 487	7 512	7 536	7 560	7 584	7 609	7 664
8 000	7 828	8 235	8 261	8 287	8 313	8 341	8 367	8 394	8 421	8 448	8 475	8 502	8 530	8 557	8 585	8 612	8 640	8 668	8 696	8 759
9 000	8 806	9 264	9 293	9 323	9 352	9 383	9 412	9 443	9 473	9 504	9 535	9 565	9 596	9 626	9 658	9 689	9 720	9 751	9 783	9 854
10 000	9 785	10 293	10 326	10 359	10 392	10 426	10 458	10 492	10 526	10 560	10 594	10 627	10 662	10 696	10 731	10 765	10 800	10 835	10 870	10 949
11 000	10 763	11 323	11 358	11 394	11 431	11 469	11 504	11 541	11 578	11 616	11 654	11 690	11 728	11 766	11 804	11 842	11 880	11 918	11 956	12 043
12 000	11 742	12 352	12 391	12 430	12 470	12 511	12 550	12 590	12 631	12 672	12 713	12 753	12 795	12 835	12 877	12 919	12 960	13 002	13 043	13 138
13 000	12 720	13 381	13 424	13 466	13 509	13 554	13 596	13 639	13 683	13 728	13 772	13 816	13 861	13 905	13 951	13 995	14 040	14 085	14 130	14 233
14 000	13 699	14 411	14 456	14 502	14 548	14 596	14 642	14 689	14 736	14 784	14 832	14 878	14 927	14 974	15 024	15 072	15 120	15 168	15 217	15 328
15 000	14 677	15 440	15 489	15 538	15 587	15 639	15 687	15 738	15 789	15 840	15 891	15 941	15 993	16 044	16 097	16 148	16 200	16 252	16 304	16 423
16 000	15 656	16 469	16 521	16 574	16 627	16 681	16 733	16 787	16 841	16 896	16 951	17 004	17 060	17 114	17 170	17 225	17 280	17 335	17 391	17 518
17 000	16 634	17 498	17 554	17 610	17 666	17 724	17 779	17 836	17 894	17 952	18 010	180 67	18 126	18 183	18 243	18 301	18 360	18 419	18 478	18 613
18 000	17 613	18 528	18 586	18 645	18 705	18 767	18 825	18 885	18 946	19 008	19 069	19 129	19 192	19 253	19 316	19 378	19 440	19 502	19 565	19 707
19 000	18 591	19 557	19 619	19 681	19 744	19 809	19 871	19 935	19 999	20 064	20 129	20 192	20 258	20 322	20 389	20 454	20 520	20 586	20 652	20 802
20 000	19 569	20 586	20 652	20 717	20 783	20 852	20 916	20 984	21 051	21 120	21 188	21 255	21 324	21 392	21 462	21 531	21 600	21 669	21 739	21 897
21 000	20 548	21 616	21 684	21 753	21 822	21 894	21 962	22 033	22 104	22 176	22 248	22 318	22 391	22 462	22 536	22 607	22 680	22 753	22 826	22 992
22 000	21 526	22 645	22 717	22 789	22 862	22 937	23 008	23 082	23 157	23 232	23 307	23 380	23 457	23 531	23 609	23 684	23 760	23 836	23 913	24 087
23 000	22 505	23 674	23 749	23 825	23 901	23 980	24 054	24 131	24 209	24 288	24 366	24 443	24 523	24 601	24 682	24 761	24 840	24 920	25 000	25 182
24 000	23 483	24 704	24 782	24 861	24 940	25 022	25 100	25 181	25 262	25 344	25 426	25 506	25 589	25 670	25 755	25 837	25 920	26 003	26 087	26 277
25 000	24 462	25 733	25 815	25 897	25 979	26 065	26 146	26 230	26 314	26 400	26 485	26 569	26 656	26 740	26 828	26 914	27 000	27 087	27 174	27 371

SPRAMEX 150/200

MASS (kg)	VOLUME (litres) at TEMPERATURE (°C)																			
	20	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180
10	10	10	10	10	10	10	10	11	11	11	11	11	11	11	11	11	11	11	11	11
20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	22	22	22	22	22	22
30	30	31	31	31	31	31	31	32	32	32	32	32	32	32	32	32	32	33	33	33
40	39	41	41	42	42	42	42	42	42	42	42	43	43	43	43	43	43	43	44	44
50	49	52	52	52	52	52	52	53	53	53	53	53	53	54	54	54	54	54	54	55
60	59	62	62	62	63	63	63	63	63	64	64	64	64	64	65	65	65	65	65	66
70	69	72	72	73	73	73	73	74	74	74	74	75	75	75	75	76	76	76	76	77
80	79	83	83	83	83	84	84	84	84	85	85	85	86	86	86	86	87	87	87	87
90	89	93	93	93	94	94	94	95	95	95	96	96	96	96	97	97	97	98	98	98
100	99	103	104	104	104	105	105	105	106	106	106	107	107	107	108	108	108	109	109	109
200	197	206	207	208	208	209	210	210	211	212	212	213	214	214	215	216	217	217	218	219
300	296	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328
400	395	413	414	415	417	418	419	421	422	423	425	426	428	429	430	432	433	434	436	437
500	494	516	518	519	521	523	524	526	528	529	531	533	534	536	538	540	541	543	545	547
600	592	619	621	623	625	627	629	631	633	635	637	639	641	643	645	647	650	652	654	656
700	691	722	725	727	729	732	734	736	739	741	743	746	748	751	753	755	758	760	763	765
800	790	825	828	831	833	836	839	841	844	847	850	852	855	858	861	863	866	869	872	874
900	888	929	932	935	938	941	944	947	950	953	956	959	962	965	968	971	974	978	981	984
1 000	987	1 032	1 035	1 038	1 042	1 045	1 048	1 052	1 055	1 059	1 062	1 065	1 069	1 072	1 076	1 079	1 083	1 086	1 090	1 093
2 000	1 974	2 064	2 070	2 077	2 084	2 090	2 097	2 104	2 110	2 117	2 124	2 131	2 138	2 144	2 151	2 158	2 165	2 172	2 179	2 186
3 000	2 962	3 096	3 106	3 115	3 125	3 135	3 145	3 156	3 165	3 176	3 186	3 196	3 206	3 217	3 227	3 237	3 248	3 258	3 269	3 279
4 000	3 949	4 127	4 141	4 154	4 167	4 180	4 194	4 207	4 220	4 234	4 248	4 261	4 275	4 289	4 303	4 316	4 331	4 344	4 358	4 372
5 000	4 936	5 159	5 176	5 192	5 209	5 225	5 242	5 259	5 276	5 293	5 310	5 327	5 344	5 361	5 378	5 396	5 413	5 431	5 448	5 465

SPRAMEX 150/200

MASS (kg)	VOLUME (litres) at TEMPERATURE (°C)																			
	20	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180
6 000	5 923	6 191	6 211	6 231	6 251	6 270	6 290	6 311	6 331	6 351	6 372	6 392	6 413	6 433	6 454	6 475	6 496	6 517	6 538	6 559
7 000	6 910	7 223	7 246	7 269	7 292	7 315	7 339	7 363	7 386	7 410	7 433	7 458	7 482	7 505	7 530	7 554	7 579	7 603	7 627	7 652
8 000	7 897	8 255	8 282	8 308	8 334	8 361	8 387	8 415	8 441	8 468	8 495	8 523	8 551	8 578	8 606	8 633	8 661	8 689	8 717	8 745
9 000	8 885	9 287	9 317	9 346	9 376	9 406	9 436	9 467	9 496	9 527	9 557	9 588	9 619	9 650	9 681	9 712	9 744	9 775	9 806	9 838
10 000	9 872	10 318	10 352	10 385	10 418	10 451	10 484	10 519	10 551	10 585	10 619	10 654	10 688	10 722	10 757	10 791	10 827	10 861	10 896	10 931
11 000	10 859	11 350	11 387	11 423	11 459	11 496	11 532	11 570	11 606	11 644	11 681	11 719	11 757	11 794	11 833	11 870	11 909	11 947	11 985	12 024
12 000	11 846	12 382	12 422	12 462	12 501	12 541	12 581	12 622	12 661	12 702	12 743	12 784	12 826	12 866	12 908	12 949	12 992	13 033	13 075	13 117
13 000	12 833	13 414	13 458	13 500	13 543	13 586	13 629	13 674	13 717	13 761	13 805	13 850	13 895	13 938	13 984	14 028	14 075	14 119	14 165	14 210
14 000	13 820	14 446	14 493	14 539	14 585	14 631	14 678	14 726	14 772	14 819	14 867	14 915	14 964	15 011	15 060	15 107	15 157	15 206	15 254	15 303
15 000	14 808	15 478	15 528	15 577	15 626	15 676	15 726	15 778	15 827	15 878	15 929	15 980	16 032	16 083	16 135	16 187	16 240	16 292	16 344	16 396
16 000	15 795	16 510	16 563	16 615	16 668	16 721	16 774	16 830	16 882	16 936	16 991	17 046	17 101	17 155	17 211	17 266	17 323	17 378	17 433	17 489
17 000	16 782	17 541	17 598	17 654	17 710	17 766	17 823	17 882	17 937	17 995	18 053	18 111	18 170	18 227	18 287	18 345	18 405	18 464	18 523	18 582
18 000	17 769	18 573	18 634	18 692	18 752	18 811	18 871	18 933	18 992	19 053	19 115	19 177	19 239	19 299	19 363	19 424	19 488	19 550	19 613	19 676
19 000	18 756	19 605	19 669	19 731	19 793	19 856	19 919	19 985	20 047	20 112	20 177	20 242	20 308	20 372	20 438	20 503	20 570	20 636	20 702	20 769
20 000	19 743	20 637	20 704	20 769	20 835	20 901	20 968	21 037	21 102	21 170	21 239	21 307	21 377	21 444	21 514	21 582	21 653	21 722	21 792	21 862
21 000	20 731	21 669	21 739	21 808	21 877	21 946	22 016	22 089	22 157	22 229	22 300	22 373	22 445	22 516	22 590	22 661	22 736	22 808	22 881	22 955
22 000	21 718	22 701	22 774	22 846	22 919	22 991	23 065	23 141	23 213	23 287	23 362	23 438	23 514	23 588	23 665	23 740	23 818	23 894	23 971	24 048
23 000	22 705	23 732	23 810	23 885	23 960	24 036	24 113	24 193	24 268	24 346	24 424	24 503	24 583	24 660	24 741	24 819	24 901	24 981	25 061	25 141
24 000	23 692	24 764	24 845	24 923	25 002	25 082	25 161	25 245	25 323	25 404	25 486	25 569	25 652	25 733	25 817	25 899	25 984	26 067	26 150	26 234
25 000	24 679	25 796	25 880	25 962	26 044	26 127	26 210	26 296	26 378	26 463	26 548	26 634	26 721	26 805	26 892	26 978	27 066	27 153	27 240	27 327

SHELMAC MC-800

MASS (kg)	VOLUME (litres) at TEMPERATURE (°C)																
	20	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135
10	10	10	10	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
20	20	21	21	21	21	21	21	21	22	22	22	22	22	22	22	22	22	22
30	31	31	31	32	32	32	32	32	32	32	32	33	33	33	33	33	33	33
40	41	42	42	42	42	43	43	43	43	43	43	43	44	44	44	44	44	44
50	51	52	52	53	53	53	53	54	54	54	54	54	55	55	55	55	55	56
60	61	63	63	63	64	64	64	64	65	65	65	65	65	66	66	66	66	67
70	72	73	73	74	74	74	75	75	75	76	76	76	76	77	77	77	77	78
80	82	84	84	84	85	85	85	86	86	86	87	87	87	88	88	88	89	89
90	92	94	94	95	95	96	96	96	97	97	97	98	98	99	99	99	100	100
100	102	105	105	106	106	106	107	107	108	108	108	109	109	109	110	110	111	111
200	204	209	210	211	212	213	214	214	215	216	217	217	218	219	220	221	221	222
300	307	314	315	317	318	319	320	321	323	324	325	326	327	328	330	331	332	333
400	409	418	419	422	424	426	427	429	430	432	433	435	436	438	440	441	443	444
500	511	523	524	528	530	532	534	536	538	540	542	543	545	547	549	551	553	555
600	613	627	629	634	636	638	641	643	645	647	650	652	655	657	659	662	664	666
700	716	732	734	739	742	745	747	750	753	755	758	761	764	766	769	772	775	778
800	818	836	839	845	848	851	854	857	860	863	866	870	873	876	879	882	885	889
900	920	941	944	950	954	957	961	964	968	971	975	978	982	985	989	992	996	1 000
1 000	1 022	1 045	1 049	1 056	1 060	1 064	1 068	1 071	1 075	1 079	1 083	1 087	1 091	1 095	1 099	1 103	1 107	1 111
2 000	2 045	2 091	2 097	2 112	2 120	2 128	2 135	2 143	2 151	2 158	2 166	2 174	2 182	2 190	2 198	2 206	2 214	2 222
3 000	3 067	3 136	3 146	3 168	3 180	3 191	3 203	3 214	3 226	3 237	3 249	3 261	3 273	3 285	3 297	3 308	3 321	3 332
4 000	4 090	4 181	4 194	4 224	4 240	4 255	4 270	4 286	4 301	4 317	4 332	4 348	4 364	4 379	4 395	4 411	4 427	4 443
5 000	5 112	5 226	5 243	5 280	5 300	5 319	5 338	5 357	5 376	5 396	5 415	5 435	5 454	5 474	5 494	5 514	5 534	5 554

SHELMAC MC-800

MASS (kg)	VOLUME (litres) at TEMPERATURE (°C)																
	20	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135
6 000	6 135	6 272	6 292	6 336	6 359	6 383	6 405	6 429	6 452	6 475	6 498	6 522	6 545	6 569	6 593	6 617	6 641	6 665
7 000	7 157	7 317	7 340	7 393	7 419	7 446	7 473	7 500	7 527	7 554	7 581	7 609	7 636	7 664	7 692	7 719	7 748	7 776
8 000	8 180	8 362	8 389	8 449	8 479	8 510	8 540	8 572	8 602	8 633	8 664	8 696	8 727	8 759	8 791	8 822	8 855	8 886
9 000	9 202	9 408	9 437	9 505	9 539	9 574	9 608	9 643	9 678	9 712	9 747	9 783	9 818	9 854	9 890	9 925	9 962	9 997
10 000	10 225	10 453	10 486	10 561	10 599	10 638	10 675	10 715	10 753	10 792	10 830	10 870	10 909	10 949	10 989	11 028	11 068	11 108
11 000	11 247	11 498	11 535	11 617	11 659	11 701	11 743	11 786	11 828	11 871	11 913	11 956	12 000	12 044	12 088	12 131	12 175	12 219
12 000	12 270	12 543	12 583	12 673	12 719	12 765	12 811	12 858	12 904	12 950	12 996	13 043	13 091	13 138	13 186	13 233	13 282	13 330
13 000	13 292	13 589	13 632	13 729	13 779	13 829	13 878	13 929	13 979	14 029	14 079	14 130	14 182	14 233	14 285	14 336	14 389	14 440
14 000	14 315	14 634	14 680	14 785	14 839	14 893	14 946	15 000	15 054	15 108	15 163	15 217	15 273	15 328	15 384	15 439	15 496	15 551
15 000	15 337	15 679	15 729	15 841	15 899	15 957	16 013	16 072	16 129	16 187	16 246	16 304	16 363	16 423	16 483	16 542	16 603	16 662
16 000	16 360	16 725	16 778	16 897	16 959	17 020	17 081	17 143	17 205	17 266	17 329	17 391	17 454	17 518	17 582	17 644	17 709	17 773
17 000	17 382	17 770	17 826	17 953	18 018	18 084	18 148	18 215	18 280	18 346	18 412	18 478	18 545	18 613	18 681	18 747	18 816	18 884
18 000	18 405	18 815	18 875	19 009	19 078	19 148	19 216	19 286	19 355	19 425	19 495	19 565	19 636	19 708	19 780	19 850	19 923	19 994
19 000	19 427	19 860	19 923	20 065	20 138	20 212	20 283	20 358	20 431	20 504	20 578	20 652	20 727	20 802	20 878	20 953	21 030	21 105
20 000	20 450	20 906	20 972	21 122	21 198	21 275	21 351	21 429	21 506	21 583	21 661	21 739	21 818	21 897	21 977	22 056	22 137	22 216
21 000	21 472	21 951	22 021	22 178	22 258	22 339	22 418	22 501	22 581	22 662	22 744	22 826	22 909	22 992	23 076	23 158	23 244	23 327
22 000	22 495	22 996	23 069	23 234	23 318	23 403	23 486	23 572	23 656	23 741	23 827	23 913	24 000	24 087	24 175	24 261	24 350	24 438
23 000	23 517	24 041	24 118	24 290	24 378	24 467	24 554	24 644	24 732	24 820	24 910	25 000	25 091	25 182	25 274	25 364	25 457	25 548
24 000	24 540	25 087	25 167	25 346	25 438	25 530	25 621	25 715	25 807	25 900	25 993	26 087	26 181	26 277	26 373	26 467	26 564	26 659
25 000	25 562	26 132	26 215	26 402	26 498	26 594	26 689	26 787	26 882	26 979	27 076	27 174	27 272	27 372	27 472	27 569	27 671	27 770

SHELMAC MC-3000

MASS (kg)	VOLUME (litres) at TEMPERATURE (°C)																						
	20	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175
10	10	10	10	10	10	10	10	10	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21	22	22	22	22	22	22	22	22	22
30	30	31	31	31	31	31	31	31	32	32	32	32	32	32	32	32	32	33	33	33	33	33	33	33
40	40	41	41	41	42	42	42	42	42	42	42	43	43	43	43	43	43	43	43	44	44	44	44	44
50	50	51	52	52	52	52	52	52	53	53	53	53	53	53	54	54	54	54	54	55	55	55	55	55
60	60	62	62	62	62	63	63	63	63	63	64	64	64	64	64	65	65	65	65	65	66	66	66	66
70	70	72	72	73	73	73	73	73	74	74	74	74	75	75	75	75	76	76	76	76	77	77	77	77
80	80	82	83	83	83	83	84	84	84	85	85	85	85	86	86	86	86	87	87	87	88	88	88	88
90	90	93	93	93	94	94	94	94	95	95	95	96	96	96	97	97	97	98	98	98	98	99	99	99
100	100	103	103	104	104	104	105	105	105	106	106	106	107	107	107	108	108	108	109	109	109	110	110	110
200	200	206	207	207	208	209	209	210	211	211	212	213	213	214	215	215	216	217	217	218	219	220	220	221
300	300	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331
400	400	412	413	415	416	417	419	420	421	423	424	425	427	428	429	431	432	434	435	436	438	439	441	442
500	501	515	517	518	520	522	523	525	527	528	530	532	533	535	537	538	540	542	544	545	547	549	551	552
600	601	618	620	622	624	626	628	630	632	634	636	638	640	642	644	646	648	650	652	654	657	659	661	663
700	701	721	723	726	728	730	732	735	737	739	742	744	747	749	751	754	756	759	761	764	766	768	771	773
800	801	824	827	829	832	834	837	840	842	845	848	850	853	856	859	861	864	867	870	873	875	878	881	884
900	901	927	930	933	936	939	942	945	948	951	954	957	960	963	966	969	972	975	978	982	985	988	991	994
1 000	1 001	1 030	1 033	1 036	1 040	1 043	1 046	1 050	1 053	1 056	1 060	1 063	1 067	1 070	1 073	1 077	1 080	1 084	1 087	1 091	1 094	1 098	1 101	1 105
2 000	2 002	2 060	2 066	2 073	2 079	2 086	2 093	2 099	2 106	2 113	2 119	2 126	2 133	2 140	2 147	2 154	2 161	2 168	2 174	2 182	2 188	2 196	2 203	2 210
3 000	3 003	3 090	3 099	3 109	3 119	3 129	3 139	3 149	3 159	3 169	3 179	3 189	3 200	3 210	3 220	3 230	3 241	3 251	3 262	3 272	3 283	3 293	3 304	3 315
4 000	4 004	4 119	4 133	4 146	4 159	4 172	4 185	4 199	4 212	4 225	4 239	4 252	4 266	4 280	4 293	4 307	4 321	4 335	4 349	4 363	4 377	4 391	4 405	4 419
5 000	5 005	5 149	5 166	5 182	5 198	5 215	5 232	5 249	5 265	5 282	5 299	5 315	5 333	5 350	5 367	5 384	5 401	5 419	5 436	5 454	5 471	5 489	5 507	5 524

SHELMAC MC-3000

MASS (kg)	VOLUME (litres) at TEMPERATURE (°C)																						
	20	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175
6 000	6 006	6 179	6 199	6 219	6 238	6 258	6 278	6 298	6 318	6 338	6 358	6 379	6 400	6 419	6 440	6 461	6 482	6 503	6 523	6 545	6 565	6 587	6 608	6 629
7 000	7 007	7 209	7 232	7 255	7 278	7 301	7 324	7 348	7 371	7 394	7 418	7 442	7 466	7 489	7 513	7 538	7 562	7 587	7 611	7635	7660	7685	7709	7734
8 000	8 008	8 239	8 265	8 292	8 317	8 344	8 370	8 398	8 424	8 451	8 478	8 505	8 533	8 559	8 587	8 614	8 642	8 670	8 698	8 726	8 754	8 783	8 811	8 839
9 000	9 009	9 269	9 298	9 328	9 357	9 387	9 417	9 447	9 477	9 507	9 537	9 568	9 599	9 629	9 660	9 691	9 723	9 754	9 785	9 817	9 848	9 880	9 912	9 944
10 000	10 010	10 298	10 331	10 364	10 397	10 430	10 463	10 497	10 530	10 564	10 597	10 631	10 666	10 699	10 733	10 768	10 803	10 838	10 872	10 908	10 942	10 978	11 013	11 049
11 000	11 011	11 328	11 364	11 401	11 436	11 473	11 509	11 547	11 583	11 620	11 657	11 694	11 733	11 769	11 807	11 845	11 883	11 922	11 959	11 998	12 037	12 076	12 115	12 153
12 000	12 012	12 358	12 398	12 437	12 476	12 516	12 556	12 596	12 636	12 676	12 717	12 757	12 799	12 839	12 880	12 922	12 964	13 006	13 047	13 089	13 131	13 174	13 216	13 258
13 000	13 013	13 388	13 431	13 474	13 516	13 559	13 602	13 646	13 689	13 733	13 776	13 820	13 866	13 909	13 953	13 999	14 044	14 089	14 134	14 180	14 225	14 272	14 317	14 363
14 000	14 014	14 418	14 464	14 510	14 555	14 602	14 648	14 696	14 742	14 789	14 836	14 883	14 932	14 979	15 027	15 075	15 124	15 173	15 221	15 271	15 319	15 370	15 419	15 468
15 000	15 015	15 448	15 497	15 547	15 595	15 646	15 695	15 746	15 795	15 845	15 896	15 946	15 999	16 049	16 100	16 152	16 204	16 257	16 308	16 362	16 413	16 467	16 520	16 573
16 000	16 016	16 477	16 530	16 583	16 635	16 689	16 741	16 795	16 848	16 902	16 955	17 009	17 066	17 118	17 174	17 229	17 285	17 341	17 395	17 452	17 508	17 565	17 621	17 678
17 000	17 017	17 507	17 563	17 620	17 675	17 732	17 787	17 845	17 901	17 958	18 015	18 072	18 132	18 188	18 247	18 306	18 365	18 425	18 483	18 543	18 602	18 663	18 723	18 783
18 000	18 018	18 537	18 596	18 656	18 714	18 775	18 834	18 895	18 954	19 014	19 075	19 136	19 199	19 258	19 320	19 383	19 445	19 508	19 570	19 634	19 696	19 761	19 824	19 887
19 000	19 019	19 567	19 629	19 693	19 754	19 818	19 880	19 944	20 007	20 071	20 134	20 199	20 265	20 328	20 394	20 459	20 526	20 592	20 657	20 725	20 790	20 859	20 925	20 992
20 000	20 020	20 597	20 663	20 729	20 794	20 861	20 926	20 994	21 060	21 127	21 194	21 262	21 332	21 398	21 467	21 536	21 606	21 676	21 744	21 815	21 885	21 957	22 027	22 097
21 000	21 021	21 627	21 696	21 765	21 833	21 904	21 972	22 044	22 113	22 183	22 254	22 325	22 399	22 468	22 540	22 613	22 686	22 760	22 832	22 906	22 979	23 054	23 128	23 202
22 000	22 022	22 656	22 729	22 802	22 873	22 947	23 019	23 094	23 166	23 240	23 314	23 388	23 465	23 538	23 614	23 690	23 766	23 844	23 919	23 997	24 073	24 152	24 229	24 307
23 000	23 023	23 686	23 762	23 838	23 913	23 990	24 065	24 143	24 219	24 296	24 373	24 451	24 532	24 608	24 687	24 767	24 847	24 927	25 006	25 088	25 167	25 250	25 331	25 412
24 000	24 024	24 716	24 795	24 875	24 952	25 033	25 111	25 193	25 272	25 352	25 433	25 514	25 598	25 678	25 760	25 843	25 927	26 011	26 093	26 179	26 262	26 348	26 432	26 517
25 000	25 025	25 746	25 828	25 911	25 992	26 076	26 158	26 243	26 326	26 409	26 493	26 577	26 665	26 748	26 834	26 920	27 007	27 095	27 180	27 269	27 356	27 446	27 533	27 621

APPENDIX B

ABBREVIATIONS

ISBN	International Standard Book Number
ISSN	International Standard Serie Number
MC	Medium curing
NORAD	Norwegian Agency for Development Cooperation
NPRA	Norwegian Public Roads Administration
NRRL	Norwegian Road Research Laboratory
PHN	Public Highway Network
PVA	Polyvinyleacelate
RC	Rapid Curing
SBR	Styrenebutadinerubber
SBS	Styrenebutadinstyrene
SC	Slow Curing
SFRDP	Feeder Road Development Programme
Sida	Swedish International Development Authority
SPMB	Semi-Priming Modified Binder
TMH	Technical Methods for Highways (South African Standards)
10% FACT	Ten percent Fines Value
AADT	Average Annual Daily Traffic

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