also takes this approach. However, McLeod and others recommend use of the actual asphalt residual fraction of the emulsion, which is usually in the neighborhood of 0.65. The nomograph method uses 0.75 as the value of the fraction (R) for emulsions.

Figure 6

Since the design application rate of the binder is obtained at 60°F from Figure 5 and the actual application temperature of the binder is higher, Figure 6 can be used to obtain the modified application rate at the desired application temperature.

Verification

Although the 1972 and 1973 field projects were designed by the McLeod and California methods, respectively, the rates of application were determined later by this nomograph method and are given in Tables 2 and 4 for comparison. Considering the performance (percent loss of cover aggregate and extent of bleeding) of these pavements and comparing the nomograph and actual application rates, it would appear that this method is reasonably suitable for low-volume roads. As expected, if the cover aggregate is flaky (Table 2, section A--aggregate 1NS has a flakiness index of 35), the nomograph method gives slightly higher application rates for binder and aggregate.

This simplified design method was used extensively for low-volume roads by the contractors and county maintenance forces in Pennsylvania during the 1980 and 1981 construction season with apparent success. It was also used with success in August 1980 on I-81 (four lanes) between the Ravine and Route 209 interchanges (2.5 miles) in Schuylkill County (10). This road carries an ADT of 11 000 vehicles (15 percent trucks), and the design speed is 55 mph.

SUMMARY AND CONCLUSIONS

Although many design methods have been developed on a rational basis in the past, most involve time-consuming or complex test procedures and/or computations. This has discouraged their use, especially for low-volume, low-cost roads. A need was felt to develop a simplified rational design method for this purpose. This was accomplished in four phases:

1. A literature review of the existing design procedures,
2. Use of two design methods on field projects,
3. Laboratory experiments to determine the relative significance of design parameters and correlations between complex and simple test properties, and
4. Development of a nomograph method and its verification in the field.

Surface treatment is still considered more an art than a science because many judgment factors are involved in the design and construction phases. However, it is believed that the suggested simplified method is suitable as a guide for low-volume, low-cost roads.

Additional research is being conducted in the Bituminous Laboratory of the Pennsylvania Department of Transportation to refine this method further while maintaining the simplified approach.

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Graded Gravel Seal (Otta Surfacing)

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A substantial number of the roads in Norway carry low traffic volumes. Most of these roads were unpaved 15-20 years ago. Today the gravel surface is partly replaced by low-cost surface dressings and premixes after only minor structural strengthening of the roads. The economic and technical requirements for the replacement surfacings are (a) the investment should be earned back in a few years through reduced maintenance costs and (b) the road user should find the riding quality comparable to that of ordinary hard-top surfacings. One of the most common and successful types of replacement surfacings, a gravel seal that has been named "Otta surfacing", is described. Otta surfacing is a 10- to 30-mm-thick bituminous surface dressing for which

graded gravel is used as covering. The binder is an ordinary liquid asphalt or a special cationic emulsion that contains 1 percent fatty amine to improve the adhesion between the moist mineral surface and the bitumen. The quality and grading requirements of the covering aggregates are normally the same as for the base. The covering aggregate has to be screened and sometimes crushed. After a minor strengthening and reshaping of the road, the bitumen and covering aggregates are spread with standard equipment. The Otta surfacing has proved to be a technically and economically sound way of improving the quality of low-volume roads in Norway. More than 10 000 km of roads have been given this type of surfacing in the past 20 years. Otta surfacing has also been introduced in several other countries. Service life and performance depend heavily on local conditions. On the average, resurfacing has been needed after 8 years (double surface dressing) and total road costs have been less than costs for gravel surfacings.

A large number of the public roads in Norway are unpaved, carry low traffic volumes [average daily traffic (ADT) of 50-500 vehicles], and have low bearing capacity. The majority of these roads have a very nonhomogeneous quality standard with regard to geometry, bearing capacity, and road surface. Stage construction improvements have been going on for many years and will have to continue.

For the past 10 years, the Norwegian Public Roads Administration has used a special kind of bituminous surface dressing as a standard "maintenance surfacing" on gravel roads that have low bearing capacity. The economic and technical requirements for this type of surfacing are very simple:

1. The investments should be earned back in a few years through reduced maintenance cost only.
2. The road user should find the quality of the road surface comparable to that of ordinary hard-top surfacings.

One advantage of using such inexpensive maintenance surfacings on low-volume gravel roads with variable bearing capacity should be mentioned: The procedure reliably localizes the weak parts of the road. This may be a cost-saving supplement to the bearing capacity measurements that have to be performed prior to the structural improvement of the road.

This paper describes one of the most common and successful maintenance surfacings, a gravel seal that has been named "Otta surfacing".

DESCRIPTION OF OTTA SURFACING

The graded gravel seal is a special kind of surface dressing developed in 1963-1966 by the Norwegian Road Research Laboratory, which is part of the Public Road Administration. This method has in Norway been called Otta surfacing after the Otta Valley, where the first large-scale trials were carried out in 1963.

Very briefly, the Otta surfacing is a 10- to 30-mm-thick bituminous surface dressing that uses graded gravel as the covering aggregate instead of single-sized chippings.

To accomplish its purpose, the method should comply with the following requirements:

1. Be cheap and easy to implement anywhere in the country,
2. Use screened natural aggregates available any place,
3. Be impervious to water in order to avoid softening of water-susceptible material in the base course,
4. Be very flexible and durable, and
5. Be easy to maintain.

Material Requirements

The binder is usually an ordinary cutback bitumen MC 800 or 3000, but RC binders may also be used. SC products are generally not recommended since they may give rise to bleeding. The binder should always contain 1 percent of a fatty amine in order to improve the adhesion between the moist mineral surface and the binder. Active adhesion is a condition for the formation of a paving course by rolling the gravel into the binder. In the past few years, cationic bituminous emulsion has also been used as a binder with excellent results.

The requirements for the covering aggregates should be relatively modest. Normally, the material requirements are the same as for the base and the grading is as shown in Figure 1. A coarse grading is preferred.

Preparation Work on the Road

Normally, only minor strengthening works have been performed on existing gravel roads prior to the use of the bituminous surface dressing. The design of the road strengthening works is usually based on the judgment of the local engineer. Priority has been given to pavement strengthening on local parts of the road that have special bearing capacity problems in the thawing period and to improvement of drainage. Some gravel is added on top before the final reshaping and compacting. However, these procedures lead to only small improvements of bearing capacity without any uniform quality standard.

Guidelines for Construction

The Otta surfacing is used for the following purposes:

Purpose	No. of Layers
Surfacing of gravel roads that have had no previous rehabilitation	1 or 2
Wearing course on gravel roads that have adequate bearing capacity	2
Temporary surface during construction period	1
Coarse seal on old bituminous surfacing	1

The equipment and working procedure are the same as for traditional surface dressings, with the following supplements:

1. The Otta surfacing may be placed in one or more layers according to local conditions and requirements.
2. Normally no prime should be applied.
3. The surface to be treated should be damp. If it is too dry, water should be added.
4. Compaction of the finished surface dressing is essential.

The spread rate for each layer and the resulting surfacing thickness for single and double layers are normally as given in Table 1. The covering aggregates should preferably be spread immediately after the binder and thoroughly rolled. A good indication that the amount of aggregate is correct is that one can scarcely see bitumen being pressed up through the aggregate in the wheel tracks of the aggregate spreader.

EXPERIENCE

The Otta surfacing method has been used in Norway for 20 years, generally with good results. Cur-

Figure 1. Envelope curves for aggregates.

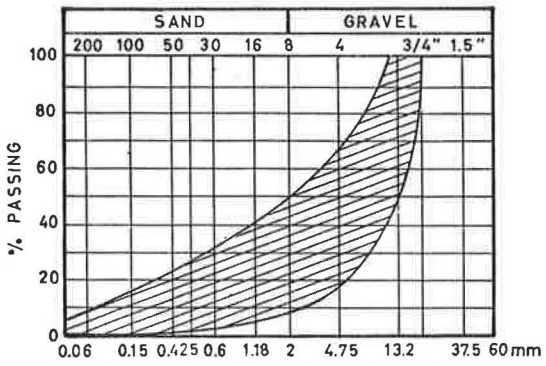

Table 1. Spread rate and resulting surface thickness of Otta surfacing.

	Aggregates		Resulting Surface Thickness	
Binder Spread Rate (L/m^2)	Fraction (mm)	Spread Rate (L/m^2)	Single Layer (mm)	Double Layer (mm)
1.5	0-12	12-15	12-14	25-30
2.0	0-20	20-25	20-22	45-50

Figure 2. Use of Otta surfacing in Kenya.

rently, the surfacing program amounts to about 1000 km of road every year. The total length of road with this kind of surfacing in Norway is about 10 000 km, or 20 percent of the paved road network.

Otta surfacing is also used in several other countries. A 260-km-long gravel road in Kenya will soon be finished with a double gravel seal (see Figure 2).

Service life and performance depend heavily on local conditions. On a road with a traffic volume of 1000 ADT and a Benkelman beam deflection of less than 1.25 mm, which indicates a reasonably good base, a double Otta surfacing may give excellent performance for 10 years or more. After 10 years, resurfacing will normally be desired due to increasing unevenness. On the other hand, a single layer on a road that has very low bearing capacity may be seriously damaged after a few years.

Roads with Low Bearing Capacity and Water-Susceptible Base

The Otta surfacing is mainly used on gravel roads that have low bearing capacity. As a rule, the base of such roads contains water-susceptible material and the bearing capacity is particularly low in the thaw period. The water is partly capillary water transported from the ground during the freezing period and partly surface water from melting snow, rain, etc.

The Otta surfacing is a thin and very flexible seal and is not considered to be a strengthening layer in itself. The surfacing is practically impervious to water, however, and prevents penetration of surface water into the water-susceptible base. On the other hand, the evaporation of capillary water will be slower with a surfacing than without it.

Practical experience in Norway shows that under normal conditions the Otta surfacing contributes substantially to the bearing capacity of secondary roads in the thaw period by reducing the water content in the upper parts of the base.

Materials, Design, and Construction

During the past few years, various types of cationic bituminous emulsion have been used as binder in a program for the further development of the Otta surfacing method. Some of the emulsions seem to perform even better than the usual binder in many respects.

The amount of binder must often be finally determined on site. The binder should form a continuous layer without any bare patches; otherwise, the amount of binder should be increased or more water should be spread prior to the spreading of the binder.

Complete coating of the mineral aggregate particles, even the fines, is essential for a good result. A cationic adhesion-improving agent or a wetting agent is therefore added to the binder. To aid in this wetting process, the covering aggregates as well as the road surface should be moist.

Cost, Service Life, and Maintenance

Total cost figures for the Otta surfacing, a few conventional surfacings, and annual maintenance of gravel roads are given below (1982 U.S. dollars):

Item	Cost ($/m²)
Annual maintenance of gravel roads	0.4-0.7
Otta surfacing	
Single layer	1-1.5
Double layer	2-3
Oil gravel cold plant mix (100 kg/m²)	3.5-5
Asphalt concrete (90 kg/m²)	6-7

This means that, on the average, a single Otta surfacing should last 3-4 years in order to break even with the accumulated maintenance cost of a gravel road. A double treatment should similarly last 5-7 years. Road-user savings will add to the advantage.

Experience in Norway shows that the average service life of a double-layer surfacing on a properly reconstructed road is 8 years and that a single layer applied directly on a secondary gravel road will last 3-4 years before resurfacing. Axle-load restrictions in the thaw period may be advisable. Due to the great flexibility of this surfacing, it performs far better than plant mix surfacings on roads that have large deflections. The Otta surfacing may therefore be a good way to improve riding quality and cut transportation costs on secondary roads. It can be maintained by applying a new treatment directly on top of the old surface or by ordinary patching with premix material. The Otta surfacing poses no problems for ordinary winter maintenance (plowing, etc.). It should be kept in mind, however, that the surfacing is thin and might be harmed by ice grading, particularly on roads with uneven frost heave.