RECENT DEVELOPMENTS IN ASPHALT TECHNIQUES FOR HYDRAULIC APPLICATIONS IN THE NETHERLANDS

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SYNOPSIS

Since 1945 and particularly after the flood in 1953, new means were developed to accelerate the construction of hydraulic engineering projects in the Netherlands. This development was initially related to paving sand dikes with durable materials. The available knowledge of the mechanical properties of asphaltic mixtures and the experience with asphalt paving technology proved to be very useful for this purpose. It enabled the application of local minerals bound with asphalt, instead of the classical stone materials and tough clay which are not always available in sufficient quantities and are difficult to handle with mechanical equipment. The success of the first projects promoted application of asphaltic mixes in a much wider field such as the construction of large harbour dams.

The paper also describes construction practices involving mixing, handling and placing of mixtures of various compositions and properties for different types of construction. In several cases the mixtures have to be applied under unusual circumstances, generally at a high rate, and always in an economical way. The most interesting asphaltic materials to be considered are:

1. Lean sand asphalt
   This is a mixture of mostly locally dredged fine sand with a low percentage of bitumen (3 to 5%). This material is used both for the permanent protection of sand dikes and dams above high water level and for the construction in closure gaps of temporary stream-resistant sills, on which later on caissons are placed to fill the gap definitely.

2. Sand-mastic asphalt
   In addition to the conventional application of mastic asphalt for grouting stone-sets, a new technique enables the application of this material at any depth under water for both grouting and paving purposes. At several places the sea bottom has now been paved with asphalt mats to prevent scour. The special equipment used is described.

3. Normal dense asphaltic concrete
   Normal dense asphaltic concrete used for revetments is comparable in composition to asphaltic concrete for road building; this material has been used on an extensive scale during the last 15 years. The application can now be considered as a matter of routine.

4. Stone asphalt ("Bitumarin concrete")
   A new composition, which is being used for the construction of harbour dams, is the so-called stone asphalt ("Bitumarin concrete").

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1Koninklijke/Shell-Laboratorium, Amsterdam, Netherlands.
In this material the gradation curve of asphaltic concrete is extended to a maximum stone size of as much as 50 cm. (20 in.). It is applied in heavy layers 2 metres (7 feet) and more in thickness. Attention must be paid in particular to its workability and stability. The preparation of these mixtures requires special large mixing plants of an entirely new design with a capacity of about 150-300 metric tons per hour each.

INTRODUCTION

The use of asphaltic mixtures for hydraulic applications in the Netherlands has developed rapidly since 1945 and in particular after the great floods in 1953. One of the main reasons for this development was the lack of the classic dike-building materials, such as stone and tough clay. In the Netherlands, only sand and gravel are available. Stone materials have to be transported from other European countries over distances of at least several hundred kilometres. Good quality tough clay is scarce.

Another powerful incentive was the need for rapid and at the same time economical methods for making dike revetments. This need came to the fore for the first time after the 1953 floods, when about 30 km. of dikes had to be built within about six months. The application of classic materials could not be considered in this case, because they are difficult to handle and to bring in place with mechanical equipment. Later, the Delta project, an undertaking started after 1953 and involving the closing of the estuaries between most of the islands in the southern part of the Netherlands, created an even stronger need for new and modern methods of constructing the revetments of the large dams to be built.

Because of their impermeability to water, dense asphaltic mixtures seemed very suitable for dike-building purposes. Sand is a very attractive material for the construction of large dike bodies having cross-sectional areas of roughly 3000 or more square metres. It is always locally available and can be handled easily with modern mechanized equipment. However, it has to be protected against the eroding forces of wind and water. The classic way of protecting the sand body is to cover it first with a layer of clay and then with a layer of stones. The replacement of this type of protective layer by a relatively thin layer of a water-tight asphaltic mixture, avoids the use of clay and stone entirely and thus enables the exclusive use of mechanized equipment for handling and placing of all the dike building materials.

Asphalt revetments have become a current feature in dike construction in the Netherlands over the last two decades. Therefore the hydraulic engineers have become familiar with the typical advantages of using asphalt materials and this has led to new developments for its large-scale application in the hydraulic field. Some of these developments are discussed in this paper.
ASPHALT MIXTURES FOR APPLICATION IN LARGE QUANTITIES

As the properties of asphaltic mixtures vary rather widely with the type of mixture it is useful to make the following classification:

(a) The lean "open" mixtures, which, owing to the use of locally available (non-graded) mineral aggregate and a small proportion of bitumen (3-5%), are among the cheapest. The voids content exceeds 10%, often by a wide margin. Depending on the circumstances these mixtures are consolidated by e.g. rolling or only loosely dumped.

(b) Mineral aggregate mixtures in which the voids are filled with an excess of bitumen. To this group belong the "sand mastic mixtures," which are characterized by the fact that under static loading they behave like a liquid with a very high viscosity ($10^6$-$10^{12}$ poises, i.e. $10^{11}$-$10^{14}$ times the viscosity of water). When the mixtures are hot their viscosity is much lower ($10^5$-$10^6$ poises) so that they are easily poured.

(c) Mineral aggregate mixtures which are in general carefully graded and to which such a proportion of bitumen has been added that the voids are just about filled. In this way a maximum resistance to static loads is obtained. These mixtures must preferably be consolidated by rolling, and are of the normal type used in road building (e.g. asphaltic concrete, sheet asphalt).

(d) Mixtures as mentioned under (c), but in which the gradation curve is extended to a maximum stone size of 50 cm. (20 in.). This type of mixture is called "stone asphalt" ("Bitumarin concrete") and is normally not consolidated by rolling or other mechanical treatment.

To assess the serviceability of these mixtures, the mechanical properties and durability must be considered. As regards the mechanical properties, bituminous mixtures when used in dikes, etc., will have to resist static and dynamic loads. The static loads are caused by the fact that the material lies on a slope. In this case the stability of the material is the determining property.

To this may be added that also the stability of the whole revetment must be taken into consideration. This stability can be endangered if water pressures acting from underneath the revetment, e.g. due to a higher water level in the dike body than outside, should become so high that the revetment is lifted from its base. The thickness (weight) of the layer must be sufficiently high to prevent this. In practice this weight consideration is often the predominant factor in design.

The dynamic loads are caused by wave action. In this case the "stiffness" of the material determines its behaviour (1, 2). Besides, a certain deformability is desirable in connection with settlement.

Durability is usually also an important factor: it is clear that in general the mechanical properties should be conserved in spite of exposure to water and air. Sometimes a high durability is only of secondary importance, e.g. when the material is almost permanently above
water level and is protected by a seal coat or when it is used for temporary structures, such as building pits.

On the basis of laboratory work (1, 2, 3, 4) and practical experience, the most important properties of the three types of asphalt mixtures mentioned, when used for hydraulic applications, may be tabulated as follows:

<table>
<thead>
<tr>
<th>Type</th>
<th>1 (Lean Mixtures)</th>
<th>2 (Sand Mastics)</th>
<th>3 (Normal Asph. Concr.)</th>
<th>4 (Stone Asphalt &quot;Bitumarin Concrete&quot;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Mechanical properties</td>
<td>satisfactory</td>
<td>moderate</td>
<td>excellent</td>
<td>excellent</td>
</tr>
<tr>
<td>1. Resistance to deformation by static loads (stability)</td>
<td>satisfactory</td>
<td>moderate</td>
<td>excellent</td>
<td>excellent</td>
</tr>
<tr>
<td>2. Ditto, by moving loads (stiffness)</td>
<td>satisfactory</td>
<td>very satisfactory</td>
<td>excellent</td>
<td>excellent</td>
</tr>
<tr>
<td>3. Deformability to moderate</td>
<td>satisfactory</td>
<td>excellent</td>
<td>satisfactory</td>
<td>satisfactory</td>
</tr>
<tr>
<td>b. Durability</td>
<td>moderate</td>
<td>excellent</td>
<td>excellent</td>
<td>excellent</td>
</tr>
</tbody>
</table>

This survey shows at once what type of materials are most suitable for a given purpose. The first three types are easily produced in large quantities with current equipment. For mixing the fourth type and handling and placing of most of the types special techniques have been developed and new equipment designed. This subject will be dealt with in the section on Recent Developments in Asphalt Techniques. But before we discuss apparatus and technique, it is essential to give a more detailed description of the main mechanical properties of the different types. Besides, some remarks will be made about durability.

OPEN "LEAN" SAND ASPHALT MIXTURES (Type 1)

A. General (compaction)

In hydraulic application the principal means of placing lean sand asphalt in large quantities are:
(a) underwater dumping from bottom-door hopper barges;
(b) continuous dumping with the aid of conveyor belts and continuous mixing plants.

Artificial compaction after dumping is often impracticable; material applied by the above methods will therefore have a relatively low density since it will consolidate solely under its own weight. An investigation (5) carried out on specimens taken from actual construction work showed that the density of the lean sand asphalt (local fine sand and 3% bitumen pen. 280/320) varied between 1.40 and 1.54, which corresponds to a percentage of voids (VIM) of 44-38.5% and to a percentage
of voids in the sand (VMA) of 49-44%. These are indeed low densities and high void percentages when compared with those of normally compacted lean sand asphalt. In consequence, mechanical tests on lean sand asphalt had to be carried out on specimens with similar low densities. Such specimens could be obtained in the laboratory in cylindrical moulds 15 cm. in diameter and 10 cm. high if very low static pressures from 0.1 to 0.2 kg./cm.² were used. These pressures are the same as exerted in practice (under water dumping up to a height of ca. 1-2 metres). The grade of bitumen and the compaction temperature appeared to have no influence on the ultimate density in this case. A lower temperature and a harder grade of bitumen only mean that the ultimate density is reached after a somewhat longer time, but even at room temperature and with bitumen grade 80/100 this density is reached in as little as 15 minutes.

B. Stability

Next to the resistance against scour stability is one of the most important properties in hydraulic applications. Only stability will be considered here.

The stability of a material is determined by the cohesion C and the angle of internal friction φ. These quantities can be measured separately with the aid of the well-known triaxial cell apparatus, but in the present case this method was considered unsuitable. It was feared that the very lightly compacted test specimens would undergo after-compaction. For this and other reasons, preference was given to the much simpler cone penetration test. This test only measures the "cone stability" which is a function of C and φ, but on the basis of previous triaxial tests it can be assumed that the φ of lean sand asphalt does not greatly differ from that of unbound sand (about 30-35°). In this way a fair idea of the value of C may be obtained, and hence of the stability of the material under other loading conditions than those prevailing in the cone penetration test.

The cone penetration tests, like the compaction tests, were carried out on cylindrical test samples 15 cm. in diameter and ca. 10 cm. high. The load on the cone (angle at apex: 90°, rough surface) was chosen so as to give a maximum penetration of about 1 cm. For this, loads of about 400 g. appeared suitable.

In view of the results of the compaction tests, pressures of 0.1 and 0.2 kg./cm.² were mostly applied, but for the study of the effect of density on stability higher pressures were applied also.

In contrast with clean sand, for which an end point of cone penetration is reached almost instantaneously, asphalt mixtures are only slowly penetrated, and at a decreasing rate, until finally the cone almost comes to a rest.

In Figure 1, the cone stability, which equals p/πr² (where p = load on the cone in kg., and r = depth of penetration = radius of the loaded surface area in cm.) for a mix consisting of 100 parts by weight of dune
Sand (grading see Table I) and 3 parts by weight of bitumen (grade 280/320) is plotted against the “stiffness” of the bitumens (in kg./cm.²). This “stiffness” was determined with the aid of van der Poel’s (2) nomogram and is a function of loading time, temperature and grade of bitumen. Stiffness values were used to eliminate the effect of using different grades and test temperatures.

Table I. Grading of Dune Sand Used

<table>
<thead>
<tr>
<th>Grading of Sieve</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>40-mesh ASTM sieve</td>
<td>--</td>
</tr>
<tr>
<td>50-mesh ASTM sieve</td>
<td>--</td>
</tr>
<tr>
<td>80-mesh ASTM sieve</td>
<td>56</td>
</tr>
<tr>
<td>100-mesh ASTM sieve</td>
<td>11</td>
</tr>
<tr>
<td>200-mesh ASTM sieve</td>
<td>31</td>
</tr>
<tr>
<td>Passing 200-mesh ASTM sieve</td>
<td>2</td>
</tr>
</tbody>
</table>
It appears that below a stiffness of $2 \times 10^{-4}$ kg./cm.$^2$ there is hardly any further decrease in cone stability, and that the ultimate cone stability is determined to a considerable degree by the voids in the mineral aggregate (VMA) and hence by the compaction pressure applied. With the densities to be expected in practice—when there is no artificial compaction—the cone stability has dropped to the relatively low value of ca. 0.15 kg./cm.$^2$, which is the same value as was determined for the dry dune sand (0.1-0.2 kg./cm.$^2$, depending on amount of compaction).

As the angle of internal friction must be approximately the same for both materials, the cohesion $C$ of lightly compacted lean sand asphalt must also be about the same as that of dry sand.

$C$ and $\phi$ of both materials being the same, it follows that also under other loading conditions than those occurring in the cone penetration test, the stability must be the same.

Lean sand asphalt has thus at least the same stability as dry sand (and a higher stability when artificial compaction is possible). Even when not compacted, however, lean sand asphalt is superior to dry sand in that it possesses a certain dynamic strength, due to the high stiffness of the binder at short loading times. This means that the heights and slopes that may be realized with dry sand only in the purely hypothetical absence of water currents, waves and winds, can be permanently attained in actual practice with slightly compacted lean sand asphalt.

Previous laboratory studies of well-compacted lean sand asphalt had revealed that the addition of 2-4% filler may lead to a fairly considerable increase in compressive strength and also in durability as measured in an accelerated durability test, e.g. the "Immersion-compression test." It was therefore investigated whether 2-4% filler (hydrated lime flour) would similarly improve loosely compacted lean sand asphalt and increase compressive strength, and durability and perhaps raise the cone stability. It appeared, however, that for very lightly compacted specimens the addition of filler leads to a lower durability and a lower or, at best, similar compressive strength.

Cone stabilities were not improved either. According to the earlier tests other fillers are even less effective than hydrated lime flour. It must therefore be concluded that the addition of filler to lightly compacted sand asphalt mixtures is not to be recommended.

Presumably the filler has no beneficial effect because the mixtures with added filler are more difficult to compact, so that the voids in the mineral aggregate of very lightly compacted mixtures are even higher than in the absence of a filler.

C. Durability

The very high voids content of loosely compacted sand asphalt mixtures makes for a limited durability. A quantitative assessment of this property is difficult, however, as up to now it has not been possible to establish a distinct correlation between actual durability of asphalt mixtures used in hydraulic applications and the results of any laboratory test, e.g. the "Immersion-compression test."
The only definite finding so far is that the hardening of the bitumen increases with void content. For the moment, therefore, it must be taken for granted that the durability of open mixtures is limited but is dependent on circumstances (above water, under water, or on the water-line). For materials situated on the water line the durability will be the lowest. A seal coat will presumably prolong the lifetime considerably.

Experience with the application of lean mixtures in the Netherlands for temporary and other constructions has thus far revealed that this material will stand up quite well for at least 5 to 15 years. Part of this experience has been laid down in a report published in 1961 in the Netherlands by an official study committee (6).

SAND MASTIC MIXTURES (Type 2)

A. General

Because in sand mastic the voids of the sand-filler mixtures are overfilled with bitumen, they will behave or almost behave like liquids with a very high viscosity when static loads are applied. In this case the term stability must be replaced by viscosity.

At normal temperatures a high or very high viscosity is of course a necessary requirement, if flow is to remain within acceptable limits. How high viscosity should be depends upon the actual conditions, such as temperature, angle of slope and thickness of the layer or dimensions of the gaps between the stones to be grouted.

When applied in large quantities, the mixtures must be pourable, so that they can be easily handled and placed. This pourability depends upon the actual viscosity at working temperature, which in practice must have a value between $10^2$-$10^4$ poises. The optimum viscosity depends upon required depth of penetration, etc.

For a certain type of application it will be possible to calculate or at least estimate the required viscosities at working and at normal temperatures in advance and to base the design of the mixture on this.

For this purpose several series of experiments were carried out, the results of which are recorded in this Section.

B. The Measurement of the Viscosity of Sand Mastic Mixtures

The viscosities of sand mastic mixtures are relatively high, even at working temperature. Besides, these mixtures contain relatively coarse mineral so that normal standard laboratory instruments cannot be used.

For the determination of the viscosity at high temperature, corresponding to the working temperature, a very simple instrument was designed. This instrument (Figure 2) consists of a 4-litre container, with a 8 cm. long tube of 4.8 cm. diameter attached to the bottom.

To measure viscosity, the container is filled up to the rim with the sand mastic mixture to be tested, the lower end of the tube being closed
Fig. 2. Viscosity Meter for Sand-Mastic Asphalt.

e.g., by a cork. The stopper is then removed and the time necessary for filling a one-litre vessel, placed underneath is measured.

As the flow through the tube is laminar, there is a simple linear relation between the product of time of outflow and specific gravity on the one hand and viscosity on the other. The relation can be calculated and checked if required by experiments with liquids of known viscosity.

For the instrument as shown in Figure 2 the relation is:

\[ \eta = 43.5 \times 10^{-3} \rho gt \]  \[1\]

where:

- \( \eta \) = viscosity in poise,
- \( \rho \) = specific gravity in g./cm.\\(^3\),
- \( g \) = acceleration of gravity in cm./sec.\\(^2\),
- \( t \) = outflow time of one litre of material, in seconds.

For \( g = 10^g \) we have: \( \eta = 43.5 \rho t \)  \[1a\]
The easiest way to carry out viscosity measurements on sand mast-tics at low temperatures is to measure the flow at the top of rectangu-
lar specimens of the material, which are placed at a certain angle of 
slope in a constant-temperature room. The relation between viscosity 
on the one hand and flow and time of flow on the other depends on thick-
ness of the specimen and angle of slope, and can be calculated to be as 
follows:

$$\eta = \frac{\rho g \sin \alpha h^2 \cdot t}{2s} \tag{2}$$

where

$\alpha$ = angle of slope

$h$ = thickness in cm.

$t$ = time of flow in seconds

$s$ = flow at the surface of the specimen in cm.

C. Relation between Composition and Viscosity

The viscosities at high (working) temperature and low (normal) 
temperature were measured of a rather large number (ca. 100) of 
specimens, consisting of four different sands mixed with different 
amounts of filler and bitumen. Particulars of the materials are given 
in Table II.

<table>
<thead>
<tr>
<th>Table II. Materials Used for the Sand Mastic Investigation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Bitumen</strong></td>
</tr>
<tr>
<td>&quot;Mexphalte&quot; grade 50/60</td>
</tr>
<tr>
<td>Penetration (25°C.) 54</td>
</tr>
<tr>
<td>Temp. Ring and Ball 53°C.</td>
</tr>
<tr>
<td>Penetration index -0.3</td>
</tr>
<tr>
<td><strong>B. Sands</strong></td>
</tr>
<tr>
<td>Spec. gravity</td>
</tr>
<tr>
<td>Dune Sand</td>
</tr>
<tr>
<td>2.66</td>
</tr>
<tr>
<td>River Sand</td>
</tr>
<tr>
<td>2.665</td>
</tr>
<tr>
<td>Crushed Limestone Sand</td>
</tr>
<tr>
<td>2.71</td>
</tr>
<tr>
<td>Passing sieve 3/8&quot; ASTM</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>40</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>60</td>
</tr>
<tr>
<td>80</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>200</td>
</tr>
<tr>
<td><strong>C. Filler</strong></td>
</tr>
<tr>
<td>&quot;Duras 15&quot; (ground marl)</td>
</tr>
<tr>
<td>Spec. gravity</td>
</tr>
<tr>
<td>2.72</td>
</tr>
<tr>
<td>Passing sieve 100 ASTM</td>
</tr>
<tr>
<td>98</td>
</tr>
<tr>
<td>Passing sieve 200 ASTM</td>
</tr>
<tr>
<td>82</td>
</tr>
</tbody>
</table>
The tests at high temperature were carried out at 140°C. The flow tests at low temperature were performed at 40°C, on 7 cm. thick specimens 20 × 20 cm. in size, placed on a 1:3 slope.

The results of the tests were plotted in a diagram in the same way as Heukelom (7) did for mixtures of bitumen and filler only. Now, however, not the bulk volume of the filler, but the bulk volume of the sand/filler mixture was plotted against the relative viscosity of the mastic, \( \eta_m/\eta_{bit} \), in which \( \eta_m \) and \( \eta_{bit} \) are the viscosities of the mastic and the bitumen, respectively. The basic concept of this way of plotting is given in the publication cited (7).

The bulk volume of the sand/filler mixture, \( V_{sf} \), is calculated from:

\[
V_{sf} = \frac{100}{100 - H_m} \cdot \frac{F + M}{F + M + B} \cdot 100
\]  

where

\( H_m = \% \) voids in the compacted sand/filler mixture;

\( F, M \) and \( B = \) the volumes of resp. the filler, sand and bitumen in the mixture.

The significance of the value \( V_{sf} \) is indicated in Figure 3. \( V_{sf} \) thus represents the "solid phase" in the mixture, i.e. the bulk volume of the compacted sand/filler mixture of which the voids are filled with "fixed" bitumen.

![Diagram of the mixture components](image)

Fig. 3. Significance of \( V_{sf} \)

When the results were plotted as described it appeared that the results of the viscosity measurements at high temperature could, in general, be represented by a single line (Figure 4), which is the same as that used by Heukelom for the filler-bitumen mixtures.

The relative viscosities at low temperature (40°C.) were a factor 3 to 5 higher, the higher factor corresponding to the mixtures with much broken sand material.
Fig. 4. Influence of $V_{sf}$ on Viscosity of Sand-Mastic Mixtures at Working Temperature.

In Figure 5 the trends of the curves are drawn on a larger scale. In this figure is also indicated the influence of the factor F/B, i.e., the ratio by volume of filler and bitumen, on the viscosities at high temperatures. This factor only influences viscosity if it is less than 0.20-0.25. The factor F/B can be associated with the amount of filler in the mixture and it is clear that this amount must have some influence as it determines the fineness of the voids in the bulk volume. As these low F/B ratios are rarely used in practice, it will suffice here to keep in mind that mixtures with low amounts of filler behave somewhat differently.

It is thus clear that the viscosities at high and low temperature of mixtures of sand, filler and bitumen are closely related to each other.
A more easily workable mixture will, in general, show a higher flow at low temperature. The flow characteristics of sand mastic mixtures at normal temperature may therefore only be compared when the viscosities at working temperature are the same.

Fig. 5. Influence of $V_{sf}$ on Viscosity of Sand-Mastic Mixtures at Working and at Low Temperature.

It further appears that the viscosities of sand mastics are, to a first approximation, determined by the bulk volume of the compacted sand/filler mixture. A simple dry compaction test, by which the voids in the mineral aggregate are determined, may thus be used as an evaluation tool.

If the ratio $F/B$ is low, it also has a certain influence. This means, that it is possible to design mixtures with a relatively low viscosity at working temperature and yet a high viscosity at normal temperature. These mixtures will however "stiffen up" much more rapidly than "normal" mixtures during the cooling process, so that a deep
penetration cannot be obtained. This is particularly important when sand mastic has to be applied under water.

D. The Design of Sand Mastic Mixtures for Hydraulic Application

It follows from the foregoing that for the design of sand mastic mixtures the following data are required:

(a) The relation between void content \(H_m\) in the compacted sand/filler mixture and filler content. An example of a material tested in the laboratory is given in Figure 6.

(b) The relation between the viscosity of the bitumen and temperature. Examples are given in Figure 7.

(c) The relation between the parameter \(V_{sf}\), bitumen content \(B'\) in per cent by weight and the void content \(H_m\). This relation can be calculated with the help of formula [3]. Results of such a calculation are given in Figure 8.

With these data and Figure 5 it is for instance possible to design a mixture which has a certain required viscosity at working temperature, while at the same time the viscosity at low temperature can be calculated and from this the flow in a particular case.

Results of such a calculation are given in Table III. This example shows how for mixtures that all have the same viscosity at working temperature \(\eta_m\) at low temperature may be increased, so as to reduce

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**Table III. Comparison of Mixtures Consisting of Sand**
(1 Part Dune Sand, 1 Part Crushed Limestone Sand, See Table II),

**Filler ("Duras 15", See Table II) and Bitumen**

<table>
<thead>
<tr>
<th>Bitumen Grade</th>
<th>80/100</th>
<th>50/60</th>
<th>20/30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required (\eta_m) at working temp. in poise</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Working temp. in (\degree C).</td>
<td>130</td>
<td>150</td>
<td>140</td>
</tr>
<tr>
<td>(\eta_{bit}) at working temp. in poise</td>
<td>5</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>(V_{sf}), % vol.</td>
<td>79</td>
<td>84</td>
<td>79</td>
</tr>
<tr>
<td>(\eta_{bit}) at 40(\degree C). in poise</td>
<td>(6 \times 10^5)</td>
<td>(6 \times 10^4)</td>
<td>(2 \times 10^6)</td>
</tr>
<tr>
<td>(\eta_{bit}) at 40(\degree C). in poise</td>
<td>(1.8 \times 10^7)</td>
<td>(4.5 \times 10^6)</td>
<td>(6 \times 10^7)</td>
</tr>
<tr>
<td>(\eta_m)-relative</td>
<td>1</td>
<td>2.5</td>
<td>3.3</td>
</tr>
<tr>
<td>Composition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bitumen—(\frac{3}{10}) weight</td>
<td>19</td>
<td>16.5</td>
<td>19</td>
</tr>
<tr>
<td>filler—(\frac{3}{10}) weight</td>
<td>16</td>
<td>16.5</td>
<td>16</td>
</tr>
<tr>
<td>sand—(\frac{3}{10}) weight</td>
<td>65</td>
<td>67</td>
<td>65</td>
</tr>
</tbody>
</table>
Fig. 7. Viscosities of Normal Bitumens as a Function of Temperature.

Fig. 8. Bulk Volume of Sand and Filler ($V_{sf}$) as a Function of Voids Content in Sand-Filler Mixture ($H_m$) and of Bitumen Content ($B^1$)
Mean Specific Gravity of Sand and Filler : 2.67
Mean Specific Gravity of Bitumen : 1.
"cold flow," by application of a higher working temperature combined with a lower bitumen content and/or a harder bitumen.

The working temperatures have been chosen such that the viscosity of the bitumen at those temperatures amounts to 5 or 2 poise, corresponding to about 500 or 200 centistokes. These are in general the limits imposed by the mixing requirements.

E. Durability

The sand mastic mixtures are entirely impermeable because any air voids will be in the form of enclosed air pockets. For this reason the durability should be extremely high.

NORMAL DENSE ASPHALTIC CONCRETE MIXTURES (Type 3)

A. Stability

Much practical experience in Europe and elsewhere over a period of 15 years and longer has proved that the stability of normal dense asphaltic concrete with a maximum stone size of ca. one inch and of the type as used for road building is more than sufficient for application on slopes up to 1 (vertical) in 1.7 (horizontal).

Extensive laboratory investigations by Nijboer (3) and others have shown that normally the cohesion $C$ and the angle of internal friction $\phi$ of this material are indeed amply sufficient to provide the required stabilities. The stability of the material itself is thus more than sufficient for application in the hydraulic field, as slopes steeper than 1:1.7 are in general not required.

The stability of the whole construction, however, is another matter, because excessive water pressures underneath a dense asphalt layer lying on a slope can endanger this stability, as was already mentioned. This point must always be carefully considered by the hydraulic engineer, as it often dictates thicknesses that are higher than would be needed just to withstand wave action.

B. Stiffness

"Stiffness" can be considered as an "apparent" Young modulus, of which the value depends upon time of loading and temperature. This term was introduced by van der Poel (1, 2), who also gave the actual relation between this quantity and composition of the mixture, time of loading and temperature.

Data are also available on the breaking strength of asphaltic concrete after a certain number of loadings (8). From these data it is possible to calculate if an asphaltic concrete layer, lying on a soil which possesses a certain elastic modulus, is likely to crack when water waves of a certain height break on its surface. Calculations of this kind, which are complicated, have been published (6). Several
assumptions had to be made to enable the calculations to be carried out, and therefore the publication warns against attaching too much absolute value to its findings. These indicate, however, that relatively thin asphaltic concrete layers, viz. 20 cm. thick on slopes of 1:6 and 40 cm. thick on slopes of 1:3 should be able to withstand without cracking the action of waves with a height of about 4 m., which, at least for the Netherlands, is high. These findings are in agreement with practice, as breaking of an asphaltic layer owing to wave attack has only been noticed in an extreme case, when a 10 cm. thick lean sand asphalt layer, with inferior dynamic mechanical properties on a sand dike was broken up during the heavy gale in 1953. Wave heights were then about 4 m., whereas according to the calculations of the committee only a wave height of much less than 1 m. would be permissible for that particular dike.

As thicknesses of 20 to 40 cm. are in many cases necessary to prevent lifting up by water pressures acting underneath, not much attention need be paid to the possibility of cracking by wave action.

C. Durability

Dense asphaltic concrete has a high durability when the void content is less than 4-6%; hardening and/or stripping of the binder can then only occur at a slow rate if at all. As the mixtures are mostly applied in relatively thick layers, only an outer layer of perhaps 1 cm. thickness might be attacked by water and air, the rest remaining in good condition. The foregoing statements are based on investigations in the laboratory of 5-30 year old specimens.

STONE ASPHALT ("BITUMARIN CONCRETE")

A. General (Stability)

As bigger and higher dikes had to be built, layer thickness increased. Now, thicknesses of 12 to 24 inches and more, are not exceptional any more.

These thick layers, with a material with a relatively small maximum stone size, however, have certain disadvantages.

It is almost impossible to place a single thick layer of such a material on a slope, because it lacks stability when still hot, owing to the higher cohesion required for thick layers. Besides, it cools very slowly because the decrease in temperature is in inverse proportion to the square of the thickness.

Application in a number of successive thinner layers would be possible, but this would add to the cost. As, moreover, thick or very thick layers are already costly in themselves, it becomes worthwhile to look for different asphaltic mixtures or other methods. A possible solution would be the use of a much larger maximum stone size in the mixture. This would have the natural consequence that the stone content could be
increased without a corresponding increase in voids content, which should remain low. Two direct advantages are thus obtained:

1. The cohesion and in consequence the stability would be significantly increased—also in the hot state—because, as is well known, an increase in quantity of stone and stone size always has this effect;

2. On account of the much wider gradation of the mineral aggregate, the voids content in the aggregate decreases, so that less bitumen is required. This will keep the cost down. It is true that more stone is required, but normally it will be of a cheaper variety.

As this idea seemed sound, Bitumarin N.V., who initiated it, went on to develop installations for the preparation of asphaltic mixtures with a maximum stone size of 20 inches or more, about twenty times the linear size normally used for road building.

This large-stone-size mixture is called "Bitumarin concrete" or "Stone-asphalt" and is now being used for protecting the new breakwaters which are under construction in IJmuiden.

B. Stiffness

As only very thick layers of stone asphalt will be applied no attention at all need be paid to the possibility of cracking by wave action. (See section on Normal Dense Asphaltic Concrete Mixtures (Type 3), B. Stiffness.) Stiffness and also breaking strength are therefore secondary factors in designing stone asphalt revetments.

For practical reasons stiffness and breaking strength of stone asphalt cannot be determined in the laboratory. It may, however, safely be assumed that these physical properties will be about the same as those of normal asphaltic concrete with a comparable composition.

C. Durability

By using not too high a total stone content, stone asphalt mixtures can be designed with a sufficiently low voids content to guarantee a high durability. If the surface of the layer is considered too open it can easily be sealed by a sand mastic mixture as described in a previous section. When these mastic mixtures have the required viscosity they penetrate easily between the large stones and thus provide the layer with a impermeable surface of high quality.
RECENT DEVELOPMENTS IN ASPHALT TECHNIQUES

A. Lean Sand Asphalt

General

The normal procedure to close a closure gap in a dam with the help of caissons is as follows:

1. The bottom of the gap is protected against scour, e.g., with the classic fascine mattresses;
2. A sill consisting of stone materials is built on this bottom protection;
3. The top and the slopes of the sill are protected by a layer of heavy stones;
4. The gap is closed provisionally with caissons;
5. The permanent dam is built up with sand and provided with a revetment.

In 1961 it was decided to replace as much as possible the stone material used hitherto in this procedure by asphaltic mixtures. To this end a construction was designed, of which the cross section is shown in Figure 9.

As can be seen on this drawing, the usual bottom protection with fascine mattresses is replaced by a layer of sand mastic. The asphalt technique to be used here will be described in Section B of this Section.

The outside parts of the sill now consist entirely of lean sand asphalt. The inside part is filled with gravel. The top of the sill is first covered with a layer of stones of 10-80 kg. (size 15-30 cm.), which are later grouted with sand mastic, applied in exactly the same way as the sand mastic for the bottom protection.

Fig. 9. Cross Section in Closure Gap of Grevelingen Dam.
(from Data Supplied by Rijkswaterstaat).
Ultimately, after placing of the caissons, the sand core is built up and finished with an asphaltic concrete layer.

This entirely new type of construction was applied in the middle of the southern closure gap of the Grevelingen dam over a length of about 120 m. The total length of the gap amounted to about 400 m.

**Building Up the Lean Sand Asphalt Sill**

The techniques used were in principle very simple. The lean sand asphalt was mixed in normal continuous Barber-Greene mixing plants. From these plants the asphalt mixture, which consisted of local fine sand and 3% bitumen grade 280/320, was transported by conveyor belts to bottom-door hopper barges. Each barge could carry about 200 metric tons of mixture.

Tugboats brought the barges to the exact place where the material had to be dumped. First two barge loads were dumped next to each other. Then the third load was discharged on top of these (Figure 10).

![Diagram](image)

**Fig. 10. Dumping of Lean Sand Asphalt with Bottom-Door Hopper Barges at Grevelingen Dam.**

This technique presented no difficulties and operations went smoothly. The only provision to be made was the following. When the lean sand asphalt material is dumped through 10 m. depth of water, it will hit the bottom at a rather high speed. As a consequence it will flatten out like a pancake if no special precautions are taken. These consisted in laying a strip of chicken-coop wire netting in every compartment of the barges before filling. After filling, the ends of the strips, sticking out above the compartment were connected to each other.

The technique described here was designed and developed by the firm of contractors Bitumarin N.V. at Zaltbommel (the Netherlands), in close cooperation with the Delta Service of Rijkswaterstaat (Netherlands Ministry of Works).
B. Sand Mastic

General

For the execution of the Delta project it is necessary to protect large areas of the sandy bottom in the channels and of the stone sills in the closure gaps of the dams against current scour. For this purpose a new method (9) has been developed for applying hot sand mastic continuously under water in 5 m. wide strips. In this way it is possible to protect the sandy bottoms direct or to grout layers of rubble uniformly. The grouting has the advantage that less and smaller stones can be applied to achieve the same result.

Description of the Method

(1) General Requirements

The sandy bottoms to be protected by mastic layers and the stone sills to be grouted were at depth up to 20 or 30 m., the maximum bottom slopes being 1 in 5 or 1 in 10. In the estuaries water velocities of 1 m/s or more and wave heights of at least 0.5 m. must be reckoned with.

The mastic mix must on the one hand have a low enough viscosity \((5 \times 10^2 - 5 \times 10^3\) poise) to permit gravity flow through a pipe at about \(120^\circ\text{C.}\); higher temperatures would cause steam to form under water. On the other hand the viscosity after cooling to water temperature must be high enough to prevent excessive flow of the mix or exposure and consequent scour of stone.

Laboratory tests as described earlier and practical tests have proved the possibility of designing mixtures that meet these requirements.

(2) Apparatus

The apparatus is essentially simple (Figure 11). The mix is supplied through pipe A; in B it is distributed over a width of 5 m., which has proved a practical size; at C it issues in jets through eight pipes. With proper dimensions and number of these pipes, on a flat bottom the jets will unite to form a layer of uniform thickness or will grout a stone layer evenly.

By making the orifice pipes narrow the viscous resistance is concentrated in the pipes. This serves the double purpose of producing uniform flow and keeping the water out, thus preventing steam formation inside. With a view to the latter eventuality the pressure in D must be higher than outside at the same level. This is achieved by keeping the level of the mix above the equilibrium level. The equilibrium level is about half-way up the apparatus because the specific gravity of the mix is nearly 2. The orifices can be closed with a valve.

(3) Auxiliary Equipment and Operation

The apparatus (weight when filled 70 tons) is fastened vertically to a ship carrying an asphalt mixing plant (Figure 12). It can be moved
Fig. 11. Sketch and Pressure Diagram of Apparatus.

up and down by means of steel cables and a powerful winch, so that any depth between 2 and 20 metres can be reached. A feeler, operating a hydraulic lifting mechanism, ensures that the nozzle is always at the same distance from the bottom.

A mastic kettle (serving as a bunker) between mixer and apparatus ensures a continuous supply.

In actual operation the bunker is first filled to capacity. Then the apparatus, being still entirely above water, is filled through the lowest charging opening, while the valve at the bottom is shut. The apparatus is then lowered to the bottom after the lower charging openings have been shut. The bottom valve is opened and the ship moved in the direction required, mastic being supplied through a suitably situated higher opening (see Figure 12). The chute from bunker to charging opening can move so as to permit filling through the same opening over a certain vertical range (5 m.).

The theoretical capacity of the apparatus ranges from 30 to 240 tons/h. The actual capacity depends upon the capacity of the mixer placed on the ship. In cases where relatively small areas have to be protected a simple pipe with a constriction at the end without a distributor and a mixer with a capacity of 10-30 ton/h will suffice.

(4) Development and Applicability

The under-water method described in the foregoing has now been fully developed and can effectively be used to apply the proper amount of mastic in the right place, even under difficult conditions.

With the big distributor (Figures 13 and 14) large bottom areas can be rapidly covered with a mastic layer. With a mixer capacity of 200
tons/h, 1000 m.$^2$ can be laid per hour. The manufacture and deposition can be entirely mechanised and rendered fully automatic, so that only 20 men are needed to carry out all operations on board the working ship.

With a simple pipe the maximum capacity will only be about 30 tons/h. This has the disadvantage that only narrow strips can be laid, and there will be many seams. The simple pipe is, however, attractive for small-scale work, while it can also be used for grouting rubble layers on slopes under water.

(5) Works Already Completed

The works described here, were necessary to protect the sandy bottoms or the stone sills in three closure gaps of the Delta project. The first two of the gaps to be mentioned have already been closed definitely. The third gap is to be closed at the end of 1964.

Fig. 12. Principle of Apparatus.
Closure Gap in Secondary Dam in the Zandkreek

The crest of the stone sill in this closure gap has been grouted with 300 kg./m.² sand mastic. The water depth varied between 3 and 7 m. owing to tidal effects.

This work was carried out in 1960 with a somewhat simpler apparatus than described here, but similar in principle. The capacity of the mixer on board of the working ship was only 30-40 ton/h.

The next two works were executed with the new apparatus, but still with a mixer of 30-40 ton/h only.

Southern Closure Gap in Secondary Dam in the Grevelingen (1961 and 1962)

This is the gap already mentioned earlier. Over an area of about 25000 m.², a mastic carpet (200 kg./m.²) was laid on a sandy bottom. The water depth varied between 7-13 m. (Figures 9 and 10). Work could proceed even under difficult conditions, such as wind force 6-7, heavy rain, current velocities of 1.5 m/s and more, and wave heights of 0.5 m and more.

The crest of the sill which consisted of a rubble layer of 10/60 kg. stone, was grouted with 400 kg./m.² mastic. Area about 7,500 m.².

Northern Closure Gap in Secondary Dam in the Grevelingen (1962)

A mastic carpet (200 kg./m.²) was laid over an area of about 50,000 m.². The depth varied between 3-5 m.

A new ship (Figure 15) has now been designed, on board of which two continuous mixing plants can be installed with a total mixing
capacity of 200 ton/h or more. This will enable the full capacity of the distributor to be utilized.

All these works, which were completed successfully, were carried out in close cooperation between the Dutch authorities involved ("Rijkswaterstaat"), the contractor Bitumin N.V. and companies of the Royal Dutch/Shell Group.

Fig. 14. Distributor of Apparatus. The Two Sliding Valves, Which Are Operated Hydraulically and Can Shut the Eight Outflow Openings, Are Clearly Visible.

C. Normal Dense Asphaltic Concrete

The application of normal dense asphaltic concrete for hydraulic engineering has gone through the same evolution as in road building. Bigger and modernized mixing plants are used but no special new techniques have been developed. Therefore this application will not further be considered in this publication.
D. Stone Asphalt ("Bitumarin Concrete")

General

New breakwaters had to be built at IJmuiden, the entrance of the port of Amsterdam, to provide this entrance with a better protection against waves, currents and silting up and thus enable much larger ships to enter.

To this end the old southern and northern breakwaters will be extended into deeper water with 2100 and 1200 m., respectively (Figure 16); the southern breakwater will then project 3 km. into the sea. It is
clear that moles extending so far will have to be heavily protected to withstand wave attack.

Construction of the Breakwaters

Rijkswaterstaat decided to construct stone dams, consisting of a core of heavy stone blocks weighing 300-1000 kg. apiece and to protect this core with revetments of 2.25 metre (about 7 feet) thick stone asphalt (Figure 17). The toe of the revetments is protected by a layer of very heavy stones weighing 1000-6000 kg. apiece.

![Diagram of Breakwaters](image)

**Fig. 17. Cross Section of New Breakwaters Under Construction at IJmuiden (from Data Supplied by Rijkswaterstaat).**

The crowns of the breakwaters will be formed by reinforced-concrete elements. These concrete elements rest on and are embedded in a foundation of smaller-sized stones, weighing 80-200 kg. apiece or less. These stones are grouted from the outside with a sand mastic. The crown elements consist of two vertical slabs (2 × 2 m. square), forming the vertical walls on top, and connected by a heavy beam. The room within these elements is also filled with stone, which is later grouted with cement-concrete and covered with an asphaltic concrete layer.

The stones for the core of the breakwaters are dumped by bottom-door hopper barges of 700 ton capacity. The stone-asphalt, the crown elements, and other materials for the top-construction are transported over the crown of the finished part of the breakwater.

To enable the final building up of the dams two lift-pontoon are used on which cranes are placed, which can move on the pontoons over a distance of 60 m. The cranes and pontoons have been specially constructed for the building of the harbour heads. The cranes can lift loads of 25 ton at radius of 56 m. (ca. 170 feet).

One crane is used for building up the core, the other for placing the stone asphalt and other materials for the top construction. Figure 18 is a sketch of the building principle.
Mixing of the Stone Asphalt

As large-sized stone had to be used, it was necessary to design and build an entirely new type of mixing plant.

This plant can be split up in four main parts:
(1) a normal continuous plant which produces the specially designed asphaltic concrete;
(2) a large oven to dry and heat the largest stones (6-20 inch size);
(3) a rotating drum to dry and heat the smaller stones (2-10 inch size);
(4) a large rotating drum which continuously mixes the materials produced by the parts of the installation mentioned under 1, 2 and 3.

Figure 19 is a sketch of such a plant for producing stone asphalt.

All operations are automatically controlled. Two small plants and two large ones were built, the smaller ones to carry out experimental work. The large plants can each produce 150-300 ton/h of stone asphalt, depending on the composition. Figure 20 is a photograph of the large plants. In total about 750,000 ton at least will have to be produced. In the present stage of development of production and application the exact compositions of the stone asphalt cannot yet be given. Roughly the types
Fig. 19. Sketch of Mixing Plant for Stone Asphalt (Bitumarin N.V., Zalt Bommel).

Fig. 20. Aerial View of the Two Stone Asphalt Mixing Plants.
used consist of 20–40% of an asphaltic concrete mixture with a maximum stone size of about 2 inches and 80–60% stones, 2-20 inches in size. The temperature of the total mix can vary between 70–120°C, depending on the type of application.

As indicated in Figure 17, the stone asphalt is placed in two stages, a submerged part and a part above the water. It is clear that the submerged stone asphalt could, and had, to be produced with a lower stability, and thus a lower stone content, on account of the cooling effect of the water. This lower stability is permissible, because temperatures under water will never be higher than about 18°C, as against 40°C for the parts exposed to direct sunshine.

Transport and Placing of the Stone Asphalt

The stone asphalt material is dumped from the large mixing drum, via a silo, in especially designed electrically driven vehicles of 20-ton capacity (Figure 21).

These transport the stone asphalt to the end of the already finished part of the dam and tip their contents into buckets (Figure 22). The cranes, with the help of a lift system carry the buckets to the exact required place, where the contents are discharged under (Figure 23) or above water, depending on circumstances. These buckets which are of a special type, can turn 180° around a horizontal axis. This ensures a rapid and complete discharge.
Fig. 22. Loading Bucket of Crane From 20-Ton Dumper.

Fig. 23. End of Breakwater Under Construction. Filled Bucket of Crane Going Under Water.
Figures 24 and 25 show the crane-lift pontoons in action as seen from the air.

Thus far (December 1964) about 600 metres of the southern breakwater have been finished and it has lately withstood a long (48 hours) and rather severe gale without any damage worth mentioning. Even the vulnerable end of the breakwater where construction is in progress, remained intact.

The stone asphalt technique described here was designed and developed by Bitumarin N.V., in close cooperation with Rijkswaterstaat.

Fig. 24. Aerial View of the Two Crane Lift Pontoons in Action.

CONCLUSION

Summing up, it can be stated that the characteristic properties of asphaltic mixtures for various construction elements in large hydraulic works, have led to the development of new construction and asphalt techniques to apply these materials in large quantities and at a high rate.

ACKNOWLEDGMENTS

After the first success with the application of sand mastic under water in 1960, industrial circles responded by founding an independent
company for the development and application of bituminous constructions under water, which was called Bitumarin N.V. established at Zaltbommel, and in which N.V. J. Heijmans, Rosmalen and Koninklijke Maatschappij Wegenbouw, Utrecht, participate.

It was this company that initiated the application of stone asphalt ("Bitumarin concrete") and was charged by "Rijkswaterstaat" (Netherlands Ministry of Works) to carry out all the asphalt works described in this publication. Only the close cooperation between authorities and contractor made it possible to accomplish these new developments for the application of asphaltic materials in hydraulic engineering.

The writer is especially indebted to Mr. P. G. Meyer of Bitumarin N.V., without whose considerable help and cooperation this paper would not have been possible.

LITERATURE CITED


**Discussion**

CHAIRMAN FINN: Thank you very much, Mr. Kerkhoven. We'll open the floor to informal discussions.

MR. W. DIXON SMITH: I would like first to make a comment. To say that I am pleased with the presentation of this paper would probably be the understatement of the year. This will add tremendously to our understanding of the techniques of uses of asphalt in hydraulic work. We have used some of these techniques to some extent, the sand mastic only to a small extent. Perhaps some of you don't know that we have had a large scale use of sand asphalt as a revetment material on the lower Mississippi River, for top bank revetment, that is, above the water line.

I am impressed with the tremendous amount of experimentation and work depicted in the slides. Mr. Kerkhoven, you did mention the cooperative nature. I was wondering if you would enlarge upon how this work was accomplished as between the contractor, Bitumarin, and the Ministry of Works, and also perhaps Shell Group Laboratories’ role in the works.

MR. KERKHOVEN: Shell came in particularly with the sand mastic application under water and only partially in the stone asphalt. This was mainly developed between the authorities and the contractor. We had only a minor part in that.

I should again stress these things are only possible in close cooperation between authorities and contractors. As the first step you must get the authorities interested if the contractor has the solution. Mr. Meyer can explain this better, but I will give you a general picture. Next some tests are carried out by the government. If these tests are successful you go on to the next step which is bigger. There have been
seven steps before the final arrangement was made between the Government and Bitumarin.

MR. SMITH: If I may, I'd like to ask one more question. I could ask questions probably the rest of the day, but I won't.

I'm impressed again with the special equipment you pictured. You mentioned that they were special. Were the asphalt plants themselves regular plants or was it all special equipment?

MR. KERKHOVEN: Everything is specially designed except normal continuous Barber-Greene mixing plants which are used there. Everything else is newly designed—the dumpers, the drying kiln, and so on.

MR. ROLAND VOKAC: I am very much impressed with those 2-meter thick "thin layers" of material. You perhaps do describe it in your paper, but I wonder if you could enlighten me on one question. You mentioned that you used a regular asphalt plant to make the asphaltic concrete and apparently from your flow chart you charge the mixer simultaneously with the pre-heated massive rock, the big stone, and the asphalt itself. They are charged simultaneously, I take it, into this revolving drum. I am curious if there are any special features that you could tell us about that mixing apparatus for handling these "little" 20-inch size aggregates.

MR. KERKHOVEN: I can give you, of course, no details. This was developed by the contractor—the size, the length and diameter of the rotating drum, number of revolutions, internal strips you have to place, and so on. I can't give you any details about that. That is still the property of the contractor.

MR. V. P. PUZINAUSKAS: About three years ago, during American Chemical Society Meeting, Dr. Saal of Royal Dutch Shell Laboratory, described the same apparatus and also placement of asphalt mixtures under water with this apparatus. At that time, he indicated that the information on the performance of such mixtures was limited. Could you tell us more about such performance?

MR. KERKHOVEN: They have performed very well. There has been one closure gap, an area where the sand mastic has been used, of about 50,000 square meters, and this closure gap took much longer, on account of experimental work, to close than was normally expected. And the water currents were much higher also than were expected. We expected not more than 2 1/2 meters a second and they went up to 4 meters a second, which was quite a lot. It took three or four months for experimental reasons, and, nevertheless, they stood up quite well.

MR. SMITH: I'll ask one more. In this sand mastic placement with the experimental tube how deep a penetration did you seek in a rock grout when you were using it for that purpose—into the rock down on the bottom of the water?
MR. KERKHOVEN: In this case the whole lot coming from the bottom door of the hopper barge was going in one bunch directly to the seawater at a depth of about 10 meters.

MR. SMITH: I don't mean the depth of the water. I mean how much penetration did you get into a rock layer?

MR. KERKHOVEN: With the sand mastic?

MR. SMITH: Yes.

MR. KERKHOVEN: The penetration depth depends upon the size of the stone, and is proportional to about the third power or the fourth power of the stone size. If the stones are 2"-3" size you cannot penetrate them. If you take these very large stones, you can penetrate 7'-8' or more.

MR. SMITH: This more or less checks our experience.