Chapter 39

BITUMEN IN COASTAL ENGINEERING

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INTRODUCTION.

Artificial coast protection is required where coasts are subjected to erosion. Where the country is low it will be necessary to build sea-walls where natural protection by dunes is not adequate or is completely lacking. In both cases it may also be necessary to protect the country from further advance of the sea by the construction of groynes and breakwaters where lateral currents cause displacement of granular shore material.

From the study of the history of coast lines and the development of their protection it is apparent that apart from the necessity of construction the governing factors of the constructions are safety and economy, or as the British "Departmental Committee on Coastal Flooding" states in its Terms of Reference, it has "to consider what margin of safety for sea defences would be reasonable and practicable having regard on the one hand to the estimated risks involved and on the other to the cost of protective measures". New methods of approach and execution of technical problems such as improved methods of observations and measurements, the use of laboratory experiments, availability of modern equipment and new materials open a wide scope for more economic construction. On the other hand, however, development in this field has been comparatively slow because the consequences of failures oblige the responsible engineer only to alter the traditional design step by step in accordance with progress made in the scientific analysis of the destructive forces of waves and of the properties of the new building materials.

The need for investigation is sometimes accentuated by a disaster such as was recently caused by the storm surge of January/February 1953 when on the East Coast of England the observed height of the water-level reached a record of 6 ft. or more than the predicted height according to the astronomical conditions for a continuous period of 15 hours as against 5 hours for former surges. In Holland a water level of 75 cm. above the highest ever recorded level was reached on some sea-walls, causing overtopping of waves. Reports by the "Delta Commissie" in Holland and the "Waverley Committee" in England as well as Papers read on the North Sea Floods for The Institution of Civil Engineers, London, and the Koninklijk Instituut van Ingenieurs, The Hague, deal with the subject adequately.

In dealing with coast defence schemes it should be borne in mind that for low lying countries designs should not only be limited to artificial works for direct protection of beaches, sea walls and dunes. Consideration should also be given to works for reducing areas liable to flooding by overtopping of or breaches in sea-walls or by damage to dunes. In such instances a "second line defence" can be usefully suggested with cross banks to divide the areas in bays or compartments. If these cross banks carry access roads, connecting the inland centres with the sea defence works, they will certainly facilitate communications before and during storms and operations for restoring conditions after storms.

In all these works bitumen can be applied to advantage for the protection of beaches, sea walls, dunes and banks as well as for road construction and maintenance works.

The use of bitumen in coastal engineering is, of course, also based on practice and theory gained from other civil engineering fields, such as road construction and the building industry. The properties of bitumen and bituminous compounds have first been gradually developed to their present standards in these fields and this knowledge has facilitated the scientific and practical approach of the application of bitumen in sea defence works.

In this paper the problem is only described from a practical point of view. After dealing with various aspects of the design of coastal works pertaining to the use of bitumen, a short review is given of the most important types, methods of application and properties of bituminous constructions and finally a number of representative examples of each of the types of application is given.

GENERAL CONSIDERATIONS IN DESIGN

SEA-WALLS

It is a known fact that, generally speaking, it is not economically feasible to build sea-walls so high that they will never be overtopped by waves. On the other hand experts on various subjects relative to the problem agree also that there are no known reasons why combinations of surge and tide, more adverse than any hitherto recorded, should not occur in future. During the North Sea Floods, 1953, "stabs in the back" of sea-walls by overtopping or seepage water have caused most of the incidents and the main lesson of the floods is perhaps that the back of any sea defence work needs to be considered just as carefully as the front.

The statements of experts thus emphasize the value of capping a sea-wall of reasonable height by a protective revetment on front and back slopes and over the crest rather than trying to design a sea-wall of sufficient height protected only on the front slope to prevent overtopping by the waves of the highest possible storm surge.

The construction of clay sea-walls is not only a problem of hydraulics but also of soil mechanics as investigations of failures in sea defence banks have confirmed. Much more attention will have to be paid in future to preventing percolation of water, avoiding cracks and planes of weakness and to stabilising clay banks. Above low water level the composition of the clay is an important factor and modern methods of soil mechanics should be applied for design and construction. Stabilised soil or clay containing sand or fine granular materials are preferably used to limit potential shrinkage of the body and surface of the banks in order to avoid detrimental formation of cracks. The bank should be built up in layers and consolidated to sufficient density at optimum moisture content. It is desirable to take precautions to maintain this moisture content within reasonable limits and here again the use of an impervious layer or revetment seems to be practical. The effect of sealing the surface with an asphalt layer needs to be studied and this will call for both field and laboratory work.

A modern method of rapid and cheap construction of sea-walls consists of forming a body of sand by the hydraulic fill method which is covered with a protective asphalt revetment. This type of work is also dealt with in the following pages.

Profile of Sea-Walls

The profile of a sea-wall determines its stability and to a certain extent the required strength of the protective revetment especially on the slope exposed to the sea.

The principal aim of the design of the exposed slope is to reduce the effect of the wave attack and uprush. As the protective facing is a costly part of a sea-wall it should be endeavoured to reduce its extent and thickness without, of course, endangering the embankment.

For convenience of description the exposed slope of a sea-wall can be divided into four regions. (figure 1.) Firstly; under mean low water level, below A, lies the zone of erosive effect of along-shore currents and oscillating currents of the waves. Secondly: between mean low water and mean high water levels perpetual but moderate wave attack can be expected which subjects a revetment especially to erosion. Thirdly: between mean high water and storm tide levels the region of extreme wave attack during storms is to be found, which subjects the facing especially to impact and uplifting forces. Fourthly: above storm flood level the revetment is only subjected to the effect of uprushing waves during storms. Above the uprushing waves over the crest and down the back slope a light revetment is provided, which will, however, have to be able to resist the effect of overtopping water during a period of 24 hours of unexpected storm surge.

The height of the uprushing waves during storms is important to determine the position of the top edge of the seaward facing. This height of the uprush Z of the critical wave is dependant on the height H of this incoming wave measured from crest to trough and on the angle a of the seaward slope with the horizontal in the following way:

$$Z = 2.7\left(\cos i - \frac{B}{L}\right) H \left(\frac{\pi}{2a}\right)^{\frac{1}{2}} \sin a.$$

in which i is the angle of incidence of the wave, B the width of a possible berm of the sea-wall and L the length of the incoming wave.

This formula indicates the uprush attained by approximately 2% of the waves. It is deduced from observations on slopes of models and of existing sea-walls varying between 1 in 3 and 1 in 8 and is applicable for open neatly set stone revetments. The uprush of waves on smooth and impervious facings is increased by nearly 15%. Although reduction of uprush of 20% can be achieved by constructing large obstacles on the slope, longer smooth revetments are less costly especially if it is possible to form a rough surface in the higher stretches where the layer of water is thin. If it is necessary to build a vertical wall to limit the uprush it should be built on the top third part of the uprush to avoid destructive sprays of water. From the formula it can be observed that the construction of a berm at or just above storm tide level can be very effective but above a width of berm equal to $\frac{1}{4}$ wave length the effect does not increase at the same rate.

A very effective means of reducing the uprush is to build a berm in the form of a shallow trench as indicated in figure 12. During a storm water accumulates in the trench and forms a cushion which increases frictional resistance considerably. Asphalt constructions are particularly suitable for building such a profile.

Protective revetments on sea-walls

Having determined the extent of the seaward heavy protective revetment it remains to determine the method of protection with bitumen of each of the four regions mentioned above. Below low water level the classic construction consists of laying fascine mattresses loaded with stones, the quantity and size of which depend on the exposure of the coast. Several methods of laying asphalt mattresses have been devised and applied on a smaller or larger scale without difficulty. Their behaviour in situ has, however, not been satisfactory everywhere for reasons which require further investigation. It is, however, evident that asphalt mats and fascine mattresses differ in performance from a hydraulic point of view. Asphalt mats have a smooth surface, are impervious and more flexible besides being

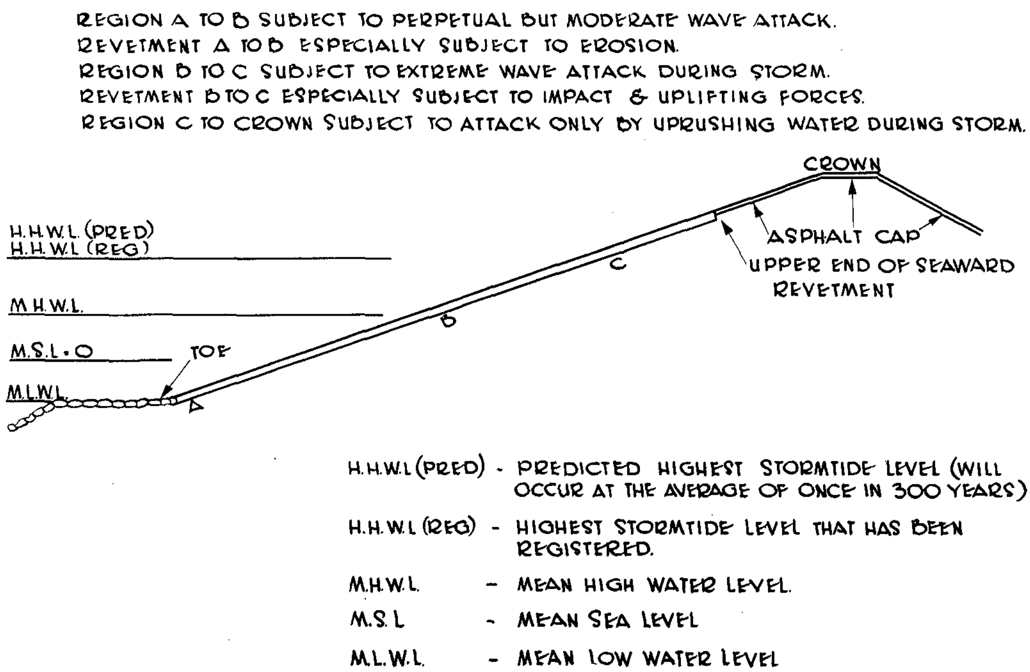

Fig. 1. Diagram of a sea wall.

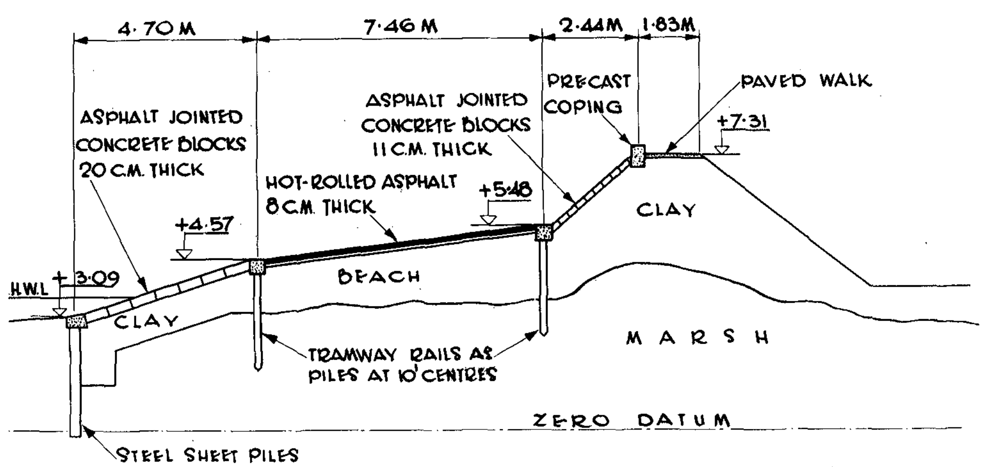

Fig. 2. Pett sea wall.

resistant to marine borers. Particular care should be taken to determine the expected dynamic effect of waves when applying asphalt mats.

The next point to consider, and a vital one, is the toe of the revetment where it meets the underwater mattress. This point is exposed to the backwash of receding waves. A short sheet piling and a berm of some width just above low water level protected by an asphalt grouted stone layer forms a practical protection of this vulnerable point.

The two regions between A and C in figure 1 are difficult to separate in nature. The revetments in these regions between mean low tide and storm flood level should therefore both be built to resist erosion by perpetual but comparatively moderate wave attack and at the same time to resist impact and uplifting forces of the strongest wave attack expected on that particular stretch of coast. The size of these forces has not been determined accurately but the waves cause a severe impact on the revetment when breaking and the water penetrates in all voids and cracks of any type of stone revetment. When the wave recedes the water under the stones cannot follow at the same rate and consequently creates a hydrostatic pressure which can lift one or more stones of the facing. Generally friction will prevent the stone or stones from falling back into its or their original position and after repeated upwards impulses waves will get direct hold on the stone or stones which will be washed away thus causing the commencement of further destruction. This process occurs because the stone facing is usually placed on a levelling layer of brick debris or coarse gravel which in its turn covers an impervious layer of clay. The total thickness of the protective facing can vary considerably according to its exposure to storms between approximately 1 m. and 2 m. formed by the impervious clay layer between 50 cm. and 1 m., the levelling layer between 10 cm. and 25 cm. and the stone revetment between 30 cm. and 60 cm.

Where maintenance costs were high and where new revetments were required, it was, therefore, logical that use was made of a bituminous compound to fill the voids by which means the revetment was rendered watertight and strengthened whilst remaining flexible and durable. Where stone was not available at a reasonable price other local materials in the form of concrete blocks and slabs in various dimensions and forms, but generally vibrated to obtain high density and greater resistance to abrasion, were used and here also asphalt joint filling developed gradually. Descriptions of such joint filling and asphalt grouting works are given in the following pages.

Soon after 1945 particular conditions in Holland made it necessary to find a cheaper method of building sea-walls and breakwaters. This led to the development of building the body of sand by the hydraulic fill method and protecting this by a hotmix asphalt revetment, varying from 40 cm. to 10 cm. in total thickness according to the exposure of the location. The asphalt revetment serves both as impervious layer and as protective layer. It is flexible and follows settlements as can occur in sea-walls, it resists abrasion, is indifferent to chemical attack by salt water and resistant to mechanical attack by ice-floes, etc., in one word it is durable. Moreover, a hotmix asphalt revetment is quick to construct and cheap. It is, however, evident that it should only be applied in the right place and in the proper way. In certain conditions it may be possible that hydrostatic pressure can occur in a sea-wall which will cause deformations in an asphalt facing and eventually destroy it as it is essentially a more or less plastic material at normal atmospheric temperatures. Descriptions of such works are given in the following pages.

One other point is worth mentioning concerning the protection of back slopes of sea walls viz. the use of bitumen emulsion to produce a superior quality of grass surface in a short period. Initially the effect of spraying a thin layer of emulsion on grass seed sown in fertile soil results in a higher percentage of germination. The film retains moisture in the surface soil and maintains the temperature of the soil some degrees higher than is normal. This assists root formation. The emulsion film also prevents the loss of seeds by birds and reduces the appearance of annual weeds. Another advantage is that the emulsion coating sheds water when subjected to deluging rains.

The method of application of an emulsion coating consists in first preparing the seed bed as usually, rolling it with a light roller and, in dry weather, soaking it with water. The actual coating is then formed by spreading about 5 m.m. clean sharp sand, then spraying a rapid breaking emulsion with a sprayer at a rate of 0.8 to 1.0 k.g. per sq.m. and sometimes covering it with another layer of sand about 5 m.m. thick. This process produces young grass of a brilliant green colour within a few days. If, however, the grass starts turning brown or yellow, the soil should be aerated with a spiked roller or fork.

SAND DUNES AND GROYNES

Sand dunes present a very different problem. Here there is a competition between two opposing tendencies. In certain storm conditions, the sea tends to remove the sand during the winter whilst during the summer the wind tends to build up the dunes again with beach sand. In designing the means of coast protection it must therefore be realised that a protective facing on the dunes may not be effective as it will not safeguard the beach. If the coastline is to be kept in its original state or if the beach is to be built up gradually, the movement of sand must be controlled and limited by the construction of a range of groynes of a length and height and at intervals so determined as to prevent or reduce the destructive lateral movement of the sand along the coast. The design of such a scheme requires a thorough knowledge of the hydrographic history of the coast and a complete understanding of the hydraulic laws governing the movement of beach material over long and short term periods along that particular part and the adjoining stretches of the coast. This applies also, of course, to a certain extent for sand beaches in front of sea-walls.

In principle groynes serve to fix the position of the low water mark along beaches and where deep channels are found they also serve to fix or cut off these channels. The length of the groynes is therefore more or less determined to reach at least to 4 m. depth of water whilst generally speaking it is practical to space them at distances of twice their length. The groynes are most efficient if they are streamlined to guide the course of sea currents with little disturbance. From the seaward end they are therefore built with a horizontal crest at maximum 75 cms. above low water level till the beach, the slope of which is followed to the foot of the dunes. The base of the groynes should, of course, be sufficiently deep to prevent erosion.

The use of bitumen has proved to be very effective in strengthening the seaward end of groynes by asphalt grouting the blocks of stone dumped under water to protect the end. Asphalt grouted groynes have endured rough seas on the North Sea coast of Holland for more than 15 years without maintenance and this asphalt treatment has become an established method of application. Recently, the use of hotmix asphalt layers and mats for the construction of streamlined groynes is being investigated on a practical scale to determine the possibility of applying locally available beach material and their long term behaviour.

BREAKWATERS

In a more or less similar way bitumen is also used to strengthen rubble mound breakwaters reaching far into the sea to protect the entrance to harbours or rivers. Under water asphalt grouting can also serve to key down stone blocks forming the foundation of vertical wall breakwaters but then it must generally be extended to a greater depth of water. Shortly work of this nature is to be carried out on a large scale at 12 m. depth since preliminary tests have been successful.

BITUMINOUS CONSTRUCTIONS

BITUMEN

Bitumen is a semi-solid product obtained from the distillation of asphaltic base crude oil. Various types of bitumen can be manufactured according to the method of distillation. In coastal engineering only straight run bitumens have been used up to the present time. These are manufactured by distilling off, in the presence of steam, the gasolene, kerosene and other oils of the crude product.

The grade of straight run bitumen is normally specified by its penetration at 25°C. The penetration figure is the figure indicating the depth in tenths of a mm. to which a needle penetrates the bitumen under specified conditions. The range of grades used in coastal engineering is from 10/20 to 180/200 penetration, the lower the figure the harder the bitumen.

Bitumen becomes a viscous liquid on the application of heat and will then coat and adhere to most types of aggregate having clean, dry surfaces. On cooling down to atmospheric temperature it has cohesive binding properties.

Bitumen offers certain advantages in hydraulic engineering because it can be applied in a number of ways. In practice, it is normally used with a mixture of mineral aggregates, such as crushed stone, gravel and sand. Mineral fillers, such as limestone dust, slate dust and asbestos fibres, may also be added so that the mixtures can be varied and their properties adjusted to fit the work for which they are used.

Bitumen is used in the form of an emulsion to assist the growth of grass on back slopes of sea-walls. A bitumen emulsion may be defined as a liquid product in which a substantial amount of bitumen is suspended in a finely divided condition in an aqueous medium by means of one or more suitable emulsifying agents.

METHODS OF USE

There are three established main methods of applying bitumen in coastal engineering: asphalt grouting, asphalt jointing and asphalt surfacing. A fourth method of using bitumen consists in laying prefabricated asphalt mattresses which, however, require further investigation of the conditions of application.

For works carried out above low water level, all three established methods can be used.

For works carried out under low water level, asphalt grouting can be used to fix stone blocks of groynes and breakwaters to prevent displacement. Asphalt mattresses are applied to protect more or less level granular surfaces from erosion by waves or currents.

Asphalt Grouting

For works above water where a hand pitched stone revetment is newly laid or requires maintenance, it can be strengthened by filling the voids between the blocks with an asphalt grout composed of approximately 72% fine sand, 10% filler and 18% bitumen by weight. The consistency of this asphalt mixture can be varied to suit conditions by increasing or reducing the bitumen content to 20%, respectively 15%. The size of the voids, the depth of penetration, the grading of the sand, and the atmospheric temperature all affect the behaviour of the hot asphalt grout. For moderate climates bitumen of 60/70 pen. is generally used but for tropical conditions, the harder bitumen of 30/40 pen. is required.

The asphalt grout is generally mixed in the usual type of hot-mix road plant fitted with a paddle mixer. It is then transported from the mixer in a lorry-mounted container fitted with a mechanical stirrer, similar to a mastic cooker as used for road construction work. If the asphalt grout is mixed at the usual temperature of 180°C. it will arrive at the site at a slightly lower temperature and can then be spread over the surface of the stones and into the voids with squeegees. For this purpose, one end of the steel chute is attached to the outlet of the container, whilst the other is moved over the surface of the stone layer. If the slope is steep, grouting should always be started at the top as otherwise the grout will be wasted by its flowing over finished work that has already cooled and set.

The quantity of grout required for a given surface will, of course, largely depend on the size of the voids. As a guide, however, it can be mentioned that a layer of basalt blocks 60 cms. thick requires about 250 kgs. per sq.m.

If the sides of the stone blocks are dry and can be well cleaned, the quality of the work can be improved by priming the sides with a mixture of 75% bitumen 10/20 and 25% kerosine.

The same method of asphalt grouting can also be adopted to a layer of dumped or roughly pitched stones instead of a layer of neatly set stone blocks. As a matter of fact, the cost of asphalt grouting can be covered by saving in costs on the stone work. The saving by using crushed local stones of smaller size and less angular in form and the saving in labour costs and time by rough laying can be appreciable. The thickness of the layer will depend on the exposure of the coast to waves. A minimum thickness of the layer is 10 cm. with stones of 5 cm. size and this will roughly require 6 kgs. of asphalt grout per sq.m. and per cm. thickness of the layer. A solid, continuous and flexible facing is obtained in this way.

For works under water asphalt grout serves the same purpose of keying down the stone blocks by forming one large flexible mass. Groynes and breakwaters are often formed by dumping large blocks in the sea or their foundations protected in that way. When maintenance costs are high owing to blocks being washed away during storms it may be worth while to consider asphalt grouting. For new structures savings in heavy construction equipment and in cost of material can be achieved by using asphalt grouted blocks of a smaller size.

The composition of an asphalt grout dumped under water as well as its mixing is similar to that used above water. The asphalt grout can be dumped into the water or can flow through a steel chute on surfaces not more than one or two meters below the surface of the water. At greater depths the asphalt grout must be lowered in a clamshell bucket which is opened near the stone surface. Little grout is lost, if any, because the water will cool the surface of the mass of grout thus forming a protective skin whilst the hot core of the grout will penetrate into the voids and find its way like a mass of hot lava from a volcano.

Without a trial it is difficult to estimate the amount of asphalt grout required to fill the voids between stone blocks as it depends on the size of the voids and the depth of penetration of the asphalt mixture but the following figures may serve as a rough guide: about 250 kgs. per sq.m. stone surface for blocks of 100 to 200 kgs., 250 to 800 kgs. per sq.m. for blocks ranging from 200 to 1000 kgs. and 800 to 1000 kgs. per sq.m. for blocks weighing 1 to 3 tons.

In order to avoid uplift by hydrostatic pressure the thickness of the grouted layer should be at least 1 m. to 1.5 m. Asphalt grout will penetrate to a greater depth between large blocks. It is sometimes possible to reduce the volume of voids and consequently the amount of grout required by partly filling the voids with smaller blocks either before grouting or else by throwing stones in the grout as it flows into the voids. The amount of smaller stones should, of course, not be so large as to prevent adequate penetration. For this type of work it is essential to bear in mind that the blocks should have an irregular form and that a certain ratio between the masses of asphalt grout and blocks is required to obtain a good result.

Photo 1. Asphalt grouting. (Copyright L. Spronk, Domburg, Holland).

Photo 2. Asphalt jointing (Photo by courtesy of the Chief Engineer - Essex River Board).

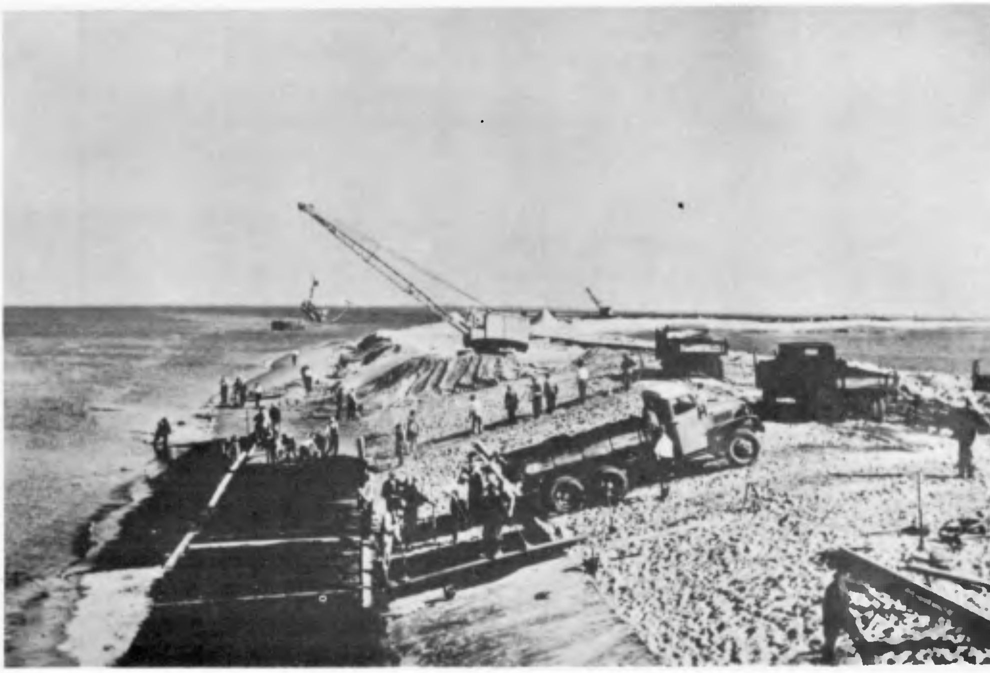

Photo 3. Asphalt surfacing. (Copyright Jac. de Boer, Den Helder, Holland).

Photo 4. Asphalt wall overtopped. (Copyright Van der Pijl, Harlingen, Holland).

Asphalt jointing

For work above water consisting of a slope protected by neatly laid stone pitching or pre-cast concrete blocks or slabs it is obvious that the use of an asphalt compound to fill the joints will give additional strength to the construction. The facing of the slope will retain a certain degree of flexibility and follow settlements gradually so that defects can be observed and, if necessary, repaired before the season of storms begins which otherwise will do great damage. Rigid constructions will cover hollows and cavities on the slopes of banks until they are smashed during a storm when repair is out of the question.

It will depend on the composition of the compound whether it can be poured into the joints or whether it must be troweled. Application by pouring is the quicker method of working. Compositions may vary considerably according to climatic conditions, (temperatures), the size of the joints, the angle of the slope and the method of application. The correct composition of the asphalt compound can, however, be determined in a laboratory by adjusting the following compositions to suit the conditions of any particular work:

Composition	Pourable	Trowelable
Bitumen 40/50	40%	25%
Fine Sand	55%	70%
Asbestos fibres 2-4 mm.	5%	5%

The percentages are given by weight. Instead of short-fibred asbestos, sawdust, waste cotton, slagwool or rice husks can be used to give the compounds stability so that they will not flow on steep slopes.

Before using an asphalt compound for joint filling on a steep slope it should be tested on resistance to flow in a laboratory. There are two methods of testing, the joint flow test and the ball flow test.

The joint flow test consists of placing the asphalt compound in an imitated joint formed by a groove in a slab of concrete placed at an angle corresponding with the slope in actual practice and subjecting it to the maximum temperature expected during a period of several days. The movement of the compound, which is not supported at its foot, is measured by the amount of displacement of white dots marked on the surface of the compound in line with horizontal white lines on the concrete slab at the start of the test. The amount of displacement should be limited and movement should cease within 24 hours.

For the ball flow test, a specified quantity of the asphalt compound is kneaded by hand into spherical shape. It is cooled to below freezing point for 2 hours and then placed for 1 hour on a flat plate in a drying oven at the maximum temperature expected. The ball is then removed and after its shape has been fixed in cold water the ratio between its diameter and its height is determined. As an indication, of the suitability of a compound for filling joints of 3 cms. width on a slope with maximum temperature of 60°C., the ratio between diameter and height of the asphalt ball after the ball flow test should be not more than 1.5 for a 1 in 1 slope, 1.8 for a 1 in 2 slope and 2.0 for a 1 in 3 slope.

In order to improve adhesion of the asphalt jointing compound to the concrete faces of the joint, the latter should be primed with a mixture of 75% bitumen 10/20 and 25% kerosine. If joints are deep it is possible to economise in joint filling material by filling the joints to within 5 to 10 cms. from the top with small stone chippings or pebbles.

Asphalt joint filling compound is generally mixed by hand in an ordinary mastic pot or in the usual type of mastic boiler equipped with paddles. First the bitumen is heated to 180°C., then the asbestos fibres are gradually stirred in and finally the sand, which has previously dried, is added to the mixture. The asphalt compound is poured from buckets provided with spouts at a temperature of at least 160°C. The rate of application varies, of course, according to the volume of the joints to be filled.

Asphalt Surfacing

Asphalt surfacing with hotmix revetments, which serve as protective layers, has been developed to a considerable extent since 1947, especially for use on sea walls in Holland.

A hotmix revetment consists of a mixture of graded mineral aggregates, filler and bitumen, which is laid hot and consolidated by rolling or tamping to form a continuous flexible protective facing varying in thickness from 10 to 40 cms. for work on sea walls. It is recommended to obtain a dense bituminous layer by choosing local mineral aggregates which are sufficiently graded to form a practically impervious compacted mix in which the voids are filled with bitumen. In principle, the maximum size of aggregate should not be more than half the thickness of the finished layer.

Dense hotmix revetments can be of the asphaltic concrete type or of the sheet asphalt type, the latter being only a mixture of sand, filler and bitumen.

Practical limits for fine and coarse graded asphaltic concrete mixes fordense revetments on slopes will be found to range as indicated in the following gradings:-

Passing A.S.T.M. sieve	1" grading	½" grading	¼" grading
1"	100%	-	-
¾"	80%	-	-
½"	60%	100%	-
¼"	46%	77%	100%
No. 10	33%	57%	75%
No. 40	17%	33%	45%
No. 80	12%	22%	30%
No.200	5%	12%	15%
Bitumen on aggregate	6-8%	7-9%	8-10%

A fine graded mix is easier to work on a slope than a coarse graded mix.

The following limits will prove to be practical for a sheet asphalt type of mixture:-

Passing A.S.T.M. sieve	
No. 10	100%
No. 40	60-90%
No. 80	30-50%
No.200	10-20%
Bitumen on aggregate	10-12%

In these grading tables the aggregate retained on the 10 mesh sieve is stone, the material between the 10 mesh and 200 mesh sieve is sand and that passing the 200 mesh sieve is filler.

Asphalt surfacing, which is in regular contact with water, should be impervious if composed of fine aggregates because otherwise water will penetrate into the asphalt layer in which deterioration will gradually occur. Dense impervious hotmix asphalt revetments contain only 2-4% voids which are attributed to small air-pockets remaining in the finished layer under the kneading action of a roller or the action of a vibrator.

On sea walls built with a sand body, it is necessary first to cover the loose sand surface with a cheap type of asphalt levelling course before being able to apply the resistant, dense and impervious asphalt surface course. Originally, the base course was composed of a mixture of sand, and 6% bitumen but for reasons of durability, it is now considered preferable to apply a base course of higher quality, especially under low water level, practically consisting of a well graded asphaltic concrete layer composed of crushed gravel, sand, filler and bitumen. As this base course cannot be properly consolidated, it will still contain 6-8% of voids, which is, however, a great improvement on the original sand asphalt base course which contained 22% or more of voids.

Generally, the top course of dense asphaltic concrete is 10 cms. thick whilst the asphalt base course varies in thickness according to the conditions of exposure of the coast. A thickness of 30 cms. has been the maximum at the foot of a sea wall whilst near the crest the asphalt base course will have a thickness of 10 cms. This base course can be continued over the crest and down the back slope till about one meter passed the inner foot of the sea wall as a protective layer against erosion of the surface of a sea wall by over-topping waves or water. A tack coat of 1 kg. per sq.m. soft bitumen is sprayed between the base and top courses.

The asphalt mixtures for hotmix revetments are mixed in special mixing plants, such as are employed for road construction. The heated mineral aggregate, the cold filler and the hot bitumen are introduced one after the other into the mixer and then mixed for at least one minute. The output of such plant varies from 5 tons per hour to 100 tons per hour, according to the size of the mixer. From the mixing plant the hotmix is transported to the laying position in insulated lorries which dump their contents on to steel plates from which the mix is laid by shovelling and raking. A roller of 2-6 tons weight finally consolidates the mixture to form a continuous asphalt layer of the required thickness. Mechanical devices for spreading and consolidating asphalt mixes on slopes of sea walls have not yet been used but there is no doubt that further development of equipment will take place in the near future.

EXAMPLES OF APPLICATION

PETT SEA WALL - SUSSEX, ENGLAND

A sea-wall over a mile long at Pett, West of Rye, was completely reconstructed in 1947 to 1950 according to the latest views on the reduction of wave attack and uprush by giving the wall a profile as shown in figure 2. A fairly flat slope reaches up to the highest recorded storm flood level where a 1 in 8, wide, berm takes the energy out of the waves which then rush up a steeper slope to hardly reach the pre-cast coping on the crest of the sea-wall. Provision is made to prevent erosion at the toe of the wall by a steel sheet piling and to prevent hydrostatic pressure caused by the receding tide by a drainage system leading through the wall to a salt-water storage ditch which can also collect spraywater.

The slopes were covered with asphalt jointed pre-cast vibrated concrete blocks: for the lower slope 2 ft. square and 8 in. thick, for the top slope 1 ft. square and 4½ in. thick, laid on clay. The asphalt jointing compound consisted approximately of 47% bitumen 20/30, 47% sand and 6% short-fibred asbestos.

On the berm the shingle was first sprayed with a bitumen emulsion as a priming coat at the rate of 1 kg. per sq.m. The asphalt surfacing was then laid in two courses. The 1 inch base course, composed of 75% sand, 10% limestone filler and 15% bitumen 180/200 served to provide a firm foundation for laying and consolidating the 2 inch top course of 72% sand, 15% limestone filler and 13% bitumen 180/200. Only fine aggregates were used in these mixes because it had been experienced on a nearby trial section that coarse mixes were more liable to deteriorate under the wear and abrasion of the continuous action of waves and shingle. A 2½ ton road roller, working parallel to the coastline, was used to consolidate the sand asphalt courses.

For quick growth of grass, the back slope of the wall was harrowed, covered with an inch of soil and suitable grass-seed sowed and raked in at a rate of 1 ounce per sq.yd. The surface was then sprayed with bitumen emulsion at a rate of 1 gallon to 6 sq.yds.

ESSEX COAST - ENGLAND

The "Essex River Board" is responsible for the maintenance of 310 miles of tidal defences. Experimental work was started in 1937 on the use of concrete blocks, slag, or Kentish rag stone, with joints filled with bituminous mortar. Since 1945 a programme for improving the sea-walls on a larger scale was started but owing to the shortage and high cost of rag stone pitching the present method of pre-cast concrete block revetments with asphalt jointing was developed in particular. The size of the blocks, made of a 1:1½:3 mix vibrated concrete, is actually standardised at 15" x 15" x 5" thickness for estuary work which is increased to 9" or even 12" in more exposed areas. The jointing compound consisting of 47% sand, 47% bitumen 20/30 and 6% asbestos fibres, is poured by hand from cans with tapered open spouts.

The value of an impermeable and flexible revetment having a tensile strength of its own was evident during severe tidal surge conditions as in 1953 and the Essex River Board has decided to use only this type of revetment on wall faces where overtopping or percolation have to be considered. Up to the present time some 365,000 sq. yards have been laid.

At Canewdon an experimental length of estuary wall was built in the autumn of 1953 with the aim of carrying out comparative tests on the erosive effect of overtopping water on grass-covered and asphalt-covered back slopes. The earth wall has been built to a level of 1 ft. above the 1953 surge tide, with front revetment of concrete blocks with asphalt jointing, wave break of pre-cast concrete slabs along the crest and with top and back asphalt surfacings, some 6", some 4" and some 2" thick. The asphalt layers consist of a mixture of 90% sand, 4% filler and 6% bitumen 40/50, mixed in a road mixing plant, transported in Decauville trucks, dumped, shovelled, raked and finally consolidated by tamping on a thick plank to obtain the required thickness.

LINCOLNSHIRE COAST - ENGLAND

Along a 12 mile section of the south bank of the river Humber near Grimsby great damage occurred in the 1953 floods. In reconstruction the bank has been raised to a reasonable level and widened to permit the passage of vehicles along the top. The seaward bank protection now consists of a layer of asphalt grouted slag pitching in separate bays formed by concrete beams at 30 ft. intervals which serve to localize possible damage during storms. The foot of this protection consists of further concrete beams carried down into the clay. At the top of the slope the construction of a small wave return wall may be considered after due settlement of the bank. The top of the bank has been stoned and will eventually carry a rolled tar or a grouted surface.

The asphalt grouted facing on the 1 in 2½ seaward slope is built up of random slag of roughly 4" to 8" size grouted with an asphalt mixture of 72% sand, 10% filler and 18% bitumen 60/70. Where slag is laid on clay core the rate of application is about 8 sq.yds. per ton of asphalt grout and where it is laid on an existing layer of slag, stone or chalk, the rate is 6 sq.yds. per ton.

The asphalt mixture was made in a normal hotmix plant erected behind the sea wall. The mix was transported in lorries fitted with mastic cookers, from which it flowed through a chute for the actual grouting.

Between Sandilands and Chapel a similar asphalt grouting was carried out but here it was a stone pitching on a newly built clay bank of some 5 miles length.

On a short stretch south of Sutton, the Acre Gap, reconstruction work consisted of building a stone bank surface grouted with cement mortar. Panels, formed by concrete beams, were built on this surface and filled with asphalt jointed concrete slabs.

HUTTES SEA-WALL - FRANCE

This sea-wall, which is submerged at high tide, forms part of the important coast defence works serving to protect the beach and the narrow stretch of dunes, behind which are situated the well known vineyards of Médoc, against the severe erosion caused by the storms in the Bay of Biscay. It was constructed in 1935 to 1938 according to the design of figure 3 to replace a former sea-wall which had been destroyed. In plan it has the appearance of the tooth-edge of a saw and is built parallel to the dunes forming large bays between the submersible wall and the dunes which collect sand deposited during high water periods to build up the beach. It is an efficient but expensive type of construction.

The step-like concrete wall was partially destroyed by war damage and in 1945 the concrete blocks forming the steps were replaced by large boulders. Asphalt grouting, partly under water, was carried out in 1949 to key down the boulders. The asphalt grout of usual composition was dumped in the voids between the boulders with a large bucket and has proved to be very effective in protecting the foundations and the sea-wall itself.

NORTH JETTY OF THE RIVER ADOUR - FRANCE

The northern concrete wall forming a jetty at the entrance of the river Adour near Bayonne is protected on the inner side by large concrete blocks of 15 and 25 tons weight. The maintenance of these blocks was expensive as they were washed away regularly during storms.

In 1949 asphalt grouting was applied in the usual way partly above and partly under water. The interesting part of this work was, however, that means were sought to reduce the volume of the voids and consequently the amount of asphalt mix required, in two ways. The first method was to build dry masonry work of small boulders in the voids before asphalt grouting in layers of 50 cm. to 80 cm. depth. In applying this method care should be taken to use boulders of sufficient size and to use a limited depth of masonry layer so as not to prevent penetration of the asphalt grouting mix to the required depth. The other method consisted

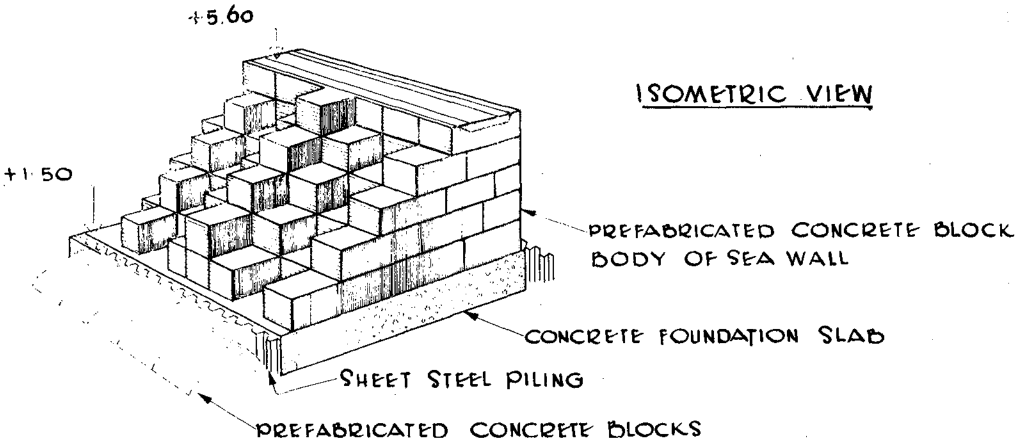

Fig. 3. Huttes sea wall, France.

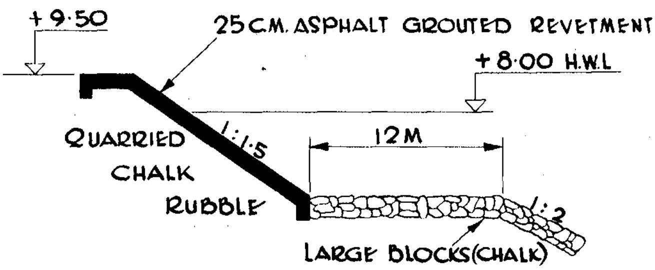

Fig. 4. Seine Estuary wall, France

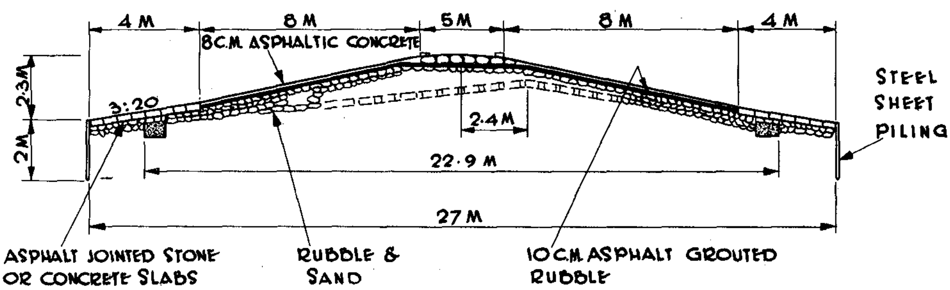

Fig. 5. Groyne at Duinberger, Belgium.

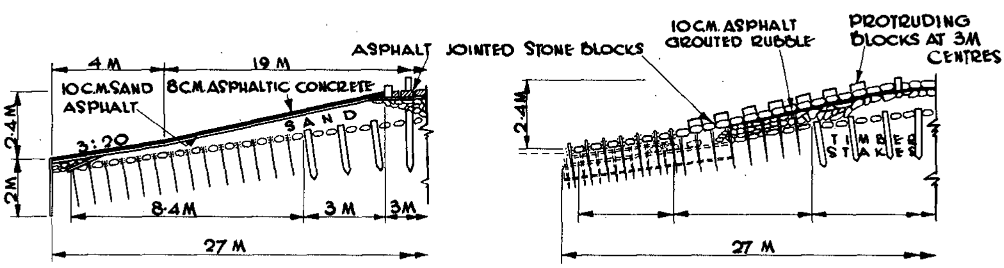

Fig. 5a. Groynes at Knokke-Zoute, Belgium.
(Existing groynes retained and built up to new level.)

in throwing small boulders in the asphalt mix as it flowed into the voids.

RIVER SEINE ESTUARY - FRANCE

For the improvement of the navigable channel in the wide entrance of the river Seine it was necessary to build an estuary wall of 13 K.M. length along the southern bank according to the cross section of figure 4. The body of sand was protected by a thick layer of quarried chalky stone. This stone is not frost-proof but as it was known from experience that its durability is satisfactory if washed daily by tidal water it could be used for the protection of the berm and lower slope in the form of blocks of some 80 kgs. weight each.

For the protection of the 1 in 1½ top slope a trial section of asphalt grouted revetment was carried out in 1951 behind an earth wall to be dredged away later on. Frost-proof silex stones, weighing 4 to 9 kgs. were laid to a thickness of 25 cm. and grouted with an asphalt mixture of 78% river sand 0-2 mm., 5% limestone filler and 17% bitumen 60/70. About 160 kgs. asphalt grout were used per sq.m. slope. At the bottom of the slope a strong foot was built by grouting a kerb in the berm of 75 cm. x 30 cm. section.

An extension of this work to a length of 2.2 K.M. was carried out in 1953. For the execution normal road mixing plant was used. The asphalt grout flowed from a steel trough attached to a mastic cooker, used as means of transport, and was spread over the stone surface with squeegees.

COAST OF KNOKKE-ZOUTE - BELGIUM

Since 1952 the protection of the eroded Belgian sand beach from Zeebrugge to the Dutch frontier is gradually being improved by the reconstruction of old and the building of new groynes.

An interesting part of the work is the use of various methods to build up the existing groynes to a new, higher, level depending on their exposure to waves and currents, (figure 5) in the following ways:-

(a) the least exposed parts are built up with a core of sand covered by an asphalt surfacing of 10 cm. sand asphalt and 8 cm. asphaltic concrete with a crest of asphalt jointed stone blocks.

(b) the more exposed parts are built up of a rubble-sand core covered by 10 cm. asphalt grouted rubble and 8 cm. asphaltic concrete and a similar crest.

(c) the most exposed parts are built up of a rubble-sand core covered by 10 cm. asphalt grouted rubble and asphalt jointed, partly protruding, stone blocks and the same type of crest.

The ends of the groynes are built up of heavy blocks which are asphalt grouted, partly under water, to a depth of 0.80 M.

SEA WALL OF KIEL BAY - GERMANY

The design and construction of this sea-wall is interesting because it is a practical application based on experiments to determine the most efficient type of seaward slope protection.

The profile of a sea wall must be determined in such a way as to resist the strength of the incoming wave and reduce its uprush. Its seaward protection must, therefore, be heavy and have a rough surface. If the sea wall is built up of sand the protective layer must also be waterproof.

These were the basic principles for the experiments carried out recently for the "Marschenbauamt Husum" by the "Hannoverschen Versuchsanstalt für Grundbau und Wasserbau" (Francius - Institut).

The results of the experiments are given in the following table:-

Type of surfacing	Slope	Coefficient of Roughness %	Uprush in M. above zero: steep waves max.	steep waves average	flat waves max.	flat waves average
Smooth concrete	1:3	0	11.00	8.91	13.50	11.37
Sand asphalt	1:4	27x	10.10	8.58	11.40	10.25
Asphaltic concrete	1:4	65x	8.50	7.75	10.40	9.43
Basalt handpitching	1:4	70x	8.30	7.78	10.00	9.15
Asphalt-Rubble pitching	1:3	100	8.30	7.43	8.50	7.60

xTaking concrete as 0 and asphalt-rubble pitching as 100.

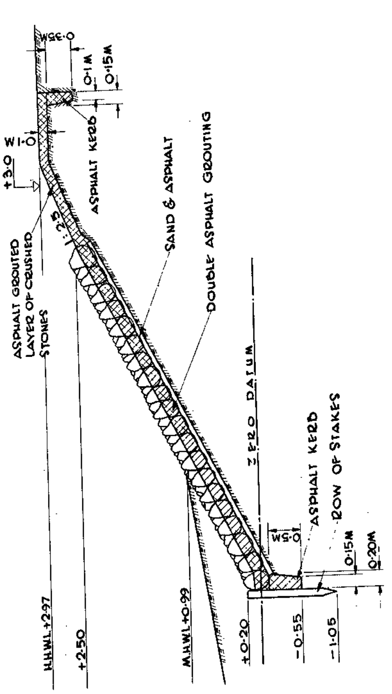

Fig. 6. Kiel Bay sea wall, Germany.

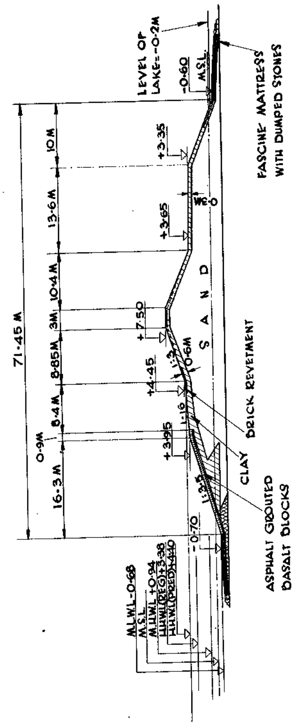

Fig. 7. Brielse Maas sea wall.

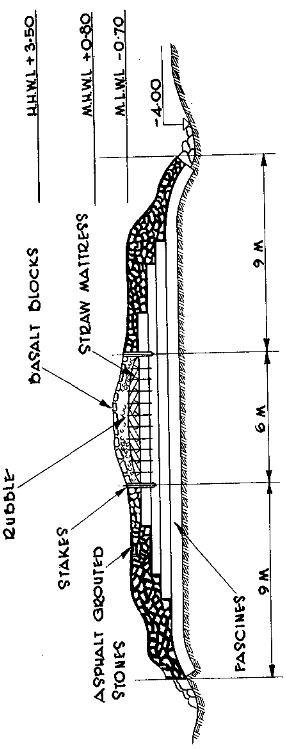

Fig. 8. Delfland groyne.

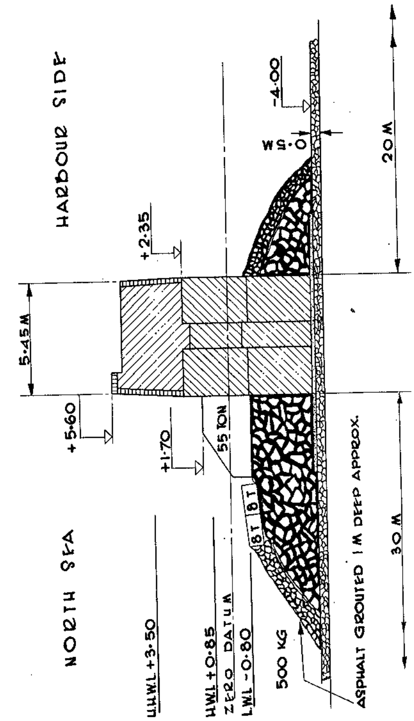

Fig. 9. Scheveningen harbour wall.

The ratio of wave height to wave length for steep waves was 1:24 against 1:42 for flat waves. The highest high water level was 3.75 M. and the crest of the waves 6 M. above zero datum. For a fair comparison the uprush on a 1 in 3 slope should be reduced because the length of friction between protective surfacing and wave is longer for a 1 in 4 slope so that the difference in uprush between the asphalt-rubble layer and the basalt handpitching is still greater than indicated in the table.

The weight of the protective asphalt grouted rubble layer at Kiel Bay (figure 6) is built up as follows:-

120 kg. per sq.m. sand asphalt
550 kg. per sq.m. rubble 35-40 cm.
50 kg. per sq.m. first asphalt grout with bitumen 80/100
30 kg. per sq.m. second asphalt grout with bitumen 60/70

750 kg. per sq.m. in total

The physical and chemical resistance of such a continuous protective surfacing is great. The rubble protrudes 15 to 20 cm. above the asphalt layer.

As regards the execution the sand asphalt surfacing consisted of 93% dunesand and 7% bitumen 180/200. Asphalt grouting is carried out in two subsequent operations after the rubble has been placed on the sandasphalt. The first asphalt grouting must penetrate to the bottom of the voids in the rubble and form a seal coat. This asphalt mixture of 60% dunesand, 20% limestone filler and 20% bitumen 80/100 therefore contains a fairly high percentage of a soft bitumen. The second asphalt grouting serves also to key down the rubble but is composed of 60% dunesand, 22% limestone filler and 18% bitumen 60/70, that is, containing less bitumen of a harder grade in order to possess more resistance to flow at a high atmospheric temperature on a 1 in 2 slope. An advantage of this construction is that the form of the stones is not so important and the laying can be rougher than if the rubble were used without an asphalt grouting.

This asphalt-grouted revetment has been in service during two winters and especially during the severe storm of January 4th 1954 in the Baltic Sea the effect of the rough surface was demonstrated as it reduced the uprush in comparison with adjacent protective revetments. It is a method of construction that can be especially recommended for the top part of sea wall revetments where the uprush of waves has to be limited.

BRIELSE MAAS SEA WALL - HOLLAND

This sea wall was built in 1952 to close the mouth of the Brielse Maas. The design of the cross section as shown in figure 7 shows a sea wall with a modern profile and a berm at storm flood level. The body was built of sand by the hydraulic fill method behind a clay wall, rising above mean high water level. The protection of the slopes of the sea wall was carried out in the conventional way with clay over the whole surface covered by rubble and heavy basalt blocks on part of the seaward slope.

This seaward slope was badly damaged during the storm of January/February 1953. It was, therefore, decided to increase the strength of the basalt slope by asphalt grouting the surface to fill the voids between the stones with a mixture of 70% dune sand, 10% filler and 20% bitumen 50/60. In total 15,000 sq.M. were treated at a rate of 170 kgs. asphalt grout per sq.M.

DELFLAND GROYNES - HOLLAND

Except for some short stretches the coast of Holland is protected by dunes which would be subjected to erosion during storms if the sandy beach were not kept in balance by groynes which limit the lateral drift of sand. Many groynes are built up of fascine mattresses covered with stones and boulders as indicated in figure 8. These groynes are satisfactory in performance but require a good deal of maintenance especially in keeping the end sufficiently protected by basalt boulders of 500 to 1000 kgs. and more weight which are frequently washed away during winter storms.

The first application of asphalt grouting, at the end of a groyne, partly above and partly under water, was carried out in 1938 on two Delfland groynes at Scheveningen with the purpose of forming one large plastic mass of boulders enclosed in an asphalt mixture composed of 70% beach sand, 10% filler and 20% bitumen 60/70. Experience showed that if the asphalt mixture had the right consistency, it would have a specific gravity of about 2, and would penetrate 1 or 2 M. into the voids between the boulders, even under water.

These groynes have now been in service for 16 years without any maintenance and this method of application is being continued all along the coast so that now more than a hundred groynes have been asphalt-grouted.

A similar type of asphalt grouting has also been carried out since 1946 on the northern and southern breakwaters of 2 K.M. length protecting the entrance of the Nieuwe Waterweg at the Hook of Holland, the main shipping canal to Rotterdam. Here also maintenance work has been reduced to a minimum.

SCHEVENINGEN HARBOUR WALL - HOLLAND

The harbour walls are of the vertical wall type, extending only about 250 m. into the sea from the shore line. They are built of precast concrete blocks on a base of fascine mattresses which prevent settlement due to erosion (figure 9). Above mean high water level each wall is capped by a concrete slab built in situ. Its foot is protected all along the outer side, round the end and partly along the inner side by basalt boulders, varying in weight from 1000 to 1500 kgs., dumped up to just above low water level. As these boulders were washed away regularly heavy concrete blocks of 55 tons each were first laid along the seaward foot of the wall, followed later on by two rows of smaller concrete blocks weighing 7 to 8 tons each.

Although damage by storms was reduced it was only a matter of calculation, based on the experience of the Delfland groynes, to conclude that asphalt grouting would save more money. First the northern breakwater was grouted in 1948 and later on also the southern one. The asphalt mixture was transported by lorry-mounted stirrer kettles from a hotmix plant over a distance of 5 k.m. right to the end of the harbour wall. There the mix flowed through a chute from the top of the wall to the surface of the boulders where the hot fluid mass was directed into the voids. About 1000 kgs. asphalt grout was used per sq.m. of stone surface. Practically no maintenance has been required any more although the harbour walls have been exposed to severe storms on the North Sea such as that of January/February 1953.

BREAKWATER AT HARLINGEN - HOLLAND

The construction of the asphalt revetment on this breakwater is important in as much as it opened new views on the use of bitumen for coastal engineering and also, as is apparent now, a new scope for applications.

In 1947 a design for a breakwater built up of a hydraulic fill sand core protected by an asphalt surfacing was determined and a trial section carried out (figure 10). Reasons for departing from the conventional type of clay and stone protection were the practical impossibility of importing suitable stone blocks under reasonable conditions and the shortage of labour for the specific type of work. There was a good opportunity to watch the behaviour of the new type of construction during the winter months and not much damage would be entailed if the construction failed. However, it did not and as a matter of fact confidence in this type of construction has increased step by step as new works have followed regularly.

The breakwater at Harlingen is subjected every winter to several storms which cause waves and occasionally a thicker layer of water to flow over the crest of the breakwater without causing any damage to the asphalt surfacing. This is the best practical test possible to demonstrate the resistance to erosion by overtopping water of an asphalt revetment on the back slope of a sea wall.

The general method of construction was first to remove the soft top layers of the sea bed by dredging until a solid sand base was obtained. On this base the core of the breakwater was built up with sand, either by dumping from hopper barges or by pumping through pipes as a sand water mixture. The sand core was then given a protective surfacing of sand asphalt mixtures of varying bitumen content and varying thickness as indicated in figure 10.

The layer of 40 cm. thickness on the sea side was composed of a mix of 90% fine sand and 10% bitumen 50/60. For the rest of the breakwater the thickness of the layer was reduced to 25 cm. and a leaner mix was used of 95% sand and 5% bitumen. The hotmix arrived from mixers as used for road work in lorries driven over steel plates on the sand or over the finished asphalt layer. The mix was dumped, spread by shovelling and raking in bays of 5 M. x 5 M., all edges being painted with hot bitumen before the laying of another bay. Consolidation was done in one layer by tamping on thick planks. This gave better results than rolling. While the surface was still warm enough for good adhesion, a seal coat of bitumen 80/100 was applied at 2 kg. per sq.m. Finally, a thin surface dressing of bitumen at 1 kg. per sq.m. was sprayed on and covered with sea-shells to give a light colour to the surface.

The foot of the outer slope is protected by creosoted timber sheet piling driven to a depth of 1.50 M. Against this sheet piling fascine mattresses were laid in a strip 15 M. wide and loaded with 700 kg. rubble per sq.m. On a section 100 m. long prefabricated asphalt mattresses 15 m. x 5 m. x 15 cm. thick were substituted for the fascine mattresses as a trial. These asphalt mattresses were composed of 80% fine sand and 20% bitumen 50/60. To facilitate handling, four 4 cm. diameter steel cables with projecting loops were incorporated in the mattresses, the cables having small steel plates attached at 1 m. intervals to prevent the asphalt mattresses from slipping on the cables under their own weight when lifted. The mattresses were prefabricated on the quay-side, conveyed to site on the deck of a barge, lifted and placed in position by floating crane.

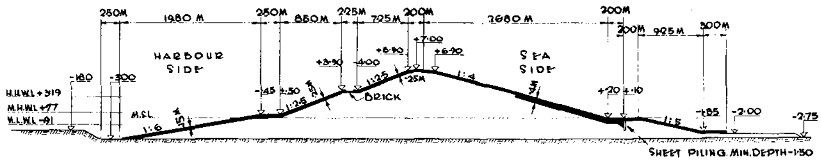

Fig. 10. Harlingen breakwater.

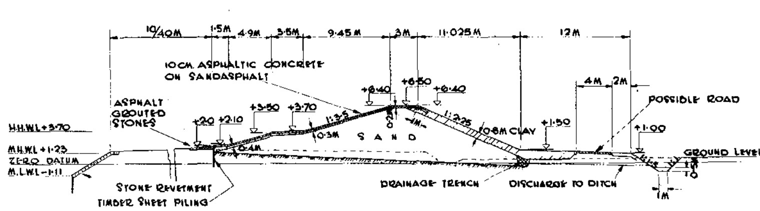

Fig. 11. Goeree - south coast sea wall.

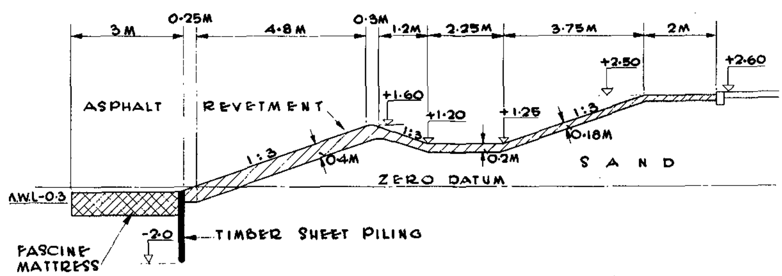

Fig. 12. Zuiderzee works - East Polder, dike at Elburg.

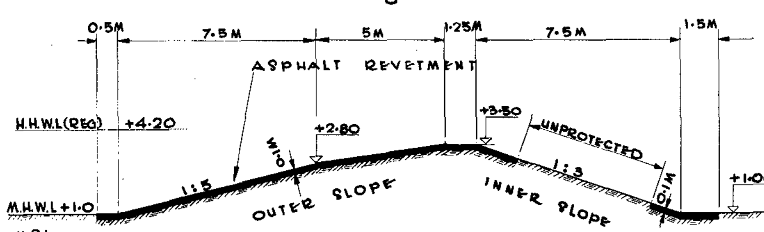

Fig. 13. Anjum sea wall.

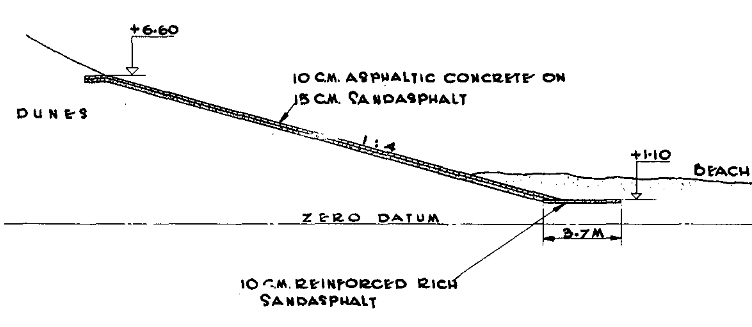

Fig. 14. Dune protection of Delfland, S. Gravenzande.

The foot of the inner slope below water level was given a 15 cm. protective layer of the richer sand asphalt mix. This layer was put down after the water enclosed between an old and this new breakwater had been pumped out.

This new breakwater is 750 m. long and was built in 1948. Although the design of the asphalt mixtures has been improved since this work was carried out the method of construction for similar works has remained practically unaltered in principle.

SEA WALLS AT DEN HELDER - HOLLAND

The construction of the structures for the important extension of the naval port at Den Helder was carried out in the dry, beginning in 1949, behind a breakwater and within a number of permanent and temporary sea walls. Because of the speed of construction and low cost the breakwater and sea walls were built of sand covered with asphalt surfacing to a total length of some 6 k.m.

The cross sections of the walls were similar to that of Harlingen but improvements were gradually made in the asphalt work till the final construction was as follows. A base course, composed of 28.5% gravel 5-20 mm., 57% sand finer than 5 mm., 8% limestone filler and 6.5% bitumen 50/60 was first laid to a thickness of 10 cm. A tack coat of 1 kg. per sq.m. bitumen 80/100 was then applied, followed by a top course of 44.0% crushed stone 5-20 mm. 38% graded sand, 10.7% filler and 7.3% bitumen 50/60 to the same thickness of 10 cm. A seal coat of 1 k.g. per sq.m. bitumen 180/200 covered with sea-shells finished the work. The base and top courses were both rolled and only contained 6-8% and 2-3% voids respectively.

SEA WALL OF GOEREE - HOLLAND

The sea walls of the Island of Goeree Overflakkee were badly damaged during the January/February storm 1953, so that it was necessary to rebuild 5 k.m. of sea wall on the Northern coast and 18 k.m. on the southern coast before the following winter.

Essentially, both sea walls are of the same construction: (figure 11), a hydraulic fill sand core with a seaward asphalt surfacing of a sand asphalt base course and an asphaltic concrete top course, continued over the crest and 1 m. down the back slope which is further protected by a layer of clay 80 cm. thick, covered with grass. A timber sheet piling with an asphalt-grouted rubble berm protects the toe of the sea wall and a drainage system at the heel of the wall prevents a harmful water level arising in the wall.

The asphalt work, carried out according to specifications well established in Holland, comprised laying 300.000 tons of asphalt mixture (equal to 500 k.m. asphalt road carpet 6 m. wide and 5 cm. thick) of which 2/3 had to be finished before the winter to protect the island adequately during the winter. Consequently there were a dozen or more hotmix asphalt plants working at various locations during the summer of 1953 when 200 m. of sea wall had to be built and finished every day.

The base course of sand asphalt, 40 cm. thick at the foot and tapering to 10 cm. towards the crest, consisted of 84% sand, 8% filler and 8% bitumen 50/60. It was laid by hand raking and tamping on thick planks. The top course of asphaltic concrete 10 cm. thick, was composed of 45% crushed gravel, 37% graded sand, 10.7% filler and 7.3% bitumen 50/60 to form a dense waterproof layer after consolidation with a roller drawn up and down the slopes by a winch.

DIKE OF THE SOUTH-EAST-POLDER - HOLLAND

For the continuation of the reclamation work of the former Zuiderzee it was necessary to find means of protecting one of the enclosing dikes to be built in the sea near Elburg over a length of more than 20 km. with a temporary revetment. This revetment will have to stand up to wave attack and, as was experienced last winter, to a considerable weight of ice-floes whilst after reclamation of the area in 5 or 6 years' time, this revetment will be situated on the dry, reclaimed, side of the dike. It will then be covered with a layer of soil and grass.

It was decided to build an asphalt surfacing of sand asphalt according to the design of figure 12 containing no filler and 6% bitumen 50/60. Both the design of the profile of the dike and the method of construction of the asphalt facing are original. The berm in the form of a shallow trench serves to reduce the uprush of waves by the resistance of water which will accumulate temporarily in the trench during storms. The execution of the asphalt work is carried out as follows: the mixer, the sand drier and the bitumen boiler are mounted on wide gauge railway trucks which proceed slowly along the track as the laying of the mix advances. For the upper slope the asphalt mix falls from the mixer on a steel conveyor belt which deposits the mix on the slope where it is shovelled and raked and finally compacted by hand tamping on a thick plank as for the other part of the work.

SEA WALL AT ANJUM - HOLLAND

This sea wall of sandy clay, nearly 6 km. in length, was built for reclamation purposes in 1950/51 as a wall submerged at high tide with its crest at + 3.50 m. whilst storm flood level rises to + 3.40 m. Otherwise than during storms the sea wall is practically not washed by sea water (figure 13).

The noteworthy part of this wall is the design of the asphalt surfacing which is laid on the seaward slope over the crest of the wall and 1.50 m. down the back slope, and as a strip of 2 m. width at the heel of the wall. The remaining part of the back slope is protected by grass. This method of protection has proved very effective, especially in preventing the beginning of erosion by overtopping water at the heel of the wall when other walls with complete grass back slopes in the neighbourhood were badly damaged.

The asphalt surfacing of 15 cm. thickness consists of a sand asphalt mix containing 6% bitumen and no filler. It is sealed with a thin layer of 2.5 kg. bitumen per sq.m. covered with sea-shells. The laying and consolidation of the revetment was carried out in the usual way.

DELFLAND DUNES - HOLLAND

During the storm of January/February 1953 the range of sand dunes along the coast of Holland was badly attacked in some places. At 's Gravenzande, near The Hague, the coast is protected by groynes and as the width of the dunes is not adequate a "second line defence" has been built some time ago in the form of a dike. Nevertheless, it has been considered wise to protect a particular stretch of the dunes themselves by an asphalt surfacing to a total length of some 600 m. This is one of the few examples of an artificial revetment on the dunes in Holland, if not the only one. (figure 14).

The foot of the asphalt protection is laid at + 1.10 m. which is just above mean high water level and generally under the level of the beach so it is covered with sand. The horizontal part of the asphalt protection is designed to be very flexible so that if erosion occurs near the outer edge, the reinforced asphalt mat of 3.70 m. width will bend to protect the foot till a new equilibrium is attained. This mat consists of a layer of 10 cm. rich sand asphalt composed of 70% beach sand, 10% filler and 20% bitumen 50/60, reinforced with sisal cord of 6 mm. diameter knotted to form a net with 10 cm. meshes. The asphalt protection on the 1 in 4 slope consists of a 15 cm. sand asphalt layer covered by a 10 cm. dense asphaltic concrete layer, both designed and built in the usual way.

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RESUME

LE ROLE DU BITUME DANS LA DÉFENSE DES CÔTES

Baron W.F. Van Asbeck

L'utilisation de bitume pour les travaux de défense des côtes peut souvent avoir des avantages lorsqu'il est nécessaire de procéder à la protection artificielle des digues, des dunes, des épis ou des jetées; ceci a été démontré par l'extension régulière des travaux bitumineux dans ce domaine pendant ces dernières dizaines d'années en Europe.

Dans ce rapport, le projet et la construction d'ouvrages de défense des côtes ne sont traités que du point de vue pratique. On étudie en premier lieu les divers aspects du projet hydraulique de ces travaux se rapportant à l'utilisation de bitume, en tenant compte des dernières expériences de la tempête de janvier/février 1953 dans la Mer du Nord. Pour les digues et les dunes, un talus côté mer à pente douce et une berme au niveau de la plus haute haute mer, ayant parfois la forme d'un fossé, réduit la force de l'attaque frontale et la montée des vagues, pour laquelle une formule a été établie. La protection du talus intérieur servant à empêcher des dégâts d'érosion par l'eau dépassant la crète de la digue, est aussi importante que la protection côté mer. On indique aussi les raisons pour lesquelles on utilise le bitume pour construire des épis "streamline" et pour solidifier les digues d'enrochements ou les fondations de digues réfléchissantes. La diversité des méthodes d'application de bitume fait qu'il convient aussi bien aux travaux économiques qu'aux travaux de défense de qualité, comme le demande chaque cas particulier.

On trouve en second lieu une description du produit bitume et de ses trois méthodes d'application établies pour les travaux des côtes. Ces méthodes sont: 1) pénétration au mastic bitumineux au dessus et au dessous du plan d'eau, 2) jointoyage au mastic bitumineux et 3) revêtement bitumineux. Puis viennent les principes de la méthode de détermination des compositions et de tous les autres facteurs importants pour l'application pratique de ces constructions bitumineuses.

Finalement, on examine en détail des exemples spécifiques de types variés de travaux de défense des côtes, comme ils ont été exécutés en Hollande, en Angleterre, en France, en Allemagne et en Belgique. Ils comprennent des travaux de génie civil sur les côtes de l'Atlantique, de la Mer du Nord et de la Mer Baltique.

Ce texte est accompagné de plusieurs plans et illustrations.