Chapter 47

MODERN DESIGN AND CONSTRUCTION OF DAMS AND DIKES BUILT WITH THE USE OF ASPHALT

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SUMARY

In recent years quite a number of important coast protection and harbour construction works in Europe, in the U.S.A. and in Japan have been built or strengthened with the use of asphalt according to established methods of construction in various countries. These works have proved to be not only technically sound and durable but also economical in initial capital investment as well as in maintenance costs. Moreover, as the results obtained have been very encouraging, new outlets and methods of construction with asphalt are being sought, and systematically investigated and developed to cover a wider field of application for coast protection and harbour construction works.

Although there are many purposes and means of applying asphalt constructions for these works, the author has limited the scope of his paper to describe in particular the fundamental problems related to the hydraulic and asphalt-technical aspects of building dams and dikes of sand according to the hydraulic fill process, covered and protected by a two course hot-mix asphalt revenuent or layer.

Assuming a general knowledge of the various facets of hydraulic dam and dike constructions and of asphalt construction methods the author deals with essential items concerning the hydraulic and strength design of asphalt revetments for dikes and dams and describes certain details of construction that require particular attention and perhaps further investigation as experience has proved.

INFEODUCTION.

In many countries it is essential that certain coastal stretches are protected against the danaging effect of waves caused by heavy storms, hurricanes, typhoones, etc. Generally these coastal sections are limited to those parts of the country, where the population is concentrated in towns and villages and where land is more valuable than in other parts, either because it is well suited for industrial development or better suited for agricultural purposes. In an increasing number of countries reclamation works are being undertaken in order to develop employment and food production. The types of coast that require artificial protection are generally situated at a low level, somewhat lower than normal high water level of the sea, whilst the beach and in some cases the dune formation, will consist of sand that may range in size from very fine sand of limited grading to coarse sand mixed with gravel of various sizes.

In this century of enormous technical progress, means have been sought to improve the methods of protection of these coasts and at the same time to reduce the cost of construction by designing dams and dikes of sound technical quality from local aggregate materials. The modern method of construction which aims at high productivity and low cost consists of building a sand core covered with and protected by an asphalt construction which is genorally laid in two courses.

Since new methods of dike and dam construction can only be investigated and tosted to a certain extent, even if experiments in a hydraulic laboratory can assist in determining the importance of various factors, many items of performance can only be judged and appreciated in actual practice. A high degree of responsibility is left to the engineer concerned in the design and construction, and it is for this reason that progress in the application of asphalt revetments has taken place in consecutive stages for various types of dams and dikes.

The first asphalt revetment was constructed on a harbour dam with a sand core, where damage to surrounding constructions and properties would be very limited in case of failure. The next step was taken when an asphalt revetment was built on a sand dam surrounding a large building pit, where damage to installations would not be irreparable but risks were greater than in the first case. Finally the last stage consisted of building dams and dikes which were designed to protect populated and valuable areas against the sea.

As it is impossible to describe all details of this asphalt development work in a paper of limited scope, the author has limited his description to those parts of the construction which are essential; firstly, for the design, both from a hydraulic and an asphalt-technical point of view; secondly, for the actual execution of the asphalt work; and finally for a satisfactory performance as based on experience gained in various countries.

DESIGN

It is assumed that a formation of fine granular aggregate of suitable bearing capacity is available, perhaps covered by a layer of silt that can and should be removed to a thickness of some 50 cm. in order to obtain a sufficiently strong and impermeable layer underneath the dam.

In order to retain the core of the dam consisting of fine sand in proper shape, two parallel retaining walls of clay or other suitable cohesive material are designed under water on either sido of the dam to a height just above normal high water level. Generally

these walls will be dumped each to a height of 2-3 m. and if a greater height is required the retaining walls are built up in stages as shown on the drawing. (Fig. 1)

The core of sand is built up either by dumping the sand under water by means of bottom-door hopper barges or by the hydraulic fill process, by which sand and water are pumped through a pipe at the end of which the sand is deposited by sedimentation and the water flows back into the sea. The sand core is finally brought into shape according to the design by means of drag lines, bulldozers and other conventional types of earth moving equipment, and compacted if necessary.

The design of the facing of the core of the dam consists of various parts, each of which has to fulfil a specific function. The foot of the dam, from low water level downwards, has to be protected against the erosive forces of currents and waves, and should consist of a flexible material, which permits the lower edge of the protective layer to follow limited deformations caused by erosion at the foot of the construction. For this purpose brushwood mattresses or nattresses of reeds, loaded with stone, have proved to be effective and durable. Some experimental stretches have been carried out with reinforced asphalt constructions, which have proved successful if constructed in situ in a continuous layer; but prefabricated reinforced asphalt mattresses of limited dimensions have sometimes resulted in less satisfactory performance, in particular where the mattresses were not laid in sufficiently deep water so that the waves were able to play on the mattresses, thus causing vertical displacements which in turn transformed the sand beneath into quick sand of reduced stability.

At low water level or in its proximity a sheet piling is generally built to a depth of some 2 m. in order to prevent or reduce the direct influx of water under the dam or dike. A timber sheet piling should remain under water practically permanently, but if concrete is used, the top of the sheet piling may be laid higher. This is generally of advantage for construction purposes and may also be preferable to obtain a stronger protection at this most vulnerable point of the dam.

There are two types of essential problems attached to the design as described above. Related to the <u>hydraulic</u> design are two important questions, viz. (1) what seaward slope should be given to the dam and (2) what should be the height of the dam. There are also two questions related to the <u>asphalt</u> design, viz. (1) how thick should the protective revetment be laid, and (2) what is the most suitable composition.

HYDRAULIC DESIGN

If anything has been learned during the centuries of dike building experience, it is this: through some unexpected event that may occur any day, waves may overtop the dike and cause a breach unless it is

also properly protected over its crest and on the back slope. Events, such as a storm flood level caused by strong winds, surpassing a previous highest registered storm flood level, or a storm of longer duration than ever experienced before, may be the cause of breaches, for a clay or turfed top soil may be soaked to such a degree, that it loses stability although it may resist the erosive action due to the flow of water. In such circumstances the protection will slide down the slope and the core will be gradually washed away until the dike, togethor with its protective revetment on the seaward side, collapses, thus causing the initial stage of a breach, followed by serious flooding, if no quick measures for repair are or can be taken.

Another experience to remember is that in coast protection work it is not technically sound or economical to try to resist the forces of waves by building very heavy, rigid and steep structures. Such structures will inevitably also collapse if attached by water from the rear. Although it may be necessary to build a somewhat higher dike, it has proved to be more effective and more economical to build a reasonably flat seaward slope and protective revetment to meet the force of breaking waves and to guide the uprush of water along a streamlined profile rather than to resist outright the force of the waves.

Engineers experienced in dike design and construction methods all seem to agree with the preference, if not the necessity, of protecting dikes of sufficient height with artificial revetments and of building streamlined structures.

These are fundamental conditions which govern modern dike design in principle, but the dimensions have still to be determined to suit specific local conditions. A great deal of research and experimental work has been carried out in post war years in various hydraulic laboratories to investigate and determine the features and performance of various types of designs for dams and dikes. Formulas have been developed, among others, for assessing approximately the uprush of waves on a revenment laid on slopes of varying angles. Various types of materials have also been subjected to these tests under varying conditions of exposure (1, 2, 3).

Note: Numbers refer to literature at the end of the paper.

A formula derived by the Hydraulic Laboratory at Delft from experiments carried out in a wind flume seems to give a practical approach for determining the vertical height of uprush of the significant wave for an open, close-set stone revetment for slopes not steeper than 1 vertical in 3.5 horizontal.

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Fig. 1. Typical dam section.

Table 1

$$Z = 8H (\cos i - \frac{B}{L}) \tan a$$

in which Z = height of uprush of waves, measured vertically above storm flood level, admitting 2% of over-topping waves.

- H = significant wave height or average anplitude of the highest third part of all recorded waves.
- i = angle of incidence of the waves.
- B = width of berm
- L = wave length
- a = angle of the slope.

Formerly the height of uprush of waves was defined as the vertical height above the highest registered storm flood level, but since 1953 a calculated storm flood level has been introduced in Holland, which is based on a combination of extreme meteorological weather conditions. Such a calculation requires, however, a great number of data and a detailed knowledge of the prevailing conditions on the coast.

A smooth, impervious surface increases the uprush by 15%.

Slopes may vary from 1 : 3 to 1: 10 according to their exposure to winds and waves; for an average 1 : 6 slope the uprush of a wave of 3 m. amplitude on an asphaltic concrete construction would be approximately 4.60 m., measured vertically.

Recently a new method of reducing the uprush of waves has been designed and investigated by the Delft Hydraulic Laboratory (4). It consists of applying a range of 4 to 5 asphaltic concrete ribs, built at 0.50 m. intervals, measured vertically, with the bottom rib equally constructed at 0.50 m. height above the maximum registered storm flood level, as shown on the drawing. The purpose of this range of ribs has been demonstrated experimentally in actual practice and has shown that the uprush of a thin layer of water which has lost the majority of its energy can be effectively reduced by 50%.

The ribs are built to a section of 30×30 cm. in lengths of 4 m. with intermediate open spaces of 0.80 m. length to allow the water to recede more freely and form a layer of resistance to the following oncoming wave.

Incidentally it should be borne in mind that on a seaward slope of any type of protective material the uprush of waves during storms

only takes place from storm flood level upwards along the slope; the strongest wave attack with the greatest impact and uplift is to be found between mean high water level and storm flood level, whilst the revetment is only subjected to moderate, but on the other hand perpetual, wave; attack with erosive action below mean high water level.

ASPHALT DESIGN

The systematic use of asphalt for dams, and later for dikes, dates from the early post-war period, when it was suggested to budid a harbour dam of a sand core protected by an asphalt facing as the most economical solution for the reconstruction of the entrance to the port of Harlingen in Holland. (1). The economical construction was based on the fact, that use could be made of local fine sand that was available in abundanco in the seas, whereas other construction materials would have had to be brought to the site from long distances. At that time considerable knowledge was available of the fundamental principles of the construction of asphalt roads, but little was known about the application of asphalt to dams, apart from the fact that asphalt constructions were cohesive to the extent of being able to resist the forces of erosive action of small waves, that asphalt constructions could be made impervious if properly designed according to fairly strict specifications, and that asphalt layers were sufficiently flexible to be able to follow limited deformations such as could be expected on dams subjected to normal settlement after construction. However, there was only one type of sand available at Harlingen and little was known not only about the required strength of the revetment but also of the strength of the asphalt material on which \mathtt{It} the determination of the thickness of the revetment would depend. was, therefore, decided to build a short trial length on the site of the dan and as its performance was good during the following winter. the whole dam was built in its entire length during the next year and protected with the tested type of revetment, consisting of a single layer of sand asphalt, 40 cm. thick, between mean low water level and maximum high water level on the seaward slope, and 25 cm. thick on the remaining seaward slope, the crest and the harbour side of the dam. After consolidation of the sand asphalt revetment the whole surface was immediately covered with a seal coat of pure bitumen and finally finished with a thin surface dressing, including a rolled layer of sea shells to obtain a light colour of the surface. The result was good and the performance of the dam during the following years was satisfactory, but it was considered that the qualities of the asphalt layer could be improved. Consequently, work was started in laboratories and in actual practice to investigate all possible means of improving the quality of the asphalt material and of obtaining a better understanding of all factors involved in this matter.

This systematic development was based on the extension of existing research work related to other types of hydraulic problems covering the construction of large dams, reservoirs, river bank protection etc., carried out in various laboratories and also on improved methods of actual asphalt construction, either by means of manual labour or with mechnical equipment.

The scope of this paper does not permit a full description of the more scientific background of the asphalt techniques related to this problem, but a summarised description is given with reference to existing literature on the subject, which will show the student of this matter the way to a more fundamental study.

As is generally known, bitumen is a solid at low temperatures but on heating it is gradually transformed into a fluid state, . whilst on cooling the reverse process takes place; expressed in more scientific terms, bitumen can be considered as a visco-elastic material.

In applied mechanics the characteristics of a purely elastic solid are defined by its modulus of elasticity, or Young's modulus, which indicates the linear relationship between stress and strain. But for a visco-elastic material this linear relationship is dependent on (a) the time of loading (for static loading conditions) or the frequency of loading (for dynamic loading conditions) and (b) the temperature. The influence of the temperature, or in other words the temperature susceptibility of a bitumen, is expressed by the "Penetration Index" or P.I. of the bitumen. By means of the inter-relationship between the loading, or frequency of loading, the ambient temperature and the P.I. of a bitumen, it has been possible to compose a nonograph from which the "stiffness modulus" of a bitumen (the equivalent value to the modulus of elasticity of a solid) can be determined under specific conditions of environment (5).

For design purposes of an asphalt hydraulic construction the engineer is, however, more concerned with the properties of a hot-mix asphalt construction consisting of mineral aggregates, filler and bitumen rather than with the performance of a pure bitumen. The relationship between the stiffness modulus of a hot-mix asphalt composition and that of a pure bitumen has been found to depend mainly on the concentration by volume of mineral aggregates in the asphalt mix. The stiffness modulus of various asphalt mixes has been detormined.

It has also been possible to determine tensile, compressive and bending strengths of asphalt mixes by means of laboratory tests and here again the properties of the mix, depend, of course, on duration of loading and temperature (6).

Finally it has been found by fatigue tests that if the cycle of loading is repeated on asphalt mixes, the number of loadings to failure increases as the stresses decrease. The relationship between the number of repetitions of loading and the bending strength at fatigue rupture has been determined (6).

For the calculation of the dimonsions of an asphalt facing on a dam subjected to dynamic forces by waves, reference can be made to a graphical method of determining bending stresses and corresponding deflections in hot-mix asphalt constructions. This method was devised by Odemark and Hogg and is based on the assumption that an asphalt revetment is virtually a flexible construction laid on and completely supported by a homogeneous, flexible sub-soil and is loaded repeatedly by a given pressure on a circular area. (7).

For the application of these graphs, it is therefore necessary to base the calculation on assumptions for the characteristics of the breaking waves. The properties of the asphalt layer, i.e. its modulus of stiffness and its designed thickness, as well as the modulas of elasticity of the sub-soil, should also be known.

The forces exerted by waves depend on a combination of factors, some of which are difficult to assess but can be found in existing literature. It seems reasonable to assume, that the striking area of a wave covers a surface, the diameter of which equals the amplitude of the wave, whereas the duration of its impact can be taken at 1/5 or 1/10 of a second. Assuming further a temperature of about 5°C, the modulus of stiffness of a hot-mix asphalt revotment will be of the order of 5 x 104 kg./sq.cm. If the asphalt revetment is laid on newly compacted sand, its modulus of elasticity can be taken at 100 kg./sq.cm.

Comparison of the bending stress, calculated as described above, with the bending strength of the hot-mix asphalt layer under repeated loading conditions will give an indication of the safety margin adopted for the design.

In connection with the stability of the core of fine sand supporting the asphalt facing the deflection of the asphalt layer should be limited to 1 mm. in which case a moist sand core will still retain its stability.

Although generally spoaking, there need not be any fear as regards the creep of a properly designed hot-mix asphalt revetment on a comparatively flat slope under noderate atmospheric temperatures, it may be desirable to consider the plastic properties of the asphalt mix under somewhat more severe conditions that may, for instance, prevail in sub-tropical or tropical countries. Under such conditions the methods of determining the characteristics of the asphalt mix can be compared with those applied in modern soil mechanics techniques for determining the properties of a soil in which, however, the soil/water system is replaced by an aggregate/bitumen system (6). By means of tho triaxial test figures can be determined for:

- (a) The angle of internal friction, (b) The initial resistance. consist
- (b) The initial resistance, consisting partly of the true interlocking rosistance of the aggregate particles and partly of the bituminous initial resistance,
- and (c) The viscosity of the mass.

These properties of bituminous mixes are again partly dependent on their temperature. For given conditions of an asphalt facing on a slope of a dam it will be possible to determine the degree of stability if the internal friction and the initial resistance are known, besides of course, the thickness and the specific gravity of the asphalt rovotment. In order to obtain equilibrium of the asphalt facing on a slope it is necessary that the difference between the shear stress due to the weight of the asphalt facing and the shear resistance due to its internal friction is at least balanced by the initial resistance of the asphalt material.

As an interesting example of the calculation of bending stresses in asphalt revetments on various constructions in Holland the following table indicates some essential figures required for this calculation. The table also shows the comparison between the calculated bending stresses in the asphalt facings and the actual bonding strengths of the various types of asphalt compounds, as determined by fatigue tests (7). See Table 1.

The bending strengths were based on a storm lasting 36 hours during which the impact of waves was repeated about 1.1 x 104 times. It will be seen that there is good correlation between the calculations and the results in actual practice, since, after the storm, constructions I, II and III wore undamaged, construction IV was of an underdesigned vory lean sand asphalt and was heavily damaged, whilst construction V showed cracks as the critical value of the bending stress for a sand mastic was reached.

From various data on the determination of bending stresses it would seen that the following maximum bending strengths of the various asphalt materials can be adapted:

Aspha	altic	concrete	30 1	cg.	/sq.	cm.
Lean	\mathbf{sand}	asphalt	15	11	n	11
Very	lean	sand asphalt	7.5	11	n.	11

. In another case the deflections of asphalt revetments have been calculated according to the above mentioned methods and the following results were found:

Thickness of construction	A cm	a cm	kg/cm ²	h/a	S kg/cn ²	E kg/cm ²	Deflection mm
North side 25 cm	75	37.5	0.25	0.57	70,000	100	0.267
35 cm	"		"	0.94	80,000	"	0.169
South side 25 cm	50	25	0 . 15	1.0	70,000	11	0.070
35 cm	"	"	"	1.4	80,000	11	0.048

In certain instances there may be a possibility of hydrostatic pressure developing underneath the asphalt facing where the height of saturation of the sand core of the dam by water due to prolonged high sea water levels, is not limited sufficiently by means of drainage. The equilibrium of the asphalt revetment is a simple matter of constructional design and is only referred to as an essontial matter of design that can be solved either by providing adequate drainage or by providing sufficient weight and thickness to the covering asphalt layer.

If a dam or a dikc is completely capped by an impervious asphalt construction, air pressure may develop in the core of the structure owing to a slight rise of the water level in the core. Since the asphalt covor is a plastic layor, it will be deformed by this pressure unloss air vents are applied at intervals of 25 m. in the form of short steel pipes filled with precoated chippings.

ASPHALT CONSTRUCTION (1)

In asphalt dan construction work it has always been found essential to construct a top course as a dense impervious asphaltic concrete layer, whilst in recent years it has also been the aim of the designers to specify a dense base course instead of the more open graded sand asphalt mix which was originally laid. The improvement in technical quality is important as compared with the slight increase in cost of the total construction. In order to obtain the required density and impermeability of the two courses it is necessary to specify a figure for the density or else to specify limits for the void content in the compacted mixes. The present figures for void contents are 2 - 4% for the top course and a maximum of 10% for the base course.

Apart from the degree of compaction, the possibility of achieving the required density depends naturally on the composition of the mix, determined by the grading of the aggregate material and filler, whilst the amount of bitumen is determined by the quantity required to fill the voids in the compacted dry mix of aggregates and filler. An average type of composition for the two asphalt courses consists at present of:

Top Course: (Asphaltic concrete)	42% crushed stone, 3 - 12 mm. 43% gradod sand finer than 2 mm. 7% limestone filler 8% bitumen 80/100
Base Course: Gravel sand asphalt)	43% gravel, 5 - 20 nm. 43% graded sand finer than 2 nm. 7% limestone filler 7% bitumen

For asphalt mattresses or asphalt grouting work the sand mastic consists of approximately 75% sand, 10% linestone filler and 15% bitumen 80/100.

The reinforcement of asphalt mattresses can consist either of sisal nets of 10 cm. mesh and 6 mm. cord diameter or of flexible steel fabric of 10 cm. mesh and 2 mm. wire diameter.

An experimental average composition for asphalt ribs to reduce the uprush of waves consisted of:

43.8% crushed stono, 5-12 nm. 41.7% graded sand 8.1% limestone filler 6.4% bitumen 80/100

The asphalt ribs are applied without difficulty with a conventional type of curb-paver as used for readwork; it is essential to apply a tack coat of a hard grade of bitumen on the sloping asphalt facing of the dam.

As for hydraulic works of various nature, such as large dams, reservoirs, canal linings, etc., the heating and mixing process of mineral aggregates, filler and bitumen is carried out in conventional types of mixing plants whilst the mix is generally transported to the site of laying by means of lorries as is current practice in readwork. Contrary to normal practice in the construction of large dams of 40 m. height and more, as well as for the construction of reservoirs and head races leading to hydro-electric plants, where laying of the asphalt linings is generally carried out by means of mechanical equipment, such as read finishers or specially constructed spreador-boxes, it is the usual practice to lay asphalt facings on dams and dikes for coast

protection by manual labour. The reasons for this fact are twofold: firstly, the surface on which the base course of the asphalt facing is laid generally consists of sand that is, even after compaction, not sufficiently stable to support the weight of modern laying equipment and, secondly, the thickness to which the base course is laid varies from at least 20 cm. to 60 cm. or more at the foot of certain dams so the advantage of mochanical laying is reduced since not much hand labour is required to spread the material. The top course of dense, impervious asphaltic concrete is laid on a good, stable support to an average thickness of 10 cm. maximum and here, of course, there should be every reason for laying and rolling the surface with modern road surfacing equipment adapted to work on fairly flat slopes. So far little use has, however, been made of mechanical equipment and the quality of the work would certainly be improved, if hand labour were roplaced by machinery.

Compaction of a thick base course is generally achieved by hand tamping on a thick plank, where no other means of compaction could be more effective in reducing the percentage of voids in the finished asphalt layer. If the base course consists of better graded aggregates, good reason exists to apply a more effective method of compaction either by means of light vibrating singlewheel steel rollers, light motor rollers or by vibrating tampers. In the latter case compaction sheuld continue till no more tracks are seen on the asphalt surface.

It is necessary to obtain a good bond between the two asphalt courses and this can best be achieved by applying a tack coat of about 0.75 kg./sq.m. of a hard grade of bitumen while the asphalt base course is still warm. Before laying the top course the asphalt surface should be thoroughly oleaned in order to obtain good adhesion.

It is generally specified, that the joints between the asphalt areas finished at the end of a day and new work should be laid staggered in the two asphalt courses. Moreover, it is also normally specified that the joints should be painted with bitumen before the adjacent asphalt area is laid.

A seal coat of approximately 2 kg./sq.m. of a soft grade of bitumen should be applied while the asphaltic concrete top course is still warm and in any caso before it has been covered by water. Because algae do not adhere to pure bitumen; only the asphalt surface above normal high water level is covered with a very thin layer of heated gravel, sand or sea shells and compacted.

EXPERIENCE AND RECOMMENDATIONS

During the post-war years much experience has been gained on the construction of asphalt works for hydraulic purposes of various types and in many countries, and in connection with the application of asphalt facings to dans and dikes, it would seem of value to review the various essential items of construction and to summarise recommendations for future work.

(1) CORE OF THE DAM

There are certain advantages and disadvantages in building parallel retaining walls of clay, beth from a constructional point of view as well as in rolation to their function in the permanent structure. It hardly need be emphasised that the clay used for this purpose must retain its stability under water and be easy to apply; rich clay is therefore unsuitable, the more so because it has a tendency to crack when drying out. It is, therefore, prudent to specify that the clay should be of suitable quality containing not less than 30% fine sand.

The clay should also be able to resist temporary erosion by waves and currents until it is protected by the facing of the dam. It should be sufficiently cohesive to protect the sides of the sand core to a certain extent during the storms and on the other hand it should not be too rich as this will cause undue differences in the degree of settlement between the retaining walls and the sand of the core.

The surface of the clay retaining walls has generally to be partly covered by the asphalt facing and its rough surface will tend to increase the quantity of asphalt material necessary for the base course. Attention should be drawn to the fact that, especially if the hydraulic fill process is applied for the construction of the dam, drainage of water contained in the sand core is prevented by the clay retaining walls. For these reasons, and also because the required quantities of clay may not always be available, it is interesting to note that a sand asphalt containing not more than 3% bitumen can be used for this purpose. This lean sand asphalt mix can be dumped under water by means of bottom-door hopper barges, and it has been proved that it can resist a certain degree of water turbulence and current velocities up to at least 3 m. per second. In the last few years the use of colliery shale instead of clay has given satisfaction for the construction of these retaining walls.

(2) CONSTRUCTION OF THE FOOT

(a) If the foot of the dam below normal low water level is protected by a permeable type of construction, such as fascine nattresses, it is essential to apply a sheet piling to resist percolation of water through the sand formation. In certain circumstances it may be of advantage to lay a continuous drain or weep holes behind the sheet piling and in order to reduce the pressure against this sheet piling, it is desirable to provide a berm of 1 m. width between the sheet piling and the foot of the sloping facing.

(b) If, on the other hand, the foot of the dam below normal low water level is protected by an impervious and flexible reinforced sand mastic layer, it is good practice to lay the asphalt mattress against the sheet piling and to cover both with asphalt grouted rubble against which the sloping asphalt facing is laid.

(3) AIRVENTS

Airvents at intervals of 25 m. should be constructed in the crest of an asphalt capped dan or dike in the form of short steel pipes filled with precoated chippings if air pressure can be expected to develop underneath the asphalt cap.

(4) ASPHALT RIBS

Care should be taken that the composition of the asphalt ribs is based primarily on stability design and that a tack coat of a hard grade of bitumen is applied to obtain good adhesion of the ribs to the sloping asphalt facing of the dam.

(5) ASPHALT JOINTS

(a) It is desirable not to lay any horizontal asphalt joints under normal high water level or even better under the highest high water level.

(b) Asphalt joints in the two courses should be laid staggered.

(c) The cold surfaces of asphalt joints should be cut obliquely and coated with a thin layer of sand mastic before finishing the day's work; these surfaces should be thoroughly cleaned before the adjacent asphalt areas are laid.

(d) Under these conditions there is no need to increase the thickness of the asphalt facing at the joints as this only complicates the construction without increasing the strength or impermeability.

(6) TACK COAT

It is essential to apply a tack coat of 0.75 kg./sq.m. of a hard grade of bitumen on the base course while it is still warm; the asphalt surface should be thoroughly cleaned before applying the top course.

(7) SEAL COAT

Before the asphalt surface has cooled off and at any rate before it has been covered by water, the whole surface of the asphaltic concrete top course should be sealed by applying 2 kg./sq.m. of a soft grade of bitumen. In order to prevent the growth and adhesion of algae, which tend to cause cracks and curling up of this seal coat, the latter is not covered below normal high water mark. Above this level the seal coat is covered either with heated chippings, gravel sand or sea shells compacted by rolling, in order to render a light coloured surface. It should be mentioned that in several instances of construction of asphalt facings on large dans and reservoirs, it has been observed that a treatment of the asphalt surface with a cement wash, containing equal parts by weight of cement and water, at a rate of 2 kg./sq.m. was effective in preventing cracks in a bituminous seal coat caused by expansion and contraction due to repeated wetting and drying of clay, silt or algae, which tend to cover the asphalt surface.

(8) COMPACTION

The mothod of compaction of the asphalt courses need not be specified, but it is essential that the courses possess the required density and impermeability; this can be achieved by specifying a void content for the asphaltic concrete top course of 2-4% and for the dense base course of a maximum of 10% by volume.

(9) CONTROL OF WORK

The quality of the asphalt construction should be controlled on the site in order to be able to adjust specifications or items of construction within a short period. Regular sieve analyses should be made of new supplies of mineral aggregates and filler, and the softening point and penetration of bitumen should be determined. Means should be available of determining the composition of the asphalt mixes, whilst the percentage of bitumen should be adjusted to fill the voids in the compacted dry mix of aggregate.

Regular control of the finished asphalt courses should also be arranged either by determining their density and impermeability in situ or else by taking samples and determining their density and impermeability in the field laboratory.

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