ASPHALT
in
HYDRAULIC STRUCTURES

THE ASPHALT INSTITUTE

FIRST EDITION NOVEMBER 1961
Fourth Printing April 1963

Manual Series No. 12 (MS-12)

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FOREWORD

This publication has been prepared to assist engineers in design and construction procedures for the use of asphaltic materials in hydraulic structures. To date, the technology in this field has been available only in miscellaneous articles, conference proceedings, papers, or the experiences of a few engineers. This manual presents examples and instruction based on these publications and experiences.

The use of asphalt in hydraulic structures has expanded widely during the past three decades. This will continue as new materials and techniques are proven in service. This manual, then, must be considered as a compilation of the presently available knowledge of this use of asphalt. Revisions of it will be made as necessary to keep pace with the developing technology in this field.

THE ASPHALT INSTITUTE
ASPHALT INSTITUTE BUILDING
COLLEGE PARK, MARYLAND

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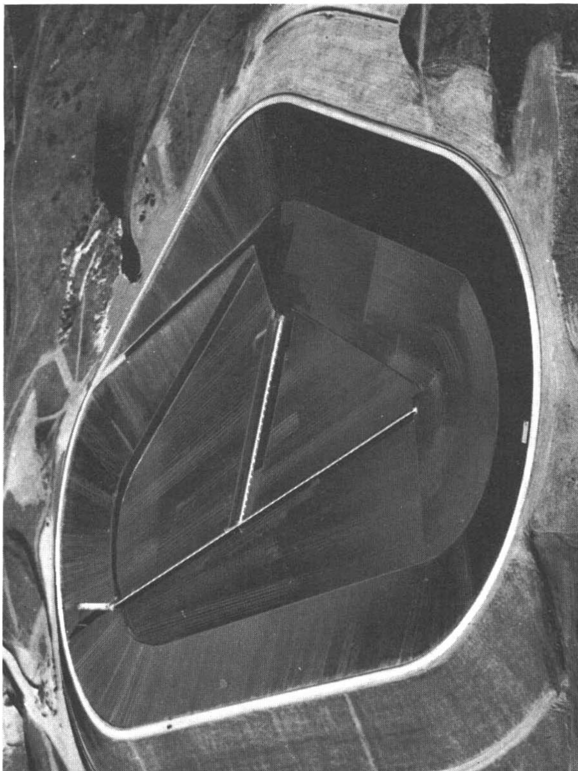


I-1—Garvey Reservoir, Los Angeles

Chapter I

INTRODUCTION

1.01 HISTORY AND BACKGROUND

In the time of the Pharaohs in ancient Egypt, asphalt was used as a mortar to cement together rocks laid up on the shores of the Nile for protection against erosion. Recent archaeological excavations in Mesopotamia and in the Indus Valley show asphalt was used as a waterproofing layer for temple baths and water tanks. These and other ancient hydraulic structures are the earliest known instances of the use of asphalt by man. The fact that some of these constructions are still in existence attests to the durability of asphalt as a material.

Our present concern, however, is with developments of the past three decades, during which there has been a progressive expansion in the use of asphalt for control, conservation, or storage of water. During this period procedures have been developed and proven for the use of asphalt in revetments, canal and reservoir linings, heavy facings for dams, grouting work, and other hydraulic structures. It is certain that these uses will continue to expand as technology in this field is improved. This technology must keep pace with the growing importance of: (1) water conservation to meet the increasing demand for our existing supplies of water; (2) irrigation, to open up new lands for cultivation; (3) flood control, to protect costly investments in industry and homes; (4) prevention of beach erosion to preserve our recreational areas and protect waterfront property.

1.02 CHARACTERISTICS

Asphalt has several qualities and characteristics which make it particularly suitable for use in hydraulic structures. It is excellent as a cementing and waterproofing material. It is very versatile in its form and in its application. One of the special or paving grade asphalt cements, or one of the liquid asphalts, will usually be found most suitable for any specialized hydraulic need. Asphalt may be used alone (as in an asphalt membrane to provide a waterproofing layer), or it may be used in combination with other materials (as mixed with graded aggregates) to produce asphalt concrete for use as a canal or reservoir lining.

The usual canal or reservoir lining requires a high degree of impermeability to water. Hence, an important attribute of asphalt is the ability to combine it with graded aggregate and mineral filler into an essentially voidless and relatively impermeable mix. Also important is the ability to combine it with an open-graded aggregate into a porous asphalt concrete for use where free passage of water or drainage is required.

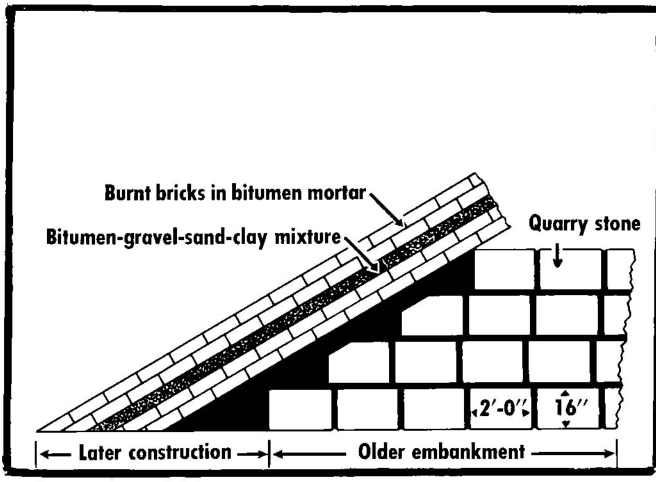
Asphaltic materials can be put down readily in strips and layers with each thoroughly bonded to the next. The strength and integrity of lining structures is thus assured even across cold construction joints.

Asphalt and asphaltic materials are very stable in the presence of chemicals. This is an important quality relating to their use for waste product reservoirs. The usual acid, salt, or other waste solutions do not harm asphalt linings. However, it is important to remember that petroleum and its derivatives are solvents of asphalt and cannot be stored in asphalt-lined structures.

Asphalt linings of reservoirs do not impart objectionable taste or smell to water stored there. Health authorities have made many tests of the hygienic qualities of asphalt linings for such uses as storing drinking water, and in each case they have met complete approval.

The degree of plasticity or flexibility, which is an inherent property of asphalt, is also very important. This enables asphalt linings, or other structures, to conform to slight irregularities, curves and angles of the subgrade, and to adjust to slight differential settlements that occur after completion of a structure.

Asphalt is readily available to almost any construction site. This follows from the size and spread of the petro-



I-2—Construction of Tigris Embankment at Assur (1300 B.C.)

leum industry which produces and supplies it. Likewise aggregates, suitable for combining with asphalt to form construction materials, can usually be found within economical haul distance of any job site.

In constructing with asphalt optimum efficiency is easily obtainable by judicious combinations of material and type and method of placement. Hydraulic structures built of asphaltic materials can usually be placed in service as soon as completed without lengthy curing periods. This efficiency also applies to maintenance and repair operations.

1.03 DESIGN AND CONSTRUCTION

Standard specifications, tests, design methods and construction procedures are generally applicable to the uses of asphaltic materials in hydraulics. These are covered in the following publications of The Asphalt Institute:

Specifications and Construction Methods for Hot-Mix Asphalt Paving, Specification Series No. 1

Specifications for Asphalt Cements and Liquid Asphalts, Specification Series No. 2

Miscellaneous Construction Specifications, Specification Series No. 4

Mix Design Methods for Hot-Mix Asphalt Paving, Manual Series No. 2

Asphalt Plant Manual, Manual Series No. 3

The Asphalt Handbook, Manual Series No. 4, has a chapter on "Asphalt in Hydraulics," which is a condensed coverage of this subject, and containing considerable general information.

There are certain more specialized publications which have been written for this field of use, or have related material. These are:

Specifications and Construction Methods for Asphalt Hot-Mix Grouting and Capping of Stone Jetties, Specification Series No. 5

Tentative Specifications for Asphaltic Membrane Lining (Hot Sprayed Type) for Canal and Reservoir Construction, Construction Series No. 94T

Specifications for Undersealing Portland Cement Concrete Pavements with Asphalt, Construction Series No. 92

Asphalt for Off-Street Paving and Play Areas, Manual Series No. 9

These specifications and instructions are adequate to guide most construction. However, it will frequently be necessary to devise new tests and construction procedures to meet special situations. And it should be emphasized that, particularly for major installations, construction should be guided by complete programs of testing and design. The following chapters will describe how both general and special procedures apply to the field of asphalt in hydraulic structures.

1.04 TERMS RELATING TO THE USE OF ASPHALT IN HYDRAULIC STRUCTURES

Asphalt Lining.—A durable, erosion-resistant and impermeable surfacing (or other layer) of a canal, reservoir, or other hydraulic structure, which acts to hold the water or other liquid inside the structure.

Asphalt Revetment.—A protective surfacing that has the principal function of preventing erosion by water. Though the term usually connotes a river bank structure, it may also apply to protective surfacing for other slopes such as seawalls, levees, and dams. The term *subaqueous* refers to that part of a revetment placed under the surface of the water. *Upper bank* paving is that part placed above the surface of the water.

Asphalt Facing.—A relatively thick, heavy-duty asphalt surfacing designed to resist severe erosion, abrasion, high water pressure, and, in some instances, ice pressure. A facing may have the additional purpose of acting as an impervious layer to prevent leakage through the structure. In some uses it might be termed a heavy-duty revetment.

Asphalt Membrane.—A layer formed by an application of a relatively hard, high-viscosity, high-softening-point asphalt, usually without filler or aggregate. Generally about ¼ inch thick, it is usually covered or buried to insure its protection and to prevent weathering.

Temperature.—Expressed in this manual in degrees Fahrenheit (°F).

Slope Steepness.—Expressed in this manual as a ratio, with the horizontal distance given first as a variable, and followed by the vertical distance which is always unity or one. For example, the steepness of a slope is expressed as 5:1, 3:1, 1½:1, etc.

Canal.—A main line channel for the controlled passage of water in an irrigation system (United States Bureau of Reclamation usage).

Lateral.—A small branch canal leading off of the main canal to local irrigation areas.

Invert.—The bottom or floor of an irrigation canal or lateral.

Cavitation.—A form of erosion caused from a pulling out of material by negative pressures developed as waters flow swiftly over inequalities in the surface.

Causeway.—A raised road, across wet or marshy ground or across water.

Riprap.—(1) A layer, facing, or protective mound of stones randomly placed to prevent erosion, scour, or sloughing of a structure or embankment; (2) the stones so used.

Rubble.—(1) Loose, water-worn stones; (2) rough, irregular fragments of broken rock.

Mean Low Water (MLW).—The average height of low waters over a 19-year period.

Mean High Water (MHW).—The average height of high waters over a 19-year period.

Littoral.—Of or pertaining to a shore, especially of the sea. A coastal region.

Littoral Drift.—The material moved in the littoral zone under the influence of waves and current.

Littoral Current.—The nearshore current, primarily due to wave action.

Breakwater.—A structure protecting a shore area, harbor, anchorage, or basin from waves.

Bulkhead.—A structure separating land and water areas, primarily designed to resist earth pressures.

Seawall.—A structure separating land and water areas, primarily designed to prevent erosion and other damage by waves.

Jetty.—(1) (U. S. usage) On open seacoasts, a structure extending into a body of water, and designed to prevent shoaling of a channel by littoral drift, and to direct and confine the stream or tidal flow. Jetties are built at the mouth of a river or tidal inlet to help deepen and stabilize a channel. (2) (British usage) Jetty is synonymous with "wharf" or pier.

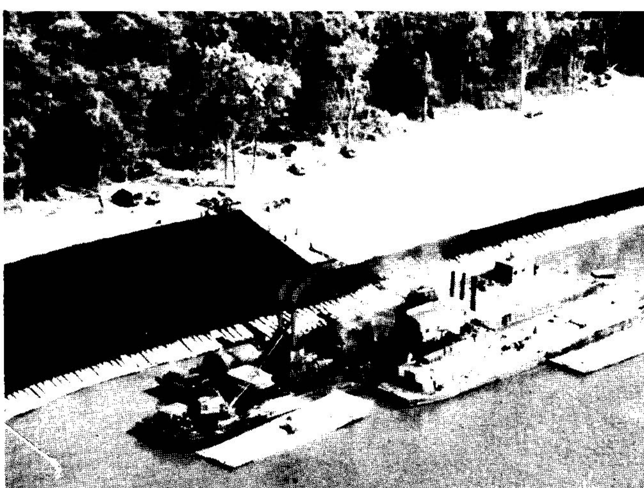
Groin.—A shore protective structure (usually built perpendicular to the shore line) to trap littoral drift or retard erosion of the shore. It is narrow in width (measured parallel to the shore line), and its length may vary from less than one hundred to several hundred feet (extending from a point landward of the shore line out into the water). Groins may be classified as impermeable or permeable. Impermeable groins are solid or nearly solid structures; permeable groins having openings through them of sufficient size to permit passage of appreciable quantities of littoral drift.

Levee.—An embankment constructed on (or near to) a river bank for the purpose of preventing the flooding of the land back of the levee.

Holiday.—An area, or spot, inadvertently missed in the coverage (by spray).

Catchment Basin.—A large, but very shallow, reservoir-like basin which is used to collect rain water as it falls. It usually discharges the collected water into a storage tank or reservoir.

Sewage Lagoon.—A large, shallow (water depths of 2½ to 3 feet are preferable) pond used for the treatment of sewage. These ponds require large surface areas for the adsorption of oxygen from the air and are often called *oxidation ponds.* Their operation is simple and economical as they rely on natural biological (aerobic) processes to decompose the unstable suspended solid matter in the sewage.



1-3—Mississippi River Bank Paving

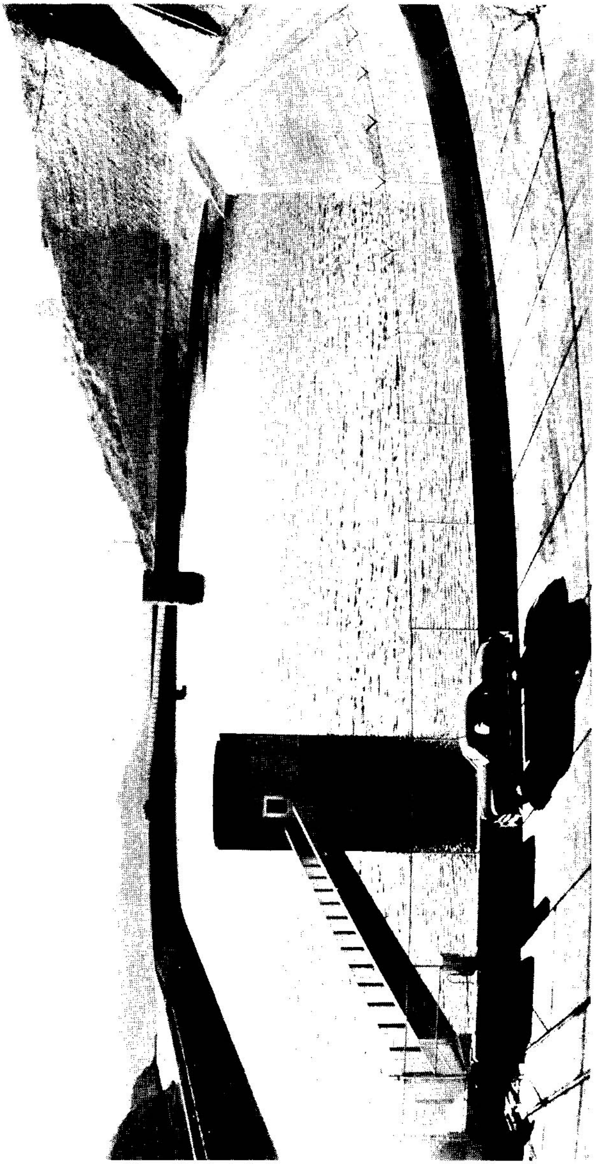


Figure II-1—Asphalt Concrete Lined Reservoir

Chapter II

ASPHALT LININGS

A. General

2.01 DEFINITION AND USE

A lining may be defined as that part of a hydraulic structure which functions as a durable, erosion-resistant surface. In the usual case its most important function is to interpose a waterproof barrier that will hold the water, or other liquid, inside the structure. Uncontrolled seepage not only loses valuable supplies of water but allows the water to permeate surrounding soil, making it unfit for agriculture, or endangering it as a foundation material.

The most important use of hydraulic linings is in the conservation of water—that is in its storage, conveyance, and delivery. The United States Bureau of Reclamation has pioneered in the development and use of asphalt linings. The Bureau has continuously sought better and more economical types of construction through its lower cost canal lining program. Municipal utility districts and certain manufacturers, particularly in California, have perfected several types and combinations of asphalt linings for reservoirs. Today numerous asphalt-lined storage reservoirs exist all over the country. Some of these have a record of more than twenty years of service.

2.02 TYPES OF ASPHALT LININGS

Types of asphalt linings which have been developed and proven in use are asphalt concrete, asphalt macadam, asphalt membrane, and prefabricated asphalt panels and rolls. Complex lining structures are constructed by combining certain of the above asphalt types, or by combining an asphalt type with other materials. There are other types which have shown promise in experiments. However, they must be proven by extensive use before they

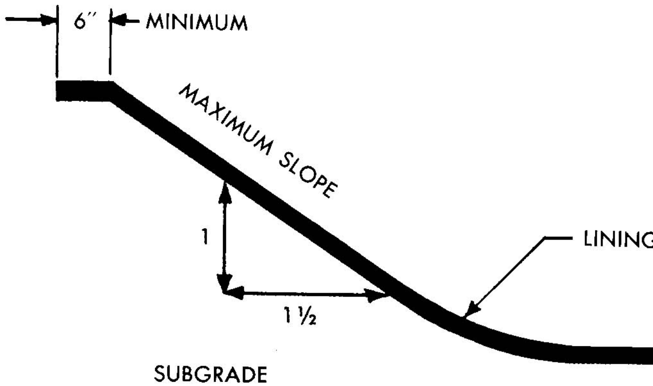


Figure II-2—Typical Section of Canal or Reservoir Lining

can be pronounced fully developed. Some examples of these are pneumatically-applied asphalt emulsion mortar linings, underwater sealing of permeable soils with asphalt emulsion, primed earth and prime-membrane asphalt linings, and asphalt grouting of permeable soils.

2.03 APPLICATIONS

Structures to which asphalt linings are applicable have a variety of names, but actually there are only two types. One is a basin to hold or impound water, and the other is a channel for the controlled movement of water from one place to another. Types of basins considered here are reservoirs, ponds, and swimming pools; and types of channels are canals, drainage ditches and storm channels.

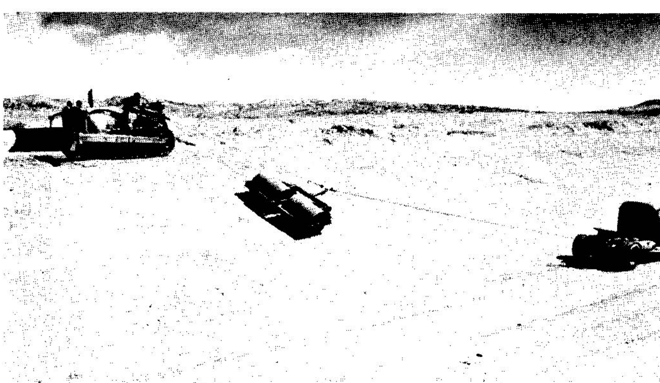
2.04 SUBGRADE PREPARATION

Subgrade preparation is usually the same, regardless of type of asphalt lining to be used. The subgrade is that portion of the sides and bottom of a canal, ditch, reservoir or pond upon which the asphalt lining is placed. The subgrade should be thoroughly cleaned of all organic and loose material. It should be compacted sufficiently to attain stability, particularly on side slopes, and to sustain the traffic of any machines used to place and compact the lining. It also should be trimmed before, during or after compaction as necessary to make it smooth and uniform, and to give the completed structure the required grade and cross-section. It is often advantageous to excavate, grade, or fill so there is some excess material for a final fine trimming after the subgrade has been compacted.

2.05 SUBGRADE SOIL

The existence of certain types of soil, or of conditions that affect them, can cause extensive damage to asphalt linings. Trapped water, which cannot drain because of underlying impervious soil layers, can exert sufficient hydrostatic back pressure to crack up or pop out large sections of the lining. When such conditions are likely to occur, preventative steps must be taken. The faulty material should be removed for a depth of at least a foot and replaced with a free draining material. If this is not possible, pipe drains may be placed under the lining to carry off the excess water.

Figure II-3—Rolling Subgrade on a Side Slope



Subgrade soils that swell considerably when wetted can exert sufficient pressure to damage asphalt linings. Inquiries should always be made regarding local experience with such soils. In the general case, when such soils are found, they should be removed to a depth of at least one foot and replaced with selected material. In small structures, where this is not economically feasible, the subgrade should be compacted at a moisture content that will make the development of adverse pressures unlikely.

Cohesionless soil, such as sands of one uniform grain size, can cause distress in thin linings by lack of support at the top of slopes, or by exerting too much pressure at the toe. This will not happen, of course, if side slopes are sufficiently flat to insure stability of the subgrade. If flattened side slopes are not possible, it will be necessary to use lining sections thick enough to withstand the increased stresses.

2.06 WEED CONTROL

Weeds and other plants are a potential hazard to

Figure II-4—Weed Shoots Breaking Through Lining

linings when certain favorable growth conditions exist. These conditions are: (1) Subgrade contaminated with weed seeds or roots of perennial plants; (2) subgrade moisture conditions favorable to seed germination or root growth; and (3) a subgrade temperature which favors growth for appreciable periods. Absence of any one of these conditions will prevent vegetation trouble but the simultaneous occurrence of all three means the eruptions of growth through the average lining. When such conditions are anticipated, the use of a soil sterilant is advisable. Where vegetation is present, the subgrade should be carefully grubbed before treatment. This will be required more frequently in lining existing structures than in new construction.

The soil sterilant desired is not a simple weed-killer but a compound which attacks roots and seeds and remains effective for an extended period. There are many commercial products which will accomplish this. Most of them are either chemical compounds or petroleum derivatives.

Chemical compounds which have proven effective in use are: sodium chlorate (must be handled carefully because organic matter treated with it becomes very combustible); combinations of sodium chlorate and calcium chloride; borates; arsenates; substituted urea compounds; and combinations of urea derivatives with chlorates and borates. It is possible that there are still other compounds with equal records of use and effectiveness.

These chemical compounds are marketed under a variety of names. Each product carries the manufacturer's recommendation for rate and method of application. Most of them are soluble or wettable powders, and are designed for spray application. Some can be applied in dry form, and one or two *must* be applied that way. For dry application, sprinkling or precipitation is relied on to carry the sterilant to the root zone. Rates of application vary from a low of about 50 pounds to the acre to a high of about 1,800 pounds to the acre.

The service history of petroleum derivatives is limited as compared to the chemicals, but certain petroleum distillates are naturally toxic to plants. Also others less toxic, such as diesel fuel, have been fortified with soluble sterilants. One such mixture is diesel fuel containing 1½ percent of pentachlorophenol. These sterilants are sprayed on the subgrade at the rate of two-thirds to one gallon per square yard in increments of about two-tenths gallons. After spraying they should be allowed to penetrate and weather for several days before the lining is placed.

2.07 TESTING, DESIGN, AND CONTROL

In general, the established principles and procedures of testing, design, and quality control apply to the construction of asphalt linings just as they do to other uses such as asphalt pavement construction for highways. These are described in the Asphalt Institute publications listed in Article 1.03, Chapter I. Sometimes special tests must be devised to meet conditions to which a particular asphalt lining will be subjected. Completing these necessary steps of testing, mix design, and determination of control procedures both prior to and during the construction of asphalt linings is most important.

B. Asphalt Concrete

2.08 GENERAL

Asphalt concrete (a carefully controlled mixture of asphalt cement and graded aggregate, mixed, placed and compacted under elevated temperature) is especially well adapted to the construction of linings for all types of hydraulic structures. It may be used for the entire lining structure or it may be a principal part of a more complex lining. Depending on mix design and placement, it may serve as a relatively impermeable layer or as a porous layer. Properly mixed and placed, it forms a stable, durable and erosion-resistant lining. The plasticity which enables asphalt concrete to undergo limited deformation

Figure II-5—Asphalt Concrete Lined Canal

without disruption is a unique characteristic which makes it particularly effective in hydraulic structures. Slight movement or differential settlements in the subgrade can thus be accommodated without damage to the lining structure. Large settlements or movements of the subgrade can severely damage large areas of a hydraulic lining. The ease and effectiveness with which these damaged areas of an asphalt concrete lining can be repaired is also an important attribute.

2.09 MIX DESIGN

Research and experience has shown that asphalt cements of 40-50 or 60-70 penetration grades are preferable for hydraulic linings. These harder asphalt cements produce linings which are more resistant to the destructive action of water, the growth of vegetation, and extremes of weather. They are more stable on side slopes than linings made with softer asphalt cements but they retain sufficient flexibility to conform to slight deformation of the subgrade.

Mix design of asphalt concrete for hydraulic linings follow general principles, such as are described in The Asphalt Institute's *Mix Design Methods for Hot-Mix Asphalt Paving,* Manual Series No. 2. However, there are certain special principles. The mixes must have a high degree of workability while hot. This is to permit quick and efficient placement by hand methods, by conventional paving machines, or by special slip-form paving machines. The completed lining must be highly impermeable (except for the porous type) and have a smooth erosion-resistant surface. And the mix must be stable enough to support its own weight on relatively steep slopes, though it need not have the very high stability of the highway pavement type mix.

The type of mix which meets these requirements may be termed the "hydraulic" type of asphalt concrete mix. To insure impermeability an essentially voidless mix is required. Therefore, hydraulic mixes are designed with dense-graded aggregates and high mineral filler and asphalt cement contents. In the field they should be compacted to at least 97% of laboratory density attained by the Marshall Method (35 blows on each side of specimen) or a comparable degree of compaction. (See Asphalt Institute Manual Series No. 2) The mix should be made from sound aggregate with the maximum size of from one-third to one-half the finished thickness of the pavement. Generally, for the two to three-inch thick lining the maximum size of aggregate permitted is three-fourths inches. Aggregates of low angularity are beneficial to the required workability of the mix. Table II-1 lists some gradation specifications (and one case of an actual gradation used) which research and experience have indicated are suitable for use in hydraulic lining construction.

Table II-1—SUGGESTED MIX COMPOSITIONS FOR DENSE-GRADED ASPHALT CONCRETE LININGS

	For Min. Thickness of 1½″	For Min. Thickness of 1″	A USBR Specification	From Wyoming Canal at Riverton
Sieve Size	Percent Passing	Percent Passing	Percent Passing	Percent Passing
¾″	100		100	100
½″	95-100		85-100	87.9
⅜″	......	100	......	......
No. 4	60-80	90-97	55-80	62.3
No. 8	45-60	70-85	......	......
(No. 10)	......	......	35-60	53.4
No. 30	28-39	42-52	......	......
(No. 40)	......	......	18-30	28.4
No. 100	16-25	20-28		
No. 200	8-15	10-16	5-12	9.9
Asphalt Cement Percent by Weight of Total Mix	6.5-8.5	7.5-9.5	6.5-9.0	7.8

A properly designed mix for the construction of a porous lining will have a greatly reduced sand content and be practically devoid of mineral dust. As a consequence, the content of asphalt cement must also be reduced. Depending on the intended use, some of these mixes have a more open gradation than others. Table II-2 gives a gradation specification (in column 1) for a porous lining used for water reservoirs of the Los Angeles Department of Water and Power. This is a surface layer of a multi-layer structure (see Figure II-13) designed to be sufficiently porous to permit drainage of excess water from the next lower earth layer into the reservoir. Column 2 gives a gradation specification of the East Bay Municipal Utility District for a free draining bottom layer of another multi-level structure (see Figure II-14). This layer permits water to drain freely to lowest levels of the lining structure where it is collected and carried off by tile drains.

Table II-2—SUGGESTED MIX COMPOSITIONS FOR POROUS ASPHALT CONCRETE LININGS

	Column 1	Column 2
Sieve Size	Percent Passing	Percent Passing
1"	100	100
¾"	95-100	93-100
½"	85-95	......
⅜"	......	35-65
No. 4	44-56	5-25
No. 8	30-40	2-15
No. 16	......	0-7
No. 30	13-22	0-3
No. 100	3-8	......
No. 200	1-4	......
Asphalt Cement Percent by Weight of Total Mix	5-6	2-4

2.10 CONSTRUCTION METHODS

Asphalt concrete hydraulic linings should be prepared and placed in accordance with established practices. The Asphalt Institute's *Specifications and Construction Methods for Hot-Mix Asphalt Paving,* (S. S. No. 1), and *Asphalt Paving Manual,* (M. S. No. 8), may be followed as general guides. However, some special aspects of construction pertaining to this particular use should be mentioned.

These mixes are placed on side slopes, on curved sections and in angles and corners, as well as on flat planes. This may be done by regular finishing machines, by spreader boxes, by hand methods, by special slope pavers or slip-form canal pavers, or by some combination of these methods.

Asphalt concrete for hydraulic linings should be very thoroughly compacted, as indicated in Article 2.09, Mix Design. Light steel wheel rollers are generally used for compacting the soft and highly workable mixes used.

Vibratory steel wheel rollers and rubber tired rollers have both had limited use for this work. Vibrating, heated ironing screeds—hand-held, or the larger ones such as are incorporated in slip-form pavers—are also effective compaction tools. Power winches and cables are generally used to maneuver towed rollers on side slopes. Self-propelled rollers may be used on flat sections and on very gentle side slopes.

The finished lining should be true to specified grade and cross-section. It should have the specified thickness though plus or minus variations of not more than 15 percent may be permitted. Linings should be as thick as necessary for the use and the stresses involved, but practical experience indicates that a finished thickness of one and one-half inches of asphalt concrete is the minimum that should be specified.

When the compacted thickness of lining is to be three inches or more, it should be placed in two courses, with all construction joints staggered. This will result in a greater degree of tightness and impermeability to resist high heads of water or other severe stresses.

In placing and compacting asphalt concrete lining, all joints must be very thoroughly bonded. In general, the techniques are those described in Articles 5.13 and 5.14, The Asphalt Institute's *Asphalt Paving Manual,* (M. S. No. 8), except that emphasis should be on a tight bond for impermeability. Smoothness for hydraulic qualities is also important. Extreme care should be taken with cold joints and the newly developed infra-red joint heater could be an extremely valuable tool for this purpose.

Side slopes should be as flat as is consistent with other construction requirements. Flat slopes avoid the concentration of compressive stresses at the lowest portions of the lining and make for ease of construction. This often means an over-all economy in spite of added expense for the subgrade. Table II-3 gives maximum steepness of slope that should be permitted for various vertical heights of slope paving.

Figure 11-6—Ygnacio Canal Lining Operations

Table II-3—SUGGESTED LIMITATIONS SIDE SLOPE STEEPNESS

Vertical Height of Slope Paving	Maximum Steepness Horizontal:Vertical
Up to 10 feet	1½ : 1
10 feet to 20 feet	1¾ : 1
20 feet to 40 feet	2 : 1
Over 40 feet	2½ : 1

The use of wire mesh reinforcement in asphalt concrete linings is *not* recommended, except in certain special cases (Article 2.13, Asphalt Concrete Storm Channels and Drainage Ditches). Experience has shown that, due to the spring in deformed wire and the differential expansion between wire and asphalt, such a reinforcement sometimes does more harm than good. When good construction and design procedures are followed, wire reinforcement is not generally needed for added strength.

2.11 CANAL AND LATERAL LINING

Asphalt concrete provides a very effective and high-type lining for canals and laterals. Such a lining is relatively impermeable. It is also smooth, erosion resistant, durable, and has excellent hydraulic properties. Normally, it is constructed to a thickness of two inches. Thicknesses of three to four inches are used for severe conditions, such as high velocities, turbulence, heavy uplift or hydrostatic back pressure, or low subgrade support. Thicknesses greater than four inches should not be required except under extraordinary circumstances.

Asphalt concrete canal lining can be readily placed and compacted by improvised methods and equipment usually used in conjunction with such conventional paving machinery as may be adaptable. For instance, on one lining placement job, the mix was dumped into a portable hopper which had a short conveyor belt for depositing it on the side slopes. Timbers were set at 11 to 12-foot intervals to guide a heavy steel screed which was pulled up the slope by a dragline to smooth and partially compact the mix. To aid in compaction, a plate vibrator had been welded to the screed. Final compaction was accomplished by single steel-wheel rollers.

It is usual in this type of work for such a single steel-wheel roller to be maneuvered by a line from a tractor winch or crane boom. In some cases two lines, one from each direction, are used to maneuver the roller. Often some hand tamping must be used in places which the roller cannot reach, such as the junction of the invert with the side slope.

Other improvisations, such as specially constructed spreader boxes, can also be used. Where canal bottoms are wide enough and have good alignment, standard paving machines and rollers should be used.

Specially designed and manufactured slip-form ditch

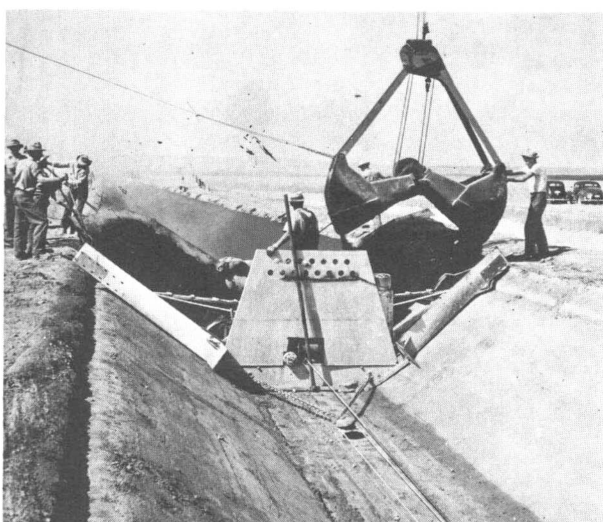


Figure II-7—Paving a Canal with a Slip Form Paver

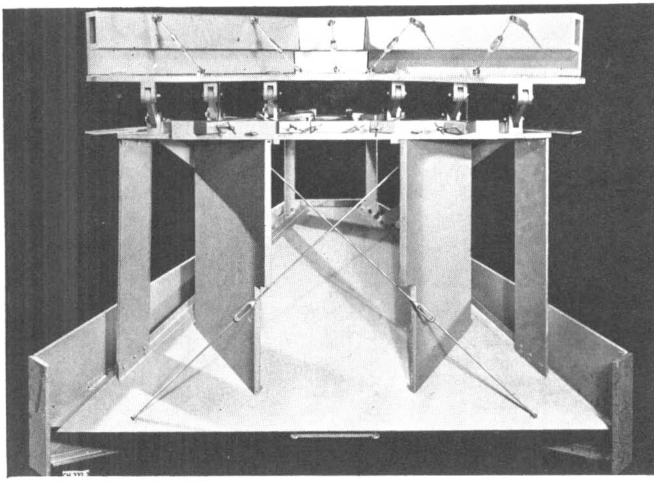


Figure II-8—Model of Slip Form Canal Paver

and canal pavers offer the most in economy and efficiency. These machines normally ride skids in the excavated and trimmed earth ditch, but sometimes are mounted on low pressure pneumatic-tire wheels. Each machine has a hopper into which the hot asphalt mix is dumped. The mixture is spread, struck off to proper thickness, and finally smoothed and compacted by a heated, weighted, vibrated and independently controlled ironing screed at the rear of the machine. With this, no further finishing or rolling is necessary. A slip-form paver can be pulled forward by line from a tractor, using either the motive power of the tractor or a power winch. The slip-form machine may have its own powered winch for this purpose. It is necessary that the strike-off screed be provided with independent controls, by section, to regulate the thickness of the finished linings. Also, thickness and grade alignment are best controlled when the forward pull is along the center line of the canal. Pictured in Figure II-8 is a model of one of the slip-form canal paver types developed by the U. S. Bureau of Reclamation.

Most installations of asphalt concrete canal and lateral

Figure II-9—Special Slope Paver and Hopper Car

linings on record are those made by the United States Bureau of Reclamation. Earliest installations were placed in the Contra Costa Canal, Central Valley Project, California, and in the Snipes Mountain Canal, Yakima Project, Washington in 1939. In 1947, some 88,000 square yards of asphalt concrete canal lining were placed on the Pasco Pump Lateral System near Pasco, Washington, using for the first time a specially designed slip-form paving machine. There has been continued use of these machines. They were used to place the lining of the Ygnacio Canal, Central Valley Project, California, and on some of the canals and laterals of the Riverton Project in Wyoming. During the fall of 1957, an estimated 40,000 square yards of a four-inch thick lining were placed on the downhill slope of the New York Canal, Boise, Idaho, using improved methods of placing.

2.12 RESERVOIR LINING

An asphalt concrete reservoir lining may be constructed either of the Table II-1 type of well-graded, dense, rich mix, or one of the porous types such as Table II-2 describes. Usually this so-called porous type is one layer of a multi-layer type of lining structure. The large cross-sectional areas of reservoirs make it relatively easy to use standard asphalt concrete paving machines and other mechanical equipment in their construction. On the slopes, cables from tractor or other winches stationed on the top are required for controlling and maneuvering the equipment, whether it is standard or special. A combination of standard paver, dump truck and 4½-ton roller, cable-controlled and maneuvered, has been successfully used to pave a reservoir slope as steep as 2:1. However, most slopes paved in this manner have been 3:1. Special slope pavers have been manufactured and used, as have been special hopper cars to feed hot-mix to the slope paver.

On some of the smaller reservoirs, and parts of the large reservoirs that are difficult to get at, hand methods of placing, spreading or compacting the mix are used. In general, standard paving machines are used on the reservoir floors. A thickness of three (3) inches is most generally used for reservoirs lined with a single layer of dense impermeable asphalt concrete. Four-inch thick linings have been employed throughout on some of the larger reservoirs, and on the critical portions (such as the

Figure II-10—Paving Slope by Improvised Methods

slopes of fill sections) of others. For very small reservoirs like the average farm pond, a thickness of two inches is sufficient.

While asphalt concrete lined reservoirs have been constructed in nearly all parts of the United States, such linings are most numerous in the Pacific Coast area. Because it has a desirable degree of flexibility which permits some deformation under stress, asphalt concrete was an early choice of California engineers. They found it made an economical, durable lining which would resist damage by earthquake. While most of these linings have been constructed since 1940, one at Oroville, California, was placed in 1924, and another at Santa Fe Springs in South Los Angeles in 1928.

Two California municipal water departments have pioneered in the development of asphalt reservoir linings. One of these, the Los Angeles Department of Water and Power, uses a multi-layered design with a three-inch surface layer of a relatively porous asphalt concrete such as that described in column 1 of Table II-2. This provides a smooth, erosion-proof, durable coating, easy to clean and maintain, and through which any excess water from the lining structure may drain into the reservoir

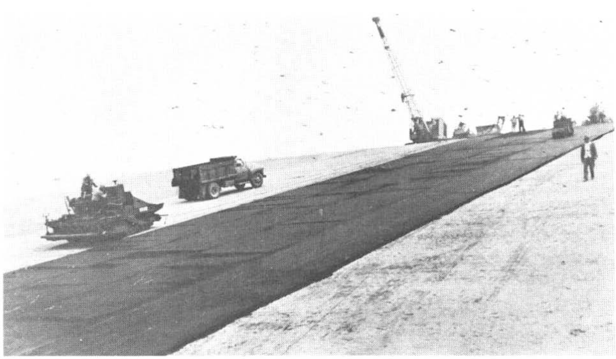


Figure II-11—Paving Slope with Standard Equipment

Figure II-12—Asphalt Lined Baldwin Hills Reservoir, Los Angeles

itself. Imperviousness is provided by an underlying blanket of select compacted earth. Perhaps the most complex lining of this type was designed for the Baldwin Hills Reservoir. Here it was necessary to prevent any leakage of water whatsoever into the subgrade. As installed, the lining actually consists of four layers: (1) an asphalt membrane seal, to stop any leakage of water into the subgrade; (2) a four-inch layer of cemented pea gravel, to drain and collect any water that does seep through the earth fill; (3) a compacted earth blanket, from 5 to 15 feet thick; and (4) the surface lining of three inches of porous asphalt concrete.

A thin sprayed coating may be used to protect the surface of the asphalt concrete from the damaging effects of surface tension caused by repeated wetting and drying of clay, silt, algae, and other very fine particles. One such coating consisted of a mixture of portland cement, ten gallons of water per sack of cement, and 7½ pounds

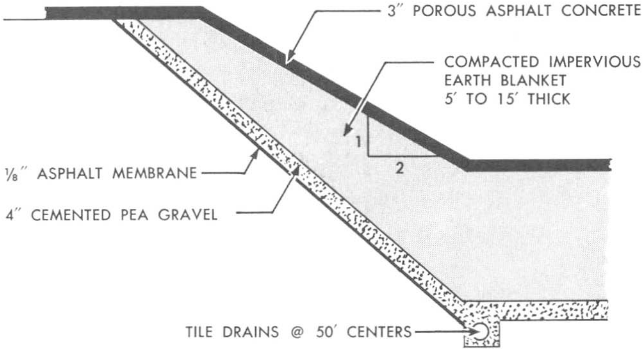


Figure II-13—Baldwin Hills Reservoir (Simplified Cross-Section)

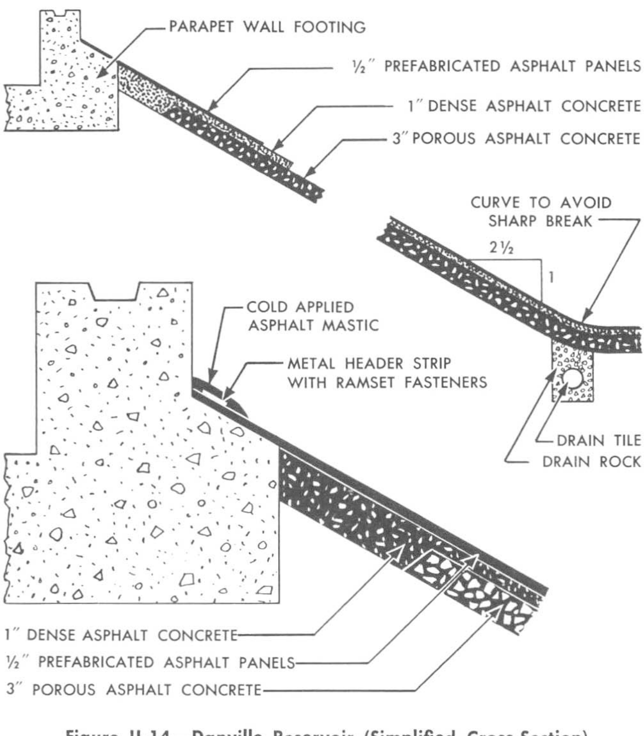


Figure II-14—Danville Reservoir (Simplified Cross-Section)

of calcium chloride per sack of cement. It was applied at the rate of one sack of cement (plus other ingredients) for 600 square feet of lining.

The East Bay Municipal Utility District, Oakland, California, has through long years of experience developed a very economical and efficient design of the multilayer type, using asphalt in all layers. The first layer on the subgrade is three inches of a porous asphalt concrete, which permits drainage of any subgrade water to the lowest point where it is carried off by tile drains. This is the open-graded mix described in column 2 of Table II-2. On this layer is placed one inch of a relatively dense asphalt concrete, which forms the backing for the surface layer of ½-inch prefabricated asphalt panels. The last, carefully engineered and placed, comprises the waterproof portion of the lining structure. This lining was designed to prevent the seepage of water into the subgrade and to prevent build-up of hydrostatic back pressure. Loss of foundation support and other difficulties caused by seepage and subsequent waterlogging made such a design necessary. The 23,000,000-gallon Maloney Reservoir and the 14,500,000-gallon Danville Reservoir, recently constructed, have linings of this design.

2.13 STORM CHANNELS

Asphalt concrete has long been used to line storm channels and drainage ditches, varying from shallow highway or street gutters through narrow high-velocity storm water channels to constructions for large river-size channels. The main purpose of such a lining is to give the channel good hydraulic properties and to prevent erosion—that is, to protect its banks and nearby property from all destructive effects of water. The lining of storm channels must be durable, tough, and have a measure of resilience to meet the severe conditions of high water velocity and turbulence that are frequently accompanied by scouring sand and high impact forces of boulders and debris. Experience has proved that a properly

Figure II-15—Storm Drainage Channel, Completely Paved

Figure II-16—River Size Storm Channel, Bottom Unpaved

designed, dense, asphalt concrete lining can successfully meet these severe conditions.

Asphalt concrete storm channel linings are usually constructed to three-inch thickness. However, thicknesses of six to nine inches have been placed to meet severe turbulence, velocities in excess of fifteen feet per second, or very high hydrostatic back pressures. For small ditches carrying water of medium or low velocity, thicknesses of two inches may be used. Since impermeability is not generally a requirement for storm channel linings, it is a good idea to provide drains through the lining at points where back pressure is likely to develop. Normally, the entire channel is lined. But in some cases, particularly the larger river-size channels, the lining is confined to the side slopes or banks. By leaving the bed of the channel unlined, "spreading areas" are created for desirable infiltration of the storm waters to the water table.

In the situations where the sides only have been paved, various methods have been used to protect the pavement from scour and undercutting at the toe of the slope. An effective one is to extend the asphalt concrete pavement

A. Improvised Strike-Off Screed

B. Compaction

Figure II-17—Flood Channel Paving Operations

for some four to six feet below the stream bed level. This can be done only if the channel is dry at the time of construction. Another method is to place heavy riprap at this critical point. A third method extensively used in Los Angeles County flood control channels is the reinforcement of the asphalt concrete with wire mesh. This allows the pavement to conform to subgrade changes caused by undercutting without breaking away entirely from the parent mass.

The use of wire reinforcement is not recommended unless severe scour and undercutting are anticipated. Then about a four-inch woven mesh of a 14 to 16 gauge galvanized wire should be used. Many fence meshes are suitable. Ties should be made about once every four inches using wire of the same gauge as the fence. Wide rolls make for a lesser amount of tying. The reinforcement should be securely anchored to the slope by metal stakes or ties to some form of dead men. Some method of insuring placement of the wire at about midpoint of the asphalt concrete must be used. This may be done by expendable props placed under the wire, or by using hooks to pull the wire up into the mix after it is placed but before it is compacted.

Other construction methods closely follow those already described for reservoir and irrigation canal linings. Small channels and ditches may be lined by hand methods or by special slip-form canal lining machines. On the larger channels, the asphalt concrete lining may

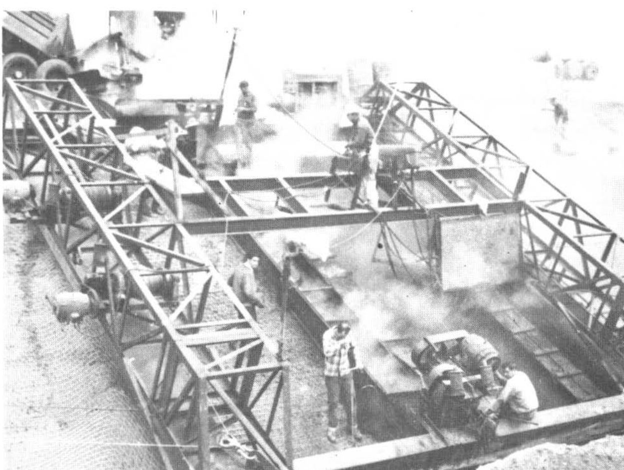


Figure II-18—Slope Paving Machine in Operation, Santa Ana River, Calif.

be placed by various combinations of standard paving equipment, specially designed slope pavers, hand raking and spreading along with timber forms to guide strike-off screeds. Compacting may be done by regular rollers, or by the single towed-type of roller, either plain or vibratory.

Asphalt concrete storm and drainage channel linings have been used in installations throughout the United States. However, their greatest use has probably been in the Pacific Coast area, where flash-flood conditions are particularly severe, and where intense land development has made strict confinement of storm water run-off necessary to prevent large property damage and loss of land by erosion. The Los Angeles County Flood Control District has been a leader in this field.

2.14 POOLS

Because of its inherent qualities asphalt concrete is an excellent material for lining or paving swimming pools. Used alone or in combination with other asphalt materials, it can provide a durable, impermeable lining with a smooth surface which is easy to clean and maintain. In essence, a pool is just a reservoir, or pond, with certain special construction details added; it utilizes the same methods of construction and the same mix design. Because swimming pools must be emptied periodically for cleaning, it is particularly important that any possibility of back pressure from ground water be eliminated. Hence, the subgrade must be a carefully compacted, substantial and well-drained course with a positive means for draining off any excess ground water. Subgrade side slopes should not be steeper than one and one-half horizontal to one vertical, with more gentle slopes preferred. Though this may somewhat restrict swimming space in a small pool, it may actually enhance the design of a large recreational type pool.

A very large pool was constructed early in 1960 by the city of Wallingford, Connecticut, as a part of its park and recreation system. This pool has a water surface area of more than 60,000 square feet and water depths ranging from three feet at the shallow end to nine and a half feet in the diving section. It is roped off into three areas. Approximately one-third, sloping to a maximum depth of three feet, is for young children and non-swimmers. Beyond the guard rope is a full 50 meter racing pool with depths up to eight feet. The third and deepest part provides a large area for diving.

The Wallingford pool existed for ten years as an unpaved community swimming pond, fed by a constant flow of water from a brook. Silt from the brook gradually created a thick layer of mud on the bottom. Finally, it was decided to create a modern swimming pool at this old site by constructing purification and desilting works for the water and paving the surface with a dense asphalt concrete.

After removing about 500 cubic yards of accumulated silt, 1,000 cubic yards of gravel was placed on the natural sand subgrade. A compacted layer of crushed stone,

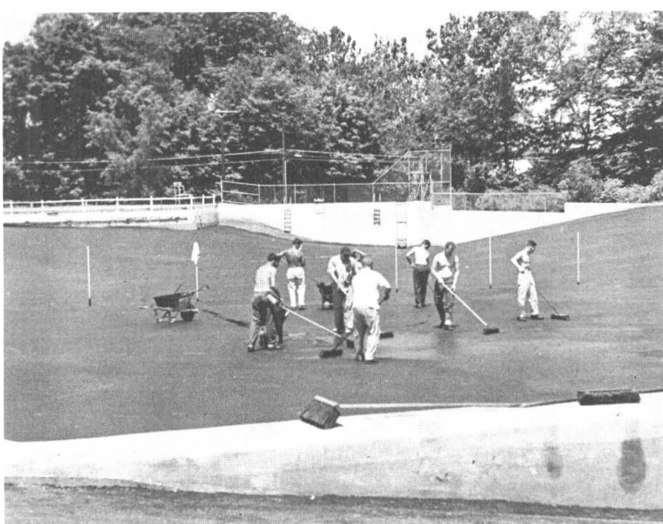


Figure II-19—Asphalt Concrete Lined Swimming Pool, Wallingford, Conn.

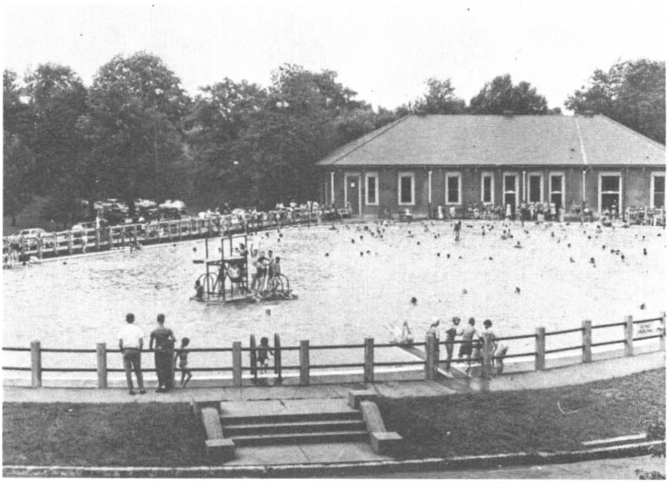


Figure II-20—Pool Resurfaced with Asphalt Concrete, Crescent Hill, Louisville, Kentucky

four to six inches thick and ranging from three-fourths inch to one and one-half inches in size, was placed on the gravel. The asphalt concrete lining was placed on this base in two courses—a two inch binder course and one inch of a dense surface type mix. The surface was primed, given a seal coat of emulsion with filler and painted a suitable color.

Another very large swimming pool in Crescent Hill, Louisville, Kentucky, was resurfaced in 1948 with asphalt concrete. This oval-shaped pool, 175 feet long by 150 feet wide, was originally of rigid-type construction, but had cracked and disintegrated so badly that it was decided to resurface with asphalt. Construction procedure consisted of patching, priming with a tack coat of rapid-curing liquid asphalt, and resurfacing with one and one-half inches of hot-mix asphalt concrete. The bottom of this pool was paved using standard paving equipment and a ten-ton roller for compaction.

Wading pools are shallow bowls sloping from zero to depths of about eighteen inches. Their surfaces are not called upon to resist any heavy superimposed loads, either from water pressure above or back pressure from ground water below. Hence, two inches of asphalt concrete, properly placed and compacted on a well-drained substantial foundation, will provide a thoroughly adequate structure.

Since impermeable asphalt concrete surfaces are not affected by freezing, asphalt-paved swimming and wading pools may be safely converted into excellent skating rinks in areas where the climate is cold enough to provide a proper ice layer.

Surfaces of asphalt concrete pools may be tinted and decorated by the use of suitable paints—that is, those having bases of a plastic (epoxy or resin), asphalt, rubber, or water. Oil-based paints should not be used, as oil is a solvent of asphalt. Asphalt concrete will not impart any offensive odor, taste, or other deleterious property to water. It has been widely approved for lining storage reservoirs for drinking water. Because there is a wide variation in regulations regarding swimming pools, all plans should be cleared with local authorities before construction is begun.

2.15 PONDS

Farm storage ponds, fish ponds, sewage lagoons, storage ponds for industrial wastes, and others, are all in effect reservoirs constructed for special purposes. Asphalt concrete makes an excellent lining for all; it is durable, economical, impermeable, erosion resistant, smooth, and easy to clean. It also withstands the action of saline solutions, acids, and most industrial wastes, except those containing appreciable quantities of petroleum or other asphalt solvents. Construction methods follow those practices already described. Since most ponds are shallow, two inches of asphalt concrete, properly placed and compacted on a smooth, substantial and well-drained subgrade, provide a sufficiently thick lining.

C. Buried Asphalt Membrane

2.16 GENERAL

An asphalt membrane lining (hot sprayed type) consists of a continuous layer of asphalt usually without filler or reinforcing of any kind. It is covered, or buried, to prevent weathering (oxidation) of the surface and to protect it from mechanical damage. Its cover may be another layer of a multi-layer lining structure, but generally it is native soil, gravel, asphalt macadam, or other substance specifically placed for this purpose. Asphalt membranes are placed to thicknesses of from 3/16 to 5/16 inch, and constitute continuous waterproof layers extending throughout the length and breadth of the canal, reservoir, or other structure being lined. Asphalt of special characteristics is used to make these membranes into tough, pliable sheets which readily conform to changes or irregularities in the subgrade. Buried under a protective coating, an asphalt membrane will retain its tough, flexible qualities indefinitely. It is one of the least expensive of current lining types, yet it affords seepage control equal to any.

2.17 CHARACTERISTICS

Asphalts used to make membranes must have very low temperature susceptibility and a high degree of toughness and durability. Further, membrane asphalt must have a high softening point to prevent sagging or flow down a slope if the cover material should be accidentally removed and the membrane exposed to the sun. The material must also be sufficiently plastic at operating temperatures to minimize the danger of rupture from earth movement; also it must not exhibit excessive cold flow tendencies in order to effectively resist the hydraulic head to which it is subjected. Considerable laboratory research and field trials have gone into the selection of the asphalts which are suitable. Those which meet the characteristics are the so-called air-blown asphalts, or more properly asphalts blown with or without chemical modifiers. The specifications in Table II-4 list characteristics and requirements which have been adopted by The Asphalt Institute.

Table II-4—SPECIFICATIONS[1] FOR ASPHALT FOR HYDRAULIC MEMBRANE CONSTRUCTION

Characteristics	AASHO Test Method	ASTM Test Method	Grade
Softening Point (Ring and Ball), °F.	T 53	D 36	175-200
Penetration of Original Sample:			
At 32°F., 200 g., 60 sec.	T 49	D 5	30+
At 77°F., 100 g., 5 sec.			50-60
At 115°F., 50 g., 5 sec.			120—
Ductility at 77°F., cms.	T 51	D 113	3.5+
Flash Point (Cleveland Open Cup), °F.	T 48	D 92	425+
Solubility in Carbon Tetrachloride, %	T 44[2]	D 4[2]	97.0+
Loss on Heating, 325°F., 5 hrs., %	T 47	D 6	1.0—
Penetration After Loss on Heating, % of Original	T 49	D 5	60+
General Requirements	The asphalt shall be prepared by the refining of petroleum. It shall be uniform in character and shall not foam when heated to 400°F.		

[1] The above specifications should be considered tentative.
[2] Except that carbon tetrachloride is used instead of carbon disulphide as solvent, Method No. 1 in AASHO Method T 44, or Procedure No. 1 in ASTM Method D 4.

2.18 SUBGRADE PREPARATION

The subgrade on which an asphalt membrane is to be placed is constructed (excavated or filled) to the proper grade, taking into account the over-all thickness of the protective cover. Although the asphalt may be satisfactorily applied on very steep side slopes, it has been demonstrated that earth and gravel cover will not be stable on slopes steeper than 1¾:1 in operating canals and other structures, with a slope no steeper than 2:1 being preferred.

Most rough subgrade surfaces should be dragged to remove any sharp angles in the section and to gather any large rocks for later removal. The drag may consist of a structural steel member or the tread of a track-laying tractor. The tractor-tread produces a slightly better surface since there is no tendency to bridge the low spots as occurs with a rigid drag. Two trips are generally adequate to dress a subgrade for smooth rolling. An excessively granular or gravelly subgrade surface should be choked with suitable fine-grained material before rolling so as to prevent loss of membrane asphalt to fill the voids.

Smooth steel rollers are used to complete the subgrade preparation, with two passes usually being sufficient for a satisfactory surface. The resultant smooth surface facilitates the construction of a uniformly thick impermeable membrane, and significantly reduces the quantity of asphalt required. The rolling operation is *not* required as a compactive measure to increase the bearing power of the subgrade.

Due to the surface tension characteristics of the very hot asphalt, dust bubbles and pinholes tend to form when it is applied over a dusty subgrade. A very light sprinkling of water over the subgrade, just prior to the asphalt application, will materially reduce this tendency.

When conditions indicate that growth of weeds or other plants is likely, soil sterilants as discussed in Article 2.06 should be applied to the subgrade.

2.19 ASPHALT APPLICATION

The application of asphalt forming the membrane should be done with great care, since the water-tightness of the completed structure is dependent on it. Membranes may be constructed during adverse (cold and wet) weather, provided sufficient asphalt and adequate

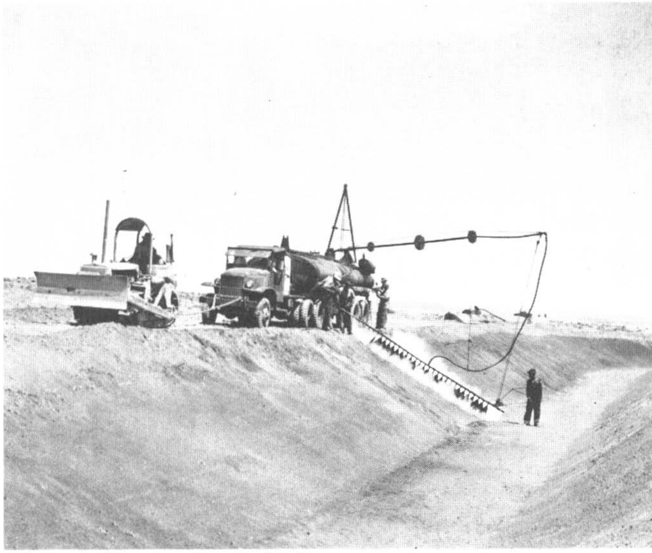


Figure II-21—Applying Asphalt Membrane by Spray Bar

care in placing are used. Application can be made under nearly any air or ground temperature, varying from over 100° to below zero. Application temperature of the asphalt should be from 350° to 400°. Temperatures above 400° should not be permitted because at higher temperatures objectionable fogging or adverse changes in the character of the asphalt could occur on emergence into free air. The only equipment required is the standard asphalt distributor, connecting hoses, hand spray bars, long spray bars, and booms for slinging spray bars to the sides of the distributor. If the burners of the distributor cannot keep the asphalt at the required heat, the addition of a retort-type heater is required. Spray bars should be of the full circulating type, and should have the slotted-type nozzles spaced to give a proper overlap of each fan of asphalt. All connecting hoses should be well insulated.

To obtain an impermeable membrane of sufficient thickness, not less than 1.25 gallons a square yard of

Figure II-22—Applying Asphalt Membrane by Hand Sprays asphalt should be used for any installation, with a specified 1.5 gallons a square yard being the preferred practice. Under normal conditions this will produce a membrane from 3/16 to 5/16 inch thick. Under adverse conditions, such as a frozen, rough or muddy subgrade (or the possibility of appreciable subgrade movements), as much as 2.5 gallons a square yard have been required. Two to three applications should be used in building up required membrane thickness. This gives a desirable "ply" effect, minimizes the occurrence of thin areas and holidays, and avoids excessive run-down of asphalt on the slopes. However, the asphalt is applied in essentially one operation, with successive passes or applications following immediately one on the other. This is possible since the high-softening-point asphalt congeals rapidly.

The hot asphalt is applied at about 50 pounds pressure and generally through spray bars twenty feet or more in length. These bars can be mounted on the rear of the distributor but more often are slung to the side, by boom and cable, as shown in Figure II-21. This enables the distributor to apply asphalt to slope and bottom with maximum efficiency and without the necessity of traveling over the membrane on successive passes. Hand held spray bars can be used for small jobs, for difficult corners, and for patching thin areas. Hand spraying requires much skill. It should be done in long slow sweeps, with the bar turned so the spray is normal to the subgrade surface. Hand or distributor bars should move over the ground at a uniform rate and at a distance (not less than six inches nor more than eighteen inches) that will prevent the asphalt spray from churning subgrade soil into the membrane.

All asphalt membrane should be carefully inspected immediately after placing. All thin areas and holidays should be marked and then corrected by hand sprays. Care should be exercised to avoid injury to the membrane during inspection and correction work.

Figure II-23—Placing Cover Over Membrane by Dump Truck and Dozer, Rutland, Vermont Reservoir

2.20 COVER MATERIAL

A cover material is always necessary to keep the asphalt membrane from weathering by sunlight, protect it from mechanical injury, and to hold it in place and prevent lifting and destruction by flowing water or hydrostatic back pressure. This covering layer should be placed as soon as possible after the application of the membrane. Where the asphalt membrane is part of a multi-layer lining structure, the outer layer or layers serve as cover. Usually, earth is used for this cover, and a minimum thickness of 12 inches is recommended. In very large canals, reservoirs, or other structures, cover thicknesses of as much as three feet have been used. Excavated material suitable for cover use should be stockpiled at conveniently close locations. If the excavated material is not suitable, it will be necessary to borrow and haul soil for cover. Graded sands and gravel generally constitute the most stable cover material, while water-deposited silts are the least desirable. Cover material is generally placed by casting from draglines. However, many methods of placing cover with standard equipment can be devised, particularly in large reservoirs. No equipment should operate on the membrane until it has an adequate thickness of cover on it; neither is it good practice to bulldoze soil over a berm and down a slope since the membrane may be injured by sliding soil or rolling rock. Cover containing large rock and boulders may puncture a membrane; therefore, when necessary to use earth containing them, about three inches of fine sandy soil should be placed over the membrane first.

Normally soil cover is *not* compacted but is allowed to gradually reach a normal density through saturation and settlement in use. Cracks appearing near the top of the soil cover due to normal settlement during the first few months of service should be bladed over as a maintenance item. While not generally done, soil cover may be compacted by smooth-faced steel rollers to meet severe conditions; such treatment also may be needed when the soil is of low stability. It is recommended that the surface of a soil cover be dragged to improve appearance of the completed work and provide some densification.

Where water velocities in a canal exceed 1.5 feet per second, where there is wave action or turbulence or where livestock may enter or cross, it is advisable to face the cover with a three to six-inch thickness of pit-run or crusher-run aggregate. The greater the velocity, turbulence or wave action, the larger should be the maximum size of aggregate in the facing. Full scale riprap should be used on large dam sections. Asphalt macadam, in which carefully graded aggregate is placed to a two or three-inch depth over the membrane and then penetrated with asphalt, may be used in lieu of other cover. Since rapid draw-down of water in a structure after extended periods of peak levels may cause sloughing of some earth covers, draw-down should be carefully controlled.

Care in the construction and maintenance of the membrane cover will add much to the serviceability and longevity of the completed lining structure.

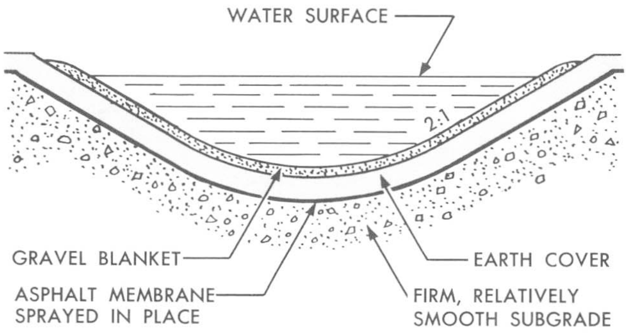


Figure II-24—Buried Asphalt Membrane Canal Lining

2.21 CANAL AND LATERAL LINING

Buried asphalt membrane construction was developed by the U. S. Bureau of Reclamation in cooperation with the asphalt industry to provide an efficient, low-cost means of controlling seepage in earth-lined irrigation structures. The first installation was in a lateral of the Klamath Project, near Klamath Falls, Oregon in 1947. Since that time, the Bureau of Reclamation has lined many miles of canal and lateral with asphalt membrane lining. These linings, some in use for more than ten years, are giving excellent service. To date there has not been a case reported where deterioration of the asphalt itself has contributed to failure of the membrane. Such failures as have occurred can be attributed to over-thin membranes, application of the membrane over a rough and uneven subgrade, loss of the protectional cover and subsequent exposure to weather and traffic, inclusion of fine subgrade material into the membrane, or rupture of the membrane due to movement of the cover.

2.22 RESERVOIRS AND PONDS

The efficiency and economy of the buried asphalt membrane make it useful in water storage reservoirs, farm ponds, ornamental ponds and a variety of hydraulic structures. It is particularly well suited to the construction of large shallow reservoirs such as are required for sewage lagoons, industrial storage and treatment reservoirs, and evaporation ponds. A protective cover for the asphalt membrane is not generally required on the bottom of sewage treatment structures; this is automatically provided by the deposition of solids. Also these structures are seldom, if ever, drained. However, the protective cover should be placed on the sides as usual.

One unusual use of an asphalt membrane was in the construction of a sand filter bed at Newburyport, Mass. Here the membrane was placed on the subgrade as usual, covered with three inches of sand for protection. This, in turn, was covered with the screened gravel and sand (total, approximately four feet) of the filter bed. Then from the filter bed to the top of the side slopes the membrane was covered with one foot of earth cover.

Figures II-23 and II-25 depict a water storage reservoir which was constructed by the city of Rutland, Vermont in the fall of 1954. This 85-million-gallon reservoir, a natural basin with an earth dam, has a surface area of about 14 acres. It has a typical buried asphalt membrane, which averaged about two gallons of asphalt per square yard covered with 12 inches of

Figure II-25—Buried Asphalt Membrane Lined Reservoir, Rutland, Vermont. (Reservoir partially filled—note marble slab cover on dam section)

sand and gravel. In addition, the upstream slope of the earth dam is faced with marble slap riprap.

Whittier and La Habra, California, both constructed municipal water supply reservoirs which employ asphalt membranes with cover layers of portland cement—concrete on the bottoms and gunite on the sides. One has a capacity of four million gallons and the other five million.

2.23 SEEPAGE CONTROL LAYERS

Buried asphalt membranes make very effective seepage control layers in earthen dams, levees, and embankments. Their use increases safety factor of these structures by preventing saturation and stopping the loss of material by migration. They may also cut down the required cross-section enough to result in a substantial saving. There is a great potential in this use of asphalt membranes.

Asphalt membranes have been placed as seepage control layers in the multi-layered lining structures of large water storage reservoirs such as those constructed by the Department of Water and Power, Los Angeles, and the East Bay Municipal Utility District, Oakland. The Baldwin Hills Reservoir, Los Angeles, employs a membrane as the bottom layer of a four-layer lining; this provides a positive water stop from the lining structure into the subgrade (see Figure II-13). The four layers of the recently constructed North Reservoir of the East Bay Municipal Utility District are shown in Figure II-26. Here the 3/16-inch layer of asphalt membrane, backed by a one-inch thickness of dense asphalt concrete forms a positive stop to prevent reservoir water from seeping through the lining into the subgrade.

2.24 MEMBRANE UNDERSEAL

An asphalt membrane placed by pumping the hot asphalt under an old deteriorated portland cement concrete lining offers an economical means of salvage. The hot liquid asphalt forms a leak-proof membrane by

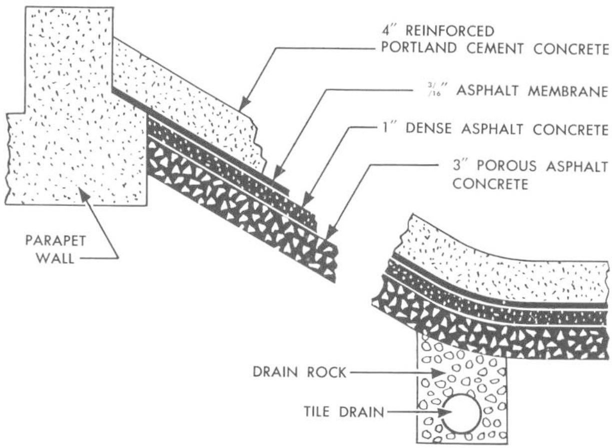


Figure II-26—North Reservoir (Simplified Cross-Section)

spreading out under the lining and filling all cavities. If desired, further pumping can restore subgrade support by actually floating the old lining. This accomplishes three things: (1) Even a slight floating assures that the membrane seal is complete; (2) the restoration of subgrade support minimizes the danger of further movement and cracking of the lining, and (3) the resultant realignment of the slabs restores the hydraulic efficiency and smoothness of the structure. The technique has long been used in highway and airfield pavement work.

Its first known use in hydraulic structures was by the U. S. Bureau of Reclamation in 1949. At that time about 400 linear feet of a badly cracked concrete lining of the Wyoming Canal, Riverton Project, was undersealed. Since then many other stretches of badly cracked and unevenly settled portland cement canal linings have been restored to usefulness by this method. Many types of surface coatings have been tried to control leakage through old deteriorated linings, but none have been effective except very thick and expensive overlays of shot-crete or asphalt concrete. Other advantages of the undersealing method are: It may be placed in subfreezing weather; the work can be done very rapidly, reducing the time when needed water supply channels are out of service; the necessary asphalt and equipment are usually readily available.

Preparation of the old surface for undersealing generally consists of drilling holes through the surface. The holes should be about 1½ inches in diameter and spaced so as to have one hole for each 10 square yards of pavement. Where there has been no settlement, the holes should be drilled 12 to 18 inches from existing cracks or joints. Where there has been settlement this spacing should be increased to 24-36 inches. Compressed air is used to blow the holes immediately before pumping begins; this cleans leakage channels and removes mud and water from below the surface. Asphalts for under-

Figure II-27—Undersealing Portland Cement Canal Lining with Asphalt

sealing are described on page 7, Asphalt Institute Specification Series No. 2, *Specifications for Asphalt Cements and Liquid Asphalts,* and on page 4, Construction Series No. 92, *Specifications for Undersealing Portland Cement Concrete Pavements with Asphalt.*

In addition to these, the membrane asphalt described in Table II-4 may be used for undersealing. The asphalt is heated to approximately 350°F and pumped through the hand hose of an asphalt distributor to the injection "gun." The gun consists of handles, a valve, and pipe fittings connecting the asphalt line to a nozzle. The nozzle has an inside diameter of one inch and an outside diameter tapering from two inches to one and a quarter inches. It usually is about 12 inches long, and is sometimes equipped with a foot stand for the operator and a rubber gasket to seal the hole against leakage. The asphalt is pumped at low pressures (usually 15 pounds per square inch) until the underside of the old concrete slab is sealed and all cavities filled, or until the old slab has been raised the required amount. When asphalt appears in the forward holes around the injection points, wooden plugs are driven into the holes until the asphalt congeals. When the forward flow slows down, the gun is moved ahead. After pumping has been completed holes are plugged, as above, with wooden plugs. After the asphalt has hardened, these plugs are removed and the holes filled with an asphalt paving mixture, thoroughly tamped in place.

The amount of asphalt required for undersealing deteriorated portland cement concrete canal lining varies with conditions, making it difficult to predict in advance. Cavities varying from a few inches to a foot or more may be found and extensive leakage channels may also exist. In the undersealing and "lifting" of concrete canal linings by the U. S. Bureau of Reclamation, the amount of asphalt required has varied from two to five gallons per square yard. While these amounts are sometimes high, resulting in higher costs, the reduction of out-of-service time for the canal, the salvage of existing lining, and the effective control of leakage make undersealing practical. Undersealing must be performed before severe disintegration of the concrete lining has occurred. Construction specifications for the method of undersealing described are contained in The Asphalt Institute's C. S. 92, *Undersealing Portland Cement Concrete Pavements with Asphalt.*

D. Asphalt Macadam

2.25 GENERAL

The use of a permeable yet erosion-resistant lining for canals, drainage ditches and reservoirs is frequently desirable. The permeability of such a lining permits the escape of water from behind the lining, preventing any build-up of hydrostatic pressure and permitting drainage of adjacent areas. A properly constructed asphalt macadam provides such a lining. It affords a tough, stable, erosion-resistant surface which is permeable because of the open gradation of aggregate used. For the above purpose it is placed directly on the prepared subgrade. Asphalt macadam may also be used as the erosion-resistant element of a multi-layer lining structure.

2.26 MATERIALS AND CONSTRUCTION

Of the utmost importance in the construction of penetrated asphalt macadam is the gradation of aggregates and the selection of asphalt for the binder. Either asphalt cement (of 60-70 or 85-100 penetration grade) or a quick-breaking asphalt emulsion with a low penetration base may be used for the binder. For the desirable deep and thorough penetration of the aggregate by the asphalt it should have an "open" grading. A grading between coarse and fine, within the limits of gradation, is advisable to develop stability. High angularity of the aggregate will also increase stability, but ordinary gravels of low angularity can be used if they are well graded and can be properly penetrated.

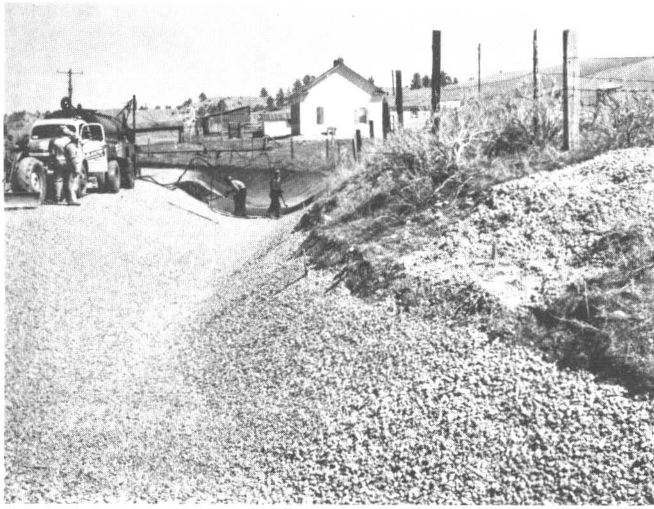


Figure II-28—Application of Asphalt (asphalt macadam lined canal)

When using an asphalt cement the aggregate is graded from 100 percent passing the 1-inch or 1½-inch screens to 0-5 percent passing the ⅜-inch screen. Aggregates finer than ⅜ inch tends to prevent the asphalt from reaching the bottom of the usual two-inch layer. In this type of construction the aggregate must be dry and free of dust for adequate bonding of asphalt to the aggregate. The proper application of the asphalt is very important. The asphalt must be applied at spraying viscosity range, 25-100 seconds, Saybolt-Furol (or temperature range 285° - 350°F) (Asphalt Institute Manual Series No. 4, *Asphalt Handbook,* pp. 69-73.) It should be applied in a "flooding" manner, moving the spraybar over the surface slowly and preferably in only one pass to avoid build-up of asphalt on the surface but allow it to penetrate deeply. On a slope the application should be started at the top. About two to three gallons per square yard is usually required for a two-inch penetrated-type hot asphalt macadam surface.

A quick-breaking emulsion is used when the asphalt is to be applied cold. For this use, the aggregate must be graded from a top size of ⅜ to 1 inch down to a minimum of ⅛ inch (0-5 percent passing the No. 8 sieve). If the aggregate for this purpose is graded too openly, poor stability may result since the film of asphalt obtained with emulsion is thinner than that of hot asphalt cement and requires more numerous points of contact (obtainable through finer aggregate particles) to attain good stability and resistance to erosion. For this application the aggregate should *not* be dry, an advantage of the cold penetration type. The asphalt emulsion is applied by spraybar and in the same "flooding" manner described above. The usual normal two-inch layer of aggregate will require two to three gallons of the asphalt emulsion per square yard for proper penetration and bond.

Slopes that are to be lined with asphalt macadam should not be steeper than 2:1 since it is difficult to hold loose stone to the desired thickness on steep slopes.

A modification of the single layer macadam may be obtained, particularly on horizontal surfaces, by first

Figure II-29—Asphalt Macadam Cover Over Asphalt Membrane

penetrating the layer of heavy stone and then immediately "choking" the resulting surface with smaller stone, preferably rolling the final surface to force the small stone into the voids. Such a surface has unusual toughness and erosion resistance and yet remains highly permeable.

When extremely high velocities are to be expected, as in storm channels, lining thicknesses greater than three inches should be used. It is advisable to place and penetrate these thicker linings in a single operation just as with the two to three-inch thick linings. This can be done provided the size of aggregate used is increased sufficiently to ensure thorough penetration.

2.27 EXAMPLES OF USE

Because it is tough, durable, erosion-resistant, and at the same time permeable, asphalt macadam may be used for many applications calling for these special characteristics. It is a type of construction which is advantageous to use because of its simple construction procedures, low cost, and maximum use of local materials.

It is particularly adaptable for use in lining storm channels and drainage ditches where permeability of the lining is desired to prevent destructive hydrostatic back pressure or to provide for draining of nearby areas. It has been so used in installations in Southern California.

It is usable with either a sprayed or prefabricated asphalt membrane to form the cover and erosion control layer of this combination type lining. This use as a cover for an asphalt membrane is very important because it eliminates the very thick covers of earth or earth and gravel which are required in either large canal sections or where high water velocities are encountered. Over-excavation for the accommodation of the cover is greatly reduced—an important factor where limited rights-of-way or rock excavation may be encountered. Those canal sections which have been lined with asphalt membrane covered with asphalt macadam have been very successful in service.

There are other hydraulic constructions where this low-cost type of stabilization and erosion control can be used. For instance, in 1959 the Pennsylvania Department of Forests and Waters constructed a public bathing beach in Pinchot Park, near York, using a penetrated asphalt macadam for a base on which to place the ten inches of beach sand. Prior to this experiment the beaches on public lakes had been constructed by spreading the sand on top of the loose-placed rock. Eventually the sand worked downward and the rock worked up to the surface, spoiling the underfooting for the bathers.

E. Prefabricated Asphalt Linings

2.28 GENERAL

There are two types of prefabricated asphalt lining material. One type, the prefabricated asphalt panel (board or sheet) has been developed for installation as a complete lining or surface layer of a lining. Properly constructed, it is almost completely watertight and provides a tough, durable, erosion-proof lining with a surface which is relatively smooth and easy to clean. The second type is a lighter, lower cost material which is usually made up in rolls like roofing. This type is designed for use where more flexibiilty and a lesser strength and toughness are required, or for use as a seepage control layer (i.e., for use as a membrane).

The construction of linings from these prefabricated materials does not require large and heavy paving machinery. Hence, their use is recommended where this machinery is unavailable, uneconomical to move, or where space limitations prevent its use. The use of these materials is also recommended where rigid compliance with specifications as to thickness, density, and impermeability is required. These qualities can be assured in the prefabricated materials because they can be manufactured under conditions of the most rigid control.

The two types are marketed under proprietary names, and manufacturing processes are generally patented. The manufacturers usually offer excellent brochures on

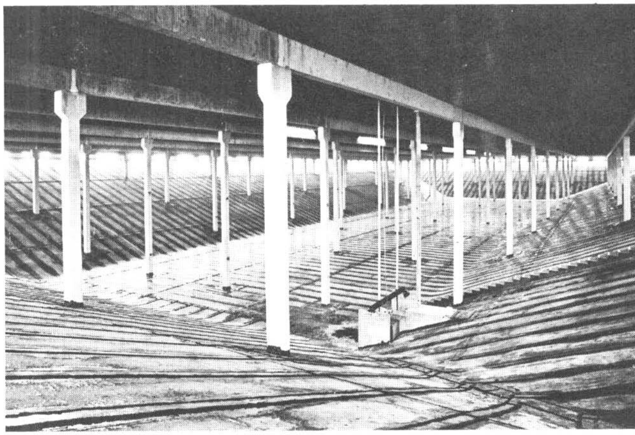


Figure II-30—Covered Reservoir with Prefabricated Asphalt Panel Lining

the construction techniques and uses of their material. Other assistance ranges all the way from simple instruction manuals to a complete engineering and construction service (i.e., the prefabricated asphalt lining is contracted for as complete and in place).

2.29 PREFABRICATED ASPHALT PANELS

The typical prefabricated asphalt panel might be compared to a sandwich. The core is a very dense mixture of asphalt and filler. On this core are the two outside layers of some tough, asphalt-impregnated material, such as an asbestos felt, or one of the fiberglass fabrics. Each of these layers may be coated on the outside with waterproofing asphalt, applied hot. The whole panel is molded together under heat and pressure. There are, of course, variations of these manufacturing procedures. The asphalts used are largely blown asphalts (blown with or without chemical modifiers).

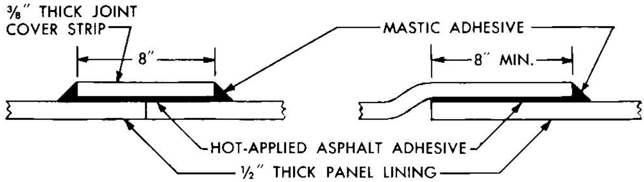
The panels are made in various thicknesses, widths and lengths. Thicknesses vary from ⅛ inch through ½ inch, with the ½ inch panel used most generally. One company manufactures panels in four-foot widths (or less as a special order) and in lengths up to 30 feet.

Lengths of 10 to 15 feet seem to be most convenient to use and handle. Another company manufactures the panels in widths of three feet and in lengths from five to 14 feet. These panels while somewhat rigid have enough plasticity and resilience to conform to angles in a cross-section (such as the juncture of slope and invert of a canal) or irregularities of the subgrade. When properly supported they are tough enough to withstand heavy erosion or animal and light vehicular traffic.

2.30 CONSTRUCTION

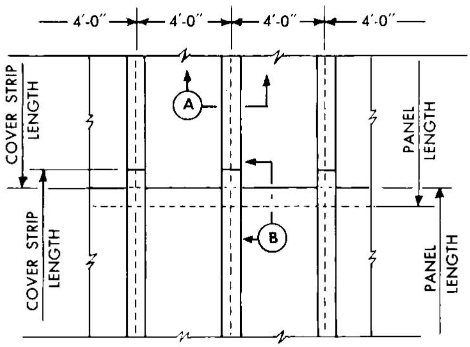
Careful planning and workmanship are required in constructing prefabricated panel linings even though actual procedures are relatively simple. The fitting together and bonding of the joints must be of high quality to develop the full strength and impermeability of the material. It is recommended that this be guided by scale drawings which show in detail how all pieces are to be fitted together. Joints may be made either by the lapped or the butt-joint methods. In the lap method each panel is lapped over the next panel by at least three inches. In the other method, the panels are butted together and the joint then covered by a batten strip at least six inches in width. See Figure II-31. Where four panels join it is well to use a third batten strip to cover the middle batten strip joint. Actually, the smoothest appearing lining results when a well-planned combination of lap and butt joints are used, with panels butted together on the long side and lapped on the ends. The bonding of the joints is accomplished by using hot asphalt adhesive or cold applied asphalt mastic. After application of the adhesive, the bond is made by pressing the sheets firmly together. In using hot adhesive the surface must be placed together before the adhesive cools. Applying a fillet of mastic, by trowel or hand, to the seam edges will improve appearance and also add to the strength and impermeability of the joint.

The subgrade is prepared in the same manner as for other types of lining. The canal or reservoir is excavated

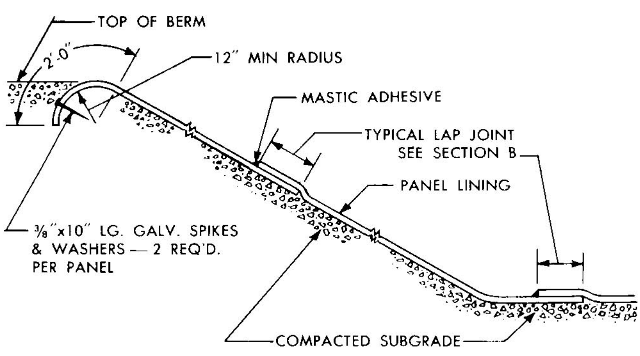


TYPICAL BUTT JOINT
SECTION A

TYPICAL LAP JOINT
SECTION B



TYPICAL PANEL LAYOUT



SLOPE LINING—TYPICAL
SECTION C

Figure II-31—Joint Details—Prefabricated Asphalt Panel Linings

or filled to grade, then smoothed and rolled. If required, the subgrade is treated with a soil sterilant to prevent plant and weed growth (See Article 2.06). For the simple one-layer type of lining the panels are placed directly on the subgrade. For the smaller installations, the lining is anchored at the top of the slopes by covering its tucked-in edge with at least six inches of earth. Larger and more elaborate reservoirs may have coping walls, paved walks or roadways around the top, and column footings, or other protuberances within the structure. The prefabricated panels must be securely bonded and fastened to all of these.

To secure the bond, the surfaces first are thoroughly cleaned and an asphalt primer applied; then, using either type adhesive, the panels are bonded to these surfaces in the same manner that panels are bonded together. Next the panels are actually fastened mechanically to the walls, footings, or other surfaces by using metal header strips and ram-set fasteners, the use of header boards and hold-down bolts, or by some similar system. These fastenings are then thoroughly waterproofed by the use of mastic adhesive to either cover them completely or at least point up all edges and corners.

Prefabricated asphalt panels are very effective for relining cracked and badly leaking linings of the rigid type. The new panel lining is placed directly over the old. Joints are made and the lining fastened at the top of slopes and around column footings as described above. Certain preparation of the old surface is required. It should be made smooth and even by eliminating high points and projections. This may be done by knocking off high points by hammer and filling in low spots with asphalt mix. Large cavities underneath the old lining should be filled by undersealing with asphalt.

Three procedures may be used in placing the panels over the old surface. On the flat and on slopes less than 1¾ : 1, where expected water velocity is very low and where old surfaces might be expected to move or settle to some degree under load, the panels may be placed

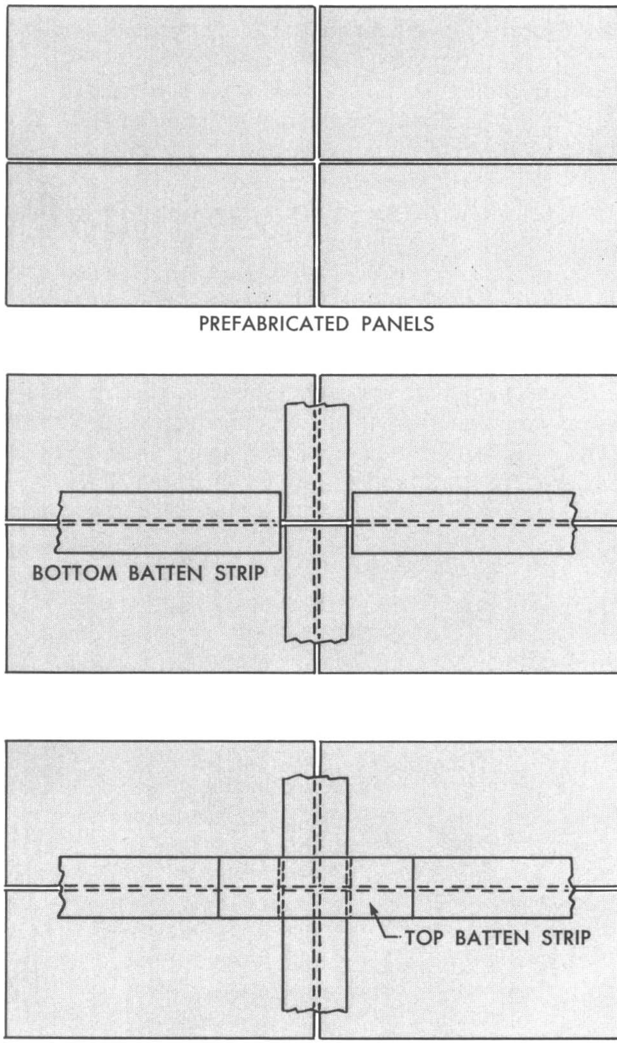


Figure II-32—Joint Details—Prefabricated Asphalt Panel Linings

directly on the old surface without any bonding material being applied. Thus movements of the old surfaces cannot set up any stresses in the prefabricated panel lining. Where future movement of the old surface is indicated to be slight, the panels may be spot bonded to it by applications of hot asphalt adhesive or cold mastic. The spots should be about 12 inches in diameter and spaced at two to three-foot intervals along the length of each panel. This method gives a measure of bonding and yet permits a large degree of movement in the old base without undue stress. Prefabricated panels so bonded can be placed on steeper slopes and the finished lining can withstand high water velocities. The third method is to apply a light asphalt primer to the old surface, then completely cover it with hot adhesive (or cold mastic) before the panels are placed. This complete bonding is only recommended when there is an overriding necessity for it, such as the danger of damaging uplift pressures from water flowing under the prefabricated lining.

Figure II-33—Prefabricated Asphalt Panel Lining under Construction

Figure II-34—Lining Ditch with Prefabricated Asphalt Panels

2.31 EXAMPLES OF USE

The most extensive use of prefabricated asphalt panel linings has been in water storage reservoirs and in industrial reservoirs for the storage and processing of liquid materials. Both of these types require linings which provide seepage control, and which are tough, durable, and easy to clean and maintain. The prefabricated asphalt panel lining is suitable for the construction of many other hydraulic structures, such as sewage lagoons, catchment basins, ponds, canals, and ditches.

Figure II-33 shows a large industrial reservoir under construction with the workmen applying batten strips over longitudinal butt joints.

An example of the installation of a prefabricated asphalt panel lining on a prepared earth subgrade is the water storage reservoir in Redding, California. This million-gallon reservoir is circular in form and its walls are shaped above ground from borrowed earth. The panels used were ½ inch thick, four feet wide, and up to 22 feet long. Both lap and butt joints were used. This reservoir was put into service about 1955.

A good example of a relining job with asphalt panels is the six-million-gallon San Pablo Clear Water Reservoir of the East Bay Municipal Utility District. This covered reservoir had a rigid-type lining which was leaking badly. In 1955 it was relined without having to remove the cover by using ½-inch prefabricated asphalt panels (up to 25 feet in length) and cold applied mastic joint sealer. All material was taken in through small access doors. The relining has effectively controlled the leakage and given excellent service in all respects.

The thinner and lighter panels (5/32 to ¼ inch) are easier to bend into conformation with curves of smaller radius. Figure II-34 shows a ditch being lined with these thinner panels. They are very advantageous in smaller installations where erosion and other forces to be resisted are not so heavy.

2.32 PREFABRICATED ROLLS

The lighter type of prefabricated asphalt lining material is made up in rolls. These rolls are standard size, three feet wide by 36 feet long. The earliest type was a 3/16-inch layer of blown asphalt on a backing of heavy kraft paper. The function of the paper was only to carry the asphalt until it was securely in place. This type was an experiment by the Bureau of Reclamation to obtain a prefabricated asphalt membrane which could be used in place of the sprayed type. However, it manifested many difficulties in shipping and handling. In hot weather the rolls stuck together, and in cold weather the asphalt cracked badly in the unrolling process.

Other types were soon developed to overcome these objections. One of these is a felted glass-fiber mat, saturated and coated with filled (dust and fiber-containing) asphalt. This material weighs about 85 pounds per roll, handles and transports well, and has given good service in a number of installations. Another type developed is an asphalt-saturated and coated asbestos felt which weighs about 50 pounds per roll. Although relatively thin, this type has had a good record of service. A newer type has a backing of rot-proofed burlap (jute or hemp fabric) which is thoroughly saturated and coated with asphalt. One variety of it is plain (the asphalt is uncoated), and is intended for use as a buried membrane. Still another is coated with granules, such as are used in the roofing industry, for protection against sun and weather. It is designed for use as a surface type lining.

2.33 CONSTRUCTION

Construction of a buried membrane lining using prefabricated material follows the same procedure as for the sprayed type, except for placement of the membrane itself. That is, the section is excavated or filled to grade, the subgrade is then dragged and rolled, making sure that all large rocks that might puncture the membrane are removed. The lining membrane is then constructed from the rolls of prefabricated material, making sure that the joints are well bonded.

For this thinner material, all joints are usually of the lapped type. All joints should be overlapped at least two inches. Adhesives used may be hot asphalt cements, cold mastics, or special cutbacks. Usually the adhesive is spread on the joint and the bond effected by applying firm pressure along the joint. For one type, the manufacturer recommends the use of a propane torch to liquefy the asphalt along the edge of the strip instead of the use of an added adhesive. This type has a slightly recessed two-inch edge so that a very smooth joint may be formed. Since this material is relatively thin, it is not necessary to point the edges with mastic for added strength and impermeability. As for the sprayed type membrane, a cover of earth or other material must be placed on the prefabricated membrane for protection, and to hold it in place. This cover should consist of a minimum of 12 inches of selected earth or combined earth and gravel; a lesser thickness of some stabilized material such as a penetrated asphalt macadam may be used. In placing the protective cover, the same care must be used as with the sprayed type in order to prevent injury or displacement of the membrane.

Construction of surface type linings from prefabricated asphalt rolls follows the techniques already described. Special care must be taken to insure that these relatively light and flexible materials are firmly anchored to the subgrade. Around top edges this can be done by curving the material into prepared ditches and back-filling with earth and rock. Similarly, the lining material can be fitted into rectangular transverse cuts, spaced at intervals along ditches and canals with rock then being placed into the cuts and thoroughly tamped. For smoothness these cuts can be covered with batten strips of the material thoroughly bonded to the lining on each side of the cuts.

2.34 USES

The lighter prefabricated asphalt linings have had considerable experimental use by the Bureau of Reclamation in canals as a substitute for the sprayed type of buried

Figure II-35—Membrane Construction from Prefabricated Asphalt Rolls (Dragline placing earth cover)

membrane lining. It also has been used with other types of protective cover, such as earth and gravel or a penetrated asphalt macadam layer. In addition, it has had some use as a seepage control membrane in industrial reservoirs. Utilizing this light prefabricated lining with about nine inches of local gravelly material for cover, one large reservoir with a 12,000-square-yard surface was completed at less cost than the sprayed type of lining could have been at that particular location.

The construction of a prefabricated buried membrane canal lining is shown in Figure II-35. The dragline is placing the protective earth cover over the membrane.

The use of this type as a surface layer is a more recent development. Being lighter and less expensive, it offers great promise for use in water reservoirs, stock ponds, fish ponds, ornamental ponds, waste storage reservoirs, sewage lagoons, catchment basins, and other hydraulic structures.

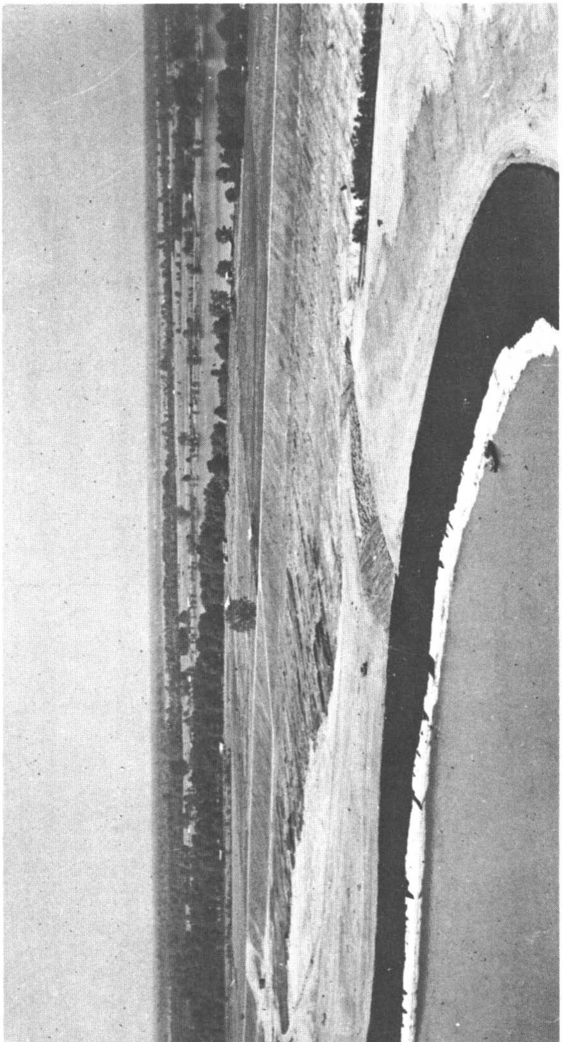


Figure III-1—Completed Revetment

Chapter III

ASPHALT REVETMENTS

A. General

3.01 BACKGROUND

A revetment is a continuous cover designed to directly protect a riverbank from the destructive effects of water currents. It interposes an erosion-proof layer between the unstable material of the bank and the moving water. It is one of two types of riverbank protection in general use in this country. The other type of bank protection is the intermittent class, such as dikes, retards, or groins. This type offers protection by deflecting the current away from the bank and by inducing accretion of material.

Riverbank protection benefits both navigation and flood control. The resultant bank stabilization decreases the amount of material in motion, thus lessening the growth of crossing bars, and in general contributing to a deeper and more stabilized channel. The more efficient hydraulic channel is easier to navigate and prevents floods by quickly carrying off excess water. Further, the prevention of bank recession protects the works of man located on or near the waterway.

Similar installations have been used to control erosion or wave wash along lake shores. In all cases, a complete engineering investigation should be made before selecting the type of revetment needed.

The Corps of Engineers, U. S. Army, is the executive agency of our government charged with river and harbor work, including flood control. Consequently almost all important riverbank protective works in this country have been developed and constructed under the over-all direction of that agency, with the vast bulk of it being placed on the Mississippi River and its tributaries. Others, of course, have contributed in their separate fields. For example, The Asphalt Institute has contributed to those developments involving the use of asphalt materials in riverbank protection works.

3.02 BANK AND REVETMENT FAILURES

The most common cause of bank failure is the attack of the river at the toe of the slope, which then steepens until it fails by subsidence or sliding. Other causes of failure are simple erosion of the channel and sloughing of completely saturated banks. The latter usually happens when there has been a protracted flood stage followed by a rapid fall.

Once constructed and in place, a revetment may fail because: The river flanks it at one end or the other; the river attacks it from behind by overbank scour; the river attacks it at the toe, due to excessive deepening of the channel; the river leaches out material in the revetment, or there are inherent weaknesses of durability, connection, and design.

3.03 DESIRED QUALITIES

To protect against these failures, the ideal revetment should: (1) Completely cover the area to be protected; (2) possess sufficient strength to withstand the attack of the river; (3) have a long life; (4) be flexible enough to conform to the irregularities of the riverbank and bed; (5) be impermeable enough to prevent material from leaching through, and (6) should not be prohibitive in cost.

Asphalt as a material for construction of revetments has many of these desirable qualities. Once constructed and in place, a dense asphalt concrete gives a very complete coverage, free from undesirable openings through which bank material can be lost. There is no question as to the strength or durability of asphalt in water, or under attack by water. This is attested by the excellent condition of asphalt revetments which have been in place for more than 25 years. Asphalt pavement can be made as impermeable as is desired, or it can be made porous to permit drainage of a riverbank, thus preventing damaging hydrostatic back pressure. It is sufficiently plastic to conform to minor irregularities of the bank and offers sufficiently good protection to prevent major irregularities from forming. And locally available aggregates can generally be used to produce a satisfactory asphalt concrete mix.

3.04 PARTS OF STANDARD REVETMENT

By reason of radically different conditions of placement or construction, a revetment consists of two distinct parts. One is the part which has to be placed below the surface of the water. The procedures for prefabricating and then placing this part are complicated. It is commonly called a *subaqueous mattress,* or simply a *mattress.* The other is the part which is placed above the water level—that is, from the edge of the subaqueous mattress to the top of the bank. It is commonly called *upper bank paving,* or simply *paving.* Upper bank paving follows more normal construction procedures.

3.05 BANK GRADING

The first part of the operation at any site selected for revetment is the preparation of the bank. The idea is to provide a bank as nearly parallel to the current as practicable, with a dressed slope of from 3:1 to 5:1. In many cases this is done by grading the bank with a bottomless scraper bucket handled by a dragline machine mounted on a barge. The working barge is held in place, between two string-out barges. This grading is carried from the top of the bank to about 40 feet in depth. After the rough grading is accomplished, the bank should be dressed smooth by heavy drags. Stumps, snags, and other such underwater obstructions must be removed. One way to do this is by the use of divers.

B. Subaqueous Reinforced Asphalt-Mattress Construction, Corps of Engineers, U. S. Army, 1932 to 1942

3.06 DESCRIPTION

A reinforced asphalt-mattress type of revetment was developed about 1932-34 for use on the lower Mississippi River. The development, and most of the subsequent construction of this type, was accomplished by the Second New Orleans District, Corps of Engineers, U. S. Army. This mattress was designed to be prefabricated on the ways of a floating plant and then immediately placed as the subaqueous portion of a riverbank revetment.

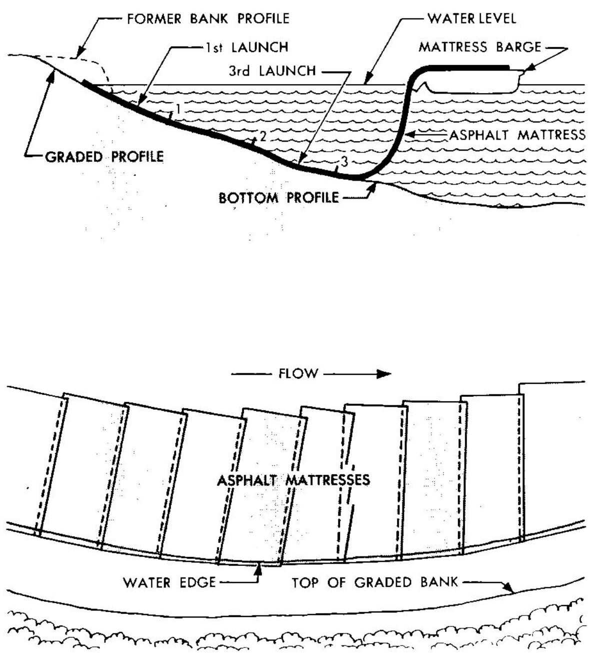


Figure III-2—General Layout Reinforced Asphalt Mattress (Subaqueous)

The mattress itself was a dense asphalt concrete (weighing about 140 pounds per cubic foot), 2 inches thick, and reinforced at its mid-section by wire mesh plus a system of cables. These mattresses were laid in depths of water as great as 170 feet in continuous unbroken sheets 217½ feet wide (the width of the launching ways), measured parallel to the river, and as long as 630 feet measured normal to the riverbank. Each mattress was a succession of launches 30 x 217½ feet, so constructed with launches following each other that the reinforcing wire, the cables, and the asphalt concrete body of the mattress were continuous until the thalweg (line following lowest part of stream bed) of the stream was reached.

Each mattress was completely waterproof except for one weep hole per 100 square feet to allow ground water from the riverbank and bed to drain freely through the mattress. Successive mattresses of this type were then placed, each overlapping the preceding one by 10 feet in the direction of the current; this formed a continuous revetment around a bend or along a reach of the river. Immediately following placement of the subaqueous mattress, the upper bank was paved to complete the revetment.

3.07 MIX DESIGN

The necessity for a competitive low cost of the asphalt mattress demanded the use of readily available local materials for the mix. It was found that an excellent mix could be made by using the river-bar sands, provided they were dug mechanically, not dredged. Search for a filler led to the selection of loess, the fine wind-blown deposit which caps the nonalluvial bluffs which border the Mississippi River basin from Cairo, Illinois, to a point near Baton Rouge, Louisiana. At several points in the New Orleans Engineer District, these bluffs were close enough to the river so that direct loading on barges was possible.

Extensive laboratory and field tests led to the selection of a mix having a Hubbard-Field (Original Method) stability of 650 pounds at 140°F, and other physical properties such that a two-inch-thick sample at 70°F, could withstand six cycles of reversed bending to a radius of 18 inches before failing. A special 40-50 penetration grade of asphalt cement was used in the mix. With the particular sand used in the beginning, the desired physical properties were obtained with the formula (all in percent by weight of the total): 12 percent asphalt cement, 22 percent loess filler, and 66 percent sand. Uses of river-bar sands of coarser gradations led to variations such as: 10 percent asphalt cement, 20 percent loess filler, and 70 percent sand; or 9 percent asphalt cement, 17 percent loess filler, and 74 percent sand.

3.08 APPLICATION

This type of construction was utilized during nine years of large-scale use. During one construction season, the plant placed 6,766,500 square feet of reinforced asphalt mattresses, using approximately 75,000 tons of hot mix. Difficulties of placement in the higher river currents encountered above Baton Rouge caused the use of this type of mattress to be discontinued after 1942.

Hence, most revetments of this type of reinforced asphalt concrete mattress have been in place for more than twenty years. Recent inspection reveals they are generally in good condition, and continue to provide very effective protection to the riverbanks on which they are placed. Also, since maintenance requirements have been low, this cost has not detracted from the original favorable economy of this type of construction.

C. Other Types of Subaqueous Asphalt Revetments

3.09 SMALL-SCALE MATTRESS

This type of construction utilizing precast, reinforced asphalt mattress elements can be readily adapted to small-scale use. The mattress elements can be precast into any size convenient to handle and place. Usually, suitable mixes can be designed using locally available materials. A variety of material can be used for the reinforcement, ranging from wire mesh to fabrics such as burlap. A simple procedure which has been used for many underwater applications follows: After mix-design, reinforcing material, and headers (for containing each end of a mattress element) have been selected, the reinforced asphalt concrete mattress elements are cast on any convenient floor or platform. When cooled, they are picked up and stacked on a barge. The barge is then towed to the work site, where the mattresses are again picked up by crane and placed as required on the bank or structure to be protected. Placement must be done carefully with the elements overlapped so that complete protection is assured. In some situations it is possible to use divers to assist in positioning the mattress elements.

Other ingenious methods have been devised for moving and placing these precast asphalt-mattress elements, particularly in European practice. In one, the asphalt mattress is slowly rolled around a large drum, which is then floated to the site. The drum is then sunk at the exact position, the asphalt mattress is unrolled, and the drum is recovered for future use. In another, the mattress is rafted into position, supported on a timber frame. At the site, water is let into the raft so as to sink the asphalt mattress into proper position. The framework is recovered for additional use. In all cases extreme care must be taken at the junction or overlap of mattress elements to insure complete protection. In some cases, asphalt-sand mastic is used to liberally cover the joints and thus insure that the edges of the mattress are fixed in place.

3.10 MASS DUMPED HOT-MIX

An experimental method tried by the U. S. Army Engineers for the protection of underwater slopes was the dumping of asphalt hot mix in mass on these slopes. The theory was that when large masses of hot sand-asphalt mixtures were dumped through a depth of water on a sloping bank, it would spread out to form a blanket cover before the mixture congealed. Various mix designs were utilized, each combining an appropriate quantity of asphalt cement with the aggregates found in sand and gravel bars along the Mississippi River. These masses of hot-mix were dropped by different methods, but usually from either a clam shell bucket or through bottom-dump barges. On one project, however, a chute was used to carry the mix down through the water to the river bottom.

In 1947, a large-scale placement of such a blanket was made on the Mississippi River at Reid-Bedford Bend near Vicksburg. The mix consisted of local bar sand, all passing the No. 10 sieve, with from 10 to 11 percent of an 85 - 100 penetration asphalt cement. The mixture was prepared by a plant erected on a barge and mixed at a temperature of approximately 400°F. From the plant, the mix was carried by conveyor belt to a large two-compartment bottom dump barge containing an insulated layer of sand. This barge was then towed to the proper position for dumping over the area to be protected. The mixture was dumped in masses of about 260 tons each at a temperature of approximately 350°F, and spread out to form a blanket varying in thickness from 3 to 13 inches. After the operation, underwater surveys revealed that adjacent dumps had not sealed together as had been expected. Therefore, this method was not adopted for standard subaqueous revetments.

Another method used for a time was the dumping of partially formed sand-asphalt blocks still retaining enough heat and plasticity to meld together on the bottom, forming a complete blanket. The basic special equipment for this technique consisted of a barge made of pontoons on all four sides and an open well in the middle. Casting pans, each for a block of asphalt 20 x 16 x 5½ inches, were suspended over this open well. These pans were designed so that the blocks could be dumped into the water through the open well.

The mix used for this operation was bar-run sand with 6 to 8 percent by weight of 85 - 100 penetration asphalt cement, mixed at a temperature of about 350°F. After the mix was placed in the pan forms, it was raked and

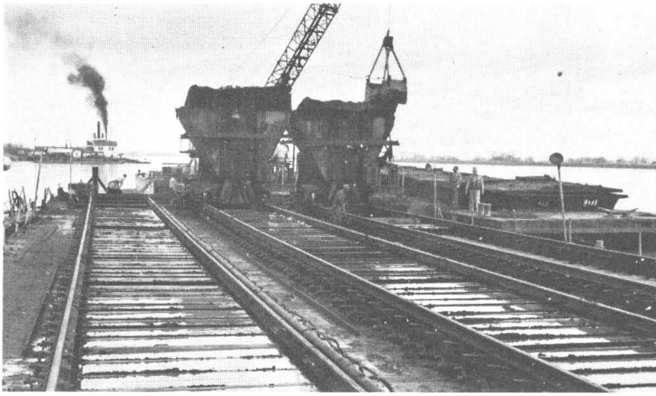


Figure III-3—Corps of Engineers' Block Asphalt Plant

screeded to be smooth but uncompacted. The pans were then covered with water for 30 minutes of cooling before being dumped.

This operation was carefully positioned and controlled along string-out barges to dump 70 blocks of asphalt mix on every 100 square feet of river bottom. Thus the average thickness of asphalt blanket placed on the river bottom was about 8½ inches.

These methods of mass dumping of asphalt hot-mix described above are considered useful for emergency underwater erosion control (as during times of high water), or for temporary underwater revetments often necessary during construction of dams, dikes or similar hydraulic structures.

D. Asphalt Upper Bank Paving

3.11 GENERAL

Upper bank paving extends from the edge of the subaqueous paving (or mattress) to the top of the bank, or to a specified paving contour. It may be accomplished essentially as part of the subaqueous paving operation, but it is usually done as a separate operation immediately afterward. With the subaqueous mattress, it completes the revetment of a bend or reach of river.

Asphalt upper bank paving is constructed in much the same manner and utilizes the same asphaltic materials as the asphalt linings described in Chapter II. The most effective and durable revetments are made of asphalt concrete. Penetrated asphalt macadams and prefabricated asphalt panels or rolls are used where their special characteristics are called for. Mix designs are modified to make maximum use of local aggregates and to fit local needs. Construction methods are adapted to the conditions of riverbank paving. The asphalt plant and its auxiliaries are usually barge mounted for ease of transport and access to construction sites. Once mixes are delivered from these floating platforms to the bank, procedures are very much the same as for paving a canal or reservoir. Regular paving machines, special slope pavers, spreader boxes, and hand methods of placing are used as they are appropriate and available. Since riverbanks are usually soft, any heavy equipment may have to be mounted on tracks or other low-ground pressure running gear. When compaction is called for, it should be accomplished with light equipment, such as the lightweight, vibrating, steel-wheel towed roller. All such

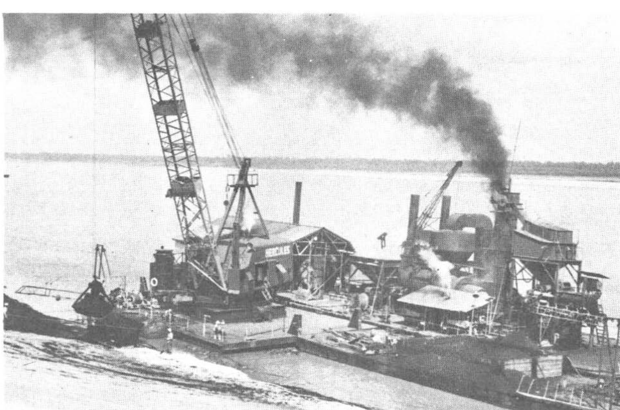


Figure III-4—Asphalt Mix Plant, Upper Bank Paving, Mississippi River

equipment can be effectively maneuvered by tractor winch and cable from the top of the slope.

3.12 AN EARLY TYPE

An asphalt upper bank paving was used on the lower Mississippi River during the 1932-42 period to complete the revetment where the reinforced asphalt mattress constituted the subaqueous part. It utilized the same asphalt concrete mix and extended from an overlap of the subaqueous portion to the top contour, where it was keyed into a small ditch to form an inverted curb. This paving was not reinforced, but it did embed the anchor cables and headers of the subaqueous revetment in asphalt mix, thus protecting them from the attacks of the elements. At first this paving was spread and tamped by hand to a compacted thickness of three inches. Later a machine was developed which spread, compacted, and finished the asphalt concrete paving while propelling itself up the riverbank. This paving followed directly behind and completed the revetment started by the placing of the subaqueous mattress.

3.13 A CURRENT TYPE

On the lower Mississippi River the Corps of Engineers, U. S. Army, is currently using a five-inch pavement of a porous uncompacted sand (bar-run)-asphalt concrete for upper bank revetment. First this pavement is designed to be porous in order to permit water from the riverbank to seep through, thus permitting drainage of the bank and avoiding damaging back pressure. The bar-run sand, being virtually devoid of material passing the 100-mesh sieve, makes up into a mix of the required porosity. Second, the pavement is left uncompacted to allow for some adjustment in the event of displacement or loss of material in the bank underneath.

Specifications require that the aggregate for this mix be composed of hard, durable, and uncoated particles, with not less than 1% or more than 8% passing the

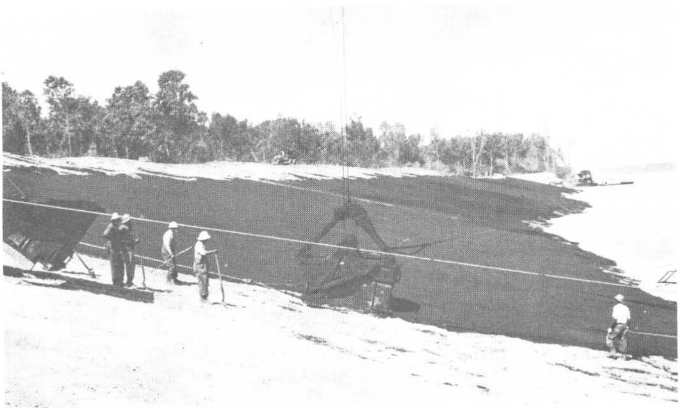


Figure III-5—Placing Mix by Spreader Box (Note empty spreader box being returned to toe of slope)

100-mesh sieve, and allowing bar-run sand, excavated but not pumped, to be used providing it does not contain more than 65% (by weight) of gravel. Actual sieve analysis of several bar-run sands used during the 1959 construction season appear in the table below.

Table III-1—BAR-RUN SAND USED FOR UPPER BANK PAVING, LOWER MISSISSIPPI RIVER

Sieve Size	Percent Passing				
	Mayersville, Miss.	Milliken Bend, La.	Diamond Point, La.	Goldbottom, Miss.	New Orleans District
No. 16	99.96	......	......	......	......
No. 30	98.07	96.6	96.7	98.2	96.6
No. 65	5.34	12.7	2.5	11.4	11.0
No. 100	1.4	5.8	1.0	4.3	5.1
No. 200	......	......	......	......	......

The asphalt cement specified is the 85-100 penetration grade. Normally the mixture consists of six percent asphalt cement (by weight of total mix) specified to be a mixture well bonded without bleeding. The mixture is placed at temperatures ranging from 225° to 275°F. The asphalt-mix plant and its auxiliaries are barge mounted. The pavement is placed by large (10 to 12-cubic yard) spreader boxes, pulled up the bank slope by tractor winch. While one box is being pulled up the slope, a second one is filled by clam-shell bucket from a steel holding bin. The continuous type mix plant discharges by belt feeder into this bin.

This revetment is placed on the graded and dressed riverbank immediately after the placing of the subaqueous portion of the revetment. It must lap the subaqueous paving by at least one foot. It extends from the subaqueous pavement to the specified top contour where it ends in an inverted curb of asphalt placed in a small key ditch six inches wide and 18 inches deep.

Outlet and lateral ditches are constructed to drain depressions behind the bank or for necessary interception of lateral drainage. These are paved as necessary to prevent erosion.

This type of revetment paving, made with a softer grade of asphalt cement than normally recommended for hydraulic work and left uncompacted, nevertheless sets

Figure III-6—Detail for Surface Drainage, Upper Bank Paving (Note texture of uncompacted sand asphalt revetment)

up into a durable and effective revetment. Current estimates by engineers give it a minimum useful service life of twenty years. These estimates are based on studies of examples that have been in place for periods up to ten years.

In the New Orleans District the levees are very close to the riverbank and are subject to attack by river current and wave wash in exposed locations, particularly during periods of high water. These exposed levee slopes have frequently been paved by using methods and asphalt-concrete mixes similar to those described above.

3.14 LAKE OKEECHOBEE REVETMENT

Lake Okeechobee, Florida has a great system of levees along 84 miles of its shore as a guard against disastrous floods resulting from tropical storms. It became necessary to revet the lakeside slopes of portions of this levee system as a guard against serious erosion and wave wash. In 1951 approximately six and a half miles of this levee

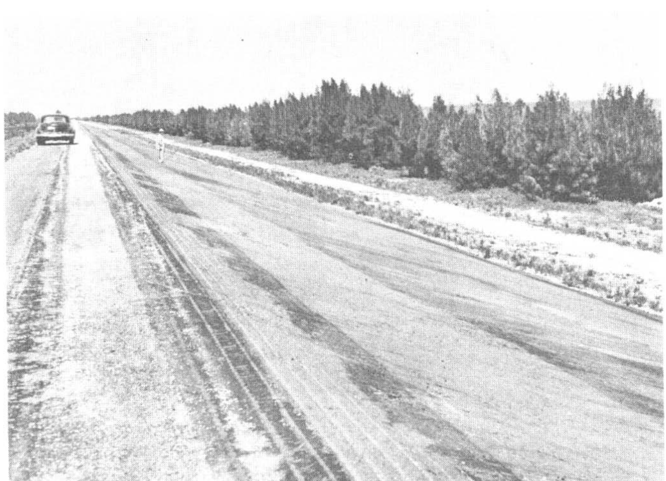


Figure III-7—Lake Okeechobee Revetment

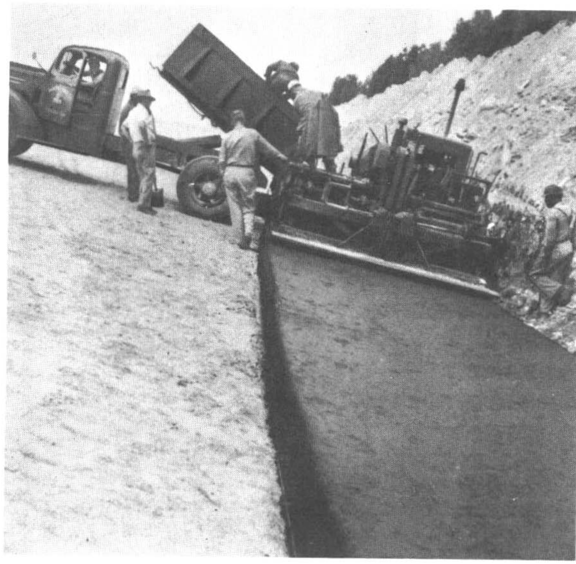


Figure III-8—Paving Machine at Toe of Slope, Lake Okeechobee

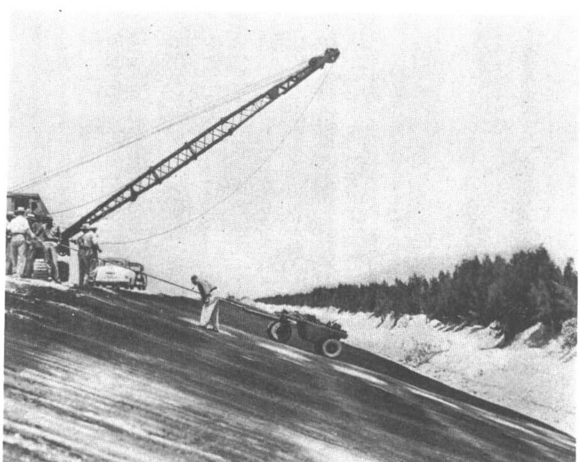


Figure III-9—Compacting Revetment Pavement, Lake Okeechobee slope were revetted with a six-inch plant-mix asphalt pavement. The bottom of this pavement was buried in a trench constructed at the toe of the levee for this purpose. The entire slope and top of the levee was covered with the asphalt pavement.

Locally available aggregate was used for the mix. It consisted principally of a mixture of sand, shell, and soft limestone or marl particles varying in size from 1½ inches to dust. The binder used was an RC-5, rapid-curing, liquid asphalt. The asphalt content of the mix varied from seven to ten percent. The paving mix was produced in a regular hot-mix plant with specified mixing temperatures of 175° to 220°F.

The slope of the levee on which the pavement was placed was 3:1. Where the subgrade was firm enough to support it, a finishing machine was used to place the paving mixture. It operated longitudinally along the slope. When the subgrade was very sandy, and low in bearing support, it was necessary to place the mix by spreader box pulled up the slope by winch.

After placing, the paving mixture was allowed to cure for 24 to 48 hours and then was rolled and compacted by two passes of a six-ton smooth-wheel roller. Two to four days later the pavement was again rolled, this time by a nine-wheel, six-ton, rubber-tired roller. The final operation was the application of a seal coat of an RC-2, rapid-curing liquid asphalt.

The construction described above was carried out by the Jacksonville District, Corps of Engineers, U. S. Army.

Chapter IV

ASPHALT BEACH EROSION CONTROL STRUCTURES

A. General

4.01 BACKGROUND

The control of erosion of ocean and inland beaches is a science of growing importance. Sands of the beaches are highly transitory materials, moving in and out by wave, tide, and storm, and being moved along the coast by littoral currents. Beach material is constantly being lost to the ocean depths. New material is gained principally from our rivers and streams. In a great many littoral areas the net result is an imbalance, either as a net loss or net gain of material. When a valuable commercial or recreational beach is being eroded (net loss of material), measures to control it are justified. Frequently

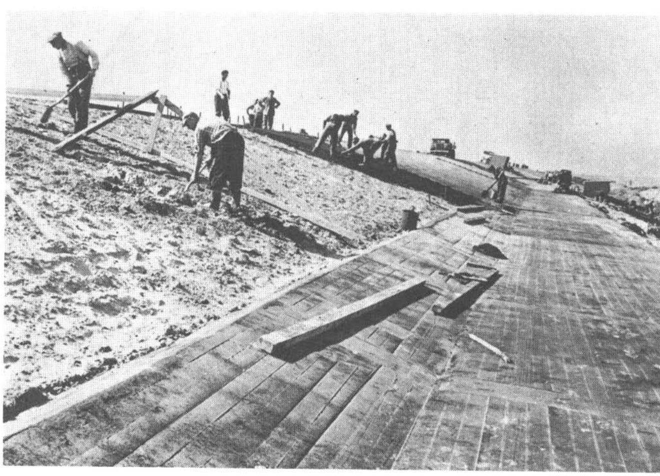


Figure IV-1—Workmen Placing a Sand Asphalt Course on a Sea Dike in Holland

of equal importance to the beach itself is the protection which it affords to the upland area immediately behind it.

Structures (even the very ones built to control erosion) can cause or add to both accretion and depletion of material. Flood control dams far inland, by causing the suspended material to deposit, can seriously affect many miles of beach adjacent to a river mouth. Jetties to control and maintain depth of channel at a river mouth generally cause material to be deposited on the updrift side, resulting in a depletion, and consequent serious erosion, on the downdrift side. Material will be deposited in the lee of an off-shore breakwater, and this again means a depletion of material in the coastal area downdrift. In fact, any structure which interrupts or hampers the littoral drift of material results in the deposit of material in one place and consequent depletion in another.

Vast sums are being spent annually by governments and by private owners to prevent erosion damage to seacoasts and lake shores. To provide a sound basis for planning and design, intensive study programs of both the natural forces involved and the development of protection works have been initiated. A leading agency in this field in the United States is the Beach Erosion Board, Corps of Engineers, U. S. Army, which has been engaged in the study of shore erosion problems since 1930. Many other governmental agencies are also active in this field. Though the science is still in the development stage, knowledge thus far gained can be used to provide a basis for the design and construction of shore protection structures.

4.02 STRUCTURE TYPES

The principal structures used to control beach erosion are seawalls, breakwaters, bulkheads, jetties and groins, each having a different function. (See Article 1.04). Beaches themselves are the most effective means of dissipating wave energy, and, when they can be maintained to adequate dimensions, afford the most effective protection for the shore area and adjoining upland. In general, seawalls and bulkheads are used where it is necessary to maintain the shore in an advanced position relative to that of adjacent shores, and where there is a scant supply of littoral material to the area and little or no protective beach (as along an eroding bluff). They are also used where it is desirable to maintain a depth of water along the shore line as for a wharf. Long groins, extending well out into the water, are used to help form beaches and build them up to the desired width by trapping material from the littoral drift. Shorter groins with low profiles are used to maintain beaches at desirable widths by retarding or preventing loss of material to the littoral currents.

4.03 MATERIAL TYPES

Asphaltic materials are used in the construction of many of these beach erosion control installations. Asphalt hot-mix concrete is used to pave or revet the slopes and tops of earth or sand seawalls; it is also employed to pave, or cap, the top surfaces of rock jetties, breakwaters, and groins, and to build low profile asphalt groins. Asphalt grouting mixtures are used to consolidate and fill in the voids of stone or rock jetties and groins, and the rock riprap facing of seawalls.

These uses have evolved because of the excellent cementing and waterproofing qualities of asphalt; because of its durability; because dense asphalt mixes offer great resistance to marine borers, and because of the very favorable economy of this type of construction.

B. Asphalt Grouting and Capping

4.04 GENERAL

Grouting and capping with asphaltic materials is a technique for making a stone or rock structure more effective and easier to construct and maintain. In brief, grouting consists of filling up the interstices in a stone structure with a very hot, rich mixture of asphalt cement, mineral filler, and fine aggregate, placed or poured in a near liquid state. Capping, which usually follows, need only be done when a traffic way is required on top of the structure.

Stone or rock breakwaters, seawalls, jetties and groins are very expensive to construct and to maintain. The stone is difficult to produce, usually has to be transported long distances to the sea coast, and the large sizes required are difficult to handle. Grouting with an asphalt hot mix has been developed to reduce the initial expense of such structures, to reduce the cost of maintaining them, and to increase their effectiveness and length of life. It acts to do this in several ways. It moves into and fills up the voids in the rock structure and hardens there. The individual rock pieces, held together in a matrix of asphalt, then act as a whole to resist the heavy attack of the sea.

This whole mass has a measure of resilience to shock because of this inherent quality of asphalt. Because they can act together, the rock pieces in the mass can be smaller and less difficult to procure and handle. Because the voids are filled, the structure is relatively impermeable. In a stone jetty this prevents infiltration of sand into the protected channel. In a riprap revetment it prevents loss of material due to erosion and cavitation. And finally, because the integrity of the structure is preserved by this consolidation, its life is lengthened and the cost of maintaining it reduced.

The modern technique of grouting with asphaltic materials was initially used on European installations early in the 1930's. The first large scale construction of this type in the United States was the Galveston, Texas Jetty, started in 1935. Since these early beginnings there has been a gradual expansion of this type of construction, particularly in Europe. The usage is certain to grow in the United States as suitable stone and rock become more difficult and expensive to procure.

4.05 DESIGN AND CONSTRUCTION

Asphalt Institute Specification Series No. 5, *Specification and Construction Methods for Asphalt Hot-Mix Grouting and Capping of Stone Jetties,* sets forth the mix designs and methods of construction for this type of work. Aggregate gradation and mix proportions are given in Table IV-1.

Table IV-1—SUGGESTED MIX COMPOSITION FOR ASPHALT HOT-MIX GROUTING AND CAPPING

Sieve Size	Passing Percent By Weight	
	Grouting Mix	Capping Mix
1½ in.		100
1 in.		90-100
½ in.		70-100
No. 4	100	45-100
No. 8	90-100	50-90
No. 30	60-100	20-65
No. 100	0-30	7-25
No. 200	0-5	5-15

Mineral filler used must have 65% of material which will pass a No. 200 sieve. An asphalt cement of the 60-70 penetration grade is required. The asphalt hot mix is to be proportioned within the following limits:

	Grouting Mix	Capping Mix
Aggregate %	60-70	76-84
Mineral Filler %	15-20	8-12
Asphalt Cement %	15-20	8-12

Further requirements are that the hot mixes be prepared at suitable temperatures so that they are delivered at the job site at 375° - 450°F for the grouting mix, and 300° - 350°F for the capping mix. The high temperature for the grouting mix is necessary to provide flow and penetration into the voids of rock structure. The ratio of asphalt cement to mineral dust must be at least 1:1 to obtain good flow characteristics of the mixes.

The wide limits specified for gradation and mix permits the maximum use of locally available materials such as beach sands, and makes for very simple job-mix formulas.

4.06 GROUTING MIX

The asphalt content and elevated temperatures of grouting mixes insure that they can be poured or flowed into place. Placing such a liquid mix on a surface above water may be done by use of a steel trough or by clam shell bucket. A clam shell bucket may also be used to place the mix just under a water surface. For somewhat deeper placement it may be necessary to use tremie methods. For deepest placement, as at the foot of a harbor breakwater, it may be necessary to lower the mix in an insulated bottom dump bucket. Divers may be used to expedite spotting of the bucket.

In grouting a large rubble-mound structure, it is important to get a maximum penetration of the mix into the voids. Dumping the mix in sufficient mass facilitates this by maintaining its temperature and fluidity long enough for maximum flow, and by having sufficient weight to push into all void spaces. The flow of the mix into the voids may be expedited by the use of long-handled vibrators. The mix is placed first along the center line of the top and from there to the sides. The mix is then worked downward and outward by vibration or other means. On the sloping sides, placement is started at the top and continued downward to the prescribed depth below mean low water, with care being taken to obtain maximum inward penetration of the mix. A heavy coating should be formed on the sides, screeded and smoothed as much as possible to prevent surface erosion by the water.

The grouting of a slope facing (as on an earth dike) of riprap is a much more simple operation. The grout is simply poured into the voids and over the riprap, then screeded, raked and troweled smooth. The individual rock pieces are thereby consolidated into a pavement surface which resists wave action and erosion by its whole mass instead of by parts, and which is impermeable enough to prevent the migration of subgrade material.

4.07 CAPPING MIX

A rubble-mound structure, after being grouted with asphalt, is usually capped to provide a traffic way for further construction and maintenance or other purposes. The cap should be laid as soon as possible after the grouting is finished to obtain the best bond. Any hydraulic type asphalt concrete, such as those described for linings or revetments, can be used for this purpose. The capping mix described in paragraph 4.05 can be handled by methods very similar to those used for the grouting mix. After being placed, the mix is evenly distributed over the top surface. Finishing operations then follow with rollers, vibrating screeds, and tampers. This insures a dense, impermeable surface which resists erosion.

4.08 EXAMPLES OF USE

Grouting and capping of the Galveston Jetty in 1935-36 was the first large scale use of this technique in the United States. The south jetty at Galveston consisted of a rubble-mound of 75 to 4,000 pound core stone covered by cap and slope stones weighing six to ten tons. The foundation was a mat of small stones, 15 to 200 pounds each. This jetty had deteriorated in grade and cross-section through foundation settlement,

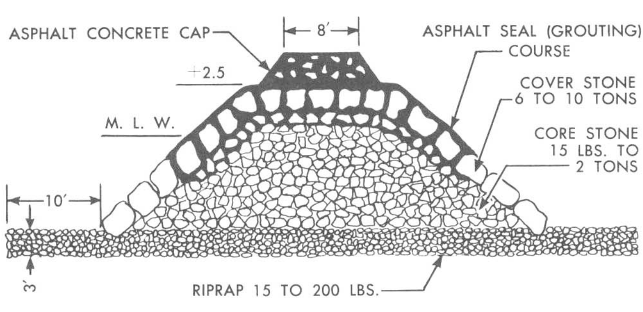


Figure IV-2—Section, South Jetty, Galveston, Texas

Figure IV-3—Galveston Jetty After Fifteen Years' Service

through grinding of core stone on each other, and through displacement of cover and core stones by wave action during storms. Also littoral currents had carried sand through the previous jetty, thus increasing maintenance dredging of the channel.

In 1935 the Corps of Engineers decided to seal and cap this jetty with asphaltic material for the double purpose of preventing the infiltration of sand and to increase the life of the jetty structure itself. Various asphalt mixes of the grouting type were used, one of the most successful consisting of 18 percent 30-40 penetration grade asphalt cement, 12 percent Mississippi River loess (filler), and 70 percent Galveston beach sand. The material was placed at 400°F and care was taken that mass dumps into the rock were made to obtain maximum penetration into the voids above and below water. Long-handled vibrators were used to facilitate this action. A stiffer mix was used to cap the structure above water; this also was compacted by vibration and smoothed by tampers to form a traffic way. The experiment proved highly successful as a means of sealing the

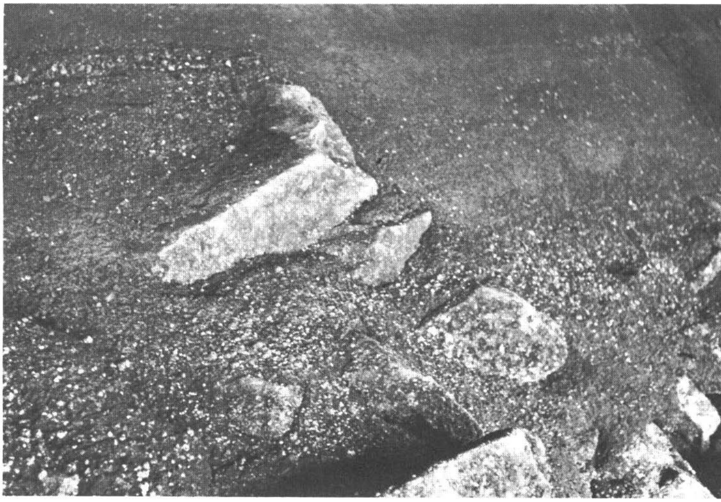


Figure IV-4—Seawall, Los Angeles Harbor (Showing texture of asphalt and embedment of stone)

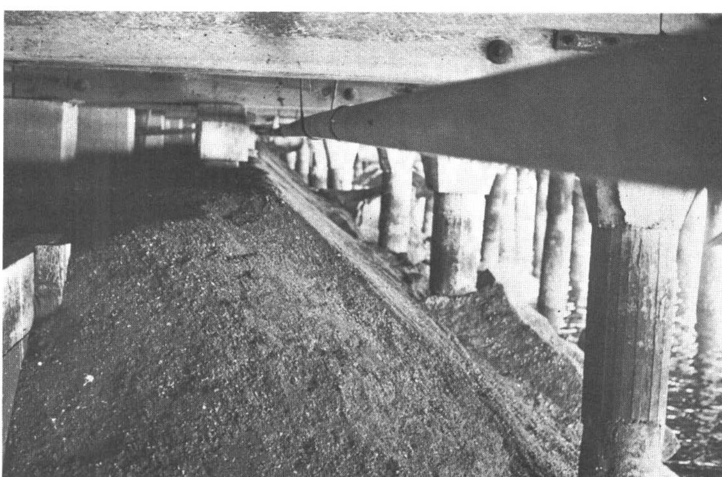


Figure IV-5—Seawall, Los Angeles Harbor (Photographed in 1960) jetty from the infiltration of sand. As a means of strengthening the jetty, it has not been quite as successful as was hoped, but nevertheless has been of value. As an early experiment it has naturally pointed the way for continued development of this type of construction.

Another noteworthy example was the use of asphalt concrete to stabilize a stone sea wall in Los Angeles Harbor during 1939. The Outer Harbor Dock and Wharf Company had lost much of the riprap underneath its wharf due to tidal action and from storms entering the harbor through passage in the breakwater. A careful laboratory study of the stabilities and densities of various mix designs led to selection of the following for this installation:

Sieve Size	Percent Passing (By Weight)
1¼ in.	100
¾ in.	80
No. 3	40
No. 10	37
No. 40	26
No. 80	15
No. 200	8
40-50 Penetration Grade Asphalt Cement (Percent by Weight of Total Mix)	6

The mix was delivered by truck and dumped through a narrow opening in the dock flooring onto the rock of the sea wall. The temperature of the mix at this point was approximately 325°F. Tamping to proper cross section was accomplished by air hammers equipped with suitable heads. Initial tamping below water level was done during low tides, and further dumps were heaped on the lower lifts in order to build up the capping gradually and to provide sufficient heat to obtain good bond. The finishing capping and reconditioning job was 350 feet long with 1:1 slopes on each side and two feet across the top. It averaged 2.5 tons of mix per linear foot. At this date, more than 20 years later, the structure is in excellent condition and continues to afford protection to the installations that are located over and behind it.

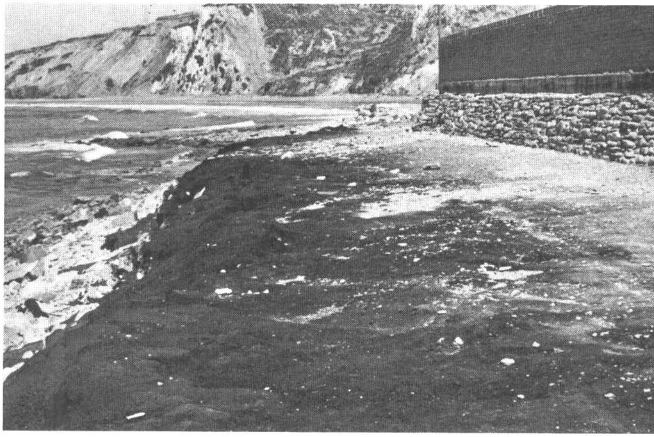


Figure IV-6—Asphalt Capped Seawall, Palos Verdes Estates, California

Recently an asphalt concrete mix has been used to consolidate the rock of the sea wall protecting the seaside swimming pool of the city of Palos Verdes Estates, California. Storm damage was threatening the enclosing brick wall and foundation of the swimming pool. The sea wall was restored to grade and profile, then grouted and capped in one operation by end dumping the hot mix from trucks. After dumping, the mix was raked, screeded and tamped into place. The mix design used sand, crusher dust, and 12-15 percent 200-300 penetration grade asphalt cement. This installation has now successfully withstood the pounding waves of several severe storms.

C. Asphalt Groins

4.09 GENERAL

A number of experiments have been made using a hot-mix asphalt concrete for the complete construction of low profile, relatively short groins. A system of such groins has the function of holding a beach at the desired width and profile and preventing the constantly moving littoral currents from eroding it away. A beach so held is ample protection against storm, wave and wind for itself and the upland behind it. These low profile groin systems are not designed to reach out into the littoral drift and cause beaches to form by trapping material therefrom.

Many of the asphalt groins constructed to date have functioned very successfully. Because of faults in mix and over-all structure design, others have had only a limited success. The type of construction was initiated because of its extremely favorable economy, utilizing, as it does, locally available beach sand for the mix and not requiring expensive construction procedures. For this reason the development is sure to continue until design principles and construction methods are fully proven. The designs and methods which currently appear best will be described in the paragraphs that follow.

4.10 DESIGN AND CONSTRUCTION

Important design features of an asphalt groin are angle, top profile elevation and grade, length, and mix design.

The groin should be set normal to the shore line. This insures that the groin intercepts the line of attack of most storms at a reasonable angle; it also results in shorter length of groin and therefore greater economy.

The elevation and grade of the top profile of the groin should match the optimum beach profile. This so-called optimum beach profile is simply that width and height offering the beach the best self-protection. Such a width and height might be the result of either material build-up or an artificial nourishment.

In length, the groin should extend from a point that anchors its inshore end against flank attacks (usually at the top elevation of the beach dunes) to a point where the projection of the optimum beach profile is about one foot below mean low water. This usually results in a total length of about 200 feet.

The typical cross-section is a small dike about three feet high and six to ten feet in width (of circular or pyramidal shape) sitting on an apron about 20 feet wide. This dike is tapered at the seaward end to the thickness of the apron at that point. In the wave wash region this apron should be hooked down into an inverted curb to prevent undercutting.

Design of the proper sand asphalt mix is very important. The gradation of the beach sand will normally be very poor with about 90 per cent passing the 30-mesh sieve and not more than five per cent passing the 100-mesh sieve. Additional aggregate and filler must be added to obtain a mix of the requisite density and stability. The mineral dust content should be about 10 per cent. A high asphalt content is necessary to insure impermeability and the requisite flexibility. In general this means that the mix will have as much asphalt as it can hold and still be shaped into the groin structure. A 60-70 penetration grade asphalt should be used. Softer asphalts lack early strength and may suffer damage from wave action in the first few hours after placement. Taking these factors into account, the mix design should be made in accordance with *Mix Design Methods for Hot-Mix Asphalt Paving,* The Asphalt Institute, Manual Series No. 2.

Proper construction of an asphalt groin depends on careful planning and timing. Construction should be started at about mid-tide, ahead of low tide, to fully utilize low tide for placing the seaward end of the groin. Construction should then proceed uninterrupted until the groin is completed. Sand dikes should be used to hold back the water. Even so, the subgrade at the seaward end will be in one to three feet of water. At this point the asphalt mix must be placed under controlled temperature in sufficient mass to allow this part of the groin to be compacted and shaped in a flooded environment. As construction progresses shoreward, the dike structure is shaped by hand, or an improvised slip form may be used. After the top surfaces of the groin are shaped they should be compacted and rolled smooth. This is necessary to give the groin a dense tough surface

A. Dozers Preparing Excavation

B. Truck Dumping First Load of Hot-Mix at Seaward End

C. Workers Shaping Upper Structure of Groin

D. Completed Groin

Figure IV-7—Asphalt Groins, Ocean City, Maryland capable of resisting the erosive forces of the sea. Small rollers and tampers, plain or vibratory, may be used for this purpose.

4.11 EXAMPLES OF USE

First American experiments with asphalt groins began in 1948 at Wrightsville Beach, North Carolina. Here three groins were constructed with hot-mix sand asphalt (low asphalt content and beach sand only), four feet high and six feet wide, with two-inch aprons extending 20 feet to each side. Each groin was built around a line of piles driven on eight-foot centers. It is doubtful these added anything to the strength of the structure. With a porous surface from the faulty mix design and a too thin apron, these structures eventually were broken up by the pounding and undercutting of the waves.

A system of 43 groins was constructed in 1954-55 at Ocean City, Maryland, by the State Roads Commission. The construction was preceded by careful engineering studies. The groins were spaced at 900-foot intervals, except for the last five. These five were placed between existing structures at various locations, resulting in a 450-foot spacing in these areas. The groins were built from the mean low water mark to the line of a sand dune fence, a distance of 200 feet. Their top profiles coincided more or less with the beach profiles. These showed an eight percent slope from mean low tide (zero elevation) for 100 feet, then a four percent slope for the next 100 feet to the sand dune fence. There were four different structure plans used, varying in slope and cross-section, with the highest elevation of the top profile established at 11.5 feet above mean low water. Figure IV-8 is a sketch of the final structure plan used. Several mix designs were used but the final design that evolved consisted of 91 percent aggregate and nine percent asphalt cement (60-70 penetration grade was used throughout).

For all but the seaward 35 feet of the groin, the aggregate used was beach sand. A bank-run sand was

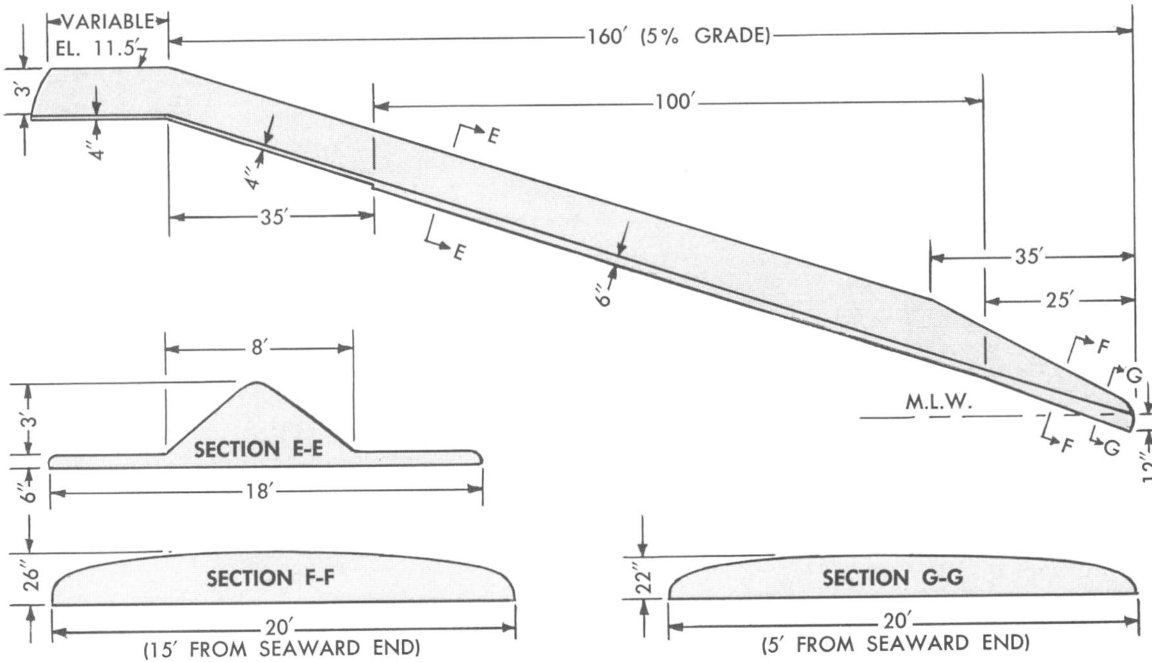


Figure IV-8—Typical Section, Ocean City Groin used for this first section in an attempt to better the aggregate gradation. This first section was placed at a temperature of about 350°F. For the remainder, where it was necessary to shape the dike by hand, a temperature of 250°F was found to be more satisfactory. These groins have suffered considerable breakage at the seaward end, and settlement has occurred in the foreshore area where there is a constant uprush and backwash of waves. The breakage indicates a need for a denser, more impermeable asphalt mix. The settlement in the foreshore area indicates a need for a groin design which will prevent undercutting.

The latest experiments in asphalt groin construction were undertaken in 1959 at Harvey Cedars, New Jersey. Here the city was faced with the great expense of periodic nourishment of the beach by pumping in sand from other locations. It was decided to construct three low-profile short asphalt groins to hold the beach at the desired profile. Previous groin designs were altered to provide better foundation and more mass. Plan and cross sections are shown in Figure IV-9. These groins have a

Table IV-2—EXTRACTION TEST RESULTS OF MIXTURE FOR LONG BEACH ISLAND (HARVEY CEDARS) ASPHALT GROINS

Sieve Size	Percent Passing
1 inch	100.0
¾ inch	93.0
⅜ inch	73.7
No. 4	62.6
No. 10	56.4
No. 40	35.7
No. 80	14.9
No. 200	9.9

% Asphalt, Total Mix	8.6
Bulk Specific Gravity	2.215
Unit Weight, Lbs. per cu. ft.	138.2

Comparing the above values with preliminary laboratory data for 9% asphalt, 5% filler, indicated this sample had 97.7% of laboratory density. Also, based on this previous data, the theoretical specific gravity of this mix was 2.318; percent air voids in total mix was indicated to be 4.4%.

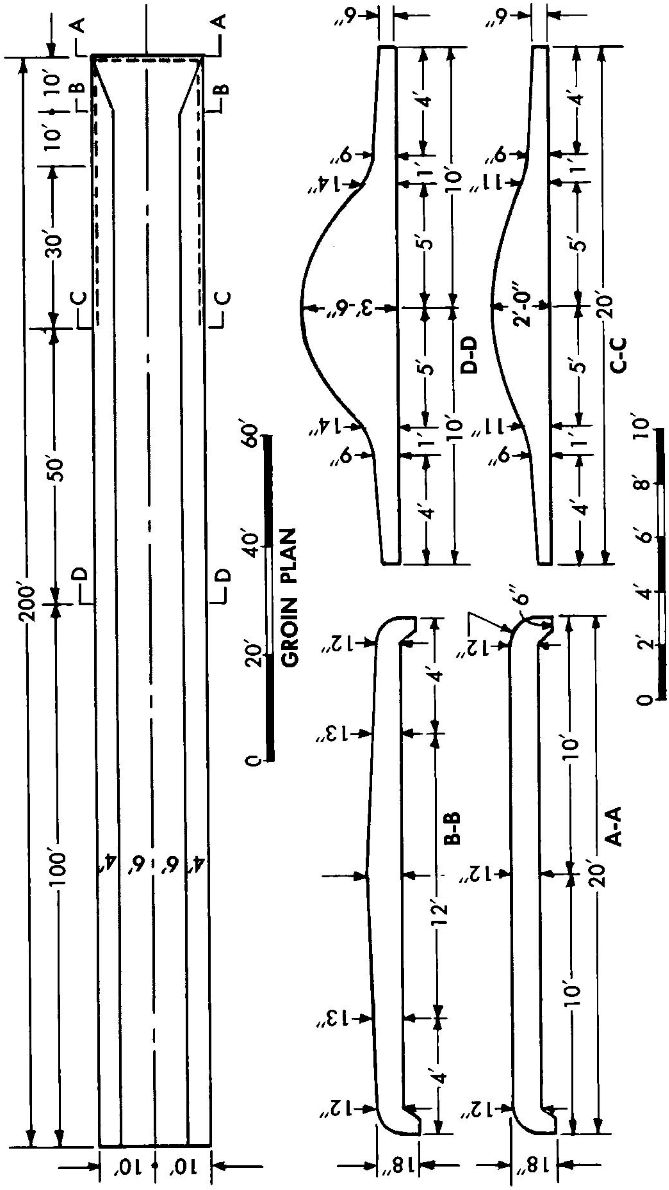


Figure IV-9—Section and Plan, Harvey Cedars Groins uniform slope of five percent throughout their length, with the top of the apron sloping from zero (M.L.W.) to a ten-foot elevation. A locally available bank-run aggregate was used for the mix. Table IV-2 shows results of laboratory extraction tests of the mix. The groins were built as monolithic structures, in one operation, starting at mid-tide.

As the tide receded, the first operation was the placing of a base of six inches of gravel and four to six inches of hot mix to support the heavily loaded trucks. Major excavation was accomplished prior to initiation of construction. For placing the toe of the groin, the beach was excavated about 18 inches below the apron level and the excavation filled with hot mix to provide greater mass at this point. The mix with nine percent asphalt had good flow characteristics and permitted pouring the toe with minimum of handling. However, this mix had too much slump for shaping the main groin section. For this section, the filler and asphalt content were reduced to seven percent each to provide a more stable mix. A small hand roller on an extended handle was used to iron and compact the top surface of the groin.

D. Miscellaneous Asphalt Beach Erosion Control Structures

4.12 SLOPE PROTECTION

Asphalt revetments may be used to protect the exposed seaside slopes of earth or sand structures (sea walls, breakwaters, natural slopes). These are very similar to the river bank revetments discussed in Chapter III. They are usually much thicker and heavier in order to resist the heavier attacks to which they are subjected. The use of asphaltic material on a sea wall slope is illustrated in Figure IV-10. The underwater revetment shown is riprap, which has been consolidated and strengthened by the application of asphalt grout. The junction of the under and above water portion of the revetment is a critical point. As shown here it is protected by sheet

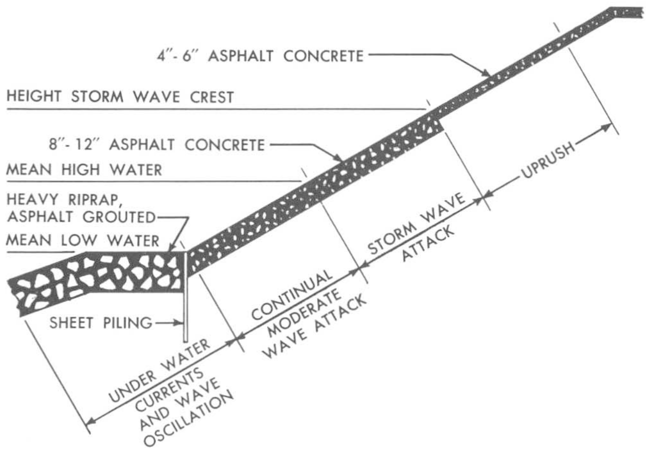


Figure IV-10—Seawall Slope Revetment

piling which should be driven five to six feet deep. The above-water revetment shown is a dense-graded, hot-mix, asphalt concrete. This can be placed on most sea wall slopes by the use of conventional paving machines because the slopes are usually no steeper than 3:1.

The use of asphaltic materials for seaside revetments is much more common in Europe than in the United States. One such use in the United States was the revetment of both sides of a road causeway by the Maryland State Roads Commission. This 2,200-foot causeway connects Point Lookout, the north point at the mouth of the Potomac River, to State Route 5. This causeway had been damaged by storms five times, the last being in 1954 during "Hurricane Hazel" when waves from Chesapeake Bay broke through and created a channel 30 feet wide and eight feet deep. The protective revetment was constructed in 1956-57.

First, heavy treated timber sheeting was driven to protect the toe of the slope. On the bay side this sheeting was reinforced by twelve-inch timber piles, driven to ten-ton bearing capacity, on 20-foot centers. The 4:1 slopes were then paved with four inches of asphalt concrete, put down in two courses. Welded wire fabric reinforcing was placed between the two courses, being first anchored to the sheet piling by nails and bolted timberwales. Paving was done with conventional paving equipment. The wire fabric was ironed out on the first two-inch course with a small lawn roller. Final compaction of the second two-inch course was accomplished by a small roller wired to a heavy motor grader for control on the slope.

4.13 CELLULAR BREAKWATER CAPPING

The capping of 133 steel cells of the Port Austin, Michigan breakwater illustrates another use of asphalt for control structures. This work was accomplished under direction of the Corps of Engineers in 1958. This 1906-foot breakwater consists of 67 main cells, 15½ to 30½ feet in diameter, connected by 66 eight-foot cells, all filled with gravel. The asphalt cap consists of a prime coat on the compacted gravel, a two-inch base course of a dense sand asphalt mix, tacked and finished with a two-inch surface course of the same dense mix. The cap is crowned at ⅛ inch per foot. The mix, heated to

Figure IV-11—Asphalt Capped Cellular Breakwater, Port Austin, Mich.

about 350°F, was trucked a distance of 42 miles from the plant in insulated trucks. The temperature loss was held to ten degrees during the trip. The trucks, using a temporary dredged road that followed the curvature of the breakwater, dumped their loads into a box; the mix was then lifted by clam shell bucket to the tops of the cells. It was spread by rake and shovels and then compacted by hand tampers and vibrating hand compactors.

Chapter V

ASPHALT APPLICATIONS IN DAM CONSTRUCTION

A. General

5.01 OUTLINE OF APPLICATIONS

Asphaltic materials have many important applications in the construction of dams. One is the use of heavy asphalt concrete facings on the upstream slopes of large earth-fill or rock-fill dams. These facings are designed to resist erosion and abrasion forces; in addition, they may act as an impervious screen to prevent leakage through the dam structure. Another is the application of an impervious asphalt layer in the core of the dam. In both methods, the impervious construction is generally continued vertically into the foundation of the dam in the form of a cut-off wall, which may also be constructed of asphaltic materials. Additionally, asphalt cut-off walls may be constructed in the abutment sections of dams to stop underflow, or flanking flow, through existing channels or fissures. And finally, hot asphalt may be injected under high pressure through pipes placed in drill holes to seal off leakage channels deep under dam structures.

5.02 PRINCIPLES

The application of asphaltic materials to dam construction follows the principles and methods already described in Chapter II and III of this manual. In fact, the construction of relatively thin asphalt sections for small dams and embankments does not differ in any important respect from the construction of linings, membranes, and revetments. This chapter will cover a heavier type of construction which is applicable to large dams. Since there are relatively few examples of these heavy asphalt applications, construction of this type is not well known. Certain respresentative cases will be described in the following sections to illustrate the principles and methods of construction.

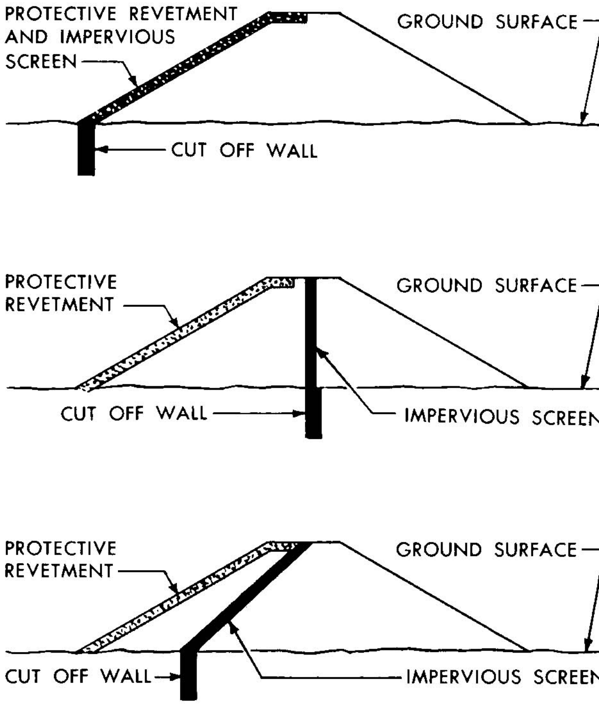


Figure V-1—Alternate Asphalt Courses for Dams

B. Protective Facing of Asphalt Concrete for Earth-Fill Dams

5.03 BONNY DAM TEST

The U. S. Bureau of Reclamation made a full scale test of an asphalt concrete facing for an earth-fill dam in 1951. For this purpose they had constructed a test embankment in the reservoir above Bonny Dam in eastern Colorado. The purpose of the test, along with others, was to find an economical substitute for the expensive riprap rock facing generally used for slope protection on earth dams. Since imperviousness of the embankment was provided by the ten-foot layer of compacted earth, the asphalt concrete facings were tested only as providing protection against erosion.

The asphalt concrete was placed in thicknesses of 6, 9, 12, 15 and 18 inches, each thickness being placed on the slope in a lane 40 feet wide. Sand and gravel aggregates for the asphalt concrete were obtained from local pits. The average grading was as follows.

Sieve Size	Percent Passing
1 inch	100
No. 4	93
No. 10	76
No. 40	34
No. 200	3

Asphalt cement used was the special 40-50 penetration grade, proportioned at from seven to eight percent by dry weight of the aggregate. Materials were mixed at a temperature of 300°F. The mix was placed by spreader box in lifts two to four inches thick, starting at the bottom of the slope. Rolling of each lift started at surface temperature of about 150°F. The densities obtained exceeded the requirement of 90 percent of laboratory density. The joints and surface of each lift were cleaned and given a light tack coat of rapid-curing cutback preparatory to placing the next lift.

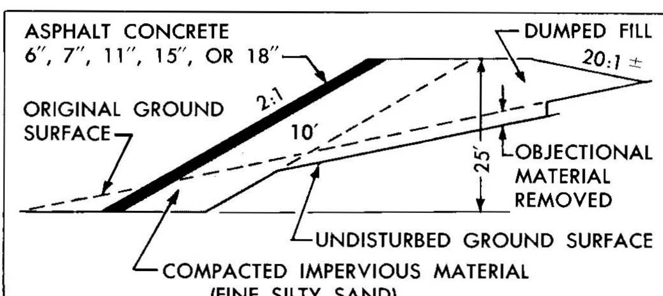


Figure V-2—Test Embankment, Bonny Dam, Colorado

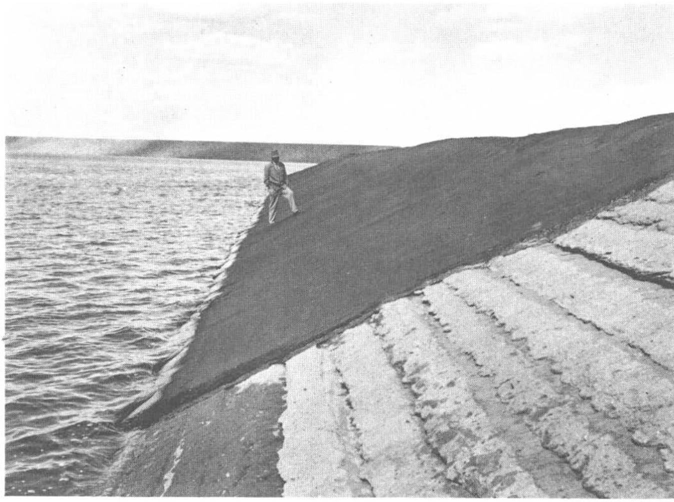


Figure V-3—Bonny Dam Test Embankment (End of asphalt concrete test section, photographed April 1952)

This Bonny Dam test section construction has provided much valuable information, even though it was constructed without the aid of today's experience and more developed standards. Failures have occurred at the end of the test section where the thinner facing was installed. These failures are attributed to undermining caused by waves entering opened construction joints and perhaps by severe overtopping by high waves such as were reported in 1954. Judgment from these tests was that, for erosion protection, dam facings should total at least 12 inches thick, and should be placed in not less than three layers, with staggered joints instead of the butt joining used in the Bonny Dam Test.

In addition to the full scale tests described, extensive laboratory tests of asphalt concrete mixtures have been made. In addition to conventional stability and immersion tests, these have included prolonged tests in a Bureau of Reclamation designed wave-action machine which subjected specimens to rapid immersion and retraction from water, inducing high air and hydrostatic pressures on the surfaces of the specimens. At 40 cycles per minute, some mixtures successfully withstood more than 2,500 hours of continuous testing.

5.04 GLEN ANNE DAM FACING

The first large field application of a protective asphalt concrete dam facing was on Glen Anne Dam, part of the U. S. Bureau of Reclamation's Cochuma Project near Santa Barbara, California. This earth dam embankment is approximately 250 feet long at the crest, with a maximum vertical height of about 100 feet above the creekbed. The upstream slope protection or facing for the dam embankment and both abutments consisted of placing a foot-thick asphalt concrete mat with a slipform in four layers, each approximately three inches thick. The dam embankment has a slope of 4:1, while the abutment slopes are both 2:1. The work was completed in February 1953 and contained approximately 11,600 tons of hot mix including material for a four-inch thick roadway surfacing on the crest.

The aggregate used was a local Vaqueros sandstone, dug from the abutment at the crest of the dam. This buff-colored, fine-to-medium-grained sandstone was very

Figure V-4—Asphalt Concrete Facing, Glen Anne Dam

friable, being easily reduced to loose sand by the fingers. The material all passed the No. 4 sieve. With this material, a dense asphalt concrete was produced, using about 15 percent of a 50-60 penetration grade asphat cement. The slipform was improvised by attaching a 14-inch wide metal plate, properly hinged and equipped with adjustable turnbuckles, to the rear of a spreader. This metal plate, or ironing screed, was angled downward and loaded with weight to obtain compaction. Additional compaction was obtained by rolling with a 1½ to 2-ton roller followed by a six to eight-ton tandem roller. The best densities were obtained when the asphalt concrete was at a temperature of from 180° to 200°F when rolling was started.

The uniformly graded sand with variable fines utilized in the asphalt concrete mix was far from being theoretically the best quality aggregate. To offset this in part, the most careful construction techniques were used. Thickness and overlap of layers was carefully controlled through use of the slipform paver. Experimentation with roller equipment and temperature control led to improved compaction. This facing appears to be performing satisfactorily, though some crack repair has been necessary.

C. Asphalt Concrete Facing, Montgomery Dam, Colorado

5.05 DESCRIPTION

The asphalt concrete facing of the Montgomery Dam is designed and constructed to act both as the watertight layer (or membrane) and as the protective layer of the upstream slope of this rockfill structure. The layer, rated as 12 inches thick over-all, is constructed of rich, dense, hot-laid, hot-mix asphalt concrete. It completely covers the upstream slope of the dam and, at the toe, hooks over and is bonded to a cement concrete cut-off wall, forming a complete watertight barrier across the valley.

The dam itself is a coreless rockfill structure, and its 1900-foot long crest is 113 feet above the lowest point of the stream bed. It was built by the City of Colorado

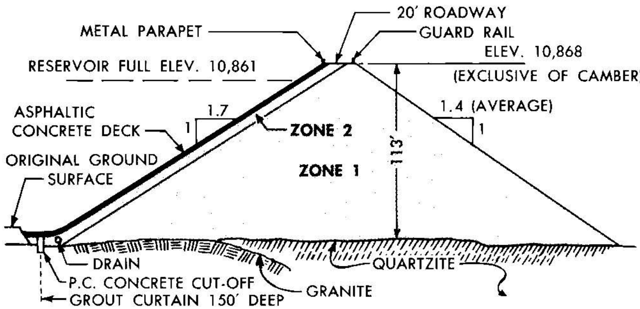


Figure V-5—Montgomery Dam, Colorado—Maximum Cross-Section

Springs on the middle fork of the South Platte River, high in the Rocky Mountains, as a part of the municipal water supply system. The elevation of the dam crest is more than two miles above sea level (10,868 feet). Its reservoir of 95 acres has a storage volume of 5,100 acre feet of water, and is connected to the city by a 30-inch pipe line. The rockfill is of granite quarried from the mountainside. The downstream slope of the fill is 1.4:1 and the upstream slope is 1.7:1. To allow for expected settlement the crest of the dam was given a camber (overfill) of three feet at the maximum section, sloping uniformly to zero at each abutment.

Construction of the dam was started in August 1954, and the rockfill proper was placed in the 1955 and 1956 seasons. The asphalt concrete facing was constructed in 1957, thus completing the dam.

This combination of a rockfill dam with asphalt concrete watertight facing was picked for Montgomery Dam for a number of reasons. The most important reason was, of course, economic; the cost would be less than for any other type affording equivalent advantages. Also, in an area where the construction season is very short, this type of construction perhaps saved a year's time. The asphalt facing was actually placed in less than two months.

The inherent properties of the materials also added to the advantages. The asphalt facing is self-adjusting to settlement expected of the rockfill; it is flexible throughout the extreme range of temperatures that prevail; should some cracking occur, it is self-healing, and should repairs become necessary they are easy to make. Finally, future plans may call for doubling the reservoir capacity by increasing the height of the dam by 50 feet. This can be done easily with both the rockfill and the asphalt facing. For the latter, it means a simple extension upward at the same slope, including extension of the cutoff wall to seal the abutments.

5.06 TEST AND MIX DESIGN

Prior to construction, an extensive testing program was carried out to assure the suitability of the materials, mix design, and placement method of the asphalt concrete facing. This testing program included routine procedures, such as those described in *Mix Design Methods for Hot-Mix Asphalt Paving* (The Asphalt Institute Manual Series No. 2) plus many special tests.

Tests of the locally available aggregates (glacial deposits) showed they were suitable for production of an excellent asphalt concrete. Extensive tests of a number of types of penetration grades of asphalts led to a tentative selection of two asphalt cements—a 50-60 penetration grade and an 85-100 penetration grade. These tentative mixes were then carefully tested to determine which was best for the purpose. Slope-flow tests, both in the laboratory and by means of a 20x120 foot field test panel, assured the suitability of the selected mix under various slope and temperature conditions. Additional special tests were used to determine other important properties or limitations. The more important of these were tests of wave action; tests of ice action; alternate freezing and thawing; contraction due to low temperatures; permeability, and flexibility at various pressures and temperatures.

The job mix finally selected was as follows:

Screen Size	Percent Passing (Washed Sample)
1½ inch	100
¾ inch	87.5
½ inch	75.9
No. 4	59.2
No. 10	47.2
No. 40	30.8
No. 80	20.6
No. 200	21.8
50-60 Penetration Grade Asphalt Cement Percent by Weight of Total Mix	7.8

In order to limit the extent of fractured faces in the aggregates, all boulders larger than six inches found in the glacial deposit were wasted.

5.07 CONSTRUCTION METHODS

The asphalt concrete facing was prescribed to rest essentially on Zone 2 material (minimum horizontal thickness of 10 feet). But it was specified that ¾ to 3-inch rock should be placed over the material in layers and compacted in such a manner that the larger inter-

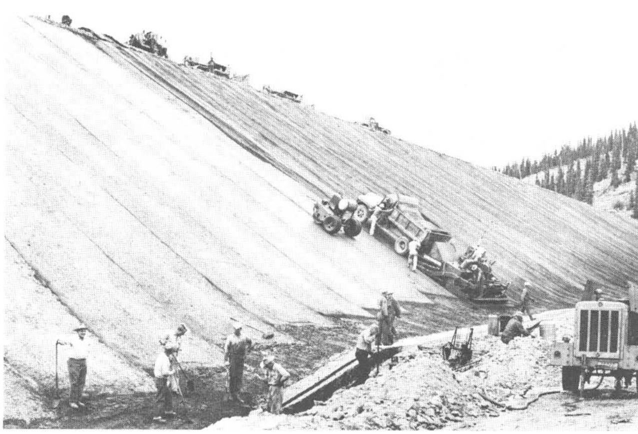


Figure V-6—Montgomery Dam, Colorado—Paving and Compacting Operations (Note cut-off wall)

stices at the surface of the Zone 2 material would be filled and the surface consolidated. When construction of the facing started, the dam slope was prepared by one pass of a vibratory roller over the entire surface, then applying a penetration coat of asphalt. Since this did not make the base suitable for the passage of a regular paving machine, a leveling course was installed. This was asphalt concrete from one to three inches thick, placed from the partially open tail gates of dump trucks as they were lowered down the slope by cable and winch. This spreading was supplemented by hand work, then compacted by a single pass of the vibratory roller.

The remainder of the asphalt facing was placed by a conventional paving machine, suitably modified to operate on the slope and supplied by dump trucks. It was placed in three lifts, which had compacted thicknesses of four inches, three and a half inches, and three inches respectively. Since the leveling course was given an assigned thickness of one and one-half inches, this resulted in the required 12-inch thickness of the asphalt deck. Each layer was placed in 12-foot widths on the upslope pass of the paving machine. All joints within the layers were required to be offset to a minimum of three feet in relation to joints in the next lower layer. Cold joints within strips were given a thin coat of the same type hot asphalt used in the mix. The high density required was achieved by the use of a standard, 3,000-pound, towed-type, single drum, vibratory roller. In two passes, one up and one down, an average density of better than 97 percent was attained. In all, 27,700 square yards of deck surface were placed, totaling about 20,000 tons of asphalt concrete.

Of special importance was the machinery and methods used to maneuver the equipment on the sloping face of the dam. A novel tractor-drawn turntable platform was constructed to handle equipment on the 20-foot roadway on top of the dam. The paving machine could move onto the platform of this machine and then be moved along the top of the dam to another 12-foot lane. Dump trucks

Figure V-7—Montgomery Dam—Tractor Drawn Turntable and Paver at Top of Dam

moved onto this same platform and were then turned 90 degrees and lowered down the slope; similarly, on the return from the slope, the truck could be turned for take-off along the top. This turntable platform was equipped with two electric-powered variable speed winches—one for the paving machine and one for the truck; this allowed them to move independently of each other and the paving to proceed without interruption. Cable from a tractor equipped with winch and boom was used to maneuver the vibratory roller on the slope.

At the toe of the dam (see Figure V-8) the asphalt deck curves out on a 10-foot minimum radius until it is horizontal. It hooks over the three-foot width of the concrete cut-off wall with a 12 x 18-inch section and extends a variable distance beyond. By this manner the water pressure itself will assure maintenance of a water-tight bond and seal at this point.*

** Note: The method of constructing a rock-filled dam and facing it with asphalt concrete that was employed on the Montgomery Dam is the subject of a patent. This patent has been granted to the estate of the late Frederick W. Scheidenhelm, who was a member of a firm of consultants retained for the project. It is Patent No. 2,949,743, dated August 23, 1960, entitled "Dam and Method of Making the Same," granted to Frederick W. Scheidenhelm, Kew Gardens, N. Y., Jean Wolff, executrix of said Frederick W. Scheidenhelm, deceased.*

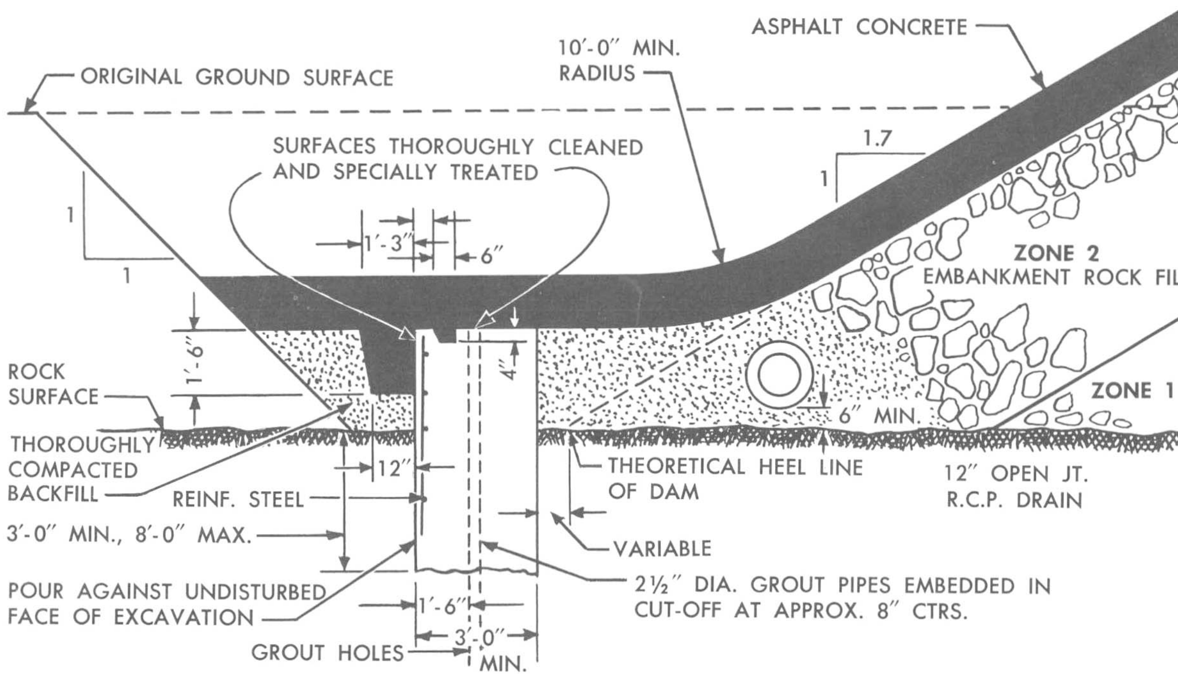


Figure V-8—Montgomery Dam Colorado—Detail of Cut-off

5.08 RESULTS

As of this date the Montgomery Dam has measured up to design expectations in all respects. Settlement of the rockfill has been very slight and it is doubtful it will ever be anywhere close to the three-foot camber allowed for that purpose. At the maximum section, a settlement of only 0.045 feet (less than an inch) was measured June 1957, compared to October 1956. At no point on the entire dam did this settlement over that period exceed 0.055 feet. Close observation of volume of discharge from the dam's drainage system indicates continued integrity of the designed watertightness of the structure. Such minor cracks as have appeared on the asphalt roadway on top of the dam and on the upper part of the slope can be easily repaired as a part of routine maintenance.

D. Asphalt Cut-off Wall, Claytor Dam

5.09 GENERAL

An asphalt cut-off wall was constructed about 1940 in the north abutment of the Claytor Dam hydro-electric project on the New River near Radford, Virginia. This wall of some 4,470 tons of a hot sand asphalt mix was poured into a sheeted trench which was sunk through the overburden to rock. The trench was 340 feet long, averaged less than four feet wide and ranged from a few feet to 150 feet deep. Its construction was necessary to check underflow through the north abutment of the dam, which consisted of dolomite rock, badly cut by solution channels and overlaid with rock fragments and clay. The north end of the dam was actually keyed into a rock cliff, but this disappeared underground a short distance beyond the crest of the slope.

Thus was constructed a cut-off or core wall, flexible enough throughout the temperature range to adjust itself to any of the forces caused by settlement and movement of the ground without cracking and without losing its

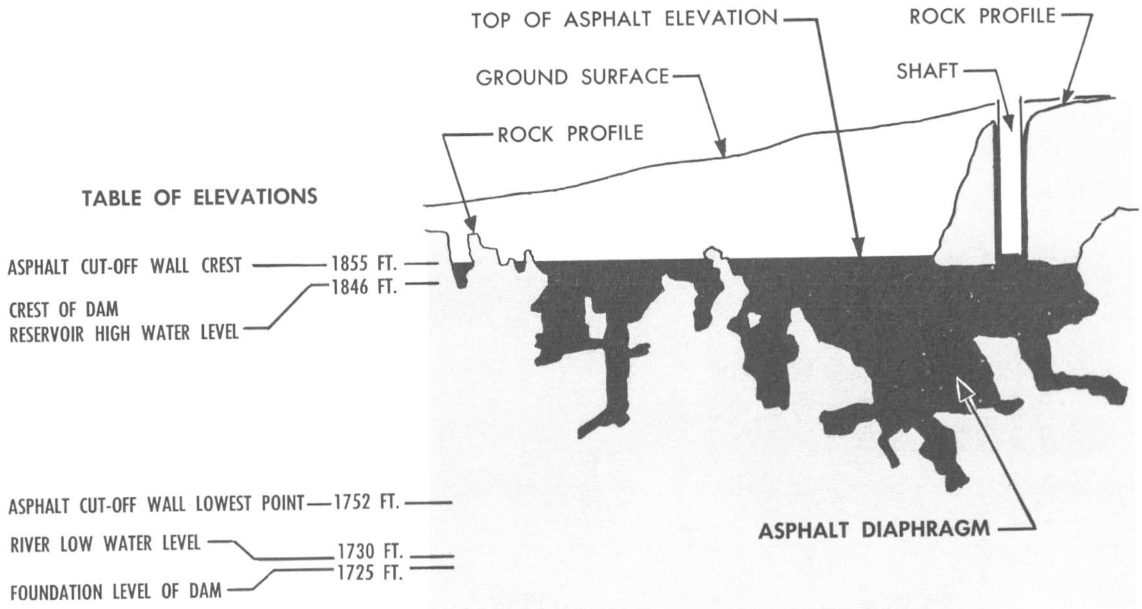


Figure V-9—Longitudinal Cross-Section of Asphalt Cut-off Wall, Claytor Dam, Virginia

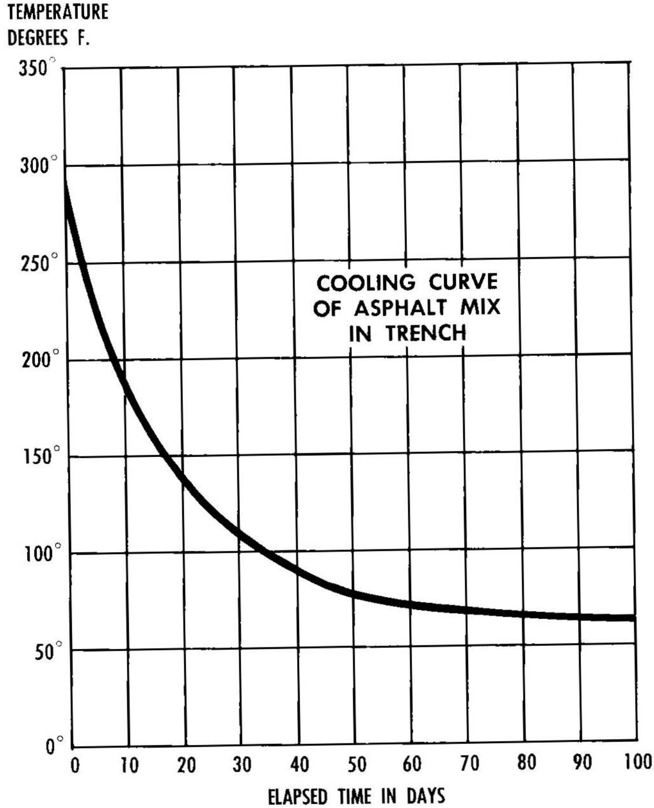


Figure V-10—Cooling Curve of Asphalt Mix in Trench, Claytor Dam

imperviousness. The same principles can be used to construct core walls of impervious layers in the interior of earthfill or rockfill dams and embankments.

5.10 SPECIFICATIONS

After many tests of various sizes and gradings of aggregate, the following specifications for asphalt and aggregate were selected, in the proportions of 11½ and 88½ percent by weights. Dolomite sand was specified as it was manufactured on the job.

ASPHALT

Specific gravity	1.015
Softening point	105°F
Penetration (77°F)	190
Furol Viscosity (210°F)	916 sec.
Flash Test	620°F

DOLOMITE SAND

Sieve Size	Percent Passing
¼ inch	100
No. 10	80.5
No. 40	41.0
No. 100	24.5

5.11 CONSTRUCTION

The placing of the asphalt mixture was very simple after preliminary work on the sheeted trench had been done. The original wood braces were removed without disturbing the sheeting and replaced with steel pipe jacks. The jacks were filled solidly to prevent passage of water through them and were designed to be left in place, as was the sheeting. The surfaces of the rock were wire brushed and primed, preparatory to placing the hot asphalt mix.

The mixing temperature was 335°F. The mixture was taken in tight-bodied dump trucks and dumped into the trench through suitably placed vertically discharging hoppers. Since the mixture stayed in a liquid or semi-liquid state for some time it was possible to pour the asphalt mixture at a rate governed only by the capacity of the mix plant and dump trucks. This rapid placing of the mix maintained sufficient pressure from succeeding pours to force the asphalt mix into all parts of the trench and into all surrounding spaces, thus completely embedding the sheeting. The solution passages were so tightly packed with the asphalt mix that even the small cracks in the rock were filled for some distance from the trench. This was demonstrated by a small inspection drift which was driven a short distance through the rock to a section of the completed cut-off wall.

Resistance thermometers were placed in the asphalt

V-11—View of Top of Trench, Claytor Dam

mix and a daily record of readings was kept until the wires were lost. (At the time the wires were lost the temperatures had closely approached normal, so no effort was made to continue the readings.) The general rate of cooling is shown in the curve in Figure V-10.

Figure V-12—Truck Dumping Hot Asphalt Mix in Trench, Claytor Dam

E. Injection of Asphalt into Leakage Channels Under Dams and Abutment Sections

5.12 GENERAL

Leakage through the underlying strata of dams or abutment sections may be controlled by the pressure injection of hot fluid asphalt into the leakage channels. This use of asphalt is particularly important since it is effective even under conditions (such as appreciable heads and water velocities) that result in the carrying away of other types of grouting materials.

Relatively hard, high-softening-point asphalt cements are used for these purposes. The hot, fluid asphalt is usually pumped through heated pipes let down into drilled holes and having perforations at the leakage strata levels. Once in the leakage channel, the asphalt spreads out to a considerable extent and hardens into a tight plug, or water stop. Due to the inherent characteristics of asphalt these plugs can adapt to slight movements of the surrounding strata and changes in water pressure. Figure V-13 is a sketch showing the probable course of this process.

Though instances of such use are not frequent, they are extremely important because excessive leakage must be stopped once it has developed through the underlying strata of dam structures. It not only may be dangerous, but can result in an intolerable loss of water. In some cases it may be necessary to restore the bearing power of the strata underlying the dam. Asphalt is not a suitable material for this purpose. But it may be used first to stop the flow of water and then be followed by the installation of a portland cement or other type of grout curtain which will restore the foundation bearing power.

Some of the principles and procedures used for this purpose are similar to those described in Article 2.24, Chapter II, dealing with the placing of asphalt membrane underseals beneath deteriorated portland cement concrete canal linings, and in The Asphalt Institute's C.S. 92, *Undersealing Portland Cement Pavements with Asphalt.* The same low penetration grade, high-softening-point

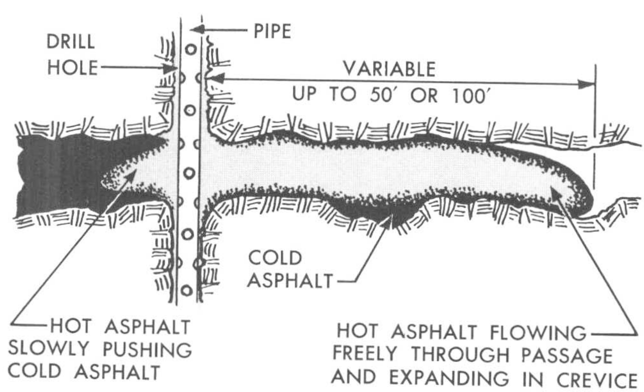


Figure V-13—Asphalt Flowing into Leakage Channel

asphalt cements are used for all of these purposes. (See page 4, C.S. 92, or page 7 of The Asphalt Institute's S.S. 2, *Specifications for Asphalt Cements and Liquid Asphalts.*) This technique is illustrated below in two examples of leakage channels that were successfully plugged up by injections of hot fluid asphalt under pressure.

5.13 HALES BAR DAM, TENNESSEE

The Hales Bar Dam is a portland cement concrete dam located on the Tennessee River at Guild, Tennessee. During its construction in 1913 the builders had much difficulty in waterproofing the underlying strata of limestone rock. In attempting to seal all leakage channels a great amount of portland cement grouting was carried out. Through the years following, leakage under the dam increased to the point where remedial action was necessary.

The inlets and outlets of the leakage channels under the dam were located. It is possible to do this through exploration by divers, through injection of colored dyes or other tracers, and by other techniques. To locate and gain access to the channels under the dam, test holes were drilled from the inspection tunnel through the dam and into the underlying rock strata. The leakage channels were found to be irregular, relatively narrow crevices in the solid rock, probably as a result of solution and disintegration set up by the river water. These channels in general varied from two to ten inches in diameter, though there were several 20-inch passages and one was 36 inches. Some were full of mud, gravel and limestone, and water flowed freely through others at sufficiently high velocity to shake the drilling tools. A water velocity of about six feet per second was measured in one channel.

Having tried other methods without success, it was decided to try plugging the channels by pumping in hot fluid asphalt. Preliminary tests indicated two things. First, that hot fluid asphalt pumped under a pressure of up to 200 pounds per square inch would slowly and surely move into and completely fill the crevices in the rock strata, congealing and hardening as it moved in. And second, that by pumping the asphalt slowly and intermittently, permitting it to cool and congeal as it entered the leakage channels, a tight plug could be formed without an excessive loss of material even where there was a rapidly flowing stream of water under pressure.

Actual operations were started in 1926. The simple equipment required consisted of asphalt heaters and suitable high pressure pumps. The asphalt was pumped through 1½ inch pipes let down into the drill holes. These pipes were extra heavy in the upper sections and of standard weight in the lower section where the creviced rock was found. The lower sections were perforated with ¾-inch holes for outflow of the asphalt. To keep the asphalt hot during pumping operations, electric resistance wires held in place by insulators were placed in the center of these pipes. The wires not only kept the asphalt sufficiently hot during pumping operations but made it possible to resume operations after a shut down by merely applying the heat for a few minutes. And they may be left in place for subsequent operations—even though it may be years later.

Sixty-eight holes were drilled, varying in depth from about 90 to 130 feet. During the operations about 2000 tons of asphalt were pumped into these holes. As the work progressed many of the visible outlets of water below the dam disappeared entirely, and others were gradually reduced. This work was checked by redrilling into the leaking strata. The check showed crevices which formerly contained rapidly flowing streams were now sealed with the plugs of hardened asphalt.

Recently the strata under this dam has started to leak again. Some of the asphalt plugs have been found downstream from the dam. It is possible that water pressure alone has forced these plugs out. But it is more likely that the pressure has been assisted by the dissolving of material from around the plugs. Operations are again under way to pump hot asphalt into the leakage channels through holes drilled into the leaking strata.

5.14 GREAT FALLS RESERVOIR, TENNESSEE

The dam here was built in 1916 to create a reservoir for a hydro-electric plant. In 1925 the height of the dam was increased by some 35 feet. Shortly afterward leakage began through the narrow rock ridge separating the reservoir from the gorge downstream of the dam. This leakage gradually increased until it amounted to about 420 cubic feet per second, representing a power loss of 14 percent.

In 1945, operations to control this leakage were started. Several rows of holes were drilled into the rocky ridge near the downstream gorge. These holes were up to 60 feet deep and extended over a length of almost a mile. In all some 608 holes were drilled over a 12-month period. Where it could be used, a portland cement grout was pumped into the holes. Where there was rapidly flowing water it was found necessary to use injections of hot liquid asphalt. In all about 4300 tons of asphalt were injected. As a result leakage was reduced by about 98 percent, and the water that had been lost was saved to produce electric power. Recent check with operating officials disclosed that this barrier is apparently holding firm against leakage.

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