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INVESTIGATION OF MASS PLACEMENT OF SAND ASPHALT FOR UNDERWATER PROTECTION OF RIVER BANKS

Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

August 1951

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CORPS OF ENGINEERS, U. S. ARMY

INVESTIGATION OF MASS PLACEMENT OF SAND ASPHALT FOR UNDERWATER PROTECTION OF RIVER BANKS

TECHNICAL MEMORANDUM NO. 3-329

CONDUCTED FOR

THE PRESIDENT, MISSISSIPPI RIVER COMMISSION

CORPS OF ENGINEERS, U. S. ARMY

BY

WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

AUGUST 1951

PREFACE

The Waterways Experiment Station was authorized to conduct laboratory tests to investigate the possibilities of increasing the fluidity of asphalt mixtures and thus reduce the quantity of asphalt used in revetments by letter from the Mississippi River Commission dated 3 November 1947, subject: "Experiments with Asphalt Revetment." A comprehensive program covering all phases of the use of asphalt for river bank protection, prepared as a "Plan of Test," was approved in part by the Mississippi River Commission in November 1948. The study of "Mass Placement of Sand Asphalt" under the "Underwater Protection" phase of the Plan of Test was an approved item.

Preliminary results of a few of the laboratory tests and the results of a limited program of dumping hot sand asphalt through a metal chute into a sump were presented in "Interim Report on Investigation of Sand-Asphalt Revetment" dated 1 July 1948. This report presents the results of all laboratory tests and therefore supersedes the interim report as far as laboratory testing is concerned. The results of the program of dumping hot sand-asphalt mixtures in the sump were inconclusive and are not repeated in this report.

The investigation was conducted by the Flexible Pavement Branch, Soils Division, Waterways Experiment Station. Experimental field work on the Mississippi River was accomplished by personnel of the floating asphalt plant of the New Orleans District. The Office of the President, Mississippi River Commission provided general over-all guidance and assisted in planning the tests and conducting field experiments on the Mississippi River.

Mr. R. M. McCrone of the Mississippi River Commission devoted considerable time to and was of material assistance in the investigation. Mr. W. K. Boyd, former chief of the Flexible Pavement Branch, was active both in the planning and conduct of the investigation. Engineers of the Waterways Experiment Station actively connected with the study were: Messrs. W. J. Turnbull, C. R. Foster, J. M. Griffith, O. B. Ray, and E. C. Meredith. This report was prepared by Mr. Meredith.

CONTENTS

INVESTIGATION OF MASS PLACEMENT OF SAND ASPHALT FOR UNDERWATER PROTECTION OF RIVER BANKS

PART I: INTRODUCTION

The Problem

1. Mass underwater placement of hot sand-asphalt mixtures for prevention of scour of river banks has been in progress in the Lower Mississippi Valley since 1946. Mass sand-asphalt revetment had been placed at Avondale, Reid Bedford, Hardscrabble, Kempe, and Milliken Bends on the Mississippi River prior to initiation of the investigation described herein. The mixtures used contained from 10 to 16 per cent 85-100 penetration asphalt cement by weight, depending upon gradation of the sand aggregate, and mix temperatures varied from 380° to 400° F. Cores taken at three of the locations indicated that the material congealed on the subaqueous bank as a homogeneous, substantially waterproof mass. Dumps made in shallow water and examined during low stages showed a tendency to pile up and leave uncovered areas.

2. Placement was accomplished by bottom-dump barges capable of handling 150 tons of material in each of two 36- by 4-ft hoppers. About 20 in. of water stood in the bottom of the barges when empty, as may be seen in photograph 1. Consequently 30 to 40 tons of sand were first placed in each hopper to avoid pouring the hot mixture into this water. Dumps were usually spotted with the aid of a string-out of light pontons, but in some cases a distance wire and sextant were used. The spacing between dumps was varied to provide coverage of 5 to 6 tons per square.

The channel end of the revetment where scour action had been severe, usually along the toe, was reinforced by double dumps. Photograph 2 is a typical view of a barge loaded with asphalt and in position for dumping. It may be noted that the sand-asphalt mix piled up at one side of each hopper as it was discharged by the hot elevator. Photograph 3 shows the same barge immediately after emptying both hoppers. It should be pointed out that the initial underwater placements were made primarily on existing mattresses for reinforcing their toes.

3. The early experiments (described above) were somewhat random in nature since use of mass sand asphalt as an underwater revetment was relatively new. Many conferences were held among the offices concerned to discuss the methods and procedures used. It was considered that a comprehensive experimental program along planned lines was desirable in order to develop the most feasible and economical methods and procedures of designing and placing mass asphalt revetments. Therefore, a comprehensive program of experimentation was prepared, and various studies undertaken. This report summarizes the investigational work accomplished to date on underwater placement of mass sand asphalt. Some of the tests performed were of little value in the light of further studies; however, they are presented herein as a matter of record.

Objectives of the Investigation

4. The general objective was to determine those properties of the asphalt mixture dropped in a mass under water which will give the best coverage, considering spread, thickness, strength or resistance to disintegration, deformability in conforming and reforming as the river bed

scours, to river-bed irregularities, velocity of the water, depth of placement, and economy of placement. Specific objectives were to:

a. Determine the effect of varying the quantity of asphalt cement on properties of the mix.

b. Determine the effects of mixing and placing temperatures on properties of the mix.

c. Determine the effect of different penetration grades of asphalt on properties of the mix.

d. Investigate means of reducing the asphalt content by admixtures.

e. Determine the effects of aggregate gradation on mix properties.

f. Determine the effects of dropping mixtures en masse through water.

g. Develop methods to simplify underwater placement.

h. Investigate the feasibility of the use of asphaltic products other than asphalt cement.

General Procedure for the Investigation

5. The three main steps followed in accomplishing the objectives were:

a. Laboratory and simple small-scale tests were used to study several possible methods of improving the desirable properties of the mixture. Methods that were infeasible were eliminated and those offering possibility of success were investigated further.

b. Investigations were made on the more promising developments of the laboratory and small-scale tests by means of field tests on as large a scale as Experiment Station facilities would permit. Scale model studies were not used since the asphalt mixture itself could not be scaled down. Mixtures were produced in a central mixing plant in sufficient volume to be dumped in ditches, pits with sloped sides, a hydraulic model, and a creek channel so that spread, thickness, conformity to irregular slopes, and effect of velocity of water on larger masses of asphalt mixtures could be determined.

c. Final experiments were conducted in the prototype. The results of these experiments are incomplete due to the length of time required for adequate observation of performance. It is expected that these tests will eventually bring to light those influencing factors which were not determined in small-scale tests such as the effect of large masses of asphalt mixture, velocity of water, depth of placement, conformity to highly irregular slopes and ability to reform and continue to protect slope after current scours the bed to greater depths, and durability of the mixture in water. A limited amount of placement has been accomplished during high water on banks that are exposed during low water. These placements will be observed during low-water stages.

PART II: PRELIMINARY STUDIES

6. It was recommended by the Mississippi River Commission in the early stages of the study that an investigation be made of the use of admixtures to affect the properties of asphalt mixtures in a manner similar to the use of air-entraining agents with portland cement. A search was made of available pertinent literature and inquires were directed to various governmental and commercial agencies and to individuals. The inquiries briefly stated the problem and requested information on any products that might prove suitable. The search for available literature proved unfruitful, and only a few of the letter inquires offered feasible suggestions. These suggestions have been tested and are included in this report in a later part.

7. One of the consultants retained by the Waterways Experiment Station recommended the study of a patented process, in which steam is injected into the asphalt just prior to mixing, causing the asphalt to foam. Fuel oil and beef tallow are used as additives. An agreement was made whereby the holders of the patent would conduct experimental tests on the underwater placement of mixtures prepared by their process. It was their opinion that the process would " ...produce a satisfactory material and eliminate troubles with standard hot mixes in cold water ..." Information received on their initial experiments in pits filled with water indicated that mixtures prepared by the patented process had more fluidity than standard mixes in the lower range of asphalt contents. Laboratory tests were attempted but they were not satisfactory. Also the producer offered the use of a dispersion chamber for field tests and such

tests were conducted as discussed later in this report.

8. Suggestions resulting from other inquires included: (a) the use of various types of admixtures ranging from acetic acid to Vel soap; (b) the use of cracked asphalts; and (c) the use of high penetration grades of asphalt cement. These and many other suggestions and ideas were tried in the laboratory.

PART III: LABORATORY SLUMP TESTS

9. The relative consistencies of the various mixtures were compared by means of a concrete slump cone. The cone was seated on a metal plate, filled with the mixture, and then carefully raised. The slump of the mixture from the original height was measured in inches. It was recognized that no correlation between inches of slump and satisfactoriness of the mixture was available, but it was considered that the mixture with the largest slump would be the most desirable because of its spreading properties. The majority of the comparisons were made in air. A few of the more promising methods of improving the mixtures were studied with slump tests made under water. The equipment, materials, and procedures for the tests are described first, followed by the tests in air and the tests under water.

Equipment, Materials, and Procedures

Equipment

10. A limited number of initial trial tests were made with a standard concrete slump cone. After these trial tests, the standard 12-in. cone was modified to a 9.5-in. height in order to reduce the quantities of ingredients used in preparing the mixtures by approximately 50 per cent and thus expedite the laboratory program. The general shape of the standard concrete slump cone was maintained. Later the cone was insulated in order that the desired mix temperature might be maintained during placement, and a base plate was attached so that the filled cone could be placed in a tub of water, the base plate released, and the cone raised. Barge dumping was

simulated by equipping the smaller orifice of the cone with a watertight trap door so that the mixture could be dumped through water with the cone inverted. The standard concrete slump cone, the first 9.5-in.-high cone, the insulated cone (9.5 in. high) equipped with base plate, and the insulated cone equipped with a trap door on a smaller orifice are shown in photograph 4. In addition, an insulated cone about the size of the standard concrete cone equipped with a trap door on the smaller orifice was used to investigate the effect of doubling the size of the mass. This cone has about twice the volume (350 cu in.) of the 9.5-in.-high cones. The slope and height of the smaller cone were maintained, but the cone diameter was increased.

Materials

11. Aggregates. Two aggregate types, coarse and fine river bar sand, were selected for use in these tests because these aggregates were normally used in field placement. Sands ranging from coarse to very fine may be present at any specific location on the river, but generally the sands along the Lower Mississippi River bars are within the limits of medium to very fine. Gradation curves for the two aggregates used in this investigation are shown on plate 1.

12. Asphalts. A fairly wide range of types and grades of asphalt was used in the laboratory tests. The materials used are listed in table 1 with test results where available. The majority of the field tests were conducted with asphalt cement, penetration 91.

13. Admixtures. A wide assortment of materials were tried in the laboratory study to improve the fluidity of the mixtures. Many of the

materials such as sodium chloride were common products but some were patented products whose exact ingredients were unknown. Table 2 lists the admixtures that were studied together with available information regarding them.

Procedures

14. Asphalt mixtures were prepared in a commercial bread-dough type of mixer. The cone was placed on a flat surface and the mixture carefully placed in the cone, when the slump tests were made in air. A spatula was inserted along the walls of the cone to insure that the mixture completely filled the cone. Any excess material was screeded off the top and the cone was raised carefully and removed. The resulting slump from the original height was determined. The underwater test was made by filling the insulated cone with the bottom base plate as before, and placing it in a tub of water. The base plate was released and the cone raised carefully and removed. Slump values were determined by direct measurement in the water. The tests to simulate barge dumping were made with the inverted cone equipped with trap door on the smaller orifice filled with the mixture, and the cone held in a shallow vat with the smaller orifice about 2 in. under the surface of the water. The trap door was opened allowing the mass to pass through about 8 in. of water onto a horizontal surface covered with sand. The water was removed when the mixture had cooled and measurements, observations, and photographs were made. Samples were obtained where necessary. It was found that measurements and observations had to be made immediately after removal of the water because the shape of the mixes at high asphalt content changed considerably after the water

was removed.

15. Some of the mixtures produced specimens of loose texture when dumped under water. It was recognized that such loose-textured mixtures would probably be subject to excessive erosion when placed on the river bank. Hence, an erosion test was devised to furnish comparative data on some of the mixes. A portion of the material was dumped under water and allowed to cool for approximately five minutes. A 3/16-in.-diameter stream of water at city pressure (approximately 40 psi) was directed against the surface of the material. The end of the nozzle was held 1/2 in. from the surface of the specimen for a period of five minutes. Dimensions of the eroded hole were then measured.

Slump Tests in Air

Effect of heat and asphalt content

16. A basis for comparing the effects of various admixtures was provided by a series of base tests made with coarse river bar sand and 116 penetration asphalt cement which are standard for underwater placement. Mixtures were prepared at asphalt contents ranging from 4 to 16 per cent at 300° F (mix temperature) and at 8, 10, 12, and 14 per cent asphalt at mix temperatures ranging from 250° to 450° F. Photograph 5 shows the spread of mixes containing 6, 12, and 16 per cent asphalt at mix temperature of 300° F. Cracking occurred at 6 per cent asphalt and free asphalt appears on the surface at 16 per cent asphalt. The results of the entire base series are shown on plate 2. The results indicate that as increments of asphalt are added, the slump decreases to a minimum at an asphalt content of 8 to 10 per cent (right-hand plot) after

which the slump increased rapidly with increments of asphalt. The plot of mix temperature versus slump (left-hand plot) indicates a decrease in slump with an increase in temperature for asphalt content of 10, 12, and 14 per cent. The decrease at the higher asphalt contents was significant. A slight increase in slump occurred with an increase in mix temperature at 8 per cent asphalt, but the slump was low even at the high temperature. The effects of high temperatures on the mixes are shown in photograph 6. The mixes at 450° F show considerably more cracking than mixes prepared at 300° F at the same asphalt contents. The general appearance of the mixes at the high temperatures indicated that the asphalt was affected detrimentally by the high temperatures, resulting in a less fluid material.

Effect of penetration grade of asphalt

17. A similar series of tests was made to study the effect of different penetration grades of asphalt. Coarse river bar sand and asphalt cements of 31, 116, and 193 penetration were used. Mixes were prepared at 8, 10, 12, and 14 per cent asphalt at 250° and 300° F mix temperatures except that no mixes were prepared at 250° with the 31 penetration grade asphalt. The results of the tests are shown on plate 3. It can be seen that the general trend is toward increased fluidity with increasing penetration grade of asphalt cement at asphalt contents above 10 per cent. At 8 per cent a slight decrease occurred with increasing penetration grade of asphalt.

Effect of cracked asphalts

18. Cracked asphalts having penetration of 90, 133, and 190 were tested in lieu of normal asphalt cement. Mixes were prepared with coarse

sand and 8, 10, and 12 per cent asphalt in order that comparison of slump values with similar mixes containing asphalt cement might be made. Indications were that slump did not increase with increase in asphalt content but rather decreased somewhat within the range of asphalt contents tested. The average values obtained, along with comparable values on two mixes containing asphalt cement, were as follows:

Asphalt Content	Slump, In. Cracked Asphalt 90 Pen.	133 Pen.	190 Pen.	Normal Asphalt Cement 100 Pen.	193 Pen.
8	4.9	4.8	5.0	4.8	4.6
10	4.4	4.8	4.6	5.2	5.9
12	4.2	3.6	3.9	6.6	7.1

Tests with admixtures

19. The tests with admixtures were conducted in the same manner as the two series described previously. Various admixtures were incorporated into the sand-asphalt mixtures to determine their respective effects on fluidity of the mixture. The percentages of each admixture were based on producers' recommendations, applicability to field use, or were determined by trial and error. Mixes were prepared at 8, 10, and 12 per cent asphalt and at mix temperatures of 200, 250, or 300° F. Coarse river bar sand was used throughout. Asphalt of 116 penetration grade was used except in a few cases. Normally slump measurements were made immediately after the mixture was prepared. However, delayed tests were conducted when a mixture offered promise of improved fluidity over the basic mixture. In these delayed tests, quantities of the mixture were placed in a constant temperature oven for specified time intervals

since it was anticipated that field practice would require filling barges several hours before actual placement. The "delayed" tests were conducted to determine whether or not the initial beneficial effects could be maintained over a reasonable period of time. The following additives produced no consistent slump greater than occurred in the base tests and detailed results are not shown for these additives: slow curing liquid asphalt (SC-2) and three compounds with fatty bases produced by the Nopco Chemical Company. The results of slump tests on mixes with additives that produced more fluidity than obtained in the base tests are shown in table 3. The table shows the asphalt content, the mix temperature, the type and percentage of admixture, the slump, and remarks about the tests. For comparison, the results of base tests with no admixture are shown. The increase in fluidity gained with most of the additives was not appreciable, and the tendencies toward cracking observed in basic mixtures continued to be prominent. Therefore, a detailed discussion of the performance of each of the many admixtures tested is not presented. The slump data indicate a general trend toward improvement in fluidity from additives up to an equivalent of about 2 per cent asphalt. It is considered that such a minor improvement does not warrant the use of other materials at low asphalt contents since, in most cases, the admixture is more expensive than an additional 2 per cent of asphalt. That is, the introduction of 14 per cent asphalt without an additive will produce slump values comparable to those obtained with 12 per cent asphalt with an additive. Many of the additives included in table 3 caused the mixture to swell excessively during preparation, but the mass usually subsided so quickly during the dumping process that improvement in fluidity was negligible.

20. A series of tests was made to determine the effect of penetration grade of asphalt on sand-asphalt mixes containing Tuffklay, Vel soap, DuPont Product BC, and sodium chloride since these admixtures showed merit. Two asphalt cements were used, one having a penetration of 100 and the other having a penetration of 193. Coarse river bar sand was used as the aggregate and all mixtures were prepared at 300° F. Slump test data are shown in table 4. The tests on straight asphalt cement indicate increasing fluidity with increasing penetration, but this trend was not obtained in mixes containing admixtures. In fact, slightly higher slump values were obtained with the lower penetration asphalt cement where admixtures were used.

Slump Tests Under Water

Tests

21. Underwater slump tests were conducted with a few of the more promising additives selected from the results of the tests in air. Tests were also made with additives which were suggested after the program of tests in air had been completed. The results of tests made with Tuffklay, sodium silicate, Vel soap, DuPont Product BC and sodium chloride are shown in table 5. The sodium chloride was mixed with water to form a thick paste before it was added to the mixes. The other additives were introduced into the mix in their normal state. The slumps immediately after mixing and after a 1-hour delay are shown. For comparison the slumps in air immediately after mixing are also shown. The table also shows the reaction to the erosion test and the degree of stripping (displacement of asphalt) that occurred. In general, the mixtures reported in table 5

showed poor surface texture and some cracking. Additional mixes were tried containing steam and water, Laykold, emulsions and slow-curing cutback asphalt. The results of these tests are described below.

a. Steam or water materially increased the fluidity but the beneficial effects lasted a very short period of time.

b. Laykold, product of the American Bitumuls Company, was used to replace up to 50 per cent of the asphalt-cement content. Decrease in slump resulted, large cracks developed under water, and stripping occurred.

c. Mixtures containing HV and HCM bitumuls, rapid-curing and slow-curing emulsions, respectively, fell apart after poor slump under water. The addition of small amounts of portland cement to the HCM bitumuls developed a limited amount of cohesion but the slump was very poor. The material sloughed instead of flowing.

d. It was found with SC-2 that mixtures containing 8 to 10 per cent liquid asphalt did not harden but remained crumbly. The mixture containing SC-5 was plastic at room temperature but was stiffer and had more cohesion than the SC-2.

Discussion

22. The results of the underwater slump tests show that for a given mixture the slump in water is consistently less than the slump in air. For example, with no additive (first line in table 5) the slump in air was 5.2 in. whereas the slump in water was only 2.2 in., a difference of 3 in. In general, the mixes reported in table 5 maintained their fluidity through the 1-hour delay period. An exception was DuPont Product BC. A vigorous reaction, which occurred when the slump test was made immediately after mixing, produced considerable fluidity. The reaction was considerably less after a 1-hour delay and the delayed slump test showed a resultant lower fluidity. The Vel soap produced a mix which stripped excessively. The other mixes reported in table 5 were reasonably satisfactory from the

standpoint of erosion resistance and stripping. Admixtures of steam and water produced foaming of the asphalt but the foaming period was very short. The mixes prepared using Laykold were much less satisfactory than those prepared with straight asphalt cement. The mixes incorporating emulsions and slow-curing cutbacks did not develop satisfactory cohesion and hardness under water.

23. From an over-all standpoint, the results indicate that none of the additives produced a significant increase in the fluidity of the mixtures in the 1-hour delay test. More significant changes in flow characteristics could be obtained by increasing the asphalt cement content. In general, any increase in fluidity obtained by the use of additives could be equalled or exceeded by increasing the asphalt content by 1 or 2 per cent. There were also indications that an asphalt content of more than 10 per cent would be required to obtain the desired texture since cracking and poor texture occurred at 10 per cent and less asphalt.

Simulated Barge Dumping Tests

24. A review of the results of the slump tests in air and water revealed that tests were needed covering a much wider range of asphalt contents. It was also considered that the method of placing the material in the cone and raising the cone, allowing the material to slump, was not realistic. The procedure described in paragraph 14 was used to simulate barge dumping.

Effect of asphalt content, heat and aggregate gradation

25. The radical change in slump test procedure and the need for covering a wider range of asphalt contents necessitated re-determination

of the basic slump curves. This was done by the simulated barge dump procedures. The surface area of the vat was sufficiently large to allow placement of mixtures covering the entire range of asphalt contents from about 10 to 90 per cent before removing the water for observations and photographs. Mixtures were prepared with coarse and fine river bar sand and 89 penetration asphalt cement. Mix temperatures were 200°, 300°, and 425° F. The results of these tests are shown in table 6. The data include slump measurement (from the original cone height), measurement of the spread, density of the mixture in place and pertinent observations. Plots showing the effect of heat, asphalt content and aggregate gradation on slump under water are presented on plate 4. The effect of asphalt content and aggregate gradation at a normal mix temperature are shown on the figure to the right and the effect of mix temperature on the fine sand mixes appears on the figure to the left.

26. Effect of asphalt content. It may be noted in table 6 that when the asphalt content was 15 to 20 per cent, depending on aggregate gradation, the mass tended to pile up rather than to spread and form a mat. Uniform spread was obtained between 20 and 40 per cent asphalt. Plate 4 shows that a sharp increase in slump occurred with increasing asphalt content up to 20 to 25 per cent asphalt. The slump increased slowly beyond this point. Specimens with an asphalt content above 40 per cent consisted of smaller and smaller inner rings of fairly uniform mat encircled by larger and larger outer rings of water-filled blisters. Density and stability decreased sharply. Mixtures placed at the normal mix temperature tended to float when the asphalt content reached 60 to 80 per cent. Photographs 7 and 8 are views of these specimens just after

water was removed from the vat. Results of these basic tests, insofar as they can be evaluated without consideration for volume, slope, and depth and velocity of water, indicate that the critical asphalt content is between 20 and 40 per cent.

27. Effect of heat. Table 6 and plate 4 (plot on left) also show the effect of heat on sand-asphalt mixtures placed under water. The slump values of mixtures containing asphalt contents within the critical range of 25 to 30 are reasonably the same at the normal mix temperature of 300° F and at the very high temperature of 425° F. Slump decreases slightly at 200° F. The two striking differences that developed by varying from the normal mix temperature were (a) the sharp decrease in density at 200° F, and (b) the rough mat with blisters at relatively low asphalt contents resulting from excessive heat at 425° F. Specimens placed at 200° F are shown in photographs 9 and 10 and those placed at 425° F appear in photograph 11.

28. Effect of aggregate gradation. The grain size of sand aggregate affects the underwater slump characteristics of a sand-asphalt mixture within the critical range of asphalt contents. The figure on the right side of plate 4 shows that the fine sand requires about 5 per cent more asphalt than the coarse sand to produce the same amount of slump until the asphalt content approaches 25 per cent. That is, the same slump value (8.1 in.) is obtained at 25 per cent asphalt with fine sand and 20 per cent asphalt with coarse sand. The difference becomes considerably less at higher asphalt contents. Practical application of these data is that gradation of the sand to be used must be determined before the minimum asphalt content required to provide adequate spread and coverage can be selected.

Effect of penetration grade of asphalt

29. Slump curves were likewise developed by simulated barge dumping for mixtures containing asphalt cement with penetrations ranging from 50 to 300. The slump measurements, density determinations and observations are shown in table 7; slump curves for mixtures containing fine sand appear on plate 5. It may be noted on plate 5 that slump curves are substantially the same for all penetration grades tested. However, table 7 reveals that the resulting mat had broken coverage at relatively low asphalt contents when the penetration exceeded 100 to 150. Routine tests on the various grades showed that for penetration of 50 to 150 the ductility exceeded 150, whereas for penetration of 150 to 300 the ductility dropped to 112 to 123. The tests indicate that the asphalts of the softer grades were less ductile and more brittle than the asphalts of lower penetration. Photograph 12 is a view of the specimens containing 200-300 penetration asphalt cement showing poor coverage above 30 per cent asphalt. On the other hand, no broken coverage was observed when the penetration was between 50 and 100. Specimens containing 50-60 penetration asphalt cement are illustrated in photograph 13. Only a limited amount of broken coverage resulted when using the 100-150 penetration grade and those breaks were in specimens having asphalt contents of 50 per cent or more. These data indicate that 50 to 100 penetration asphalts are more satisfactory for underwater placement than higher penetration grades of asphalt. However, asphalts from other crude sources may not be in agreement with these data.

Effect of size of mass

30. A limited laboratory study of the effect of the size of the mass

was made by approximately doubling the volume of the inverted cone from 172 to 350 cu in. A slump curve was developed at mix temperature of 300° F with a mixture of fine sand and 85-100 penetration asphalt. Values were almost identical with those obtained with the smaller mass and the resulting mat was of about the same texture for a given asphalt content. It was decided to perform the remainder of the laboratory tests with the smaller slump cone because of the similar results and the additional dumping area and material required with the larger cone.

Effect of other grades of asphalt

31. Roofing and waterproofing asphalts were tested as possible substitutes for the average asphalt cement because of the advantages contemplated in the field from their high softening points. The roofing asphalt had a softening point of 195 and penetration of 25 and the waterproofing asphalt had a softening point of 160 and penetration of 32. Determination of underwater slump values was difficult in both cases because the material had poor slump characteristics, practically no flexibility, and yet the mass would collapse upon removal of water from the vat. However, it was determined that slump values were somewhat less with waterproofing asphalt than with the average asphalt cement and considerably less with roofing asphalt. A view of specimens containing roofing asphalt is shown in photograph 14.

32. Two products of the American Bitumuls Company were tested for use in mixtures for mass underwater placement. The recommended proportion of 65 per cent hot asphalt cement and 35 per cent Laykold (cold tempering fluid), when mixed with fine sand, produced a mix temperature of only 190° F

and slump measurements were quite low. Cold HV bitumuls (rapid breaking emulsion) was mixed with hot sand and the resulting mix temperature was about 170° F. Stripping occurred when mixtures containing 15 to 30 per cent of this emulsion were dumped under water, and testing was abandoned. The producer was notified of this condition and referred the problem to its physical research laboratory. The laboratory concluded that reemulsification took place and that it might also take place in a less severe manner with Laykold. The introduction of about 1 per cent aluminum sulphate (concentrated solution), based on the weight of asphalt cement, was recommended. Tests were then repeated with Laykold and aluminum sulphate. The slump was greatly increased over previous tests but continued to be considerably less than with asphalt cement and the resulting underwater mat remained soft and unstable. Tests with HV bitumuls and aluminum sulphate additive indicated that the stripping condition could be corrected but that slump measurements were quite low. These low slump values have been found for all mixtures tested when the final mix temperature was below 200° F.

33. A product of the Berry Asphalt Company known as "Baro-Mix" was also considered for underwater placement. This product has a melting point of about 150° F, penetration of 40 to 50, and specific gravity of 1.24. Satisfactory spread and coverage were obtained at 30 per cent asphalt and at a mix temperature of 300° F. Densities were somewhat higher than those obtained with regular asphalt cement. However, the specimens were much less flexible (cracking was observed) and the range of acceptable asphalt contents for a desirable mat was much more limited than with asphalt cement.

Effect of wet sand in mix

34. A slump curve was developed for an average asphalt cement and wet, fine sand at 150° F. The intended uses of this mixture, if proved successful, are for underwater mats with high asphalt contents and dike, levee, and dam construction with low asphalt contents. The main intent is to eliminate the heating of the sand aggregate. Mixtures containing up to 40 per cent asphalt had to be forced through the slump cone and slump values were extremely low. Foaming occurred when richer mixes were prepared. The slump was inadequate for an underwater mat in all cases and about 40 per cent asphalt was required to develop any appreciable fluidity in air or under water. Small-scale field tests on wet sand mixes are subsequently described.

Tests with admixtures

35. Tests with sodium chloride as an admixture were limited to mixtures in the range of 15 to 30 per cent asphalt since previous results had indicated that the moderate improvement in slump caused by this admixture could also be obtained by a small additional amount of asphalt cement. Previous laboratory tests at low asphalt contents (10-12) had indicated that the introduction of about 3 to 5 per cent sodium chloride, based on the asphalt content, moderately increased fluidity. The additional tests with sodium chloride indicated negligible fluidity benefits in the range of 15 to 30 per cent asphalt cement.

36. A limited number of underwater slump tests with fuel oil additive indicated that the fluidity of the basic mixture could be greatly improved. Viscosity tests had showed that about 10 per cent fuel

oil appreciably increased the fluidity of the asphalt cement itself at reasonable mix temperatures. Adequate curing was obtained with rich mixes when as much as 5 per cent of the fluid portion was fuel oil and with lean mixes when up to 10 per cent fuel oil was used. Fuel oil content exceeding these amounts caused the mixture to remain unstable and to continue to spread over the bottom of the vat for more than a week. The introduction of fuel oil produces a cutback asphalt; therefore it was decided to conduct a few slump tests with commercially produced RC-2 and SC-3 cutback asphalt for comparison. Some of the asphalt and mixing oil separated from the mass and appeared on the surface of the water as globules. This action continued until coverage was unsatisfactory. Deterioration was more severe with the SC-3 than with the RC-2. No detailed laboratory testing program utilizing fuel oil as an additive was entered into since the use of this material in small-scale field tests in connection with investigation of the patented process was planned. The results are described later.

Summary of simulated barge dump tests

37. Laboratory underwater slump tests simulating barge dumping and covering a wide range of asphalt contents indicate the trends listed below. The trends are based principally on results of tests with fine river bar sand since it is more generally available for river-bank paving. Coarse sand was used for comparison in only a portion of the tests. All data are based on hot mixes using dry sand except as otherwise noted.

a. Mixtures containing over 30 per cent asphalt cement with an average river bar sand produce irregular mats having water- and/or air-filled blisters; the density decreases sharply with increasing asphalt content.

b. Mixtures containing less than 20 to 25 per cent asphalt cement (depending upon the gradation of the sand) do not provide adequate spread and coverage.

c. The minimum asphalt content required to provide adequate spread and coverage is directly dependent on the gradation of the aggregate in the mix. For the two aggregate types tested, about 5 per cent more asphalt is required with fine sand than with coarse sand.

d. Asphalt cements with penetration from 50 to 300 produce substantially the same slump for a given asphalt content (above 15 per cent) at average mix temperature of 300° F.

e. Adequacy of coverage varied with the penetration grade of asphalt cement in the mix, although the spread (slump) was about the same. Coverage was complete and uniform at the critical asphalt content of 25-30 per cent when penetration was 50-150, but breaks were detected in the mat when penetration grade exceeded 150.

f. Increase in mix temperature from 300° F to above 400° F does not improve the fluidity and is detrimental to the texture of the resulting mat. Decrease in mix temperatures from 300° F to 200° F lowers fluidity and density of the mass. The 300° F mix temperature appears best for underwater placement but remains to be confirmed in the field.

g. The use of cold wet sand in lieu of hot dry sand (mix temperature 150° F) greatly decreases the fluidity and necessitates increasing the asphalt content to approximately 50 per cent to obtain spread and coverage.

h. The use of waterproofing and roofing asphalts in lieu of straight asphalt cement is not satisfactory because of the lower slump values obtained at a given asphalt content.

i. The use of emulsified asphalt in lieu of straight asphalt cement is not desirable because of the lower slump values obtained at the lower mix temperature and because of the susceptibility of emulsified asphalt to reemulsification and stripping.

j. No additives were found that satisfactorily improved the fluidity of a sand-asphalt mixture within the range of asphalt contents required to develop a relatively thin mat, with the possible exception of fuel oil. (Curing characteristics of fuel oil were investigated in the field as subsequently described.)

PART IV: FIELD TESTS

Small-scale Field Tests

38. Field tests on as large a scale as the Waterways Experiment Station facilities permitted were conducted for the purposes of proving the validity of laboratory tests and of extending the scope of the study to include larger masses and as many variables as possible. It was not considered feasible to construct model facilities which in any way approached river conditions nor was it considered practical to use model scales and transference equations to estimate from small-scale tests what might happen in the river. Many influencing factors cannot be fully investigated by small-scale tests. Among these are method of placement, depth of placement, velocity of the water, size of mass, required thickness of mat, and coverage difficulties due to irregular slopes. Such factors will require investigation under actual river conditions. However, it was expected that certain tests would indicate probable behavior in the river, and it was considered that if an idea were shown to be unworkable in small-scale tests it could be assumed to be impracticable for use under the more severe conditions which occur in the river.

Tests in ditches

39. Tests. Initial small-scale field experiments on mass underwater placement were made in shallow ditches. The main objective was to observe the performance of plant-produced mixtures covering a wide range of asphalt contents prior to large-scale placement at Natchez Island

Chute, where the protection of about 700 ft of subaqueous bank with a sand asphalt mat was contemplated. Excavation of the ditch was accomplished by a ditching machine. Ditches with a width of 2 ft, a depth of from 2 ft at one end to 4 ft at the other, and a grade of about 0.5 per cent were constructed. Several methods of placement were considered but dumping from a truck into a dry ditch appeared to be the most practical for this series of tests. The shallow (2 ft deep) end of each ditch was prepared for dry dumping by placing a steel plate, to serve as a gate, 8 ft from the end thus providing about 32 cu ft of dumping space. Water was then placed to various heights in the lower ends of the ditches. Thus a head was available to accelerate flow of the mass when the metal plate was raised.

40. Mixes for tests in the ditches were prepared at asphalt contents of 20, 50, and 80 per cent. Mixes were produced in a central asphalt plant at temperatures of 300° F or below. The asphalt cement used had penetration of 85 to 100. The majority of the mixes were made with fine sand of the same gradation as that used in laboratory tests. Tests were made at 80 per cent asphalt with limestone dust, the same as that used for mineral filler in asphaltic concrete mixtures, and with baroid clay. This clay has a specific gravity greater than 4 and was used in an effort to increase the specific gravity of the mix and avoid flotation, if possible.

41. Results. Results of the ditch tests are summarized in table 8. It may be noted from the table that test dumps prepared with 20 per cent asphalt were made without causing any flotation whereas mixes containing 50 and 80 per cent asphalt segregated in the truck bed, foamed,

and produced excessive to complete flotation when placed at reasonable mix temperatures. In certain cases, the mixing time at the plant was extended to lower the temperature well below 300° F. This mixing action produced a mass which, though normally much heavier than water, contained enough entrapped air to force it back to the surface of the water as soon as it passed under the steel gate. Photograph 15 is a view of the 20 per cent asphalt mix after removal of water from the ditch. The rough texture and nonuniform coverage may be noted. A view of the 50 per cent asphalt mix, showing floating material as it cools and sinks, is shown on photograph 16. The 80 per cent asphalt mix, showing initial flow on top of the water, is illustrated in photograph 17. Mixtures containing 80 per cent asphalt and either limestone dust or baroid acted in the same manner.

42. Indicated trends. Results of this limited number of tests in ditches, admittedly conducted by procedures not comparable to barge dumping on the river, do, however, show the following trends:

a. A mixture containing 20 per cent asphalt cement and fine sand can be dumped satisfactorily but is not sufficiently fluid to develop a relatively thin and uniform mat.

b. Mixtures containing 50 per cent or more asphalt cement cannot be placed satisfactorily under normal field conditions (mix temperature of 300° F) because of the flotation difficulties.

c. A mixture containing 80 per cent asphalt cement, even when a special aggregate heavier than the average sand is used, cannot be expected to sink when dumped through water.

d. Considerable segregation takes place in mixtures containing 50 per cent or more asphalt between the time of mixing at the plant and dumping. This was evidenced by the large amount of sand left in the truck bed after dumping, and was substantiated by extraction tests.

e. Mix temperatures become more critical as the asphalt content is increased, and extended mixing to lower mix temperature prior to dumping is unsatisfactory in that air voids in the mass are increased.

Tests in sloped pits

43. Tests. The most extensive small-scale field testing was conducted in pits prepared with a bulldozer where dumps were made from a truck onto 1 on 3 slopes. All mixtures were prepared in the central asphalt plant and the size of the mass was held constant at one ton. Placement was accomplished by quickly releasing the mass from a dump truck and allowing it to fall on a dry upper bank and flow under water into place. Asphalt contents ranging from 10 to 30 per cent were selected on the basis of results of laboratory and initial field tests. Regular hot sand-asphalt mixes and mixes produced by a patented process were tested. The regular hot mix consisted of 85 to 100 penetration asphalt cement and river bar sand. No mineral filler or additives were introduced. The patented process was included to determine if the resulting mix was more fluid than the regular hot mix at an equal or lower asphalt content. The fluid portion of the special mix consisted of 85 to 100 penetration asphalt cement with small amounts of fuel oil and melted beef tallow. These liquids were placed in a dispersion chamber into which steam could be injected before the liquid portion was introduced into the pug mill with the hot sand. Plant alterations required to produce these mixes were limited, the main change being to connect the asphalt and steam lines to the dispersion chamber.

44. Results. Twenty-six 1-ton batches were placed under water in this series of tests. Thirteen batches were regular hot mixes and thirteen

batches were produced by the patented process. Results and observations are shown in table 9. It may be noted from this table that considerable difficulty was had in regard to mix temperature but that valuable information was thus gained. Mixtures placed at 175° F would not flow and were discarded. Mixtures placed at a temperature of more than 300° F caused excessive temporary flotation, and when the material did sink, the resulting mat was irregular and rough. It was almost impossible to distinguish the various asphalt contents when the water was removed from one pit where very hot mixes had been placed. However, flotation was negligible when mix temperatures were between 230° and 295° F, and the different asphalt contents were easily detected. Typical views of mats produced by hot mixes and the special mixes at various asphalt contents are shown by photographs 18 and 19, respectively. The mixes appearing on photograph 18 from left to right are numbered "hot mix" 11, 10, 9, and 8, respectively, in table 9. The mixes in photograph 19 from left to right are numbered "special mix" 9, 10, and 11, respectively, in the same table.

45. Discussion and analysis of results. The principal phase of this series of tests was concerned with evaluation of the regular hot mix. For the average fine river bar sand, the results indicated that a minimum of about 25 per cent asphalt is required to obtain satisfactory spread and coverage when placed under water. The minimum percentage of asphalt might be reduced to about 20 per cent if a coarser sand is used. The fluidity increases sharply when 30 per cent asphalt is introduced into the mix, but under certain conditions the mass tends to float temporarily. Furthermore, the density of the mass begins to decrease rather rapidly. Also, the mat is soft and continued flow with a resulting reduction in thickness of

the mat can be expected to take place if the mat is exposed during low water. No additional flow was detected in these field tests as long as the mat remained submerged.

46. A second phase of this series of field tests was concerned with evaluation of the patented process in relation to the hot mix. Analysis is based on personal observations of engineers from the Mississippi River Commission and the Waterways Experiment Station as well as the data in table 9 and photographs 18 and 19. First, it may be noted that very little flow took place with any of the mixes containing 20 per cent or less asphalt. Steam alone was used in special mixes 2 and 4, and there is no indication that the incorporation of steam produced either greater linear flow or coverage than was obtained with the regular hot mixes.

47. Varying percentages of fuel oil and tallow were included in the mixes containing 25 and 30 per cent asphalt in addition to steam. These mixes were materially improved over the mixes with lower asphalt contents with respect to their capacity to flow; however, the special mixtures were no better than regular hot mixes in this respect. For this reason it was concluded that there was no appreciable merit in the process for mass underwater placement. Large-scale placement of such mixtures in the river therefore was not recommended.

Tests in moving water

48. Tests in creek. A limited number of trial dumps were made from a creek bank to observe the effect of current on underwater placement. The results of the tests in sloped pits were used as a basis for

these tests. Three 1-ton batches of regular hot mix (25, 30, and 40 per cent asphalt with fine sand at about 240° F) were dumped from a truck onto the bank of Durden Creek. The drain pipe from the Waterways Experiment Station lake was opened temporarily to produce a current and a reasonable depth of water. The bank was coated with sand asphalt, prior to placement, to eliminate the need for a chute or tremie. The appearance of these mixes in place after the water level had been lowered is shown by photograph 20. Photographs 21, 22, and 23 are close-ups of the 25, 30, and 40 per cent asphalt mixes, respectively.

49. Results of tests in creek. Placement of the three mixes was quite satisfactory. There was no tendency for the material to float at a mix temperature of 240° F even when the mass contained 40 per cent asphalt. The 25 per cent mix was not appreciably affected by the current, and the mass produced a dense mat approximately 3 in. thick extending across the creek channel. The 30 and 40 per cent mixes were affected somewhat by the current in the creek during dumping. A heavy rain caused a sudden rise in the creek about seven months after placement, and that portion of the 25 per cent asphalt mat extending across the channel was rolled off to the side by the current. The exposed bottom of the mat showed that it had seated itself in the gravel in the channel. However, this high velocity within a confined area was sufficient to move the relatively stable and dense mass, indicating that additional thickness is needed. Results of these tests indicate that, from the standpoint of thickness, stability, density, and ability to resist displacement by moving water, the least possible amount of asphalt in the mix that will provide adequate spread and coverage is the most desirable in moving water.

50. Test in model. One half-ton batch of the 25 per cent mix at 240° F was dumped directly from a truck into a small model of a Mississippi River bend (Reid Bedford) with the model in operation at bankfull stage. Placement was quite satisfactory. Photograph 24 shows the resulting mat. The point of dumping and the water level at the time of placement are indicated by the arrow. The formation of the mat in the model could be observed readily during placement. The mass flowed across the bed of the stream, with only a slight tendency to flow downstream from effect of the current, to a final average thickness of about 3 in. The mat was quite stable and yet flexible upon examination under moving water. No eddy action or turbulence resulted from placement of the mat. Upon removal of the water and exposure to sunshine the material softened and continued to flow.

Summary of small-scale field tests

51. In general, results from small-scale field tests were in reasonable agreement with laboratory test results. Results relative to comparable influencing factors were as follows:

a. Fine river bar sand containing about 25 per cent of 85 to 100 penetration asphalt cement, which was the most promising mixture developed in the laboratory, proved to be the most satisfactory in the field.

b. Increasing the size of the mass from 11 lb in the laboratory to 2,000 lb in the field had no appreciable effect on observed trends.

c. Mix temperature of the mass in field tests was more critical than in laboratory tests. Laboratory mixes were satisfactory from 212° F to more than 300° F, whereas field mixes could be placed most satisfactorily between 212° and 250° F, with reasonable success from 250° to about 300° F, but with little success above 300° F.

d. Thicknesses of underwater mats placed in the field were somewhat greater than those placed in the laboratory for a given asphalt content. For the 25 per cent mix an average thickness of 1.5 in. was determined in the laboratory while in field placement the thickness varied from 2 to 3 in.

e. No suitable admixtures were developed to improve the fluidity of a sand-asphalt mixture within the range of asphalt contents required to produce a mat having satisfactory spread and coverage. Most of the additives were given consideration only in the laboratory because of negative results. Steam and fuel oil were utilized in the plant-produced special mixes but did not improve the fluidity over basic sand-asphalt mixtures.

Tests with Wet Sand Mixes

Tests in air

52. As mentioned in paragraph 34, consideration was given to the possibilities of preparing and placing plant-produced asphalt mixtures where the sand was not dried or heated. Plant mixes were first prepared and dumped on the ground for observation. An aggregate bin was filled with fine sand that had been run through the dryer as cool as possible, coming out at 225° F. A trial batch with this dry sand containing 5 per cent asphalt cement had a temperature of 255° F. Batches containing 5, 10, 15, 20, 30, and 40 per cent asphalt and having mix temperatures between 165° and 195° F were then produced by introducing hot, dry sand into the pug mill and cooling it back with water before introducing the asphalt. The moisture content of the sand averaged about 5 per cent. The mixtures appeared to be quite uniform with the asphalt cement dispersed throughout; however, close examination revealed that the sand particles were surrounded by films of water and left uncoated. The water dried out after being subjected to sunshine, and the particles appeared to be coated.

Batches containing 60 to 80 per cent asphalt were produced by placing cold, wet sand from the stockpile into the pug mill and slowly introducing the asphalt in small increments. Foaming was unavoidable, but the materials appeared to mix satisfactorily. The mixtures were dumped from a dump truck and the resulting slopes and coverage are shown in table 10. After several heavy rains there was no evidence of stripping. The leaner mixes had become quite hard, whereas mixes containing 40 per cent or more asphalt remained flexible.

Test under water

53. A mix of 50 per cent hot asphalt and 50 per cent cool, wet sand (1,000 lb) was produced in two 500-lb batches and placed under water in a sloped pit (observations included in table 10). The mix temperature was 200° F and the initial volume, because of foaming, was equal to the volume of the truck bed of a 1-1/2-ton dump truck. However, the mass subsided to half that volume in the course of transporting the load from the plant to the pit. Dumping on the dry bank in the same manner as with regular hot mixes was satisfactory, with no appreciable flotation. The pit was dewatered a few days later, and the coverage was found to be uniform, measuring 78 sq ft or the equivalent of the 40 per cent asphalt mix dumped in air. This spread is considerably greater than was obtained with the 30 per cent hot mix. The mat was very flexible and only 1 in. thick. The density, determined from a sample obtained on the slope, was 87 lb per cu ft as compared to about 105 lb per cu ft on the 30 per cent hot mix. Refilling of the pit with water was begun but before it could be completed continued flow near the top of the slope produced an

overlapping on the lower portion of the mat. This overlapping extended a few inches into the water where it chilled and stopped.

Indicated trends

54. Results of tests with mixtures containing wet sand indicate the following:

- a. The use of wet sand in sand-asphalt mixtures for levee, dike and dam construction is unsatisfactory.
- b. The use of wet sand in sand-asphalt mixtures for underwater mats is likewise unsatisfactory. The amount of asphalt cement required is excessive and the resulting mat is low in density and subject to excessive flow when not submerged.

Laminated Dike Experiments

In model

55. Special procedure. An experiment was conducted to determine the feasibility of using a bottom-dump barge to discharge a load of saturated sand covered with a thin layer of sand asphalt into water in successive lifts, thus constructing a laminated dike. A wedge-shaped bottom-dump metal box, 36 in. long and measuring 15 in. across the top and 8 in. across the bottom, was used for placement. The box was equipped with a metal partition to provide separate compartments for wet sand and for sand asphalt. Trial dumps were made with several proportions of sand asphalt to sand. The sand asphalt consisted of 50 per cent asphalt cement (85-100 penetration) and 50 per cent dry sand and was dumped at mix temperature of approximately 240° F. A sand-sand asphalt ratio of 85-15 was selected for use in construction of a small dike by making successive dumps in moving water. The metal box in dumping position is shown in

photograph 25. The sand compartment is on the upstream side and the asphalt compartment is on the downstream side, simulating the proposed method of barge dumping.

56. Placement and observations. Dumps with the metal box were made from one position near the outside bank of a model bend. The model was in operation at bankfull stage and at average velocity of 1.5 ft per sec. Successive dumps were made until the dike extended above the water line. The majority of the sand asphalt settled on the crown and downstream apron of the dike. The material that did flow toward the upstream side tended to roll up and double back over the top from the effect of the current. The entire surface area (above and below water), upon completion of the final dump, was sealed with a relatively heavy and thick treatment of sand asphalt. The area between the crown of the dike and the bank was built up with the same mix to prevent further scour and the model was kept in operation for about one hour. Portions of the sand asphalt on the upstream and riverside aprons of the dike rolled up and the sand underneath began to wash away. This indicates that a thicker and more stable seal is required to keep the dike intact, assuming that successive lifts of sand and sand asphalt would stay in place until the sealing could be accomplished. Photograph 26 is a view of the dike after removal of the water. The size and final slopes of the dike, as well as the change in bank line, can readily be seen. Three tube samples taken from different sections of the dike indicate relative thicknesses of sand and sand-asphalt strata. Views of the three sliced tube samples are shown in photograph 27. The top of the sample is on the left side in each case. The clean sand that appears on the

right in each sample is from the bed of the stream beneath the dike.

57. Discussion of results. The sand-sand asphalt dike experiment showed that it was possible to place a laminated mass under water, but the difficulties involved in such a placement cannot be overemphasized. Furthermore, the durability of such a mass, assuming that it can be properly sealed, has not been determined. Large-scale placement in the river, where observations can be made under actual field conditions over a period of time, will be necessary to develop construction techniques and to study influencing factors that could not be considered in a small model. An actual experiment in the river was made in cooperation with the New Orleans District and engineers of the Mississippi River Commission and is discussed briefly in the following paragraph.

In river

58. The full-scale experiment in laminated dike construction was made in the Mississippi River during December 1949 near the upper end of the existing revetment at False Point. The experiment was similar to the one conducted in a model at the Waterways Experiment Station. The main differences were: (a) dumping in the river was accomplished with a 2-1/2-ton truck equipped with a baffle plate to separate sand and sand asphalt; and (b) the sand asphalt was replaced by pure asphalt cement containing about 15 per cent powdered sulphur (specific gravity of 2±) to add weight and insure sinking. Bend tests in the laboratory had indicated that this amount of sulphur did not seriously reduce flexibility, and penetration tests indicated that as much as 40 per cent sulphur could be incorporated without causing the membrane to be too brittle. Successive dumps of wet

sand and 5-10 per cent asphalt and sulphur were made from one position at the end of a barge until the dike extended approximately 2 ft above water. No attempt was made to seal the small mass since it was not large enough to serve any practical purpose. The plant set-up and a view of that part of the dike which is above water are shown in photographs 28 and 29, respectively. The top layer of asphalt that may be seen in photograph 29, as well as the layers beneath, is only a fraction of an inch thick. It has not as yet been determined if such thin layers of asphalt can hold large volumes of sand in place for any length of time. A sample of the asphalt and sulphur blend was obtained during the experiment, and the specific gravity was found to be 1.14. It was noted during the final dumps above water that the asphalt tended to float temporarily before flowing into place under water. It is believed that the asphalt layers of the mass should be thicker and heavier if a stable mass of this type is to be expected.

On creek bank

59. Placement of successive layers of wet sand and asphalt-sulphur was undertaken during the fall of 1950 on a creek bank at the Waterways Experiment Station for the purpose of observing the behavior of the materials. Placement was accomplished on a dry upper bank and the materials were allowed to flow into a shallow pool of water. A 2-1/2-ton truck was equipped with an asphalt container suspended above the tail gate and all sand was dumped prior to releasing the asphalt to insure lamination rather than mixing. The asphalt-sulphur mixture contained 18 per cent sulphur by weight, which produced a mixture only slightly

heavier than water. The amount of asphalt-sulphur released with each load of wet sand ranged from 6 to 8 per cent by weight. Photograph 30 illustrates the method of placement. The area of placement and the equipment used may also be observed.

60. The desired lamination was effected in the earlier dumps. However, difficulties were experienced in placing the thin membrane over the larger surface area as the size of the mass increased. Each load of sand dumped from one location tended to disrupt the previous laminations. The sand piled up at the top of the bank and most of the asphalt flowed to the lower part of the dike. Photograph 31 is a view of the partially completed dike. The entire surface area was sealed with asphalt after the final truckload was placed. The average slope of the dike was 1 on 1.5 to 1 on 2. The mass continued to slough during the next twelve hours, and the seal was broken on the upper portion, as illustrated in photograph 32. The asphalt that did not sink during placement (5 per cent of total amount placed) can be seen in the foreground. This flotation was attributed to entrained air from continuous circulation at 350° F in the asphalt trailer tank as well as to the fact that the asphalt-sulphur was only slightly heavier than water. The pool of water was released to expose the lower extremities of the dike. The rapid drawdown had very little effect on this well-sealed area, as may be noted in photograph 33.

61. Much of the asphalt flowed across the creek channel within five days after placement and formed an apron 3-4 in. thick, as shown in photograph 34. It may also be noted that the seal on the lower half of the dike broke and the mass flattened out and assumed the approximate slope of the natural bank. The lower half of the dike was resealed, covered

with sand to minimize flow, and left in this condition for observation.

62. The dike was subjected to considerable attack within thirty days by water that came over the spillway from the Waterways Experiment Station lake following a heavy rain. The asphalt-sulphur apron across the creek channel was moved by the overflow current and most of the sand in the lower part of the dike leached out. The condition of the dike after the attack may be observed in photograph 35.

63. The materials and procedures used in these tests did not produce a satisfactory laminated dike because (a) as each layer of sand was dumped, it disrupted the asphalt seal on the preceding layer, and (b) the sand assumed an angle of repose when dumped which was too steep for permanent stability, and sloughing occurred for a period of several days which disrupted the asphalt membranes.

64. The two main difficulties experienced with the asphalt-sulphur were that the membrane was not bonded to the underlying sand layer, and the material was not heavy enough for placement through water. Examination of the mat after cooling showed that where the sand was included within the asphalt it was not coated with asphalt indicating that no bond was obtained. The asphalt-sulphur mixture had a specific gravity of about 1.3 which would give a density of only 80 lb per cu ft if it were a complete solid. The in-place density averaged 70-75 lb per cu ft because of entrained air. The density was about the same in some cases as that of water, as evidenced by the flotation that occurred. The observations made during similar placement in the river (paragraph 58) in regard to the need for a heavier membrane were substantiated in this test where the behavior of the material could be more readily observed.

PART V: LARGE-SCALE PLACEMENT

65. Only a limited amount of experimentation in connection with large-scale mass placement in the river has been accomplished to date. Therefore, many influencing factors remain to be investigated. However, several improvements in underwater construction and in asphalt mixtures have been accomplished since the beginning of this investigation which are considered worthy of mention in this report. This office did not necessarily participate in the actual placement but did make observations.

66. One major change in the type of placement equipment described in paragraph 2 is applicable to the construction items subsequently set forth. The bottom-dump scow barge having two hoppers was replaced with a bottom-dump barge having six bins. The doors at the bottom of each bin are 8 ft by 17 ft and are designed so that the bottom will be dry when the barge is empty. The dumps are made by bins rather than by barge and no sand cushion is required since each bin is dry. However, the bins are not leakproof and when rather rich mixes were used it was necessary to place layers of lean sand asphalt several inches thick over the doors before introducing a fluid mix.

Dike Construction

67. An asphalt groin or dike was constructed in 1948 on the east bank of the Mississippi River at the lower end of the existing revetment at Fitler Bend (river station 468.3). Construction was accomplished during high water and the dike consisted of two tiers. It is understood that the lower tier was placed under water from a bottom-dump barge and

that the upper tier was placed with a clamshell above water. The dike core consists of local river bar sand and about 5 per cent asphalt cement, and the core is sealed with a rather thin treatment of a richer mix (approximately 15 per cent asphalt cement). A protective apron was also placed around the dike with this richer mix. Photograph 36 shows the dike during low water in 1949. Photograph 37 is a close-up view showing a portion of the seal on the lower tier displaced. Some cracks can be seen in the core, but it is understood that these have existed since construction and are not getting any worse. The dike was apparently effective in shifting the current away from the bank.

Placement of Experimental Sand-asphalt Mixes

68. Experimental dumps of sand asphalt covering a wide range of asphalt contents were made during high water (46.0 ft on Natchez gage) in Natchez Island Chute in February 1949. Approximately 700 tons of mix (mainly in 25-ton batches) were placed for the purpose of determining flow pattern for use in revetments. Asphalt contents ranged from 10 to 60 per cent, with the majority of the batches containing 20 per cent. The average mix temperature was 250° F. Dumping was satisfactory with up to 20 per cent asphalt in the mix. Leaking occurred at the bin doors when the mix contained 30 per cent or more asphalt, and there was considerable flotation when the mass was dumped.

69. An inspection trip was made to the site during the low water in November 1949. There was a considerable height of dry bank to observe but only scattered small areas covered with sand asphalt could be seen. Bank slopes were very irregular, being vertical in many places. A close-up

view of a section of the bank where placement of the 20 per cent mix was made is shown in photograph 38, indicating quite clearly the steepness and irregularity of the slope and condition of the bank. The most apparent observation is that the bank was too steep for placement of any type of asphalt mat. A large amount of the asphalt that was placed probably settled further down the slope. Nevertheless, poor coverage of the 20 per cent asphalt mat found above water was noted. A sample taken from the bank had a thickness of about 3 inches, was rather brittle, and had the typically rough surface of a mat that did not contain enough asphalt to provide uniform spread. At another point along the bank where the 40 per cent mix was placed, only a few small areas were found where the mat was in place. This fact may again be attributed primarily to the steep slope on which the material was dumped. The mat was one inch thick, quite flexible, and had a fairly smooth surface. It appears, on the basis of the construction data and these limited observations, that a more uniform and flatter slope is required for placement of a sand-asphalt mix and that the mix (with local river bar sand) should contain more than 20 per cent asphalt. If it is determined that more thickness is required, which seems probable, this can be accomplished by additional dumps.

Underwater Placement at False Point

70. In December 1949 underwater placement was accomplished during low water at four critical points upstream from the existing revetment at False Point on the Mississippi River. A general view of the area, with the asphalt plant in the background, is shown in photograph 39. The arrows indicate the four natural spurs which were covered with a 6- to

12-inch thickness of sand asphalt in 1948. Bank recession that has taken place between the spurs can be readily seen, indicating that attack was severe at the in-shore ends. Surveys indicate that considerable scour also took place out from the bank between the spurs. The sand asphalt was placed on the spurs to arrest bank recession and prevent flanking action on the upstream end of the revetment. The sand asphalt that can be seen above water on each of the four points was placed by clamshell to minimize sloughing of the bank during underwater placement. Information relative to the sand-asphalt mix placed under water is presented in the next paragraph. The performance of the rehabilitated spurs after another period of high water (1950) was not encouraging. Loss of bank and asphalt at the in-shore ends continued. A general view of the area after the 1950 high water is shown in photograph 40. The picture was taken from approximately the same position as photograph 39 (upstream edge of revetment) in order that general comparisons could be made. A small area of the existing revetment at the upstream end was lost in 1950. A view of this failed area is shown in photograph 41. Maintenance engineers have concluded that no benefits can be expected from underwater mass asphalt placement of the type employed at this location in 1949. Articulated concrete mattress has been placed at the failed upper end of the revetment in an effort to stabilize the bank at that point.

71. The Waterways Experiment Station, upon request, recommended that a minimum of 20 per cent asphalt cement (85-100 penetration) be used with local river bar sand for the spur reinforcement placed in 1949. Previous placements, with the exception of experiments described in paragraphs 68 and 69, had been confined to mixtures containing not more than

16 to 18 per cent asphalt. A mix containing 20 per cent asphalt was approved with a request that the amount of segregation in such a mix be determined during placement. Samples were taken at various depths in the bins of the barge about two hours after mixing and just prior to placement. Results of extraction tests indicate that segregation does take place but that it is not excessive. Asphalt contents of material placed in a bin to a depth of about 30 in. were found to be about 21 per cent at 6 in., 20 per cent at 12 in, 18.5 per cent at 18 in., and 17 per cent at 30 in. A limited number of in-place samples were recovered with a wire basket in from 25 to 85 ft of water and from 12 to 25 ft from the center of the dump. The average density of the mass was 112 lb per cu ft and the asphalt content was in reasonable agreement with the 20 per cent introduced at the plant. Accurate determinations of thickness and surface appearance were not possible because of the distorted shape of this plastic material upon recovery by wire basket. The extent of spread and coverage resulting from placement of this mix is also undetermined. It is believed that pattern sampling, rather than a surface elevation survey, will be required to determine these factors, but such sampling has not as yet been attempted. The nearest approach to date has been a diving investigation conducted at another site and discussed in paragraph 73.

Underwater Placement at Natchez Island

72. The asphalt plant, accessory equipment, and forces used in the placement work at False Point, were ordered to Natchez Island late in December 1949 because of a break in the revetment. The original revetment, the placement of which was completed during the fall of 1949, was

constructed with conventional concrete mattress on both the underwater bank and graded upper bank. An attempt to repair the failed area of about 500 ft was made by placing under water more than 6,000 tons of sand asphalt containing 20 per cent asphalt cement along 1,000 ft of bank in a pattern designed to provide a continuous mat. The spacing of the underwater dumps (usually 50 tons from each of six bins on barge) was such that, theoretically, 3 tons of sand asphalt were placed per square. This volume would produce an average thickness of about 6 in. for an estimated density of 112 lb per cu ft. In addition about 600 tons of a leaner sand asphalt (10 per cent asphalt cement) were placed by clamshell along the upper bank to provide shore connections. Placement was at a rate of 4 tons per square for an average thickness of about 8 in.

73. Placement at Natchez Island was essentially the same as at False Point from a mechanical standpoint. The river was rising sharply at Natchez Island rather than being at a stand as at False Point. After placement a diving investigation was conducted at Natchez Island to determine the extent and the condition of the new asphalt blanket. The divers, equipped with probing bar and small drill, began their observations in shallow water and proceeded toward the thalweg of the river. They operated from a tag line and made observations at 10-ft intervals. Comments differed greatly and observations were limited in many cases but a rather definite pattern can be discerned at all of the points investigated. The following analysis was made from the observations.

a. Spread and coverage. Coverage over the theoretical area that averaged 200 ft in width (shore to thalweg) was very irregular. Thickness in the shore connection averaged 8 in. Thickness in the next 50 ft was in excess of the estimated 6 in., but probings were not extensive enough to determine maximum thickness. It was noted that the steep slopes within this 50-ft distance were not completely covered. Thickness in the next 115 ft, where the slope was flatter and more uniform, averaged 2-3 in., and no breaks in coverage were observed. Observations over this distance were difficult to make since a layer of sand had been deposited over the asphalt. No asphalt was found in the next 35 ft (near thalweg of river) of the area that was supposed to be covered. It is a matter of conjecture as to what happened to the asphalt which was dumped to cover this area, also to the 3-4 in. of asphalt which is lacking in the mat immediately up the slope.

b. Surface condition. The diver referred throughout his comments to "rough" asphalt, thin in places and in large chunks in others. He was seldom able to drill through the asphalt but could locate "crevices" and probe through. Thus, the material was apparently too brittle to form a solid mat, indicating that more asphalt was needed in the mix to obtain the necessary plasticity. The brittleness or lack of adequate flow properties seems to account, in part, for the broken coverage.

c. Irregular slopes. The average slope from the landside to riverside limits of the asphalt was 1 on 4.5. However, the main drop in elevation is within a limited area near landside. The slope is also very irregular in this area. The diver stated several times that he went down a slope of 1 on 1 to 1 on 2 and then had to go uphill before continuing on to more uniform and flatter slopes. The broken coverage was more pronounced in these irregular areas and can be attributed to steep and irregular slopes as well as to the poor flow properties of the asphalt as described in the preceding paragraph.

d. Overlying sand deposit. A layer of sand from 6 in. to 4 ft thick formed over the asphalt mat on the flatter slopes between the time of placement and observation (2 or 3 days). Also, it was found that a layer of sand existed in many cases, between the asphalt and the concrete mattress. Thus, it is apparent that unstable river-bed conditions must be reckoned with regardless of the type of mat used.

74. The over-all picture regarding the underwater sand-asphalt mat at Natchez Island is not too encouraging. The mat may provide better and longer protection than is evident at this time. Surveys after one year indicate that the mass has remained intact and is serving its intended

purpose. However, the observations indicate that consideration should be given to the following:

a. The asphalt content should be increased to about 25 per cent (depending upon gradation of the sand) to improve the flow properties of the mixture and thus obtain more complete and uniform coverage. An increase in the amount of segregation in the barge will result, but it is believed that some decrease in uniformity of the mix is warranted to gain the advantages of a richer mix. The actual degree of segregation should be determined in the field.

b. The use of a richer mix should result in decreased thickness. The dumps should be overlapped to obtain desired thickness. It is recommended that overlapping and/or successive dumps be made as soon as possible after the original dump in order to eliminate, as nearly as possible, the formation of a sand layer between the dumps.

c. Methods must be devised to prevent loss of asphalt in deep water near the thalweg of the river.

PART VI: GENERAL REVIEW AND ANALYSIS

Accomplishments

75. The scheme chosen for presenting data on such a broad subject makes advisable a general review to sum up the knowledge gained from various sources. The results of the laboratory tests and small-scale and large-scale field tests concerned with each specific objective of the investigation are analyzed collectively in the following paragraphs, with a view toward arriving at logical conclusions. Briefly, the knowledge gained regarding those specific objectives set forth in paragraph 4 follows plus the results of tests of two proposed innovations in construction procedure -- use of wet sand mixes and construction of laminated sand-asphalt dikes.

Effect of varying the quantity of asphalt cement

76. The entire range of asphalt contents was given consideration in this study with an average asphalt cement (85-100 penetration) and without consideration of the economic aspects as regards the amount of asphalt. Initial testing was concerned with rather lean mixtures (8-12 per cent bitumen), but it was soon determined that none of these mixtures were adequate for the purpose or final objective. It also was quickly determined that tests would have to be made under water rather than in air if they were to be indicative. Thus, tests of asphalt contents from admittedly low to 100 per cent made possible the detection of disadvantages of mixes of either extreme as well as determination of the most satisfactory quantity. All tests conducted were considered, from small amounts of

material in the laboratory to large masses in the river, and it appears that more than 20 per cent and less than 30 per cent asphalt cement is required to provide the most satisfactory mattress obtainable in a hot sand-asphalt mixture for underwater protection of river banks. The exact amount is dependent upon the gradation of the sand aggregate. The limiting values are based on numerous observations of the poor performance of (a) the leaner mixtures owing to poor flow characteristics, and (b) richer mixtures owing to insufficient thickness, flotation difficulties and low strength or resistance to disintegration.

Effects of mixing and placing temperatures

77. Data collected in regard to mix temperature are consistent, conclusive, and contrary to earlier concepts that very hot mixtures have better flow characteristics than mixtures at normal hot-mix temperatures of 250° to 300° F. Tests conducted in air on very lean mixtures and under water on successively richer mixtures indicate that temperatures of 400°-450° F not only fail to improve fluidity but in many cases lower it. In addition, the surface of the resulting mat becomes rough, there is always the danger of burning the bitumen, and there is a strong tendency for the mass to float temporarily when the mix contains the required amount of asphalt. Decrease in mix temperature to below the boiling point of water or about 200° F substantially lowers the fluidity and density of the mass as compared to 300° F. The mix temperature of large masses in field tests was more critical than that of small masses in the laboratory. Laboratory mixes performed satisfactorily from 212° to more than 300° F, whereas field mixes had to be in the order of 240° F to function properly

at the critical asphalt content. A mix temperature of 250° F, plus or minus 25°, is recommended on the basis of observations of placement of one-ton batches since no extensive study of this factor has yet been made with larger masses. However, limited observations of river placement indicate production of the mixture at 300° - 325° F to be satisfactory as the material then will not become too cool for dumping about an hour or so later.

Effect of penetration grade of asphalt

78. Penetration grades of asphalt cement ranging from 40 to 300 and other types of asphalt having penetration of less than 40 were used in the laboratory but not in the field. Results of slump tests were considered conclusive enough to limit field testing to the use of an average asphalt cement (85-100 penetration). The conclusive results are, briefly, as follows: (a) penetration grades of less than about 50 substantially reduced the fluidity of a sand-asphalt mixture and caused it to be brittle; (b) penetration grades between 50 and 150 provided optimum fluidity of the mixes (plate 4); and (c) penetration grades above 150 produced mixes which gave poor coverage. The penetration grade is not as critical as the asphalt content. The 85-100 penetration grade that has been most used in river work to date appears to be quite satisfactory. It is believed that, for general use, this grade should be considered as the minimum since asphalt has a tendency to become more brittle with age.

Admixtures

79. The improvement in fluidity gained by incorporating small

amounts of an admixture was negligible in most cases, being equivalent to the addition of about 2 per cent asphalt. Steam and fuel oil as admixtures were investigated in plant-produced mixtures that were placed under water in sloped pits and again the results were negative. Less fluidity resulted at rather low asphalt contents than with the basic mixture, whereas some improvement was noted when about 30 per cent asphalt plus the additives was used. However, the over-all analysis indicated that a special process of injecting steam into the mixture and including a small amount of fuel oil was not warranted. It was concluded, on the basis of tests conducted, that the increased material and plant costs required to incorporate additives into a sand-asphalt mixture are not justified by the results obtained.

Effects of aggregate gradation

80. Only two aggregate types (plate 1) were utilized in this study. Most sand aggregates available on river bars are similar to or grade between the two sands used in the study. The aggregate gradation controls the amount of asphalt needed to produce a satisfactory mix. The variation in asphalt content was only about 5 per cent for the range of gradations shown on plate 1, so it can be seen that the gradation is not critical.

Effect of dropping mixtures en masse through water

81. This item is a rather broad objective, and it has not been investigated fully because of limited observations of large-scale placement in the river to date. It was quickly determined in the laboratory that

difference in slump characteristics between placement in air and through water was of considerable magnitude. This was assumed to be caused partly by the rapid cooling of a small mass; subsequent placement of much larger masses proved that the amount of asphalt in the mix controlled its behavior and that differences in cooling effects were negligible. The effects of placement through relatively deep water and in currents having high velocity have not been adequately determined.

Simplification of underwater placement

82. It is not considered that a complete investigation of this factor has been made because of the limited amount of placement in the river to date. The final methods employed for placement in the laboratory (insulated slump cone with smaller orifice equipped with trap door and placed just below water level) and in small-scale field tests with facilities available to the Waterways Experiment Station (placement by dump truck into sloped pits, model, and on creek bank) are considered adequate for the purpose they were to serve. Large-scale placement in the river was accelerated and apparently improved by changing from the old-type, bottom-dump barge having two partially submerged hoppers to the new-type barge having six bins that are free of water.

Feasibility of the use of asphaltic products other than asphalt cement

83. Asphaltic materials other than standard asphalt cements were tested in the laboratory. None of these materials were tried in the field because of the negative results obtained in the laboratory. Results of tests with typical products developed by the asphalt industry may be summed

up as follows: (a) hard asphalts specially prepared for waterproofing and roofing work decreased the fluidity of the sand-asphalt mixture considerably; (b) slow-curing liquid asphalt and rapid- and medium-curing cutback asphalts of various grades are not acceptable because of their susceptibility to stripping when placed under water and because of separation of the asphalt and mixing oil; (c) all emulsified asphalts tested, including slow-curing, rapid-curing, and specially prepared mixes with admixtures, were inadequate because of stripping or poor flow characteristics. Thus, none of the types of asphalt other than asphalt cement are recommended.

Wet sand mixes

84. The expense of heating and drying sand for a sand-asphalt mixture has been a matter of concern where large masses are involved and this prompted a limited amount of testing on mixtures made with wet sand. It was determined that mixtures of cool, wet sand and hot asphalt cement could be produced in the laboratory without too much difficulty and in the field by considerably altering the plant set-up. However, it was found in both cases upon experimentation that the sand was not coated thoroughly with asphalt. The temperatures of the leaner mixes were low and the resulting mix was not sufficiently fluid for placement. An excess of asphalt (40 to 50 per cent as compared to 25 per cent with the regular hot mix) was required to obtain fluidity. The mat produced by these rich mixes dumped from a truck was thin, low in density, and vulnerable to attack by heat from the sun when not submerged. Therefore, mixtures prepared with wet sand are not recommended.

Laminated dike

85. Attempts were made to construct a laminated structure consisting of successive layers of wet sand and thin asphalt membranes. The structure would be used for the same purpose as any other type of dike such as the mass sand-asphalt dike at Fitler Bend, discussed in paragraph 67 and illustrated in photograph 36. The primary objective was to develop a more economical structure than was possible with sand asphalt by eliminating heating the sand and by reducing the total amount of asphalt in the mass. Trial dumps of sand and "heavy" asphalt (sulphurated) were made from double-compartment, bottom-dump boxes into a hydraulic model, from divided truck beds into the river, and from trucks equipped with asphalt containers onto a creek bank. Satisfactory results were not obtained in the tests. The limited amount of testing to date precludes the projection of the relative merits as compared to mass sand asphalt.

Unrealized Objective

86. The limited amount of field work accomplished to date has assisted greatly in determination of those properties of the asphalt mixture that will give the best coverage when dropped in a mass under water. It is believed that these properties have been adequately determined and that the best possible asphalt mixture for developing an underwater mat has been attained. However, it should be pointed out that determination of the best mixture for such a purpose does not insure that this type of revetment will function properly. Additional large-scale placement, detailed survey and/or sampling thereof, and observation of mat performance over a period of time are necessary before factors such as thickness,

strength or resistance to disintegration, and deformability in conforming to river bed irregularities can be determined. Economy of placement of the asphalt mixes depends primarily on the volume (thickness) of material required and further simplification of placement procedures. No saving can be expected by reducing the asphalt content below the recommended minimum because the desirable properties of the mixture will be forfeited.

PART VII: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

87. Data collected during tests on sand-asphalt mixtures, in combination with observations made during the test period by the various engineers connected with the study, warrant the following conclusions:

a. Mass sand-asphalt mixtures for underwater protection of river banks should contain approximately 25 per cent asphalt cement with the average clean fine river bar sand for proper spreading and coverage characteristics. Use of coarser sand will permit this percentage to be lowered two to five points, but when the sand contains a considerable amount of silt, the percentage must be raised two or three points.

b. The mix temperature of a sand-asphalt mixture at time of placement is rather critical. It should in no case be less than about 225° F, and a maximum of about 275° F is recommended. Higher temperatures do not improve fluidity but rather encourage flotation and cause the resulting mat surface to be rough.

c. The asphalt cement should be of penetration grade between 50 and 150, with preference for the average 85-100 penetration grade. This grade is not too soft to allow broken coverage because of poor ductility and yet is soft enough to withstand considerable hardening with age.

d. No admixtures proved satisfactory for improving the fluidity of the mixes.

e. Aggregates covering the range of gradations that can be expected from Mississippi River sand bar material are adequate for use in producing sand-asphalt mixtures, the main requirement being to adjust the asphalt content for a given gradation.

f. A sand-asphalt mixture can be dropped in a large mass through a considerable depth of water and develop a mat having satisfactory coverage, within certain limitations. Placement should be on rather smooth slopes that are not too steep. The mixture must contain enough asphalt to provide adequate spread. Placement should be accomplished in relatively low current velocities with low turbulence. The effect of cooling on the size of the mass normally used is negligible. The effects of placement in currents having high velocity were not fully determined.

g. The present method of underwater placement by bottom-dump barge, though not the ultimate, appears to have promise.

h. None of the types of asphalt tested in lieu of asphalt cement were satisfactory.

i. The use of cool, wet sand in lieu of hot, dry sand in asphalt mixtures for underwater placement is not considered satisfactory.

j. Adequate procedures have not been fully developed for laminated dikes composed of successive layers of wet sand and asphalt but small-scale tests conducted to date show little promise. The asphalt membrane was not heavy enough for placement through water. The weight of this membrane should be increased so as to have a minimum specific gravity of 1.5.

k. Observation of the performance of a mass sand-asphalt dike (Fitler Bend) indicates the practicability of such a material for underwater groins provided it is possible to place the mixture on a firm foundation.

l. The adequacy of sand asphalt for underwater revetments with properties as recommended on the basis of this investigation cannot be fully ascertained until large-scale placements covering a wider range of conditions are made and observed over a period of years.

Recommendations

88. It is recommended that future underwater placement of sand asphalt be studied and that careful evaluation of the effectiveness be made after placement by survey, sampling and observation of performance.

89. It is recommended that the possibilities of utilizing a heavier asphalt, such as asphalt-baroid, in the mix be investigated, on the basis of the difficulties experienced with sand-asphalt mats having low density.

Mix design could be accomplished in the laboratory but evaluation of performance would have to be determined under actual field conditions.

TABLES

Table 1

SUMMARY OF TYPES OF ASPHALT TESTED

Material	Producer	Properties
Asphalt cement, 30-40 penetration	Drawn from stock	Penetration 31
Asphalt cement, 50-60 penetration	Lion Oil Company, El Dorado, Ark.	Penetration 55, flash point 645 F, softening point 128 F, and ductility 150+
Asphalt cement, 85-100 penetration	Lion Oil Company, El Dorado, Ark.	[a]Penetration 89, Sp gr 1.02, flash point 640 F, softening point 117 F and ductility 150+
Asphalt cement, 85-100 penetration	Southland Oil Company, Yazoo City, Miss.	[b]Penetration 91, Sp gr 1.01, flash point 595 F, softening point 123 F, and ductility 135+
Asphalt cement, 85-100 penetration	Shell Oil Company	Penetration 90
Asphalt cement, 85-100 penetration	Southland Oil Company, Yazoo City, Miss.	[c]Penetration 98-100, Sp gr 102, flash point 555 F, softening point 114 F and ductility 74+
Asphalt cement, 100-150 penetration	Drawn from stock	Penetration 116
Asphalt cement, 100-150 penetration	Lion Oil Company, El Dorado, Ark.	Penetration 110, flash point 645, softening point 110, and ductility 150+
Asphalt cement, 150-200 penetration	Lion Oil Company, El Dorado, Ark.	Penetration 150, flash point 620, softening point 108, and ductility 123+
Asphalt cement, 200-300 penetration	Lion Oil Company, El Dorado, Ark.	Penetration 200, flash point 615, softening point 100, and ductility 112+
"Baromix" paving cement, 40-50 penetration	Berry Asphalt Company, Waterloo, Ark.	Penetration 41, softening point 150 F, and Sp gr 1.24
Cracked asphalt, 90 penetration	Socony-Vacuum Oil Co., Inc., Augusta, Kan.	Penetration 90
Cracked asphalt, 133 penetration	Socony-Vacuum Oil Co., Inc., Augusta, Kan.	Penetration 133
Cracked asphalt, 190 penetration	Socony-Vacuum Oil Co., Inc., Augusta, Kan.	Penetration 190
Waterproofing asphalt	Lion Oil Company, El Dorado, Ark.	Penetration 32 and softening point 160 F
Roofing asphalt	Lion Oil Company, El Dorado, Ark.	Penetration 25 and softening point 195 F
Rapid curing emulsion (HV bitumuls)	American Bitumuls Co., Baton Rouge, La.	-------
Slow curing emulsion (HCM bitumuls)	American Bitumuls Co., Baton Rouge, La.	60% asphalt, penetration 124, ductility 74, miscibility with water 48%, demulsibility 0

Notes: [a] This material used for majority of laboratory underwater slump tests.
[b] This material used for majority of small-scale field tests.
[c] This material used for majority of laboratory slump tests in air.
See table 2 for properties of RC and SC.

Table 2

LIST OF ADMIXTURES TESTED

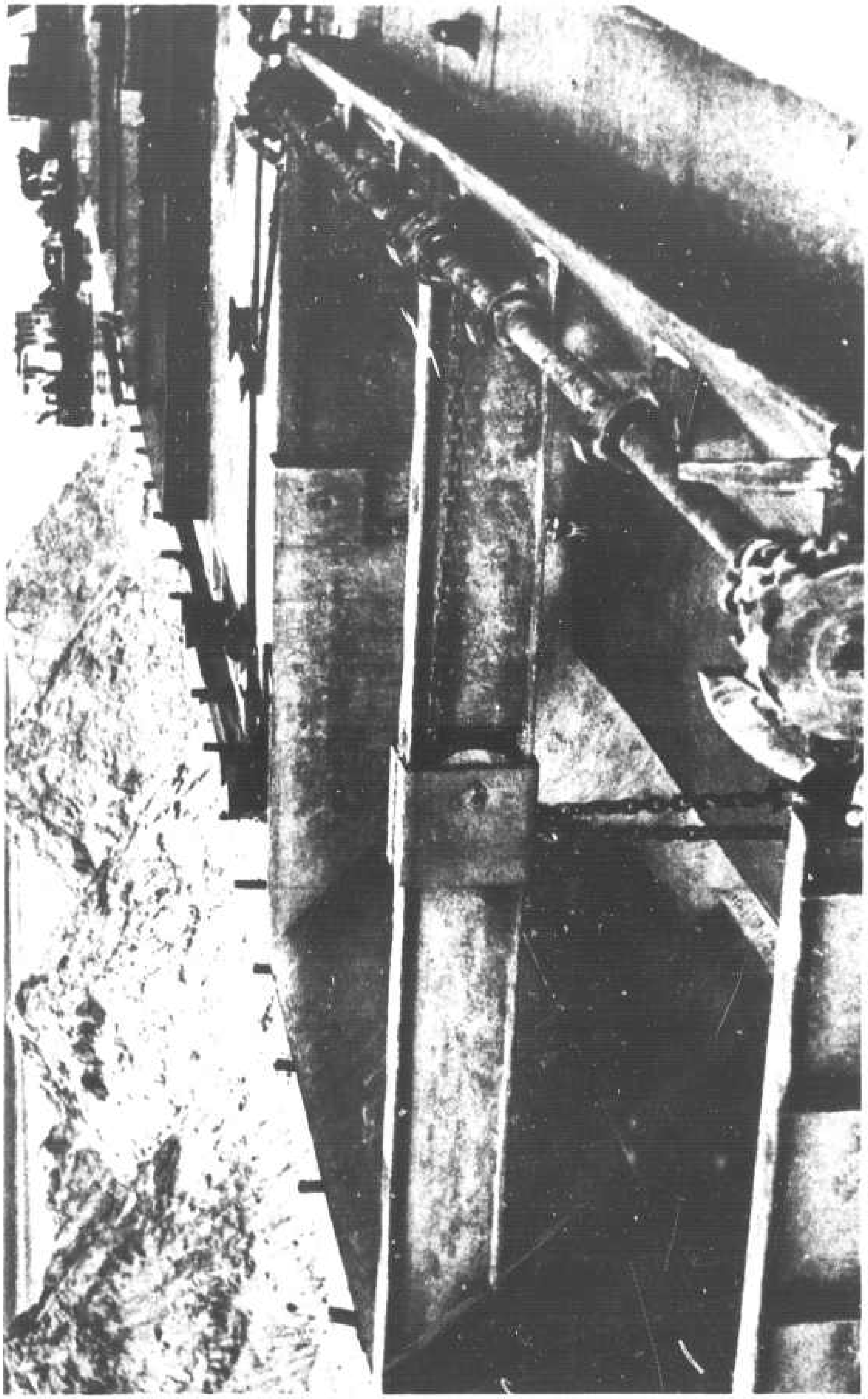
Name	Producer	Remarks
Acetic Acid	----	----
Alum	----	----
Calcium chloride	----	Suggested by Miss. River Commission
Cutback asphalt (RC-2)	Drawn from stock	Considered for comparison with fuel oil admixture
Fuel oil	----	Considered for its ability to increase viscosity
Fuel oil, beef tallow and steam	----	Recommended by A. H. Benedict, consultant, in connection with a patented process
Laykold	American Bitumuls Co., Baton Rouge, La.	Cold tempering fluid added to hot asphalt cement; recommended by producer
Nopcogen 12-0 Nopcogen 20-0 Nopcogen 20-T	Nopco Chemical Co., Harrison, N. Y.	Fats or compounds with fatty bases, recommended by producer following inquiry suggested by Miss. River Commission
Product BC Product QB Retarder LA	DuPont Company, Wilmington, Del.	Cationic active agents suggested by the producer in reply to inquiry
Resin, Abalyn Resin, Hercolyn Resin, Flexalyn	Hercules Powder Co., Wilmington, Del.	Resin modifiers suggested by the Lion Oil Company
SC-2 SC-3 SC-5	Lion Oil Company, El Dorado, Ark.	Considered primarily because of the possible desirability of slower curing
Steam or water	----	----
Sodium chloride	----	Suggested by Miss. River Commission
Sodium phosphate	----	Suggested by Miss. River Commission
Sodium silicate	----	Suggested by Miss. River Commission
Stearic acid	----	----
Tall oil, crude	Arizona Chemical Co., Panama City, Fla.	Use in combination with sodium hydroxide and water. Recommended by producer in reply to inquiry
Tar (RT-6)	Drawn from stock	----
Tar (RT-10)	Drawn from stock	----
Tuffklay	Tuffalt Inc., Pittsburgh, Pa.	Soil grout used in paste form
Vel soap	----	Detergent suggested by Miss. River Commission

Table 3

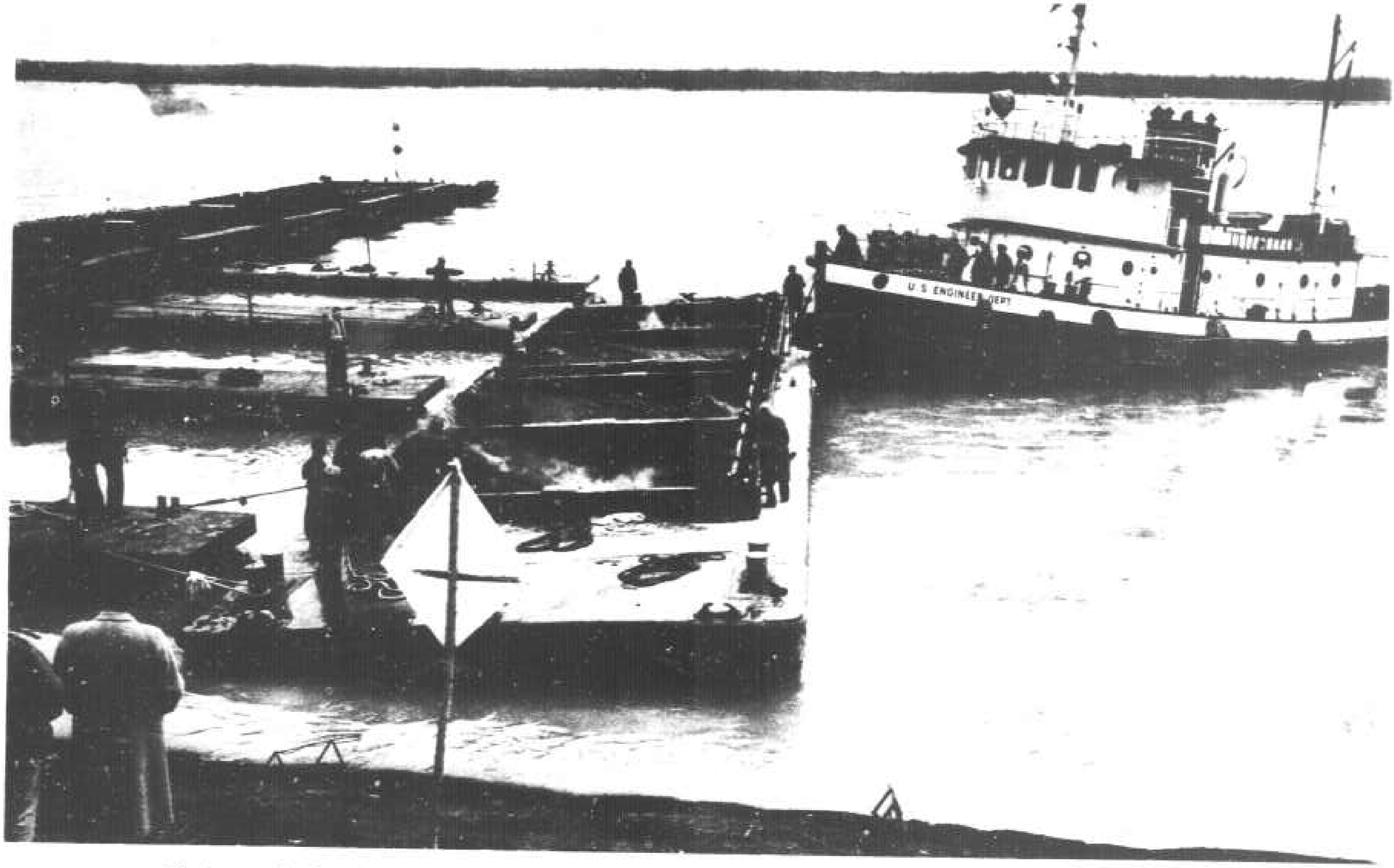
SLUMP TESTS IN AIR WITH ADMIXTURES

Asphalt %[a]	Aggregate Type	Mix Temp. F	Admixture Type	Admixture %[b]	Slump From 9.5-in. Cone in./in.	Remarks
8	Coarse sand	300	None	---	4.8	Base test for 8 per cent mixes
8	Coarse sand	300	Sodium chloride	0.5	4.9	Small cracks on edges
8	Coarse sand	300	Laykold	25	5.0	Large cracks on top and sides
8	Coarse sand	300	Sodium chloride Water	5 2	5.0	Some cracking
8	Coarse sand	300	Laykold	50	5.0	Loose, crumbly and cracked
8	Coarse sand	300	Tar, RT-6	25	5.0	Material crumbly, sides sloughed
8	Coarse sand	300	Tar, RT-10	25	5.0	Material crumbly, sides sloughed
8	Coarse sand	300	Laykold	35	5.1	Large cracks, little cohesion
8	Coarse sand	300	Sodium chloride	3	5.1	Small cracks on edges
8	Coarse sand	300	Vel soap	5	5.1	Cracks on sides to 3/4-in. depth, excessive swell[c]
8	Coarse sand	300	Vel soap	1	5.2	Cracks on sides to 3/4-in. depth, excessive swell[c]
8	Coarse sand	300	DuPont retarder LA	3	5.3	Cracks to 1/2-in. depth on top and sides, excessive swell[c]
8	Coarse sand	300	DuPont retarder LA	5	5.3	Cracks to 1/2-in. depth on top and sides, excessive swell[c]
8	Coarse sand	300	DuPont product BC	3	5.3	Cracks to 3/4-in. depth, excessive swell[c]
8	Coarse sand	300	DuPont product BC	5	5.3	Cracks to 1/2-in. depth, excessive swell[c]
8	Coarse sand	300	DuPont product QB Tall oil	1 2	5.3	Cracks to 1/2-in. depth, excessive swell[c]
8	Coarse sand	300	Sodium hydroxide Water	2 3	5.3	Some cracking
8	Coarse sand	300	Sodium chloride	1	5.4	Small cracks on edges
8	Coarse sand	300	Vel soap	10	5.4	Cracking on sides to 1/2-in. depth, excessive swell[c]
8	Coarse sand	300	Water	10	5.4	Only temporary increase in fluidity
8	Coarse sand	300	DuPont product QB	3	5.4	Cracks to 3/4-in. depth on top and sides, excessive swell[c]
8	Coarse sand	300	Alum	10	5.4	Some shearing and excessive swell[c]
8 (193)	Coarse sand	300	Tuffklay	10	5.4	Cracking on sides, excessive swell[c]
8	Coarse sand	250	Sodium silicate	5	5.5	Cracking on sides to 1-in. depth, excessive swell[c]
8	Coarse sand	300	DuPont product QB	5	5.5	Cracks to 1/2-in. depth on top and sides, excessive swell[c]
8	Coarse sand	300	Tar, RT-6	50	5.6	Material crumbly, sides sloughed
8	Coarse sand	300	Water Tall oil	5 4	5.6	Only temporary increase in fluidity
8	Coarse sand	300	Sodium hydroxide Water	2 3	5.6	Some cracking
8	Coarse sand	300	DuPont retarder LA	1	5.6	Cracks to 1/2-in. depth, excessive swell[c]
8	Coarse sand	300	Tar, RT-10	50	5.7	Material crumbly, sides sloughed
8	Coarse sand	300	Sodium silicate	5	5.8	Cracks on sides to 1-1/4-in. depth, excessive swell[c]
8	Coarse sand	250	Acetic acid	2	5.9	Considerable cracking to 1/2-in. depth, excessive swell[c]
8 (193)	Coarse sand	200	Tuffklay	10	6.5	Cracking on top and sides to 1-in. depth, excessive swell[c]
8	Coarse sand	300	Tuffklay	10	6.7	Cracking on top and sides to 1-in. depth, excessive swell[c]
10	Coarse sand	300	None	---	5.2	Base test for 10 per cent mixes
10	Coarse sand	300	DuPont product QB	5	5.4	Cracks to 3/4-in. depth on top and sides, excessive swell[c]
10	Coarse sand	300	Sodium phosphate	1	5.5	Cracking on sides, excessive swell[c]
10	Coarse sand	300	Tar, RT-6	50	5.6	Material crumbly, sides sloughed
10	Coarse sand	300	Tar, RT-10	50	5.6	Material crumbly, sides sloughed
10	Coarse sand	300	Calcium chloride	0.5	5.8	Some cracking
10 (193)	Coarse sand	300	None	---	5.9	Some cracking
10	Coarse sand	300	Calcium chloride	1	6.0	Some cracking
10	Coarse sand	300	Hercolyn	10	6.0	Some cracking
10	Coarse sand	300	Flexalyn	10	6.1	Some cracking
10	Coarse sand	300	Sodium phosphate	0.5	6.1	Cracking on sides, excessive swell[c]
10 (193)	Coarse sand	250	None	---	6.2	Some cracking
10	Coarse sand	300	Sodium chloride	10	6.2	Some cracking
10	Coarse sand	300	Acetic acid	5	6.3	Some cracking, excessive swell[c]
10	Coarse sand	300	Sodium chloride	0.5	6.3	Small cracks on edges
10	Coarse sand	300	Vel soap	1	6.3	Cracks to 3/4-in. depth, excessive swell[c]
10	Coarse sand	300	DuPont product BC	3	6.4	Cracks to 3/4-in. depth, excessive swell[c]
10	Coarse sand	300	DuPont product BC	1	6.5	Cracks to 3/4-in. depth, excessive swell[c]
10	Coarse sand	300	Sodium chloride	5	6.6	Small cracks on edges
10 (193)	Coarse sand	200	Tuffklay	10	6.6	Cracking on sides to 3/4-in. depth, excessive swell[c]
10	Coarse sand	300	Sodium chloride	1	6.6	Small cracks on edges
10	Coarse sand	300	Stearic acid	10	6.8	Increased acidity from Ph of 6.4 to 4.9
10	Coarse sand	300	Abalyn	10	6.8	Some cracking
10	Coarse sand	300	Sodium chloride	3	7.0	Some cracking
10	Coarse sand	300	Acetic acid	2	7.0	Cracks to 1/2-in. depth, excessive swell[c]
10	Coarse sand	300	DuPont product BC	5	7.1	Cracks to 1/2-in. depth, excessive swell[c]
10	Coarse sand	250	Sodium silicate	5	7.1	Large cracks on sides to 1-in. depth
10 (193)	Coarse sand	300	Tuffklay	10	7.3	Cracking on sides, excessive swell[c]
10	Coarse sand	300	Vel soap	5	7.3	Some cracking, excessive swell[c]
10	Coarse sand	300	Tuffklay	10	7.5	Cracking on top and sides to 3/4-in. depth, excessive swell
12	Coarse sand	300	None	---	6.6	Base test for 12 per cent mixes
12 (193)	Coarse sand	200	Tuffklay	10	6.8	Cracks on sides to 1-in. depth, excessive swell[c]
12	Coarse sand	300	SC-5	30	7.0	Slight cracking
12 (193)	Coarse sand	300	None	---	7.0	No cracking
12	Coarse sand	300	Sodium phosphate	0.5	7.1	Small cracks on sides, excessive swell[c]
12	Coarse sand	300	Sodium phosphate	1	7.1	No cracking, excessive swell[c]
12	Coarse sand	300	Calcium chloride	0.5	7.1	No cracking
12	Coarse sand	300	None	---	7.1	Same as base test except for one hour delay
12	Coarse sand	300	Water	10	7.2	Only temporary increase in fluidity
12	Coarse sand	300	Calcium chloride	1	7.2	No cracking
12	Coarse sand	300	Vel soap	1	7.3	No cracking, excessive swell[c]
12	Coarse sand	300	DuPont product BC	1	7.3	Cracks to 1/4-in. depth, excessive swell[c]
12	Coarse sand	300	Sodium chloride	5	7.3	Small cracks on outside edges
12	Coarse sand	300	Flexalyn	10	7.4	No cracking
12	Coarse sand	300	Sodium chloride	0.5	7.4	No cracking
12	Coarse sand	300	Abalyn	10	7.4	No cracking
12	Coarse sand	300	DuPont product BC	3	7.4	No cracking, excessive swell[c]
12	Coarse sand	250	Acetic acid	2	7.5	Some cracking to 1/2-in. depth, excessive swell[c]
12	Coarse sand	300	Sodium chloride	10	7.5	No cracking
12	Coarse sand	300	Hercolyn	10	7.5	No cracking
12 (193)	Coarse sand	250	None	---	7.5	No cracking
12	Coarse sand	300	Sodium chloride	1	7.5	No cracking
12 (SC-5)	Coarse sand	300	SC-5	100	7.6	Mass remained plastic but did not harden
12	Coarse sand	300	Sodium silicate	5	7.6	Cracks on top and sides to 1/2-in. depth
12	Coarse sand	300	Stearic acid	10	7.7	Increased acidity
12	Coarse sand	300	Sodium chloride	3	7.7	No cracking
12	Coarse sand	300	DuPont product BC	5	7.7	No cracking, excessive swell[c]
12 (193)	Coarse sand	300	Tuffklay	10	7.8	Cracking on sides, excessive swell[c]
12	Coarse sand	300	Sodium silicate	5	7.8	Cracking on sides to 1/4-in. depth
12	Coarse sand	300	Tuffklay	10	8.0	No cracking, excessive swell[c]
12	Coarse sand	300	Vel soap	5	8.1	No cracking, excessive swell[c]

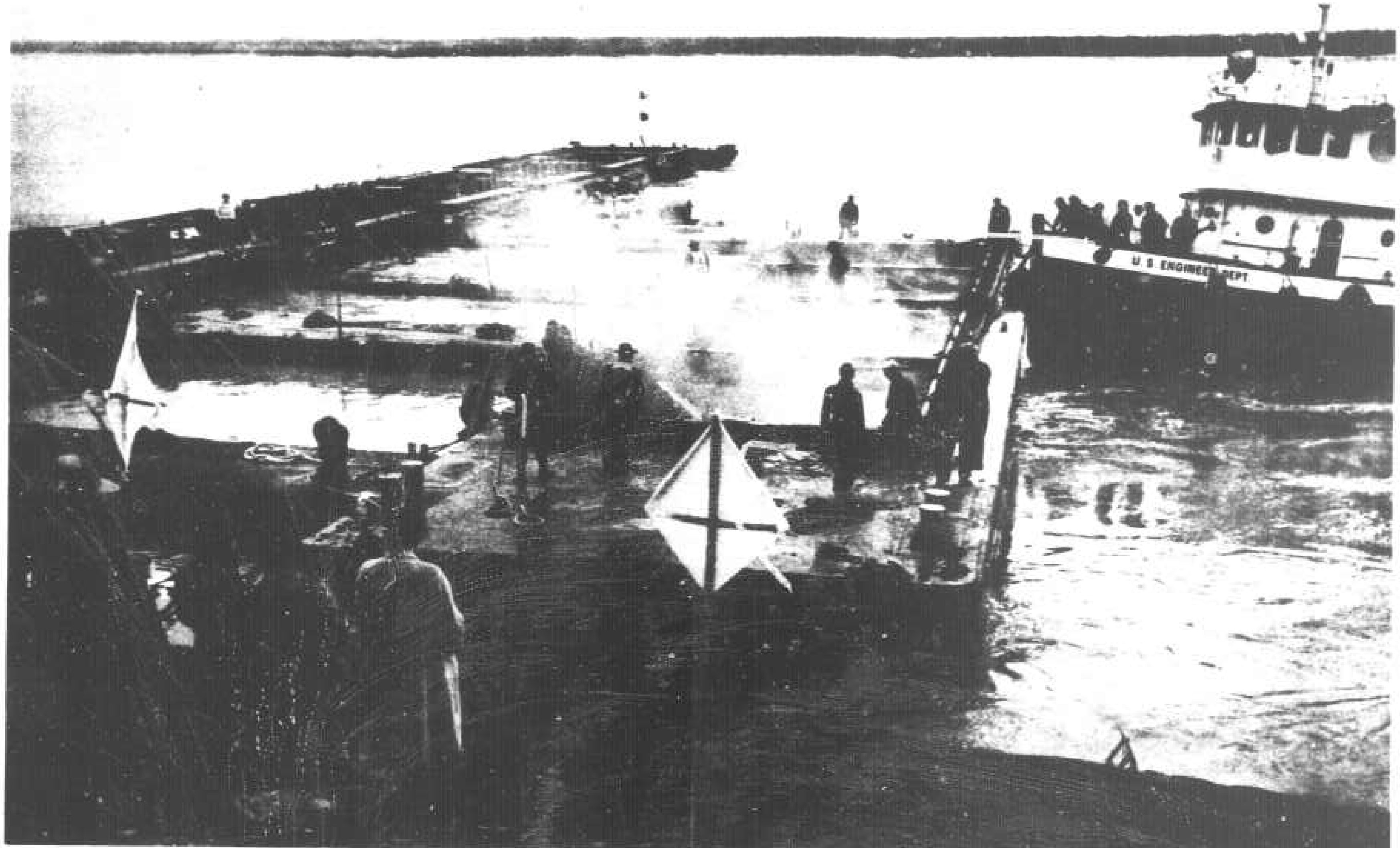
Notes: [a] Penetration of asphalt cement approximately 100 except where noted in parentheses.
[b] Percentage based on weight of asphalt in mix. [c] Excessive swell during mixing; usually diminishing during slump test.



Photograph 1. Bottom-dump, scow barges, for dumping asphalt, moored to Mississippi River bank



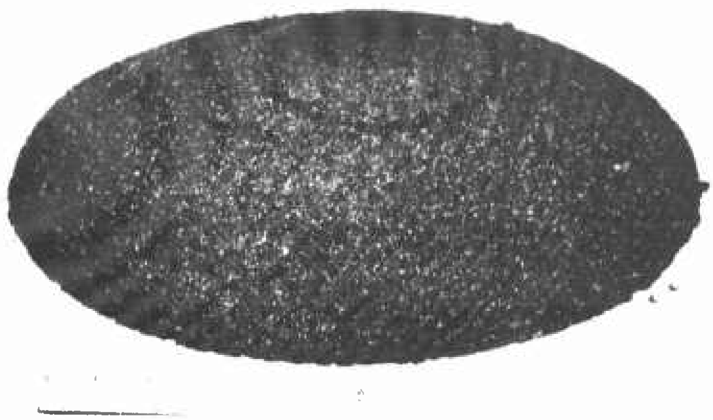
Photograph 2. Dumping mass asphalt from bottom-dump scow barge, Mississippi River



Photograph 3. Bottom-dump scow barge just emptied of mass asphalt. Temperature recordings in left foreground. Light mist over hoppers is steam

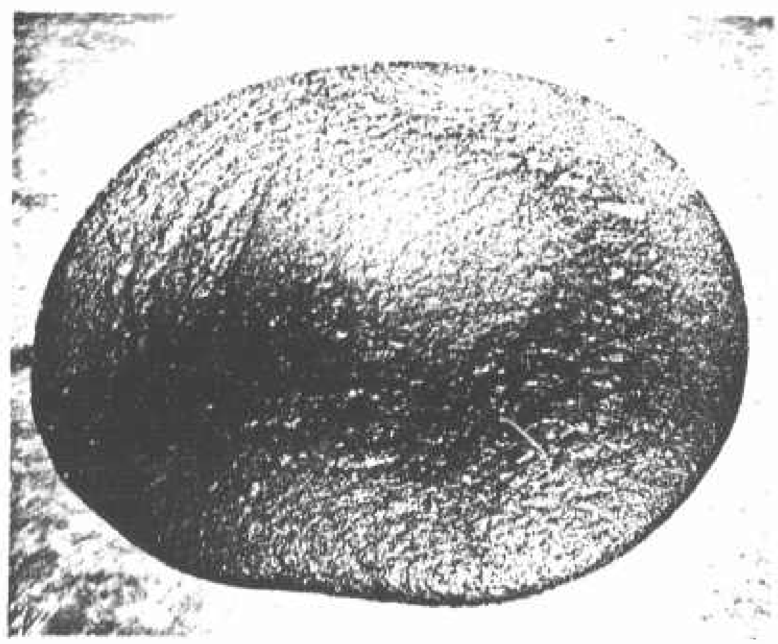
Photograph 4. Slump cones used to measure relative fluidity of asphaltic mixtures: (1) standard concrete slump cone; (2) slump cone with one-half volume of standard cone; (3) insulated slump cone with base plate on large orifice; and (4) insulated slump cone with trap door on small orifice

6% asphalt cement,
300 F,
5.3-in. slump

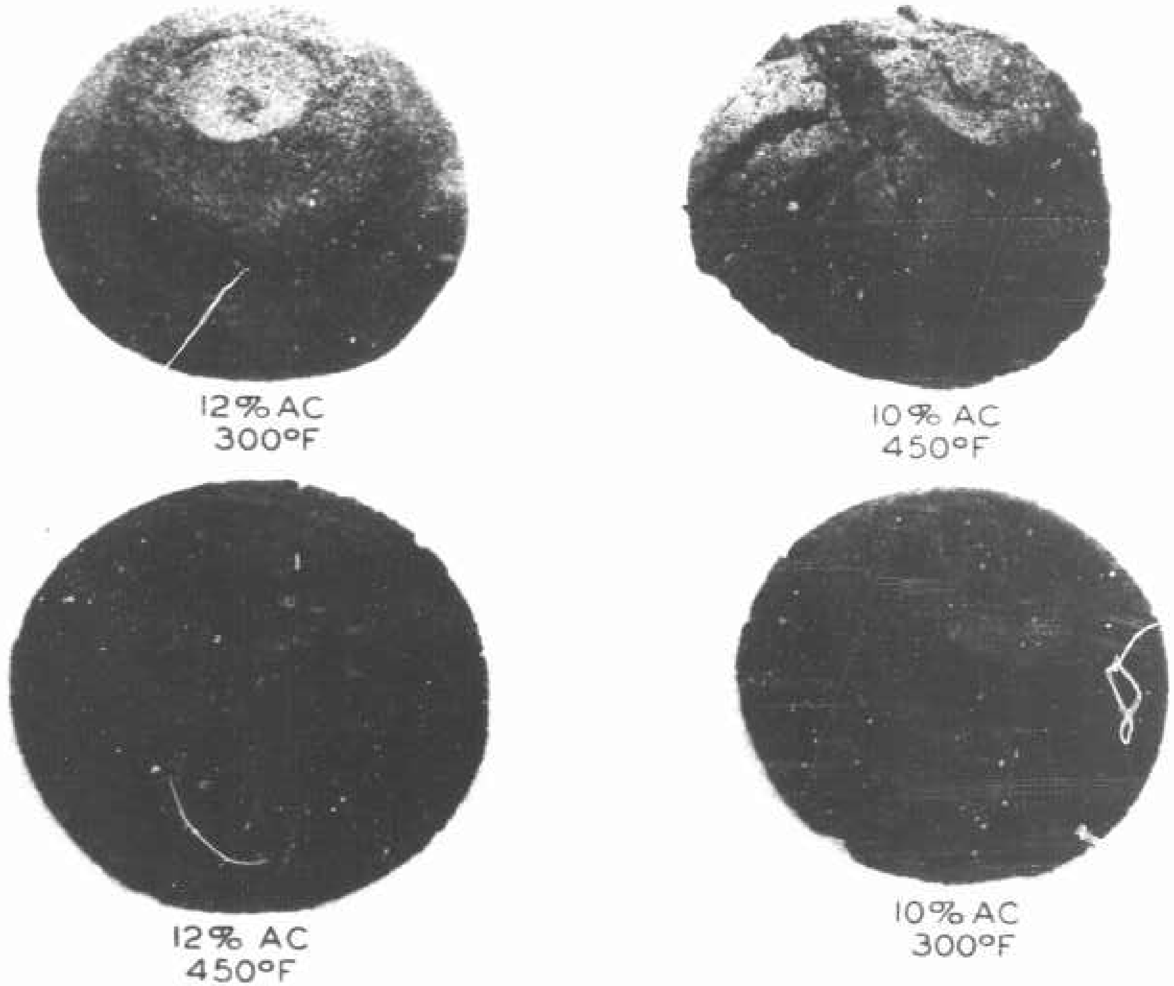


12% asphalt cement,
300 F,
6.6-in. slump

16% asphalt cement,
300 F,
7.9-in. slump



Photograph 5. Appearance of typical slumped sand-asphalt mixtures dumped in air from slump cone 9.5 in. high



Photograph 6. Sand-asphalt mixtures dumped in air from slump cone 9.5 in. high. Note effect of high temperature on mixtures containing 10 and 12 per cent asphalt

Photograph 7. Mixes of coarse sand aggregate and 85-100 penetration asphalt cement in percentages noted, slumped under water. Placed at 300 F

Photograph 8. Mixes of fine sand aggregate and 85-100 penetration asphalt cement in percentages noted, slumped under water. Placed at 300 F

Table 4

SLUMP TESTS IN AIR
COMPARISON OF SELECTED ADMIXTURES WITH PENETRATION GRADES OF ASPHALT CEMENT

Asphalt Cement: Mix[a] %	Asphalt Cement: Penetration	Admixture: Type	Admixture: %	Slump from 9.5-in. Cone Ht/in.	Remarks
10	100	None	--	5.2	Base test
10	193	None	--	5.9	Base test; improved fluidity
12	100	None	--	6.6	Base test
12	193	None	--	7.0	Base test; improved fluidity
10	100	Tuffklay	10	7.5	
10	193	Tuffklay	10	7.1	No improvement
12	100	Tuffklay	10	8.0	
12	193	Tuffklay	10	7.8	No improvement
10	100	Vel soap	5	7.3	
10	193	Vel soap	5	7.3	No improvement
10	100	DuPont Product BC	5	7.1	
10	193	DuPont Product BC	5	5.1	Decreased fluidity
10	100	Sodium Chloride	3	7.0	
10	193	Sodium Chloride	3	5.3	Decreased fluidity

Notes: Coarse sand aggregate used in all tests, mix temperature was 300 F for all tests.
[a] Percentage based on weight of asphalt in mix.

Table 5

SUMMARY OF UNDERWATER SLUMP
EROSION AND STRIPPING TESTS WITH SELECTED ADMIXTURES

Admixture: Type	Admixture: %[a]	Slump in Air From 9.5-in. Cone Ht/in.	Underwater slump from 9.5-in. cone Ht/in.: Tested immediately after mixing	Underwater slump from 9.5-in. cone Ht/in.: Tested after 1-hr oven curing	Erosion	Stripping
None	--	5.2	2.2	4.9	Slight	Trace
Tuffklay	10	7.5	3.4	4.3	Slight	Trace
Sodium silicate	5	7.3	5.1	5.9	Slight	Trace
Vel soap	5	7.3	5.3	5.5	Slight	Excessive
DuPont Product BC	5	7.1	6.8[c]	4.4[b]	Slight	Trace
Sodium chloride	3	7.0	6.3	5.8	Slight	Trace

Notes: 10 per cent of 90-penetration asphalt, coarse sand aggregate and mix temperature 300 F used for all tests.
[a] Percentage based on weight of asphalt in mix.
[b] Vigorous reaction when placed underwater immediately after mixing but considerably less after one hour delay, resulting in sharp decrease in fluidity.

Table 6

UNDERWATER SLUMP TESTS -- EFFECT OF ASPHALT CONTENT AND EFFECT OF COARSE AND FINE SAND

Asphalt[a] %	Aggregate Type	Mix Temp. F	Slump from 9.5-in. Cone[b] Ht/In.	Avg. Diam. In.	Density Lb/cu ft	Remarks
10	Coarse sand	300	4.0	----	---	Very poor spread
15	Coarse sand	300	7.6	11.0	112	Poor spread
20	Coarse sand	300	8.1	14.2	114	Fair spread
25	Coarse sand	300	8.3	17.0	110	Satisfactory spread
30	Coarse sand	300	8.5	18.5	107	Satisfactory spread
40	Coarse sand	300	8.9	22.5	88	Blisters formed
50	Coarse sand	300	8.9	24.0	83	Increased blisters
60	Coarse sand	300	9.1	25.0	75	Increased blisters and flotation[c]
15	Coarse sand	200	6.6	9.2	117	Poor spread
20	Coarse sand	200	8.0	11.2	109	Fair spread
25	Coarse sand	200	8.1	12.7	106	Satisfactory spread
30	Coarse sand	200	8.4	13.6	95	Satisfactory spread
40	Coarse sand	200	8.5	18.6	93	Maximum spread
50	Coarse sand	200	8.8	16.2	87	Decreasing spread; mat too light
60	Coarse sand	200	8.4	15.2	81	Decreasing spread; mat too light
70	Coarse sand	200	8.3	14.0	75	Decreasing spread; mat too light
80	Coarse sand	200	8.0	12.7	69	Decreasing spread; mat too light
90	Coarse sand	200	7.9	12.0	67	Decreasing spread; mat too light
15	Coarse sand	425	6.6	11.2	121	Poor spread
20	Coarse sand	425	7.7	15.0	118	Fair spread but rough mat
25	Coarse sand	425	7.8	15.5	112	Fair spread but rough mat
30	Coarse sand	425	8.0	15.6	---	Satisfactory spread but rough mat
40	Coarse sand	425	8.2	16.0	---	Rough mat and blisters formed[d]
50	Coarse sand	425	8.5	20.0	---	Increased blisters and flotation[c]
15	Fine sand	300	0.5	----	---	Practically no spread
17.5	Fine sand	300	4.2	----	---	Very poor spread
20	Fine sand	300	6.5	8.6	---	Poor spread
25	Fine sand	300	8.1	13.6	---	Satisfactory spread
30	Fine sand	300	8.3	15.1	---	Satisfactory spread
40	Fine sand	300	8.6	21.3	---	Satisfactory spread
50	Fine sand	300	8.7	23.0	---	Satisfactory spread, blisters formed
60	Fine sand	300	9.2	26.7	---	Maximum spread, increased blisters
70	Fine sand	300	9.2	25.0	---	Increased blisters
80	Fine sand	300	9.2	21.7	---	Increased blisters and flotation[c]
20	Fine sand	200	6.9	7.5	106	Very poor spread
25	Fine sand	200	7.5	9.5	98	Poor spread
30	Fine sand	200	7.8	11.4	89	Fair spread
40	Fine sand	200	8.3	14.5	87	Satisfactory spread
50	Fine sand	200	8.6	17.2	83	Satisfactory spread
60	Fine sand	200	8.8	17.3	80	Satisfactory spread
70	Fine sand	200	8.8	20.5	76	Maximum spread; mat unstable
80	Fine sand	200	8.4	15.7	71	Decreasing spread; mat too light
90	Fine sand	200	8.1	14.8	66	Decreasing spread; mat too light
20	Fine sand	425	7.0	10.5	109	Poor spread
25	Fine sand	425	8.0	13.5	113	Fair spread; rough mat
30	Fine sand	425	8.5	19.0	103	Satisfactory spread; rough mat
40	Fine sand	425	8.8	22.0	---	Very rough mat; blisters formed
50	Fine sand	425	9.0	22.0	---	Increased blisters
60	Fine sand	425	9.0	22.5	---	Increased blisters
70	Fine sand	425	8.7	22.0	---	Increased blisters and flotation[c]

Notes: [a] 85-100 penetration.
[b] Volume of cone, 172 cu in.
[c] Flotation indicates that a part or all of the mix rose to the surface of the water.
[d] More pronounced than at 300 F.

Table 7

UNDERWATER SLUMP TESTS - EFFECT OF PENETRATION GRADES OF ASPHALT CEMENT

Asphalt Cement %	Asphalt Cement Penetration Grade	Aggregate Type	Mix Temp. F	Slump[a] from 9.5-in. Cone Ht/in.	Avg. Diam. In.	Density Lb/cu ft	Remarks
15	50-60	Coarse sand	300	7.8	10.5	115	Fair spread
20	50-60	Coarse sand	300	8.2	13.0	120	Satisfactory spread
25	50-60	Coarse sand	300	8.5	16.4	112	Satisfactory spread and uniform coverage
30	50-60	Coarse sand	300	8.6	16.5	108	Satisfactory spread and uniform coverage
40	50-60	Coarse sand	300	8.8	21.0	98	Blisters formed
50	50-60	Coarse sand	300	8.8	21.0	88	Increased blisters
60	50-60	Coarse sand	300	9.0	22.7	79	Increased blisters and flotation[b]
20	50-60	Fine sand	300	6.3	10.0	107	Poor spread
25	50-60	Fine sand	300	8.1	14.5	117	Satisfactory spread
30	50-60	Fine sand	300	8.5	16.4	106	Satisfactory spread and uniform coverage
40	50-60	Fine sand	300	8.7	20.8	95	Blisters formed
50	50-60	Fine sand	300	8.8	23.4	89	Increased blisters
60	50-60	Fine sand	300	9.0	24.1	82	Increased blisters
20	100-150	Fine sand	300	6.5	10.0	107	Poor spread
25	100-150	Fine sand	300	8.0	14.0	106	Satisfactory spread
30	100-150	Fine sand	300	8.4	16.4	105	Satisfactory spread and uniform coverage
40	100-150	Fine sand	300	8.7	20.0	95	Blisters formed but no break in coverage
50	100-150	Fine sand	300	9.0	23.4	--	Increased blisters and small breaks in coverage
60	100-150	Fine sand	300	9.2	27.6	--	Increased blisters and more breaks in coverage
20	150-200	Fine sand	300	7.1	9.7	107	Poor spread
25	150-200	Fine sand	300	8.0	14.0	110	Satisfactory spread
30	150-200	Fine sand	300	8.3	16.5	103	Satisfactory spread and uniform coverage
40	150-200	Fine sand	300	8.8	23.2	--	Blisters formed and small breaks in coverage
50	150-200	Fine sand	300	9.0	26.5	--	Increased blisters and more breaks in coverage
60	150-200	Fine sand	300	9.1	27.2	--	Increased blisters and more breaks in coverage
15	200-300	Coarse sand	300	7.8	12.7	117	Fair spread
20	200-300	Coarse sand	300	8.3	15.4	115	Satisfactory spread
25	200-300	Coarse sand	300	8.5	16.9	109	Satisfactory spread
30	200-300	Coarse sand	300	9.0	20.7	104	Satisfactory spread but break in coverage
40	200-300	Coarse sand	300	9.0	21.4	91	Blisters formed and more breaks in coverage
50	200-300	Coarse sand	300	9.1	24.5	--	Increased blisters, more breaks in coverage, and flotation[b]
60	200-300	Coarse sand	300	9.1	24.9	--	Increased blisters, more breaks in coverage, and flotation[b]
20	200-300	Fine sand	300	7.1	10.5	107	Poor spread
25	200-300	Fine sand	300	8.0	14.9	110	Satisfactory spread
30	200-300	Fine sand	300	8.5	21.2	103	Small blisters formed and small breaks in coverage
40	200-300	Fine sand	300	9.0	23.2	--	Increased blisters and more small breaks in coverage
50	200-300	Fine sand	300	9.1	25.5	--	Increased blisters and more small breaks in coverage
60	200-300	Fine sand	300	9.2	26.0	--	Increased blisters and more small breaks in coverage

Notes: [a] Slump data for average asphalt cement (85-100 penetration) is shown on Table 6.
[b] Flotation indicates that a part or all of the mix rose to the surface of the water.

Table 8

SMALL-SCALE FIELD TESTS IN DITCHES

Test No.	Asphalt %	Aggregate Type	Mass Weight lb	Mix Temp. F	Water Ht. in Ditch In.	Flow[a] Initial Ft	Flow[a] Total Ft	Flotation[b]	Avg. Thickness In.	Strength	Deformability
1	20	Fine sand	4,000	425	12	24	24	None	12-1[h]	Excellent	Slight
1A[c]	20	Fine sand	3,500	265	3	24	24	None	12-1[h]	Excellent	Slight
2	50	Fine sand	3,000	300	12	30	55	Limited	2	Adequate	Adequate
2A[d]	50	Fine sand	2,800	275	3	50[g]	50	Complete	2	Weak	Excessive
2B	50	Fine sand	2,000	255[f]	12	30[g]	30	Complete	6-1[h]	Weak	Excessive
3	80	Fine sand	2,000	290	4	55[g]	55	Complete	2	Weak	Excessive
3A[e]	80	Fine sand	1,800	250[f]	3	50[g]	66	Complete	2	Weak	Excessive
4	80	Limestone dust	2,000	250[f]	12	--	--	Complete	---	----	-----
5	80	Baroid	2,000	205[f]	12	--	--	Complete	---	----	-----

Notes:
a Flow measurements include length of dry ditch (8 ft) into which mix was dumped.
b Flotation indicates that a part or all of the mix rose to the surface of the water.
c Check test on 20 per cent mix with lower mix temperature and less water in ditch; same results.
d Check test on 50 per cent mix with less water in ditch, causing flow on top of water.
e Check test on 80 per cent mix with lower mix temperature in effort to reduce flotation but without success.
f Mix temperature after extended mixing at plant and after aeration and cooling in dry ditch.
g Initial flow on top of water.
h Two thickness values indicate maximum and minimum measurements from point of dumping to end of flow.

Table 9

SMALL-SCALE FIELD TESTS IN SLOPED PITS

Test No.	AC 8 %	Type Aggregate	Additive	Mass Weight Lb	Mix Temp. F	Linear Flow Ft	Avg Width Ft	Computed Coverage Sq Ft	Average Thickness In.	Density Lb/cu ft	Remarks
Hot mix 2	10	Fine sand	None	2,000	295	6	6	28	8	110	Very brittle
Hot mix 7	10	Fine sand	None	2,000	285	6	6	28	---	---	Very brittle
Hot mix 4	15	Fine sand	None	2,000	270	10	5	50	4.5	109	Fairly brittle and cracked
Hot mix 8	15	Fine sand	None	2,000	285	9	6	54	---	---	Fairly brittle and cracked
Spec. mix 1	16	Fine sand	6 gal. oil, 3 pt. tallow	2,000	175	--	---	--	---	---	Material cold, would not flow
Spec. mix 2	16	Fine sand	None	2,000	175	--	---	--	5.5	111	Material cold, would not flow
Spec. mix 12	15	Coarse sand	2 gal. oil	2,000	230	8	6	48	---	---	Quite brittle and cracked, poor spread
Hot mix 12	15	Coarse sand	None	2,000	240	12	6	72	---	---	Less brittle and considerable spread
Hot mix 1	20	Fine sand	None	2,000	275	12	6	72	3.2	108	Fairly brittle and cracked
Hot mix 9	20	Fine sand	None	2,000	285	13	6	78	---	---	Fairly brittle and cracked
Spec. mix 3	20	Fine sand	8 gal. oil, 3 pt. tallow	2,000	270	7	5	35	6.5	121	Soft but less fluid than hot mix
Spec. mix 4	20	Fine sand	None	2,000	225	11	5	55	3.5	113	Fairly brittle and less fluid than hot mix
Spec. mix 9	20	Fine sand	2 gal. oil, 3 pt. tallow	2,000	250	9	6	54	---	---	Fairly brittle and less fluid than hot mix
Hot mix 5	25	Fine sand	None	2,000	360	15	6	90	2.5	116	Excessive flotation, rough mat
Hot mix 10	25	Fine sand	None	2,000	280	16	5.5	88	---	---	Flexible mat, irregular coverage
Spec. mix 5	25	Fine sand	2 gal. oil, 3 pt. tallow	2,000	230	19	7	133	1.7	116	Flexible mat, uniform coverage
Spec. mix 7	25	Fine sand	2 gal. oil, 3 pt. tallow	2,000	310	14	6	84	2.7	108	Excessive flotation, rough mat
Spec. mix 8	25	Fine sand	2 gal. oil, 3 pt. tallow	2,000	325	14	6	84	---	---	Excessive flotation, rough mat
Spec. mix 10	25	Fine sand	2 gal. oil, 3 pt. tallow	2,000	240	17	5	85	---	---	Flexible mat, irregular coverage
Spec. mix 13	25	Coarse sand	2 gal. oil	2,000	230	15	6	90	---	---	Flexible mat, fair coverage
Hot mix 13	25	Coarse sand	None	2,000	250	16	6.5	104	---	---	Flexible mat, good coverage
Hot mix 3	30	Fine sand	None	2,000	275	18	6.7	120	1.9	103	Flexible mat, irregular coverage
Hot mix 6	30	Fine sand	None	2,000	315	17	6	102	2.2	105	Excessive flotation, rough mat
Hot mix 11	30	Fine sand	None	2,000	275	16	6	96	---	---	Flexible mat, uniform coverage
Spec. mix 6	30	Fine sand	2 gal. oil, 3 pt. tallow	2,000	300	16	7	112	2.1	104	Excessive flotation, rough mat
Spec. mix 11	30	Fine sand	2 gal. oil 3 pt. tallow	2,000	250	18	8.5	153	---	---	Very soft and flexible mat with most coverage of all tests

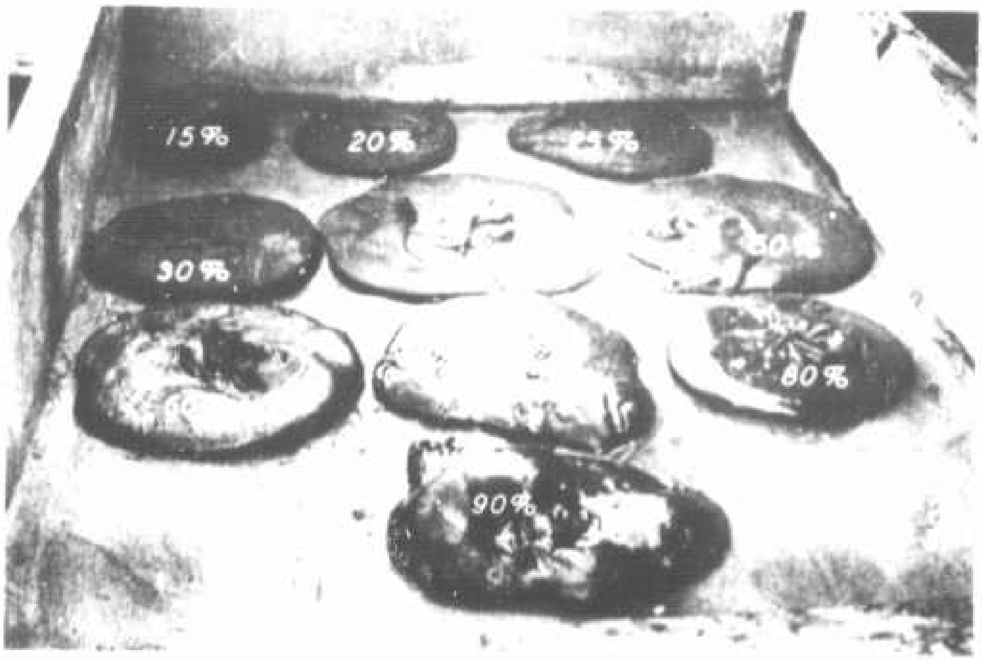
Table 10

SMALL-SCALE FIELD TESTS - ASPHALT AND WET AGGREGATE

Test No.[a]	Mass Weight, lb	Asphalt %	Sand Temp. F	Mix Temp. F	Slope When Dumped	Coverage Sq Ft	Remarks
1	1000	5	225	255	45-50°	13	Slow setting up
2	1000	5	180	190	45-50°	13	Faster setting up
3	1000	10	170	195	40°	17	Material lumpy
4	1000	15	150	170	40°	24	Material lumpy
5	1000	20	125	165	Flat	40	Material fluid
6	1000	30	105	175	Flat	50	Material more fluid
7	1000	40	105	190	Flat	80	Material more fluid
8	1000	60	55	195	Flat	120	Material very fluid
9	1000	80	55	220	Flat	200	Material extremely fluid and boiling
10	1000	50	70	200	--	78	Dumped underwater in sloped pit, fairly uniform coverage

Note: [a] 1-9 made in air.

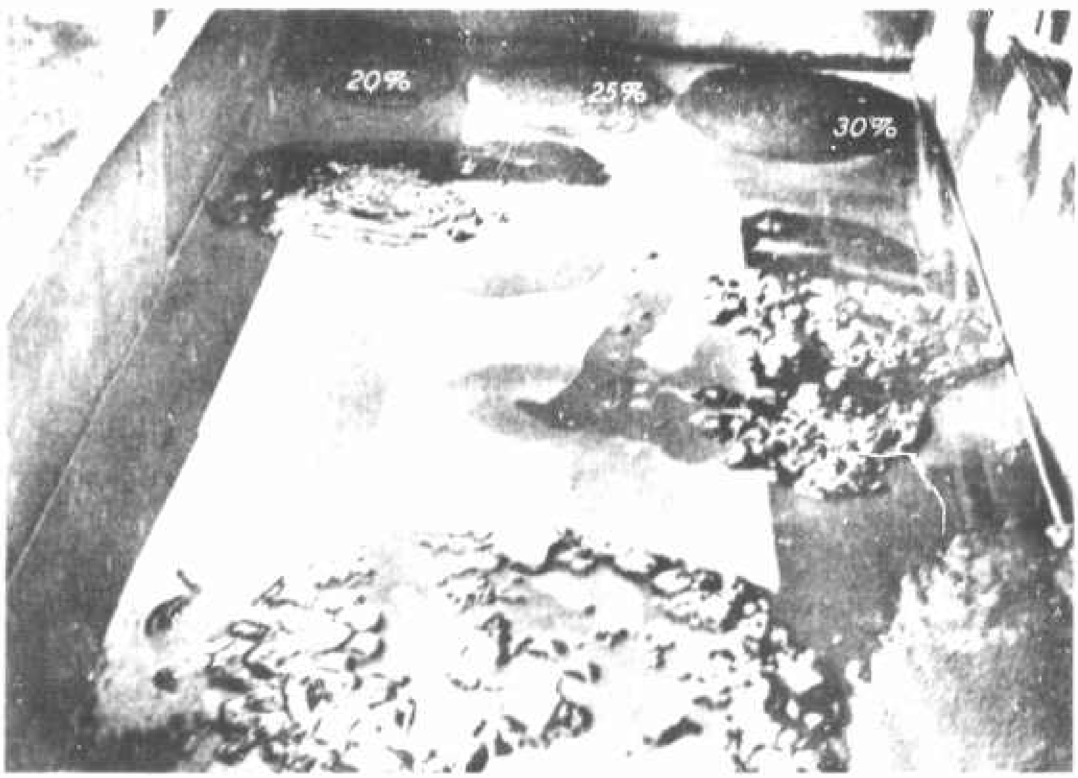
PHOTOGRAPHS



Photograph 9. Mixes of coarse sand aggregate and 85-100 penetration asphalt cement in percentages noted, slumped under water. Placed at 200 F

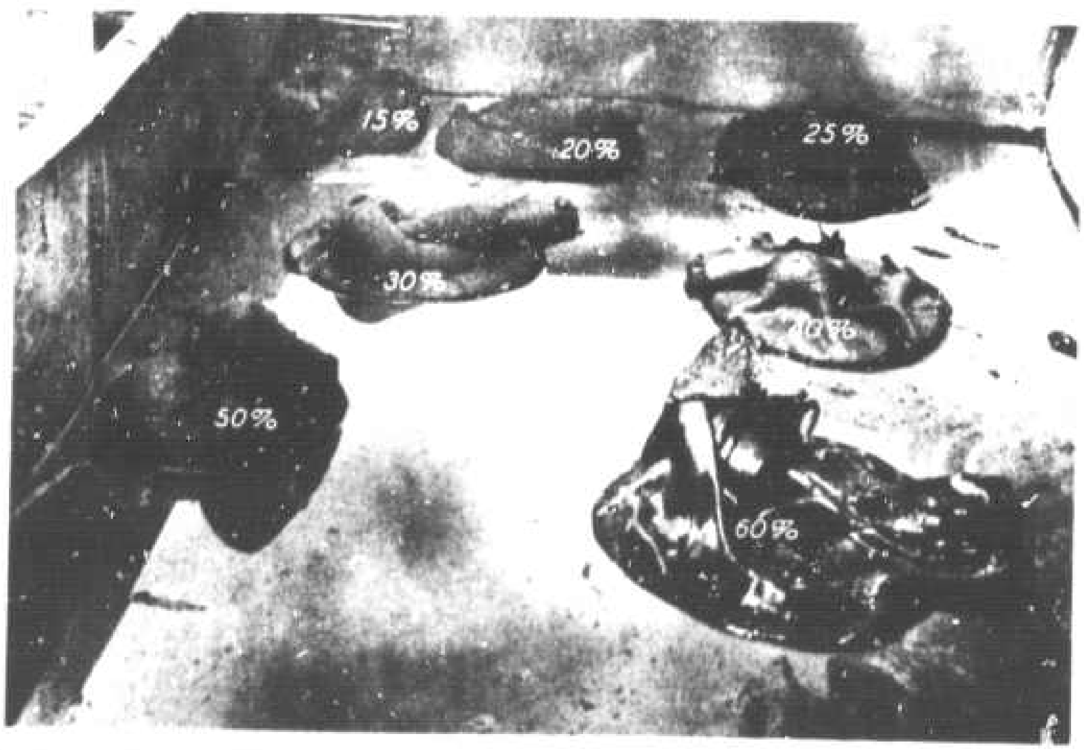
Photograph 10. Mixes of fine sand aggregate and 85-100 penetration asphalt cement in percentages noted, slumped under water. Placed at 200 F

Photograph 11. Mixes of fine sand aggregate and 85-100 penetration asphalt cement in percentages noted, slumped under water. Placed at 425 F

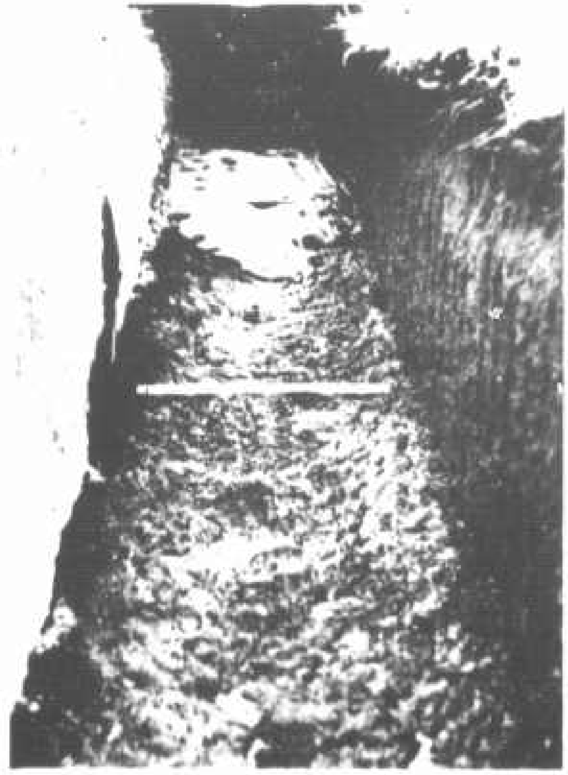


Photograph 12. Mixes of fine sand aggregate and 200-300 penetration asphalt cement in percentages noted, slumped under water. Placed at 300 F

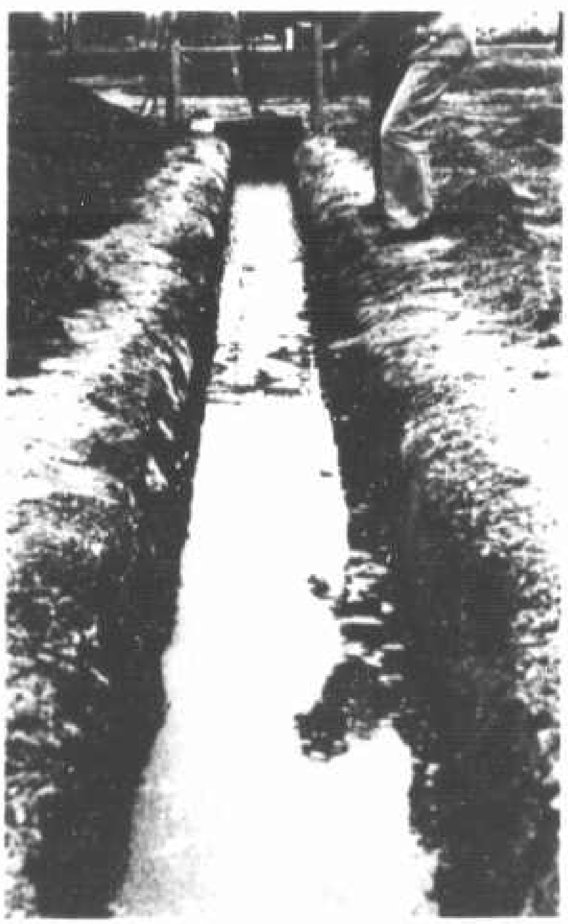
Photograph 13. Mixes of coarse sand aggregate and 50-60 penetration asphalt cement in percentages noted, slumped under water. Placed at 300 F



Photograph 14. Mixes of coarse sand aggregate and roofing asphalt (180-200 softening point) in percentages noted, slumped under water. Placed at 300 F



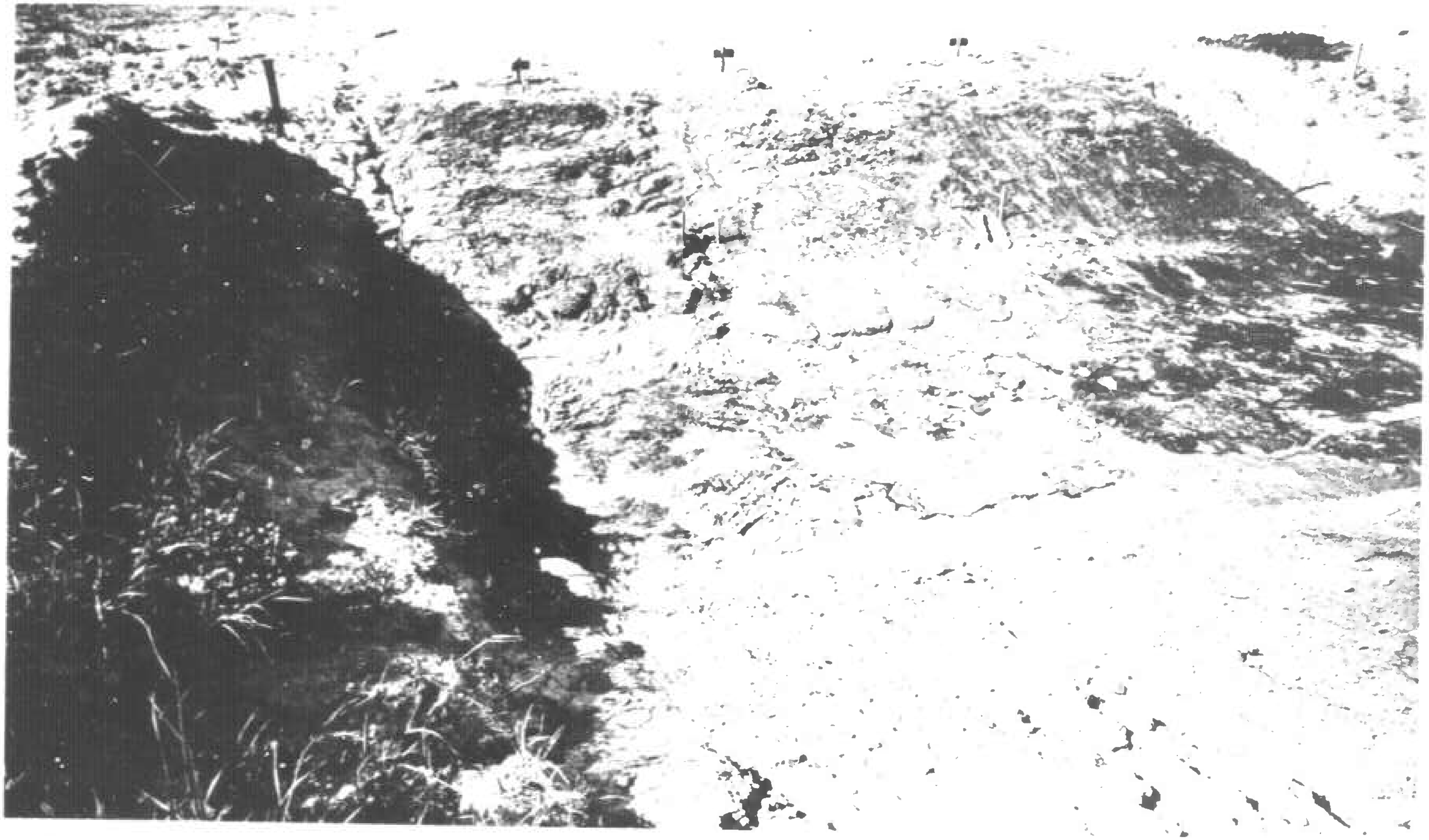
Photograph 15. Sand-asphalt mixture placed in ditch which was partially filled with water. Mixture contained 20 per cent of 85-100 penetration asphalt cement and fine sand aggregate



Photograph 16. Sand-asphalt mixture being placed in ditch partially filled with water; mixture is released from the reservoir at upper end of ditch. This mixture contains 50 per cent of 85-100 penetration asphalt cement and fine sand aggregate. Note partial flotation of mixture

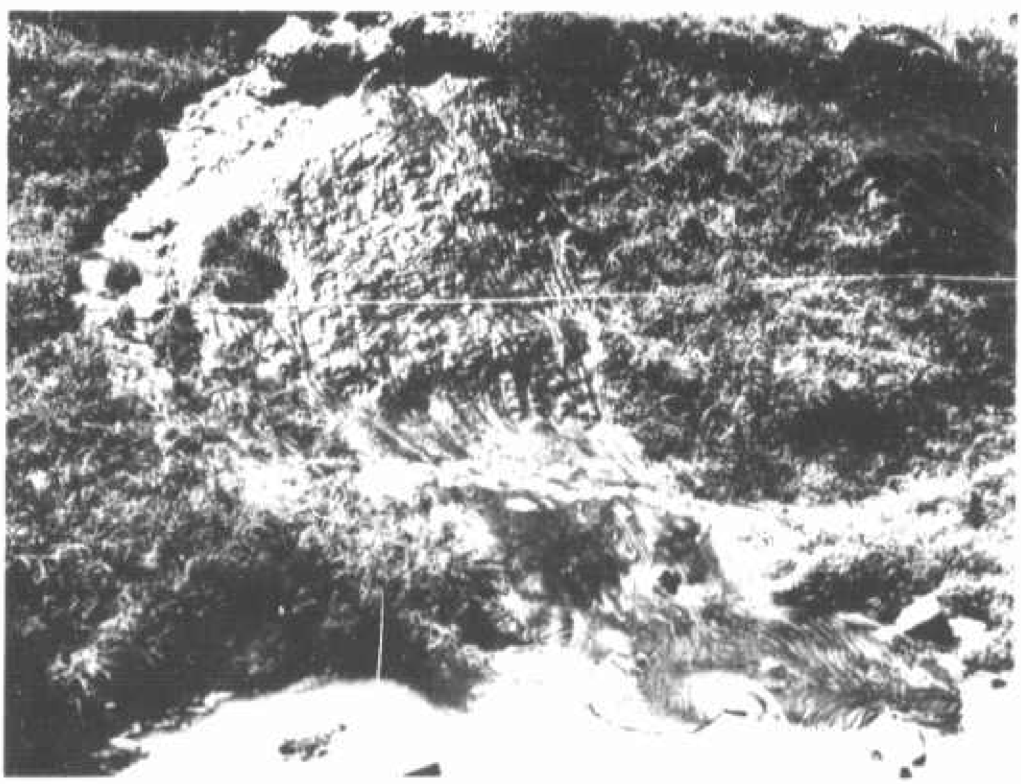
Photograph 17. Sand-asphalt mixture placed in ditch partially filled with water. Mixture contained 80 per cent of 85-100 penetration asphalt cement and fine sand aggregate. Note flotation of mixture

Photograph 18. Sand-asphalt mixtures prepared in the usual manner and dumped from truck onto sloped bank of pit filled with water. The four mixtures, from left to right, contain 30, 25, 20, and 15 per cent, respectively, of 85-100 penetration asphalt cement. Mixing temperature was 280 F



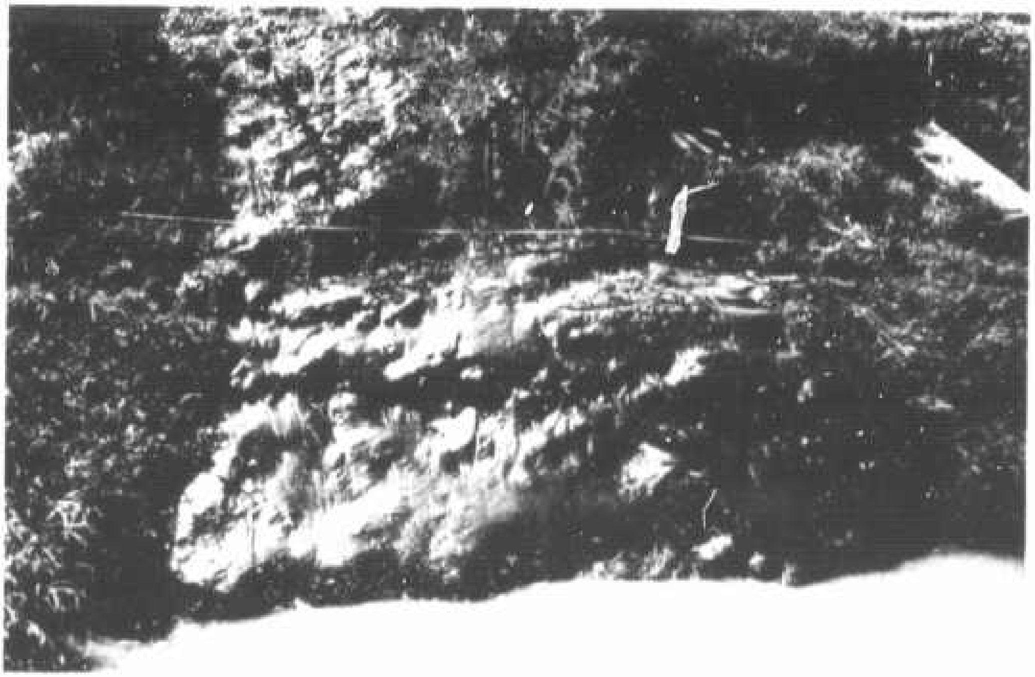
Photograph 19. Sand-asphalt mixtures prepared by a patented process, including fuel oil additive, and dumped from truck onto sloped bank of pit filled with water. The three mixtures which can be distinguished in the photograph contain, from left to right, 20, 25, and 30 per cent asphalt cement, respectively. Mixing temperature was 250 F

Photograph 20. Sand-asphalt mixtures dumped on creek bank and into flowing water. Mixtures from left to right contain 25, 30, and 40 per cent 85-100 penetration asphalt cement, respectively. The 25 per cent mixture is only partially visible at upper end of string line which indicates water elevation during placement

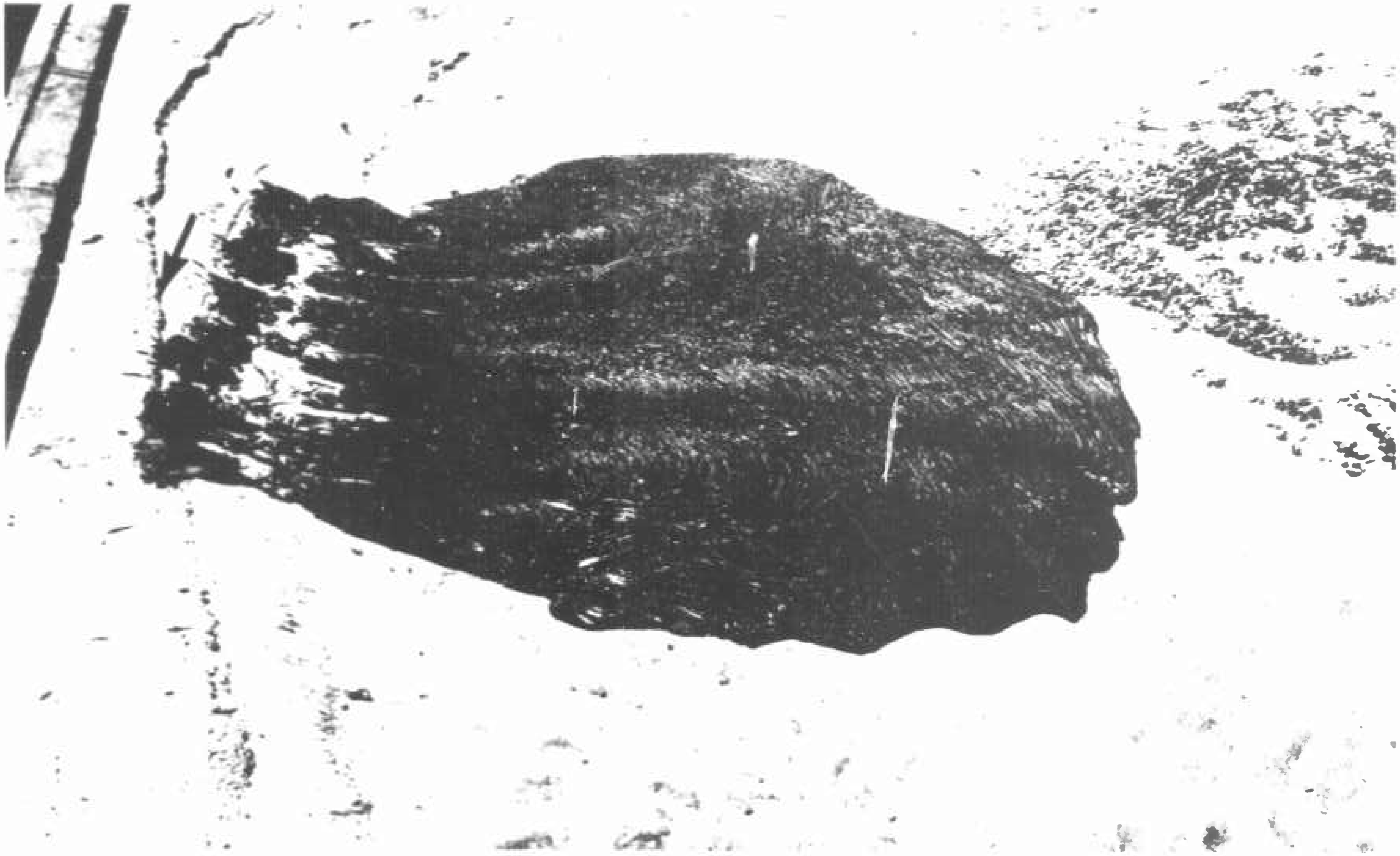


Photograph 21. Close-up of 25 per cent mix noted in photograph 20 shortly after placement

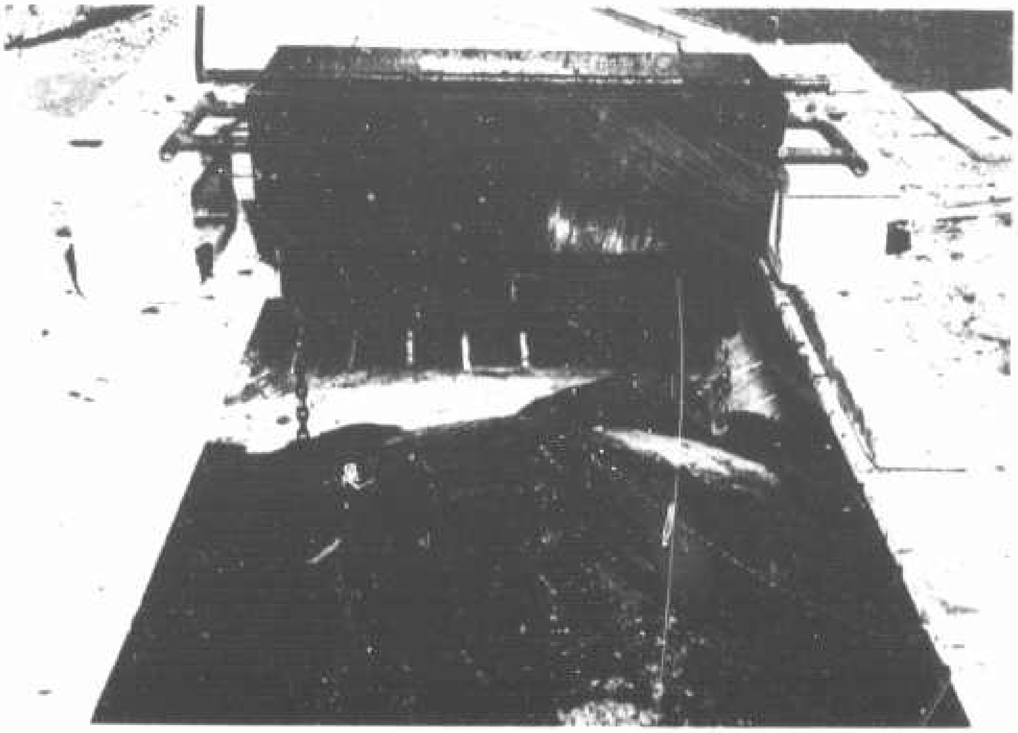
Photograph 22. Close-up of 30 per cent mix noted in photograph 20 shortly after placement. String line indicates water elevation during placement



Photograph 23. Close-up of 40 per cent mix noted in photograph 20 shortly after placement

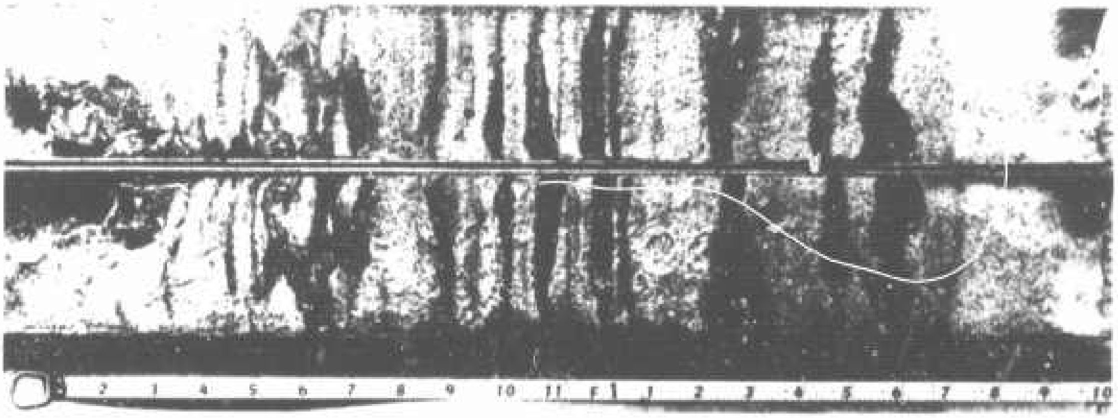


Photograph 24. Sand-asphalt mixture dumped into moving water in hydraulic model. The point of dumping and the water level during dumping are indicated by arrow. The mix contains 25 per cent asphalt cement

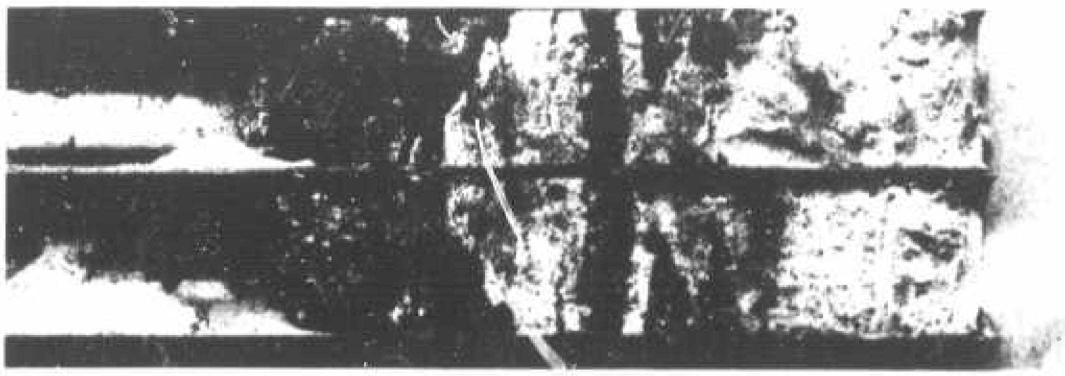


Photograph 25. Two-compartment metal box used for making laminated dumps of sand and rich sand-asphalt in moving water. Water flowed from rear to front in making the dump. View shows upper portion of laminated dike

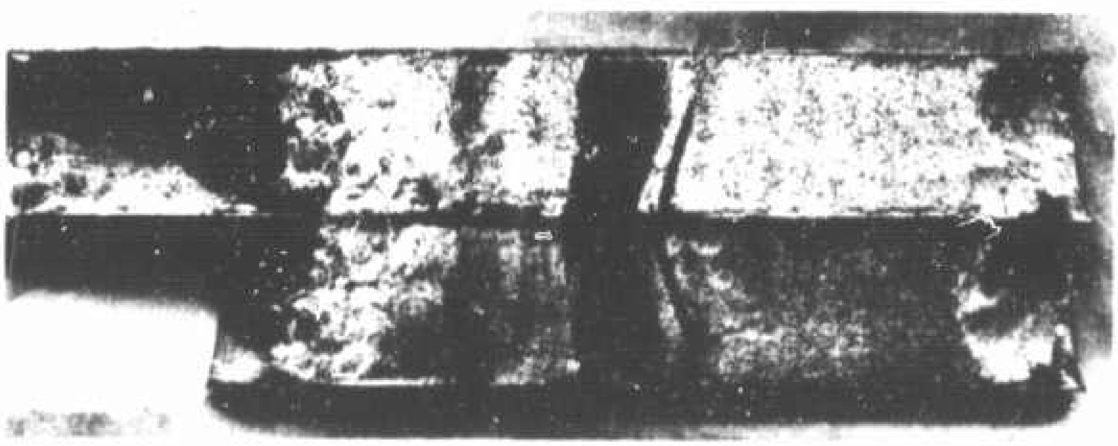
Photograph 26. Completed laminated dike partially shown in photograph 25



a. Core of dike

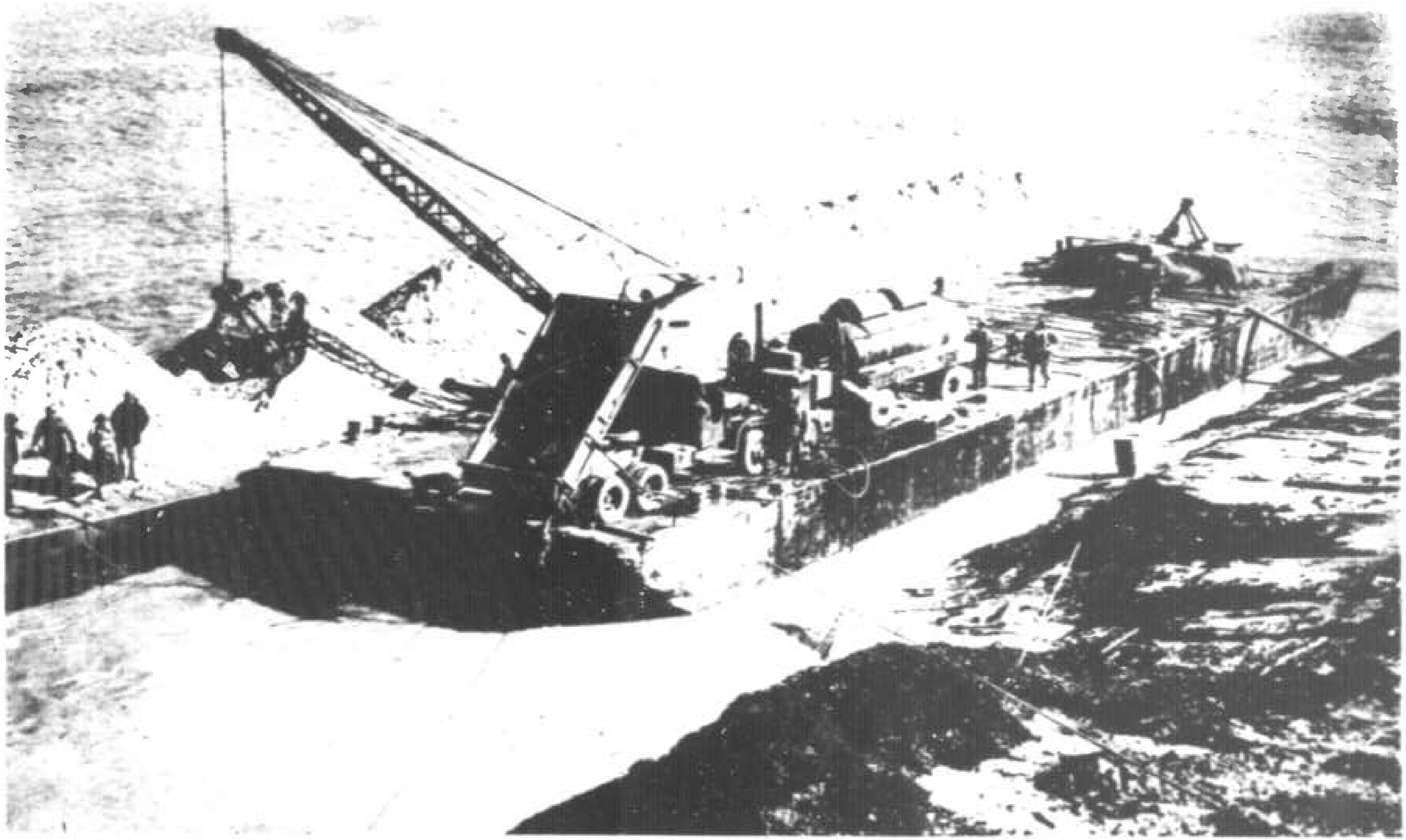


b. Downstream apron

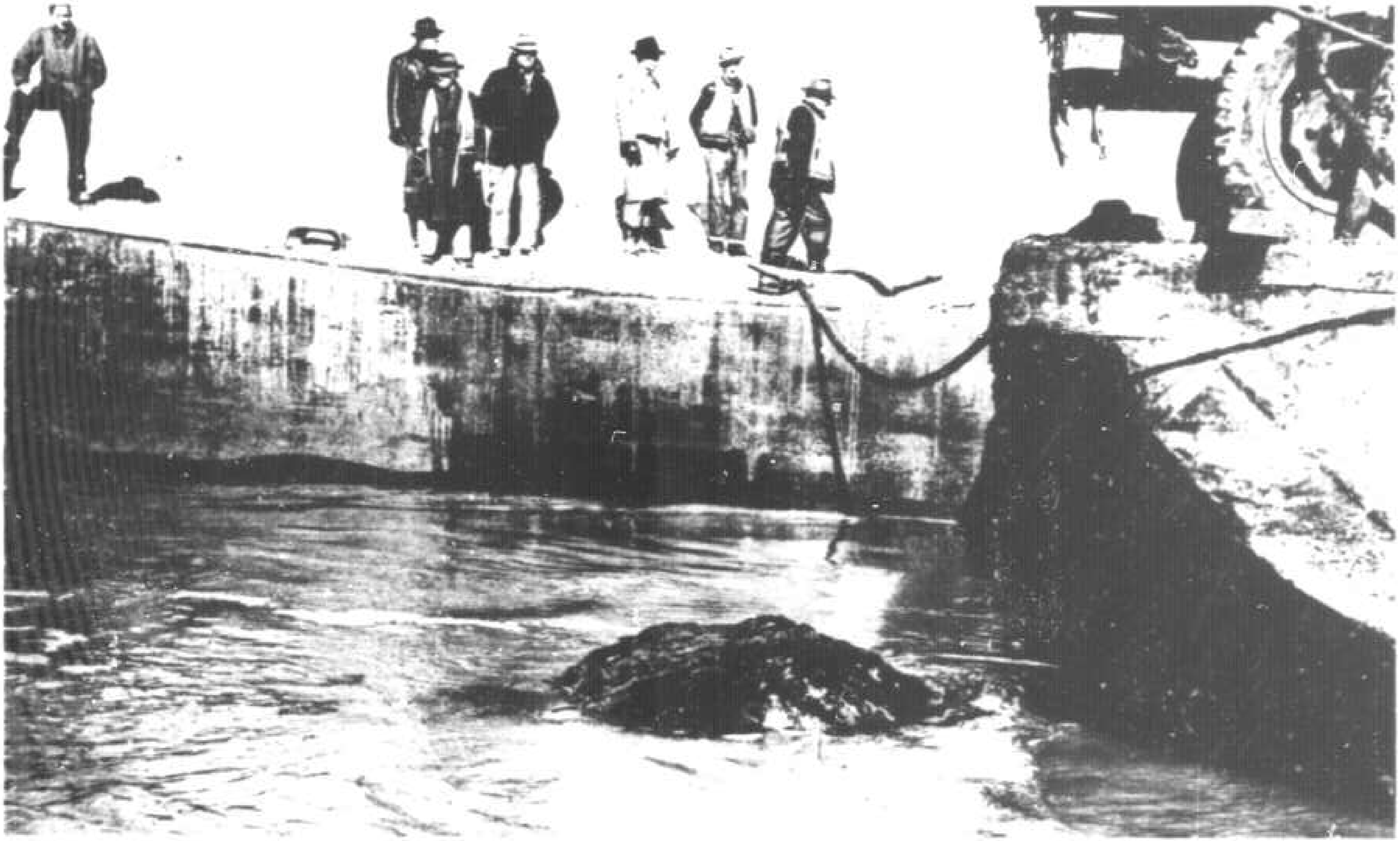


c. Riverside apron

Photograph 27. Split-core samples of dike illustrated in photograph 26. Tops of samples on left, clean sand from stream bed on right

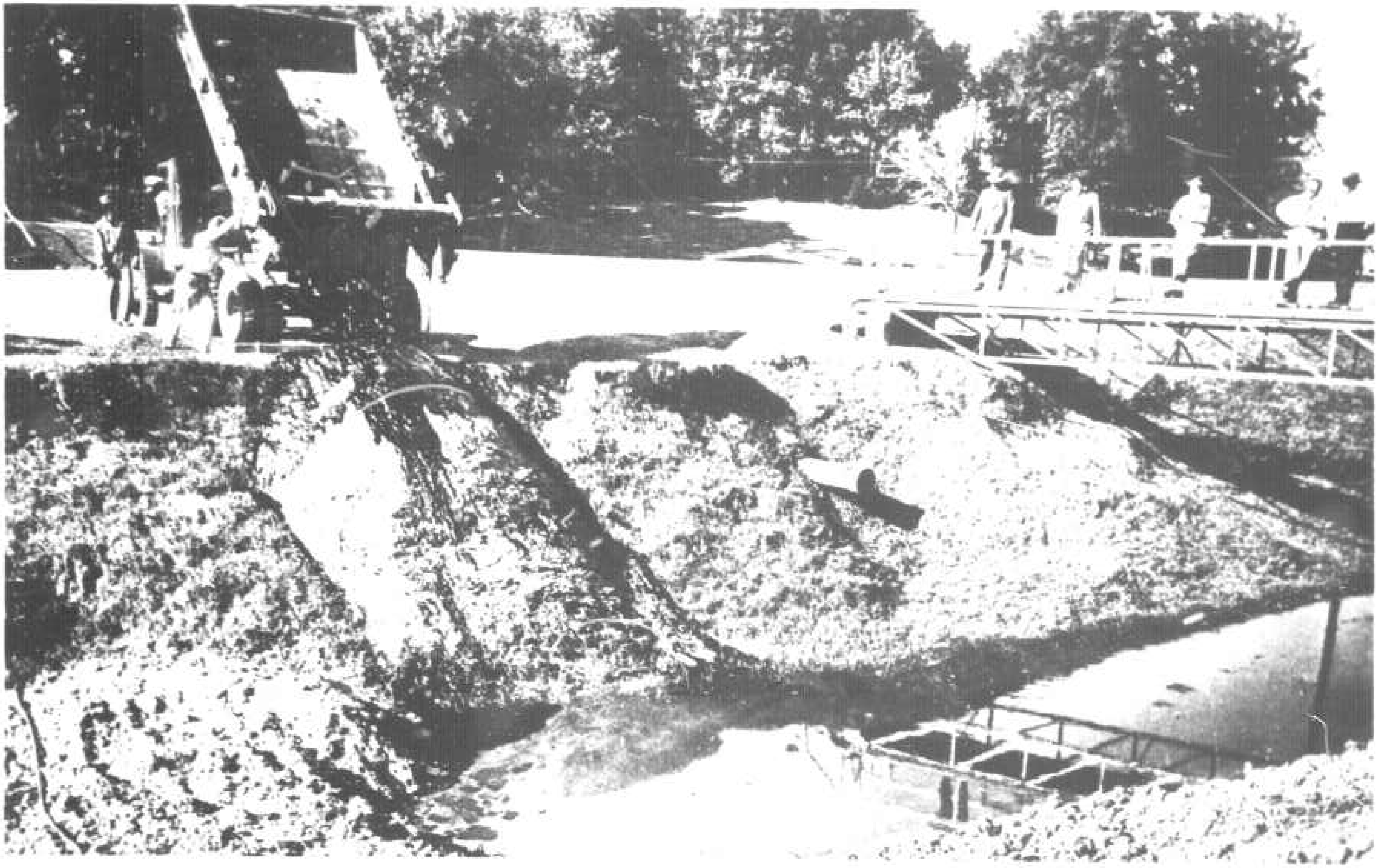


Photograph 28. Construction of laminated dike near upper end of False Point revetment on the Mississippi River. Dumps were made from trucks containing separate compartment for mastic

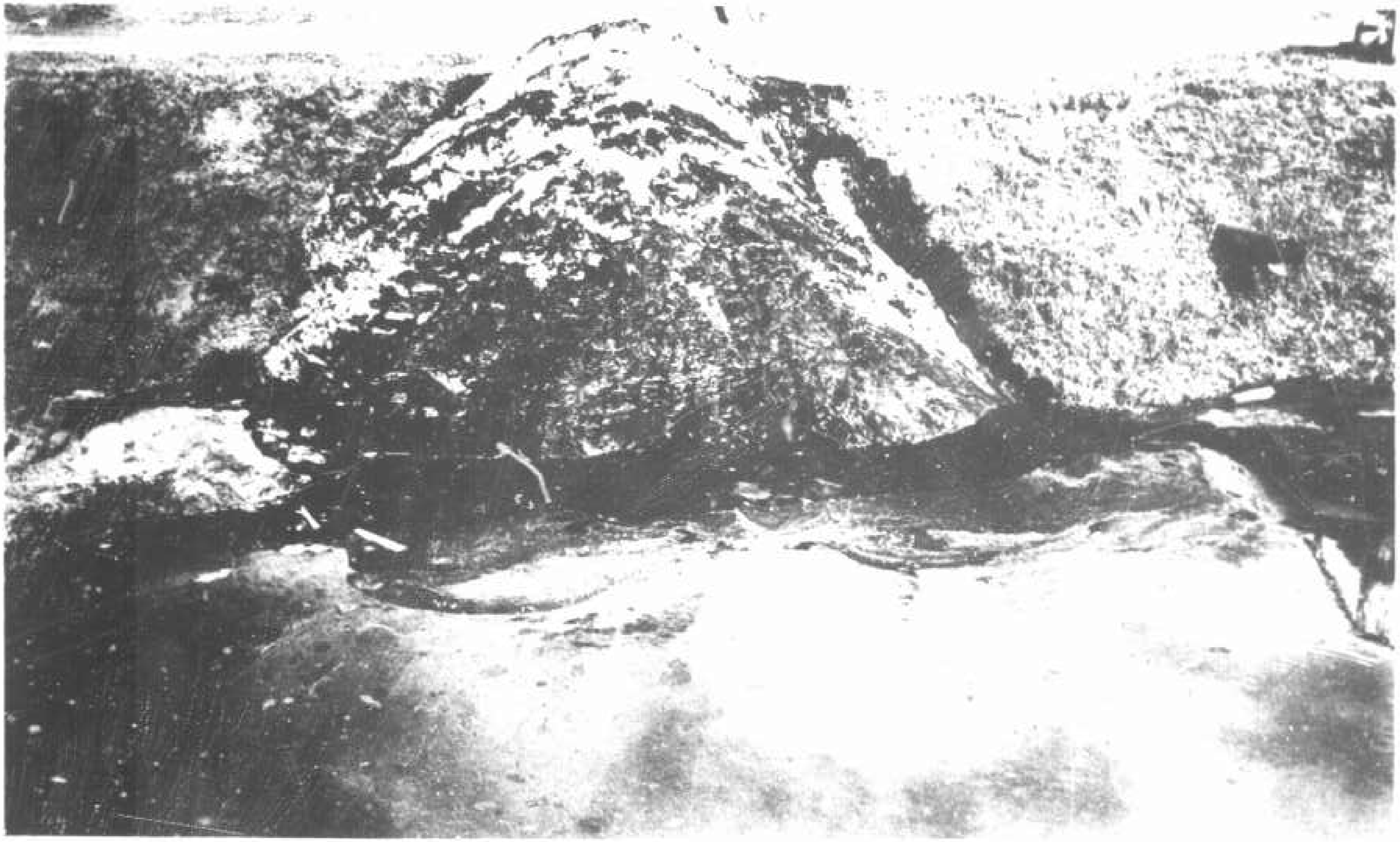


Photograph 29. Construction of laminated dike near upper end of False Point revetment on the Mississippi River. The dike is just visible above the water line

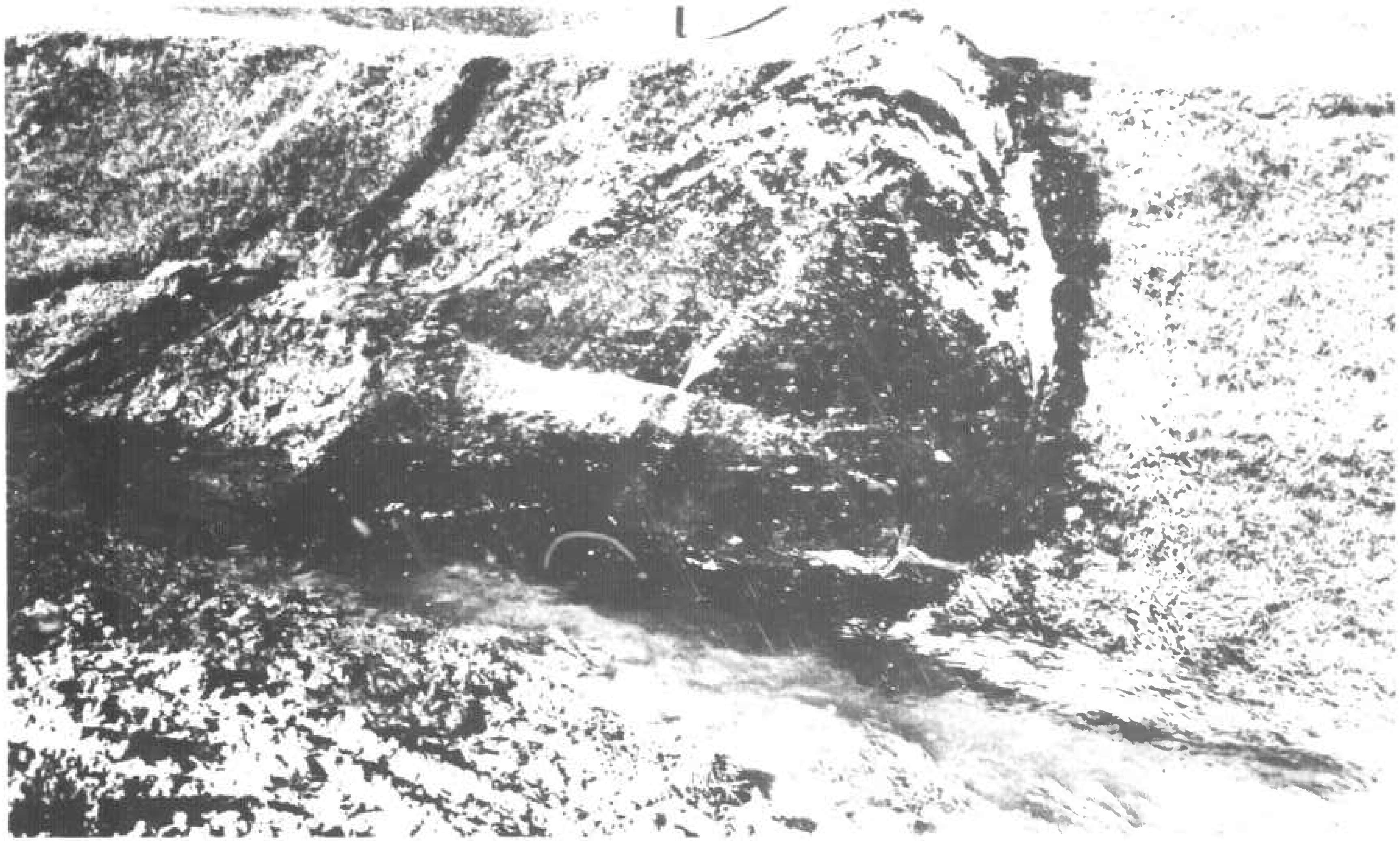
Photograph 30. Layout and placement procedure for laminated dike experiment on creek bank



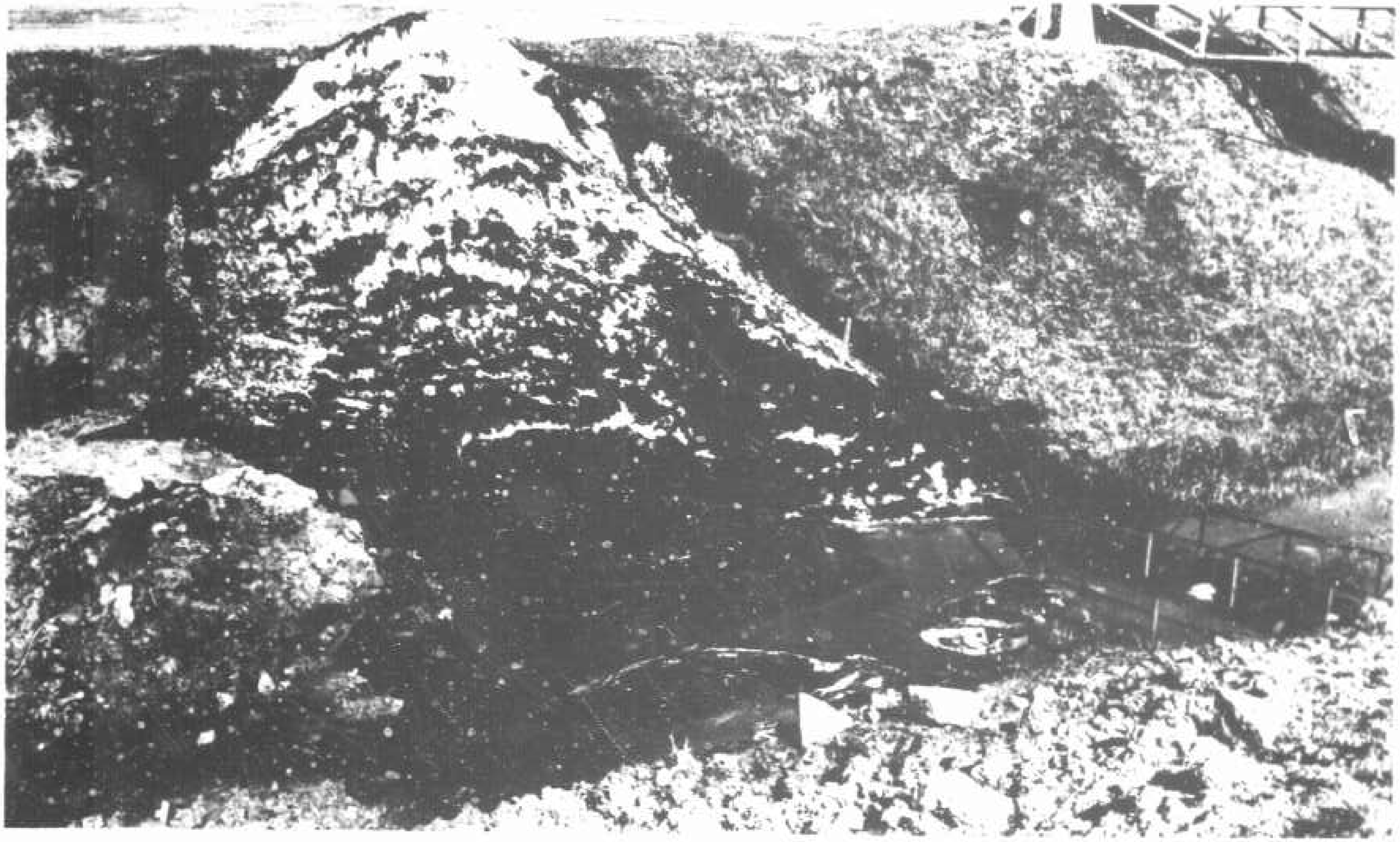
Photograph 31. Partially completed laminated dike. Note difficulty in covering sand with asphalt membrane



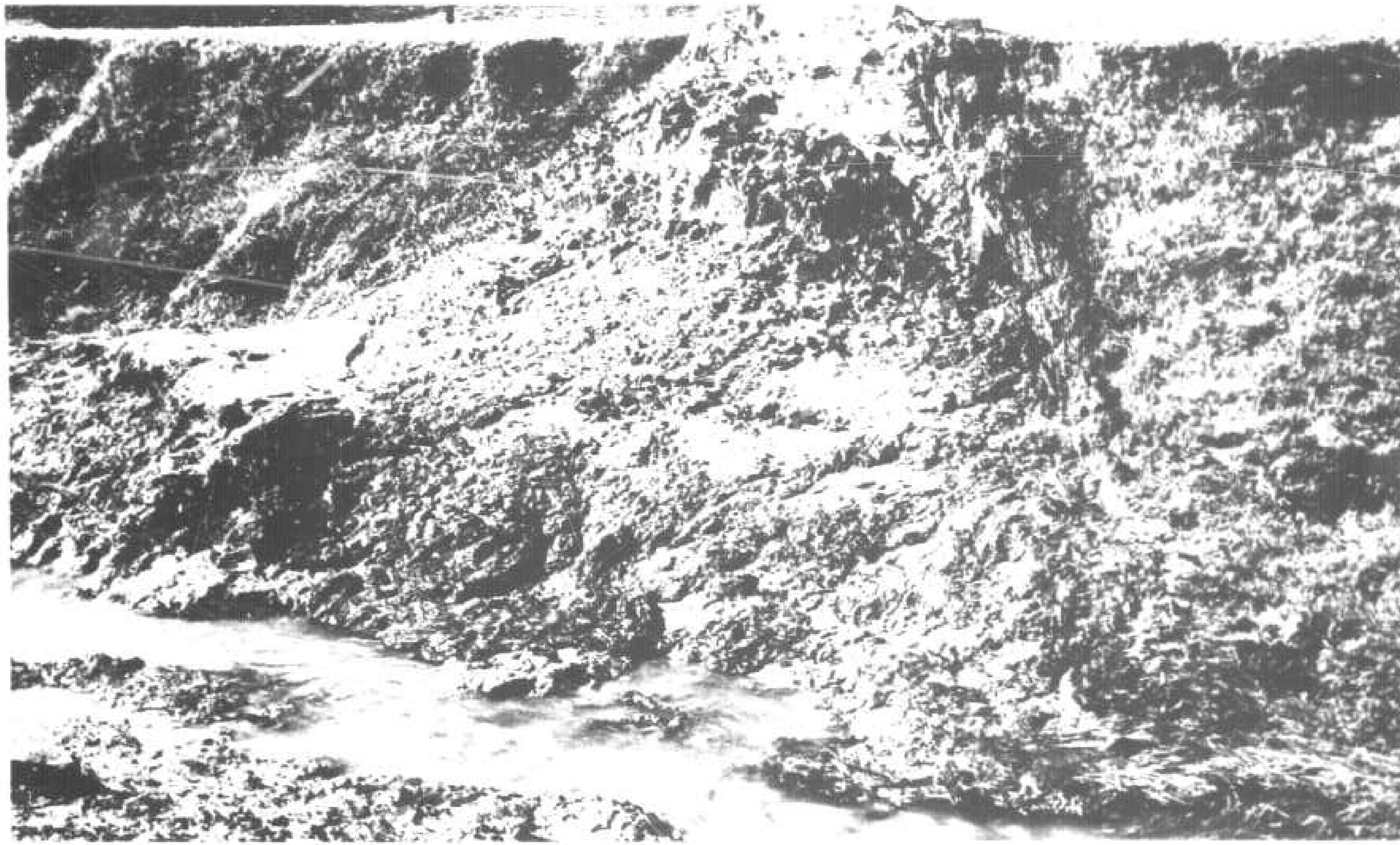
Photograph 32. Completed laminated dike in creek 12 hours after placement. Note sloughing and broken seal at top. Asphalt on the water floated during placement



Photograph 33. Appearance of laminated dike after rapid drawdown of pool of water. Maximum elevation of water indicated by arrow

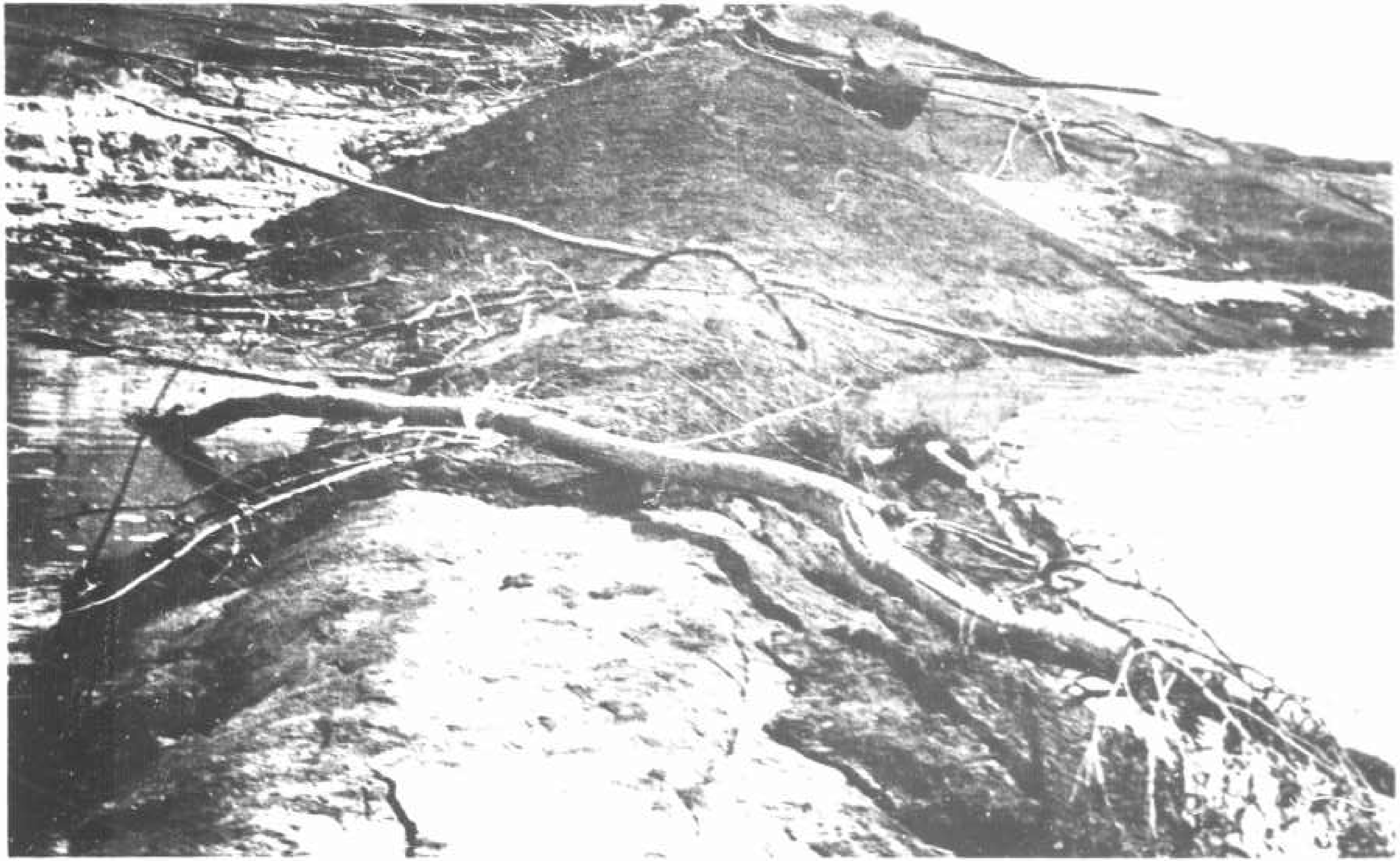


Photograph 34. Condition of laminated dike after exposure to sunshine for five days. Note asphalt apron across channel, partly exposed

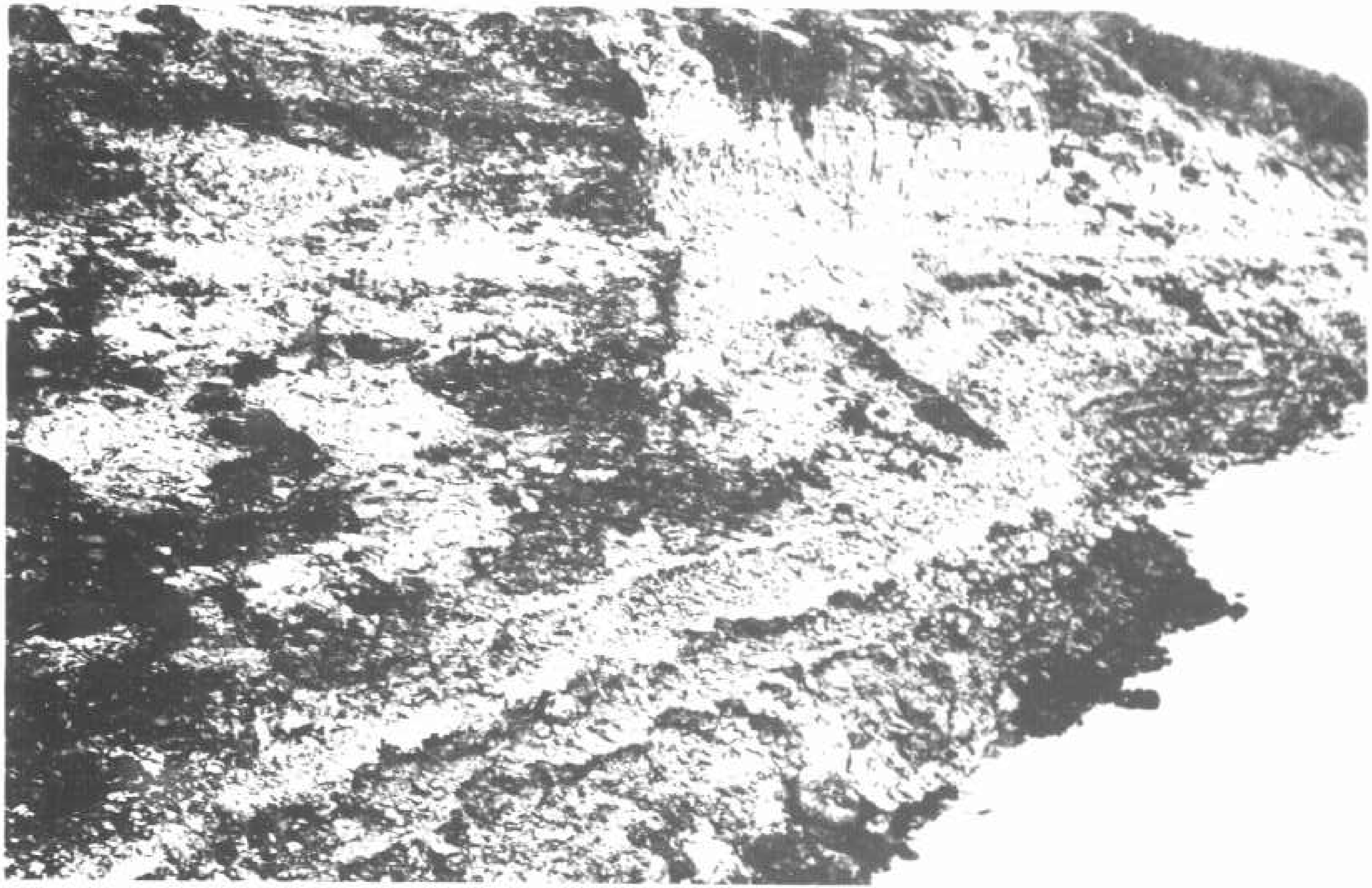


Photograph 35. Laminated dike in creek after attack by overflow current. Note disappearance of asphalt apron across creek channel

Photograph 36. Low-water view of asphalt dike or groin placed near the lower end of existing revetment at Fitler Bend, Mississippi River. Dike was constructed during high water

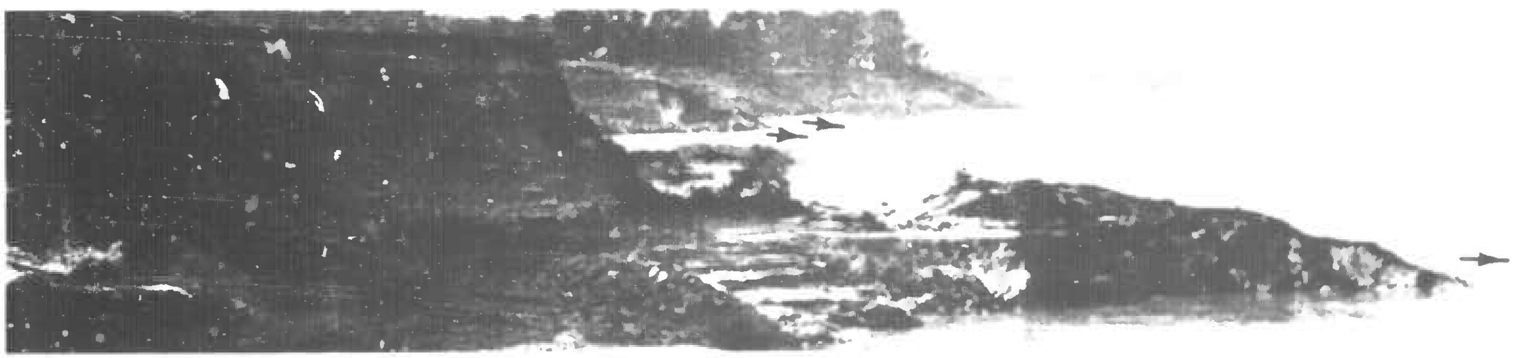


Photograph 37. Close-up of lower tier of Fitler dike. Note displaced seal coat and cracks in core

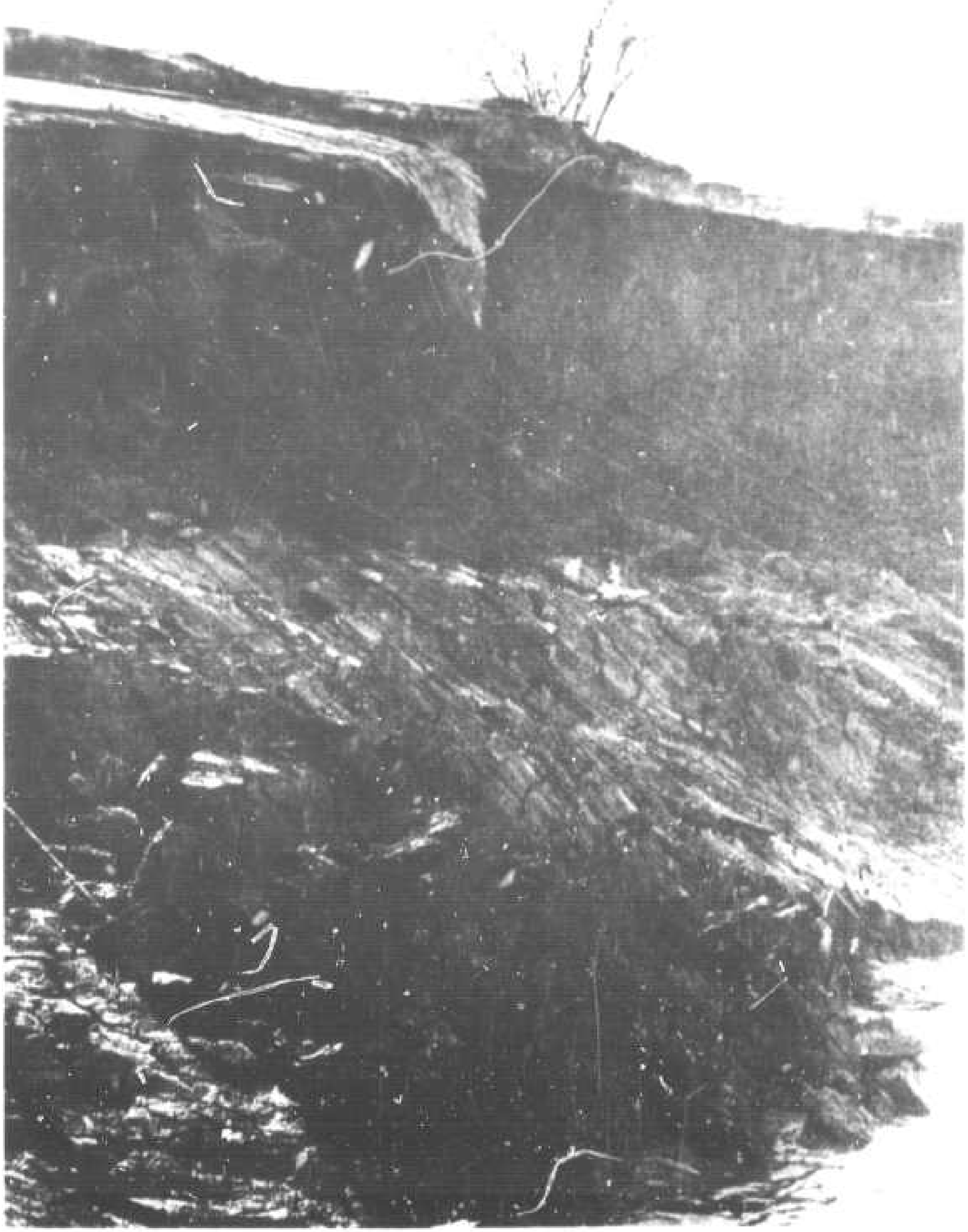


Photograph 38. Low-water view of dump made during high water at Natchez Island Chute, Mississippi River, showing at left, a partial coverage of a hot sand-asphalt mix containing 20 per cent asphalt cement

Photograph 39. Sand-asphalt spur dikes (arrows) placed under water on unrevetted bank at upper end of False Point revetment in 1948 and rehabilitated by mass underwater placement of 20% asphalt cement mixture in 1949

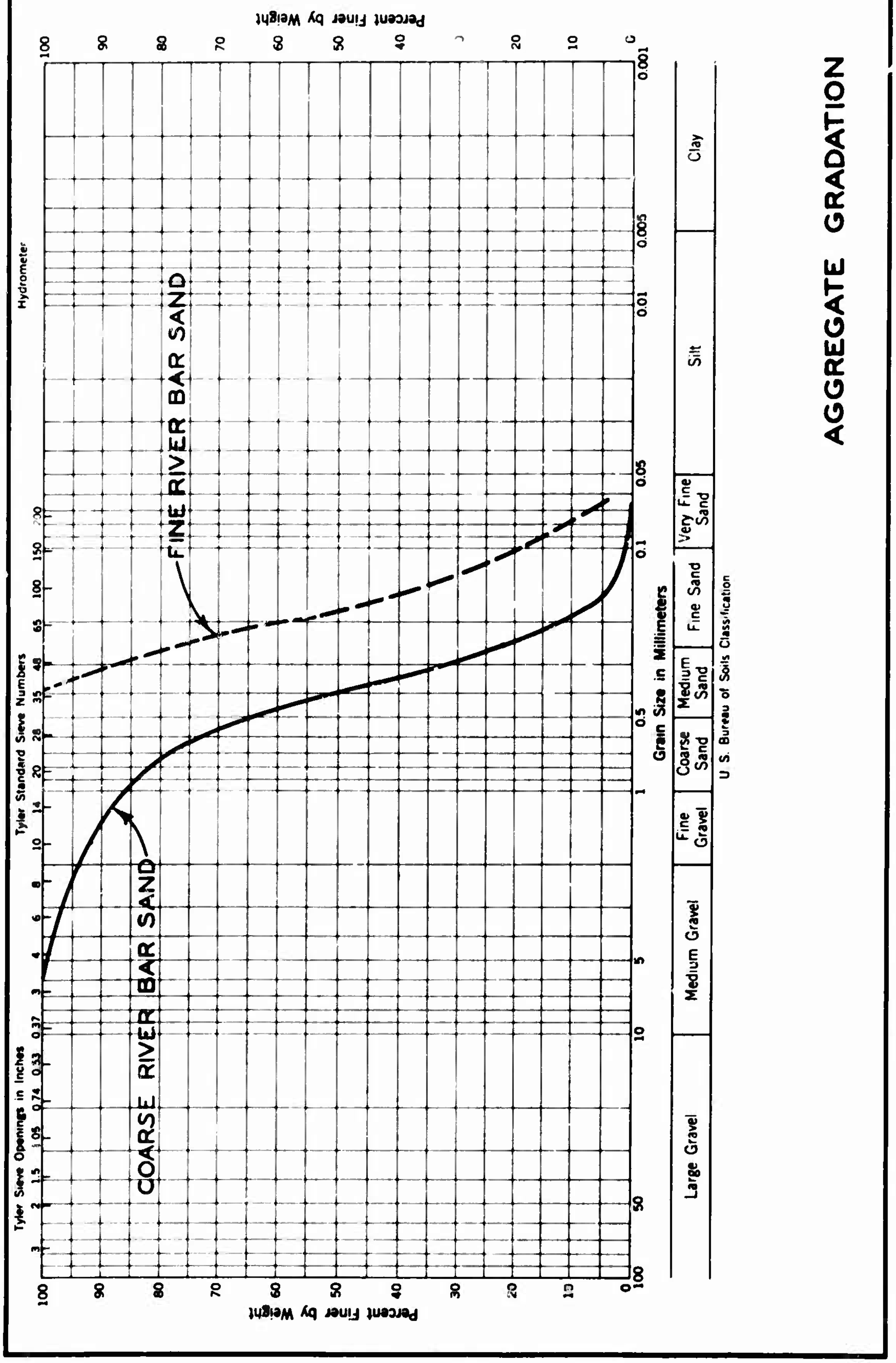


Photograph 40. Condition in 1950 of banks adjacent to dikes shown in photograph 39 with failed area of revetment in foreground



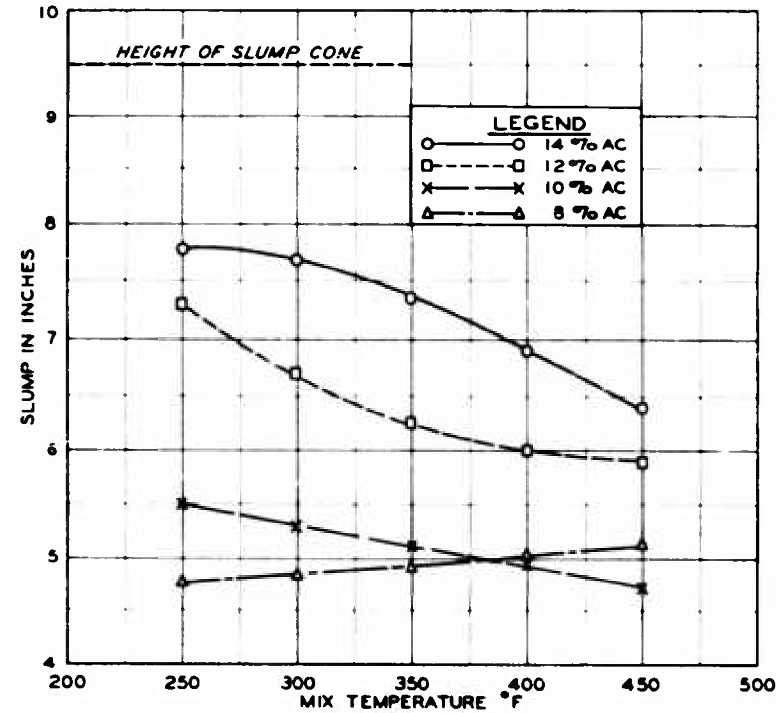
Photograph 41. Close-up of failed area at upstream end of False Point revetment in 1950

PLATES

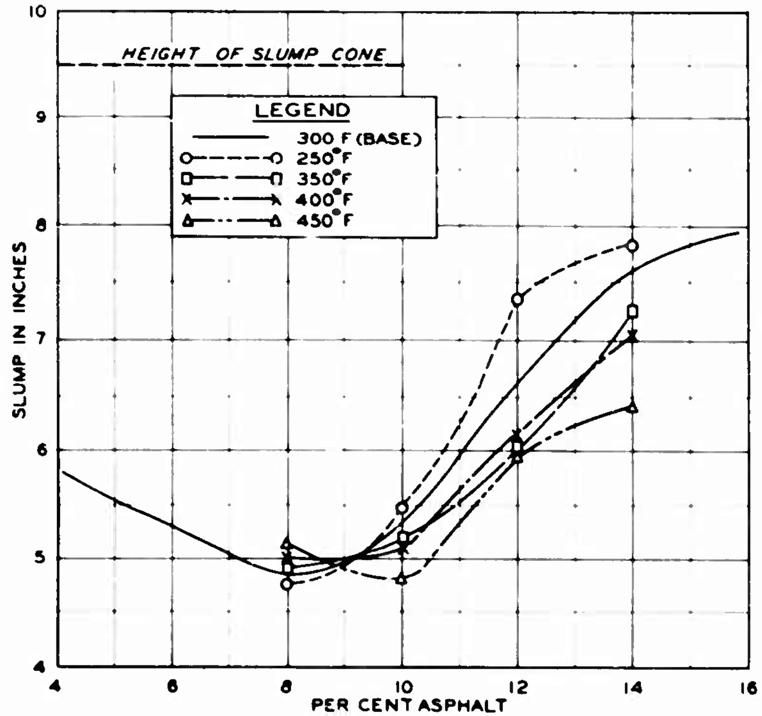


AGGREGATE GRADATION

PLATE I



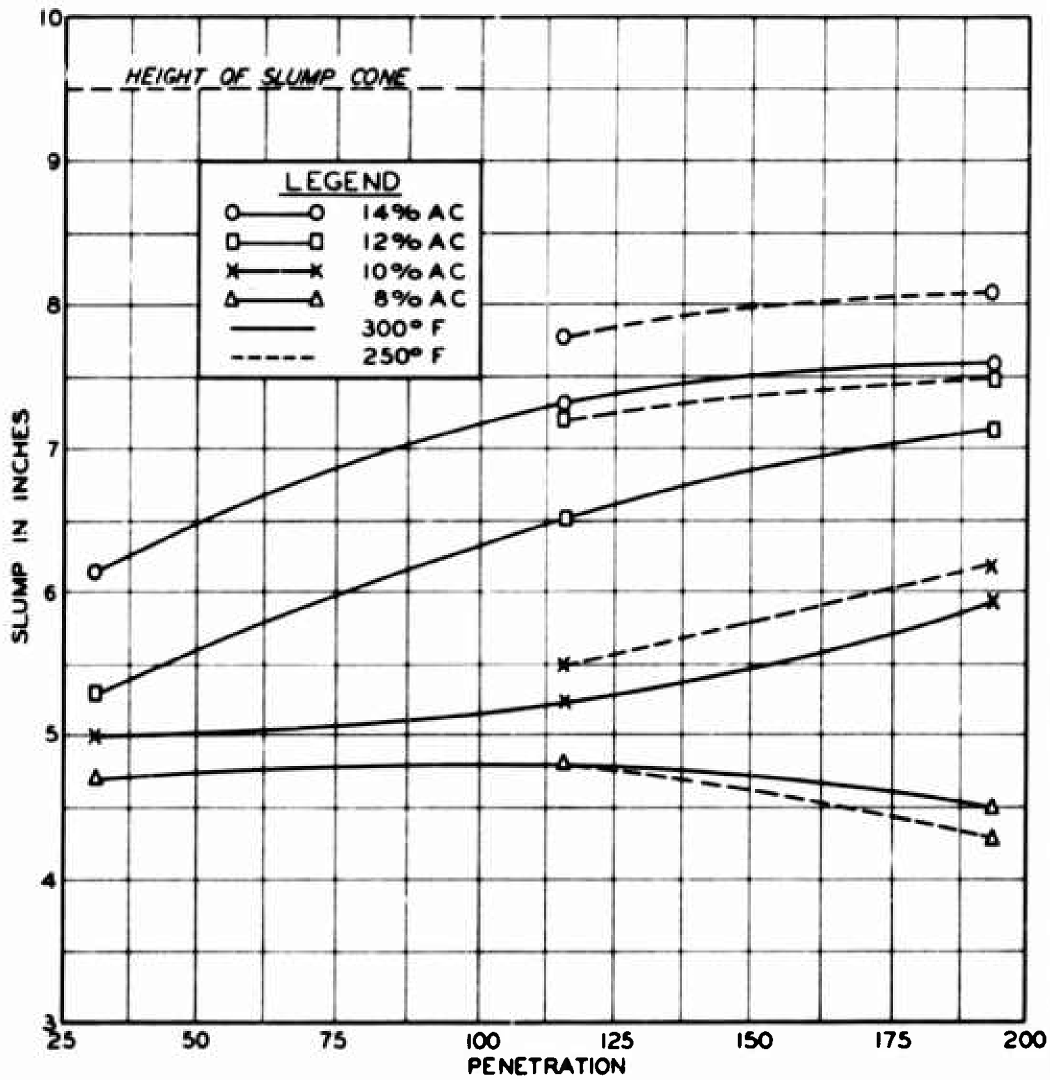
MIX TEMPERATURE VS SLUMP



ASPHALT CONTENT VS SLUMP

EFFECT OF HEAT AND ASPHALT CONTENT
ON FLUIDITY OF SAND ASPHALT IN AIR

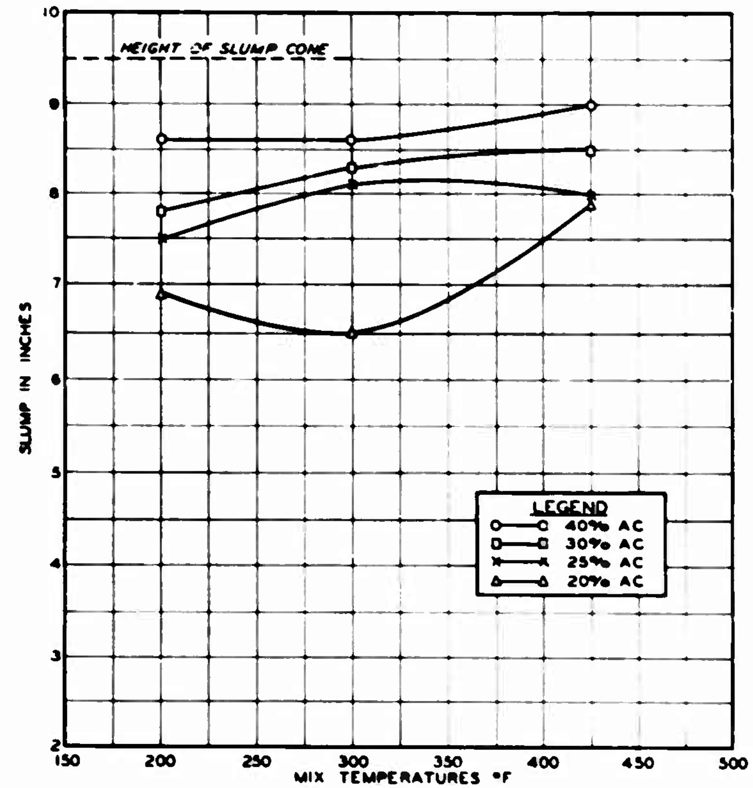
PLATE 2



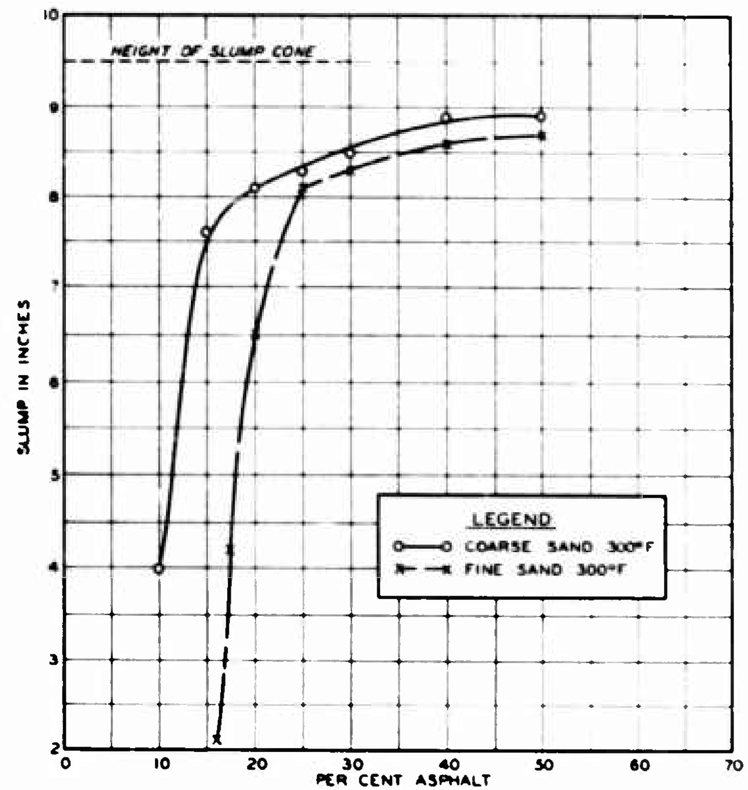
EFFECT OF PENETRATION GRADE ON SLUMP IN AIR

COARSE SAND AGGREGATE

PLATE 3



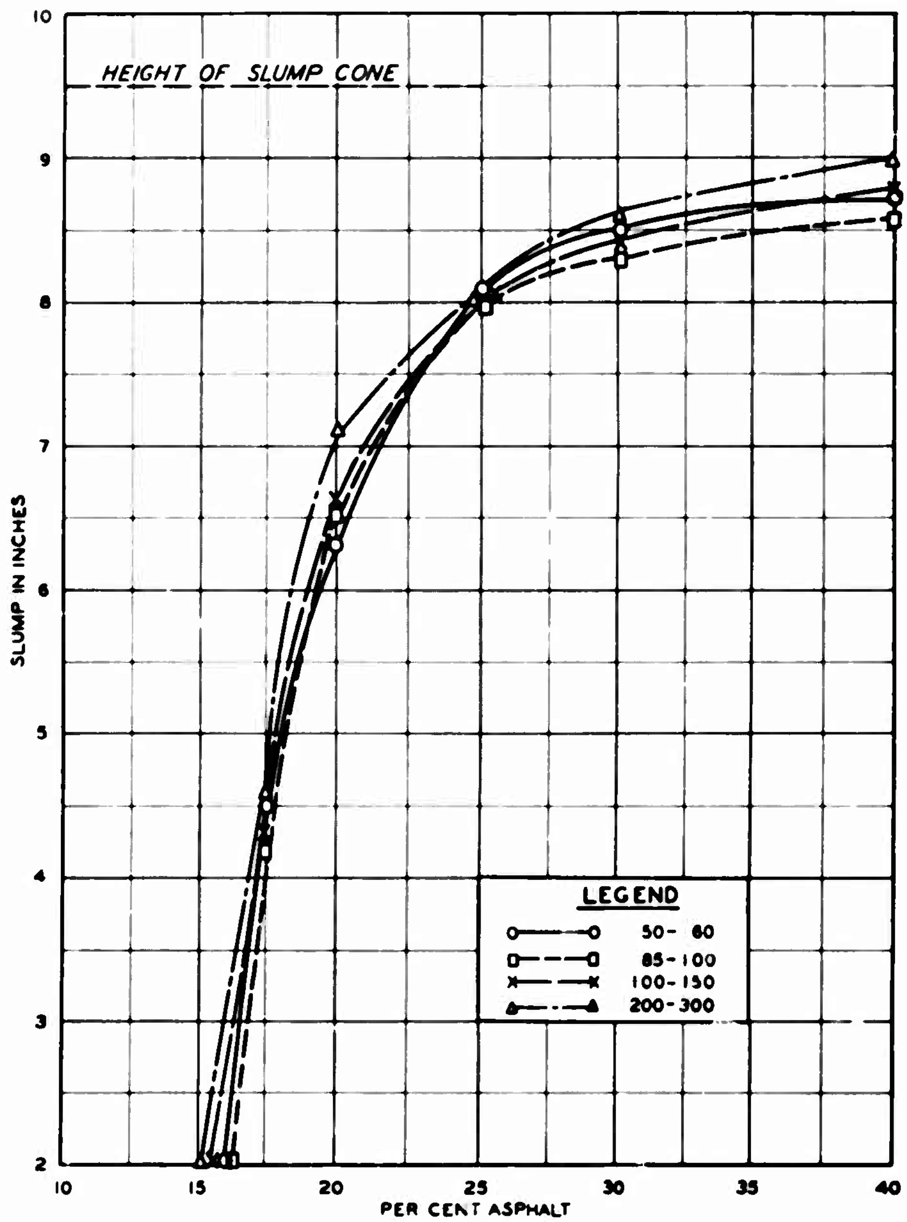
MIX TEMPERATURES VS SLUMP
FINE SAND AGGREGATE



ASPHALT CONTENT AND AGGREGATE GRADATION VS SLUMP

EFFECT OF HEAT, ASPHALT CONTENT
AND AGGREGATE GRADATION
ON SLUMP UNDERWATER
(SIMULATED BARGE DUMPING)

PLATE 4



EFFECT OF PENETRATION GRADE ON SLUMP UNDERWATER

FINE SAND AGGREGATE

PLATE 5