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STABILIZATION OF IOWA SOILS WITH CUTBACK ASPHALT

by

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The Requirements for the Degree of
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Approved:

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Dean of Graduate College

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INTRODUCTION

Soil stabilization may be broadly defined as any regulated process that alters or controls soil properties for the purpose of improving the capacity of soil to perform and sustain an intended function. Processes by which soils may be stabilized include the use of other soil or chemical additives or cements, compaction, moisture control or combinations of these. Asphalt is one of the cements used in soil stabilization for base or subbase courses of pavements.

Asphalt is a petroleum product, and most commercial asphalts are residues from crude oil after partial removal of volatile constituents by fractional distillation. Asphalt also occurs naturally in asphalt lakes or "tar" pits and in mineral seams. Pfeiffer (49) describes asphalt as a dark, highly viscous to almost solid substance, consisting of hydrocarbons and derivatives in four basic forms: (a) saturated aliphatic groups, (b) naphthenic groups, (c) groups composed of aromatic rings and (d) aliphatic groups with olefinic double bonds. Each group is represented by a large number of different structures and molecular weights.

Asphalt Cement, commonly used in road work, is usually classified according to its consistency as measured by the penetration of a standard needle (ASTM designation: D5-49) (3). Because of their relatively high viscosity, asphalt cements as such are seldom used in soil stabilization. Use of an asphalt cement normally requires preheating of both the asphalt and the aggregate, adding considerably to the cost of processing. Such processing is of course used in preparation of higher types of mixes such as asphaltic concrete. Recent research by Csanyi and co-workers (17, 18) has demonstrated the feasibility of using asphalt cement in soil stabilization.

Two types of asphalts at normal or slightly elevated temperatures are suitable for mixing with soil; these are the cutbacks and the emulsions. In cutbacks, the viscosity of the asphalt cement is lowered by use of a solvent such as naptha, kerosene or fuel oil. In the usual emulsions, asphalt cement is reduced to colloidal size droplets and dispersed in water. Use of emulsions with soils is complicated by the fact that clays or fine silts may cause the emulsions to "break" or separate into the constituent asphalt cement and water. This causes mixing difficulties. But excellent results have been reported when the emulsions can be maintained until after mixing. The usual construction procedure is to mix, then allow the emulsion to break, and aerate to reduce water in the mix prior to compaction. Usually the emulsion must be designed for the soil used.

At present, cutbacks are the most practical asphalts for soil stabilization. So-called road oils are equivalent to cutbacks made with slowly volatile fuel oil. For economic reasons, the road oils are usually prepared as direct residuals from fractional distillation, and they are the lowest cost asphalts. Because of their slow-curing characteristics, road oils are not the most suitable for the stabilization of soil mixes; however, they have been used for many years as surface treatments to reduce dust on gravel roads. Road oils can penetrate some soils, and continued annual treatment may build up a satisfactory stabilized mat on a light traffic road after four or five years. Treatment with road oil has the disadvantage that roads must be closed to traffic for long periods after treatment.

Medium-curing cutbacks (called MC) and rapid-curing cutbacks (RC) seem to be suitable types of liquid asphalt for soil stabilization. Different grades of cutbacks are designated from 0 to 5, depending on the percent solvent contained. MC-0 and RC-0 each contain about 50% solvent, and the percentage decreases to about 18% solvent for MC-5 and RC-5. RC cutbacks, in addition to having a more volatile solvent, are made up with a harder asphaltic cement, contributing to better binding in the finally compacted and cured mix. The choice between MC and RC will depend largely on climate, soil type, and construction practice. Cutbacks cure by an evaporation of volatiles. RC cutbacks especially the higher grades may harden before mixing is completed; lower grades contain more solvent and cure more slowly.

The choice of grade of MC or RC depends on mixing conditions, usually the more solvent the greater ease of mixing. Solvents cost about the same as the asphalt and do not directly contribute to strength. The use of high solvent content cutback asphalts may greatly prolong the curing time. For these reasons MC-0 and RC-0 are little used, and MC-2 and 3 and RC-2 and 3 represent good compromises. The final choice can be made only after laboratory tests on the soil to be used and after due consideration of climatic conditions. Usually finer-grained soils require a lower viscosity cutback for mixing.

Asphalts are useful for soil stabilization because of their cementing and waterproofing qualities. The cementation property is generally considered to be most effective in providing increased stability in non-cohesive or very slightly cohesive granular soils, such as gravels and sands. The waterproofing property is utilized to greatest advantage in the more cohesive soils or soil-aggregate mixtures. Waterproofing assists in the preservation of the natural stability that these soils possess when in a dry and well compacted condition.

Of the theories that have been offered to explain the mechanism of asphalt soil stabilization (10, 12, 25, 37, 38), the "intimate mix" and "plug" theories of Endersby (25) seem to have gained widest recognition. Granular materials appear to best fit the "intimate mix" theory that particles are individually coated and stuck together. The theory does not apply to clay materials, where the fine size offers an immense surface area to be coated. Also, clays retain a natural cohesion and cannot be separated readily into individual particles. In a fine-grained soil, asphalt usually coats the soil in small aggregates or clods. The asphalt coats these clods and acts as a waterproofer by plugging voids. This is a modification of the "plug" theory. The plug theory does not appear to apply to purely granular soils.

To summarize the mechanisms: asphalt is mixed with granular soils to coat the grains and act as a waterproofer and binder. In clay-containing soils the clay is a natural binder as long as water is kept out; asphalt is added as a waterproofer for the small clay-cemented agglomerations.

The presence of water during the mixing and compaction phases of asphalt soil stabilization has long been recognized as an important factor. During mixing, water facilitates the even distribution of asphalt throughout the mass as shown by Cape (14). The amount of moisture required for thorough distribution of cutback asphalt apparently increases as the amount of fine material in the soil increases. Asphalt cement can be distributed if the amount of water used is enough to produce a slurry (56). This phenomenon has been used to develop a surface sealing material of soil and asphalt cement (2, 16). Hancock (30) has found the use of wetting agents improves the stability of cutback asphalt treated soils.

During the compaction phase the amount of water becomes important mainly because of its effect on density. Usually a soil-asphalt mixture is the strongest at its maximum density.

The amount of moisture required for maximum density of a soil-asphalt mixture is not the same as that for the soil alone.

The desirable moisture content of a soil-cutback asphalt mixture during mixing and during compaction are major factors which have not been investigated thoroughly. A literature review indicates that moisture content is a controversial subject to say the least (36). Moisture contents used in mixing asphalt with soil include: optimum moisture for maximum density of the soil, moisture content at the "fluff point"*, optimum moisture for maximum density of the soil minus cutback asphalt content and one-half optimum moisture for maximum density of the soil. Different concepts of the relation of cutback asphalt content to water content used vary from the belief that 2% cutback asphalt replaces 1% water to the belief that cutback asphalt and water have an equivalent lubricating effect on soil grains during compaction.

The effects due to asphalt volatiles during compaction of soil-asphalt mixtures are not clearly understood. The use of cutback asphalts as soil stabilizers dictates that a study of this variable be conducted. Usual practice includes a period of aeration between mixing and compaction of soil-cutback asphalt mixtures with a wide variance in the duration of the aeration. A reduction by aeration of the combined percentage of water and asphalt volatiles varies from one fifth

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*See review of literature.

to one half of the original content. The asphalt volatile loss is thought to be responsible for an increase in strength of the compacted material.

The foregoing discussion emphasizes the need of this investigation which, broadly stated, is to study and interpret the effects of water during mixing and during compaction and the effects of asphalt volatiles during compaction on the stabilization of soil with cutback asphalt. A complete understanding of the effects of these variables on a compacted mix should aid in arriving at a more intelligent and efficient design of soil-cutback asphalt mixtures than exists today.

REVIEW OF LITERATURE

The discovery and use of asphaltic materials no doubt goes back to primitive era. According to legend asphalt was used as a coating for the reed basket in which the infant King Sargon of Sumar was cast adrift on the floodwaters of the Euphrates River. This legendary tale corresponds closely to the Biblical story of Moses.

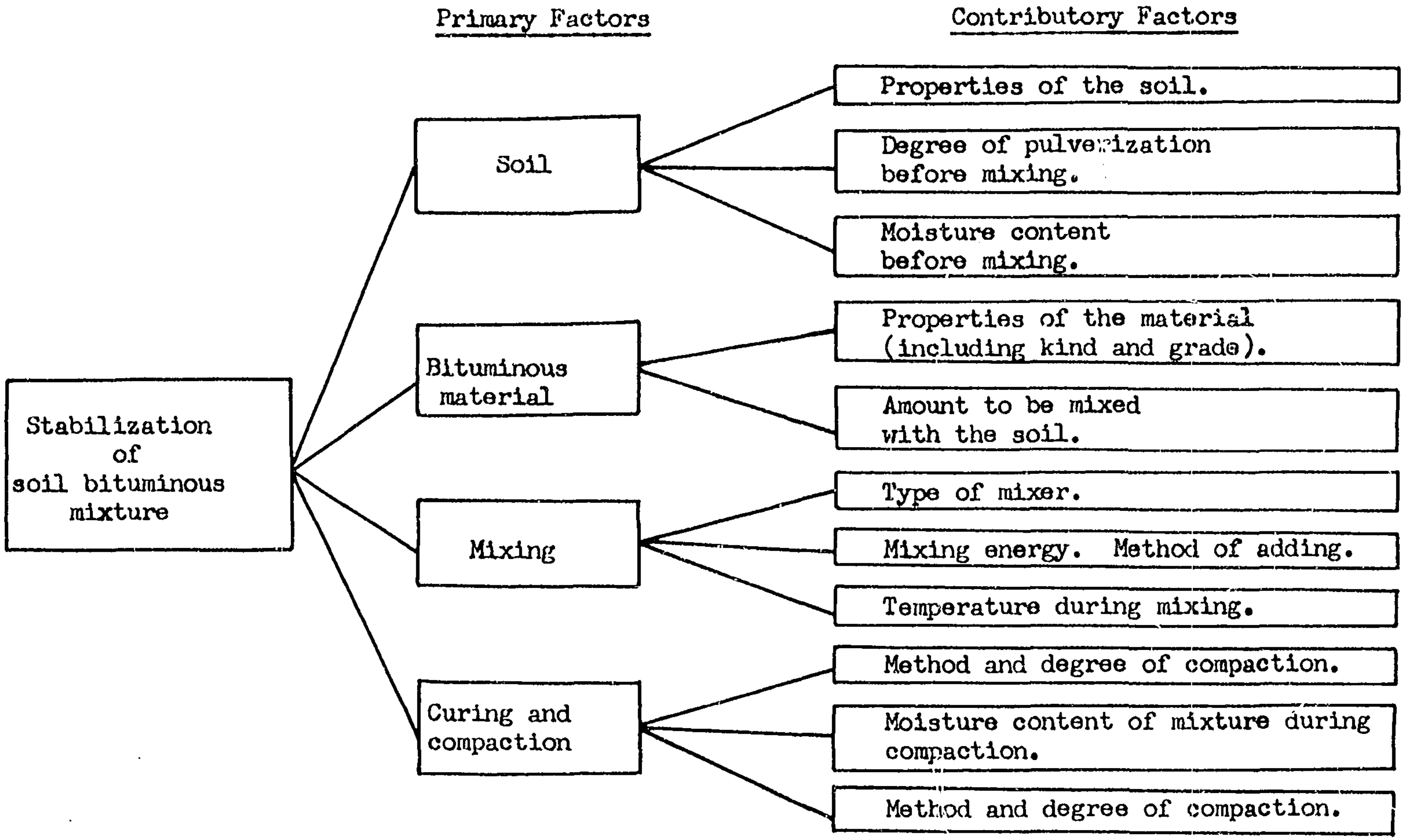
Many recordings of asphalt and its various uses appear in the ancient languages of Sumerian, Sanskrit, Hebrew, Greek, Latin and others. Asphalt was used in these early times primarily as a cement for keeping various objects in place. One of the earliest recorded uses of asphalt in pavements was by the Babylonian King Nabopolassar about 600 B. C. The use of asphalt since these times has been as a cement in building, as a medicine, a weapon of war, a preservative and for other purposes. The Inca Indians of Peru paved some of their highways with a bituminous macadam, but it wasn't until about 1832 in Gloucestershire, England, that modern bituminous paving started. The first asphalt roadway in the United States appears to have been a small experimental strip of rock asphalt laid in Newark, New Jersey in 1870; Pennsylvania Avenue in Washington, D. C., was paved with Trinidad asphalt in 1871 (1).

Since the introduction of asphalt as a paving material in the United States, an enormous amount of written material has appeared on the subjects of surface and base course construction with asphalt. There has been relatively little scientific information published about stabilization of soils with asphalt.

Asphalt soil stabilization is at present mostly limited to nonplastic and mildly plastic granular soils such as gravels, sands, and soil-aggregate mixtures (9, 37, 38, 44, 46, 52, 63). Economics permitting, granular borrow materials have been added to fine grained soils to render them liable to treatment with asphalt. Successful application of asphalt to fine-grained plastic soils without granular admixtures has been somewhat limited (9, 62, 64). Recently laboratory investigations have been conducted on the stabilization of medium-plastic soils with asphalt (11, 12, 33, 37, 62, 66, 67).

The use of asphalt as a soil stabilizing agent has been quite extensive and is one of the older soil stabilizing methods. Although this is true, actually less is known about the theory of asphalt soil stabilization than is known about some of the newer methods. Most of the knowledge on the subject has been derived from field experience which does not allow a close control of variables such as can be maintained in the laboratory. The complexity of asphalt soil stabilization is illustrated in Figure 1 by a listing of the major variables inherent in the subject. It is interesting to note that a detailed study of only one of the contributory factors

Figure 1. Variables affecting stability of soil-bituminous mixtures.


Primary Factors
Contributory Factors
Stabilization of soil bituminous mixture
Soil
Properties of the soil.
Degree of pulverization before mixing.
Moisture content before mixing.
Bituminous material
Properties of the material (including kind and grade).
Amount to be mixed with the soil.
Mixing
Type of mixer.
Mixing energy. Method of adding.
Temperature during mixing.
Curing and compaction
Method and degree of compaction.
Moisture content of mixture during compaction.
Method and degree of compaction.

would require a total of about 8,000 test specimens. The total number of specimens required for a complete analysis and understanding of all possible variables reaches an astronomical figure of the order of a billion billion or more. Fortunately the number of samples needed can be reduced considerably by eliminating study of factors which have very little effect on the final result.

The foregoing statements explain why there are so many seemingly contradictory statements about asphalt soil stabilization and why a state of mild confusion has resulted. A large part of the confusion appears due to a failure to differentiate the purposes of asphalt in soil, that is, whether it is to function as a waterproofer or a cement. Other contributors to confusion are the reasons for the presence of water and hydrocarbon volatiles when cutback are used.

As previously stated, the presence of moisture during mixing and compaction of soil-asphalt mixes is of prime importance. The purpose of having moisture present during mixing is entirely different than during compaction. During mixing water aids in the distribution of the asphalt, but during compaction water is necessary for density control.

Although the importance of moisture during these phases of stabilization has been recognized, a satisfactory agreement on the amount of moisture needed has never been reached. A value of moisture content which has been proposed is called the "fluff-point" of the soil (12). The term "fluff-point" may be misleading in that it does not always represent a specific moisture content but may be taken from a range in moisture content. The "fluff-point" is determined by comparison of the density of a number of samples of dry soil to each of which has been added a different amount of water. The moisture and soil are thoroughly mixed and the moisture content of the sample exhibiting the greatest bulkiness or mealiness of texture is called the "fluff-point". The only reason for this choice of moisture content is that there is a maximum void ratio and grain separation when the minimum density occurs. Apparently the logic of this choice was heavily influenced by great faith in the "plug" theory.

Other choices of moisture content have been made on the basis of the optimum moisture content for maximum density as determined on soil alone by the Proctor density test. This moisture content is usually reduced to allow for the lubricating effect of the liquid asphalt added. Opinions vary as to the amount of water reduction as pointed out previously.

Some research workers in Germany and in the United States have demonstrated the practicability of mixing asphalt cement with soil by using enough water to make a paste (16, 56). This resultant slurry mixture is called "Schlämme" and has been used primarily as a seal coat for roads.

The strength of a compacted soil-cutback asphalt mixture normally increases with increase in the oven dry unit weight of the compacted mix. The amount of moisture present during compaction influences the resultant density considerably (14). Mixtures containing small amounts of cutback asphalt are much more sensitive to moisture content than mixtures containing large amounts of cutback asphalt. However, moisture is necessary in all soil-cutback asphalt mixes (14, 36, 38). The moisture content prior to compaction may be controlled by the addition of water or by a period of aeration following mixing.

Aeration of a mixture of soil, cutback asphalt and water to control moisture also results in the loss of some of the hydrocarbon volatiles. Here again there is disagreement. Johnson (36) states that it is desirable to reduce the amount of kerosene cutter-stock in an MC-3 or MC-4 by at least one-half. He also states that if water and volatiles are calculated together the total liquid should be reduced to the range of one-fifth to one-third of the original volume. Other users of cutback asphalt believe that the combined moisture and volatiles should be reduced by fifty percent. Cape (14) has stated that it is usually necessary to allow some volatile escape before compaction when clean sands are used. He also found that clay soils are stronger and more waterproof when compacted with the hydrocarbon volatiles present.

MATERIALS

Soils

The major upland surficial soil deposits in Iowa are loess and glacial till. Sand ranks as an important minor upland surficial deposit in the eastern part of the state. The morphology and genesis of these materials have been thoroughly described by many authors (6, 19, 20, 31, 42, 65).

Soil samples have been chosen from these three materials to represent not only the material but also textural variations of soil in general. The loess samples were chosen because they represent the deep loess sections in western and eastern Iowa which constitute the major amount of loess in the state. The glacial till and the sand samples were chosen on the same basis. The soil samples also represent materials of a sandy, a silty and a clayey texture.

Four Wisconsin age loess samples (20-2, 100-8, 26-1, 43½-1) have been used in this investigation. Samples 20-2 and 100-8 represent the friable, calcareous loess in Iowa. 20-2 was sampled from the deep loess bordering the Missouri river and 100-8 was sampled from the deep loess along the Mississippi river. The Missouri river loess contains calcite and that from the Mississippi river border contains dolomite. A sub-study comparing testing apparatus was made using samples 26-1 and 43½-1 which represent the plastic loess in southwestern Iowa.

Sample S-6-2 is a fine sand from east central Iowa with a low clay content of only 2 percent. This material represents the fluvial fine sand deposits of the area.

Sample 411 is a Kansas glacial till from southwestern Iowa. The Kansan glacier deposited glacial till over the entire state, but the latter Wisconsin glacier deposited material only in the northern half of Iowa. Kansas till is one of the most abundant surficial materials in the southern part of Iowa and may be found in almost all parts of Iowa. Riggs (54) has reported that the particle size distribution of Kansan till is in general very uniform in all areas where it is found.

Sample locations, soil series and physical properties of the soil materials are presented in Tables 1 and 2.

Asphalt

Cutback asphalts of grades MC-0, MC-2 and MC-4 were used. The properties of the asphalts are listed in Table 3 as furnished by the manufacturer. Medium-curing cutback asphalts were selected for the reasons previously given.

Table 1. Locations of soil samples

Sample no.	County	Section	Tier North	Range	Soil series	Sampling depth, ft.	Horizon
20-2	Harrison	S-15[a]	78	43-W	Hamburg	39-40	C
100-8	Scott	NW¼,SE¼,S-13	77	2-E	Fayette	25-25½	C
S-6-2	Benton	NE¼,SE¼,S-16	86	10-W	Carrington	3-6	C
411	Page	S-27	69	36-W	Shelby	3-23	C
26-1	Shelby	S-21	81	40-W	Marshall	4-5	C
43½-1	Fremont	NW¼,NW½,S-36	69	40-W	Marshall	4½-5½	C

[a] Sample 20-2 was obtained behind the third ward school in Missouri Valley.

Table 2. Properties of soils

	Sample number					
	20-2	100-8	S-6-2	411	26-1	43½-1
Physical properties						
L.L., %	30.8	27.1	19.0	41.8	39.4	51.9
P.L., %	24.6	19.8	N.P.	14.9	26.9	18.5
P.I., %	6.2	7.3	--	26.9	12.5	33.4
C.M.E., %	19.6	--	--	21.7	19.5	28.5
S.L., %	22.3	20.6	14.8	12.3	23.3	19.1
Sp. Gr.	2.71	2.72	2.68	2.67	2.71	2.72
Lower fluff point, %[a]	8	5	1.5	11.0	9.0	11.5
Std. Proct. density, pcf.	109.9		109.9	111.9	107.0	104.3
Opt. M.C., %	18.2	15.8	12.3	15.5	17.7	19.1
Chemical properties						
Organic matter, %	0.17	0.2	0.04	0.11	0.18	0.37
Carbonates, %	10.17	20.0	--	--	--	0.5
Cat. Ex. Cap.	8.7	7.9	--	20.0	18.2	24.4
pH	8.7	7.9	6.5	--	--	6.7
Textural composition, %[b]						
Sand	0.4	2.8	94.4	32.7	0.9	0.4
Silt	79.8	85.2	3.4	30.8	69.7	60.2
Clay	19.8	12.0	2.2	36.5	8.07	39.4
Colloidal clay	14.5	8.9	1.1	26.0	21.4	29.8
Textural classification[c] (B.P.R. system)	Silty loam	Silty loam	Sand	Clay	Silty clay	Silty clay
Engineering classification (AASHO)	A-4(8)	A-4(8)	A-3(0)	A-7-6 (18)	A-6(9)	A-7-6 (18)

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[a] Defined by Benson and Becker (12).

[b] Sand - 2.0 to 0.74 mm, silt - 0.074 to 0.005 mm, clay - less than 0.005 mm, colloidal clay - less than 0.001 mm.

[c] Classified texturally by the Bureau of Public Roads System except that sand and silt sizes are separated by the No. 200 sieve.

Table 3. Properties of cutback asphalts[a]

Properties	Test method	Specification designation			
		MC-0	MC-2	MC-4	RC-2
Furol viscosity at 77°F., sec.	ASTM D 88	98			
Furol viscosity at 122°F., sec.					
Furol viscosity at 140°F., sec.			143		
Furol viscosity at 180°F., sec.				211	138
Specific gravity (77°/77°F.)	AASHO T 43	0.939		0.967	0.949
Distillation					
Distillate (percent of total distillate to 680°F.)					
To 370°F.	ASTM D 402				
To 437°F.			2.3	0.0	
To 500°F.		71.4	20.9	9.5	41.7
To 600°F.			72.1	57.1	73
Residue from distillation to 680°F. Volume percent by difference		65	78.5	89.5	76
Sp. gravity of distillate (77°/77°F.)		0.79	0.83	0.84	--
Tests on residue from distillation, pen. 77°F., 100g., 5 sec.		1000	210	215	96
Sp. gravity of residue (77°/77°F.)	ASTM D 71	1.005	1.015	1.005	1.012
Solubility in carbon tetrachloride	ASTM D 4	99.95	99.99	99.98	99.56
Temperature of use for mixing, °F.		50-120	100-120	175-225	80-150
Oliensis spot test		Neg.	Neg.	Neg.	Neg.

[a] Properties furnished by the Standard Oil Company of Indiana.

LABORATORY PROCEDURES AND TESTS

Standard tests and laboratory techniques are not always sufficient or applicable procedures for conducting research. This was found to be true in the present investigation, and a number of sub-investigations were necessary to develop suitable methods of test. Most of the sub-investigations are presented in the appendices.

Proportioning of materials

All additions of water and cutback asphalt were calculated as a percentage of the weight of oven-dry soil with which they were mixed. Cutback asphalt percentages represent the total weight of asphalt cement plus hydrocarbon volatiles. In other words 6 percent cutback asphalt means that 6 lb of liquid cutback asphalt were mixed with 100 lb of oven-dry soil.

Moisture and hydrocarbon volatile determinations

Determinations of moisture content in samples devoid of cutback asphalt were made by drying the samples in an oven at 105° to 110°C. Moisture contents of samples containing cutback asphalt were determined by distillation of all volatile material from the sample with a subsequent separation and measurement of the amount of water and hydrocarbon volatile material (see Appendix E). The latter method gives both water content and hydrocarbon volatile content of the sample.

Mixing of materials

Test specimens were prepared from batches mixed by a Hobart C-100 kitchen mixer. The required amount of water* and 1500 grams of soil were first machine mixed for two minutes. Next the sides of the mixing bowl were scraped and the materials mixed for an additional three minutes. The soil-water mixture was then stored in an air-tight container for 16 to 24 hours before the addition of cutback asphalt. The cutback asphalt was heated to the middle of the range of temperatures recommended by the Asphalt Institute and hand mixed into the moist soil to prevent splashing. Next the materials were machine mixed in the following order: 1½ minutes of mixing, sides were scraped, 1½ minutes of mixing, sides again scraped and a final two minutes of mixing. The development of this mixing procedure is discussed in Appendix D.

One of the sub-investigations was a study of the amount of hydrocarbon volatile material lost during the process of mixing cutback asphalt with soil. Determination of the loss of hydrocarbon volatiles while mixing 10 percent MC-0 at room temperature with oven-dry soil, and with air-dry soil at room

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*Varied with experiment performed.

temperature showed that the loss is very small; the loss after seven minutes of mixing with oven-dry soil at 110°C and cooled down to room temperature in a desiccator was 1.27 percent of the hydrocarbon volatiles and the loss using air-dry soil was 1.21 percent. The smaller loss in the presence of hydroscopic moisture can be explained by considering the mechanism of mass transfer:

Loss of hydrocarbon volatiles through evaporation in a system of this type is essentially a diffusional phenomenon. The system can also be considered to consist of two immiscible liquids, water and kerosene or water and gasoline. Each component liquid exists in a pure state and therefore exerts its normal equilibrium vapor pressure at the existing temperature. The rate of evaporation in either a static or dynamic atmosphere is proportional to the surface exposed multiplied by the difference between the partial pressures of the evaporating component at the interface and in the surrounding atmosphere. Increased water contents do not effect partial pressures and therefore produce a reduction in the amount of hydrocarbon volatile loss by reducing the exposed surface area of the more volatile hydrocarbon material. Since the loss in the presence of a small amount of water was negligible, the loss with larger amounts of water present will be even less and for practical purposes can be considered negligible.

Aging mixtures

Batches of cutback asphalt-soil-water mixtures that were used for studying the amount of water required during mixing were stored four hours in an air-tight container before molding specimens. The purpose of this aging was to bring the moisture in the soil to an equilibrium.

Drying-back mixtures

Batches of cutback asphalt-soil-water mixtures used for studying the amount of water and hydrocarbon volatile material remaining before molding were air-dried for various periods of time. The cutback asphalt-soil-water mixtures were placed in shallow pans and covered with a layer of gauze and a one inch layer of cotton. The coverings are necessary to reduce thermal gradients and vapor concentration gradients which in turn reduce the rate of vapor phase mass transfer from the surface of the drying material. The reduced rate of surface mass transfer causes the liquid and vapor conditions to remain static and fairly close to equilibrium throughout the drying mixture.

Molding

Following either aging or drying-back, soil-cutback asphalt mixtures were molded into 2-inch diameter by 2-inch high specimens using standard Proctor compactive effort (21). The mold was a 5-inch long brass cylinder having a 2-inch inside diameter. Compacted material in excess of 2 inches was extruded from the cylinder and trimmed. The specimen remained within the cylinder through testing. See Appendix B.

Testing specimens

The stability of specimens was evaluated by the Iowa Bearing Value test immediately following the soaking period. The Iowa Bearing Value test, abbreviated to IBV test, was chosen as a means of stability evaluation for several reasons (See Appendix A). It is believed to more nearly simulate field conditions than other tests, it requires 1/20 the amount of material and less than 1/2 the time required by the CBR test. The IBV test molds are small and require little space in humidity or storage cabinets. A singular disadvantage is the fact that the IBV test is limited to medium and fine-grained soils, although a limited amount of research indicates that materials containing up to 25 percent 1/4-inch gravel may be tested (21). The soil materials used in this study were medium and fine grained.

The IBV test is a miniature bearing test patterned after the California Bearing Ratio test. The test specimen is compacted into a 2-inch diameter mold and struck off to a height of 2 inches. A 5/8-inch penetration rod is forced into the specimen by a testing machine, and the load at various depths of penetration is recorded and graphed. In this investigation the load corresponding to 0.08-inch penetration is called the IBV.

In the IBV test specimens may be tested in any condition such as soaked, air-dry or after freezing and thawing. In the present investigation specimens in brass cylinders were immersed in distilled water at room temperature with surcharge (equivalent to that used in the CBR test) and allowed to soak for 7 days before testing (Figures 18 and 19, Appendix B). Seven days was chosen as the soaking period because it was found that a maximum loss in stability, as measured by strength, occurs within this period (see Appendix C).

The IBV test was developed in the Engineering Experiment Station of the Iowa State College and is being correlated with the CBR test (6, 21, 40).

Review of procedure

A brief stepwise review of the laboratory procedure is presented as follows for the sake of clarity:

1. Proportion soil and water
2. Mix
3. Store 16 to 24 hours
4. Mix by hand

5. Add liquid cutback asphalt
6. Mix by hand
7. Machine mix
8. Age or dry-back
9. Mold
10. Immerse in distilled water
11. Test

INVESTIGATION

Water contents during mixing and during compaction of soil-cutback asphalt mixtures have marked effects on the properties of the resulting stabilized material. The amount of moisture present during mixing also has a decided influence on the final distribution of cutback asphalt in the soil mass. The main purpose of this investigation was to determine what moisture control should be exercised in order to ensure a stabilized material having an optimum combination of properties. Two processes of cutback asphalt soil stabilization were investigated: in Process I, soil, cutback asphalt and water are mixed and immediately compacted; in Process II, soil, asphalt and water are mixed and the mixture is dried back to some lower moisture content before compaction.

The difference between Process I and Process II was the stage in the process at which the water content was varied. In Process I the water content was varied during mixing and the mixture was compacted with a water content equal to that used in mixing. In Process II the water content during mixing was sufficiently high to ensure good cutback asphalt distribution and was changed from that used during mixing by drying back before compaction.

Process I

The effects of moisture content during mixing on the density, IBV, absorption, expansion and the total 7 day soaked moisture content were studied by testing specimens molded from different batches of soil, asphalt and water in which the water content was varied. All other quantities and qualities such as the amount and type of soil, and the amount and type of cutback asphalt were maintained constant for any one study. Each of the four soils was studied in this manner and compared using admixtures of 6 and 10 percent MC-2 and MC-4 cutback asphalt. The sand sample (S-6-2) was treated with only 3 percent MC-2 since higher percentages of MC-2 cutback asphalt produced mixtures of such a liquid consistency that molding was impossible. The use of MC-4 with the sand permitted treatments of both 3 and 6 percent. Again it is emphasized that water content was the only variable in any study of constant cutback asphalt content. The method of analysis can be clarified by an examination of the data presented.

Density was calculated as weight of dry soil per unit volume and is expressed in pounds per cubic foot. IBV was expressed in pounds, absorption was calculated as the amount of moisture gained by a specimen during the seven day immersion period and was expressed as a percentage of the oven-dry weight of soil contained in the specimen. Expansion of specimens was expressed as a percentage of the original height of the specimen concerned since the specimens were laterally confined and expansion occurred in one dimension only. Total 7 day soaked moisture content was expressed as percentage of the oven-dry weight of soil contained in a specimen.

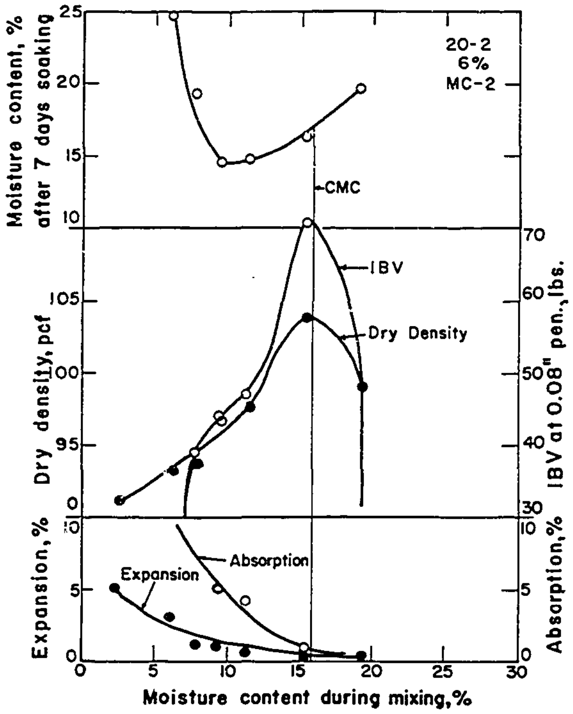
The data are presented in Figures (2, 3, 4) as graphs with density, IBV, absorption, expansion and total 7 day soaked moisture content treated as dependent variables. The independent variable is the water content <u>during mixing</u>, expressed as a percentage of the oven-dry weight of the soil in each specimen. Each point on the graphs represents an average of three values.

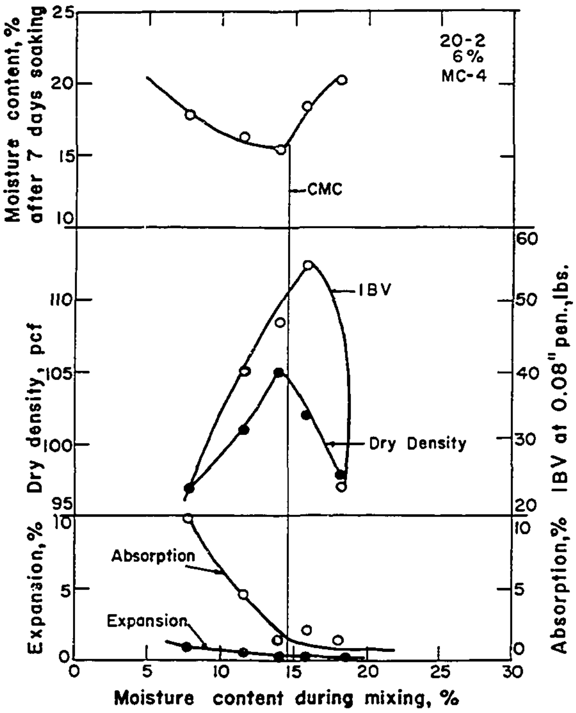
The curves of IBV, density and of total moisture content after 7 days soaking all show either a maxima or a minima where an optimum mixing moisture content exists for each combination of soil, type and amount of cutback asphalt. The optimum moisture contents for the foregoing are seldom coincident.

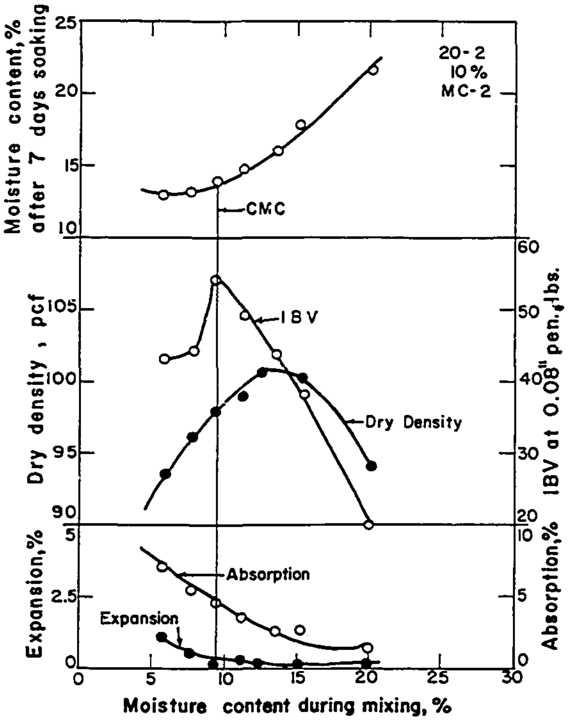
The absorption and expansion curves are similar in character. Both sets of curves are, in general, a logarithmic type assymtotic to some minimum value. The curves indicate that the best absorption and expansion performances are obtained with the highest mixing water content possible. However, a gain in absorption and expansion performance by increasing the mixing water content is obtained only at the expense of other desirable properties.

Somewhere within the range of moisture studied there is

Figure 2. Graphs of moisture content during mixing versus the IBV, dry density, absorption, expansion and total moisture content after 7 days soaking of soil-cutback asphalt compacted specimens. The soil-cutback asphalt compositions are listed on each graph. The amount of residual asphalt cement in 6 and 10 percent MC-2 is 4.93 and 8.2 percent, and in 6 and 10 percent MC-4 is 5.47 and 9.11 percent. The vertical line in the center of the graph indicates the CMC.


20-2
6%
MC-2
CMC
IBV
Dry Density
Absorption
Expansion
Moisture content, % after 7 days soaking
Dry density, pcf
IBV at 0.08" pen., lbs.
Expansion, %
Absorption, %
Moisture content during mixing, %
25
20
15
10
105
100
95
0
70
60
50
40
30
10
5
0
5
10
15
20
25
30


20-2
6%
MC-4
CMC
IBV
Dry Density
Absorption
Expansion
Moisture content, % after 7 days soaking
Dry density, pcf
IBV at 0.08" pen., lbs.
Expansion, %
Absorption, %
Moisture content during mixing, %
25
20
15
10
110
105
100
95
60
50
40
30
20
10
5
0
5
10
15
20
25
30


20-2
10%
MC-2
CMC
IBV
Dry Density
Absorption
Expansion
Moisture content, % after 7 days soaking
Dry density, pcf
IBV at 0.08" pen., lbs.
Expansion, %
Absorption, %
Moisture content during mixing, %
25
20
15
10
105
100
95
90
60
50
40
30
20
5
2.5
0
10
5
0
5
10
15
20
25
30

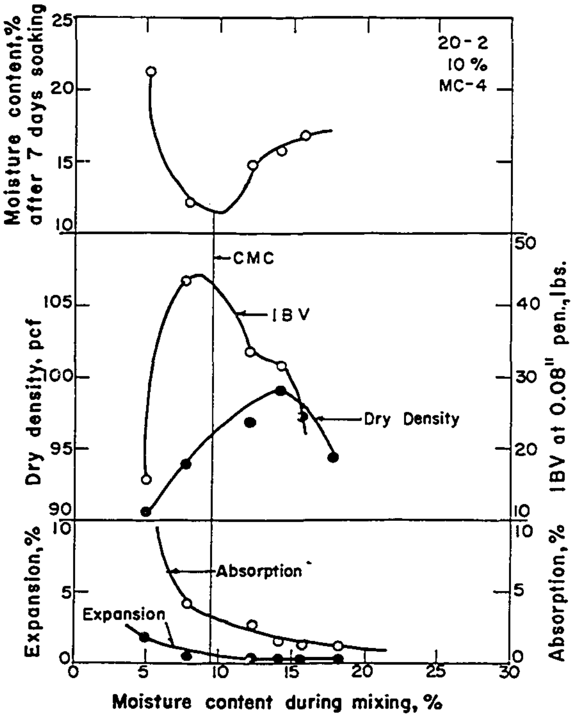
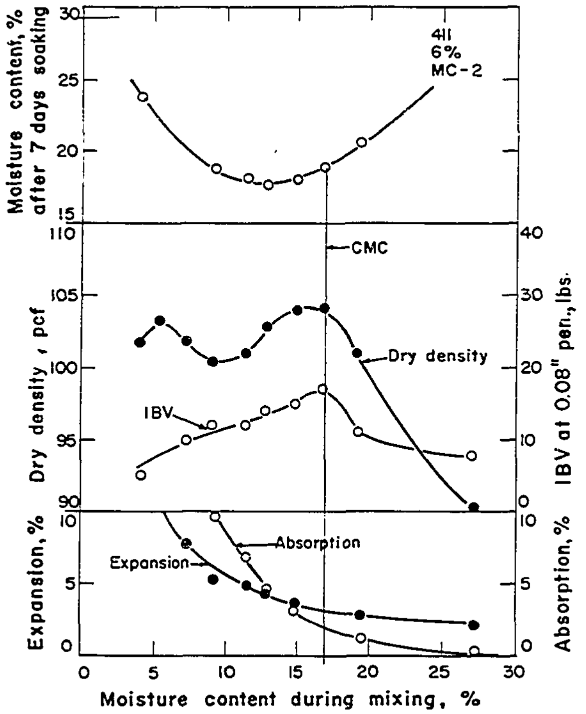
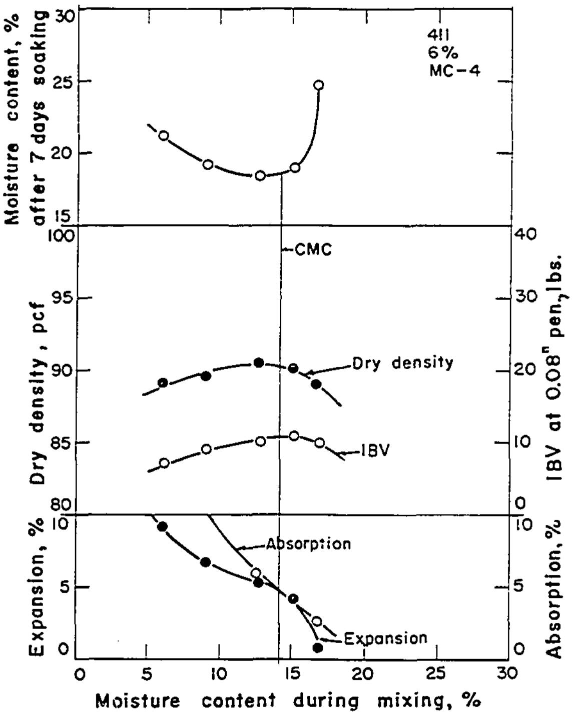
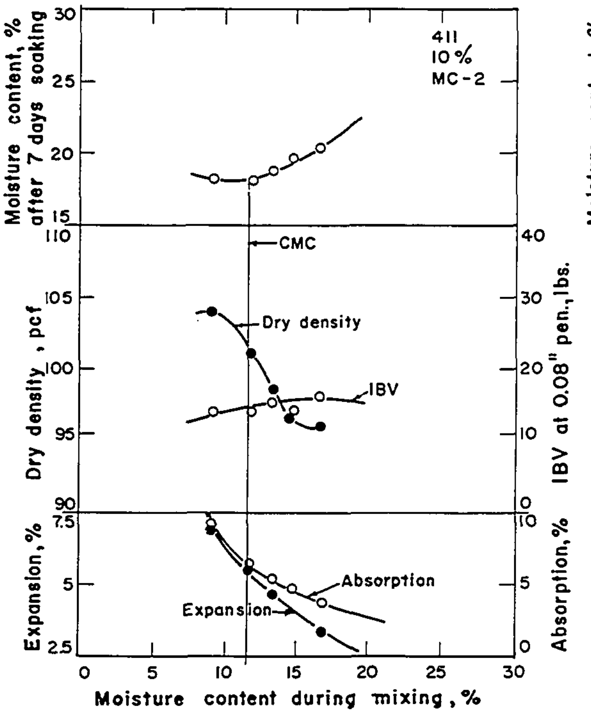

20-2
10%
MC-4
CMC
IBV
Dry Density
Absorption
Expansion
Moisture content, % after 7 days soaking
Dry density, pcf
IBV at 0.08" pen., lbs.
Expansion, %
Absorption, %
Moisture content during mixing, %
25
20
15
10
105
100
95
90
50
40
30
20
10
10
5
0
5
10
15
20
25
30

Figure 3. Graphs of moisture content during mixing versus the IBV, dry density, absorption, expansion and total moisture content after 7 days soaking of soil-cutback asphalt compacted specimens. The soil-cutback asphalt compositions are listed on each graph. The amount of residual asphalt in 3, 6 and 10 percent MC-2 is 2.47, 4.93, and 8.2 percent, and in 3 and 6 percent MC-4 is 2.7 and 5.4 percent. The vertical line in the center of the graph indicates the CMC.


411
6%
MC-2
Moisture content, % after 7 days soaking
15
20
25
30
CMC
Dry density, pcf
90
95
100
105
110
IBV at 0.08" pen., lbs.
0
10
20
30
40
Dry density
IBV
Expansion, %
0
5
10
Absorption, %
0
5
10
Absorption
Expansion
Moisture content during mixing, %
0
5
10
15
20
25
30


411
6%
MC-4
Moisture content, % after 7 days soaking
15
20
25
30
CMC
Dry density, pcf
80
85
90
95
100
IBV at 0.08" pen., lbs.
0
10
20
30
40
Dry density
IBV
Expansion, %
0
5
10
Absorption, %
0
5
10
Absorption
Expansion
Moisture content during mixing, %
0
5
10
15
20
25
30


411
10%
MC-2
Moisture content, % after 7 days soaking
15
20
25
30
CMC
Dry density, pcf
90
95
100
105
110
IBV at 0.08" pen., lbs.
0
10
20
30
40
Dry density
IBV
Expansion, %
2.5
5
7.5
Absorption, %
0
5
10
Absorption
Expansion
Moisture content during mixing, %
0
5
10
15
20
25
30

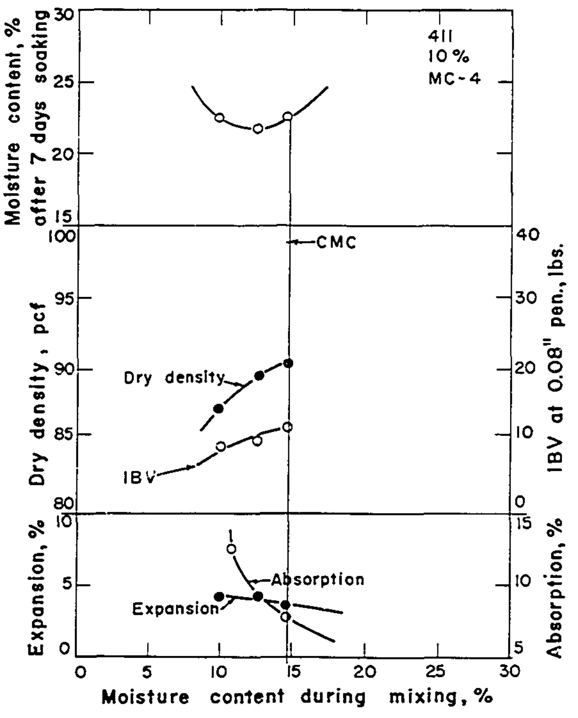
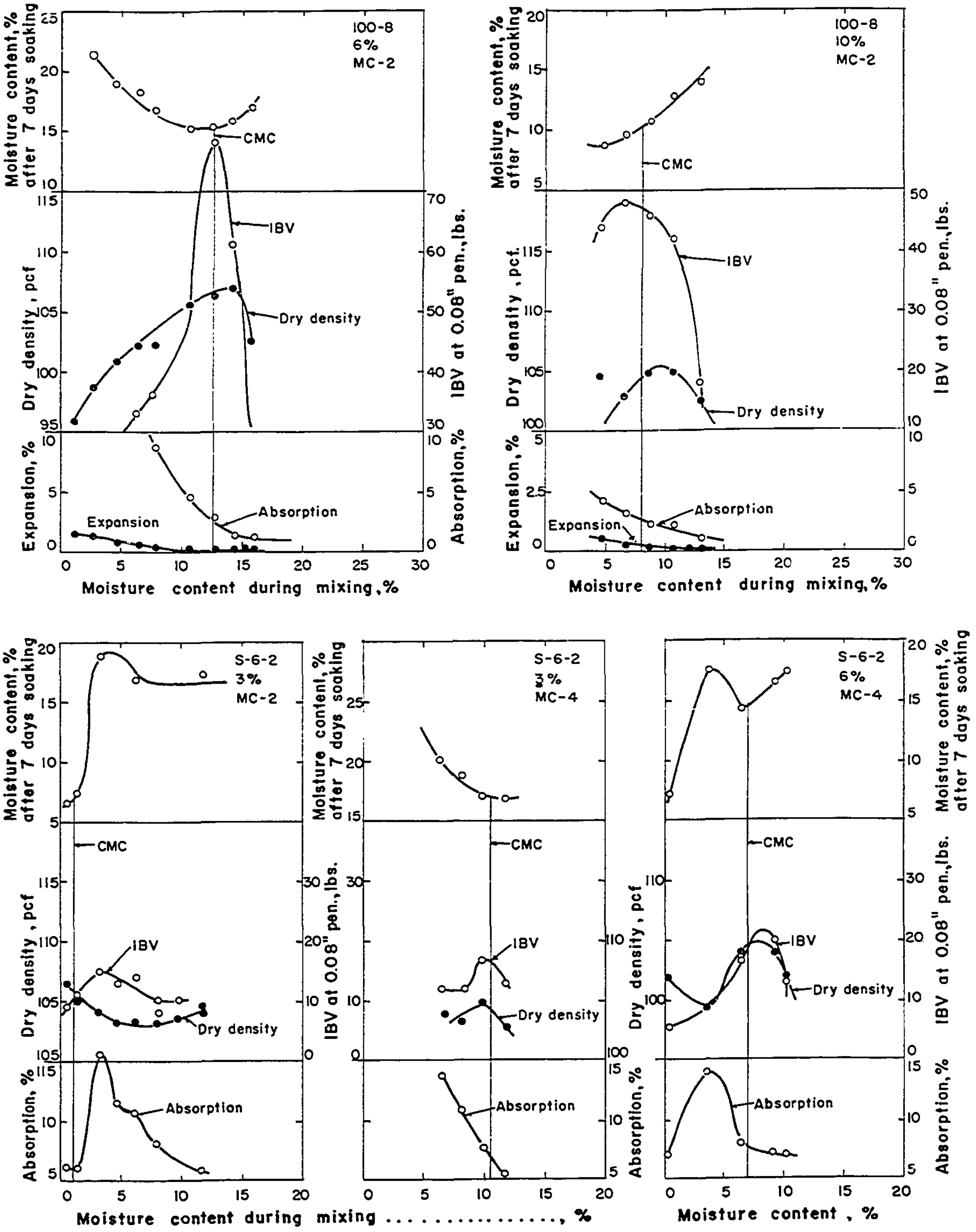

411
10%
MC-4
Moisture content, % after 7 days soaking
15
20
25
30
CMC
Dry density, pcf
80
85
90
95
100
IBV at 0.08" pen., lbs.
0
10
20
30
40
Dry density
IBV
Expansion, %
0
5
10
Absorption, %
5
10
15
Absorption
Expansion
Moisture content during mixing, %
0
5
10
15
20
25
30

Figure 4. Graphs of moisture content during mixing versus the IBV, dry density, absorption, expansion and total moisture content after 7 days soaking of soil-cutback asphalt compacted specimens. The soil-cutback asphalt compositions are listed on each graph. The amount of residual asphalt cement in 6 and 10 percent MC-2 is 4.93 and 8.2 percent, and in 6 and 10 percent MC-4 is 5.47 and 9.11 percent. The vertical line in the center of the graph indicates the CMC.


100-8
6%
MC-2
Moisture content, % after 7 days soaking
Dry density, pcf
IBV at 0.08" pen., lbs.
Expansion, %
Absorption, %
CMC
IBV
Dry density
Expansion
Absorption
Moisture content during mixing, %
100-8
10%
MC-2
S-6-2
3%
MC-2
S-6-2
3%
MC-4
S-6-2
6%
MC-4
Moisture content during mixing ...., %
Moisture content, %

a mixing moisture content which represents the best compromise when all properties are considered. The compromise point was found by graphical analysis of the data, using the method of first powers in which a minimization of the summation of individual property deviations from a datum is calculated. More accurate methods of analysis could be performed by using either the method of least squares or the method of least cubes. However, the latter methods are far more complex and require an exact knowledge of the equations relating the properties in question for accuracy. Curves could be fitted to the numerical data but in so doing errors of a serious nature are apt to be introduced. Errors of this type more than offset the increased accuracy of the more complex methods so the simplest method was used.

Each property exhibits one best value, either a maximum or a minimum, which was used as a datum. The difference between a property value and the datum value was then calculated as a percentage of the datum value at each moisture content. Deviation percentages of all properties from their respective datums were calculated and summed at each mixing moisture content. The summations of deviations were then plotted versus mixing moisture content. The mixing moisture content corresponding to the minimum value of the summation of deviations is then the best compromise moisture content (CMC). The mixing CMC was found by this method for all soils and combinations of cutback asphalt used except for some of the sand mixes in which no definite maxima or minima were evident. The CMC for the latter cases were visually estimated.

The data resulting from the tests and calculations are given in Tables 4 and 5. Optimum moisture for the raw soil is included primarily as a matter of interest. The mixing moisture content corresponding to maximum IBV, maximum density and minimum total moisture content after seven days immersion are shown for comparison with the mixing CMC at which the best over-all results are obtained.

Examination of these data show that the mixing moisture for maximum IBV and for maximum density closely correspond to the mixing CMC. Exact correspondence would produce a straight line graph passing through the origin with a slope of 45 degrees in each case. Plots of mixing moisture for maximum IBV and for maximum density versus CMC are shown in Figure 5. Both plots follow a 45 degree line fairly well. The mixing moisture for maximum IBV appears to give the best correlation; however, the mixing moisture for maximum density gives a good correlation.

Absorption or expansion due to soaking cannot be used as criteria for predicting mixing moisture for maximum performance because there is no convenient control point on the curves as shown in Figures (2, 3, and 4). The only possible point of control is the minimum value for each case and the minimum values lie too far to the right of the CMC for maximum per-

Table 4. Data from Process I - mixed and molded

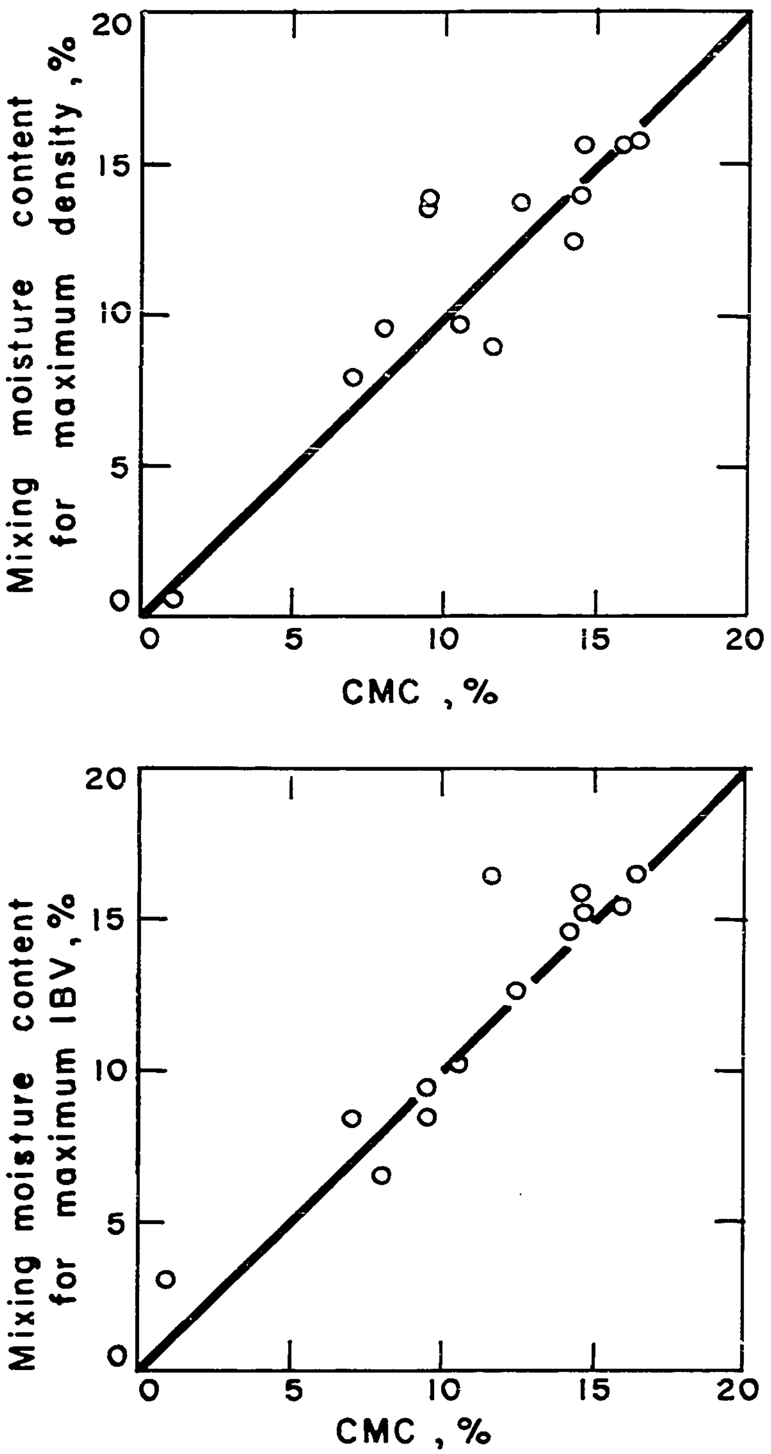
			Moisture content during mixing at:			
Soil	Amount and type of cutback asphalt[a]	Optimum moisture of soil, %	Maximum IBV	Maximum dry density	Minimum moisture content after 7 days soaking	Calculated MC where minimum summation of deviations occurs, %
20-2	6% MC-2	18.0	15.5	15.7	10.1	15.8
	10%		9.6	13.6	7.2	9.5
	6% MC-4		16.0	14.0	13.8	14.5
	10%		8.5	13.9	10.0	9.5
100-8	6% MC-2	15.8	12.7	13.8	11.5	12.5
	10%		6.6	9.6	4.5[b]	8.0[b]
411	6% MC-2		16.6	15.8	12.3	16.3
	10%		16.5	9.0	10.4	11.6
	6% MC-4		14.7	12.5	13.1	14.2
	10%		15.2	15.7	12.3	14.6
S-6-2	3% MC-2	12.3	3.2	0.5[b]	0.5[b]	1.0[b]
	3% MC-4		10.0	9.8	11.7	10.5
	6%		8.5	8.0	0.5[b]	7.0^5

---

[a] Amount of residue in 6% MC-2 cutback asphalt as 4.93%, 10% is 8.2% and in 6% MC-4 5.47% and in 10% MC-4 9.11%.

[b] Visually estimated because maxima and minima were indefinite.

Figure 5. Graphs comparing mixing moisture content for maximum standard Proctor density and mixing moisture content for maximum IBV with the compromise moisture content. Exact correlation of the experimental data would fall on the indicated 45 degree line. This relation holds true for silty and clayey soils used in this investigation.


Mixing moisture content for maximum density, %
0
5
10
15
20
CMC, %
0
5
10
15
20
Mixing moisture content for maximum IBV, %
0
5
10
15
20
CMC, %
0
5
10
15
20

Process I

Table 5. Data from specimens made from 1500 gram batches of soil containing the indicated admixtures - mixing study

Soil	Amount of cutback asphalt	Moisture content during mixing, %	Moisture + volatile material during molding, %	IBV @ .08" pen lb.	Absorption, %	Expansion, %	Oven dry density pcf	Total MC of specimen after 7 days absorption, %
20-2	6% MC-2	2.5	3.57	3	26	5.25	91.2	28.5
		4.1	5.17	8	23.9	3.6	90.3	28.0
		6.2	7.27	13	18.5	3.18	93.1	24.7
		7.9	8.97	39	10.1	1.43	93.7	19.1
		9.5	10.57	44	5.0	1.2	96.7	14.5
		11.4	12.47	47	4.3	0.85	97.7	14.7
		15.4	16.47	71	1.00	0.42	103.8	16.4
		19.2	20.27	22	0.3	0.5	99	19.5
		25.4	26.47	Not possible to mold				
		Heated 325°F.	--	18	8.7	2.2	85.6	
20-2	10% MC-2	5.8	7.6	43	7.2	1.1	93.6	13.0
		7.6	9.4	44	5.5	0.51	96.2	13.1
		9.4	11.2	54	4.6	0.2	98.0	14.0
		11.2	13.0	49	3.6	0.3	99.0	14.8
		13.5	15.3	44	2.6	0.2	100.6	16.1
		15.2	17.0	38	2.7	0.2	100.0	17.9
		20.0	21.8	20	1.5	0.2	94	21.5
20-2	6% MC-4	7.9	8.43	24	10.0	1.0	96.5	17.9
		11.6	12.13	40	4.7	0.6	101	16.3
		14.0	14.53	47	1.5	0.4	105	15.5
		15.8	16.33	55	2.2	0.35	102	18.0
		18.1	18.63	24	1.4	0.2	97.8	20.3

Table 5. (Continued)

Soil	Amount of cutback asphalt	Moisture content during mixing, %	Moisture + volatile material during molding, %	IBV @ .08" pen lb.	Absorption, %	Expansion, %	Oven dry density pcf	Total MC of specimen after 7 days absorption, %
20-2	10% MC-4	5.1	5.99	16	16.3	1.7	90.6	21.4
		7.9	8.79	44	4.37	0.5	94.4	12.27
		12.1	12.99	34	2.81	0.4	97	14.91
		14.2	15.09	32	1.59	0.4	99.3	15.79
		15.6	16.49	25	1.3	0.4	97.4	16.9
100-8	6% MC-2	1.2	2.27	7	22.6	1.5	95.7	23.8
		2.7	3.77	6	18.7	1.5	98.9	21.4
		4.6	5.67	27	14.3	0.8	101	18.9
		6.5	7.57	33	11.6	0.6	102.2	18.1
		7.9	8.97	36	8.7	0.37	102.4	16.6
		10.6	11.67	51	4.5	0.2	105.5	15.1
		12.6	13.67	78	2.8	0.2	106.5	15.4
		14.2	15.27	61	1.4	0.18	107.0	15.6
		15.9	16.97	6	1.1	0.13	103.0	17.0
		Heated 325°F.	--	19	10.5	1.7	95.6	--
100-8	10% MC-2	4.7	5.77	44	4.06	0.5	104.5	8.76
		6.6	7.67	48	3.13	0.25	102.9	9.73
		8.7	9.77	46	2.18	0.1	104.8	10.88
		10.7	11.77	42	2.2	0.1	105.0	12.9
		13.0	14.07	19	1.07	0.05	102.5	14.07

Table 5. (Continued)

Soil	Amount of cutback asphalt	Moisture content during mixing, %	Moisture + volatile material during molding, %	IBV @ .08" pen lb.	Absorption, %	Expansion, %	Oven dry density pcf	Total MC of specimen after 7 days absorption, %
S-6-2	3% MC-2	0.5	1.03	9	6.1	-ve	106.4	6.6
		1.4	1.93	11	6	-ve	105	7.4
		3.2	3.73	15	15.7	-ve	104	18.9
		4.7	5.23	13	12.4	-ve	103.2	17.1
		6.2	6.73	14	10.7	-ve	103.2	16.9
		8.0	8.53	10	8.1	-ve	104.0	17.63
		9.53	10.06	10	5.2	-ve	103.5	14.73
		11.6	12.13	9	5.8	-ve	104.0	17.4
		Heated 325°F.	--	16	--	--	--	--
S-6-2	3% MC-4	0.2	0.47	No distribution of cutback possible				
		2.3	2.57	" " " " "				
		4.1	4.37	Some distribution - specimens cannot be molded				
		6.5	6.77	12	13.7	-ve	103.8	20.2
		8.1	8.37	12	10.8	-ve	102.9	18.9
		9.8	10.07	17	7.5	-ve	104.8	173.
		11.7	11.97	13	5.4	-ve	102.8	17.1
S-6-2	6% MC-4	0.2	0.73	6	7.1	-ve	102.0	7.3
		3.6	4.13	9	14.0	-ve	99.4	17.6
		6.4	6.93	17	8.0	-ve	104.0	14.4
		9.2	9.73	20	7.3	-ve	104.2	16.5
		10.1	10.63	13	7.2	-ve	102.0	17.3

Table 5. (Continued)

Soil	Amount of cutback asphalt	Moisture content during mixing, %	Moisture + volatile material during molding, %	IBV @ .08" pen lb.	Absorption, %	Expansion, %	Oven dry density pcf	Total MC of specimen after 7 days absorption, %
411	6% MC-2	4.1	5.17	5	19.8	11.6	101.8	23.9
		5.4	6.47	7	16.5	10.9	103.2	21.9
		7.3	8.37	10	13.2	7.7	101.9	20.5
		9.2	10.27	12	9.6	5.4	100.5	18.8
		11.5	12.57	12	6.8	4.9	101.0	18.3
		12.9	13.97	14	4.7	4.5	102.9	17.6
		15.0	16.07	15	3.04	3.7	104.0	18.04
		16.8	17.87	17	2.1	4.8	104.2	18.9
		19.4	20.47	12	1.3	0.85	101	20.7
		27.2	28.27	8	0.2	2.1	90.1	27.4
411	10% MC-2	9.1	10.9	14	9.1	6.8	104	18.2
		11.9	13.7	14	6.2	5.7	101	18.1
		13.4	15.2	16	5.3	4.7	98.5	19.9
		14.8	16.6	15	4.7	2.5	97	19.5
		16.7	18.5	17	3.7	3.3	96.1	20.4
411	6% MC-4	6.2	6.73	7	15.0	9.2	89.1	21.2
		9.1	9.63	9	10.1	7.8	89.6	19.2
		12.8	13.33	10	5.6	5.2	90.5	18.4
		15.1	15.63	11	3.7	3.7	90.2	18.8
		16.8	17.33	10	2.1	0.8	89.1	24.9
411	10% MC-4	10.0	10.89	9	12.5	4.2	87.4	22.5
		12.6	13.49	10	9.2	4.1	89.5	21.8
		14.7	15.59	12	7.8	3.6	90.5	22.5

formance. These properties require a week of soaking before they can be determined. The properties are also dependent on the moisture content at the beginning of the soaking period since the amount of absorption or expansion is partially dependent on the amount of air void space available for the entry of water. The moisture content at the beginning of the soaking period is variable so the amount of absorption or expansion in a relative value.

The mixing moisture for the maximum density of the soil asphalt mix is the most practical moisture content for use as a guide in determining water requirements for cutback asphalt soil stabilization. The density tests can be run in a relatively short time, whereas the use of the IBV test as a criterion requires at least a week.

Process II

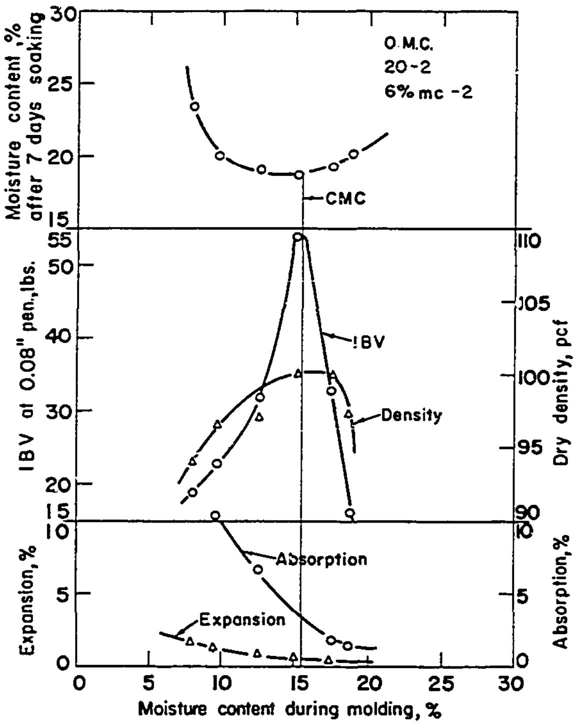
The effects of moisture content during compaction on the density, IBV, expansion and the total 7 day soaked moisture content were studied by testing specimens molded from different batches of soil, asphalt and water in which the moisture and hydrocarbon volatile content had been changed by drying the material after mixing. All other quantities and qualities such as the amount and type of soil, and the amount and type of asphalt were maintained constant for any one study. Batches were mixed at either the standard Proctor optimum moisture or at the liquid limit of the raw soil and in some cases at the plastic limit. Each soil was studied in this manner and compared to other soils using 6 and 10 percent MC-2 and MC-4 cutback asphalt. The sand sample was again treated as stated in the previous section describing Process I. Property values were calculated and expressed in the same units as before.

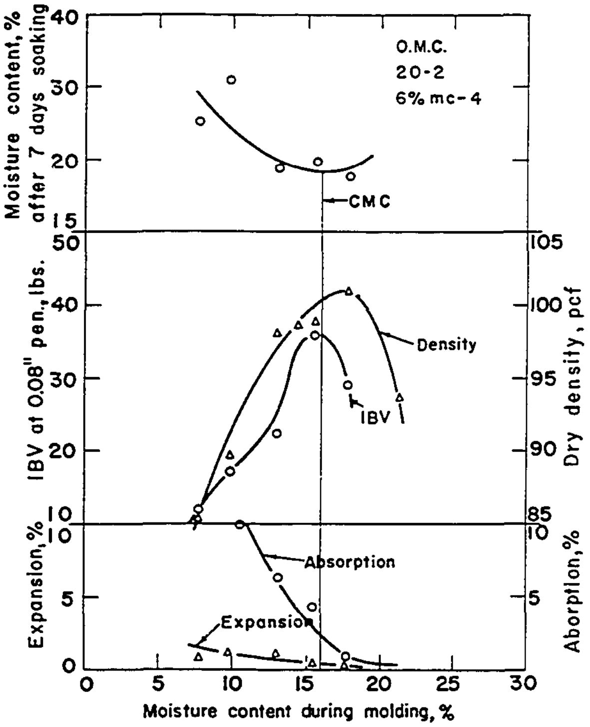
The data are presented in Figures (6, 7, 8, 9) as graphs with density, IBV, expansion and total 7 day soaked moisture content treated as dependent variables. The independent variable is the water content <u>during</u> <u>molding</u>. Each point on the graphs represents an average of three values.

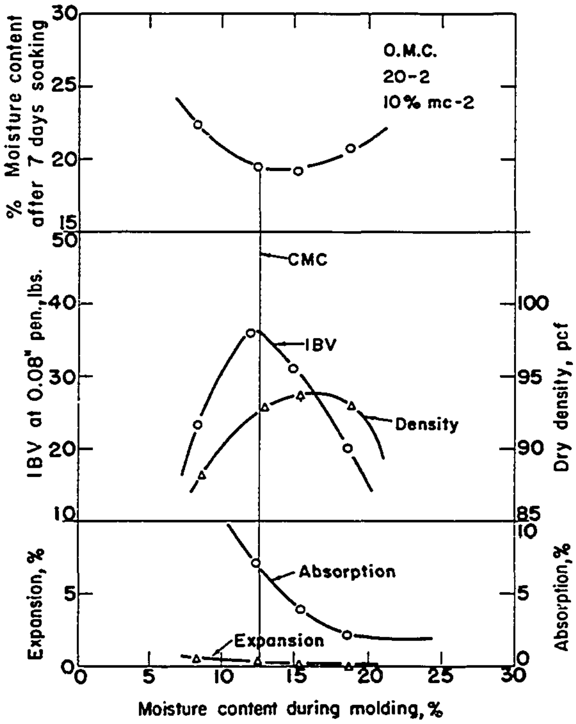
The data are presented in Figures (6, 7, 8, 9) in the same manner as the data for Process I. The resulting curves behave in the same general fashion as those obtained in Process I and were analyzed as described under Process I.

The data resulting from the tests and calculations are given in Tables 6, 7, and 8. A close correlation, except for sand, exists between either the moisture contents for maximum density or maximum IBV and the dried back CMC as shown in Figure 10; the results from sand tend to be errotic and the CMC must be estimated by age. Both plots follow a 45 degree line and the same general statements apply as were discussed under Process I. It is important to note that the dried back moisture content for maximum density of the soil-asphalt mix is the most practical criterion for determining the water

Figure 6. Graphs of moisture content during molding versus the IBV, dry density, absorption, expansion and total moisture content after 7 days soaking of soil-cutback asphalt compacted specimens. The soil-cutback asphalt compositions and the moisture content at which the mixes were mixed are listed on each graph. The amount of residual asphalt cement in 6 and 10 percent MC-2 is 4.93 and 8.2 percent, and in 6 and 10 percent MC-4 is 5.47 and 9.11 percent. The vertical line in the center of the graph indicates the CMC.


O.M.C.
20-2
6% mc -2
Moisture content ,% after 7 days soaking
CMC
IBV at 0.08" pen., lbs.
Dry density, pcf
IBV
Density
Expansion, %
Absorption, %
Absorption
Expansion
Moisture content during molding, %


O.M.C.
20-2
6% mc-4
Moisture content, % after 7 days soaking
CMC
IBV at 0.08" pen., lbs.
Dry density, pcf
Density
IBV
Expansion, %
Aborption, %
Absorption
Expansion
Moisture content during molding, %


O.M.C.
20-2
10% mc-2
% Moisture content after 7 days soaking
CMC
IBV at 0.08" pen., lbs.
Dry density, pcf
IBV
Density
Expansion, %
Absorption, %
Absorption
Expansion
Moisture content during molding, %

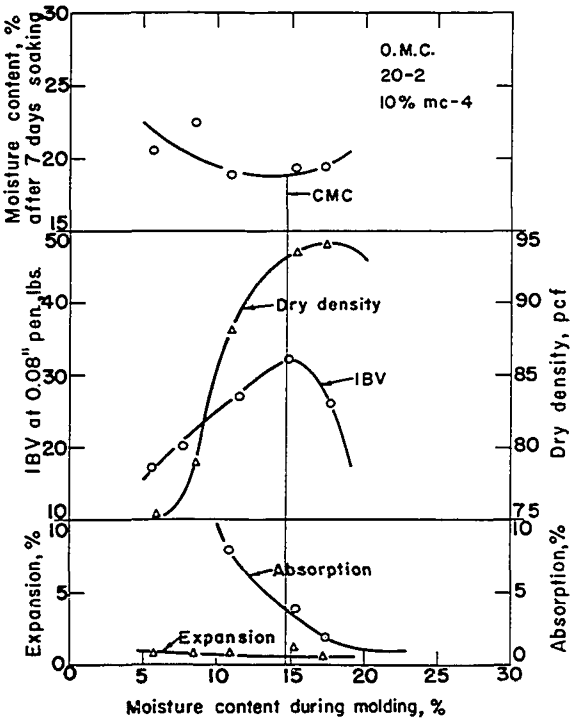
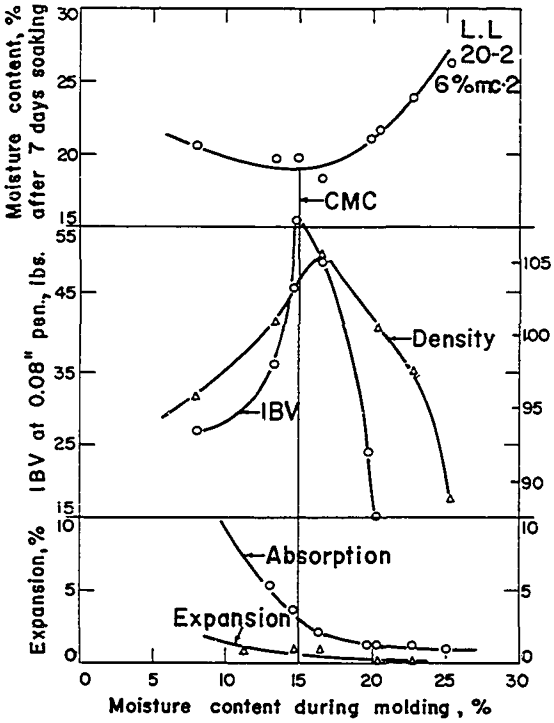
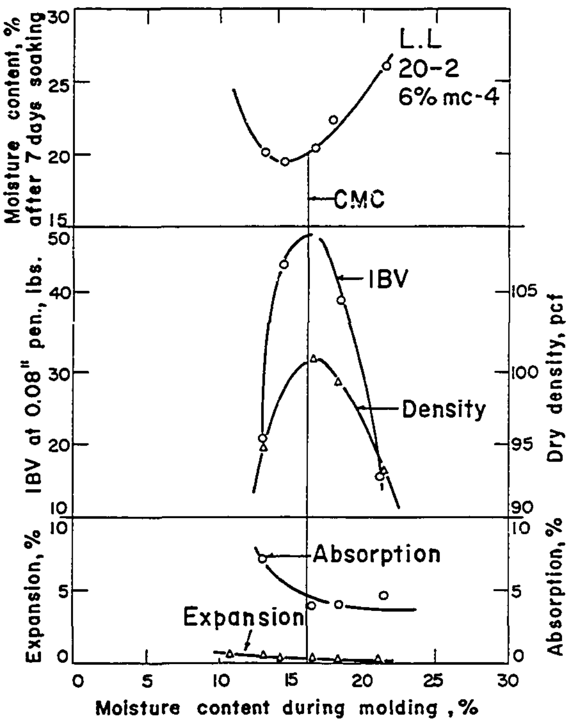
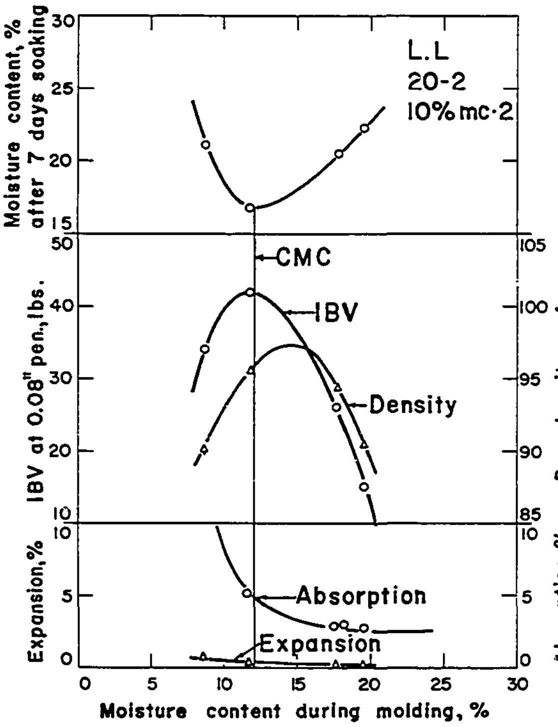
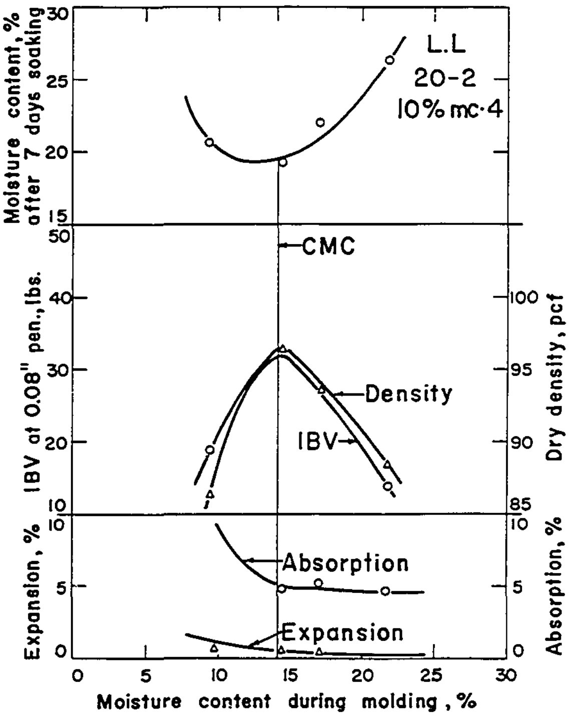

O.M.C.
20-2
10% mc-4
Moisture content, % after 7 days soaking
CMC
IBV at 0.08" pen., lbs.
Dry density, pcf
Dry density
IBV
Expansion, %
Absorption, %
Absorption
Expansion
Moisture content during molding, %

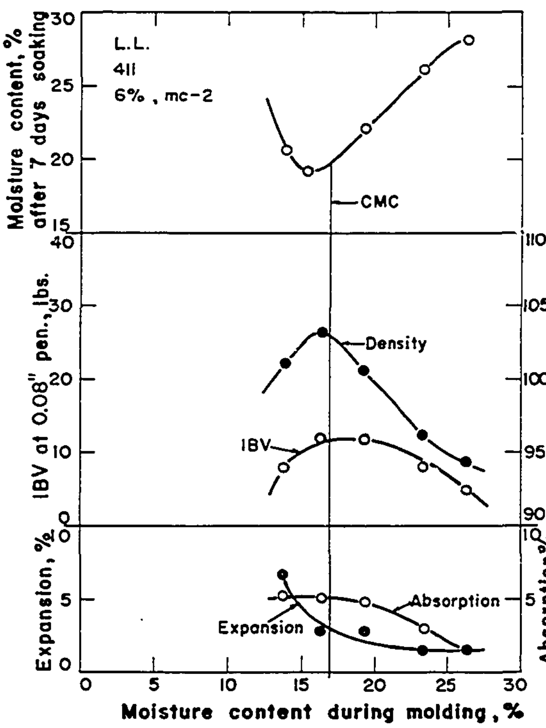
Figure 8. Graphs of moisture content during molding versus the IBV, dry density, absorption, expansion and total moisture content after 7 days soaking of soil-cutback asphalt compacted specimens. The soil-cutback asphalt compositions and the moisture content at which the mixes were mixed are listed on each graph. The amount of residual asphalt cement in 6 percent MC-2 is 4.93 percent. The vertical line in the center of the graphs indicates the CMC.

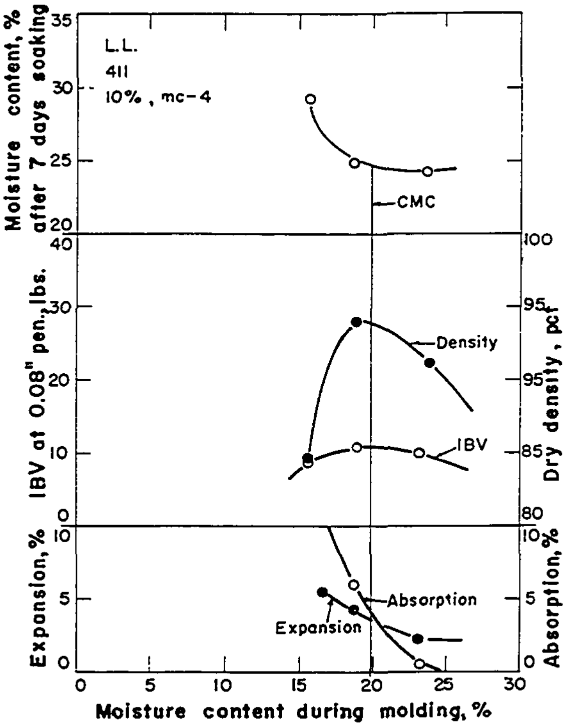

L.L
20-2
6%mc-2
Moisture content, % after 7 days soaking
30
25
20
15
CMC
IBV at 0.08" pen., lbs.
55
45
35
25
15
Density
IBV
Dry density, pcf
105
100
95
90
Expansion, %
Absorption, %
10
5
0
Absorption
Expansion
0
5
10
15
20
25
30
Moisture content during molding, %

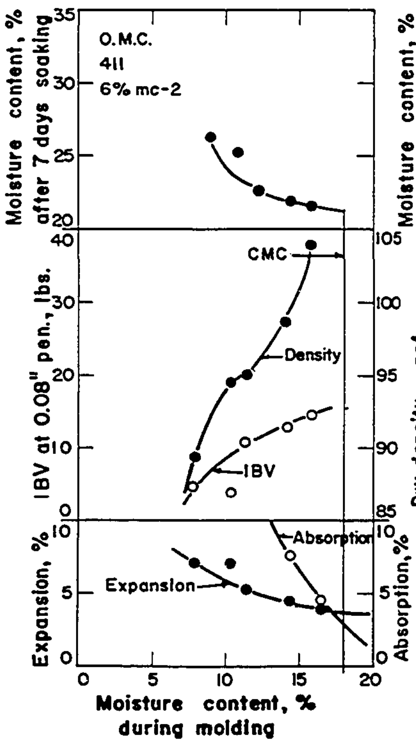

L.L
20-2
6% mc-4
Moisture content, % after 7 days soaking
30
25
20
15
CMC
IBV at 0.08" pen., lbs.
50
40
30
20
10
IBV
Density
Dry density, pcf
105
100
95
90
Expansion, %
Absorption, %
10
5
0
Absorption
Expansion
0
5
10
15
20
25
30
Moisture content during molding, %


L.L
20-2
10%mc-2
Moisture content, % after 7 days soaking
30
25
20
15
CMC
IBV at 0.08" pen., lbs.
50
40
30
20
10
IBV
Density
Dry density, pcf
105
100
95
90
85
Expansion, %
Absorption, %
10
5
0
Absorption
Expansion
0
5
10
15
20
25
30
Moisture content during molding, %


L.L
20-2
10% mc-4
Moisture content, % after 7 days soaking
30
25
20
15
CMC
IBV at 0.08" pen., lbs.
50
40
30
20
10
Density
IBV
Dry density, pcf
100
95
90
85
Expansion, %
Absorption, %
10
5
0
Absorption
Expansion
0
5
10
15
20
25
30
Moisture content during molding, %


Moisture content, % after 7 days soaking
L.L.
411
6% , mc-2
CMC
IBV at 0.08" pen., lbs.
Density
IBV
Dry density , pcf
Expansion, %
Absorption, %
Absorption
Expansion
Moisture content during molding, %


Moisture content, % after 7 days soaking
L.L.
411
10% , mc-4
CMC
IBV at 0.08" pen., lbs.
Density
IBV
Dry density , pcf
Expansion, %
Absorption, %
Absorption
Expansion
Moisture content during molding, %


Moisture content, % after 7 days soaking
O.M.C.
411
6% mc-2
CMC
Density
IBV
IBV at 0.08" pen., lbs.
Dry density, pcf
Expansion, %
Absorption, %
Absorption
Expansion
Moisture content, % during molding

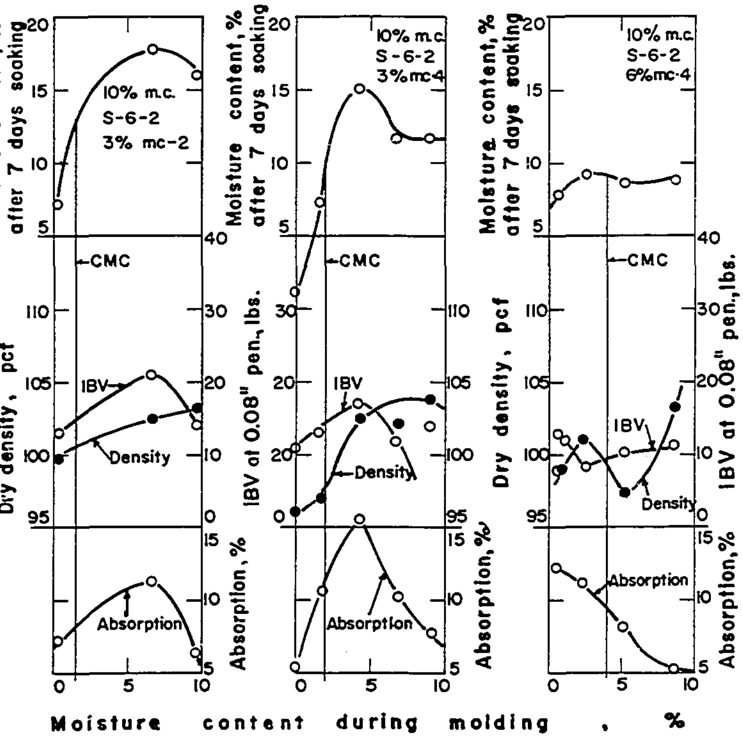
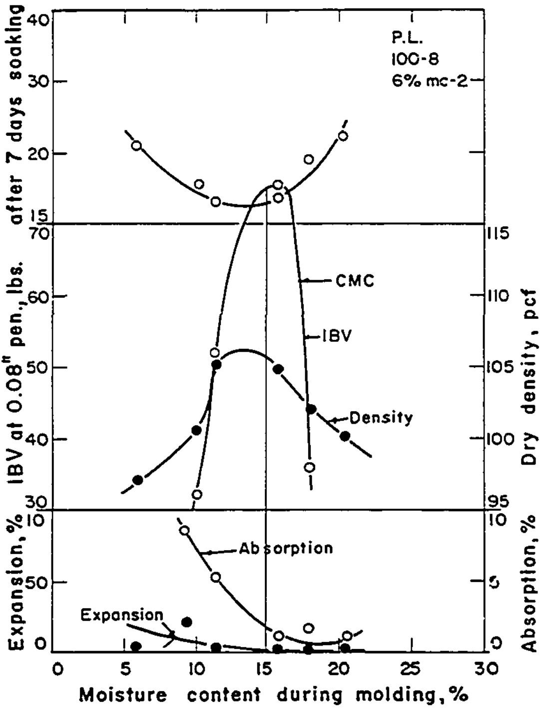
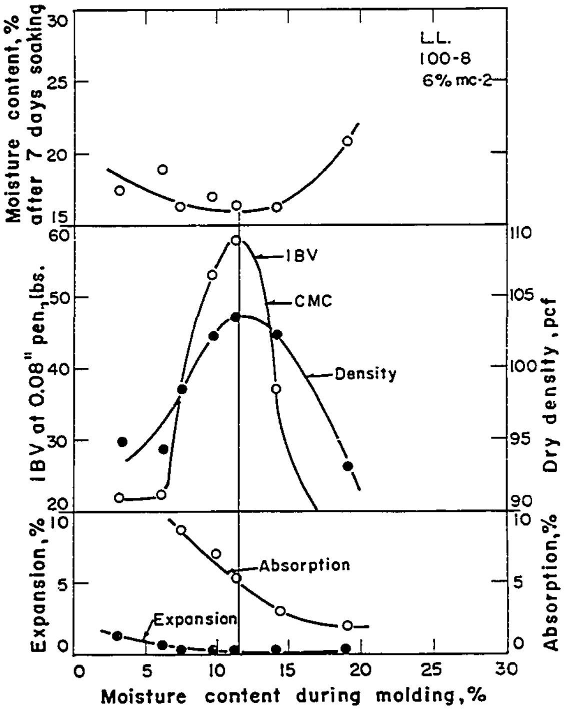
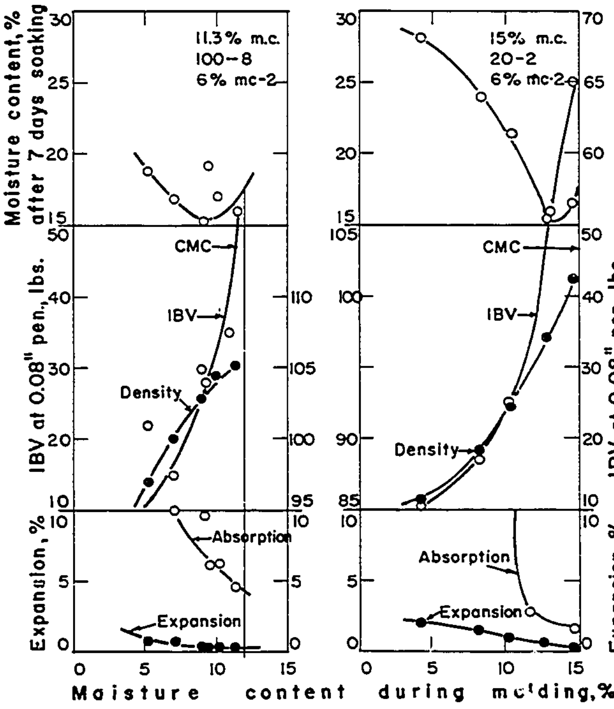

Moisture content, % after 7 days soaking
10% m.c.
S-6-2
3% mc-2
CMC
IBV
Density
Dry density, pcf
Absorption, %
Absorption
10% m.c.
S-6-2
3%mc-4
IBV at 0.08" pen., lbs.
10% m.c.
S-6-2
6%mc-4
Moisture content during molding , %

Figure 9. Graphs of moisture content during molding versus the IBV, dry density, absorption, expansion and total moisture content after 7 days soaking of soil-cutback asphalt compacted specimens. The soil-cutback asphalt compositions and the moisture content at which the mixes were mixed are listed on each graph. The amount of residual asphalt cement in 3, 6 and 10 percent MC-2 is 2.47, 4.93 and 8.2 percent, and in 3, 6 and 10 percent MC-4 is 2.7, 5.47 and 9.11 percent. The vertical line in the center of the graphs indicates the CMC.


P.L.
100-8
6% mc-2
Moisture content, % after 7 days soaking
40
30
20
15
IBV at 0.08" pen., lbs.
70
60
50
40
30
Dry density, pcf
115
110
105
100
95
CMC
IBV
Density
Expansion, %
10
50
0
Absorption, %
10
5
0
Absorption
Expansion
0
5
10
15
20
25
30
Moisture content during molding, %


L.L.
100-8
6% mc-2
Moisture content, % after 7 days soaking
30
25
20
15
IBV at 0.08" pen., lbs.
60
50
40
30
20
Dry density, pcf
110
105
100
95
90
IBV
CMC
Density
Expansion, %
10
5
0
Absorption, %
10
5
0
Absorption
Expansion
0
5
10
15
20
25
30
Moisture content during molding, %


11.3% m.c.
100-8
6% mc-2
Moisture content, % after 7 days soaking
30
25
20
15
IBV at 0.08" pen., lbs.
50
40
30
20
10
110
105
100
95
CMC
IBV
Density
Expansion, %
10
5
0
10
5
0
Absorption
Expansion
0
5
10
15
15% m.c.
20-2
6% mc-2
30
25
20
15
70
65
60
105
100
90
85
50
40
30
20
10
CMC
IBV
Density
10
5
0
10
0
Absorption
Expansion
0
5
10
15
Moisture content during mc'ding, %

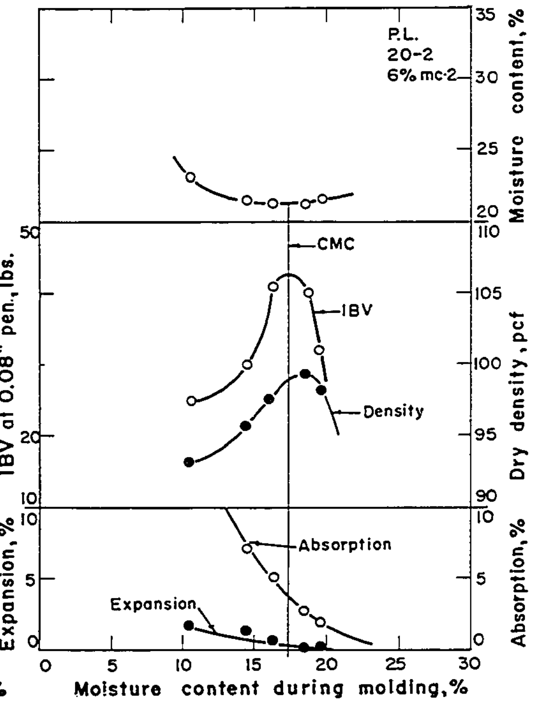

P.L.
20-2
6% mc-2
Moisture content, %
35
30
25
20
IBV at 0.08" pen., lbs.
50
20
10
Dry density, pcf
110
105
100
95
90
CMC
IBV
Density
Expansion, %
10
5
0
Absorption, %
10
5
0
Absorption
Expansion
0
5
10
15
20
25
30
Moisture content during molding, %

Table 6. Data from Process II: mixed - dried - molded

Soil	Amount and type of cutback asphalt	Moisture content during mixing	Optimum moisture content of soil	Moisture content during molding, %, at:			Calculated moisture content where minimum summation of deviation occurs, %
				Maximum IBV	Maximum dry density	Minimum moisture content after 7 days soaking	
20-2	6% MC-2	14.8	18.0	14.8[a]	14.8[a]	13.5	15.0[a]
		O.M.C.		15.4	16.7	14.2	15.5
		P.L.		17.4	18.5	16.0	17.3
		L.L.		14.8	16.5	14.5	15.2
	10% MC-2	O.M.C.	18.0	12.3	16.5	13.6	12.7
		L.L.		11.6	14.5	12.2	12.1
	6% MC-4	O.M.C.	18.0	15.6	17.3	16.2	15.9
		L.L.		16.2	16.6	14.5	16.2
	10% MC-4	O.M.C.	18.0	14.8	17.5	13.5	14.7
		L.L.		14.5	14.5	12.4	14.1
100-8	6% MC-2	11.3	15.8	11.3[a]	11.3[a]	9.2	12.0[a]
		P.L.	15.8	15.5	13.5	13.8	14.9
		L.L.	15.8	11.4	11.4	12.0	11.5

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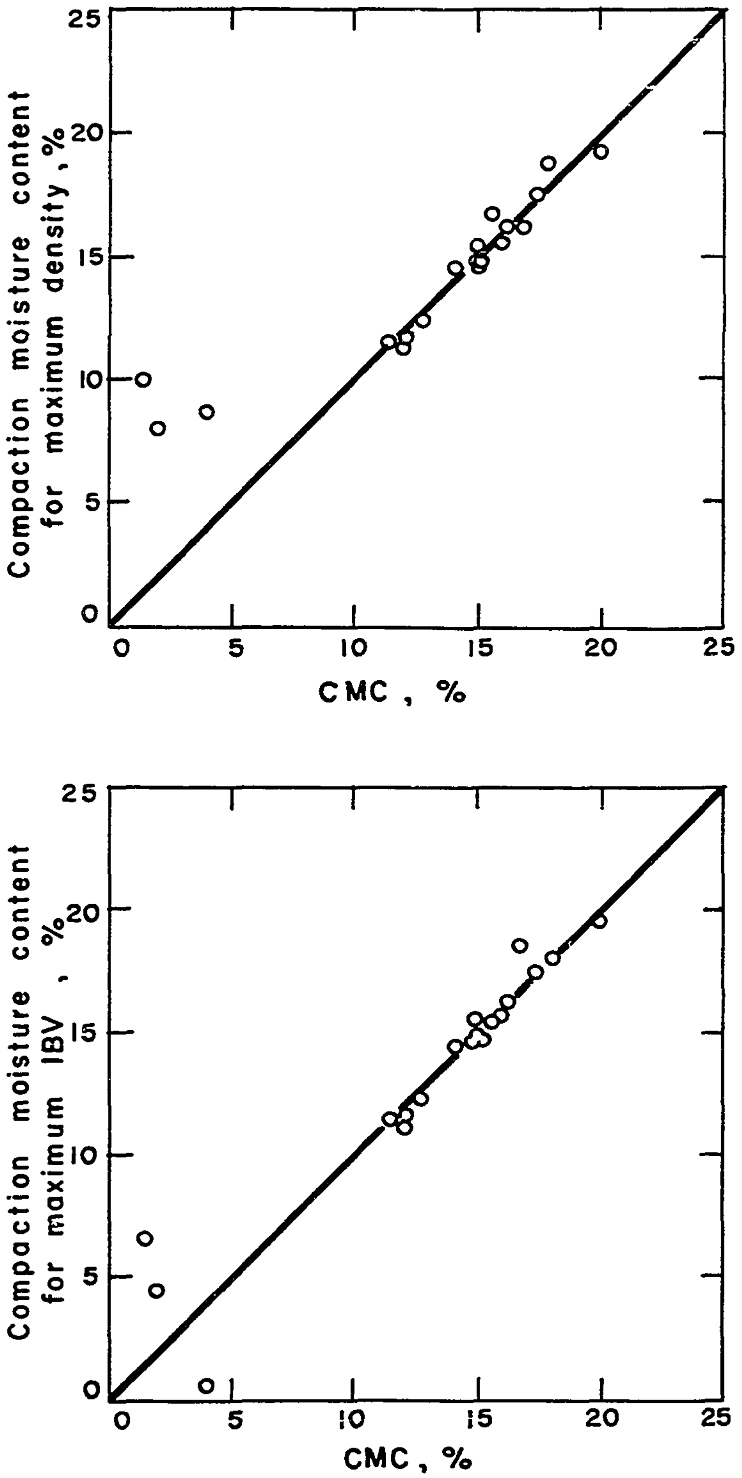
[a] Visually estimated because maxima and minima were indefinite.

Table 6. (Continued)

Soil	Amount and type of cutback asphalt	Moisture content during mixing	Optimum moisture content of soil	Moisture content during molding, %, at:			Calculated moisture content where minimum summation of deviation occurs, %
				Maximum IBV	Maximum dry density	Minimum moisture content after 7 days soaking	
411	6% MC-2	O.M.C.	15.5	18.0[a]	19.0[a]	16.5[a]	18.0[a]
		L.L.		18.5	16.2	15.5	16.8
	10% MC-4	L.L.	15.5	19.5	19.3	23.0	19.9
S-6-2	3% MC-2	10%	12.3	6.6	10.0[a]	6.9[a]	1.5[a]
	3% MC-4	10%	12.3	4.4	8.0	--	2.0[a]
	6% MC-4	10%	12.3	0.5[a]	8.7[a]	--	4.0[a]

Figure 10. Graph comparing compaction moisture content for maximum standard Proctor density and compaction moisture content for maximum IBV with the compromise moisture content. Exact correlation of the experimental data would fall on the indicated 45 degree line. This relation holds true for silty and clayey soils used in this investigation.


Compaction moisture content for maximum density, %
0
5
10
15
20
25
CMC, %
Compaction moisture content for maximum IBV, %
CMC, %

Process II

Table 7. Test data from drying back study - Process II

Mix no.	Mixture	Moisture content during molding, %		Volatile material present during molding, %	Moisture content + volatiles during molding, %	IBV @ .08" pen. lbs.	Oven dry density, pcf	Absorption, %	Expansion, %	Moisture content after absorption, %
		VST method	ASTM method							
A-0	Soil 20-2	18.7	18.6	1.10	19.8	16	97.5	1.5	0.2	20.2
A-1	6% MC-2	17.5	17.2	1.09	18.59	33	100.1	1.9	0.5	19.4
A-2	18.9%	15.1	14.7	1.06	10.16	54	100.1	3.8	0.7	18.9
A-3	H_2O	12.6	12.1	1.04	13.64	32	97.1	6.6	1.0	19.2
A-4		9.7	9.7	1.04	10.74	23	96.7	10.4	1.45	20.1
A-5		8.0	7.5	0.80	8.80	19	94.0	15.5	1.7	23.5
B-0	Soil 20-2	24.4	24.7	1.09	25.49	--	--	--	--	--
B-1	6% MC-2	19.6	19.8	1.07	20.67	32	98.4	2.0	0.1	21.6
B-2	25.4%	18.5	19.5	1.05	19.55	40	99.5	2.7	0.15	21.2
B-3	H_2O	16.3	16.1	1.05	17.35	41	97.6	5.1	0.51	21.4
B-4		14.5	14.3	1.06	15.56	30	95.6	7.06	1.4	21.56
B-5		10.5	10.3	0.98	11.48	25	93.2	12.6	1.6	23.1
C-0	Soil 20-2	31.3	31.7	1.08	32.38	--	--	--	--	--
C-1	6% MC-2	25.1	25.8	1.06	26.16	5	88.7	1.02	-ve	26.12
C-2	31.7%	22.7	22.0	1.01	23.71	9	97.6	1.2	0.05	23.9
C-3	H_2O	20.3	19.9	1.03	21.33	15	100.8	1.3	0.23	21.6
C-4		19.7	19.7	1.03	20.73	24	104.0	1.3	0.50	21.0
C-5		16.4	16.4	1.03	17.43	50	105.5	2.01	1.0	18.41
C-6		14.6	14.7	1.03	15.63	56	103.4	5.2	0.9	19.8
C-7		13.2	12.4	1.03	14.23	36	101.2	6.4	0.9	19.6
C-8		7.9	7.4	1.00	8.9	27	95.8	12.6	--	20.5

Table 7. (Continued)

Mix no.	Mixture	Moisture content during molding, %		Volatile material present during molding, %	Moisture content - volatiles during molding, %	IBV @ .08" pen. lbs.	Oven dry density, pcf	Absorption, %	Expansion, %	Moisture content after absorption, %
		VST method	ASTM method							
D-0	Soil 20-2	18.7	18.6	1.84	20.54	20	93.0	2.2	0.15	20.9
D-1	10% MC-2	15.3	15.0	1.53	10.83	31	93.6	3.95	0.5	19.25
D-2	18.7%	12.5	12.0	1.18	13.68	36	93.0	7.0	0.3	19.5
D-3	H_2O	8.4	8.5	0.87	9.27	23	88.1	13.8	0.65	22.2
E-0	Soil 20-2	33.8	33.2	1.81	35.61	--	--	--	--	--
E-1	10% MC-2	19.5	18.7	1.30	20.80	15	90.5	2.68	0.05	22.18
E-2	33.8%	17.6	16.8	1.31	18.91	26	94.5	2.82	0.25	20.42
E-3	H_2O	11.7	12.3	0.97	12.67	42	95.6	5.1	0.4	16.8
E-4		8.6	7.6	0.98	9.58	34	90.2	12.4	0.7	21.0
F-0	Soil 20-2	17.7	18.3	0.72	18.42	29	101	0.97	0.25	18.67
F-1	6% MC-4	15.5	14.3	0.71	10.21	36	99	4.4	0.5	19.9
F-2	17.8%	13.0	12.9	0.68	13.68	22	98.3	6.4	1.1	19.4
F-3	H_2O	9.9	9.8	0.65	10.55	17	89.6	15.5	1.25	25.4
F-4		7.8	6.5	0.65	8.45	12	85.5	14.9	0.9	22.7
G-0	Soil 20-2	30.7	30.5	0.67	31.37	--	--	--	--	--
G-1	6% MC-4	21.3	21.1	0.66	21.90	16	93.5	4.7	0.2	26.0
G-2	30.8%	18.3	17.7	0.66	18.96	40	99.5	4.0	0.45	22.3
G-3	H_2O	16.5	16.0	0.66	17.16	49	101.2	4.0	0.45	20.5
G-4		14.4	14.1	0.65	15.05	45	98.7	5.0	0.50	19.4
G-5		16.0	12.3	0.64	13.64	21	95	7.2	0.65	20.2

Table 7. (Continued)

Mix no.	Mixture	Moisture content during molding, %		Volatile material present during molding, %	Moisture content - volatiles during molding, %	IBV @ .08" pen. lbs.	Oven dry density, pcf	Absorption, %	Expansion, %	Moisture content after absorption, %
		VSM method	ASTM method							
H-0	Soil 20-2	17.3	17.6	1.18	18.48	26	94.4	2.0	0.5	19.3
H-1	10% MC-4	15.3	14.6	1.05	16.35	32	93.6	4.02	1.1	19.3
H-2	17.8%	11.0	11.5	0.97	11.97	27	88.2	8.0	0.65	19.0
H-3	H_2O	8.6	7.7	0.84	8.84	20	79	13.9	0.65	22.5
H-4		5.9	5.6	0.82	5.82	17	75	14.7	0.90	20.6
I-0	Soil 20-2	30.7	30.4	1.20	31.92	--	--	--	--	--
I-1	10% MC-4	21.6	20.6	1.15	22.75	14	88.5	4.65	0.3	26.25
I-2	30.8%	17.0	16.9	1.13	18.13	26	93.6	5.2	0.35	22.2
I-3	H_2O	14.4	14.4	1.14	15.54	32	96.5	4.9	0.6	19.3
I-4		9.4	8.9	1.09	10.49	19	86.4	11.2	0.6	20.6
J-0	Soil 411	16.8	17.3	1.30	18.10	15	104	4.5	4.1	21.3
J-1	6% MC-2	14.3	14.1	1.31	15.6	13	98.7	7.6	4.6	21.9
J-2	15.6%	12.4	11.4	1.00	13.4	11	95.0	10.2	5.4	22.6
J-3	H_2O	10.8	9.6	1.00	11.8	4	94.6	14.4	7.1	25.2
J-4		8.8	7.9	1.00	9.8	5	89.5	17.5	7.1	26.3
K-0	Soil 411	42.0	42.6	1.32	43.32	--	--	--	--	--
K-1	6% MC-2	30.0	29.9	1.30	31.3	--	--	--	--	--
K-2	43.0%	26.3	26.3	1.17	27.47	9	92.5	1.81	1.5	28.11
K-3	H_2O	23.3	22.8	1.19	24.49	8	96.2	2.9	2.8	26.2
K-4		19.3	19.2	1.10	20.40	12	100.6	2.9	4.9	22.2
K-5		16.4	17.1	1.13	17.53	12	103.2	2.8	5.0	19.2
K-6		13.9	13.7	1.05	14.95	8	101.0	2.7	5.3	20.6

Table 7. (Continued)

Mix no.	Mixture	Moisture content during molding, %		Volatile material present during molding, %	Moisture content - volatiles during molding, %	IBS @ .08" pen. lbs.	Oven dry density, pcf	Absorption,%	Expansion,%	Moisture content after absorption,%
		VSM method	ASTM method							
L-0	Soil 411	42.4	41.9	1.14	43.54	--	--	--	--	--
L-1	10% MC-4	23.9	23.5	1.10	25.0	10	91	0.0	2.4	24.3
L-2	41.5%	18.9	18.7	1.09	19.99	11	93.8	6.0	4.4	24.9
L-3	H_2O	15.7	14.3	1.09	16.79	8	84.5	13.7	5.5	29.4
M-0	Soil S-6-2	0.3	--	0.23	0.53	9	106.8	5.6	-ve	5.9
M-1	3% MC-2	0.2	--	0.13	0.33	14	104.5	5.1	-ve	5.8
M-2	0.3%	nil	--	0.11	0.11	7	102.4	6.8	-ve	6.8
M-3	H_2O	nil	--	0.08	0.08	10	102.0	6.7	-ve	6.7
N-0	Soil S-6-2	9.8	9.4	0.46	10.26	14	103.2	6.4	-ve	10.2
N-1	3% MC-2	6.7	6.7	0.45	7.15	21	102.5	11.2	-ve	17.9
N-2	9.8% H_2O	0.2	nil	0.20	0.40	13	100	7.1	-ve	7.3
O-0	Soil S-6-2	9.0	9.0	0.35	9.35	14	103.5	7.8	-ve	16.8
O-1	3% MC-4	6.8	6.7	0.34	7.14	12	102.0	10.1	-ve	16.9
O-2	9.6%	4.3	4.6	0.25	4.55	17	102.5	15.7	-ve	20.0
O-3	H_2O	1.7	1.28	0.13	1.83	13	97.0	10.6	-ve	12.3
O-4		0.0	0.0	0.11	0.11	11	96.0	6.0	-ve	6.0
P-0	Soil S-6-2	8.7	8.7	0.53	9.23	11	103.2	5.2	-ve	13.9
P-1	6% MC-4	5.3	5.3	0.48	5.78	10	97.2	8.3	-ve	13.6
P-2	9.2%	2.5	2.5	0.35	2.85	8	101.2	11.7	-ve	14.2
P-3	H_2O	0.6	0.6	0.13	0.73	11	99	12.3	-ve	12.9

Table 8. Test data of drying back study, wherein only ASTM method was used for determining moisture content

Soil no.	Mix no.	M.C. during mixing, %	Type of cutback asphalt	Amount of cutback asphalt added, %	M.C. during molding, % ASTM	IBV @ .08" pen.	Oven dry density, pcf	Absorption, %	Expansion, %	Total moisture content after absorption, %
100-8	Q-0	11.3	MC-2	6	11.3	52	105.3	4.7	0.1	16.0
	Q-1	"	"	"	10.8	35	104.5	6.3	0.2	17.1
	Q-2	"	"	"	9.3	28	103.1	9.9	0.2	19.2
	Q-3	"	"	"	9	30	102.9	6.2	0.4	15.2
	Q-4	"	"	"	7.0	15	100.0	10	0.65	17.0
	Q-5	"	"	"	5.1	22	97.0	13.7	0.7	18.8
100-8	R-0	20.3	MC-2	6	20.2	12	100	1.08	0.1	21.28
	R-1	"	"	"	17.9	36	102	1.6	nil	19.5
	R-2	"	"	"	15.8	76	104.9	1.1	nil	16.9
	R-3	"	"	"	11.4	52	105.2	5.3	0.1	16.7
	R-4	"	"	"	9.3	32	100.5	8.5	2.2	17.8
	R-5	"	"	"	5.8	26	97.2	14.7	0.4	20.5
100-8	S-0	28.4	MC-2	6	19.0	12	93	1.8	0.2	20.8
	S-1	"	"	"	14.2	37	102.5	2.9	0.1	17.1
	S-2	"	"	"	11.3	58	103.5	5.1	0.1	16.4
	S-3	"	"	"	9.8	53	102.2	7.0	0.2	16.8
	S-4	"	"	"	7.5	37	98.5	8.7	0.2	16.2
	S-5	"	"	"	6.2	22	94.5	12.7	0.5	18.9
	S-6	"	"	"	3.1	22	95	14.3	1.1	17.4

Table 8. (Continued)

Soil no.	Mix no.	M.C. during mixing, %	Type of cutback asphalt	Amount of cutback asphalt added, %	M.C. during molding, % ASTM	IBV @ .08" pen.	Oven dry density, pcf	Absorption, %	Expansion, %	Total moisture content after absorption, %
20-2	T-0	14.8	MC-2	6	14.8	65	101.2	1.7	0.2	16.5
	T-1	"	"	"	12.6	52	97	2.8	0.6	15.4
	T-2	"	"	"	10.3	25	92.2	11.4	1.0	21.4
	T-3	"	"	"	8.2	17	89	15.6	1.5	23.8
	T-4	"	"	"	4.4	10	85.6	23.6	2.0	28.0

requirements of Process II, with the possible exception of sand. The data indicate that for sand the CMC lies on the dry side of the dried back moisture content for standard Proctor density.

Comparisons of Processes I and II

Tables 9 and 10 compare Processes I and II on the basis of the values of IBV, density and total 7-day soaked moisture content obtained at the CMC of each process. All property values of specimens resulting from Process I were superior to those of corresponding specimens prepared by Process II with the exception of total 7 day soaked moisture content of the sand specimens mixed with MC-4. It would then appear that Process I produces the best results with the textural types of soil studied.

Heavier clays may require the use of Process II since the CMC of Process I may lie within the plastic range of the soil. Should this be so, adequate mixing of such a soil with asphalt at the CMC of Process I is impossible. The higher mixing moisture contents employed in Process II become the only possible solution because mixing is easily done near the liquid limit of highly plastic soils. The use of Process II increases the cost since the drying back stage is added and may therefore economically limit the application and use of cutback asphalt soil stabilization to medium to non-plastic soils.

Table 9. Best attainable values of IBV, density and total 7 day soaked moisture content at CMC using MC-2 cutback asphalt

		Process I			Process II				
					M.C. during mixing				
Soil no.	Amount of asphalt, %	IBV lbs.	Density pcf	Total moisture content, %	%	Corre-sponds to	IBV lbs.	Density pcf	Total moisture content, %
20-2	6	71	105	16.8	15.0		65	102	17.5
						O.M.C.	54	100	18.9
						P.L.	42	99	21.2
						L.L.	56	104	19.0
	10	54	98	14.8		O.M.C.	36	93	19.4
						L.L.	42	96	16.9
100-8	6	78	107	15.3	11.3		52	105	17.6
						P.L.	75	106	16.5
						L.L.	69	104	16.0
411	6	17	104	18.3		O.M.C.	15	105	21.3
						L.L.	12	103	19.7
S-6-2	3	10	106	7.0			15	101	13.0

Table 10. Best attainable values of IBV, density and total 7 day soaked moisture content at CMC using MC-4 cutback asphalt

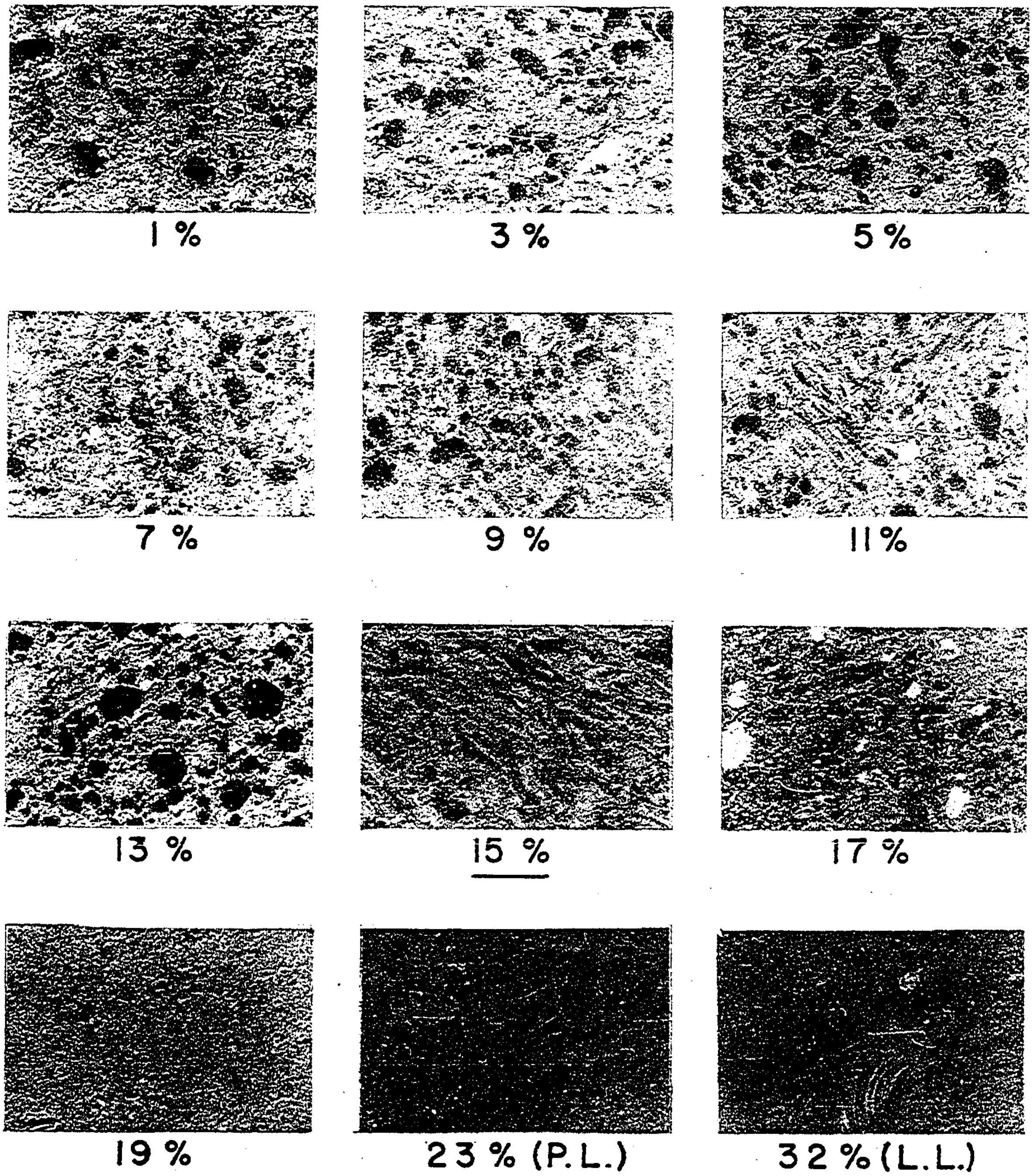
Soil no.	Amount of asphalt, %	Process I			Process II				
					M.C. during mixing				
		IBV lbs.	Density pcf	Total moisture content, %	%	Corre-sponds to	IBV lbs.	Density pcf	Total moisture content, %
20-2	6	51	105	15.9		O.M.C.	36	100	19.2
						L.L.	50	101	20.1
	10	43	96	11.5		O.M.C.	32	93	19.8
						L.L.	32	97	19.5
411	10	12	90	22.3		L.L.	11	94	24.5
S-6-2	3	17	105	17.0	10.0		24	98	10.0
	6	19	105	14.6	10.0		10	99	9.2

Distribution of asphalt

The water in soil-cutback asphalt mixtures not only aids in attaining maximum densities but also aids in obtaining even distribution of asphalt throughout the soil mass. A study of this was made by mixing batches of soil with a constant percentage of asphalt and varying amounts of water from one percent to percentages slightly above the liquid limit of the soil. Specimens were prepared by compaction and curing. Curing was done to remove moisture so that the areas containing cutback asphalt showed a high contrast to the areas containing little or no cutback asphalt. Photographs of specimens from each batch were made and are shown in Figure 11 to 15. The percentages indicated below each photograph represents the moisture content during mixing. The underlined percentage is the moisture content that lies the closest (of those shown) to the compromise moisture content as determined from the experimental data.

Figures 11 to 15, which are photographs of compacted cutback asphalt treated loess and glacial till, show that the asphalt tends to be locally concentrated and poorly distributed at low mixing moisture contents as indicated by the dark areas which contain the highest cutback asphalt concentrations. The distribution of cutback asphalt improves as the amount of mixing water is increased and the most uniform

Figure 11. Photographs of Process I compacted specimens of 20-2 (loess) treated with 6 percent MC-2 and various percentages of mixing water. The percentage of mixing water is indicated below each graph. The underlined percentage indicates the moisture content that is the closest to the cmc of the mixtures shown. Photographs of specimens mixed at the plastic limit and the liquid limit of the soil are indicated by the initials P.L. and L.L. following the appropriate moisture percentages. The residual asphalt cement content is 4.93 percent.



1 %　3 %　5 %

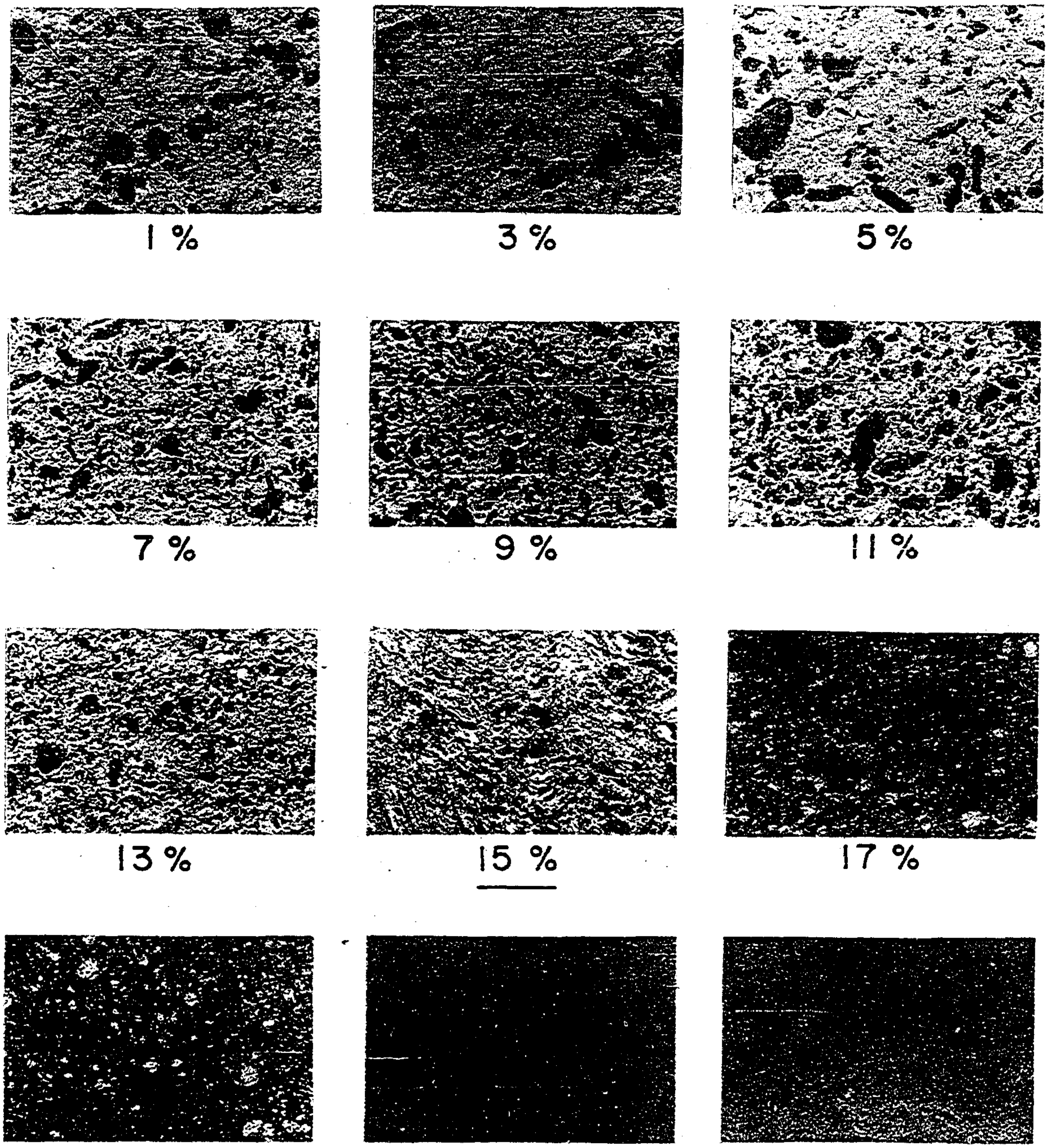
7 %　9 %　11 %

13 %　15 %　17 %

19 %　23 % (P.L.)　32 % (L.L.)

20 - 2 (loess) 6 %, MC-2

Figure 12. Photographs of Process I compacted specimens of 20-2 (loess) treated with 6 percent MC-4 and various percentages of mixing water. The percentage of mixing water is indicated below each graph. The underlined percentage indicates the moisture content that is the closest to the CMC of the mixture shown. Photographs of specimens mixed at the plastic limit and the liquid limit of the soil are indicated by the initials P.L. and L.L. following the appropriate moisture percentages. The residual asphalt cement content is 5.47 percent.



1 %

3 %

5 %

7 %

9 %

11 %

13 %

<u>15 %</u>

17 %

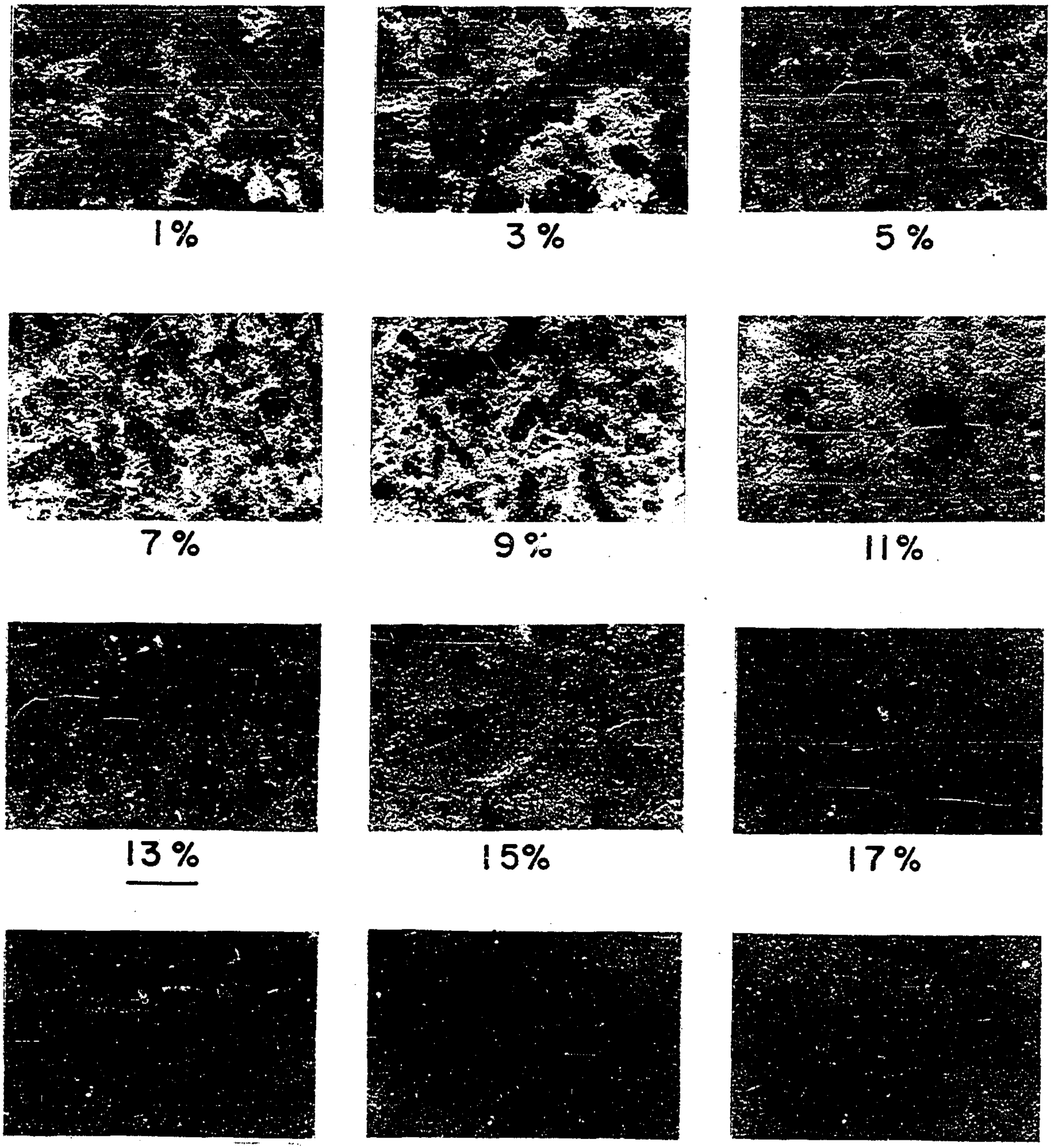
19 %

23 %(P.L.)

32 %(L.L.)

20-2 (loess) 6%, MC-4

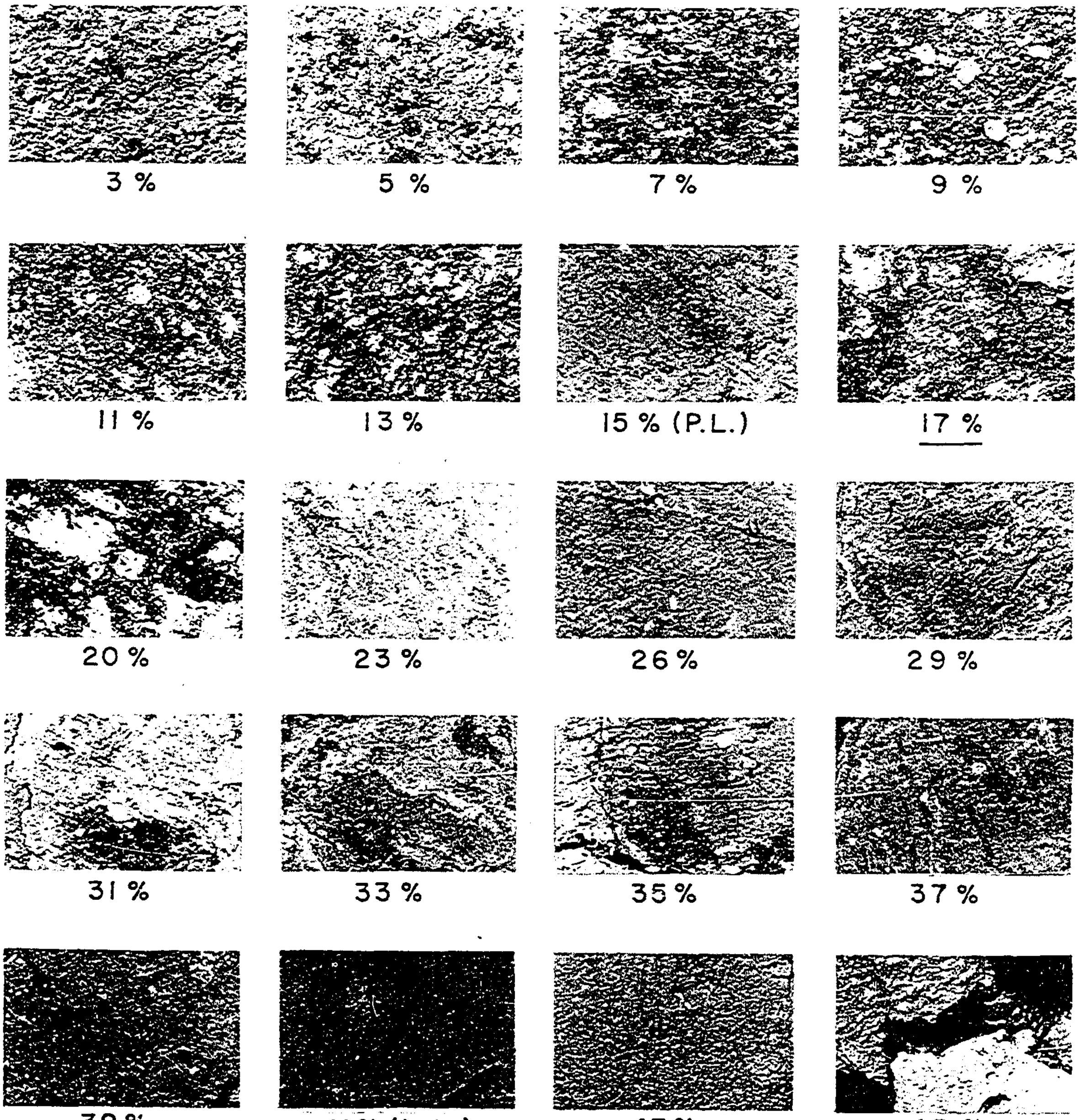
Figure 13. Photographs of Process I compacted specimens of 100-8 (loess) treated with 6 percent MC-2 and various percentages of mixing water. The percentage of mixing water is indicated below each graph. The underlined percentage indicates the moisture content that is the closest to the CMC of the mixture shown. Photographs of specimens mixed at the plastic limit and the liquid limit of the soil are indicated by the initials P.L. and L.L. following the appropriate moisture percentages. The residual asphalt cement content is 4.93 percent.



1%
3 %
5 %
7 %
9 %
11%
13 %
15%
17 %
20 % (P.L.)
27 % (L.L.)
31 %

100-8 (loess) 6 %, MC-2

Figure 14. Photographs of Process I compacted specimens of 411 (glacial till) treated with 6 percent MC-2 and various percentages of mixing water. The percentage of mixing water is indicated below each graph. The underlined percentage indicates the moisture content that is the closest to the CMC of the mixture shown. Photographs of specimens mixed at the plastic limit and the liquid limit of the soil are indicated by the initials P.L. and L.L. following the appropriate moisture percentages. The residual asphalt content is 4.93 percent.



3 %

5 %

7 %

9 %

11 %

13 %

15 % (P.L.)

17 %

20 %

23 %

26 %

29 %

31 %

33 %

35 %

37 %

39 %

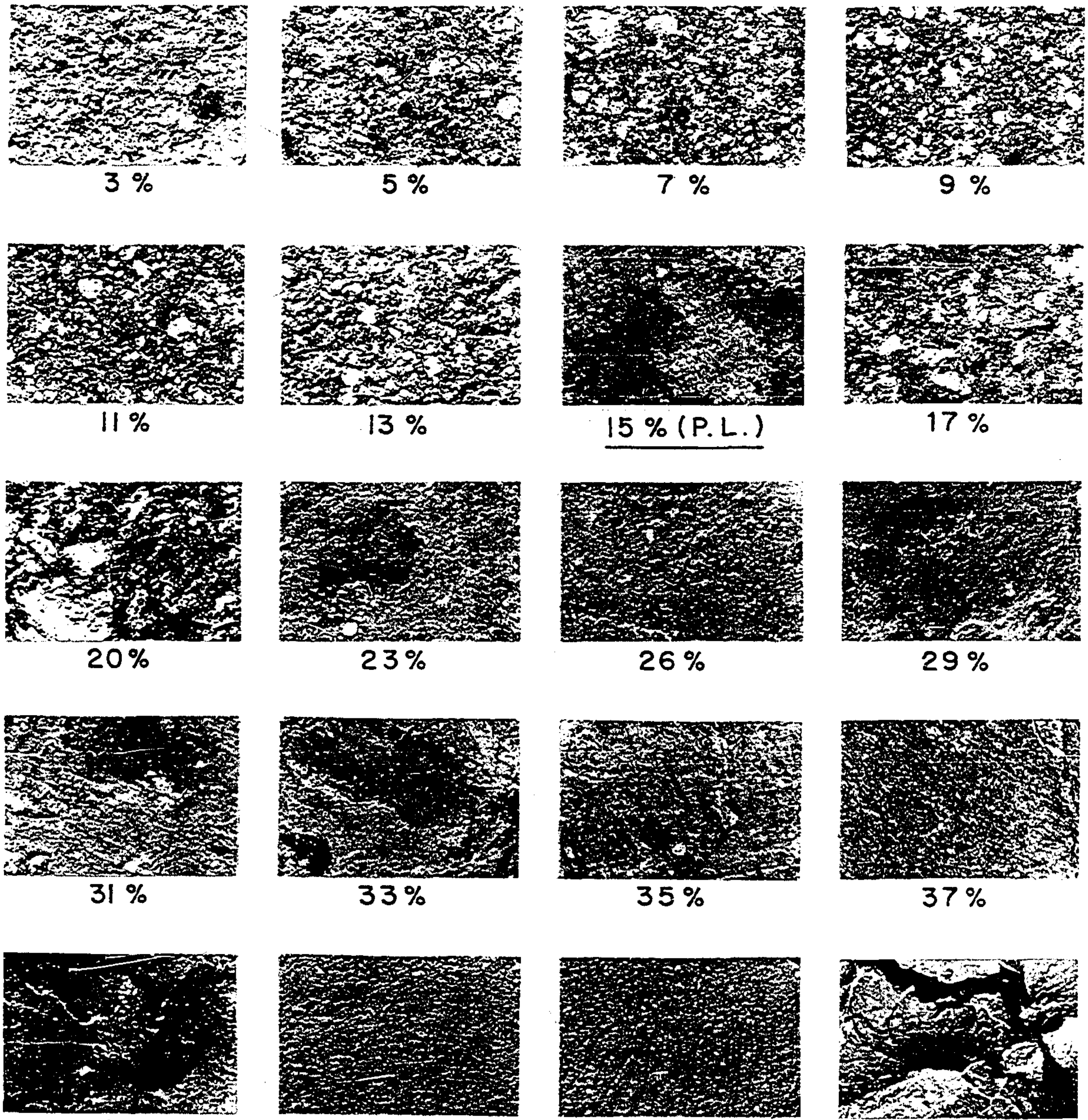
41 % (L.L.)

43 %

45 %

411 (till) 6%, MC-2

Figure 15. Photographs of Process I compacted specimen of 411 (glacial till) treated with 6 percent MC-4 and various percentages of mixing water. The percentage of mixing water is indicated below each graph. The underlined percentage indicates the moisture content that is the closest to the CMC of the mixture shown. Photographs of specimens mixed at the plastic limit and the liquid limit of the soil are indicated by the initials P.L. and L.L. following the appropriate moisture percentages. The residual asphalt cement content is 5.47 percent.



3 % 5 % 7 % 9 %

11 % 13 % 15 % (P.L.) 17 %

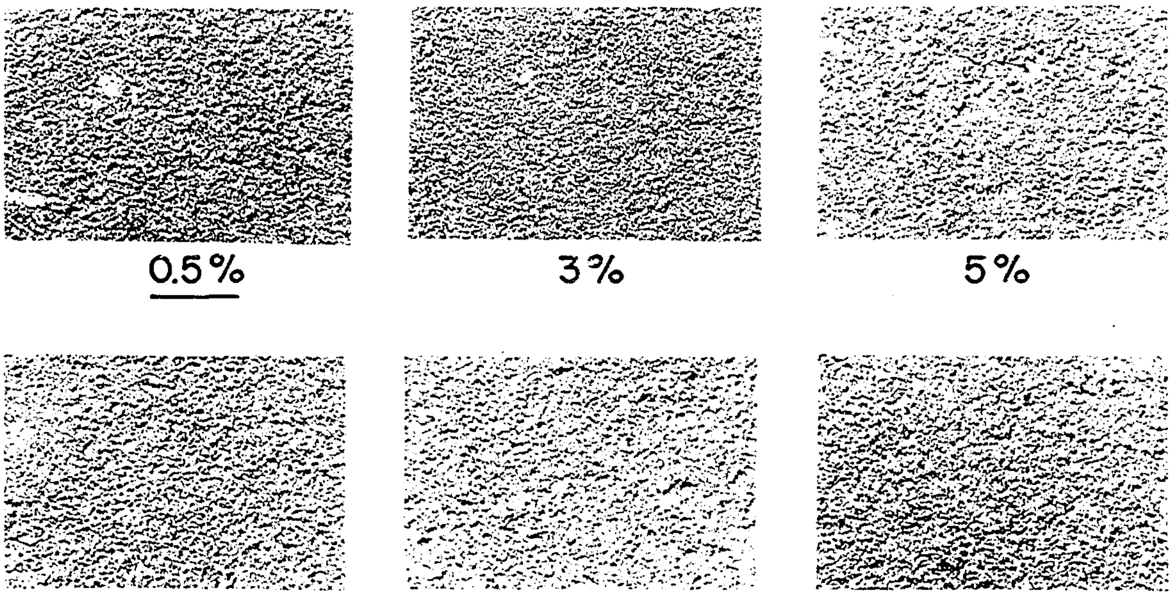
20% 23% 26 % 29 %

31 % 33% 35 % 37 %

39% 41% (L.L.) 43 % 45%

411 (till) 6%, MC-4

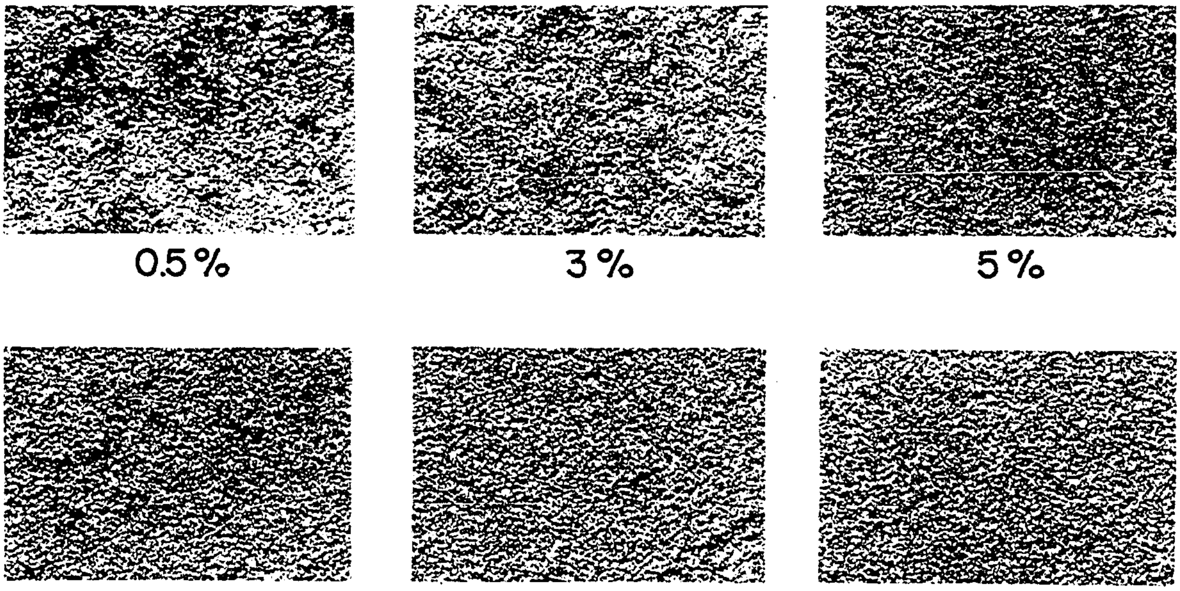
Figure 16. Photographs of Process I compacted specimen of S-6-2 (sand) treated with 3 percent MC-2 and MC-4 and various percentages of mixing water. The percentage of mixing water is indicated below each graph. The underlined percentage indicates the moisture content that is the closest to the CMC of the mixture shown. The residual asphalt cement content is 2.47 percent for MC-2 mixes and 2.74 percent for MC-4 mixes.



0.5% 3% 5%

7% 9% 11%

S-6-2 (sand) 3% MC-2



0.5% 3% 5%

7% 9% 11%

S-6-2 (sand) 3% MC-4

distribution appears to be somewhere in the neighborhood of the liquid limit of the soil. No difference in distribution pattern was noticed between MC-2 and MC-4 treatment of these soils.

Loess. The photographs show that the compromise moisture content (CMC) for the two loess (20-2 and 100-8) soils occurs at about the mixing moisture content where the asphalt appears to be streaked or smeared in the soil rather than uniformly distributed. The CMC also lies well below the plastic limit of the soil. Mixing moisture contents above the CMC produce much more uniform distribution of asphalt but evidently the asphalt films resulting from mixing in this moisture range do not produce optimum cohesion and lower permeability. The loess soils mixed easily with asphalt at all moisture contents.

Glacial till. The photographs of the glacial till show that the asphalt is generally more poorly distributed than in the loess, but the asphalt also shows a smeared appearance near the CMC, though the smeared condition is not as clearly indicated as in the loess samples. The glacial till was very difficult to mix with asphalt when the mixing moisture was in a range of 2 to 8 percent above the plastic limit of the soil. Resistance to mixing was sufficient to break the mixing machine, and machine mixing was only carried on for about one half a minute; no supplemental hand mixing was used. The mixing limitations imposed by the highly plastic character of this soil are, no doubt, partially responsible for the poor distribution of asphalt. Extensive planes of asphalt resulted in many mixes when the system was in the plastic state due to moisture content. Specimens prepared from mixtures with moisture contents above the plastic limit showed a decided tendency to develop shrinkage cracks during drying; the amount and size of the cracks increased with the mixing moisture content as shown in Figures 14 and 15.

Sand. Figure 16 shows that a different water relationship exists in the sand (S-6-2) specimens treated with MC-2 and MC-4. The top six photographs are of sand treated with MC-2 and the bottom six are of sand treated with MC-4. The MC-2 treated specimens have an estimated CMC of 1 percent whereas the MC-4 treated specimens have a CMC of 11 percent. Close examination of these photographs shows decreased coating of sand grains as the mixing water content increased above 1 percent. With MC-4 cutback asphalt, better distribution was obtained as the mixing water content increased up to 11 percent. Evidently with MC-4 treatment water is beneficial to asphalt distribution; with MC-2 very little water is needed.

Failure to coat some grains was also noted in the loess and glacial till specimens that were mixed with the higher water contents. The number of uncoated grains was small since the failure to coat occurred on the sand grains which constitute only a fraction of the total soil used.

DISCUSSION

The data in the foregoing section indicate that cutback asphalt stabilization of the sandy, silty and clayey soils investigated is best accomplished by a process (Process I) in which the soil, cutback asphalt and water are mixed for a specific period of time following which the mixture is immediately compacted. The moisture content at which the silty and clayey soils are best stabilized with either MC-2 or MC-4 asphalt corresponds closely to the optimum moisture content for maximum standard Proctor density of the soil-asphalt mixture. The sandy soil required little or no moisture when stabilized with MC-2 asphalt but required enough water for maximum standard Proctor density when stabilized with MC-4.

The process (Process II) of mixing the materials at high moisture contents with a drying back period between mixing and compaction produced inferior results at the quantities of binder used. The high moisture contents were used to obtain a cutback asphalt distribution approaching that of an intimate mix. The drying back periods were necessary to reduce the moisture content of the mixture to that needed for maximum compacted densities. Even though Process II produces better distribution of cutback asphalt than Process I and both produce comparable compacted densities, Process I produces a compacted mixture that is more stable than that resulting from Process II. This indicates that the most thorough cutback asphalt distribution of the percentages used does not ensure the most stability of silty and clayey soils. There is some visual evidence that for sandy soils the moisture content for maximum density and the moisture content for maximum cutback asphalt distribution are coincident.

The photographic study of the effect of moisture content on the distribution of asphalt is not as precise as the quantitative moisture-property studies since the photograph showing best distribution of cutback asphalt must be estimated. However, the general range of moisture content in which the best distribution of cutback asphalt occurs is quite obvious.

The findings of this investigation are generally in agreement with Benson's and Becker's (12) conclusions that the maximum stability of cutback asphalt stabilized soil is reached at some definite degree of cutback asphalt distribution less than an intimate mix. The structure of the soil-cutback asphalt system at the point of maximum stability is believed to consist of small irregular soil aggregates within which there is no effective bituminous material. The surface of the soil aggregates are covered with asphalt films that vary in thickness and amount of coverage. Compaction of such a system produces a dense mass of individually waterproofed soil aggregates.

The basic structural system is thought to be established during the process of this type of mixing. The cutback asphalt is first dispersed throughout the soil in small globules as a discontinuous phase with the soil as a continuous phase. At this point in the mixing process, paths through the soil-cutback asphalt system may be found which do not pass through any cutback asphalt barriers. Continued mixing causes an inversion of the phases of the cutback asphalt and the soil; the soil tends to become discontinuous, and the cutback asphalt tends to become a continuous phase. The continuity of the cutback asphalt is probably never complete because the amount of cutback asphalt that can be used economically is too small.

Benson and Becker have proposed a phase-mixing theory based on the above observations. They propose, in essence, that maximum protection occurs for a soil treated with asphaltic material when the thickest film of asphaltic material which can be closely and permanently held on or absorbed into the surfaces of soil aggregates is secured. The system must be compacted and the soil aggregates must contain sufficient absorbed moisture to develop certain degrees of cohesiveness and plasticity.

The present investigation indicates that the special geometry of the Benson and Becker theory is correct and that moisture must be present to produce cohesiveness and plasticity in the soil aggregates. This investigation also indicates that moisture must be present for the purpose of attaining near maximum density in the individual soil aggregates and as an aid in the distribution of cutback asphalt. Maximum density of the soil aggregates must occur at nearly the same moisture content at which maximum density of the soil-cutback asphalt mass occurs since, for the percentages of cutback asphalt used, density is changed very little due to differences in specific gravity. The density of the mass is dependent mainly on the density of the individual soil aggregates.

Any amount of water greater than that required for maximum densities serves only to aid in obtaining a degree of distribution of cutback asphalt approaching an intimate mix. The excess water must then be evaporated in order to obtain good densification by compaction. Evidently, enough mixing to give high degrees of asphalt distribution results in films of asphalt too thin for optimum waterproofing and cutback asphalt cohesion, and a simultaneous occurence of small soil aggregates in which some of the strength properties are destroyed.

A soil aggregate particle coated with cutback asphalt is penetrated to some depth by the constituents of the bituminous material. The core of such a particle remains in its natural untreated state and retains its inherent strength properties. The soil material of the outer layer of the particle has lost its natural cohesion and the frictional properties have been reduced due to the waterproofing and lubricating effects of cutback asphalt. A treated particle may be weaker than an untreated particle of equivalent size, however the treated particle will be the most waterproof, The strength data and the photographs indicate that as individual soil aggregate particles grow smaller and smaller the strength of the mass also decreases. This is thought to be due to reduction in size of the natural soil cores with a proportional loss in strength since the depth of asphalt penetration into a soil aggregate will be the same regardless of the size of the aggregate particles. A very small particle is apt to be thoroughly penetrated by cutback asphalt and will then possess only the cohesive strength of the cutback asphalt.

The following tabulation of generalized physical properties and phases of the soil and of the asphalt within compacted soil-cutback asphalt mixtures have been derived from the data:

Little or no mixing water	Intermediate amounts of mixing water	High amount of mixing water
	Soil	
Large soil aggregates	Intermediate soil aggregates	Small soil aggregates
Low soil strength	Maximum soil strength	Low soil strength
Low density	Maximum density	Low density
No shrinkage	Little shrinkage	High shrinkage

Little or no mixing water	Intermediate amounts of mixing water	High amount of mixing water
	Cutback asphalt	
Cutback asphalt globules	Thick cutback asphalt films	Thin cutback asphalt films
Discontinuous cutback asphalt	Semi-continuous cutback asphalt	Continuous cutback asphalt
Low cutback asphalt cohesion	Intermediate cohesion	High cutback asphalt cohesion
Low waterproofing	High waterproofing	Low waterproofing

Examination of this tabulation indicates that the optimum properties of a compacted soil-cutback asphalt mixture lie within the intermediate range of mixing moisture contents. The determination of the compromise moisture content (CMC) gives a mixing water content at which the best combination of properties results. The degree of distribution of cutback asphalt is a function of the amount of mixing water, better distribution being obtained as the amount of water is increased with this type of mixing. The CMC also represents a mixing moisture content at which a compromise degree of asphalt distribution occurs.

As a general rule cutback asphalt stabilization of the soil types investigated is best accomplished by mixing the moist soil and the asphalt at the water content needed for maximum standard Proctor density of the soil-cutback asphalt system. The duration of mixing is also important for optimum results and it is essential to maximum stability that compaction be carried out immediately following mixing. Further investigation of the foregoing should be conducted to determine the effects of wetting agents on the water requirements.

SUMMARY AND CONCLUSIONS

The effects of water content, during mixing and during compaction of soil-cutback asphalt mixtures, on the physical properties of the compacted product have not been clearly defined in the past. The primary objectives of this investigation have been to study and evaluate these effects.

The following conclusions concerning cutback asphalt soil stabilization are made on the basis of observations and results of the investigation. It is believed that the conclusions should apply in general to all soils of similar textural and mineralogical composition.

1. The degree of cutback asphalt dispersion in a soil mass is a function of the amount of water present during mixing. The resulting mixture varies from poor, when little water is present, to a quasi-homogenous or intimate mix when a high percentage of water is present.
2. Compaction of a soil-cutback asphalt-water system immediately following mixing produces a more stable product than a procedure in which a drying back period is included between mixing and compaction.
3. An intimate mix does not produce the most desirable properties of the compacted mixture.
4. The percentage of mixing water required to produce maximum IBV, maximum standard Proctor density,

minimum total moisture content after seven days immersion, and minimum expansion in compacted specimens is different for each property mentioned. However, the range of water percentages over which these minimum or maximum properties occur is only several percent.

5. A compromise moisture content (CMC) for mixing may be found at which the variance of the properties mentioned in Conclusion 4 will be a minimum. The CMC is most advantageously determined by the method of first powers.
6. The CMC is very close to the mixing moisture content at which maximum standard Proctor density of the soil-cutback asphalt-water system occurs. Thus the moisture content corresponding to maximum standard Proctor density of the soil-cutback asphalt-water mixture provides the most convenient and easily determined moisture control point for cutback asphalt soil stabilization.
7. The value of the CMC or standard Proctor optimum moisture depends on the type of soil, the type and amount of cutback asphalt used.
8. The best overall stability results for a sandy soil and MC-2 cutback asphalt are obtained when little or no mixing moisture is used; however when

treating with MC-4 cutback asphalt the moisture corresponding to the CMC or standard Proctor optimum moisture content should be present during mixing.

9. Quasi-homogeneous soil-cutback asphalt systems can be produced with silty and clayey soils if the amount of mixing water used is at least equivalent to the liquid limit of the soil being mixed. Mixing of clayey soil-water-asphalt systems is nearly impossible within reasonable limits when the moisture content lies within the plastic range of the soil-water system.
10. There is an optimum duration of mixing of soil-cutback asphalt-water systems for each type of mixing equipment.
11. The "fluff-point" moisture content and the mixing moisture content required to produce an optimum combination of stability properties do not correspond.
12. The moisture content of cutback asphalt-soil mixtures may be determined accurately by simultaneous distillation of the water and hydrocarbon volatiles.

The foregoing conclusions answer the objectives of the investigation and uniquely describe the previously questionable role of water in cutback asphalt soil stabilization.

Extensions of the investigation should be done in order to understand the effects of the amount and type of cutback asphalt, emulsions, and wetting agents on the mixing water requirements of all types of soils normally encountered in the field of soil stabilization. Field trials of cutback asphalt soil stabilization should be conducted in order to adapt the findings of this investigation to the types of field equipment in current use.

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APPENDIX A COMPARISON OF TESTING METHODS

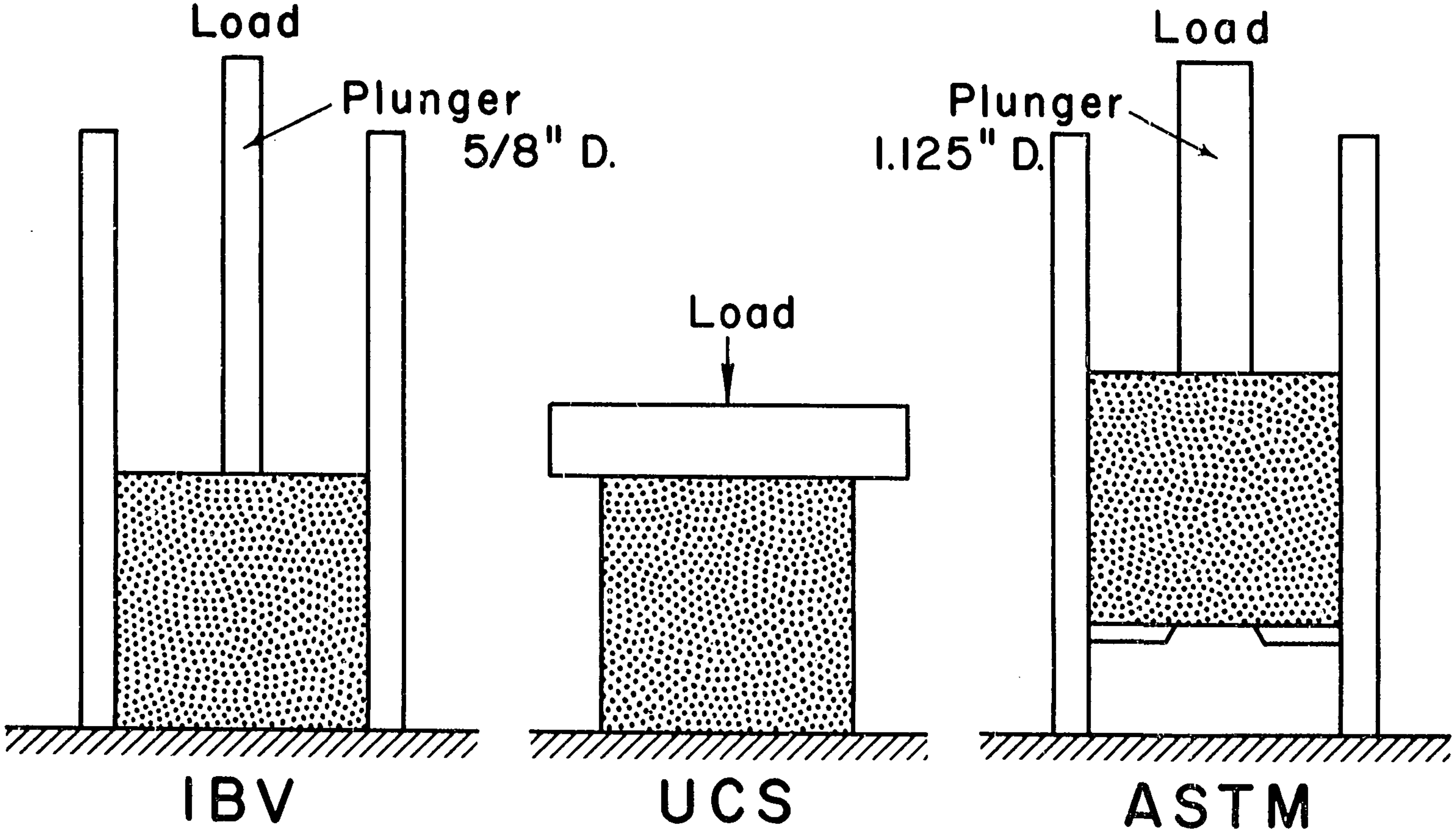
Several methods of testing soil-asphalt mixtures for strength are in current use; none of them has gained wide acceptance. Before adopting the IBV test for this investigation it was considered desirable to compare the IBV test with two of the more common test methods used for evaluating soil-asphalt mixtures. A comparison of the IBV test, the unconfined compressive test, and the ASTM extrusion test (D 915-47T) was made on the basis of sensitivity of each method to soil type, amount of asphalt and duration of immersion in water.

Specimens tested by each method were 2 inches in diameter and 2 inches in height and were molded to near standard Proctor density. The ASTM extrusion test normally requires specimens to be half immersed in distilled water for seven days before testing. A number of specimens were totally immersed for periods of 0, 1 and 2 days before being subjected to the extrusion test, in addition to the specimens that were tested normally. The unconfined compressive test specimens were totally immersed for 0, 1 and 2 days. IBV test specimens were totally immersed for 7 days. The test data is given in Table 11.

Comparison of the three tests is difficult because of the different nature of each test (see Figure 17); the extrusion test primarily measures total shearing strength, the unconfined compression test primarily measures the cohesion element of shearing strength, and the IBV test measures total shearing strength plus bearing resistance. The results obtained by each test method were therefore expressed as a fraction of one arbitrarily chosen base value. These ratios reflect the relative sensitivity of each test method: the more the ratio differs from one, the more sensitive the test to the variable being measured. The sensitivity of the different test methods to strength of different soil types, to strength loss by immersion, and to strength gain or loss due to amount of cutback asphalt can be estimated by use of the strength ratio.

Sensitivity to immersion was determined with a ratio calculated by dividing soaked strength values by unsoaked strength values; the unsoaked value has a strength ratio of one. Results are given in Table 12. The sensitivity of the three test methods relative to each other is indicated by the magnitude of the difference between the strength ratio at no immersion (one) and the strength ratio for a given immersion time. Considering soil 100-8 with 8 percent asphalt: the ratio difference between no immersion and 48 hours immersion is 0.40 for the extrusion test and 0.43 for for the unconfined compression test; taking 7 days immersion of IBV specimens as equivalent to 48 hours immersion for

Figure 17. Comparison of the essential features of the three strength testing instruments used in the investigation. The drawings illustrate the different types of strength measured by each instrument.


Load
Plunger
5/8" D.
Load
Load
Plunger
1.125" D.
IBV
UCS
ASTM

specimens and in the other tests,* the ratio difference for the IBV test is 0.17. The largest ratio difference is obtained with the unconfined compressive test, indicating that this test is more sensitive to strength loss by immersion on the basis of one soil and one percentage of asphalt. This same indication of relative sensitivity also holds true for all the soils and cutback asphalt contents studied.

In Table 13 strength ratios were determined using the unsoaked strength of specimens of each soil containing 8 percent asphalt as a base value. Results indicate that the IBV test is the most sensitive to variation of asphalt content by the same reasoning given in the preceding paragraph.

The sensitivity of the test methods to clay content was determined from strength ratios calculated by using unsoaked strength values of the soil containing the least amount of clay (100-8) as the base value. The results are given in Table 14. The largest difference between strength ratios occurs for the unconfined compressive strength test, indicating that this test is the most sensitive to the clay content of soil.

Visual inspection of ASTM extrusion test specimens after the specified seven days of half immersion indicated that results would be erratic because the lower parts of

---

*IBV specimens are soaked in a mold which exposes only two surfaces to water, whereas the other specimens have all surfaces exposed.

some of the specimens separated from the main body of the specimen. Strength values obtained with such specimens represent only the unsoaked portion of the specimen. Since all specimens did not behave in this manner the overall results with the ASTM test cannot be fairly compared. Examination of the half immersion strength ratios in Table 14 verifies this visual finding, since there is no consistent trend in these ratios.

Comparison of strength ratios that indicate sensitivity to water, asphalt or clay content shows that the IBV test compares favorably with the other two tests. The IBV test is believed to more nearly duplicate field conditions than either of the other tests. It is a relatively simple test and permits direct correlation with the CBR method of design.

Table 11. Test data for the comparison of four instruments for evaluating soil-water-cutback asphalt mixtures

Test	Immersion	Strength in lb. of soil-water-MC-cutback asphalt mixtures							
		100-8 soil sample cutback asphalt %		20-2 soil sample cutback asphalt %		26-1 soil sample cutback asphalt %		$43\frac{1}{2}$-1 soil sample cutback asphalt %	
		8	10	8	10	8	10	8	10
ASTM Extrusion test D 915-47T	None	266	259	288	290	330	297	380	348
	24 hours (complete)	160	180	206	216	257	295	130	135
	48 hours (complete)	160	162	195	200	160	288	90	93
	7-day (half)	49	62	202	245	54	242	163	202
Unconfined compressive strength test	None	90	90	105	104	142	132	146	158
	24 hours	60	60	72	77	62	82	29	38
	48 hours	51	45	58	62	45	66	17	18
IBV @ 0.3" penetration	None	169	149	174	130	142	118	109	101
	7-day	140	116	142	123	75	79	58	55

Table 12. Strength ratios based on strength immediately after molding

Test	Immersion	Strength ratios							
		Soil 100-8		Soil 20-2		Soil 26-1		Soil 43½-1	
		8% MC-2	10% MC-2	8% MC-2	10% MC-2	8% MC-2	10% MC-2	8% MC-2	10% MC-2
ET (extrusion test)	None	1	1	1	1	1	1	1	1
	24 hours	0.60	0.70	0.71	0.75	0.78	0.99	0.34	0.39
	48 hours	0.60	0.63	0.68	0.69	0.49	0.97	0.24	0.27
	7 days (half immersion)	0.18	0.24	0.70	0.85	0.16	0.82	0.43	0.58
UCS	None	1	1	1	1	1	1	1	1
	24 hours	0.67	0.67	0.69	0.74	0.44	0.62	0.20	0.24
	48 hours	0.57	0.50	0.55	0.60	0.32	0.50	0.12	0.11
IBV	None	1	1	1	1	1	1	1	1
	7 days	0.83	0.78	0.82	0.95	0.53	0.67	0.53	0.54

Table 13. Strength ratios based on strength of specimens containing 8% cutback asphalt. Identical soils are compared

Test	Immersion	Strength ratios							
		Soil 100-8		Soil 20-2		Soil 26-1		Soil 43½-1	
		8% MC-2	10% MC-2	8% MC-2	10% MC-2	8% MC-2	10% MC-2	8% MC-2	10% MC-2
ET	None	1	0.97	1	1.01	1	0.90	1	1.01
UCS	None	1	1	1	1	1	0.93	1	1.09
IBV	None	1	0.88	1	0.75	1	0.83	1	0.93

Table 14. Strength ratios based on the strength of specimens containing the least clay. Equal percentages of asphalt are compared

Test	Immersion	Strength ratios							
		Soil 100-8		Soil 20-2		Soil 26-1		Soil 43½-1	
		8% MC-2	10% MC-2	8% MC-2	10% MC-2	8% MC-2	10% MC-2	8% MC-2	10% MC-2
ET	None	1	1	1.08	1.12	1.24	1.15	1.43	1.38
UCS	None	1	1	1.17	1.15	1.58	1.46	1.62	1.75
IBV	None	1	1	1.03	0.87	0.84	0.79	0.65	0.68

APPENDIX B THE IOWA BEARING VALUE TEST

The following is the procedure for determining the Iowa Bearing Value of soils and soil-aggregate mixtures which pass the No. 10 (2mm) sieve 100 percent and do not contain more than 80 percent of sand-size material.

Apparatus (Figure 18)

(a) Mold - A cylindrical metal mold having an internal diameter of 2.0 ± 0.001 inches and a height of 5.0 ± 0.005 inches is used. The mold is provided with a detachable collar of approximately 2 inches in height.

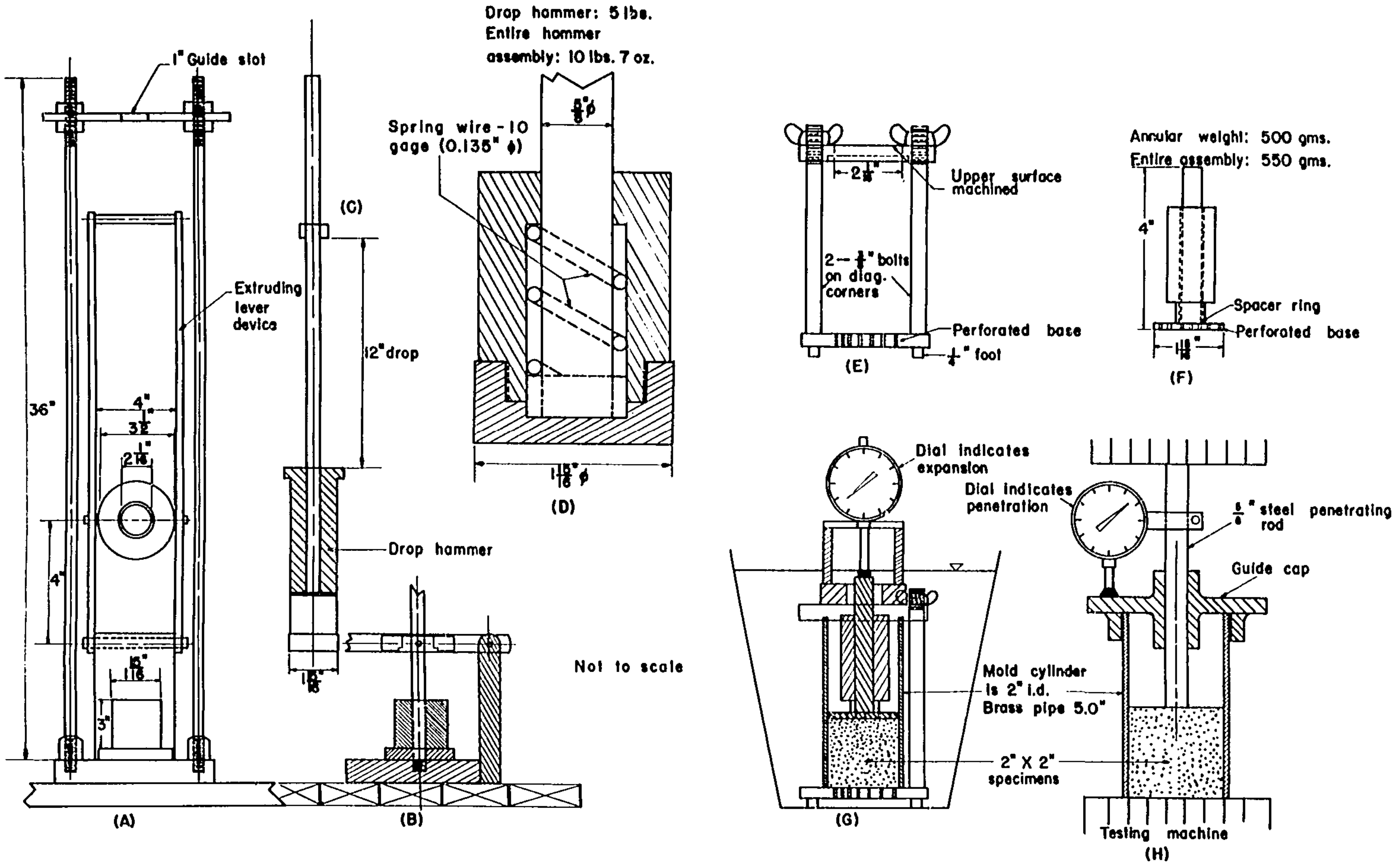
(b) Base - The base is cylindrical with a diameter of 1 15/16 inch and a height of 3.0 ± 0.001 inches.

(c) Temporary supports - Temporary supports, approximately 2 inches in height, hold the mold above the bottom of the base until after the first blow with the hammer.

(d) Frame - A frame of two steel rods, a base plate, and a cross-member having a semi-circular notch guides the hammer during compaction. The frame has a lever for forcing the mold to the bottom of the base after molding.

(e) Hammers - Two metal hammers, one 5 lb, and one 10 lb, drop 12 inches. The 5 lb hammer is used for standard Proctor density; the 10 lb one for modified AASHO.

Figure 18. IBV test apparatus
(A) molding frame, front view
(B) molding frame, side view
(C) drop hammer
(D) drop hammer head
(E) soaking frame
(F) annular weight assembly
(G) specimen during soaking
(H) specimen during pentration test.


1" Guide slot
Extruding lever device
36"
4"
3 1/2"
2 1/16"
4"
1 15/16"
3"
(A)
(B)
(C)
12" drop
Drop hammer
1 15/16"
Drop hammer: 5 lbs.
Entire hammer assembly: 10 lbs. 7 oz.
5/8" φ
Spring wire - 10 gage (0.135" φ)
1 15/16" φ
(D)
Not to scale
2 1/8"
Upper surface machined
2 — 1/8" bolts on diag. corners
Perforated base
1/4" foot
(E)
Annular weight: 500 gms.
Entire assembly: 550 gms.
4"
Spacer ring
Perforated base
1 15/16"
(F)
Dial indicates expansion
Mold cylinder is 2" i.d. Brass pipe 5.0"
2" X 2" specimens
(G)
Dial indicates penetration
5/8" steel penetrating rod
Guide cap
Testing machine
(H)

(f) Penetration rod - A steel penetration rod 5/8 inch in diameter indicates depth of penetration with a dial.

(g) Guiding device - A metal device fits over the mold during testing and maintains the penetration rod in a vertical position.

(h) Testing machine - A machine capable of constant movement of the testing head continuously indicated the load.

(i) Soaking frame - A frame with perforated base holds the mold during immersion.

(j) Annular weight - A weight with perforated base and spacer ring weighs 550 grams.

(k) Balance - A balance with a capacity of 1000 g sensitive to 0.1 g is required.

(l) Straightedge - A rigid steel straightedge with one beveled edge is required.

(m) Mixing tools - Miscellaneous tools include a mixing pan, spoon, trowel, spatula, or a suitable mechanical mixer for mixing the soil thoroughly with water.

(n) Container - A suitable container is used for immersion of specimens.

Sample

(a) Prepare the sample by breaking up soil aggregations to pass the No. 10 (2mm) sieve in such a manner as to avoid reducing the natural size of the individual particles.

(b) Weigh a representative sample large enough to form three 2-inch diameter by 2-inch high specimens from the soil prepared as described in paragraph (a) above.

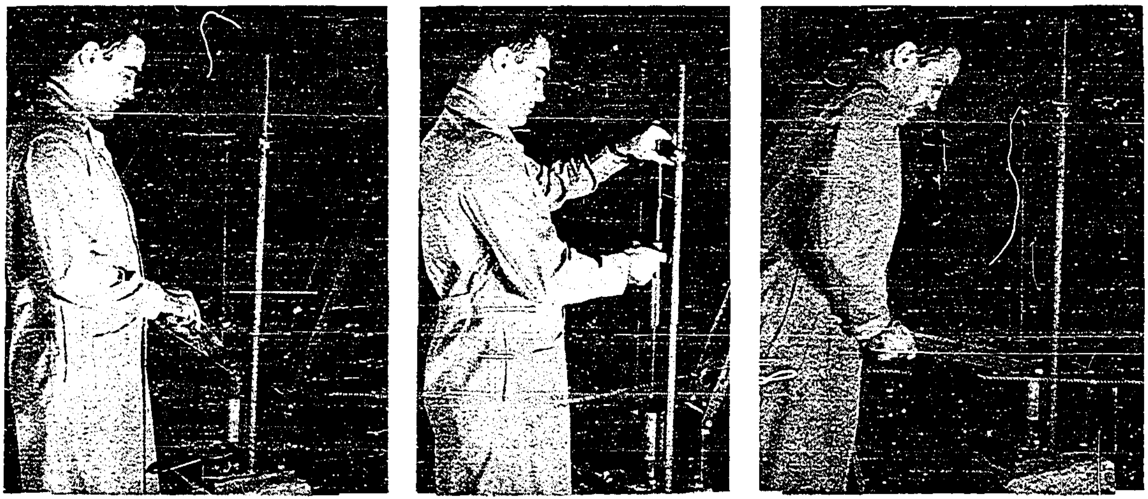
Procedure

(a) Add the required amount of water to the soil and mix thoroughly.

(b) Form a specimen in one layer by compacting the soil in the mold, which has the collar attached and is supported on the temporary supports (Figure 19). When compacting to standard Proctor density use the 5 lb hammer and compact the specimen with five blows on each end. When compacting to modified AASHO density use the 10 lb hammer and compact the specimen with ten blows on each end. Remove the temporary supports after the first blow with the hammer. After compaction, force the specimen to one end of the mold by pushing the mold down around the base with the lever. With the straightedge strike off the excess portion of the specimen.

(c) If the specimen is to be soaked, place the mold in the soaking frame with the specimen at the bottom, place the annular weight assembly on the specimen, and immerse the entire assembly in the soaking container for a period of 7 days (Figure 18). Before testing permit the specimen

Figure 19. (A) Preparation of the IBV specimen
(B) Comparison of IBV and CBR specimens.

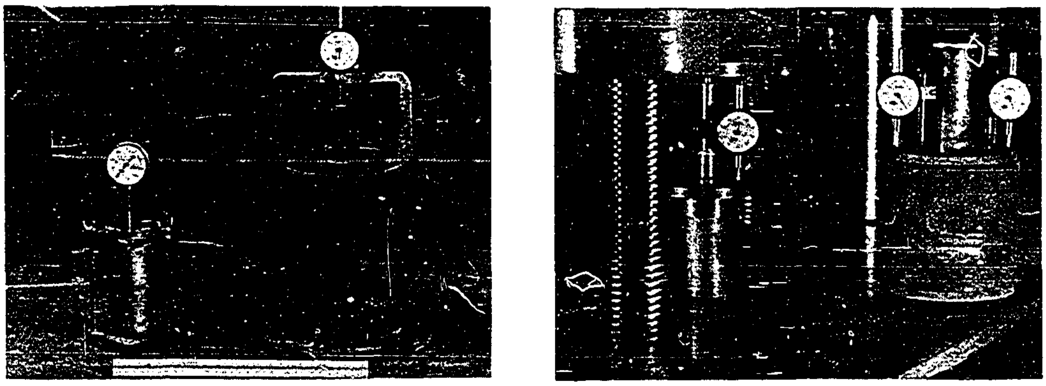


Pouring soil into the mold.

Compacting the specimen.

Extruding that part of the specimen in excess of 2 inches.

(A)



IBV and CBR specimens prepared for immersion with expansion reading devices in place.

Penetration test of IBV specimen; the CBR specimen is ready for testing.

(B)

to drain for 5 minutes.

(d) To test the specimen place the guiding device over the mold and insert the penetration rod, being careful not to disturb the surface of the specimen. Apply the load so that the rate of penetration is 0.05 inches per minute. Record the load at increments of 0.02 inch up to a penetration of 0.10 inch. The Iowa Bearing Value of the material at any penetration is equal to the mean of the loads on three specimens at that penetration.

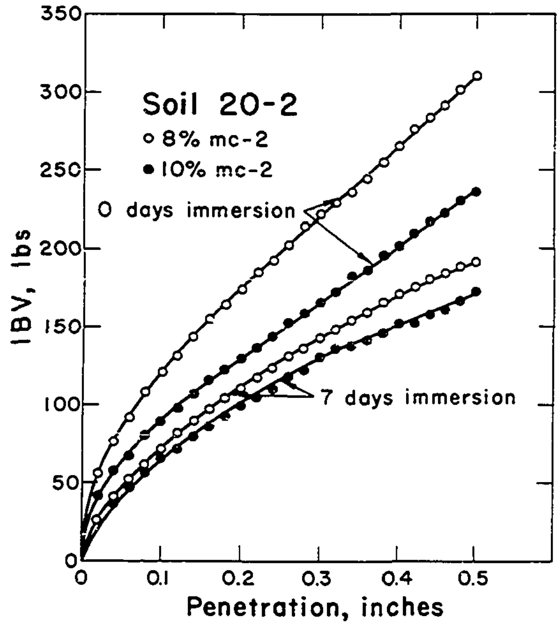
APPENDIX C DETERMINATION OF IMMERSION TIME

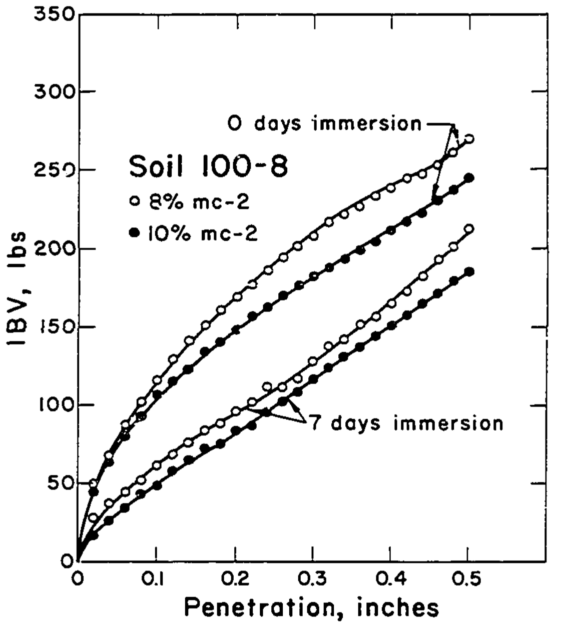
This study was made to determine the relationship between strength and time of water immersion. It was desired to determine the minimum period of immersion necessary to produce near maximum strength loss. The IBV was used as a criterion for studying this relationship.

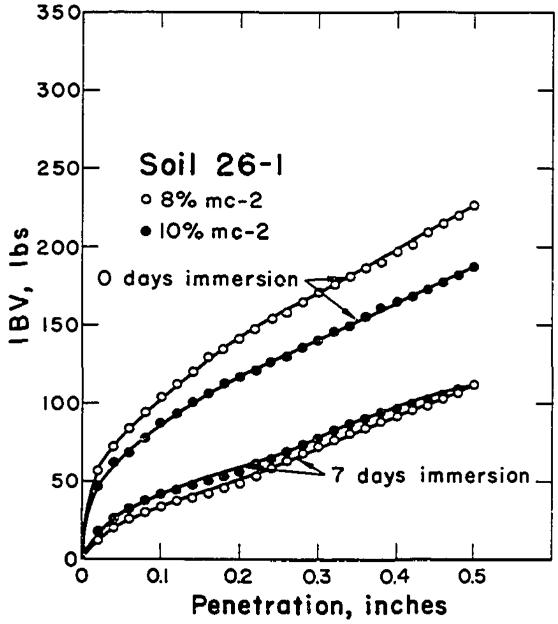
Specimens were molded from mixtures prepared with 8 and 10 percent MC-2 and soils 20-2, 26-1, 43½-1 and 100-8. The choice of asphalt percentage was based on previous work reported by Katti (37). One group of specimens was tested for IBV immediately after molding and another group was soaked for seven days before testing. The results are plotted in Figure 20 as IBV versus penetration. Examination of these curves shows that soils 20-2 and 100-8 suffered the least strength loss after seven days soaking. Since soils 20-2 and 100-8 are very similar in properties and strength performance only one (20-2) was chosen for further study of the strength-time of immersion relationship. It was felt that a soaking period giving maximum strength loss with this soil would be sufficient to produce maximum strength loss with the other soils to be used in the main investigation.

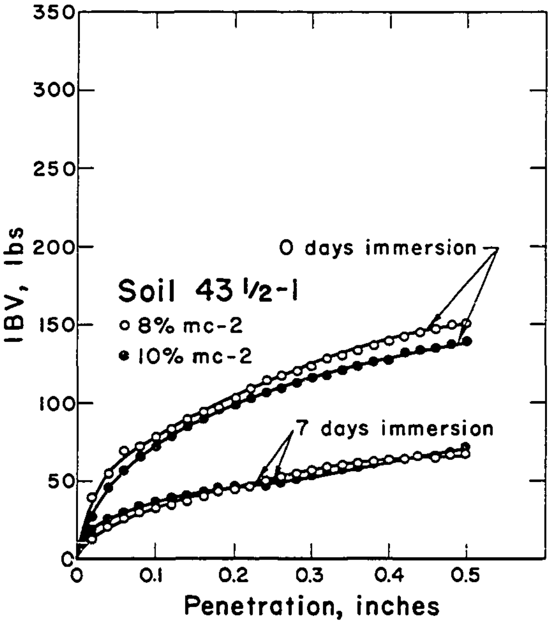
Specimens were molded from mixtures of soil 20-2 and 10 percent RC-2, then immediately immersed for various periods of time and tested for IBV. RC-2 was used because this type

Figure 20. IBV penetration relationships for the soils and cutback asphalt percentages indicated on each graph.


Soil 20-2
○ 8% mc-2
● 10% mc-2
0 days immersion
7 days immersion
IBV, lbs
Penetration, inches
0
50
100
150
200
250
300
350
0
0.1
0.2
0.3
0.4
0.5


Soil 100-8
○ 8% mc-2
● 10% mc-2
0 days immersion
7 days immersion
IBV, lbs
Penetration, inches
0
50
100
150
200
250
300
350
0
0.1
0.2
0.3
0.4
0.5


Soil 26-1
○ 8% mc-2
● 10% mc-2
0 days immersion
7 days immersion
IBV, lbs
Penetration, inches
0
50
100
150
200
250
300
350
0
0.1
0.2
0.3
0.4
0.5


Soil 43 1/2-1
○ 8% mc-2
● 10% mc-2
0 days immersion
7 days immersion
IBV, lbs
Penetration, inches
0
50
100
150
200
250
300
350
0
0.1
0.2
0.3
0.4
0.5

of asphalt produced higher strengths in earlier work (37). The results are plotted in Figure 21 as IBV versus time of immersion with separate curves for each depth of penetration. The curves show that the greatest rate of strength loss occurs during the first day and a maximum loss in strength occurs after six days. Seven days immersion gave strengths comparable to six day strengths but a little higher. The apparent gain in strength of the seven day value over the six day value may be attributed to the difficulty in determining the zero reading of the strain gage. Errors of several thousandths of an inch raise or lower the IBV at all penetrations after a given period of immersion. However, errors included, the curves show definite trends that are too large to be attributed to errors. One such trend occurs after four days immersion at penetrations greater than about 0.25 inch. Here there is a definite increase in IBV followed by a drop to values that might be expected. The increase in IBV is thought to be due to a transferrence of load to water, causing excess hydrostatic pressure. Lower penetrations do not exhibit this transferrence because the escape route of water is short preventing the development of excess hydrostatic pressure.

It was concluded from this study that an immersion time of seven days is sufficient for maximum water absorption and strength loss to occur.

Figure 21. IBV plotted as a fraction of the duration of immersion in distilled water for compacted specimens of the indicated soil and cutback asphalt treatment.

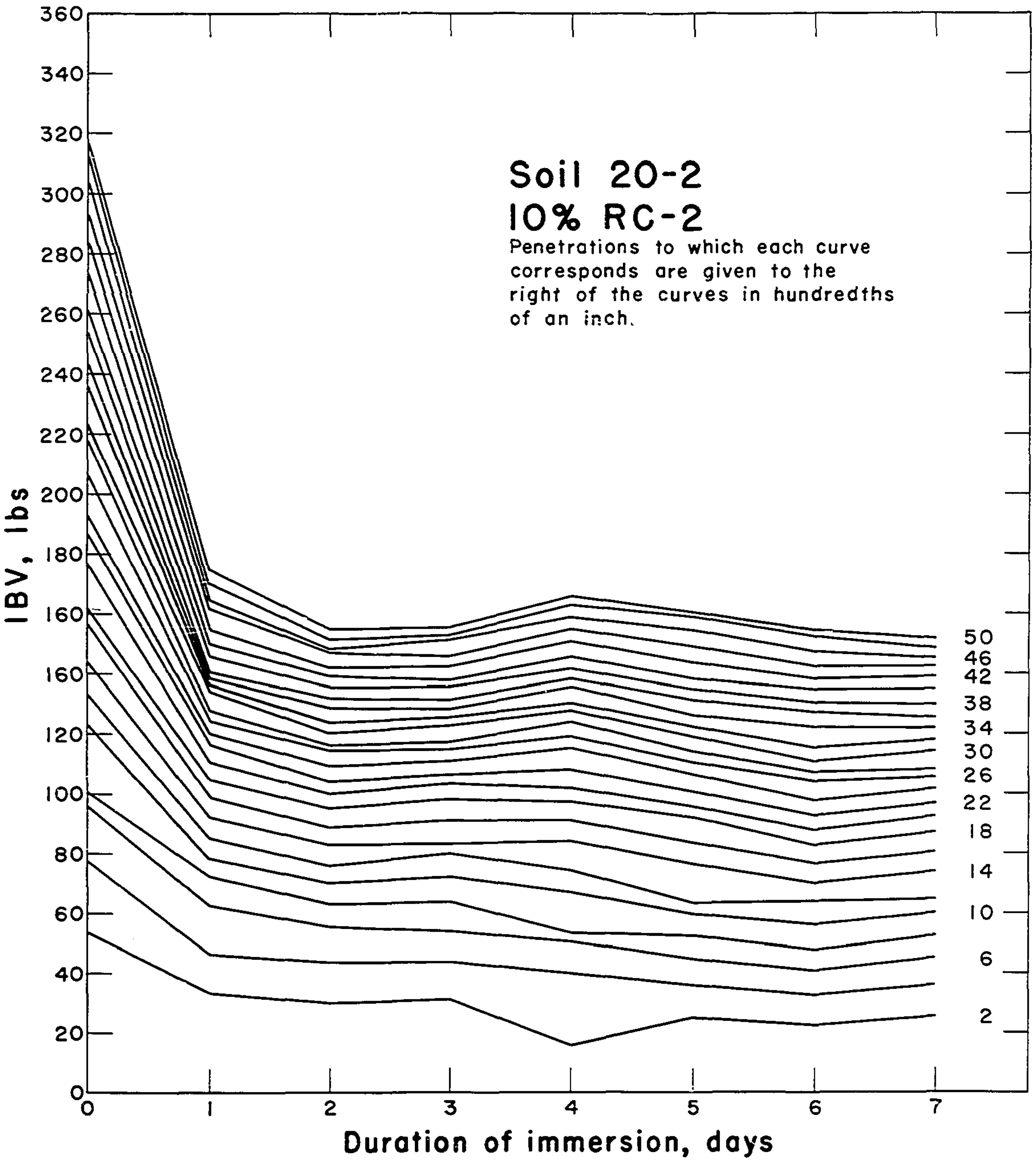

Soil 20-2
10% RC-2
Penetrations to which each curve corresponds are given to the right of the curves in hundredths of an inch.
IBV, lbs
360
340
320
300
280
260
240
220
200
180
160
160
120
100
80
60
40
20
0
Duration of immersion, days
0
1
2
3
4
5
6
7
50
46
42
38
34
30
26
22
18
14
10
6
2

Table 15. IBV test data of 2 in. by 2 in. specimens for soaking time study

Soil sample	Amount and type cutback asphalt, %	No. of days of immersion	IBV test load in lbs Penetration in inches																								
			0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20	0.22	0.24	0.26	0.28	0.30	0.32	0.34	0.36	0.38	0.40	0.42	0.44	0.46	0.48	0.5
43½-1	8% MC-2	0	41	58	71	79	86	92	97	101	105	109	113	116	120	124	128	132	136	138	141	144	146	148	151	153	156
		7	18	23	28	31	33	37	38	41	44	47	48	50	53	56	58	60	61	63	63	63	65	66	67	67	69
	10% MC-2	0	36	47	58	67	74	80	87	92	97	101	105	108	112	116	119	121	123	126	128	131	134	136	139	141	143
		7	17	26	30	33	35	39	41	43	46	46	48	50	50	52	55	58	60	60	63	64	67	68	68	69	71
26-1	8% MC-2	0	55	72	85	96	107	114	122	129	135	142	149	154	160	166	172	176	182	188	192	200	204	210	215	220	225
		7	14	21	26	31	33	37	40	42	47	52	55	60	65	70	75	77	80	85	88	92	96	99	103	108	111
	10% MC-2	0	45	61	69	78	88	94	101	107	111	118	122	128	133	138	141	147	152	157	162	165	169	173	178	183	188
		7	16	24	33	39	42	45	47	51	55	58	63	66	69	74	79	82	87	91	94	97	100	103	104	107	111
100-8	8% MC-2	0	50	72	89	103	117	130	142	152	161	169	178	186	194	203	211	218	222	228	234	240	245	250	255	262	269
		7	28	38	44	51	62	71	75	84	90	98	107	113	120	132	140	147	156	160	169	175	185	191	197	205	213
	10% MC-2	0	47	68	81	94	107	117	126	135	143	149	156	163	169	176	182	188	193	198	204	209	216	222	231	237	242
		7	17	26	34	42	49	57	65	71	76	82	89	95	101	108	116	124	131	140	145	152	159	165	173	180	188
20-2	6% MC-2	0	58	82	100	114	129	142	153	165	175	185	194	206	216	227	234	243	252	261	269	274	280	289	305	313	322
		7	18	28	35	41	45	51	56	62	70	76	82	87	89	98	106	110	116	120	125	129	134	140	145	148	152
	8% MC-2	0	56	78	94	109	122	132	144	154	164	174	184	192	203	216	221	230	236	246	256	267	278	284	292	302	309
		7	27	41	52	63	75	81	88	98	105	110	118	125	130	138	142	147	153	160	166	170	175	180	185	189	192
	10% MC-2	0	43	56	65	79	89	97	106	115	122	130	137	144	151	158	165	172	180	186	193	199	207	214	222	229	236
		7	25	37	45	55	64	70	79	86	92	99	103	108	116	118	123	130	135	139	142	145	152	155	162	166	171
	10% RC-2	0	57	78	96	111	124	133	145	157	162	177	186	193	206	218	223	235	242	253	261	272	283	293	305	312	316
		1	34	47	63	72	79	86	93	99	105	111	116	120	124	128	134	137	141	146	150	152	155	162	165	170	175
		2	30	44	55	63	70	76	83	89	95	100	104	109	115	117	121	125	129	133	136	139	143	147	149	153	155
		3	32	44	54	64	73	80	83	93	98	103	106	111	115	118	123	126	129	132	136	138	143	146	152	153	156
		4	16	40	50	54	67	74	84	91	96	102	108	116	120	124	127	131	136	139	142	146	152	155	159	164	166
		5	25	36	45	53	60	64	77	84	93	96	101	107	111	114	119	123	127	132	135	139	145	150	155	160	162
		6	22	33	41	48	57	64	70	77	83	88	93	98	105	107	111	116	118	123	128	132	135	139	143	148	153
		7	25	36	45	53	60	65	74	81	87	92	97	102	106	109	114	118	122	126	130	135	140	143	146	149	153

APPENDIX D MIXING CUTBACK ASPHALT, SOIL AND WATER

The pug mill mixer is generally believed to be the type of laboratory mixer that most nearly duplicates the central plant mixing of asphalt, soil and water under field conditions. It is not known how pug mill mixing compares with the usual type of soil stabilization field mixing. Laboratory size pug mill mixers offer a disadvantage due to the amount of material required to produce efficient mixing. Approximately a minimum of 10,000 grams of soil is required whereas only 1200 to 2500 grams are used to mold specimens. The difference is wasted.

A standard laboratory mixer has not been established. Mixers that have a capacity consistent with the batch size demands include the Blakeslee Kitchen Aid mixer and the Hobart C-100. Considerable experimentation has been done with the Blakeslee mixer since the ASTM has recommended its use for laboratory experimentation.

One purpose of this investigation was to compare the efficiency and capacity of the Blakeslee* mixer and the Hobart** mixer with that of a laboratory pug mill mixer. These comparisons served as a basis for the choice of the

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*Manufactured by G. S. Blakeslee and Co., Chicago, Illinois.

**Manufactured by Hobart Manufacturing Co., Troy, Ohio.

mixer used throughout the main investigation. Identically composed batches of cutback asphalt, soil 20-2 and water were mixed in each type of mixer, then molded and tested for IBV, moisture absorption and dry density. The resulting data is presented in Table 16.

The IBV density and moisture absorption data show that batches mixed with the smaller machines have a quality as good or better than mixtures produced by the pug mill. Either of the two smaller machines may therefore be used to mix laboratory batches of asphalt, soil and water that have a quality comparable to pug mill mixes.

Further examination of the IBV, density and absorption data shows that the Blakeslee machine produces near optimum results with batches in the size range of 2000 to 2500 grams for different combinations of soils and asphalts. The Hobart machine produces near optimum results with batches in the range of 1000 to 2000 grams as indicated by the data obtained using medium and heavy clay soils with MC-0, MC-2 and MC-4.

On the basis of the comparison study the Hobart machine was chosen for use in the main investigation since it produces well mixed small-size batches. A batch-size of fifteen hundred grams was selected since it provides six 200 gram test specimens. This amount is in the middle of the optimum batch-size range for the Hobart machine.

Table 16. Comparison of mixers[a]

Mixer	Cutback asphalt type	Soil no.	Amount of soil, grams	IBV at 0.09 in. penetration lbs.	Moisture absorption,[b] %	Dry density, pcf
Pug mill[f]	MC-0	20-2	10,000[d]	25	7.6	100.1
			10,000[e]	40	6.1	99.6
Blakeslee[c]	MC-0	20-2	1,500	44	7.1	98.4
			2,000	45	5.9	98.8
			2,500	46	5.7	99.8
			3,000	40	5.9	100.0

---

[a] Batches were mixed using the indicated soil fluff-point moisture and 6% liquid cutback asphalt (except 3% was used with sand S-6-2). The percent of asphalt was calculated on the basis of dry soil. The asphalt was added to the soil in the pug mill by a spray at 25 psi and at temperatures recommended by the Asphalt Institute. The Hobart and Blakeslee batches were mixed for 5 minutes, for pug mill batches, see "d" and "e."

[b] Moisture absorption after 7 days immersion is expressed on the basis of the dry soil.

[c] Speed control set at No. 2 for all batches.

[d] Mixed for one minute.

[e] Mixed for two minutes.

[f] The Pug mill mixer used in this investigation is supposed to be used for mixing 3/4 inch blended material.

Table 16. (Continued)

Mixer	Cutback asphalt type	Soil no.	Amount of soil, grams	IBV at 0.09 in. penetration lbs.	Moisture absorption,[b] %	Dry density, pcf
Pug mill[f]	MC-2	20-2	10,000[d]	16	8.8	99.5
			10,000[e]	30	7.4	99.4
Blakeslee[c]	MC-2	20-2	1,200	21	13.0	96.7
			1,500	25	11.7	97.1
			2,000	34	11.3	97.1
			2,500	41	9.3	97.6
			3,000	44	8.1	97.8
	MC-0	100-8	1,500	35	5.8	99.6
			2,000	40	5.8	100.4
			2,500	36	5.9	102.1
			3,000	30	4.7	100.6
	MC-0 3%	S-6-2	1,500	7	5.4	107.2
			2,000	8	7.8	107.0
			2,500	10	7.3	105.8
			3,000	9	6.6	106.0
Hobart[g] C-100	MC-2	20-2	700	16	13.7	95.0
			900	22	12.1	95.1
			1,200	26	12.6	94.9

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[g] Speed control set at No. 1 for all batches.

Table 16. (Continued)

Mixer	Cutback asphalt type	Soil no.	Amount of soil, grams	IBV at 0.09 in. penetration lbs.	Moisture absorption,[b] %	Dry density, pcf
Hobart[g] C-100	MC-2	20-2	1,500	28	12.3	94.5
			1,800	26	13.2	94.3
			2,100	26	13.0	96.0
	MC-4	20-2	700	32	1.6	103.9
			1,000	37	1.5	103.2
			1,500	38	1.5	105.1
			2,000	39	1.6	104.3
			2,500	40	1.6	105.0
	MC-0	411	700	12	7.3	107.1
			1,000	13	7.4	109.1
			1,500	13	7.3	109.2
			2,000	11	6.9	109.6
			2,500	12	6.7	109.4
	MC-2	411	700	9	10.4	102.8
			1,000	11	10.8	99.4
			1,500	12	13.8	98.8
			2,000	13	11.2	99.0
			2,500	12	14.1	100.0

Since the duration of machine mixing produces considerable variance in the properties of molded specimens (12), it was desired to determine a uniform time of mixing. Batches of soil, 6 percent MC-2 or MC-4 and fluff-point moisture were mixed in the Hobart mixer for specific periods of time. Specimens were molded from the resulting mixtures and tested for absorption of water, dry density, expansion due to absorption of water, and IBV at 0.08 inches penetration. Balling of the mixture and its adhesion to the mixing bowl necessitated using hand mixing between periods of machine mixing. The duration of mixing represents the total machine mixing time only and does not include hand mixing time. The resulting data are graphed in Figure 22.

Examination of the figures shows that maximum values are obtained for dry density and IBV after a five minute mixing period, minimum absorption and expansion also occur after a five minute mixing period. Mixing for five minutes was adopted for the main investigation.

Figure 22. Graphs illustrating the effects of the duration of mixing time on IBV, dry density, absorption and expansion. The soil and cutback asphalt treatment are indicated on the right hand side of the graph to which they apply. Hobart model C-100 mixer was used.

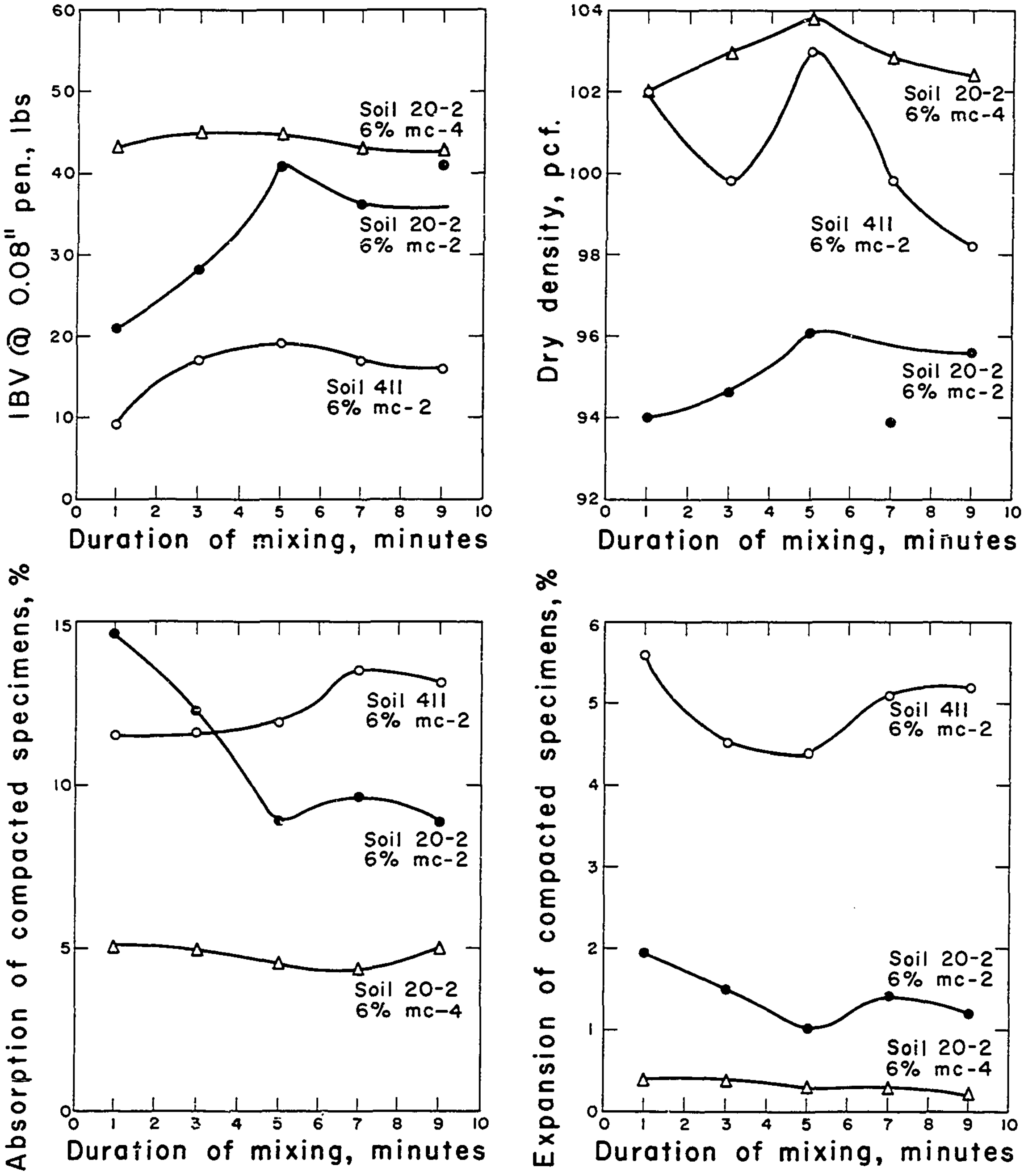
IBV @ 0.08" pen., lbs
60
50
40
30
20
10
0
Soil 20-2
6% mc-4
Soil 20-2
6% mc-2
Soil 411
6% mc-2
0 1 2 3 4 5 6 7 8 9 10
Duration of mixing, minutes
Dry density, pcf.
104
102
100
98
96
94
92
Soil 20-2
6% mc-4
Soil 411
6% mc-2
Soil 20-2
6% mc-2
0 1 2 3 4 5 6 7 8 9 10
Duration of mixing, minutes
Absorption of compacted specimens, %
15
10
5
0
Soil 411
6% mc-2
Soil 20-2
6% mc-2
Soil 20-2
6% mc-4
0 1 2 3 4 5 6 7 8 9 10
Duration of mixing, minutes
Expansion of compacted specimens, %
6
5
4
3
2
1
0
Soil 411
6% mc-2
Soil 20-2
6% mc-2
Soil 20-2
6% mc-4
0 1 2 3 4 5 6 7 8 9 10
Duration of mixing, minutes

Table 17. Duration of mixing time

Soil no.	Type of asphalt	Water content %	Duration of mixing min.	Dry density pcf	IBV lbs	Absorption %	Expansion %
20-2	MC-2	8.4	1	94.1	21	14.6	1.9
			3	94.6	28	12.3	1.5
			5	96.1	41	8.9	1.0
			7	93.9	36	9.6	1.4
			9	95.4	41	8.8	1.2
20-2	MC-4	16.3	1	102.0	43	5.1	0.4
			3	102.0	45	5.0	0.4
			5	103.8	45	4.5	0.3
			7	102.8	43	4.4	0.3
			9	102.4	42	5.1	0.2
411	MC-2	11.3	1	102.0	9	11.5	5.6
			3	99.8	12	11.7	4.5
			5	103.0	14	11.9	4.4
			7	96.8	12	13.5	5.1
			9	98.1	11	13.2	5.2

APPENDIX E SIMULTANEOUS DETERMINATION OF HYDROCARBON VOLATILE MATERIAL AND WATER

Due to the lack of a standard method for the determination of the amount of hydrocarbon volatile material contained in cutback asphalt-water-soil system it was necessary to devise a method. A brass retort of the type used in ASTM D 402-55 was connected to a water cooled condenser via a goose-neck glass tube. The cutback asphalt-water-soil mixture was placed in the brass retort and gradually heated to 680°F as specified in D 402-55. All volatile material distilled was collected and centrifuged at 1000 RPM for two minutes to ensure a complete separation of the hydrocarbon volatiles and water. The volume of each liquid was determined, converted to weight and expressed as a percentage by weight of the oven-dry soil. The test has been given the name "volatile separation test" and will henceforth be called the VST.

Since the VST method determines water content as well as hydrocarbon volatile content it was decided to compare the accuracy of this water determination with standard methods of water determination. Mixtures of soil containing various liquid-cutback asphalts and varying amounts of water were tested for water content by three methods: ASTM D 244-55, VST and oven drying at 105 to 110°C. Samples for the determination of water content by oven drying were taken from the soil-water mixture just before the addition of cutback asphalt. A comparison of the water content determination by the three methods are shown in Table 18.

Examination of the data in Table 18 shows no significant difference in the amount of water as determined by the three methods except in the absence of cutback asphalt, particularly in the soils containing the highest amount of silt and clay. The ASTM and the VST methods compare favorably but both indicate a higher amount of water than is indicated by oven drying. The difference can be explained readily since both the ASTM method and the VST are carried out at temperatures high enough to cause the release of interlayer water from the clay minerals. The interlayer water is not released at temperatures below 110°C.

The VST was adopted for moisture determinations since it compares favorably to the ASTM method and gives the added advantage of simultaneous hydrocarbon volatile material determination.

Table 18. Comparison of water contents of liquid cutback asphalt-soil water systems as determined by the oven-dry, VST and ASTM methods

Soil no.	Type of asphalt	Amount of asphalt	Water content oven-dry %	Water content VST %	Water content ASTM %
20-2	--	0	14.8	16.3	16.8
	MC-2	6	18.9	18.7	18.6
	MC-2	6	25.4	24.4	24.7
	MC-2	6	31.7	31.3	31.7
	MC-2	10	18.7	18.6	18.8
	MC-2	10	33.8	33.8	33.2
	MC-4	6	17.8	17.7	18.3
	MC-4	6	30.8	30.7	30.5
	MC-4	10	17.8	17.3	17.6
	MC-4	10	30.8	30.7	30.4
100-8	--	0	10.0	10.5	10.6
411	--	0	12.8	14.2	13.9
	MC-2	6	15.6	16.8	17.3
	MC-2	6	43.0	42.0	42.6
	MC-4	10	41.5	42.4	41.9
S-6-2	--	0	7.2	7.5	7.3
	MC-2	3	0.3	0.3	--
	MC-2	3	9.8	9.8	9.4
	MC-4	3	9.6	9.0	9.0
	MC-4	6	9.2	8.7	8.7