TECHNICAL MANUAL
No. 5-822-8
AIR FORCE MANUAL
AFM 88-6, CHAPTER 9

HEADQUARTERS
DEPARTMENTS OF THE ARMY
AND THE AIR FORCE
WASHINGTON, DC, *30 July 1987*

BITUMINOUS PAVEMENTS STANDARD PRACTICE

*This manual supersedes TM 5-822-8 dated December 1971 and AFM 88-6, chapter 9, dated 20 June 1972.

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1-1. Purpose and scope.

This manual provides guidance for the preparation of plans and specifications for road and airfield pavements using bituminous materials. All elements of the Departments of the Army and Air Force responsible for military construction will use this manual. Other agencies and organizations using similar design and construction procedures for road and airfield pavement construction using bituminous materials may also find the manual useful.

1-2. Background.

Bituminous concrete mixtures provide a resilient, relatively waterproof, load-distributing medium that protects the base course from the harmful effects of water and the abrasion of traffic. Wear, weathering, and deterioration from aging all act on bituminous pavements, and therefore maintenance of these pavements is necessary for a long life. The flexibility of bituminous concrete allows a pavement structure to adjust slightly to consolidation of underlying layers or deformation due to load without affecting pavement performance. Bituminous pavements also allow stage construction and may use a wide range of construction materials, often leading to substantial savings from the use of locally available materials. Additional pavement courses can be placed on existing pavements to provide additional structural strength as total loads or traffic intensity increase. The paving engineer must design and construct the most economical pavement that will satisfy the objective of long pavement life.

1-3. References.

Appendix A contains a list of references used in this document.

1-4. Definitions.

The most common terms related to bituminous pavements are not defined here since they may be found in many references. Certain terms whose definitions have not been universally accepted or that have limited usage are defined for this manual as follows:

a. Coarse aggregate. The aggregate retained on the Number (No.) 4 sieve, as described in American Society for Testing and Materials (ASTM) E 11.

b. Fine aggregate. The aggregate passing the No. 4 sieve and retained on the No. 200 sieve, often referred to as sand. Natural sand (fine aggregate) is that material which is found naturally and not manufactured by crushing.

c. Mineral filler. Mineral aggregate particles passing a No. 200 sieve or commercially available materials such as lime or cement.

d. Bituminous base course. One or more coures of bituminous mixture placed on a subbase or subgrade to serve as a base course. This mixture is sometimes called a black base. A bituminous base course is covered with an intermediate course and surface course.

e. Intermediate course. That portion of a pavement placed on the base course to serve as a leveling or transition layer between the base and surface courses. Intermediate courses are sometimes called leveling or binder courses.

f. Surface course. The top course of a bituminous pavement. The surface course is referred to as wearing course by many pavement engineers.

g. Optimum bitumen content. The bitumen content of a paving mixture, determined by the Marshall or gyratory methods of design, that satisfies the applicable Department of Army and Air Force pavement mix design criteria.

h. Marshall stability value. The maximum load in pounds required to produce shear failure in a compacted specimen of bituminous paving mixture when tested in the Marshall apparatus.

i. Flow. The deformation, measured in hundredths of an inch, that occurs in a compacted specimen of a paving mixture at the point where maximum load begins to decrease when subjected to the Marshall stability test.

j. Percent voids total mix (VTM). The percentage of the compacted bituminous mixture not occupied by the aggregate or bitumen.

k. Voids in mineral aggregate (VMA). The percentage of the compacted bituminous mixture not occupied by the aggregate. The percentage of VTM plus the percentage of bituminous cement by volume is equal to VMA.

l. Percent voids filled with bitumen. The percentage of the VMA in the compacted aggregate mass that is filled with bitumen.

1-5. Properties of compacted bituminous mixture.

The components of a compacted bituminous mixture are shown in figure 1-1. A given volume of compacted bituminous concrete consists of air, bitumen, and aggregate. The properties of the compacted mixture can be calculated from the following formulas:

Percent voids total mix (VTM)

$$VTM = \frac{V_{air}}{V_{total}} \times 100 \qquad \text{(eq 1-1)}$$

Percent voids in mineral aggregate (VMA)

$$VMA = \frac{V_{air} + V_{bitumen}}{V_{total}} \times 100 \qquad \text{(eq 1-2)}$$

Percent voids filled with bitumen (VF)

$$VF = \frac{V_{bitumen}}{V_{air} + V_{bitumen}} \times 100 \qquad \text{(eq 1-3)}$$

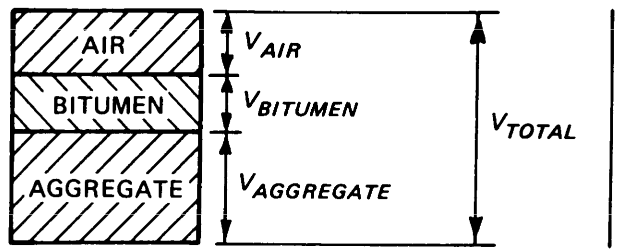


Figure 1-1. Components of compacted bituminous mixture.

CHAPTER 2

ADVANTAGES, DISADVANTAGES, AND USES OF BITUMINOUS PAVING MIXTURE, SPRAY APPLICATIONS, AND SURFACE TREATMENTS

2-1. General.

Many types of bituminous paving mixtures, spray applications, and surface treatment materials have been developed for various uses. In the following paragraphs, the various types are described and the advantages and disadvantages of each are discussed. Hot mixes have been emphasized because they are more often used for high-performance pavements. Alternate types of mixtures and treatments are presented because of their possible use in other areas. The type of mixture, spray application, or surface treatment should be selected based on traffic conditions and the availability of satisfactory materials. Additional concerning mixtures, spray applications, and surface treatments is provided in later chapters.

2-2. Safety requirements.

The policy of the Departments of the Army and Air Force is to construct pavements that will provide the maximum safety for traffic. A non-skid surface is essential, and proper grade control is required to provide rapid removal of surface water to minimize hydroplaning. All pavement surfaces should exhibit a sufficiently coarse texture to provide skid resistance, but the surface texture should not be harsh or contain sharp aggregate particles which may cause excessive tire wear. Aggregate types known to have a history of polishing should be avoided because they are probably the greatest cause of low skid resistance, especially in surface treatments and seal coats. Construction techniques are important for surface treatments and seal coats to ensure good bond between the asphalt and aggregate providing for satisfactory aggregate retention. Coatings that do not include aggregate should not generally be applied to bituminous surfaces in areas of high-speed traffic.

2-3. Hot-mix bituminous mixtures.

Hot-mix bituminous mixtures consist of mineral aggregate and bituminous cement. These hot-mix bituminous mixtures are particularly suitable for airfield pavements, roads and streets, and storage areas. In general, from 3 to 6 percent bitumen is required for bituminous base or intermediate courses, 4 to 7 percent bitumen for surface courses, and 5 to 7 percent for porous friction courses. However, the optimum bitumen content should be determined as discussed later. The aggregate gradations specified for bituminous concrete pavements are shown in table 2-1.

a. Advantages and disadvantages. The hot-mix method of preparing paving mixtures provides for thorough coating of the aggregates with a uniform film of bitumen and accurate control of aggregate sizes and quantity of bitumen. Hot-mix pavements require no curing period after being laid and can be used as soon as the pavement has cooled. However, the paving mixtures must be rolled while sufficiently hot to be workable because rolling is relatively ineffective after the mixture has cooled. Hot-mix pavements can be constructed rapidly with a minimum probability of damage to unfinished pavements from unfavorable weather conditions. Immediately after adequate rolling and a cooling period, the pavement has a high degree of stability from the interlocking of the coarse aggregate and adhesion of the bituminous cement, as well as a high resistance of frost and moisture. The initial cost of bituminous hot-mix exceeds that of other bituminous mixtures.

b. Uses. Paving mixtures can be designed that are satisfactory for a bituminous base course, intermediate course, surface course, or porous friction course. Wheel loads, wheel spacing, tire pressures, intensity of traffic, and subgrade strength (California bearing ratio (CBR) dictate the thickness of pavement (TM 5-825-2/AFM 88-6, Chapter 2). Normally, bituminous base courses of any desired total thickness may be constructed in layers up to 6 inches thick. Hot-mix bituminous concrete will be used as the intermediate and surface courses for types A, B, C, and D traffic areas, blast areas, and any other areas (even non-traffic) where their use is economical. The four types of traffic areas (A, B, C, and D) are described in TM 5-803-4 and TM 5-824-1/AFM 88-6, Chapter 1. Porous friction courses shall be used primarily to prevent hydroplaning on runways or other high-speed pavements.

Table 2-1. Aggregate gradations for bituminous concrete pavements

Sieve size	1-1/2-in. Maximum[a]		1-in. Maximum		3/4-in. Maximum		1/2-in. Maximum		3/8-in. Maximum		No. 4 Maximum	
	Low pressure[b]	High pressure[c]	Low pressure	High pressure	Low pressure	High pressure	Low pressure	High pressure	Low pressure	High pressure	Low pressure	High pressure
					Surface course							
1-1/2 inch	100	--	--	--	--	--	--	--	--	--	--	--
1 inch	87±8	--	100	100	--	--	--	--	--	--	--	--
3/4 inch	79±9	--	90±7	90±6	100	100	--	--	--	--	--	--
1/2 inch	70±9	--	81±9	81±7	89±9	89±7	100	100	--	--	--	--
3/8 inch	63±9	--	75±9	75±7	82±9	82±7	86±9	86±7	100	--	--	--
No. 4	51±9	--	60±9	60±7	66±9	66±7	66±9	66±7	85±9	--	100	--
No. 8	42±9	--	47±9	47±7	53±9	53±7	53±9	53±7	71±9	--	87±9	--
No. 16	34±9	--	37±9	37±7	41±9	41±7	41±9	41±7	57±9	--	72±9	--
No. 30	26±9	--	27±9	27±7	31±9	31±7	31±9	31±7	43±9	--	57±9	--
No. 50	19±8	--	19±8	19±6	21±8	21±6	21±8	21±6	31±8	--	43±8	--
No. 100	13±5	--	13±5	13±4	13±6	13±5	13±6	13±5	19±6	--	33±6	--
No. 200	4.5±2.5	--	4.5±2.5	4.5±1.5	4.5±2.5	4.5±1.5	4.5±2.5	4.5±1.5	6±3	--	7±3	--
					Intermediate course							
1-1/2 inch	100	--	--	--		--	--	--	--	--	--	--
1 inch	84±9	--	100	--	--	--	--	--	--	--	--	--
3/4 inch	76±9	--	83±9	--	--	--	--	--	--	--	--	--
1/2 inch	66±9	--	73±9	--	100	--	100	--	--	--	--	--
3/8 inch	59±9	--	64±9	--	82±9	--	83±9	--	--	--	--	--
No. 4	45±9	--	48±9	--	72±9	--	62±9	--	--	--	--	--
No. 8	35±9	--	37±9	--	54±9	--	47±9	--	--	--	--	--
No. 16	27±9	--	28±9	--	41±9	--	36±9	--	--	--	--	--
No. 30	20±9	--	21±9	--	32±9	--	28±9	--	--	--	--	--
No. 50	14±7	--	16±7	--	24±9	--	20±7	--	--	--	--	--
No. 100	9±5	--	11±5	--	17±7	--	14±5	--	--	--	--	--
No. 200	5±2	--	5±2	--	12±5 5±2	--	5±2	--	--	--	--	--

[a] 1-1/2-inch maximum surface source gradation will be used only for thick-lift pavements (3 inches or more).

[b] Regular gradation will be used for conventional traffic.

[c] High-pressure gradation will be used for pavements to be subjected to aircraft with tire pressures greater than 100 psi, tracked vehicles, and vehicles with solid tires.

2-4. Plant-mix cold-laid bituminous mixtures.

Cold-laid bituminous mixtures are composed of well-graded mineral aggregate and one of the following binder materials: asphalt cement and liquefier, liquid asphalt, powdered asphalt and flux oil, emulsified asphalt, or tar. The term "plant-mix cold-laid bituminous concrete" is a broad one, covering a wide variety of types and grades of bitumen and of aggregate gradings. Plant-mix cold-laid bituminous concrete is similar in appearance and general physical characteristics to hot-mix bituminous concrete. One type of cold-laid bituminous concrete is composed of graded mineral aggregate and liquid asphalt prepared in a conventional paving plant. This type of mixture is commonly laid at or near atmospheric temperatures in the same manner as hot-mix bituminous concrete. Liquid asphalt mixtures generally require aeration after mixing to permit sufficient evaporation of the volatiles or excessive moisture so that the mixtures can gain sufficient stability to support the compaction rollers. Air temperature, moisture, and wind control the length of time the cold mix must cure. In many cases, the moisture in the cold mixture can be reduced satisfactorily by exposure to sun and wind. The amount of asphalt required is generally the same as that for hot-mix bituminous concrete. When cutbacks or emulsions are used, an initially higher liquid content is required to obtain the same final asphalt content. Other types of cold-laid bituminous pavements are prepared in a conventional paving plant using aggregates, containing no more than 2 percent moisture, mixed with a liquefier and asphalt cement of 80 to 120 penetraton. This method allows more flexibility in varying the asphalt viscosity as needed. Sometimes a small percentage of lime, usually about 0.5 to 1.5 percent by weight, is added prior to the addition of the asphalt cement. The lime, combined with the liquefier, assists in coating the aggregate with asphalt cement. The curing period can be varied by regulating the amount of liquefier used. Emulsified asphalt and tar are also used for producing cold-laid plant mixes.

a. Advantages and disadvantages. The plant-mix cold-laid mixtures can be prepared with little or no heating of the aggregate or bitumen. Curing is required to permit the evaporation of the volatiles, liquefier, and/or excessive moisture. High density is difficult to obtain by rolling in cold weather, and the initial stability is low. Cold-laid mixtures have special advantages in that they can be manufactured at a central plant, shipped by rail or truck to the site, and stockpiled for a period of time.

b. Uses. In general, the cold-laid bituminous plant mixes are laid in the same manner and have the same uses as hot-mix bituminous concrete. They are especially adaptable for patchwork. Cold mixes will not be used on the surface of heavy-duty airfields or heliports, but may be considered for pavements subjected to low volumes of traffic with low tire pressures (100 pounds per square inch (psi) or less).

2-5. Sand-asphalt or sand-tar mixtures.

In regions, such as coastal areas, where sand of good quality is the only local aggregate available, the sand can be used to produce an economical base or surface course. Sand mixtures meeting these minimum requirements may be considered for paving roads and streets where light loads are anticipated and where considerable savings may be realized by using locally available sand. Mineral filler is often added to increase the density and stability of the mixture, but mineral filler is sometimes omitted in designing sand-asphalt mixtures for bituminous-stabilized base courses. Asphalt cement, liquid asphalt, tar, or emulsified asphalt may be used for binder. Cold-laid bituminous mixtures may be mixed at a central plant, mixed with a travel plant, or mixed in place. Hot bituminous mixtures are mixed at a central plant. Sand mixes are fine textured, dense, and relatively impermeable. The stability and durability of the sand mixes depend on the quality and grading of the fine aggregate, the amount and grade of bituminous binder, and the degree of control exercised in construction operations. The sand should be sufficiently well graded to meet the specified aggregate requirements for the type of course to be constructed and should be free from excessive amounts of foreign matter. In many cases the proper gradation may be obtained by selecting and blending locally available sands.

a. Advantages and disadvantages. Sand-asphalt or sand-tar mixes can be produced with locally available materials at a relatively low cost. The use of sand mixes is limited due to the relative lack of strength and durability.

b. Uses. Sand mixes will not be used as surface or intermediate courses for airfield and heliport pavements designed for high-pressure tires or for pavements designed for solid-rubber tires, steel wheels, or tracked vehicles. Sand mixes may be considered for bituminous base courses for all types of traffic areas and for any course for nontraffic areas. Sand mixes may be considered for surface and intermediate courses for pavements subjected to low-pressure tires (100 psi or less) and low traffic volumes. In this case, trial mixes should be made and tested in the laboratory.

2-6. Sheet asphalt pavements.

Sheet asphalt is a refined type of hot sand-asphalt pavement in which the grading, quality of sand, amount of mineral filler, and asphalt cement content are carefully controlled. The percentage of asphalt required is generally higher than that used for sand asphalt. Sheet asphalt provides a smooth, impermeable, homogeneous surface course that gives best service when traffic is spread evenly over the pavement. Normally, sheet asphalt is used for surface courses only and is constructed 1½ to 2 inches thick over an intermediate course.

a. Advantages and disadvantages. Since closer control is exercised sheet asphalt pavements perform better than sand-asphalt mixtures, but the cost of sheet asphalt is greater.

b. Uses. Sheet asphalt pavements have the same uses as sand-asphalt mixtures.

2-7. Stone-filled sheet asphalt mixtures.

Stone-filled sheet asphalt normally consists of up to 35 percent coarse aggregate, well-graded sand, mineral filler, and asphalt cement prepared in the same manner as sheet asphalt. The coarse aggregate should pass the ⅝-inch sieve. The stone-filled sheet asphalt mixture is a type of sheet asphalt mixture and has the same general characteristics. The percentage of coarse aggregate will vary proportionally when the specific gravities of the fine aggregate and coarse aggregate portions are not uniform. Stone-filled sheet asphalt pavement is used generally as a surface course constructed 1½ to 2 inches thick and is sometimes called "Topeka Mix."

a. Advantages and disadvantages. The addition of stone increases the strength of the sand mixture significantly. However, the addition of stone may increase the cost and in some case produce a loose aggregate problem resulting in broken windshields or foreign object damage.

b. Uses. Stone-filled sheet asphalt pavements have the same uses as sand-asphalt mixtures.

2-8. Bituminous macadam penetration pavement.

A penetration macadam surface course is constructed beginning with a layer of rolled coarse aggregate, followed by pressure application of bituminous cement. Next, the surface voids in the coarse aggregate layer are filled with fine aggregate to key in the coarse aggregate, followed by an additional application of bituminous cement, which is then covered with fine screenings and rolled.

a. Advantages and disadvantages. A minimum amount of equipment is required for construction, and the pavement is particularly adapted for jobs in remote localities involving small yardage. Macadam surfacing is not considered equal in quality to bituminous concrete produced by central paving plants since this method of construction cannot be as carefully controlled.

b. Uses. Penetration-type surfaces may be considered for use on roads and streets not subjected to traffic by tracked vehicles.

2-9. Rock-asphalt pavement.

Rock-asphalt pavement is composed of crushed, natural asphalt-impregnated limestone or sandstone, or a combination of these, used alone or mixed with additional asphalt or flux oil. Rock-asphalt pavement is laid cold in the same manner as cold-laid asphaltic concrete. Rock asphalt will only be used in surface courses for roads and will not be constructed over 1½ and 2 inches thick for blended and fluxed rock asphalt, respectively. Kentucky, Alabama, Texas, New Mexico, Oklahoma, and Utah have natural rock-asphalt deposits where paving material is produced commercially. The character and quantity of the aggregate and asphalt in the material varies among the different deposits and sometimes varies within the same deposit. Rock asphalt pavement is prepared by blending into the natural asphalt a crushed impregnated limestone or sandstone or a combination of the two in proper proportions to produce a properly graded mixture with a specified asphalt content. The natural rock asphalt must be enriched (that is, more asphalt must be added to the mixture) if the material contains insufficient asphalt in its natural state to produce a satisfactory mixture. Hot mixes are sometimes produced by heating crushed limestone impregnated with relatively hard asphalt, alone or with added sand, and mixing with additional asphalt cement in a conventional plant.

a. Advantages and disadvantages. The advantages and disadvantages are the same as those for plant-mix cold-laid bituminous mixtures. In addition the use of rock-asphalt pavement reduces cost because this mixture already contains binder material.

b. Uses. Rock-asphalt pavements are used for roads and streets not subjected to traffic by tracked vehicles. Rock asphalts are sometimes used as the aggregate in slurry seals, but only predominantly sandstone rock asphalts should be used in slurry seals, since some limestone rock asphalts polish under traffic and thus produce a slick pavement surface.

2–10. Bituminous road mix.

Bituminous road mixes are normally mixed in place by the use of travel plants or common types of road-building equipment, such as blade graders, disk harrows, drags, and pressure distributors. The binders used in road-mix construction may be either liquid asphalts, emulsified asphalts, or tars. The percentage of bitumen required is generally the same as for cold-laid bituminous concrete and depends upon the type and gradation of the aggregate used. Aggregates used in road mixes may be existing subgrade materials, loosened existing subgrade materials blended with imported materials, or properly processed imported materials placed on the existing base or subgrade. When the amount of minus 200 material exceeds 20 percent, stabilization with asphalt is difficult. A wide range of aggregates may be used, and the gradation requirements are less strict than those for hot or cold plant-mixed types. The bitumen is normally applied by a pressure distributor to the processed aggregate on the base or subgrade and then thoroughly mixed with the aggregate. A travel-type mixing plant combines the aggregates with a bituminous material and continuously discharges the mixture at the rear of the machine as the plant travels along the strip being paved. The use of a travel plant permits more accurate proportioning of the bitumen and aggregate and generally produces a more uniform and higher quality mixture. Further, because more viscous types of liquid asphalt and tar may be used, the curing time is reduced. Curing is usually required to reduce the volatiles in the liquid asphalt and tar or water in the asphalt emulsion prior to spreading and compacting, because excessive amounts of volatiles and water affect the compactibility of the mixture and the stability of the finished pavement. Manipulation with blades or other road machines may speed up curing.

a. Advantages and disadvantages. Much less equipment is required for construction using bituminous road mix than is required using asphalt concrete, thus resulting in cost savings. The use of locally available materials also results in significant cost savings. Bituminous road mix, however, does not have the strength or durability of asphalt concrete. The road-mix type of pavement provides an economical means of obtaining a satisfactory surface for roads and streets when the required amount of pavement is small, when the natural soil is suitable as aggregate, or when satisfactory aggregates are nearby. Seal coats with aggregate cover should be applied as a part of road-mix construction, since road mixes are often open graded or of relatively low density and are therefore susceptible to oxidation and abrasion.

b. Uses. When properly designed and constructed on a suitable existing subgrade or using locally available aggregates, the quality of road-mix construction approaches that of cold-laid plant mix. Road mix is used for intermediate or surface courses, but because of the less accurate control, it is considered inferior to plant mixtures. Road mix is not suitable for use above the base course for airfields. Road mix may be used as a wearing course for temporary roads and streets, or as the first step in stage construction for permanent roads and streets when these are to be supplemented by plant-mix surfaces as the demands of traffic increase and warrant the increased thickness. Seal coats reduce infiltration of air and water and thus improve the durability of road-mix pavements.

2–11. Surface treatments.

Surface treatments consist of a thin mat of mineral aggregate cemented together with various grades of bituminous materials. The bituminous material is applied by a pressure distributor to any prepared base, followed by an application of mineral aggregate of high quality, and finished by rolling. Surface treatments range from a light application of bituminous material followed by a light cover of sand and rolling to a succession of layers built up to various thicknesses, generally not exceeding ¾ inch. The quantity and type of bitumen and aggregate to be used for the treatment depend upon the pavement condition. The bitumen should be capable of readily bonding the cover aggregate in a uniform layer.

a. Advantages and disadvantages. The advantages and disadvantages are the same as those for bituminous macadam penetration pavement.

b. Uses. Surface treatments are used for surfacing airfield overrun areas and certain roads and streets. Surface treatments provide wearing resistance as well as waterproofing to base courses, new pavements (such as plant-mix, cold-laid, mixed-in-place, and sand mixtures), and worn or aged bituminous pavements. Multiple surface treatments are used to provide even greater wearing resistance and some structural strength.

2-12. Surface treatment covered by plant mix.

Base courses, bituminous concrete, and portland cement concrete (PCC) may be treated with an application of bitumen covered with aggregate, followed by a tack coat and a layer of either cold or hot plant mix. The aggregate is rolled prior to placement of the surface course.

a. Advantages and disadvantages. This treatment results in greater initial cost; however, this cost may be offset by impoved performance when overlaying cracked pavements.

b. Uses. A surface treatment covered by plant mix is sometimes known as a keystone course because it provides a bond between the base and surface course and tends to level irregularities when used over old pavements. This treatment has also been used to help control reflection cracking.

2-13. Prime coat.

Before a bituminous mixture is placed on a nonbituminous base course, a prime coat of bituminous cutback or emulsion should be applied. Prime coats are applied with pressure distributors. Low viscosity medium-curing (MC) grades of liquid asphalt (or comparable grades of tar or asphalt emulsions) usually are specified when dense, hard-to-penetrate bases are to be primed. When the surface is sufficiently open, higher viscosity MC grades or low viscosity rapid-curing (RC) grades of liquid asphalt may be used provided penetration is achieved without deposition of excessive asphalt on the surface. As much bitumen as can be completely absorbed within 24 hours should be used. Generally most of the absorption will take place during the first hour.

a. Advantages and disadvantages. When excessive amounts of bituminous cutback or asphalt emulsion are used, the surplus material is absorbed by the overlying pavement and in some cases is a contributing factor to failure. Excessive material should be blotted with sand prior to overlay. Excessive prime coat also causes lateral movement of the bituminous concrete during rolling operations. The desired application rate depends upon the density or porosity of the base course. Tar makes a particularly good prime coat because of its penetrating qualities. In some instances, the prime coat cures slowly in cold or damp climates, and it may be necessary to eliminate the prime. A primed surface in good condition will not require a tack coat unless the surface has been subjected to construction or other traffic.

b. Uses. The purpose of a prime coat is to penetrate and reduce the voids in the surface of the base course and to bind the particles together to form a tight, tough surface on which the bituminous concrete can be placed.

2-14. Tack coat.

When a bituminous mixture is to be placed over an existing PCC or existing bituminous concrete mixture or on new bituminous courses, a heated tack coat of RC liquid asphalt or an emulsified asphalt (normally SS or RS grades are used) should be applied to the cleaned surface before the new course is constructed to insure a good bond between the two layers. The application should be made with a pressure distributor.

a. Advantages and disadvantages. A tack coat results in improved bond if properly applied. Excess tack coat, however, will create compaction problems and also result in the loss of bond.

b. Uses. A tack coat is used during construction to bond the asphalt concrete mixture to the existing asphalt concrete or PCC.

2-15. Seal coat.

A seal coat is a type of protective treatment consisting of bitumen and aggregate applied to an existing pavement. A properly designed and newly constructed bituminous-concrete mixture does not require a seal coat. Road-mix and plant-mix cold-laid pavements should receive a seal coat as part of the initial construction. Pavement surface conditions will dictate the type and application rates for the seal coat.

a. Advantages and disadvantages. Seal coats can be placed with a minimal amount of labor and equipment. However, loose aggregate sometimes results in broken windshields. Seal coats without aggregates should not be used in high-speed traffic areas because the surface may become slippery.

b. Uses. Seal coats are sometimes used to change surface texture or color and as an antiskid treatment. Seal coats are also particularly adapted for treating old bituminous mixtures that are dry, raveling, or beginning to show hairline cracks. The additional bitumen tends to improve flexibility in the pavement surface, and the treatment fills cracks or surface voids.

2-16. Slurry seal.

Slurry seal is a mixture of asphalt emulsion, crushed fine aggregate, mineral filler, and water.

The materials are combined to produce a mixture of slurry consistency that can be properly applied to the pavement.

a. Advantages and disadvantages. The cost of placing a slurry seal is relatively small, but this mixture does not provide additional strength to the pavement and does not wear rapidly under a high volume of traffic.

b. Uses. Slurry seals are used for treating old bituminous pavements that are dry, raveling, or beginning to crack. A properly placed slurry seal will fill small cracks and coat the surface of the pavement to a depth of ⅛ to ¼ inch. Slurry seals are most effective on lightly used pavements as a protective measure to reduce weathering effects or as an antiskid treatment. They are not well suited to surfaces subjected to large volumes of traffic.

2-17. Waterproofing coat.

The waterproofing coating consists of a cutback asphalt or an emulsified asphalt applied with a pressure distributor. The best type of asphalt for this coat varies with climate and the type of material being coated. The material selected should form a protective coating over the soil, and most of the volatiles shold be evaporated before the next course is placed. The type of asphalt selected and the application procedures used should be the same as for the prime coat.

a. Advantages and disadvantages. The placement of a waterproofing coat is costly and may initially delay construction. During times of bad weather, however, this material will protect the underlying material and allow construction to start soon after rainfall.

b. Uses. During construction protection of a completed layer of subbase or subgrade material from rainfall may be desirable. This protection is most often needed when a soil that is sensitive to moisture is exposed. The layer to be waterproofed should have a transverse slope of about 1 percent or more so that surface water can completely drain.

CHAPTER 3

PLANTS AND RELATED EQUIPMENT

3-1. General.

The objective of an asphalt plant is to produce a mixture properly coated with asphalt that consistently meets the requirements specified in the job mix formula (JMF) for aggregate gradation, asphalt content, and temperature. Control of the mixture quality must be initiated at the stockpiles. Each nominal aggregate size should be stockpiled such that no mixing with other aggregate stockpiles nor segregation within the stockpile occurs. The stockpiled material is normally fed into the aggregate hopper with a front-end loader. A separate hopper is provided for each aggregate to be fed into the mixture.

3-2. Batch and continuous mix plants.

a. General. Batch and continuous mix plants are illustrated in figures 3-1 and 3-2, respectively. Cold feed hoppers have individual feeders for each of the aggregates to be used in the mixture. These feeders must be set so that the desired percentage of each aggregate is fed into the plant. The rate of feed may be controlled by the gate opening, belt speed, or other methods depending on the type of cold feed. If the aggregate feeders are improperly set, a combination of the following problems may occur:

- One of the aggregate hot bins will overflow with material while another hot bin runs low on material.
- The gradation of the aggregate in the mix being produced will not meet the design gradation.
- The amount of natural sand may vary from design proportion and may exceed the amount allowed in the specifications.

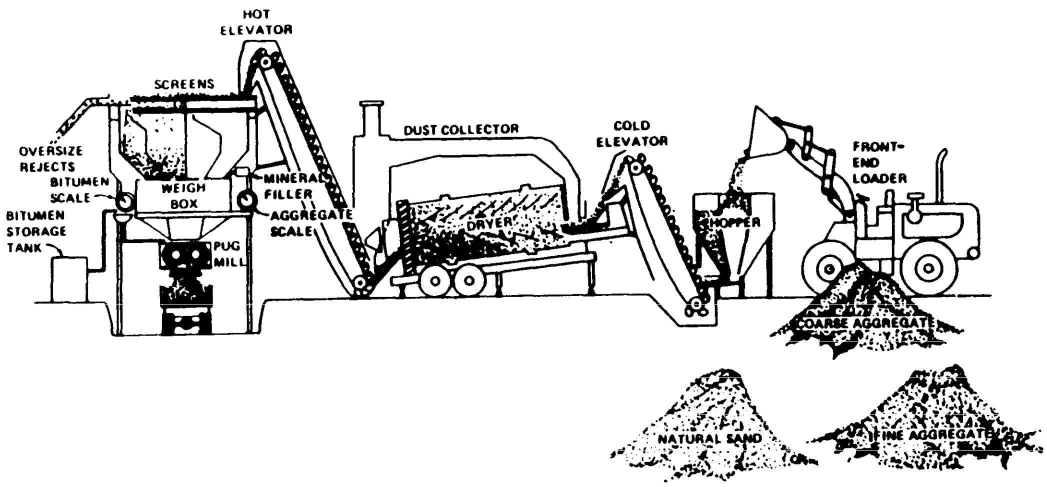


Figure 3-1. Batch plant.

b. Cold feed calibration. Before the start of a project the cold feeds should be calibrated so that each feeder can feed the desired rate of material. The cold feed calibration involves feeding one aggregate at a time onto a belt that is common to all aggregates. The speed of this belt should be determined prior to calibration of the feeders. One way to do this is to divide the belt length by the time required for one revolution. After the material is fed onto the belt, the material over a given length (for example, 5 feet) should be completely removed and weighed. The following relationship can be used to convert the weight of the sample taken to tons per hour:

$$R = \frac{1.8WS}{L} \qquad \text{(eq 3-1)}$$

where

R = rate of feed, tons per hour
W = weight of sample, pounds
S = speed of belt, feet per second
L = length of belt sampled, feet

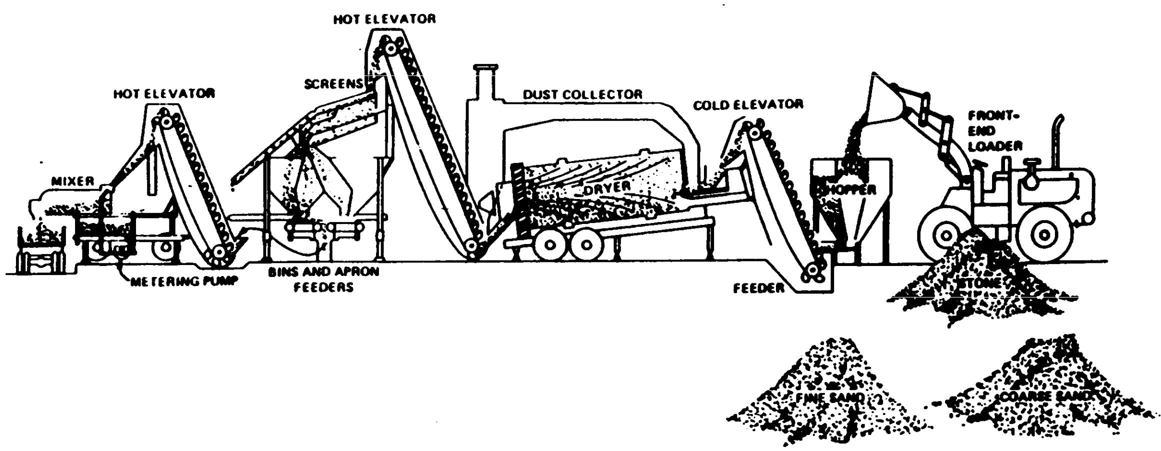


Figure 3-2. Continuous mix plant.

Each aggregate should be fed at four to five different feeder settings and the rate of feed determined. A plot of this data showing the relationship between rate of feed (tons per hour) and feeder setting (gate opening, feeder belt speed, or other method for setting aggregate feeder) should be prepared for each aggregate. These plots can be used to set each feeder to feed at the desired rate.

c. Dryer. After the aggregate feeders have been properly set, the aggregate is carried up the cold elevator and through the dryer. The dryer removes the moisture from the aggregate and heats the aggregate to the desired temperature.

d. Dust collector. A dust collector collects the dust created in the dryer and other plant components and adds all or any portion of it back to the mix at the hot elevator. Many mixes have an excessive amount of dust, and the excess should be removed. The plant should have the capability to remove any desired portion of the collected dust from the mixture.

e. Screening. The aggregate exits the dryer and is carried, along with the returned dust, up the hot elevator, over the screening deck, and into the hot bins. Screen sizes are selected such that the oversize material will be rejected and the remaining aggregates are separated into various sizes. Ideally, the screen sizes should be selected so that the amount of material going into each hot bin is proportional to the relative volume of that hot bin. For example, suppose that hot bin No. 1 has a volume of 100 cubic feet, hot bin No. 2 has a volume of 50 cubic feet, and hot bin No. 3 has a volume of 50 cubic feet. Screens should be selected so that 50 percent of the material will go into bin No. 1, 25 percent into bin No. 2, and 25 percent into bin No. 3.

f. Percentage of each hot bin. The percentage of each hot bin to be used in the mixture should be determined. To do this the cold feeds should be set properly and the material run into the hot bins. Samples of each hot bin should then be taken and the gradation for each sample determined. The percentage of each bin to be used should be selected so that the graduation of the combined materials from the hot bin is equal to the JMF.

g. Mixing aggregate and asphalt. After the cold feeds and hot bins are properly set the combined aggregate from the hot bins is mixed with the proper amount of asphalt. The mixing time, generally 5 seconds for dry mixing and 25 to 40 seconds for wet mixing, should be selected so that all aggregate is coated. The plant should now be set to produce a uniform asphalt concrete mixture having proper aggregate gradation, asphalt content, and temperature. The aggregate feeders, cold elevator, dryer, dust collector, hot elevator, screening deck, and hot bins are similar for batch and continuous mix plants. Batch and continuous mix plants differ in the proportioning and mixing of the asphalt mixture. The batch plant weighs the various nominal size aggregates and asphalt to produce a batch of material that is then mixed for a specified period of time. The continuous mix plant continuously adds aggregate and asphalt to the mixer while the final mixed product exits the mixer. For a continuous mix plant, the hot bin feeders and asphalt feeder must be calibrated to insure that the correct proportions of each are added to the mixture. The mixing time is computed by dividing the mixer capacity by the rate of feed of material into the mixer.

3-3. Drum mixer.

a. General. An asphalt plant that has become popular through-out the paving industry is the drum mixer (fig 3-3). The drum mixer is less expensive than the common batch plant and generally produces material at a higher production rate. When a drum mixer is used, the gradation must be controlled at the cold feeds because no additional screening of the mixture occurs. The drum mixer is frequently used in the production of recycled asphalt concrete as well as conventional asphalt concrete.

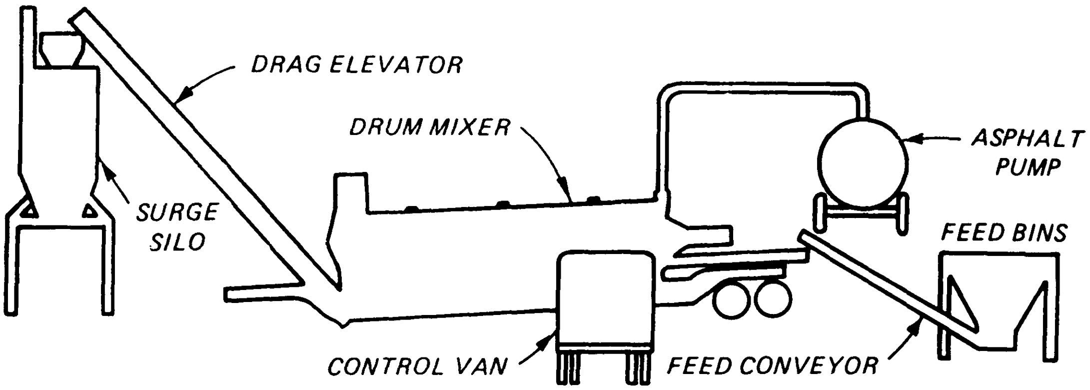


Figure 3-3. Drum mixer.

b. Cold feed calibration. The cold feed is set up much the same way as for the batch plant, but the drum mixers have a weight sensor on the aggregate feed belt that weighs a given length of the loaded belt. Thus, to calibrate the cold feeds, each aggregate can be fed onto the belt at various gate openings or individual belt speeds, weighed, and the feed rate computed. These steps should be followed for each of the aggregates to be added to the mixture, and a calibration curve should be developed. A meter is used to measure and thus control the rate of asphalt added to the mixture.

c. Dryer. For the drum mixer the burner for the dryer is located on the high side of the drum. The aggregate enters the dryer just below the burner and helps to shield the asphalt binder from direct contact with the flame. The asphalt is added to the dryer at approximately the midpoint to two-thirds the length to prevent close contact with the flame, which could cause over-heating and damage the asphalt binder.

3-4. Bituminous storage silo.

Bituminous storage silos are often used to store bituminous mixture before loading onto trucks. Thus, plants can run continuously even when there is a temporary shortage of trucks. Material can be stored in silos for short periods of time, but if stored too long, the material may oxidize excessively causing the bituminous binder to become hard and brittle. There are many types of storage silos, with some doing less damage than others to the asphalt concrete, but as a general rule bituminous concrete mixtures should be stored more than 4 hours regardless of the type of storage silo used. If segregation of aggregate or drainage of bitumen occurs in the silo, use of the silo should be disallowed or changes should be made to prevent segregation and drainage.

3-5. Travel plant.

A travel plant is often used to produce cold mix in place. This type of plant does not provide control of materials or mixing as well as central plants do. Aggregate is fed to the travel plant, and the proper amount of asphalt binder is continuously mixed with the aggregate. The bituminous mixture is placed to the desired grade and compacted. The aggregate to be mixed is normally windrowed before being picked up and mixed using the travel plant.

CHAPTER 4

PLACEMENT EQUIPMENT

4–1. Asphalt spreader.

a. Types of spreaders. An asphalt spreader is used to place most mixture types such as hot mix, cold mix, and base course material. Spreaders now in use operate on either tracks or rubber tires and most have a vibrating screed to strike off and smooth the paving mix. Some spreaders use a tamping bar in conjunction with the screed, or an oscillating screed with a vibrating compactor, and others use a vibrating screed for both strike off and initial compaction. Conventional paving machines in use are capable of placing hot-mix paving mixtures satisfactorily, provided they are maintained in good mechanical condition, kept properly adjusted, and operated by experienced personnel. Poor pavement surfaces result if the screed plates are worn or rusty or if the tamping bars are worn or not properly adjusted.

b. Automatic grade control. Bituminous spreaders should have a means of automatically controlling the grade. If an automatic grade control device is used on the spreader for constructing pavements that consist of two paving lanes, it should include a sensing device for control of one end of the screed and a slope-control mechanism for control of the other end of the screed or a sensing device on each end of the screed. Where the paver is used for constructing pavements with multiple paving lanes (more than two paving lanes), sensing devices will be used on each side of the spreader for control of the screed. The slope-control mechanism will not be used for grade control in multiple paving lane operation.

4–2. Joint heaters.

Joint-heating devices for attachment to bituminous spreaders have been used on construction projects. They are used to heat the edge of an adjacent pavement lane during placement so that a hot joint is obtained. Experience with joint heaters has shown that there is a danger of overheating the existing bituminous mixture. Accordingly, it is the policy of the Office, Chief of Engineers (OCE), and the Air Force that pavement joint heaters will not be used without the written authorization of the respective office. If a contractor should desire to use a pavement joint heater, a request will be submitted to Headquarters, Department of the Army (DAEN-ECE-G) or the appropriate Air Force major command. The request will include a description of the controls which the proposed joint heater has to assure that the bituminous mixture will not be detrimentally affected.

4–3. Bituminous distributor.

Bituminous distributors are used to apply bituminous material evenly over a surface. All nozzles should be free and open, and should be the same size and at the same angle with reference to the spray bar to produce a uniform fan of bituminous material. The height of the spray bar above the surface is important for uniform application. When the bar is too high or too low, a light application in the middle of the spray fan and heavy application at the ends will occur, causing streaking. The height of the spray bar should be adjusted so that a double or triple overlap of the spray fan is obtained. The Asphalt Institute's Manual Series No. 13 offers guidance for calibrating and checking application equipment.

4–4. Rollers.

a. Roller types. A number of roller types are being used for paving operations. Rollers used to compact bituminous mixtures are static steel-wheel, vibratory steel-wheel, and rubber-tired rollers.

(1) *Static steel-wheel rollers.* The static steel-wheel rollers consist of two-wheel (tandem), and three-wheel (tandem), and three-wheel (tricycle) versions. These rollers are generally used for breakdown and finish rolling. Static steel-wheel rollers leave a smooth finish on the pavement surface, but excessive rolling may result in lateral movement of the mixture causing surface cracking and a general loss in density. These rollers should be equipped with a system for watering the drums and should have scrapers to remove any material that sticks to the drums.

(2) *Vibratory steel-wheel rollers.* The vibratory steel-wheel rollers are commonly used for compacting bituminous mixtures. They may consist of dual-drum vibration, single-drum vibration and single-drum static, or single-drum vibration and rubber tires on the rear axle. These rollers can be used for breakdown, intermediate, and finish rolling. Breakdown and intermediate rolling are performed in the vibratory mode, while finish rolling is performed in the static mode. Although

the vibratory roller is used for intermediate rolling, it does not replace a rubber-tired roller. The vibratory roller should have a watering system on steel drums and rubber tires (if applicable) along with scrapers on the steel drums and scrapers and pads on the rubber tires.

(3) *Rubber-tired roller.* Rubber-tired rollers are used for intermediate rolling of bituminous mixtures. These rollers provide for an increase in compaction after breakdown rolling and produce a watertight surface. A large rubber-tired roller (capable of being loaded to a minimum of 4,500 pounds per tire and capable of minimum tire inflation pressure of 90 psi) should be available for construction of heavy-duty pavements on roads or airfields. The rubber-tired roller should have a watering system for the tires and should have scrapers and pads to prevent accumulation of materials on tires. A large rubber-tired roller should be used for compaction of all heavy-duty bituminous concrete pavements.

b. Operation of rollers. Rollers should generally be operated at or below a rate of 3 to 5 miles per hour (fast walking speed). Quick turns on freshly laid mixture should not be allowed.

4–5. Aggregate spreaders.

Aggregate spreaders are used during the construction of bituminous surface treatments to apply the aggregate to the surface being treated. The spreader should be designed and calibrated to apply a predetermined amount of aggregate uniformly over the surface. Some of the aggregate spreaders are self-propelled, while others are propelled by the truck hauling the aggregate. The self-propelled aggregate spreaders are desirable because they allow for a more uniform application of material and a smoother operation.

4–6. Slurry seal machine.

A slurry seal machine is used to mix aggregate, filler, asphalt emulsion, and water in the correct proportions and to uniformly apply the material to the surface to be sealed. The slurry seal machine generally contains storage for the aggregate, filler, emulsion, and water. These materials are mixed and deposited into a squeegee box from which the slurry seal is squeegeed onto the surface at a thickness approximately equal to the maximum aggregate size.

CHAPTER 5

MATERIALS

5–1. Bituminous materials.

Bituminous materials used in paving operations include asphalt or tar products conforming to the specifications listed in table 5-1.

Table 5-1. Specification references for bituminous materials

Bitumen type	Specification
Asphalt cement	ASTM D 946 or D 3381
Asphalt cement for cold regions	Paragraph 6-2d and e
Cutback asphalt (slow-curing type)	ASTM D 2026
Cutback asphalt (medium-curing type)	ASTM D 2027
Cutback asphalt (rapid-curing type)	ASTM D 2028
Asphalt, emulsified	ASTM D 977
Asphalt, cationic emulsified	ASTM D 2397
Tar	ASTM D 490
Tar cement (base for rubberized tar)	ASTM D 2993
Rubberized tar cement	ASTM D 2993

5–2. Aggregates.

Aggregates for use in bituminous concrete should be clean, hard, and durable. Angular aggregates provide more stable bituminous concrete mixtures than do rounded aggregates.

a. Sieve analysis. Aggregates to be used in a paving mix should be subjected to a sieve analysis. An experienced engineer can obtain information from an aggregate's grading curve concerning the suitability of the aggregate for a paving mix, the quantity of bitumen required, and whether mineral filler should be added. Also, a sieve analyis is required if the aggregate is to be used in laboratory tests for conducting bituminous concrete mix design, as described in chapter 6. Sieve analysis of fine and coarse aggregates shall be conducted according to ASTM C 136. Figure 5-1 shows a form suggested for recording and calculating data obtained from laboratory sieve analyses. Included in the form are sieve analysis data for typical coarse aggregate, fine aggregate, sand, and mineral filler used in a paving mixture.

b. Specific gravity. Specific gravity values for aggregates used in paving mixture are required in the computation of percent voids total mix and percent voids filled with bitumen in the compacted specimens. Criteria have been established to specify limiting values for these properties. However, specific gravity values must be carefully determined following specified procedures to insure that the criteria are properly applied. Three different methods for specific gravity determinations are provided, and the selection of the appropriate test procedure depends in part on the water absorption of each aggregate blend.

c. ASTM apparent specific gravity. Apparent specific gravity of the fine and coarse aggregate shall be used only with aggregate blends showing water absorption of less than 2.5 percent. The apparent specific gravity shall be determined as described in ASTM C 127 for coarse aggregate, ASTM C 128 for fine aggregate, and ASTM C 188 or D 854 (whichever is applicable) for mineral filler. Figure 5-2 shows a form suggested for use in recording data to determine the apparent specific gravity. Typical data have been supplied in this form as an illustration of its use. Properly weighted values, based on the amount of each type of material in a given blend, should be used in computations subsequently discussed. The apparent specific gravity of the aggregate is used to determine the theoretical maximum specific gravity when the water absorption is less than 2.5 percent.

d. Bulk-impregnated specific gravity. For aggregate blends showing water absorption to be 2.5 percent or greater, the bulk-impregnated specific gravity can be used to determine the theoretical maximum specific gravity. This specific gravity is determined by the procedure outlined in MIL-STD-620, Method 105.

e. Theoretical maximum specific gravity. The theoretical maximum specific gravity can be determined by the test method described in ASTM D 2041. This test is conducted on the bituminous

SIEVE ANALYSIS

JOB NO.:	PROJECT: TYPICAL MIX	DATE:

STOCKPILE SAMPLES

DRY GRADATION

SAMPLE NO. Crushed Coarse Aggregate

U.S. STAND. SIEVE NO.	WEIGHT RETAINED	% RETAINED	% PASS
3/4			100
1/2	225.9	30.0	70.0
3/8	267.3	35.5	34.5
NO. 4	237.2	31.5	3.0
NO. 8	22.6	3.0	
NO. 16			
NO. 30			
NO. 50			
NO. 100			
NO. 200			
-200			
TOTAL	753.0		

WEIGHT ORIGINAL SAMPLE

SAMPLE NO. Crushed Fine Aggregate

U.S. STAND. SIEVE NO.	WEIGHT RETAINED	% RETAINED	% PASS
3/4			
1/2			100
3/8	1.1	0.2	99.8
NO. 4	53.9	9.8	90.0
NO. 8	104.6	19.0	71.0
NO. 16	104.6	19.0	52.0
NO. 30	96.3	17.5	34.5
NO. 50	82.5	15.0	19.5
NO. 100	60.5	11.0	8.5
NO. 200	30.3	5.5	3.0
-200	16.5	3.0	
TOTAL	550.3		

WEIGHT ORIGINAL SAMPLE

WASHED GRADATION

SAMPLE NO. Natural Sand

U.S. STAND. SIEVE NO.	WEIGHT RETAINED	% RETAINED	% PASS
3/4			
1/2			
3/8			
NO. 4			
NO. 8			
NO. 16			
NO. 30			100
NO. 50	9.4	4.5	95.5
NO. 100	54.6	26.0	69.5
NO. 200	124.9	59.5	10.0
-200 (T)	21.0	10.0	
TOTAL	209.9		

(A) WEIGHT ORIGINAL SAMPLE 209.2 GM
(B) WEIGHT AFTER WASHED 193.7 GM
(C) WASH LOSS (A − B) 15.5 GM
(S) -200 FROM SIEVING 5.5 GM
(T) TOTAL -200 C + S 21.0 GM
USE "T" TO CALCULATE PERCENTAGES

SAMPLE NO. Limestone Filler

U.S. STAND. SIEVE NO.	WEIGHT RETAINED	% RETAINED	% PASS
3/4			
1/2			
3/8			
NO. 4			
NO. 8			
NO. 16			
NO. 30			
NO. 50			100
NO. 100	2.3	2.0	98.0
NO. 200	9.4	8.0	90.0
-200 (T)	105.3	90.0	
TOTAL	117.0		

(A) WEIGHT ORIGINAL SAMPLE 117.4 GM
(B) WEIGHT AFTER WASHED 18.9 GM
(C) WASH LOSS (A − B) 98.5 GM
(S) -200 FROM SIEVING 6.8 GM
(T) TOTAL -200 C + S 105.3 GM
USE "T" TO CALCULATE PERCENTAGES

TESTED BY:	COMPUTED BY:	CHECKED BY:

Figure 5-1. Form for recording sieve analysis data and calculating aggregate gradation.

SPECIFIC GRAVITY OF AGGREGATES				DATE
PROJECT	JOB TYPICAL MIX			

COARSE AGGREGATE	UNITS (Grams)			
MATERIAL PASSING 3/4" SIEVE AND RETAINED ON No. 4 SIEVE				
SAMPLE NUMBER				
1. WEIGHT OF OVEN-DRY AGGREGATE	378.3			
2. WEIGHT OF SATURATED AGGREGATE IN WATER	241.0			
3. DIFFERENCE (Line 1 minus 2)	137.3			
APPARENT SPECIFIC GRAVITY, $G = \frac{(Line\ 1)}{(Line\ 3)}$	2.755			

FINE AGGREGATE	UNITS (Grams)			
MATERIAL PASSING NUMBER No. 4 SIEVE				
SAMPLE NUMBER				
4. WEIGHT OF OVEN-DRY MATERIAL	478.8			
5. WEIGHT OF FLASK FILLED WITH WATER AT 23° C	678.6			
6. SUM (Line 4 plus 5)	1157.4			
7. WEIGHT OF FLASK + AGGREGATE + WATER AT 23° C	977.4			
8. DIFFERENCE (Line 6 minus 7)	180.0			
APPARENT SPECIFIC GRAVITY, $G = \frac{(Line\ 4)}{(Line\ 8)}$	2.660			

FILLER	UNITS (Grams)			
SAMPLE NUMBER				
9. WEIGHT OF OVEN-DRY MATERIAL	466.5			
10. WEIGHT OF FLASK FILLED WITH WATER AT 23° C	676.1			
11. SUM (Line 9 plus 10)	1142.6			
12. WEIGHT OF FLASK + AGGREGATE + WATER AT 23° C	973.8			
13. DIFFERENCE (Line 11 minus 12)	168.8			
APPARENT SPECIFIC GRAVITY, $G = \frac{(Line\ 9)}{(Line\ 13)}$	2.764			

REMARKS

(SAMPLE NO. 1)		(SAMPLE NO. 2)	
FLASK NO.	________	FLASK NO.	________
BEAKER NO.	________	BEAKER NO.	________
TARE WT.	________	TARE WT.	________
TR.+SAMPLE WT.	________	TR.+SAMPLE WT.	________
SAMPLE WT.	________	SAMPLE WT.	________

TECHNICIAN (Signature)	COMPUTED BY (Signature)	CHECKED BY (Signature)

WES FORM JUN 77 2123

Figure 5-2. Form for determining specific gravity of aggregate components.

SPECIFIC GRAVITY OF BITUMENS

$77^{\circ}/77^{\circ}F$

Job No. ____________ Lab. No. ____________

		PYCNOMETER No. 1	No. ____
CALIBRATION WEIGHTS			
Wt of pycnometer + water, gr	(b)	61.9595	
Wt. of pycnometer, gr	(a)	37.9215	
Wt. of water, gr	(b-a)	24.0380	
TEST WEIGHTS			
Wt. of bitumen + pycnometer + water, gr	(d)	62.1568	
Wt. of bitumen + pycnometer, gr	(c)	47.8617	
Wt. of water, gr	(d-c)	14.2951	
CALCULATIONS			
Wt of bitumen + pycnometer, gr	(c)	47.8617	
Wt. of pycnometer, gr	(a)	37.9215	
Wt. of bitumen, gr	(c-a)	9.9402	
Wt. of water from calibration	(b-a)	24.0380	
Wt. of water from test	(d-c)	14.2951	
Wt. of water less bitumen	(b-a)-(d-c)	9.7429	
Specific gravity = $\frac{c-a}{(b-a)-(d-c)}$	=	1.020	
	Average		

REMARKS

DATE ____________ TECHNICIAN ____________

WES Form 988
Nov. '57

Figure 5-2. Form for determining specific gravity of aggregate components—continued.

mixture and does not require a specific gravity test on the individual aggregates. This method can be used for aggregate blends having any amount of water absorption.

f. Wear requirements for coarse aggregate. The determination of percentage of wear for coarse aggregates may not be necessary if the aggregate has been found satisfactory by previous tests and/or performance. However, coarse aggregates obtained from new or doubtful deposits shall be tested for conformance to specification requirements using ASTM C 131.

g. Soundness test. The soundness test is used where damage from freezing is expected to be a problem. The soundness test need not be performed on aggregate that has been found satisfactory by previous tests or performance data. However, aggregate obtained from new or doubtful deposits will be tested for conformance to specification requirements using ASTM C 88.

h. Combining aggregates. When bituminous mixtures are produced, aggregates from two or more sources must be combined. Methods and procedures described in this manual will permit determination of the most suitable aggregate blend available and will prescribe the proper bitumen content for the particular aggregate blend determined to be the most suitable. Whenever a bituminous mixture does not meet established criteria, either the gradation of the aggregate must be improved, another aggregate must be used, or the asphalt content must be modified. The choice as to improvement of gradation or the use of another aggregate is a matter of engineering judgment involving an analysis of the available aggregate supplies and cost considerations.

5-3. Mineral fillers.

a. General. Some mineral fillers are more desirable in asphalt paving mixtures than others. For example, fine sands and clays are less suitable fillers than limestone filler or portland cement, and well-graded materials are more suitable than poorly graded materials. Satisfactory pavements may be designed using commercial fillers that conform to ASTM specifications. The specific gravity of the mineral filler is required to perform a void computation. The specific gravity will be determined following ASTM D 854 or ASTM C 188 (as appropriate), except that when the bulk-impregnated specific gravity or ASTM D 2041 is used, the mineral filler shall be included in the blended aggregate. Figure 5-2 presents a form suggested for the tabulation and computation of these data to determine apparent specific gravity. Typical data have been entered in this form to illustrate its use.

b. Addition of mineral filler. The filler requirements of each aggregate blend must be estimated after the blends to be tested in the laboratory have been selected. The quantity of mineral filler to be added generally depends on the amount of filler naturally present in the aggregate. The amount of filler that exists naturally in most aggregates is sufficient to produce satisfactory bituminous concrete. Research has indicated that under normal circumstances and within reasonable limits, the addition of mineral filler reduces the quantity of bitumen required for the paving mixture. The addition of a satisfactory mineral filler within practical limits also increases the stability of a paving mixture. Excessive amounts of filler, however, may decrease the durability of the paving mixture because of the decrease in bitumen film thickness. Filler contents should never exceed 10 percent by weight of total aggregate for bituminous concrete and 20 percent for sand asphalts. Practical considerations and optimum performance usually will dictate quantities of about 5 percent filler for a bituminous-concrete mixture and 10 percent for sand-asphalt mixture.

5-4. Antistrip agents.

a. General. Several antistrip agents have been successfully used to reduce the probability of the asphalt stripping from the aggregate. Some antistrip agents are added to the asphalt binder before it leaves the refinery, while others are added as mineral filler directly into the mixer. The immersion compression test described in MIL-STD-620 is used to evaluate the stripping property of a dense-graded bituminous hot mix.

b. Recommended procedure. The recommended procedure for improving the resistance of an aggregate to stripping is to add 1 percent hydrated lime to the mixture. This 1 percent lime must be included in the determination of the aggregate gradation.

5-5. Antifoam agents.

Silicone additives have been successfully used to suppress foaming of bitumen in asphalt plants. The silicone that has been used for this purpose is Dow Corning 200 (DC-200) or its equivalent mixed at the rate of 1 ounce per 5,000 gallons of asphalt. The silicone additive has successfully prevented slumping of mixes in trucks, which sometimes occurs when the hot-mix gradation is such that the mix traps escaping steam. In addition, silicones have provided better finishing qualities to pavement mixtures. Testing by several agencies has revealed no detrimental effects on the properties of asphalts when silicone is used in the recommended concentrations. Comparable test data are not available on the effects of silicones on tar or rubberized tar, but limited experience has indicated no adverse effects.

CHAPTER 6

HOT-MIX BITUMINOUS MIXTURES DESIGN AND CONTROL

6-1. General.

The term "hot-mix bituminous mixture" refers to several types of mixtures that are applied hot. These mixtures which consist of aggregate and bituminous material are used in new pavement construction to increase the strength of an existing pavement, to improve skid resistance, or to maintain satisfactory quality on the surface of an existing pavement. Two types of hot-mix bituminous mixtures are bituminous concrete and porous friction course.

6-2. Bituminous concrete.

a. General. Bituminous concrete consists of a mixture of aggregate and binder (asphalt cement, tar, or rubberized tar). This material is produced at a central plant, laid to the desired grade with a bituminous spreader, and compacted. Bituminous concrete provides a high-strength, waterproof, smooth riding surface.

b. Bituminous materials. Bituminous materials used in preparing hot-mix bituminous concrete are listed in table 6-1 along with applicable ASTM specifications.

Table 6-1. Reference specification for various types of bitumen

Bitumen type	Specification
Asphalt cement	ASTM D 946 or D 3381
Asphalt cement for cold regions	TM 5-818-2/AFM 88-6, Ch 4
Rubberized tar cement	ASTM D 2993
Tar	ASTM D 490 and D 2993

c. Asphalt cements. In general, the softest grade of asphalt cement consistent with traffic and climate should be used. The asphalt cements listed in ASTM D 946 and D 3381 are those currently being produced in the United States. It is the consensus of asphalt technologists that viscosity grades AC-2.5, AC-5, AC-10, AC-20, and AC-40 will cover most combinations of climate, traffic, and construction considerations. The Departments of the Army and Air Force concur in this opinion. However, many states have found a need for AC-30, and hence this asphalt cement is specified in some locations. The Departments of the Army and Air Force require an asphalt cement that will perform satisfactorily in very cold climates such as Alaska, Greenland, and the northern continental United States. These requirements are discussed in the following subparagraphs.

d. Selection of grade of asphalt based on climate. Figure 6-1 provides guidance for selection of the proper viscosity grade of asphalt cement based on geographical location and climatic conditions. In the northern area, the viscosity grade which will provide asphalt cement with a penetration of approximately 120 to 150 will usually be selected. The cold weather criteria should also be satisfied in the northern area when the temperature index is less than +30. In the central area, the viscosity grade which will provide asphalt cement with a penetration of approximately 85 to 100 will usually be satisfactory. In the southern area, the viscosity grade which will provide an asphalt cement with a penetration of approximately 60 to 70 will be selected. The areas shown in figure 6-1 are approximate, and a pavement temperature index may be computed for specific locations in order to determine the proper grade of asphalt cement. For areas of warm climate having an average monthly maximum temperature above 75 degrees Fahrenheit (°F), the pavement index is determined by summing the increments of average monthly maximums above 75° F. In this case, only positive increments are used. For cold climates where the average monthly maximum is never above 75° F, the number of degrees by which the hottest month fails to reach 75° F is taken as the negative pavement temperature index. Pavement temperature is then related to desired asphalt penetration as shown in Table 6-2.

Table 6-2. Desired asphalt penetration based on bituminous pavement temperature index

Bituminous pavement temperature index, °F	Desired asphalt penetration
−20 to +30	TM 5-818-2/ AFM 88-6, Chap 4
+30 to +80	85 to 100
+81 and above	60 to 70

e. Cold regions requirements. To minimize cracking of pavements in cold regions (temperature index, −20° to +30°F), consideration must be given to the low-temperature susceptibility of asphalt cements as related to the combination of penetration and viscosity values which are reflected in the Pen-Vis number (PVN) of the asphalt cement. The PVN was proposed by N. W. McLeod (*Proceedings, Association of Asphalt Paving Technologists*, Vol. 41) and is illustrated in figure 6-2. Thickness design requirements for cold regions are provided in TM 5-818-2/AFM 88-6, Chapter 4. Asphalt concrete designs (including mix designs), asphalt cement testing, and project specifications for pavement projects in cold regions areas (including areas outside the continental United States) are to be submitted to DAEN-ECE-G for information.

f. Laboratory testing for mix design.

(1) *General procedure.* Laboratory tests are conducted on laboratory-compacted samples with densities equal to densities anticipated in the in-place asphalt concrete after being subjected to traffic. A final selection of aggregate blend and bitumen content will be based on these data with due consideration to relative costs of the various mixes. The procedures set forth in the following paragraphs are directly applicable to all mixes containing not more than 10 percent by weight of total aggregate retained on the 1-inch sieve. The procedure to follow when a mix contains more than 10 percent aggregate exceeding the 1-inch-maximum size is outlined in MIL-STD-620, Method 103.

(2) *Preparation of test specimens.* The selection of materials for use in designing the paving mix has been discussed earlier. As an example, suppose that an aggregate gradation for a hot-mix design shall be the median of the limiting gradation curves in figure 6-3. Design data are required on this blend. The initial mix design tests will usually be conducted in a central testing laboratory on samples of stockpile materials submitted by the contractor. The procedure for proportioning stockpile samples to produce a blend of materials to meet a specified gradation is outlined below. The final mix design will be based on samples taken from the bituminous plant and will usually be conducted in a field laboratory near the plant.

(a) Proportioning of stockpile samples. As a preliminary step in mixture design and manufacture, it is necessary to determine the approximate proportions of the different available stockpiled materials required to produce the desired gradation of aggregate. This step is necessary to determine whether a suitable blend can be produced and, if so, the approximate proportion of each aggregate to be fed from the cold feeders into the dryer. Sieve analyses are conducted on material from each of the stockpiles, and the data entered on a form as illustrated at the top of figure 6-4. The data are shown graphically in figure 6-5. These four aggregate fractions must be combined to produce the desired blend. The estimated percentage of each fraction needed to produce this blend is entered in the form at the middle of figure 6-4. These estimated percentages are most easily determined by trial-and-error calculations. Two or three trials are normally required to obtain the desired blended gradation.

(b) Proportioning of bin samples (excluding drum-mix plants). Once it is demonstrated that a suitable blend can be prepared from the available materials, samples of these materials can then be processed through the asphalt plant for verification of mix design. Sieve analyses must be conducted for each batch of processed aggregate. Results from these sieve analyses should be entered on a form as shown at the top of figure 6-6. The data are shown graphically in figure 6-7. The hot-bin aggregates should be blended to produce the same gradation as that produced at the cold feeders. The percentage of each bin is estimated and calculations are made to determine the gradation produced from these estimated percentages. The gradation of this recombined blend is then checked against the desired gradation (fig 6-6). Two or three trials are usually sufficient to produce a combined mixture having a gradation within the allowable tolerances.

(3) *Bitumen contents for specimens.* The quantity of bitumen required for a particular aggregate is very important in paving mixture design. The procedures to follow are described in (4) below. An estimate for the optimum amount of bitumen based on total weight of mix is normally made in order to

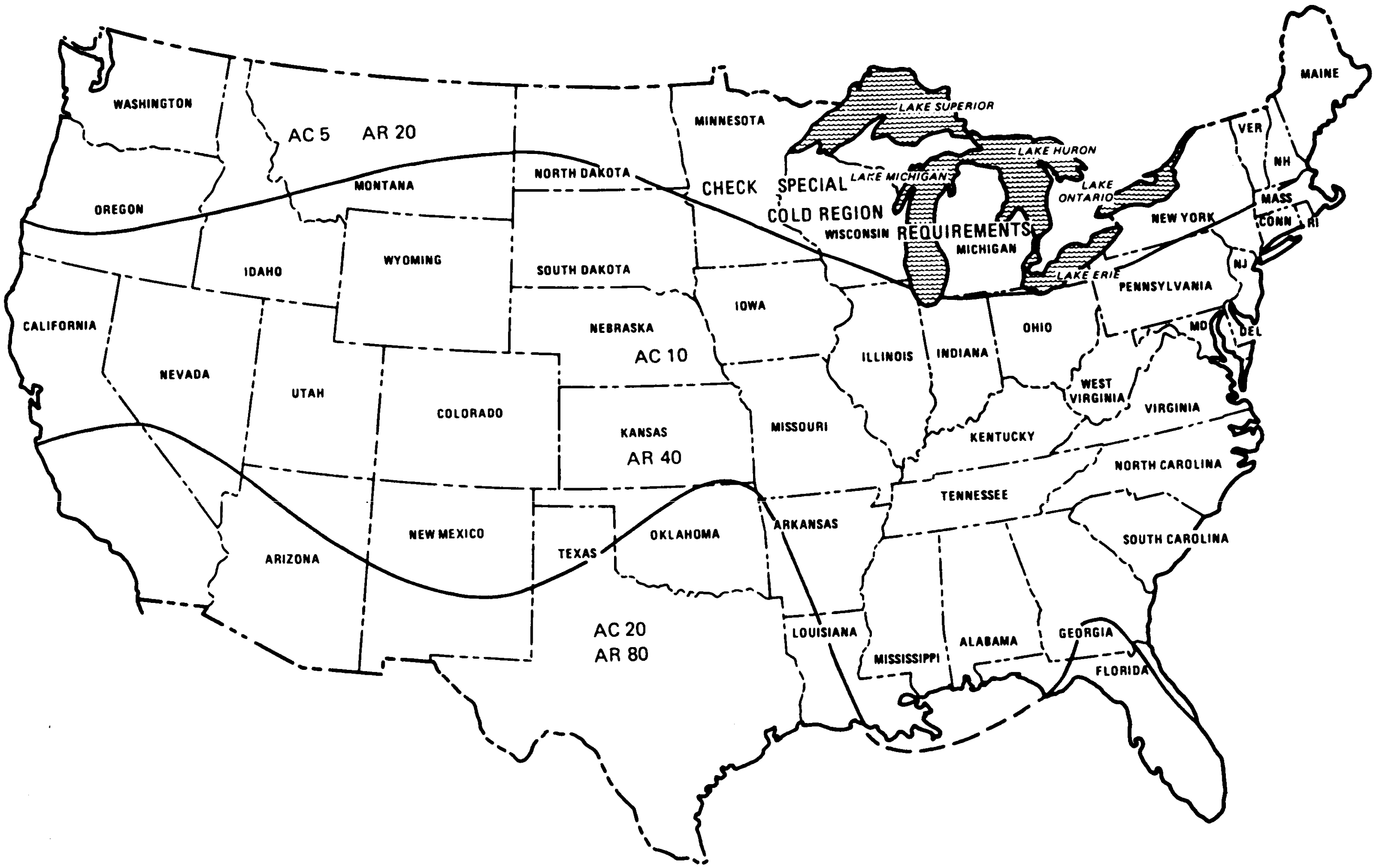


Figure 6-1. Guide for selection of grade of asphalt cement in the continental United States.

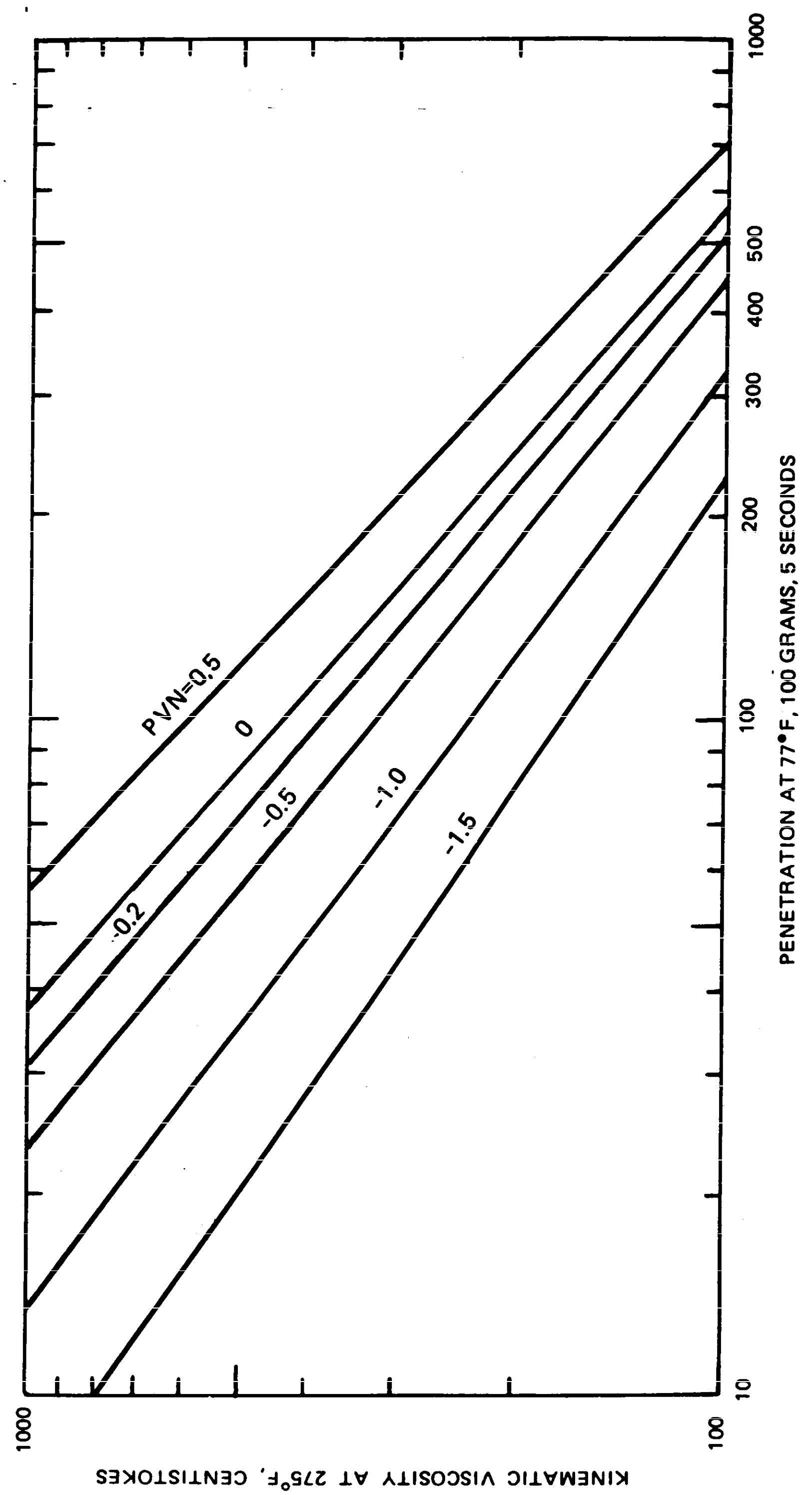


Figure 6-2. Pen-Vis numbers of asphalt cement.

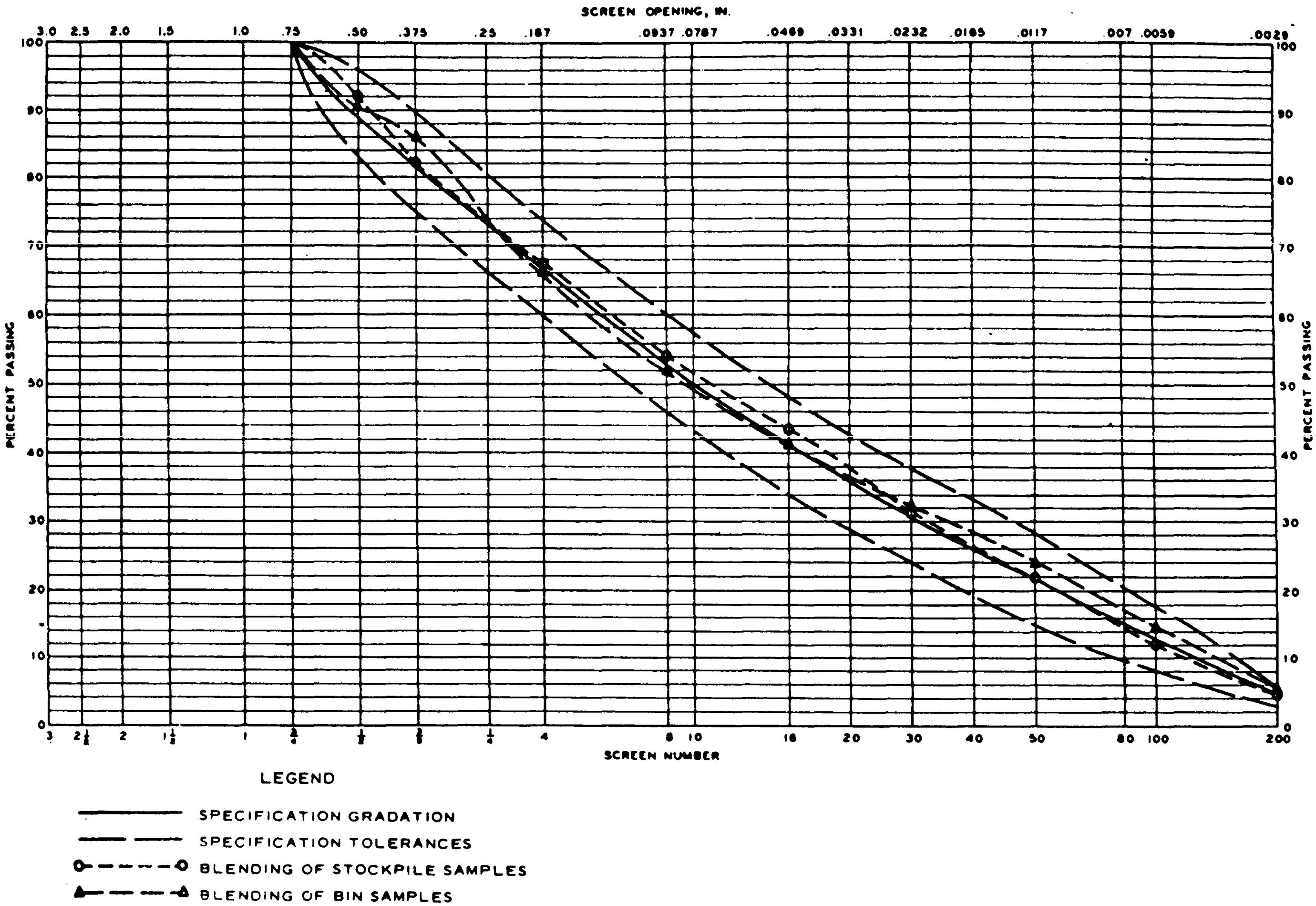


Figure 6-3. Gradation data for hot-mix design.

BITUMINOUS MIX DESIGN (TRIAL METHOD)												
JOB NO.:		PROJECT Typical Mix						DATE:				
GRADATION OF MATERIAL												
SIEVE SIZE	PERCENT USED	SIEVE SIZE - PERCENT PASSING										
		1	3/4	1/2	3/8	4	8	16	30	50	100	200
Cr C A	100		100	70.0	34.5	3.0						
Cr F A	100		100	100	99.8	90.0	71.0	52.0	34.5	19.5	11.0	7.0
Sand	100		100	100	100	100	100	100	100	95.5	69.5	10.0
LSF	100		100	100	100	100	100	100	100	100	98.0	90.0
COMBINED GRADATION FOR BLEND - TRIAL NO. 1												
SIEVE SIZE	PERCENT USED	SIEVE SIZE - PERCENT PASSING										
		1	3/4	1/2	3/8	4	8	16	30	50	100	200
Cr C A	27.0		27.0	18.9	9.3	0.8						
Cr F A	65.0		65.0	65.0	64.9	58.5	46.2	33.8	22.4	12.7	7.2	4.6
Sand	8.0		8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.7	5.6	0.8
BLEND			100	91.9	82.2	67.3	54.2	41.8	30.4	20.4	12.8	5.4
DESIRED			100	89.0	82.0	67.0	53.0	41.0	31.0	22.0	13.0	4.5
COMBINED GRADATION FOR BLEND - TRIAL NO.												
SIEVE SIZE	PERCENT USED	SIEVE SIZE - PERCENT PASSING										
		1	3/4	1/2	3/8	4	8	16	30	50	100	200
BLEND												
DESIRED												
COMPUTED BY:							CHECKED BY:					

WES FORM NO. 1506
SEPT 65

Figure 6-4. Blending of stockpile samples

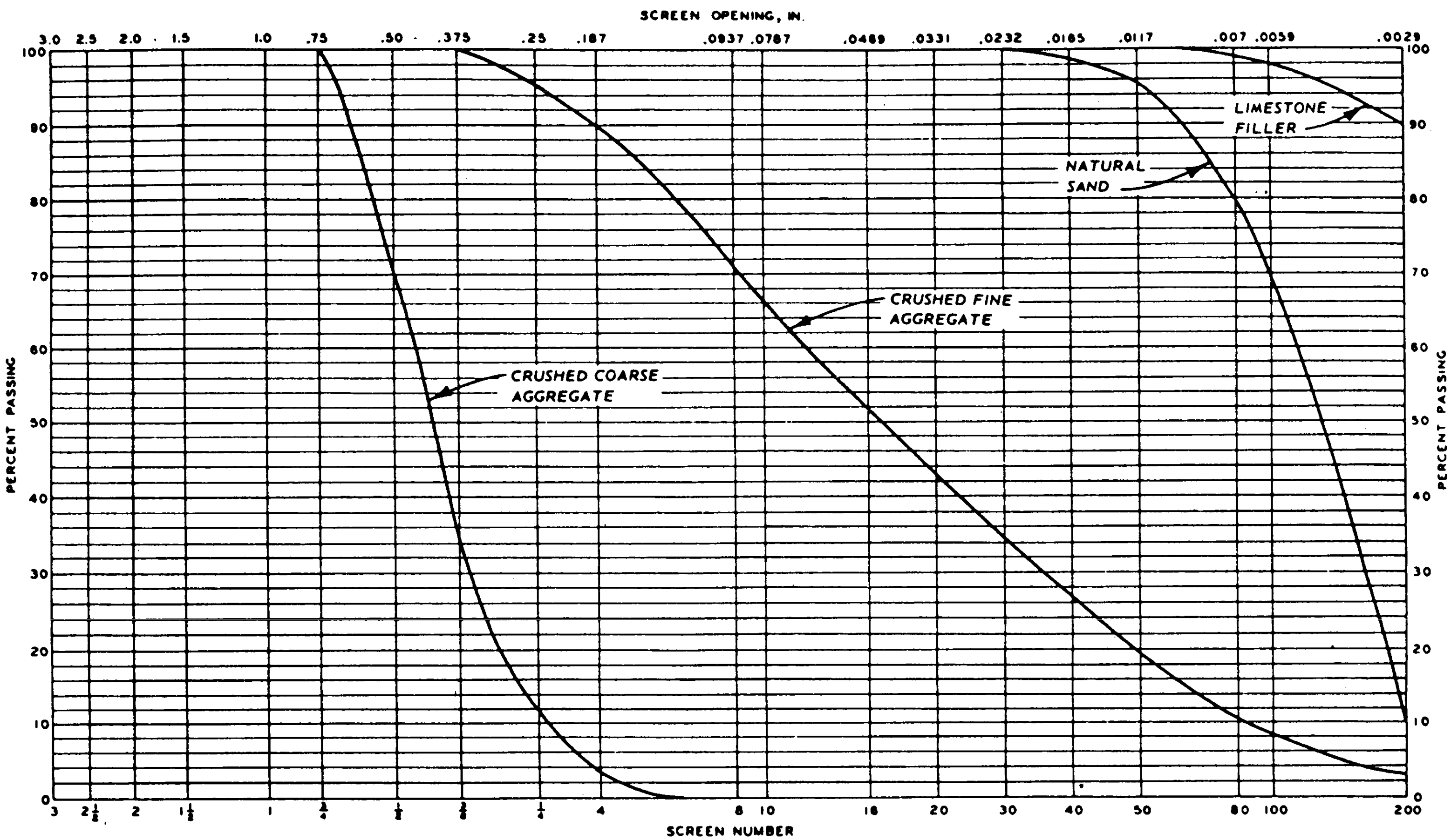


Figure 6-5. Gradation curves for stockpile aggregates.

BITUMINOUS MIX DESIGN
(TRIAL METHOD)

JOB NO.:	PROJECT Typical Mix	DATE:

GRADATION OF MATERIAL

SIEVE SIZE	PERCENT USED	SIEVE SIZE - PERCENT PASSING										
		1	3/4	1/2	3/8	4	8	16	30	50	100	200
3/4-3/8	100		100	50.0	24.0	7.0	1.0					
3/8-8	100		100	100	100	49.0	10.0	1.0				
-No. 8	100		100	100	100	100	100	84.0	65.0	46.5	26.5	10.0
LSF	100		100	100	100	100	100	100	100	100	98.0	90.0

COMBINED GRADATION FOR BLEND - TRIAL NO. 1

SIEVE SIZE	PERCENT USED	SIEVE SIZE - PERCENT PASSING										
		1	3/4	1/2	3/8	4	8	16	30	50	100	200
3/4-3/8	18.0		18.0	9.0	4.3	1.3	0.2					
3/8-8	34.0		34.0	34.0	34.0	16.6	3.4	0.3				
-No. 8	48.0		48.0	48.0	48.0	48.0	48.0	40.3	31.2	22.3	12.7	4.5
BLEND			100	91.0	86.3	65.9	51.6	40.6	31.2	22.3	12.7	4.8
DESIRED			100	89.0	82.0	67.0	53.0	41.0	31.0	22.0	13.0	4.5

COMBINED GRADATION FOR BLEND - TRIAL NO.________

SIEVE SIZE	PERCENT USED	SIEVE SIZE - PERCENT PASSING										
		1	3/4	1/2	3/8	4	8	16	30	50	100	200
BLEND												
DESIRED												

COMPUTED BY:	CHECKED BY:

WES FORM NO. 1506
SEPT 65

Figure 6-6. Blending of processed samples.

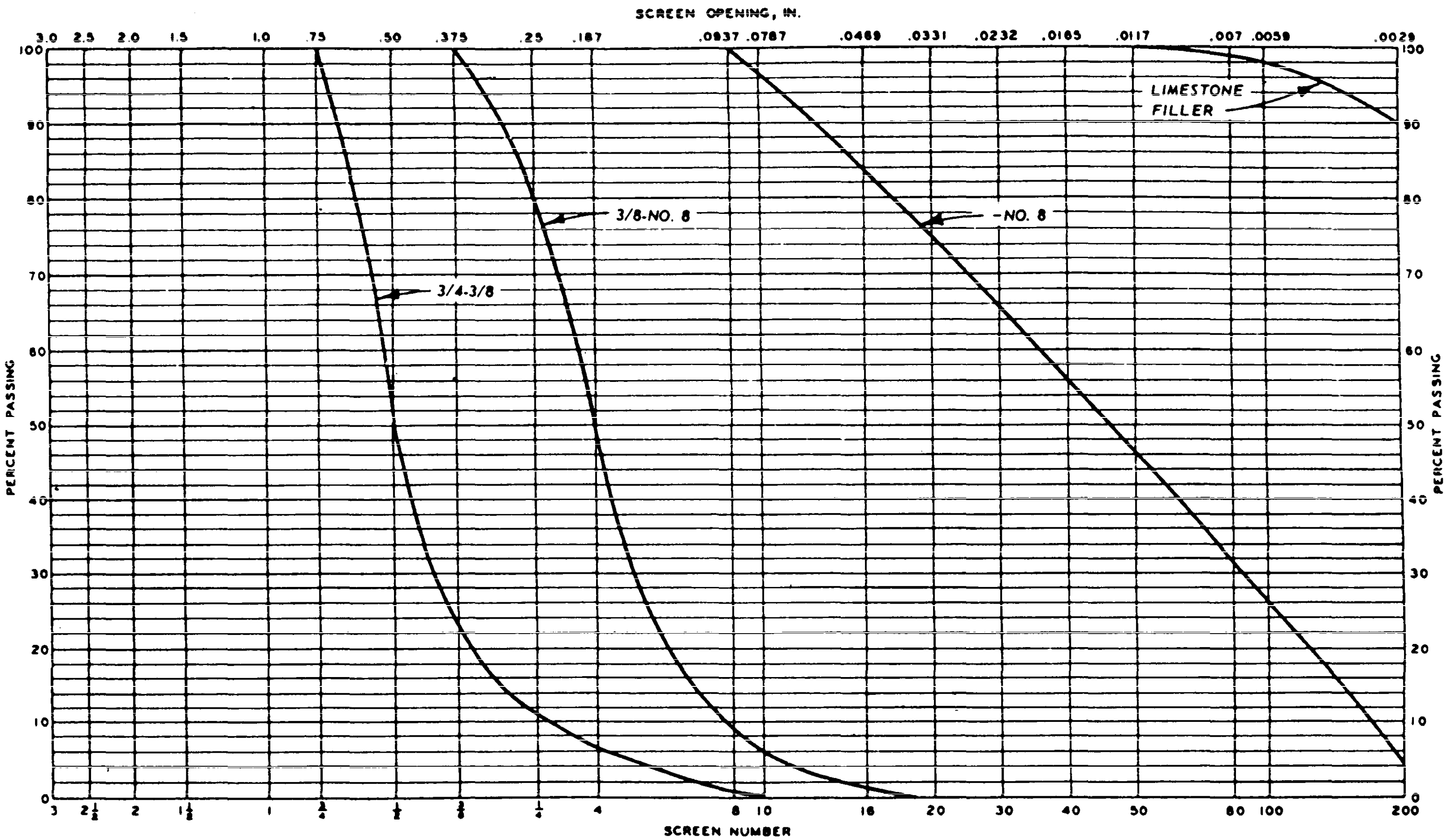


Figure 6-7. Gradation curves for bin samples.

start the laboratory tests. Laboratory tests usually are conducted for a minimum of five bitumen contents: two above, two below, and one at the estimated optimum content. Incremental changes of 1 percent of bitumen may be used for preliminary work, but increments of ½ percent are generally used when the approximate optimum bitumen content is known and for final design. Tar and rubberized tar generally require about the same volume of bitumen, but since tar is heavier than asphalt, the percentage by weight will be somewhat higher.

(4) *Selection of design method.* The Departments of the Army and Air Force allow two methods of design of bituminous paving mixtures in the laboratory—the Marshall and the gyratory methods. The procedures for conducting these mix-design tests are described in MIL-STD-620, Methods 100 and 102, respectively. Method 101 is complementary to Methods 100 and 102. Laboratory design compaction requirements are summarized in table 6-3.

Table 6-3. Traffic type and design compaction requirements

Type of traffic	Design compaction requirements
Tire pressures less than 100 psi	50 blows or equivalent gyratory compaction
Tire pressures greater than 100 psi	75 blows or equivalent gyratory compaction

(5) *Tabulation of data.* After the laboratory design method has been selected and test specimens have been prepared, data should be tabulated on forms similar to those shown in MIL-STD-620, Methods 100 and 101 if the Marshall procedure is used. These forms, along with the forms shown in MIL-STD-620, Method 102, are normally used for the gyratory procedure. A form similar to that shown in figure 6-8 will facilitate tabulation of specimen test property data and is preferable to similar but less complete forms used in MIL-STD-620, Methods 100 and 101. Plots of data from figure 6-8 for stability, flow, unit weight, percent voids total mix, and percent voids filled with bitumen should be made, using a form similar to that shown in figure 6-9. The average actual specific gravity is obtained for each set of test specimens, as shown in column G of figure 6-8. Each average value is multiplied by 62.4 to obtain density in pounds per cubic foot (pcf), and these data are entered in column L. The density values thus obtained are plotted as shown in figure 6-9, and the best-fit (by eye) smooth curve is then drawn. The data from columns J and K are used to plot curves for percent voids total mix and voids filled with bitumen, respectively, in figure 6-9. The corrected stability values in column N and the flow values in column O of figure 6-8 are plotted on figure 6-9 to evaluate stability and flow properties of the mixture.

(6) *Relationship of test properties to bitumen content.* Test property curves, plotted as described above, have been found to follow a reasonably consistent pattern for mixes made with penetration and viscosity grades of asphalt cement, tar cement, and rubberized tar. Trends generally noted are outlined as follows:

(a) Flow. The flow value increases with increasing bitumen content at a progressive rate except at bitumen contents significantly below optimum.

(b) Stability. The Marshall stability increases with increasing bitumen content up to a point, after which it decreases.

(c) Unit weight. The curve for unit weight of total mix is similar to the curve for stability, except that the peak of the unit-weight curve is normally at a slightly higher bitumen content than the peak of the stability curve.

(d) Voids total mix. Voids total mix decreases with increasing bitumen content in the lower range of bitumen contents. There is a minimum void content for each aggregate blend and compactive effort, and the voids cannot be decreased below this minimum without increasing the compactive effort. The void content of the compacted mix approaches this minimum void content as the bitumen content of the mix is increased.

(e) Voids filled with bitumen. Percent voids filled with bitumen increases with increasing bitumen content and approaches a maximum value in much the same manner as the voids total mix discussed above approaches a minimum value.

(7) *Requirement for additional test specimens.* The curves in figure 6-9 are typical of those normally obtained when penetration or viscosity grades of asphalt cement, tar cement, or rubberized tar are used with aggregate mixes. Aggregate blends may be encountered that will furnish erratic data such

COMPUTATION OF PROPERTIES OF ASPHALT MIXTURES

Job No.: | Project: Typical Mix | Description of Blend: | Date:

Specimen No.	Asphalt Cement - %	Thickness In.	Weight - Grams In Air	Weight - Grams In Water	Volume cc	Specific Gravity Actual	Specific Gravity Theor.	AC by Volume - %	Voids - Per Cent Total Mix	Voids - Per Cent Filled	Unit Weight Total Mix Lb/Cu Ft	Stability - Lb Measured	Stability - Lb Converted	Flow Units of 1/100 In.
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
					(D-E)	(D)/(F)		(BxG)/(Sp. Gr. of AC)	(100-100 G/H)	I/(I+J)	(Gx62.4)		*	
A-3.5 1	3.5		1228.3	716.3	512.0	2.399						2020	2020	11
2			1219.5	712.2	507.3	2.404						1862	1936	10
3			1205.5	705.3	500.2	2.410						1821	1894	8
4			1206.2	708.4	497.8	2.423						1892	1968	8
Avg						2.409					150.3		1955	9
Curve						2.409	2.579	8.3	6.6	55.7	150.3			
A-4.0 1	4.0		1276.9	747.3	529.6	2.411						2110	2026	10
2			1252.6	733.3	519.3	2.412						2025	2025	9
3			1243.5	730.7	512.8	2.425						1995	1995	9
4			1230.4	722.8	507.6	2.424						2020	2101	9
Avg						2.418					150.9		2037	9
Curve						2.421	2.559	9.5	5.4	63.8	151.1			
A-4.5 1	4.5		1254.4	738.2	516.2	2.430						2050	2050	12
2			1238.3	726.8	511.5	2.421						2095	2095	9
3			1239.0	724.9	514.1	2.410						2110	2110	10
4			1273.5	752.0	521.5	2.442						2045	2045	10
Avg						2.426					151.4		2075	10
Curve						2.426	2.539	10.7	4.5	70.4	151.4			

*From conversion table | Computed by: | Checked by:

Sp. Gr. of Bit.=1.020

SHEET 1 of 2

Figure 6-8. Computation of properties of asphalt mixtures.

COMPUTATION OF PROPERTIES OF ASPHALT MIXTURES

Job No.:	Project: Typical Mix	Description of Blend:	Date:

Specimen No.	Asphalt Cement - %	Thickness In.	Weight - Grams In Air	Weight - Grams In Water	Volume cc	Specific Gravity Actual	Specific Gravity Theor.	AC by Volume - %	Voids - Per Cent Total Mix	Voids - Per Cent Filled	Unit Weight Total Mix Lb/Cu Ft	Stability - Lb Measured	Stability - Lb Converted	Flow Units of 1/100 In.
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
					(D-E)	(D)/(F)		(BxG)/(Sp. Gr. of AC)	(100-100 G/H)	I/(I+J)	(Gx62.4)		*	
A-5.0 1	5.0		1237.9	727.0	510.9	2.423						1875	1875	14
2			1300.0	763.7	536.3	2.424						2130	1981	10
3			1273.6	746.9	526.7	2.418						1900	1824	12
4			1247.9	731.8	516.1	2.418						1855	1855	12
Avg						2.421					151.1		1884	12
Curve						2.421	2.519	11.9	3.9	75.3	151.1			
A-5.5 1	5.5		1237.3	724.1	513.2	2.411						1450	1450	12
2			1264.0	740.6	523.4	2.415						1530	1469	14
3			1286.4	752.4	534.0	2.409						1615	1550	13
4			1253.5	733.8	519.7	2.412						1505	1505	16
Avg						2.412					150.5		1494	14
Curve						2.409	2.500	13.0	3.6	78.3	150.3			

*From conversion table	Computed by:	Checked by:

SHEET 2 of 2

Figure 6-8. Computation of properties of asphalt mixtures—continued.

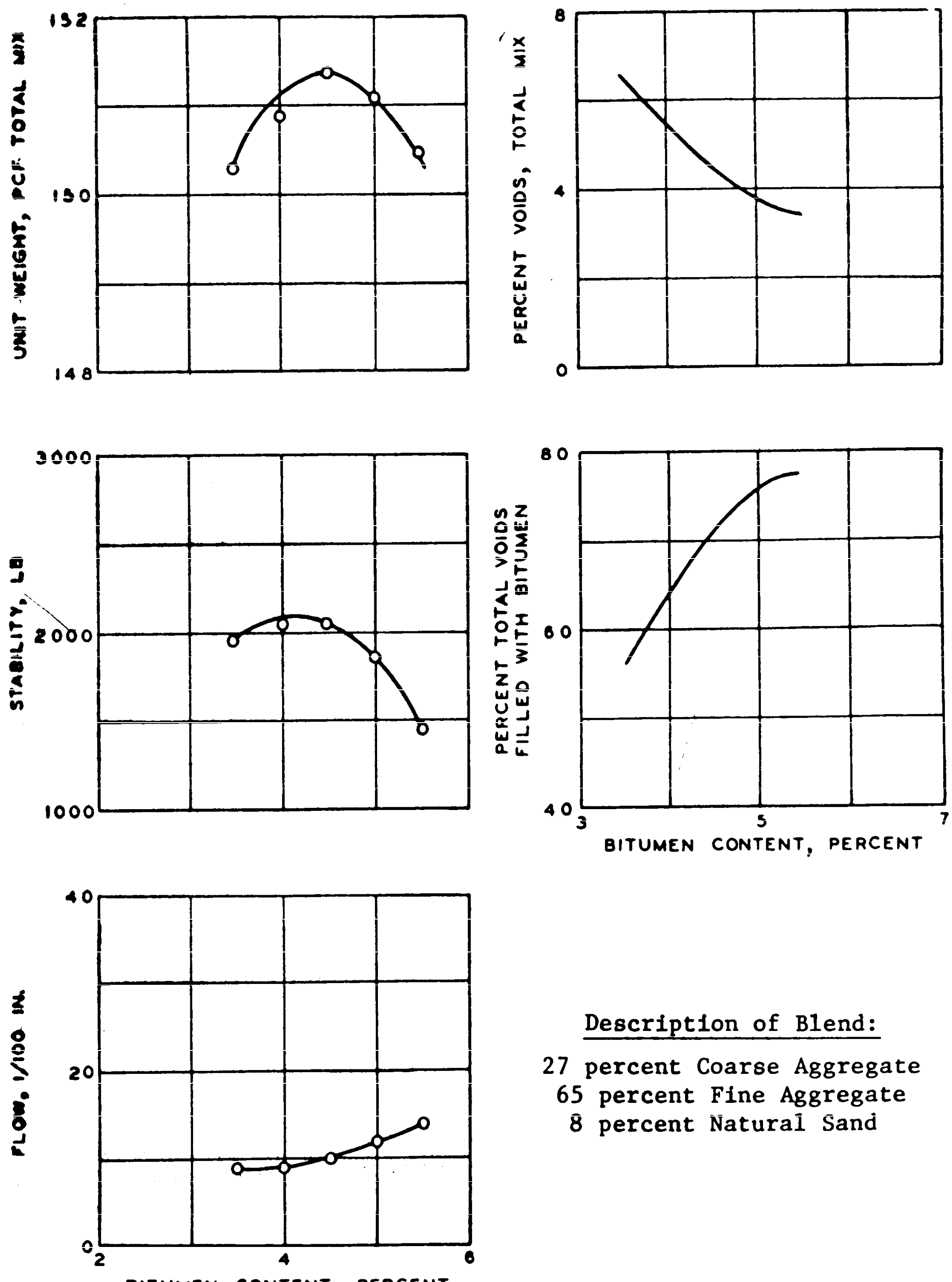


Figure 6-9. Asphalt paving mix design for typical mix.

that plotting of the typical curves is difficult. In most of these cases, an increase in the number of specimens tested at each bitumen content will normally result in data that will plot as typical curves.

g. Optimum bitumen and design test properties.

(1) *Selection of bitumen content.* Previous testing has indicated that the optimum bitumen content is one of the most important factors in the proper design of a bituminous paving mixture. Extensive research and pavement behavior studies have resulted in establishment of certain criteria for determining the proper or optimum bitumen content for a given blend of aggregates. Criteria have also been established to determine whether the aggregate will furnish a satisfactory paving mix at the selected optimum bitumen content.

(2) *Determination of optimum bitumen content and acceptability of mix by Marshall method.* Data plotted in graphical form in figure 6-9 are used to determine optimum bitumen content. In addition, optimum bitumen content and acceptability of the mix are determined based on table 6-4 when the water absorption of the aggregate blend is not more than 2.5 percent. If the water absorption is greater than 2.5 percent, table 6-5 is used to determine the optimum bitumen content and acceptability of the mix. Separate criteria are shown for use where specimens were prepared with 50- and 75-blow compactive efforts. As shown in table 6-6, the optimum bitumen content (average) is computed as 4.6 percent. Table 6-7 shows the criteria for acceptability of the mix for a 75-blow compactive effort at the optimum bitumen content of 4.6 percent.

*Table 6-6. Computation of optimum bitumen content**

Peak of stability curve	4.3 percent
Peak of unit-weight curve	4.5 percent
4 percent voids in total mix (bituminous concrete)	4.8 percent
75 percent total voids filled with asphalt (bituminous concrete)	4.9 percent
Average	4.6 percent

*Based on data in figure 6-9.

Table 6-7. Evaluation for acceptability of design mix

Test property	At optimum of 4.6 percent bitumen	Criteria for acceptability
Flow	11	Less than 16
Stability	2,050	More than 1,800
Percent voids in total mix	4.3	3-5 percent (bituminous concrete)
Percent total voids filled with bitumen	72	70-80 percent (bituminous concrete)

(3) *Determination of optimum bitumen content by gyratory method.*

(a) Paragraph 4.4 of MIL-STD-620, Method 102 describes the procedure for selecting optimum bitumen content when using the gyratory method of design. The principal criteria are the peak of the unit weight aggregate only curve and the gyrograph recordings. Generally, optimum bitumen content occurs at the peak of the unit weight aggregate only curve at the highest bitumen content at which little or no spreading of the gyrograph trace occurs. The bitumen content determined by these two criteria will usually be nearly identical. In no case, however, should a bitumen content be selected that would be high enough to cause more than faint spreading of the gyrograph trace.

(b) The optimum binder content determined with the gyratory machine will in most cases produce a bituminous mixture with satisfactory characteristics without resorting to further test procedures. However, the mix should be tested for stability and flow. Density and voids data should also be obtained. Stability and flow criteria shown above for the Marshall procedures should be applied to paving mixtures designed by the gyratory method. It is necessary to determine density at optimum bitumen content to establish field rolling requirements. If the 240-psi, 1-degree, 60-revolution compactive effort described in MIL-STD-620, Method 102 is used in design of a paving mixture, density values will result that require greater rolling effort in the field to obtain 98 percent of laboratory density than by the Marshall design method.

(c) Selection of optimum bitumen content by the gyratory method may result in the paving mixture having lower percent voids total mix than would be permissible with the Marshall procedure. For example, the voids total mix of a paving mixture designed for traffic by aircraft with tire pressures of 200 psi 9 or higher might be only 2.5 percent, as compared with a specified range from 3 to 5 percent in the Marshall criteria. By the gyratory procedure, the lower percent voids total mix is acceptable.

(4) *Selection of paving mix.* When two or more paving mixes have been investigated, the one used for field construction should be the most economical mix that satisfies all of the established criteria.

h. Quality control.

Table 6-4. Design criteria for use with ASTM apparent specific gravity or theoretical maximum specific gravity (ASTM D 2041)

Section 1. Procedure for determining optimum bitumen content			
		Point of curve	
Test property	Type of mix	50 Blows	75 Blows
Marshall stability	Bituminous-concrete surface course	Peak of curve	Peak of curve
	Bituminous-concrete intermediate course	Peak of curve[a]	Peak of curve[a]
	Sand asphalt	Peak of curve	b
Unit weight	Bituminous-concrete surface course	Peak of curve	Peak of curve
	Bituminous-concrete intermediate course	Not used	Not used
	Sand asphalt	Peak of curve	b
Flow	--	Not used	Not used
Percent voids total mix	Bituminous-concrete surface course	4	4
	Bituminous-concrete intermediate course	5	5
	Sand asphalt	6	b
Percent voids filled with bitumen	Bituminous-concrete surface course	80	75
	Bituminous-concrete intermediate course	70[a]	60[a]
	Sand asphalt	70	b

(Continued)

[a] If this inclusion of bitumen contents at these points in the average causes the voids total mix to fall outside the limits, then the optimum bitumen content should be adjusted so that the voids total mix is within the limits.

[b] Sand asphalt will not be used in designing pavements for traffic with tire pressures in excess of 100 psi.

Table 6-4. Design criteria for use with ASTM apparent specific gravity or theoretical malximum specific gravity (ASTM D 2041)—continued

Section 2. Procedure for determining acceptability of mix			
		Criteria	
Test property	Type of mix	50 Blows	75 Blows
Marshall stability	Bituminous-concrete surface course	500 pounds or higher	1800 pounds or higher
	Bituminous-concrete intermediate course	500 pounds or higher	1800 pounds or higher
	Sand asphalt	500 pounds or higher	b
Unit weight	--	Not used	Not used
Flow	Bituminous-concrete surface course	20 (0.01 inch) or less	16 (0.01 inch) or less
	Bituminous-concrete intermediate course	20 (0.01 inch) or less	16 (0.01 inch) or less
	Sand asphalt	20 (0.01 inch) or less	b
Percent voids total mix	Bituminous-concrete surface course	3-5 percent	3-5 percent
	Bituminous-concrete intermediate course	4-6 percent	5-7 percent
	Sand asphalt	5-7 percent	b
Percent voids filled with bitumen	Bituminous-concrete surface course	75-85 percent	70-80 percent
	Bituminous-concrete intermediate course	65-75 percent	50-70 percent
	Sand asphalt	65-75 percent	b

[b] Sand asphalt will not be used in designing pavements for traffic with tire pressures in excess of 100 psi.

Table 6-5. Design criteria for use with bulk impregnated specific gravity for theoretical maximum specific gravity (ASTM D 2041)

Section 1. Procedure for determining optimum bitumen content			
		Point of curve	
Test property	Type of mix	50 Blows	75 Blows
Marshall stability	Bituminous-concrete surface course	Peak of curve	Peak of curve
	Bituminous-concrete intermediate course	Peak of curve[a]	Peak of curve[a]
	Sand asphalt	Peak of curve	b
Unit weight	Bituminous-concrete surface course	Peak of curve	Peak of curve
	Bituminous-concrete intermediate course	Not used	Not used
	Sand asphalt	Peak of curve	b
Flow	--	Not used	Not used
Percent voids total mix	Bituminous-concrete surface course	3.0	3.0
	Bituminous-concrete intermediate course	4.0	5.0
	Sand asphalt	5.0	b
Percent voids filled with bitumen	Bituminous-concrete surface course	85	80
	Bituminous-concrete intermediate course	75[a]	65[a]
	Sand asphalt	75	b

(Continued)

[a] If this inclusion of bitumen contents at these points in the average causes the voids total mix to fall outside the limits, then the optimum bitumen content should be adjusted so that the voids total mix is within the limits.

[b] Sand asphalt will not be used in designing pavements for traffic with tire pressures in excess of 100 psi.

Table 6-5. Design criteria for use with bulk impregnated specific gravity for theoretical maximum specific gravity (ASTM D 2041)—continued

Section 2. Procedure for determining acceptability of mix

Test property	Type of mix	Criteria 50 Blows	Criteria 75 Blows
Marshall stability	Bituminous-concrete surface course	500 pounds or higher	1800 pounds or higher
	Bituminous-concrete intermediate course	500 pounds or higher	1800 pounds or higher
	Sand asphalt	500 pounds or higher	b
Unit weight	--	Not used	Not used
Flow	Bituminous-concrete surface course	20 (0.01 inch) or less	16 (0.01 inch) or less
	Bituminous-concrete intermediate course	20 (0.01 inch) or less	16 (0.01 inch) or less
	Sand asphalt	20 (0.01 inch) or less	b
Percent voids total mix	Bituminous-concrete surface course	2-4 percent	2-4 percent
	Bituminous-concrete intermediate course	3-5 percent	4-6 percent
	Sand asphalt	4-6 percent	b
Percent voids filled with bitumen	Bituminous-concrete surface course	80-90 percent	75-85 percent
	Bituminous-concrete intermediate course	70-80 percent	55-75 percent
	Sand asphalt	70-80 percent	b

[b] Sand asphalt will not be used in designing pavements for traffic with tire pressures in excess of 100 psi.

(1) The aggregates and asphalt must be fed through the plant uniformly to obtain efficient plant operation and to produce a mixture conforming to requirements. The approximate proportion of aggregates and asphalt to be fed into the plant is determined from the laboratory mix design. However, some adjustment in these proportions is usually required because a gradation of the stockpile aggregates generally will not entirely duplicate the gradation of the aggregate samples obtained for laboratory design use; fines may be lost or manufactured while passing through the dryer; aggregate may degrade in the dryer; and material mixed at an asphalt plant is more uniformly coated with asphalt than materials mixed in the laboratory.

(2) To evaluate the quality of the material produced and to insure the best possible paving mixture, a reasonably complete plant laboratory is necessary. The laboratory should be located at the plant site and should contain about the same equipment listed in MIL-STD-620, Method 100. Because of the capacity of most asphalt plants, at least two technicians should be assigned to conduct control tests; otherwise, all necessary testing cannot be completed in a timely manner.

(3) The heaviest demands on plant laboratory facilities occur at the initiation of plant production. Preliminary computations may be made to determine the weight of material from each bin that will provide the gradation on which the mixture design is based. However, the gradation of the aggregate supplied by the plant may not precisely reproduce the desired gradation. The gradation of the plant-produced aggregate generally approximates the gradation used in design, within reasonable tolerances, if initial sampling for design purposes has been accomplished properly and if the plant is operated efficiently. Certain steps should be taken, however, to insure that satisfactory mixtures are produced from the beginning and throughout the period of plant production. Procedures subsequently outlined will insure that satisfactory paving mixes are produced.

(4) The aggregates obtained from the bins (as described in (3) above) for continuous mix and batch plants sometimes cannot be proportioned to satisfactorily reproduce the gradation of the aggregate used in the laboratory design. It is then necessary to redesign the mix using plant-produced aggregates. Specimens are prepared and tested for the new design in the same manner as for the original design tests. Optimum bitumen content and acceptability of the mix produced by the plant are determined. Occasions may arise where the gradation of the plant-produced aggregate will differ from that on which the laboratory design was based to the extent that specified criteria cannot be met. Necessary steps should be taken to produce a bituminous mixture meeting the specification requirements. Sufficient additional tests should be performed to establish optimum bitumen requirements and to insure that the mix will meet applicable criteria.

(5) After the aggregate and asphalt binder qualities have been determined to be satisfactory and a proper mix design has been completed, the next step is to insure that the JMF is produced at the asphalt plant. Five items must be routinely controlled during the production and laydown operation to provide an acceptable pavement. These items are: aggregate gradation, asphalt content, density, smoothness, and final grade. The Departments of the Army and Air Force require that these items be measured and analyzed statistically. When these items do not meet the specified requirements, the contract unit price is reduced or the mixture is rejected.

(6) In order to evaluate the quality of the job the work is divided into lots. Each lot is considered a separate job and as such is evaluated solely on the test results for that lot. A lot should generally not exceed 1,000 tons of production or one day's work. The lot should be subdivided into four equal sublots, and one random sample should be taken from each sublot for evaluation of aggregate gradation, bitumen content, and density.

(7) The asphalt content and aggregate gradation will be determined from samples of the asphalt mix taken somewhere between the production and the laydown operation. The exact location of the sample is not important, but the sample should be taken from the same location each time (for example, truck at asphalt plant, truck at laydown site, bituminous storage bin, or other locations). The same sample of bituminous mixture should be used for determining asphalt content and aggregate gradation.

(8) If a lot size equal to 1,000 tons is selected, a sample of bituminous mix will have to be taken for each 250 tons produced. Any approved method for locating random samples can be used. As an example, suppose that a random number is selected between 1 and 250 and is determined to be 200. This selection means that the 200th ton batched will be sampled.

(9) After the four aggregate gradations and asphalt contents are determined for a lot, these results are compared with the JMF and the absolute difference is determined. Suppose the design asphalt content is 5.5 percent and the four extracted asphalt contents are determined to be 5.2, 5.4, 5.5, and 5.8.

The mean absolute deviation from the JMF is determined to be

$$\text{Mean absolute deviation} = \frac{0.3 + 0.1 + 0.0 + 0.3}{4} = 0.175$$

The same procedure is used to determine the mean absolute deviation for each sieve sized for the aggregate gradation. After the mean absolute deviation is determined for the asphalt content and aggregate gradation of a lot, the maximum percent payment for that lot can be determined from the tables provided in the specification requirements.

(10) Density must be determined within the mat and at the joints between mats. One sample should be obtained in the mat and one in the joint for each sublot. The total linear feet of joint constructed for a given lot will be divided into quarters and one random sample taken for each sublot. These sample locations can be determined in a similar way as that for aggregate gradation and asphalt content. All mat samples should be taken at least 1 foot from the edge of mat or joint. In order to determine sample locations in the mat, each sublot must be divided into grids. The number of possible sampling locations will be approximately equal to (length − 1) times (width − 1).

(11) As an example, suppose that 1,000 tons (one lot) of asphalt concrete were placed in two adjacent lanes, one lane 6,000 feet long and the other 2,400 feet long. The joint length between the two lanes would be 2,400 feet; thus, one sample would be taken at random for each 600 feet of joint length to evaluate joint density. The total length of the two lanes would be 8,400 feet; therefore, one random sample should be taken from the mat for each 2,100 feet of asphalt concrete. The first 2,100 feet would have 2,099 × 9 possible sampling locations if a 10-foot-wide paver was used. (Possible sample locations are at 1-foot intervals and no closer than 1 foot to the edge.) Hence, there are 18,891 possible sampling locations for each of the 4 cores to be taken from the mat. Suppose that the random number selected was 8,720. Divide 8,720 by 9 to get 968 with a remainder of 8. Hence, the sample should be taken 969 feet (horizontal distance + 1) from the origin and 9 feet (transverse distance + 1) from the edge (since the start point is 1 foot from the edge and 1 foot from the beginning). The random samples do not have to be precisely located, but it is important that the surface appearance does not affect the selection of sample locations.

(12) The average net density and average joint density will be expressed as a percentage of the laboratory density. The laboratory density for each lot will be the average density determined from at least two sets of samples representing the in-place material compacted in the laboratory. Suppose that the average laboratory density is 150 pcf, the four mat samples have individual densities of 145.0, 147.0, 146.5, and 148.1, and the four joint samples have individual densities of 144.2, 145.0, 146.2, and 145.1. Based on these results the average mat density would be

$$\text{Mat density} = \frac{145.0 + 147.0 + 146.5 + 148.1}{4(150.0)} = 97.8 \text{ percent}$$

and the average joint density would be

$$\text{Joint density} = \frac{144.2 + 145.0 + 146.2 + 145.1}{4(150.0)} = 96.8 \text{ percent}$$

The average density in the mat and the average density in the joint can be used along with the tables in the specifications to determine the maximum percent payment for the lot of material being evaluated.

(13) The surface of the completed pavement will be evaluated on a systematic basis to determine the acceptability of grade and smoothness. The results will be compared with the specification requirements to determine percent payment for grade and smoothness.

(14) In order to properly evaluate quality control of a mixture and maintain up-to-date records of test results control charts should be maintained. It is recommended that the control charts be plotted for each sieve size specified in the gradation requirements, asphalt content, laboratory density, stability, flow, voids in total mixture, voids filled with bitumen, mat density, and joint density. A plot should be made of individual values and for the running average of four samples.

(15) An example of the use of control charts follows. Assume the density results shown in table 6-8 were obtained from the in-place mat.

Table 6-8. Lot density as a percent of laboratory density

	Lot 1	Lot 2	Lot 3	Lot 4	Lot 5
	95.2	98.4	99.5	98.1	100.0
	96.4	99.1	98.0	96.8	99.1
	97.8	97.3	97.5	99.8	98.3
	96.6	98.1	98.3	98.6	98.9
Avg	96.5	98.2	98.3	98.3	99.1

(16) Figure 6-10 shows the control charts for mat density. The first test result obtained is plotted in figure 6-10a. Note that this measurement falls below the desired range. At this point, it should have been concluded that the process was out of control; thus the operation should be stopped until the cause of the deficiency is identified and corrected.

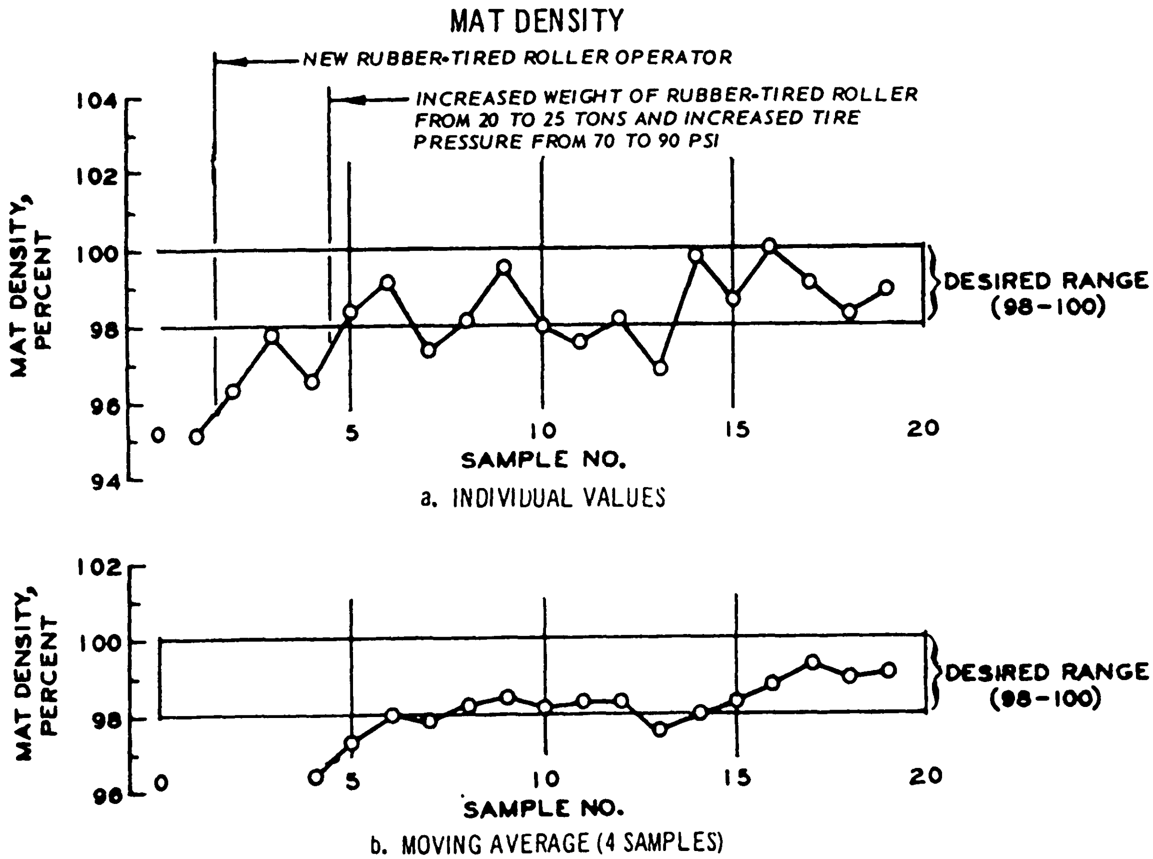


Figure 6-10. Mat density control chart.

(17) The second, third, and fourth samples were obtained after corrections were made to the process and found to be higher but still below the desired range. At this point, the weight of the rubber-tired roller used in compacting the mat was increased from 20 to 25 tons, and the tire pressure was increased from 70 to 90 psi. After these changes, the density results were generally within the desired range.

(18) The moving average is determined for the last four samples tested (fig 6-10b). Plotting the moving average smooths out the plot of individual values and allows trends to be spotted earlier.

i. Significance of changes in mixture properties.

(1) *General.* A measurable increase in flow value generally indicates that either the gradation of the mix has changed sufficiently to require a revision in the optimum bitumen content for the mix, or too much bitumen is being incorporated in the mix. A review of the control charts should indicate the problem. Substantial changes in stability or void content also may serve as an indication of these factors. As a general rule, the flow and stability values are obtainable quickly and are reasonably reliable indicators of the consistency of the plant-produced mix. Mix proportions shall be adjusted whenever any

test property consistently falls outside of the specified tolerances. In the case of batch plants, the use of faulty scales and the failure of the operator to accurately weigh the required proportions of materials are common causes for paving-mixture deficiencies. Improper weighing or faulty scales may be detected readily and corrective measures taken by maintaining a close check of load weights. Figure 6-11 lists other probable causes of paving-mixture deficiencies.

(2) *Extraction tests.*

(a) Representative samples of paving mixture should be obtained for extraction tests to determine the percentage of bitumen in the mix and the gradation of the extracted aggregates. Extraction tests shall be made according to ASTM D 2172 using trichloroethylene as the extraction solvent. Sieve analyses of recovered aggregates shall follow procedures specified previously.

(b) Nuclear gages are currently being used to determine asphalt content. After the nuclear gage is calibrated, it can be used to check the asphalt content of a mixture in a few minutes. Results indicate that this procedure is more accurate than the conventional extraction test, but the aggregate gradation is not determined by this test. Therefore, extraction tests must also be conducted to determine the aggregate gradation.

(3) *Hot-bin gradations.* Hot-bin gradation tests should be made on the aggregate in the fine bin at least twice daily during operation. Hot-bin gradations shall be determined on all bins in conjunction with sampling of the pavement mixture. Washed sieve analyses shall be determined initially. When dry gradations are to be conducted, a correction factor to be applied to unwashed (dry) gradations will be calculated. Dry sieve analyses shall be conducted frequently as required to maintain control.

(4) *Construction control.* Well-designed mixes can be compacted by adequate field rolling to about 98 percent or greater of the density obtained by compacting specimens with previously specified laboratory procedures. Bituminous intermediate, base course, or surface course mixes shall be rolled to the density specified in applicable Department of the Army and Air Force guide specifications.

(5) *Pavement sampling.* Samples for determining pavement density and thickness may be taken either with a coring machine (at least 4 inches nominal diameter) or by cutting out a section of pavement at least 4 inches square with a concrete saw. These samples should include the entire thickness of the pavement. Density samples of each day's production should be taken and delivered to the project laboratory by noon of the following day, and the density determinations made by the end of the day. Any changes in placing technique necessary to obtain the required density can be made before a large amount of pavement is placed.

(6) *Testing pavement samples.*

(a) Pavement samples shall be prepared for testing by carefully removing all particles of base material or other foreign matter. All broken or damaged edges of sawed samples for density tests shall be carefully trimmed from the sample. Thickness measurements shall be made before separating the sample into layers. A sample consisting of an intermediate course and surface course shall be split at the interface of these layers before testing. The density of the sawed samples shall be determined by weighing in air and in water as previously described. Samples from which density measurements are desired shall be discarded if damage is apparent. Additional samples will be taken from the same sublot.

(b) Nuclear gages are currently being used to check density of asphalt concrete. This method is fast, but the results are often questionable. Some factors which affect the results of density measurements with the nuclear gage are thickness of bituminous mixture, density of material below bituminous mixture, and smoothness at test location. The nuclear gage is useful for developing roller patterns, but density tests for acceptance should be conducted by removing samples from the pavement and weighing in air and water.

(7) *Density data.* Density data obtained from specimens in the manner previously described will be compared with the average laboratory density determined for the same lot.

(8) *Pavement imperfections and probable causes.* Many types of pavement imperfections result from improper laying and rolling operations as well as from improper mixes or faulty plant operation. These imperfections can be controlled only by proper inspection. Figure 6-12 presents the pavement imperfections that may result from laying unsatisfactory mixes or using faulty construction procedures.

6-3. Porous friction course.

a. General. A porous friction course (PFC) is an open-graded free-draining bituminous paving mixture that can be placed on an existing pavement to minimize hydroplaning and to improve skid resistance in wet weather. The course is placed in a layer usually varying from approximately ¾ to 1

Probable Causes of Deficiencies in Hot Plant Mix Paving Mixtures

Item	Probable cause
1	Aggregate scales out of adjustment
2	Bridging of hot aggregate in bin
3	Bitumen scales out of adjustment
4	Lack of proper weighing by operator
5	Faulty pug mill dump gate
6	Bitumen temperature too high
7	Drum feed not uniform
8	Improper dryer operation
9	Too little bitumen
10	Too much bitumen
11	Sampling method not uniform
12	Excessive moisture content of aggregate
13	Bin overflow pipes not functioning
14	Leaky bins
15	Segregation of aggregates in bins
16	Mixing time not uniform
17	Mineral filler feed not uniform
18	Aggregate temperature too high
19	Temperature mechanism out of adjustment
20	Improper feed of aggregates to dryer
21	Overrated dryer capacity
22	Faulty screen operation
23	Overloaded pug mill
24	Improper set on pug mill
25	Bitumen and aggregate feed out of adjustment
26	Bitumen pump not functioning properly
27	Not sufficient hot aggregate in storage bins
28	Aggregate gates not properly set

Types of Deficiencies That May Be Encountered in Producing Hot Plant Mix Paving Mixtures (Types of Hot Mix Trouble)

Types of Hot Mix Trouble	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Bitumen content fails to check job-mix formula	X		X	X	X				X	X	X		X	X		X	X			X				X	X	X	X	X
Gradation fails to check job-mix formula	X	X		X	X						X		X	X	X		X			X		X		X	X		X	X
Poorly mixed loads					X	X										X							X	X				
Fat, rich mixtures	X		X	X	X	X				X	X			X			X			X					X	X		X
Lean or burned mixtures	X		X	X	X	X		X	X		X			X				X	X	X					X	X		X
Mixture temperature fails to check job mix						X	X	X										X	X		X							
Smoking loads							X	X										X	X	X								
Steaming loads							X	X				X							X	X	X							
Overweight or underweight loads		X	X	X	X														X									
Lack of uniformity of mixtures in loads		X	X	X	X	X			X	X		X	X	X	X	X	X		X	X	X	X	X	X	X		X	X

Items 6 to 23 are applicable to all types plants. Items 1 to 5 and items 24 to 28 are applicable to batch plants and volumetric plants respectively.

Figure 6-11. Types of hot plant-mix paving mixture deficiencies and probable causes.

Types of Pavement Imperfections That May Be Encountered in Laying Hot Plant Mix Paving Mixtures	Excessive primecoat	Improper proportioning	Unsatisfactory batches in load	Poor handwork behind spreader	Excessive segregation in laying	Inadequate rolling	Poor spreader operation	Mixture too hot or burned	Mixture too cold	Rolling mixture when too hot	Rolling mixture when too cold	Poorly graded mixture	Unstable basecourse	Faulty allowance for compaction	Roller standing on hot pavement	Mixture too coarse	Lack of bitumen in mixture	Excess of bitumen in mixture	Inadequate cross rolling	Not cut back to uniform thickness	Excessive moisture in mixture
Bleeding	X	X	X		X							X				X		X			
Brown, dead appearance								X									X				X
Poor surface texture		X	X		X							X				X					
Rough uneven surface		X	X	X	X	X	X		X	X	X		X		X				X		
Uneven joints				X			X		X		X			X						X	
Roller marks						X					X								X		
Shoving		X	X					X	X	X		X						X			X
Waves				X			X		X	X			X		X						
Cracking		X	X		X				X		X	X				X	X				
Honeycomb		X	X	X	X		X		X							X					
Tearing of surface during laying			X				X		X								X				

Probable Causes of Imperfections in Finished Pavements

Figure 6-12. Types of hot plant-mix pavement imperfections and probable causes.

inch in thickness. A PFC has a coarse surface texture and is sufficiently porous to permit drainage of water internally as well as along the surface. A combination of water pressure relief through the internal and surface voids and the rough surface texture promote tire-to-aggregate contact. PFC paving mixtures are produced in bituminous hot-mix plants and placed with conventional bituminous paving machines. They should be placed only on pavements which are in good condition. A leveling course may be required to achieve the desired conditions before construction of the PFC.

b. Materials.

(1) *Aggregates.* The important properties of aggregates are discussed in chapter 5. Table 6-9 presents the aggregate gradation requirements for porous friction courses.

Table 6-9. Aggregate gradation for PFC's

Sieve designation (square openings)	Percent passing by weight of total aggregates: Gradation "A" ¾-inch maximum (compacted nominal thickness, 1 inch)	Percent passing by weight of total aggregates: Gradation "B" ½-inch maximum (compacted nominal thickness, ¾ inch)
¾ inch	100	100
½ inch	70-100	100
⅜ inch	35-75	80-100
No. 4	25-40	25-40
No. 8	10-20	10-20
No. 30	3-10	3-10
No. 200	0-5	0-5

(2) *Bitumen.* Test requirements for asphalt cements are outlined in the appropriate specification (ASTM D 946 or D 3381). The asphalt type should be selected as indicated in paragraph 6-2. Several PFC's with 1-½ percent neoprene rubber added to the asphalt have been constructed. The addition of neoprene rubber improves the ability of the asphalt to hold aggregate in place. When economically available, the use of this rubberized binder should be specified.

c. Mix design.

(1) *Proportioning of aggregates.* The proper aggregate gradation should be selected from table 6-9.

(2) *Bitumen content.* The bitumen content of PFC's is expressed as a percentage of the total mix by weight. A surface area constant, K_c, as described in appendix B, is used to determine the optimum asphalt content. The K_c value is used in the relation $2K_c + 4.0$ to determine the Estimate of Asphalt (EOA). This asphalt content is valid for aggregates with an apparent specific gravity in the range of 2.60 to 2.80 and with a water absorption less than 2.50 percent when tested by ASTM C 127 for coarse aggregate and ASTM C 128 for fine aggregate. A slight increase in asphalt content (up to 0.5 percent) is required when the absorption is greater than 2.50 percent. The EOA is inversely proportional to the specific gravity of the aggregate used and adjustments must be made when the specific gravity is outside of the 2.60 to 2.80 range.

(3) *Mixing temperature.* The mixing temperature shall be chosen to provide an asphalt viscosity of 275 ± 25 centistokes. To obtain this temperature, the temperature-viscosity relationship must be evaluated for the type of asphalt selected at a minimum of three temperatures (ASTM D 2170 and ASTM D 2171). Plotting this information on a graph with temperature versus log viscosity will normally result in a straight-line relationship, and the temperature for the correct viscosity can be chosen from the graph.

(4) *Validation tests.* The following tests can provide background information on how well the mix design can be expected to work. Large discrepancies in these tests can indicate problems with the mix design.

(5) *Drainage test.* Although not proven to be sensitive for all types of aggregates, this test can be used to insure that detrimental drainage of asphalt does not occur. The test is conducted by preparing a 300-gram sample of the mixture at design binder content, placing the sample in a 6-inch-diameter clear culture dish, and placing the dish in an oven for 2 hours at 250° F. After 2 hours the asphalt drainage on the bottom of the dish is observed. More than 50 percent coverage is considered excessive, and a reduction in asphalt content or mixing temperature should be considered.

(6) *Permeability test.* Appendix C describes the permeability test method used. Permeability can be affected by gradation, asphalt content, and mixing temperature. A low permeability may require an adjustment in the binder content or mixing temperature.

d. Plant control.

(1) *Plant laboratory.* A plant laboratory is needed to insure that the aggregate is properly graded and that the mix contains the prescribed percentage of bituminous material. The laboratory should be located at the plant to minimize the time between production and testing. If the laboratory is not located at the plant, testing could fall behind and cause considerable quantities of unsatisfactory mix to be produced.

(2) *Sieve analysis.* All sieve analyses should be conducted by the method described in ASTM C 136. Recommended sieve sizes for plant sieve analysis are: ¾ inch, ½ inch, ⅜ inch, No. 4, No. 8, No. 30, and No. 200. For batch- and continuous-mix plants, sieve analyses shall be made on material from each plant hot bin. Samples for these sieve analyses shall be obtained after a few tons of aggregate have been processed through the dryer and screens in order that the sample will be representative. For drum mixers, the sieve analysis must be made directly from the cold feeds. Final mix proportions may be determined on the basis of these analyses.

(3) *Extraction tests.* Extraction tests shall be made in accordance with ASTM D 2172 using trichloroethylene as the extraction solvent. Sieve analysis of recovered aggregates shall follow procedures specified in ASTM C 136.

(4) *Mix proportions.* Mix proportions shall be adjusted whenever tests indicate that specified tolerances are not being met. In the case of batch plants, faulty scales and failure of the operator to accurately weigh the required proportions of materials are common causes for paving-mixture deficiencies. Improper weighing or faulty scales may be detected readily and corrective measures taken by maintaining a close check of load weights. Figure 6-11 presents other probable causes of paving-mixture deficiencies due to improper plant operations.

(5) *Controlling plant production.* The plant inspector should obtain a sample of the PFC mix after the plant has been in production about 30 minutes. The sample should be tested as rapidly as possible for compliance with gradation and asphalt content requirements.

e. Construction.

(1) *Pavement control.* A PFC pavement has no density requirements. A characteristic of this overlay is its rapid cooling. If minimum asphalt drainage is desired, the roller should closely follow the paver to initially set the PFC so that asphalt drainage is minimized. If more drainage is desired, the roller should wait longer before rolling the PFC. Rich spots will tend to drain if rolling is delayed. Two passes with a 10-ton steel-wheel roller should be satisfactory to properly seat the PFC mix.

(2) *Pavement sampling.* Samples for determining thickness (ASTM D 979) may be taken either with a coring machine or by cutting out a sample of pavement at least 4 inches square with a concrete saw. The sample should include the entire thickness of the PFC.

(3) *Storage silos.* Storage of PFC mix should be avoided whenever possible; the maximum allowable storage time under any circumstance should not exceed 15 minutes. Excessive storage time will allow the asphalt to drain, causing segregation of the mixture. Proper coordination between the plant and the laydown operations will eliminate the need for extended storage.

(4) *Pavement operations under normal conditions.* The Army and Air Force guide specifications do not permit placement of PFC when the surface temperature of the existing pavement is below 60° F. The most important consideration is whether the contractor can apply the necessary rolling before the mixture becomes too cool to be properly seated. Generally, all rolling should be performed before the PFC mixture cools to 175° F. A PFC will cool quickly because of the thin layer of material and high void content in the thin PFC layer. Thus, judgment should be used in the application of the temperature limitations in the guide specifications to avoid shutting down operations during periods when satisfactory final pavement properties could be obtained.

CHAPTER 7

PLANT-MIX COLD-LAID BITUMINOUS PAVEMENTS DESIGN AND CONTROL

7–1. General.

Cold-mix bituminous pavements are often used as a low-cost surface for low-volume roads. While cold mixes do not provide pavements with the same quality hot mixes do, cold mixes do perform satisfactorily for the purposes intended. Because fuel is not needed to heat cold mixes, these pavements can, generally be constructed at lower costs than hot mixes. Some disadvantages of using cold mixes are that a lower density is usually obtained in cold mixes than in the construction of hot mixes and that a curing period is needed to allow water or volatiles to evaporate so that a satisfactory shear strength is obtained.

7–2. Design.

a. Preliminary work. The first step in designing a paving mixture is to make a survey to insure that the materials needed are available in suitable quantities and their use is economically feasible in the pavement construction. Sufficient samples of material should be obtained during the survey to accomplish the tests described later. Materials normally required for the paving mix are coarse aggregate, fine aggregate, mineral filler, and bitumen.

b. Sampling. Test reports reflecting the results of sampling and testing of the aggregates and bitumious materials will be prepared. A gradation analysis must be conducted on the aggregates to determine whether the aggregates can be blended to meet the contract gradation specifications. Representative samples of materials must be furnished for laboratory testing. Large samples must be divided into sizes usable for testing in the laboratory, in a way that will represent field conditions. Sufficient quantities of materials will be obtained at the time of sampling to meet the ASTM requirements and for laboratory pavement design tests subsquently described. Normally, aggregates that will produce 200 pounds of the desired gradation and 5 gallons of bitumen will be sufficient for these tests.

7–3. Materials.

a. Tests on aggregates.

(1) Aggregates for use in a bituminous pavement should be clean, hard, and durable. Angular aggregates provide more stable pavements than do rounded aggregates. Most of the tests of aggregates required in the design of hot-mix, hot-laid bituminous concrete are also applicable to the cold-laid type. Table 7-1 lists the aggregate gradation requirements.

Table 7-1. Aggregate gradations for plant-mix cold-laid bituminous pavements

Sieve size	Percent passing sieve by weight	
	½-inch maximum	⅜-inch maximum
1/2 inch	100	
3/8 inch	86 ± 9	100
No. 4	66 ± 9	85 ± 9
No. 8	53 ± 9	71 ± 9
No. 16	41 ± 9	57 ± 9
No. 30	31 ± 9	43 ± 9
No. 50	21 ± 8	31 ± 8
No. 100	13 ± 6	19 ± 6
No. 200	4.5 ± 1.5	6 ± 3

(2) Generally, aggregates must be combined from two or more sources for paving mixes. The addition of the mineral filler sometimes required depends on the amount of filler naturally present in the aggregate. Mathematical equations are available for making such combinations, but are not presented in

this manual because they are lengthy and trial-and-error procedures are normally easier. The method of combining stockpile sample gradations is described in paragraph 6-2*f*(2)(*a*) and (*b*). The gradation of the aggregate must fall within the limits of the gradations chosen from table 7-1 for the project specifications and shall present a smooth curve when plotted with sieve size versus percent passing.

b. Tests on bituminous materials.

(1) The specific gravity of the bituminous material must be known to determine the percent by volume of bituminous materials in the mix. Because only the residual asphalt will be used in calculating the percent binder, the amount of residual asphalt cement in liquid asphalts and asphalt emulsions will be determined as specified in ASTM D 402, Section 7 and ASTM D 244, Section 8. Specific gravity of the residual asphalt or asphalt cement shall be determined as described in ASTM D 70.

(2) Plant-mix cold-laid pavements may be made with asphalt cement and liquefier, liquid asphalts, emulsified asphalts, or tar. The asphalt cement and liquefier type is recommended because the wetting action of the liquefier insures good adhesion of the asphalt to the aggregate, the amount of liquefier can be adjusted to give any desired shelf life before the mix is to be placed, the amount of residual asphalt from design is actually measured into the mix, and the penetration grade of the residual asphalt can be easily varied. Asphalt emulsions are advantageous in that no heat is required in the mixing process and the emulsions can be added to damp aggregates. Mixes made with asphalt emulsions cannot be stockpiled unless the emulsions has been specifically formulated for stockpiling purposes. Liquid asphalts can be contained in a single tank, and only the standard pipelines and spray bar are necessary, but additional equipment is necessary for handling the liquefier for the asphalt cement and liquefier type. The choice of type of bituminous material depends primarily on the most economical available type and on the type of equipment to be used. Table 7-2 is provided as a guide to the selection of the proper grade of bituminous material. The table is given in two parts, one for bitumen for mixes to be used immediately and the other for bitumen in mixes for stockpiling for later use.

7-4. Mix design.

Several equations based on the surface area of the aggregate are available for calculating the optimum amount of bituminous material in the mix. Although these equations give an approximation of the binder content, they do not properly account for porosity of the aggregate or the compaction characteristics of the mix and, therefore, can be misleading. The following procedure is recommended for determining the amount of bituminous material to be used in the paving mix for plant-mix cold-laid pavements. This design procedure is similar to the procedure used for designing plant-mix hot-laid mixes for roads and streets. The laboratory equipment and test procedures shall be determined by MIL-STD-620, Methods 100 and 101.

a. Bitumen contents for specimens. The quantity of bitumen required for a particular aggregate is the most important factor in the design of a paving mixture. An estimate of the optimum amount of bitumen for the aggregate to be tested should be made in order to start the laboratory tests. Laboratory tests normally are conducted for a minimum of five bitumen contents: two above, two below, and one at the estimated optimum content. Incremental changes of 1 percent may be used for preliminary work, but increments of ½ percent are generally used where the approximate optimum bitumen content is known and for final designs. The bitumen content will be determined using asphalt cement except that paving grade tar will be used in the test procedure when tar is to be the binder medium of the pavement being designed. Tar generally requires about the same volume of bitumen, but because tar is heavier than asphalt, the percentage by weight is generally higher.

b. Proportioning of aggregates. As a preliminary step in mixture design and manufacture, it is necessary to determine the approximate proportions of the different available stockpiled materials required to produce the desired gradation of aggregate. The above-mentioned step is necessary to determine whether a suitable blend can be produced and, if so, the approximate proportion of aggregates to be fed from the cold feeders into the dryer. Sieve analyses are conducted on material from each of the stockpiles. The aggregates are combined as described in chapter 6. After a suitable blend has been prepared from the available materials, then samples of these materials can be processed for use in the laboratory design tests as specified in MIL-STD-620.

c. Determination of optimum bitumen content. The optimum bitumen content will be taken as the average of the asphalt contents corresponding to the mix properties in table 7-3. The optimum bitumen content will be the amount of asphalt cement or tar that will be incorporated into the mix. The percent of liquid asphalts and emulsified asphalts will be corrected to give a residual asphalt content equal to the

Table 7-2. Selection of bitumen

Bituminous material	Cold (less than 60° F)	Moderate (60°-80° F)	Hot (above 80° F)
	Immediate construction		
Asphalt cement penetration	85-100	85-100	120-150
Viscosity	AC-20	AC-20	AC-10
Liquefier (kerosene), gallons per ton mix	2.0	1.7	1.5
Liquid asphalts	RC 70 - RC-250	RC-250 - RC-800	RC-800 - RC-3000
Emulsified asphalts	MS-2h SS-1h	MS-2 - MS-2h SS-1 - SS-1h	MS-2 SS-1
Tar	RT-7 - RT-9	RT-7 - RT-9	RT-7 - RT-9
	Stockpile material		
Asphalt cement penetration	85-100	85-100	120-150
Viscosity	AC-20	AC-20	AC-10
Liquefier, gallons per ton mix	4.5	3.7	3.0
Liquid asphalts	MC-70 - MC-250	MC-250 - MC-800	MC-800 - MC-3000
Tar	RT-5 - RT-7	RT-5 - RT-7	RT-5 - RT-7
Emulsified asphalts*	MS-2h SS-1h	MS-2 - MS-2h SS-1 - SS-1h	MS-2 SS-1

Note: MC = medium curing; RC = rapid curing; MS = medium set; SS = slow set; and RT = road tar.

*Specifically formulated for stockpile use.

optimum asphalt content determined by the tests. Because all of the volatiles do not evaporate, the amount of bitumen to be added as determined by this mix design procedure should be decreased slightly. When the asphalt cement and liquefier type mix is to be used, the desired amount of liquefier will be added to the actual paving mix in addition to the optimum asphalt content determined from the laboratory design. When tar is to be used in the mix, the amount of tar will be the same as the optimum value determined by the laboratory tests.

Table 7-3. Selection of optimum bitumen content

Mix property	Value for determining optimum bitumen content
Unit weight of mix, pcf	Peak of curve
Voids total mix, percent	4 ± 1
Voids filled with bitumen, percent	75 ± 5

d. Plant control. Plant control is discussed in chapter 3.

e. Plant operation. The plant operation varies with the type of bituminous material used in the mix. For mixes using asphalt cement and liquefier bitumen, the liquefier and asphalt cement must be introduced onto the aggregate at different times. Drying of aggregate is not necessary with asphalt emulsions, but aggregates should be heated to between 100° and 225° F before mixing with the other liquid types of bituminous materials. Aggregates should not be hotter than 200° F when mixed with liquid asphalts or asphalt cement and kerosene. The bituminous materials should be in the temperature ranges given in table 7-4 when introduced into the pugmill.

Table 7-4. Mixing temperatures for bituminous materials

Bituminous material Type	Grade	Temperature range, ° F
Emulsified asphalts	MS-2	100-160
	MS-2h	100-160
	SS-1	75-130
	SS-1h	75-130
Liquid asphalts	RC-70	100-135
	RC-250	135-175
	RC-800	170-205
	RC-70	100-135
	RC-250	135-175
	RC-800	170-205
Tar	RT-5	80-150
	RT-6	80-150
	RT-7	150-225
	RT-8	150-225
	RT-9	150-225

Note: MC = medium curing; RC = rapid curing; MS = medium set; SS = slow set; and RT = road tar.

f. Plant laboratory. Use of a plant laboratory will insure that the aggregate is of the proper gradation and that the mix contains the prescribed percentage of bituminous material. The plant laboratory should contain the following major equipment:

—Hand- or power-driven mechanical sieve shaker. The sieve shaker shall have a capacity of not less than eight full-height 8-inch-diameter sieves.

—Full-height 8-inch-diameter sieve for each of the following sieve openings: 1/2 inch, 3/8 inch, No. 4, No. 8, No. 16, No. 30, No. 50, No. 100, and No. 200. The sieves shall have square openings and shall conform to requirements of ASTM E 11.

—Extractor suitable for obtaining bitumen content within close tolerances.

—Balance having a capacity of 2 kilograms and sensitive to 0.1 gram.

—Marshall equipment for compacting and testing samples to verify mixture design.

g. Adjusting mix proportions. Mix proportions shall be adjusted whenever the above tests indicate that specified tolerances are not being met. In the case of batch plants, faulty scales and failure of operator to accurately weigh the required proportions of materials are common causes for paving-mixture deficiencies. The total weight of each load of mixture produced shall not vary more than plus or minus 2 percent from the total of the batch weights dumped into the truck. Improper weighing or faulty scales may be detected readily and corrective measures taken by maintaining a close check of load weights. Figure 6-12 presents other probable causes of paving-mixture deficiencies due to improper plant operations.

7-5. Preparation of construction specifications.

a. Specifications. Plant-mix cold-laid asphalt mixtures will be produced according to provisions of guide specifications except when small quantities of mix, less than 100 tons, may be necessary for limited use of repair. In this case, the procedures specified in the guide specification would not be economical. When such an exception is deemed necessary, locally available cold-laid bituminous mix produced according to local state highway department specifications may be used when approved by the Division Engineer. When the quantity exceeds 100 tons for Army projects, approval of the DAEN-ECE-G will be required. A copy of the specification or proper reference thereto and information regarding traffic conditions and facilities to be paved will accompany the request for approval.

b. Placing. Although closer control of layer thickness and better prevention of segregation of the mix can be achieved with a mechanical spreader, a motor grader is sometimes desirable for spreading plant-mix cold-laid pavements. Aeration of the mix to remove some of the volatile material is often necessary to bring the mix to the proper condition for compaction. A motor grader can aerate the mix by blading it back and forth across the roadbed.

c. Compaction of mixture. At the time of compaction, the bituminous material in the mixture must provide a proper amount of cohesion, so that the desired density can be reached. Cohesion of the mixture will be controlled by the type of bituminous material, volatile content, and temperature of the mixture. Low cohesion will cause the mix to be unstable under the roller, while high cohesion will cause the mix to be too stiff to be compacted. The mixture should be compacted as soon as it will support the roller without undue displacement.

CHAPTER 8

SPRAY APPLICATION OF BITUMINOUS MATERIALS AND MIXTURES

8-1. General.

Spray application is a broad term used to describe many different types of bituminous applications. Some applications include aggregates, while other applications are made without aggregates. More maintenance and repair work is accomplished by spray applications of a bituminous material than by any other technique in maintaining flexible pavements. When properly constructed, bituminous spray applications are economical as well as long lasting and are beneficial in treating or improving the pavement condition and increasing the life of the pavement. Where additional thickness is needed to increase the structural strength of pavements, additional spray applications are of little help because they contribute little to the structural strength. The different types of spray applications to be discussed in more detail in this chapter are as follows:

—Prime coats.
—Tack coats.
—Fog seals and rejuvenators.
—Seal coats.
—Single and double bituminous surface treatments.
—Bituminous penetration macadam.

8-2. Prime coat.

a. General. Bituminous prime coat consists of a low-viscosity liquid bituminous material applied by a pressure distributor to a nonbituminous base course before placement of a bituminous concrete or a PCC pavement. Purposes of the prime coat are to prevent raveling of the nonbituminous base during pavement construction; to waterproof during pavement construction; and to form a tight, tough base to which a bituminous pavement will adhere. To accomplish these purposes, the prime material must penetrate into the nonbituminous base and fill the void spaces. A completed nonbituminous base is susceptible to serious damage from rain, wind, and traffic. An adequate prime is insurance against this water and traffic damage. Prime coat material should be applied to a dust-free nonbituminous base as soon as the base has been thoroughly compacted and before construction or other traffic loosens surface material in the compacted base. Sufficient time should be allowed to permit prime material to penetrate thoroughly into the compacted base.

b. Materials.

(1) Low-viscosity bituminous material should be used as prime material, but the selection of type and grade must be given special consideration. Some items to consider in selecting the priming material are as follows:

—Air temperature.
—Humidity.
—Void content of base course.
—Curing time of prime material.
—Environmental restrictions.
—Available materials.

(2) The recommended priming materials are emulsified asphalts, cutback (liquid) asphalt, and road tars. The recommended types and grades are shown in table 8-1.

Table 8-1. Prime coat materials

Type	Grade
Cutback	SC-70
	SC-250
	MC-30
	MC-70
	MC-250
	RC-70
	RC-250
Emulsion	SS-1
	SS-1h
	CSS-1
	CSS-1h
Road tar	RT-1
	RT-2
	RT-3

(3) A prime can only work if it penetrates into the base course. Open-textured (high-void content) bases can be primed easily, but a tight surface (low voids) cannot be readily penetrated. The less viscous cutbacks, such as RC-70, MC-30, MC-70, and SC-70, should be considered. If penetration does not occur, an asphalt film will be left on the base surface, causing slippage of the bituminous surface during and after construction. Caution should also be urged in using RC-70 or RC-250 because the solvent in the cutback may evaporate rapidly or be absorbed by the base-course fines and leave an asphalt film deposited on the surface. Undiluted emulsions can also cause asphalt film problems if the base-course surface is tight.

(4) Weather can influence the choice of the correct priming materials. Since emulsions are dependent on the evaporation of water before they break and cure, low temperature or high humidity can slow or stop the curing. Cutbacks are not as dependent on weather conditions as emulsions. In cold weather, the rapid curing cutbacks (RC's) may perform better than the slower curing cutbacks (MC's and SC's).

(5) Environmental restrictions have begun to limit the types of prime material available in some areas of the United States. As a result, some cutback asphalts are not available for priming. Therefore, asphalt emulsion primes are becoming more numerous. Asphalt emulsions must be diluted with water before being applied as a prime, and special handling and storage considerations to prevent freezing, settling, and breaking must be exercised.

c. Application rate. Prime coats are usually applied in quantities of 0.10 to 0.25 gallon per square yard. The optimum amount of prime is highly dependent on the plasticity index of the base material, the amount of fines in the base, the granular nature of fines, the tightness of the surface, and the moisture content of the base. Therefore, the optimum amount of prime required should be determined by field trial. Test sections at various application rates are recommended for determining the optimum amount of prime. After 48 hours of curing, if there is free or excess bitumen on the surface or if the base continues to appear shiny, the base is probably overprimed. Generally most of the prime should be absorbed into the base within 2 to 3 hours. When excessive prime is used, the surplus can be absorbed into the overlying bituminous pavements. In turn, the absorption of the excess may contribute to pavement slippage or cracking. Where excessive prime is applied, the excess may be blotted with an application of clean fine sand or mineral dust. The ideal end result is to obtain maximum penetration without leaving free prime on the surface.

d. Placement. Surfaces to be primed which contain appreciable amounts of loose material or are dusty should be broomed. A dusty surface will sometimes cause prime to "freckle," that is, have small areas with no prime and adjacent areas with drops of excess prime. A light application of water just before applying the prime will aid in reducing "freckles" and getting good distribution of the prime. Priming should be uniformly applied with a pressure distributor at the required application rate and at the proper temperature for the bitumen used. Minimum curing time will vary according to the grade and type of bitumen being used, the nature of the base, temperature, and humidity, but generally curing should take place within 48 hours.

e. Control. Since most prime is applied with a pressure distributor, the distributor must be calibrated and checked for the specified application rate before applying the prime. ASTM D 2995 offers a method for determining the application rate of bituminous distributors. In addition, all nozzles should be free and open, the same size, and to the same angle in reference to the spray bar to produce a uniform fan of prime. The height of the spray bar above the surface is important because a bar too high or too low will give a light application in the middle of the spray fan and a heavy application at the ends, causing streaking. The height of the spray bar should be such that a double or triple lap of the spray fan is obtained.

8-3. Tack coat.

a. General. A tack coat is a light application of a bituminous material to an existing pavement or bituminous base course immediately prior to placing the next pavement layer or course. The purpose of the tack coat is to provide a bond between the two pavement layers or course. The tack coat is applied by pressure distributor to cleaned surfaces. The tack coat must be applied in a light and uniform application.

b. Materials.

(1) The tack coat material may be either asphalt or tar, but tar should only be used with tar or rubberized tar pavements. Emulsions and cutbacks are the most common types of asphalt material used as tack, but asphalt cements may be used in some situations if the correct spraying viscosities can be obtained. The recommended tack coat materials are shown in table 8-2.

Table 8-2. Tack coat materials and spray application temperatures

Type	Grade	Application Temperature ° F
Cutback	RC-70	120-200
	RC-250	165-250
Emulsion	RS-1	70-140
	MS-1	70-160
	HFMS-1	70-160
	SS-1	70-160
	SS-1h	70-160
	CRS-1	125-185
	CSS-1	70-160
	CSS-1h	70-160
Asphalt cement	200-300 pen	265+
	120-150 pen	270+
	85-100 pen	280+
	AC-2.5	270+
	AC-5	280+
	AC-10	280+
	AR-1000	275+
	AR-2000	285+
	AR-4000	290+
Road tar	RT-6	80-150
	RT-7	150-225
	RT-8	150-225
	RT-9	150-225

(2) The cutbacks and emulsions can be sprayed at relatively low temperatures, but the asphalt cements may require considerable heating to reach a viscosity suitable for spraying.

(3) In cold weather, the cutbacks can be used with less concern than emulsions which contain water. However, environmental restrictions limit the use of cutback materials, making them unavailable at many locations. The use of emulsions for tack coats may require that the emulsion be diluted with water so that a light tack is applied, and its use also requires that special consideration be given to weather conditions, storage and handling requirements, and curing time. All tack coats should be cured before placing the new pavement layer.

c. Application rate. Tack coats are usually applied in quantities of 0.05 to 0.10 gallon per square yard, but the exact quantities should be adjusted to suit field conditions. Light applications are preferred since heavy applications can cause serious pavement slippage and bleeding problems. However, failure to use any tack coat can also cause pavement slippage problems.

d. Placement. Tack coats should be applied to clean, dustfree bituminous pavement courses immediately before placing the overlying pavement layer. A tack may be required on a nonbituminous base course when the prime coat on that surface has been subjected to construction traffic or other traffic. A pressure distributor should be used to apply tack coats at an application temperature which will produce a viscosity between 10 and 60 seconds, Saybolt Furol, or between 20 and 120 centistokes, kinematic viscosity. The suggested spray application temperatures in degrees Fahrenheit for tack coat materials are shown in table 8-2. When an even or uniform coating is not obtained, an improved coverage may be possible by making several passes over the freshly applied tack coat with a pneumatic-tired roller. The tack coat should be completely cured (volatiles or water evaporated) before the overlying layer is placed. A properly cured surface will feel tacky. Work should be planned so that no more tack coat than is necessary for one day of operation is placed on the surface. All nonessential traffic should be kept off the tack coat so that dust, mud, or sand will not be tracked onto the surface.

e. Control. To insure that the tack coat is applied as specified, the bituminous distributor should be calibrated and checked. ASTM D 2995 offers a method for determining the application rate of bituminous distributors. In addition, all nozzles must be free and open, the same size, and at the same angle in reference to the spray bar to produce a uniform spray of tack. Spray bar height above the surface is also important for uniform application. A bar too high or too low will give a light application in the middle of the spray fan and a heavy application at the edges. The spray bar should be adjusted to a height that provides a double or triple lap.

8-4. Fog seals.

a. General. A fog seal is a very light spray application of a diluted emulsified asphalt or rejuvenator to an existing bituminous pavement. The fog seal is used to maintain old pavements, reduce raveling, waterproof, and in general, extend the life of the existing pavement. Fog seals are especially good for treating pavements which carry little or no traffic. However, there are several considerations when using fog seals:

(1) The pavement skid resistance can be reduced.

(2) Rejuvenators used as fog seal can soften the asphalt binder, increase the penetration, and lower the viscosity.

(3) The pavement air voids or permeability can be reduced.

(4) The pavement should be closed to traffic for 12 to 24 hours to allow for proper cure of the seal material.

(5) Rejuvenators used as fog seals will soften slurry seals, surface treatments, and seal coats enough to cause reduction in skid resistance.

b. Materials. In the past, asphalt emulsions and some cutbacks were used for fog seals, but in recent years the materials used are emulsions and rejuvenators. The emulsions most often used are SS-1, SS-1h, CSS-1, and CSS-1h. Several rejuvenators are available, but they are proprietary materials and are not listed here. These materials are usually diluted before application.

c. Application rate.

(1) The proper application and dilution rate for fog seal will vary with the absorption characteristics of the existing pavement. Field test sections should be placed to determine the best application rate for the existing pavement. The application rate should be adjusted so that the pavement does not become slick or unstable nor have an excess of free material on the surface after curing 12 to 24 hours.

(2) The amount of dilution must be evaluated for each job. Asphalt emulsion can be applied at full strength or can be diluted as much as 1 part emulsion to 10 parts water. Normal application dilution is in the range of 1 to 4 parts water. Rejuvenator may also require dilution, but manufacturers' recommendations should be followed. When highly diluted fog seals are used, a small amount of surface residue is obtained and the skid resistance would be only slightly reduced.

d. Placement. Only a pressure distributor which has been calibrated to deliver the fog seal at the specified rate should be used to apply the seal material. All surfaces to which the seal is applied must be clean. The fog seal should be applied when the ambient temperature is above 40°F, but warmer temperatures are desired because the material will break and cure faster. The seal material may be aplied to a damp pavement if the dilution material is water, but the pavement must not be too wet or the seal will not break properly and penetrate into the pavement. Excess seal left on the surface may be blotted with clean sand and broomed.

8-5. Seal coat.

a. General. A bituminous seal coat consists of an application of bituminous material on a prepared surface, followed immediately by a single layer of cover aggregate. A seal coat is similar to a single bituminous surface treatment except that the cover aggregate is smaller. The purpose of a seal coat is to retard pavement raveling and deterioration, modify surface texture, improve skid resistance, and provide a waterproof wear-resistant surface. As a general rule, a seal coat is used on a existing pavement which has light to moderate amounts of traffic.

b. Materials.

(1) Bituminous materials. See paragraph 8-6*b*.

(2) Aggregates. The quality of aggregate is discussed in paragraph 8-6*c*. Table 8-3 summarizes the recommended aggregate gradations.

Table 8-3. Seal coat aggregate gradations

Sieve size	Percent passing by weight 1	2	3
½ inch	100	—	—
⅜ inch	85-100	100	—
No. 4	10-30	85-100	100
No. 8	0-10	10-40	10-40
No. 16	0-5	0-10	0-10
No. 50	—	0-5	0-5

c. Design. Several methods are available for determining the application rates for both bituminous binder and aggregate, but the application rates will require adjustments for aggregate whipoff, the porosity of the aggregate and existing surface, and the amount of traffic. Table 8-4 gives a range of application rates for bituminous binder for each aggregate gradation specified. Bituminous application rates will be increased by 10 percent when emulsions are used as the bituminous material. The lower binder application rates shown in table 8-4 should be used for aggregate having a gradation on the fine side of the specified limits. The weight of aggregate shown in table 8-4 is based on an aggregate specific gravity of 2.70. If the specific gravity of the aggregate is less than 2.60 or more than 2.80, a correction must be made in the application rate.

Table 8-4. Seal coat application rates

Gradation No.	Bituminous binder gallon/square yard	Aggregate pounds/square yard
1	0.20 to 0.35	20 to 25
2	0.15 to 0.25	15 to 20
3	0.15 to 0.20	10 to 15

d. Equipment and construction. For information on equipment and construction, see paragraphs 8-6 *l* through *p*.

8–6. Single and double bituminous surface treatments.

a. General. A single bituminous surface treatment (SBST) consists of an application of bituminous material on a prepared surface followed immediately by a single layer of cover aggregate. Double bituminous surface treatment (DBST) is similar to a SBST except that two applications of bitumen and cover aggregate are used. The first application of aggregate uses a coarser aggregate than the second application and usually determines the DBST thickness. The second application of aggregate partially fills the surface voids and keys the aggregate in the first aggregate course. The purpose of the surface treatment is to retard pavement raveling and deterioration, to provide an abrasion-resistant surface, to improve skid resistance, and to seal the underlying pavement with a waterproof surface. SBST's and DBST's are used on prepared base courses and new or old pavements.

b. Bituminous materials.

(1) The functions of the bituminous binder are to hold the aggregate in place, bond it to the underlying surface, and seal the underlying surface to prevent the entrance of moisture and air. The binders specified for SBST and DBST are cutback asphalts, emulsified asphalts, asphalt cements, and road tars. The types and grades are shown in table 8–5.

Table 8–5. Surface treatment bituminous materials

Type	Grade
Cutback	RC–250
	RC–800
	RC–3000
Emulsion	RS–1
	RS–2
	CRS–1
	CRS–2
Asphalt cement	120–150 pen
	200–300 pen
	AC–2.5
	AC–5
Road tar	RT–6
	RT–7
	RT–8
	RT–9
	RT–10
	RT–11
	RT–12

(2) The type and grade of binder must be carefully selected. Some items to consider are as follows:
—Climatic conditions.
—Curing time of binder.
—Environmental restrictions.
—Available materials.
—Temperature of surface.
—Condition of surface.
—Condition of aggregate.

(3) Rapid curing cutback asphalts have often been used for surface treatments. RC–250 has been used when cooler temperatures are anticipated, and RC–3000 when very warm temperatures are anticipated. However, environmental requirements limit the availability of cutback asphalts, and as a result, use of emulsified asphalt binders is increasing.

(4) Emulsions require some special handling and storage considerations to prevent freezing, settling, and premature breaking, but they can be applied with little or no additional heating. In selecting the type of emulsion, the compatibility of the aggregate and emulsion must be considered. As a general rule, anionic emulsions adhere better to limestones and other aggregates composed of predominantly calcium minerals. Cationic emulsions generally adhere better to aggregates high in silica, such as chert and quartz gravels. Cationic and anionic emulsions adhere well to damp aggregates.

(5) Asphalt cements harden quickly so that the cover aggregate is held in place better than other binders provided the asphalt cement does not chill before the cover aggregate is applied. Chilling of the binder before applying the aggregate is one major disadvantage with asphalt cement binders. To insure good bond the chips are often heated when asphalt cements are used. Another disadvantage with the use of asphalt cements is the high amount of heat required for spraying. Because of the difficulties encountered with asphalt cements, cutbacks or emulsions instead of asphalt cement should be carefully considered.

(6) Road tars adhere well to dam aggregates and are less susceptible to stripping than are asphalts, but they are more apt to produce a bleeding surface in hot weather and a brittle binder in cold weather.

c. Aggregates.

(1) The aggregate will have an effect on the degree of wear resistance, riding quality, and skid resistance of the surface treatment. Only clean, dry aggregate fragments, free from dust or dried films of harmful material, should be used. The aggregate should also have a 1-size (uniform) gradation and be composed of hard, angular, polish-resistant material. Flat and elongated aggregate particles and wet or dusty aggregates are not used. Small quantities of moisture up to about 1 percent do not create a problem, especially in warm weather, but dust can prevent the adhesion of the binder to the aggregate. Aggregate with up to 3 percent moisture may be used when the binder used is an emulsion.

(2) Tables 8-6 and 8-7 give the recommended aggregate gradations for SBST and DBST, respectively. For DBST, gradations Nos. 1 and 2 and gradations Nos. 3 and 4 from table 8-7 will be used in combination.

Table 8-6. Gradation for SBST

Sieve size	Percent passing by weight, gradation designation		
	No. 1	No. 2	No. 3
1 inch	100	—	—
¾ inch	90-100	100	—
½ inch	20-55	90-100	100
⅜ inch	0-15	40-70	85-100
No. 4	0-5	0-15	10-30
No. 8	—	0-5	0-10
No. 16	—	—	0-5

Table 8-7. Gradation for DBST

Sieve size	Percent passing by weight, gradation designation			
	No. 1	No. 2	No. 3	No. 4
1 inch	100	—	—	—
¾ inch	90-100	—	100	—
½ inch	20-55	100	90-100	—
⅜ inch	0-15	85-100	40-70	100
No. 4	0-5	10-30	0-15	85-100
No. 8	—	0-10	0-5	10-40
No. 16	—	0-5	—	0-10
No. 50	—	—	—	0-5

d. Design. Tables 8-8 and 8-9 present general application rate ranges for SBST and DBST, respectively. A range of application rates is given for both bituminous material and aggregate with the high and low limits of these ranges corresponding to the coarse and fine limits of the gradation band. Bituminous application rates will be increased by 10 percent when emulsions are used as the bituminous material. The weight of aggregate is based on an aggregate with a specific gravity of 2.70. A correction should be made in the application rate for aggregates with a specific gravity higher than 2.80 or lower than 2.60. These application rates may be varied according to local conditions and experience.

Table 8-8. Application rates for SBST

Gradation No.	Bituminous material (gallon/square yard)	Aggregate (pounds/square yard)
1	0.40–0.50	40–50
2	0.30–0.45	25–30
3	0.20--0.35	20–25

Table 8-9. Application rates for DBST

Gradation No.	Bituminous material (gallon/ square yard) first application	Aggregate (pounds/ square yard) first spreading	Bituminous material (gallon/ square yard) second application*	Aggregate (pounds/ square yard) second spreading
1	0.20–0.30	40–50		
2			0.30–0.45	20–25
3	0.15–0.20	25–30		
4			0.20–0.30	15–20

*The second bituminous material application shall be 50 percent greater than the first application.

e. Methods for determining application rates. The application rates for bituminous material for a specific cover aggregate can be determined by use of figure 8–1 and table 8–10 for SBST and figure 8–2 and table 8–11 for DBST. The various factors to be used in figures 8–1 and 8–2 are discussed below and design examples are given. Coarse aggregate defines the first aggregate applications, and the fine aggregate is that used in the second application of a DBST. The application rates as determined from figure 8–1 or 8–2 will require adjustment for aggregate whip-off, the porosity of the aggregate and existing surface, and the amount of traffic.

Table 8-10. Bituminous volume requirements for SBST

Traffic type	Bituminous material, percent of voids filled with bitumen
Parking areas and seldom trafficked areas	85
Light	75
Medium	70
Heavy	65

Table 8-11. Bituminous volume requirements for DBST

Traffic type	Bituminous material, percent by volume
Parking areas and seldom trafficked areas	22
Light	20
Medium	19
Heavy	18

f. Volume of traffic. As the volume of traffic increases, the amount of bituminous material needed is decreased. Table 8–10 gives the recommended bituminous volume requirements for SBST, and table 8–11 gives the requirements for DBST. The percent of bituminous material by percent voids filled and by volume should be used in figures 8–1 and 8–2, respectively.

g. Average aggregate particle size. The average particle sizes (APS) for both SBST and DBST to be used in figures 8–1 and 8–2 are determined from the gradation of the project aggregate using equation 8–1:

$$APS = 0.1\,(a + d) + 0.4\,(b + c) \qquad \text{(eq 8-1)}$$

where

a = aggregate size corresponding to 100 percent passing
b = aggregate size corresponding to 80 percent passing
c = aggregate size corresponding to 20 percent passing
d = aggregate size corresponding to 0 percent passing

Figure 8–3 illustrates the gradation and average particle size relationship.

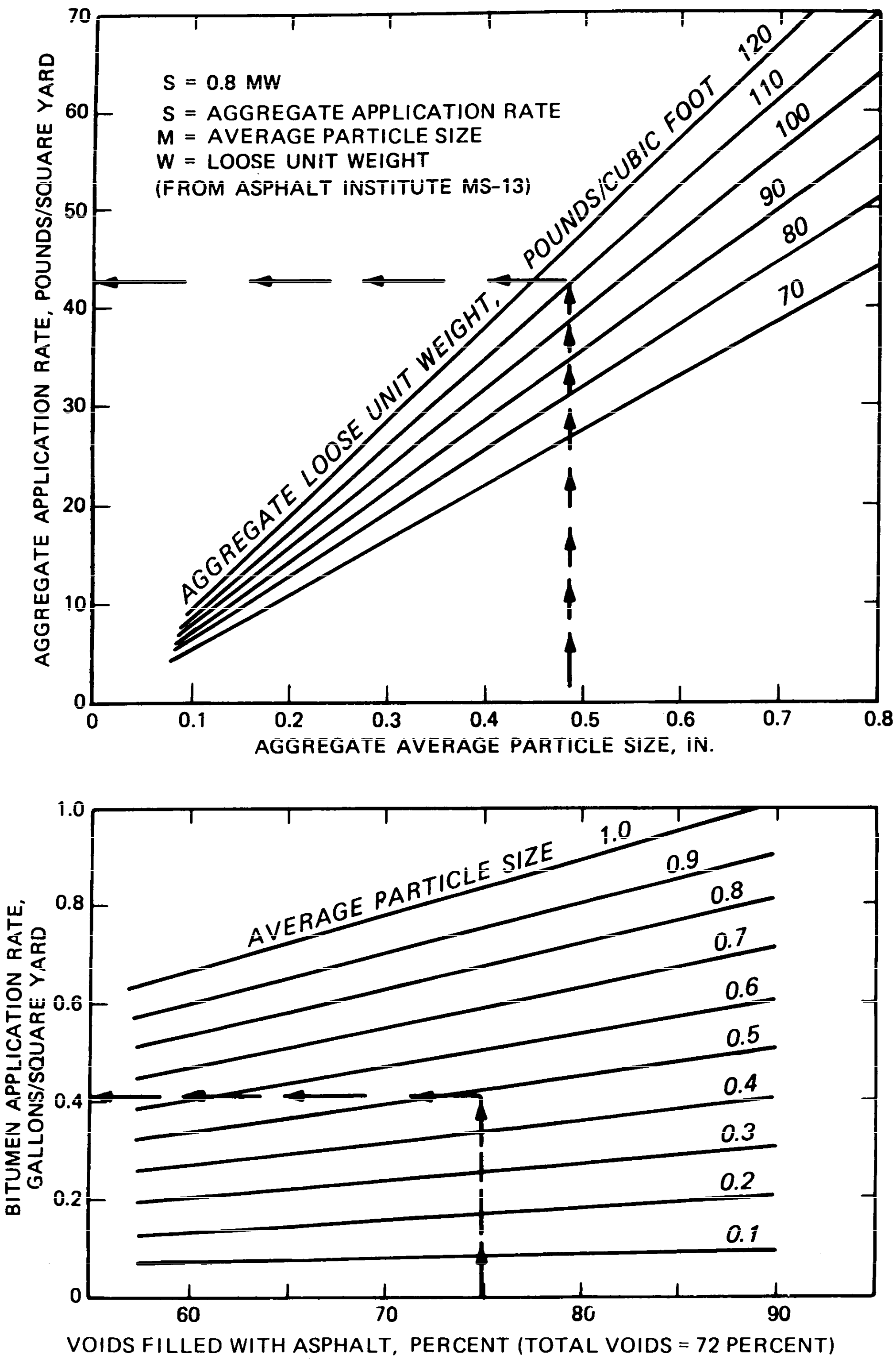


Figure 8-1. Examples of aggregate and bitumen application rates for SBST.

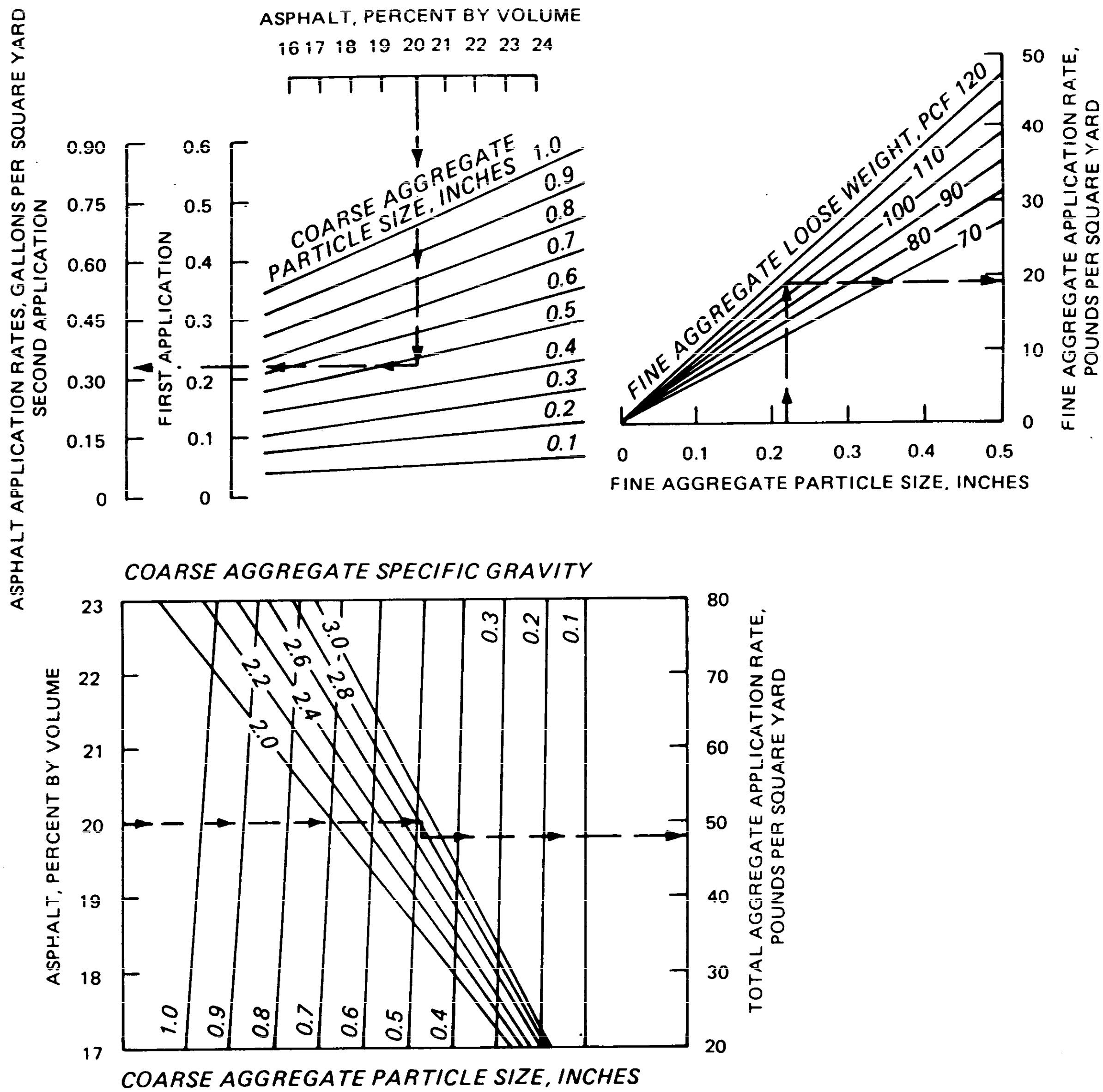


Figure 8-2. Application rates for aggregates and bituminous materials for DBST.

h. Aggregate loose unit weight. The loose unit weight of the project aggregate that is to be used in figure 8-1 or 8-2 should be determined as described in ASTM C 29.

i. Aggregate specific gravity. The bulk specific gravity of the coarse aggregate to be used in figure 8-2 should be determined as described in ASTM C 127.

j. Example of SBST.

(1) The following example is given to illustrate the use of figure 8-1.

Given:

Aggregate average particle size = 0.484 inch

Aggregate loose unit weight = 110 pcf

Medium traffic area design = 75 percent of the voids filled with bitumen

(2) Enter figure 8-1a with the aggregate average particle size (0.484 inch), proceed vertically to the aggregate loose unit weight (110 pcf), and then horizontally to obtain the aggregate application rate of 43 pounds per square yard. Next enter figure 8-1b with the percent voids filled value (75 percent), proceed vertically to the average particle size (0.484 inch), and then horizontally to obtain the bitumen application rate of 0.41 gallon per square yard.

k. Example of DBST. The following example is given to illustrate the use of figure 8-2.

Given:

Coarse aggregate average particle size = 0.484 inch
Fine aggregate average particle size = 0.220 inch
Fine aggregate loose unit weight = 110 pcf
Coarse aggregate bulk specific gravity = 2.70
Light traffic area design = 20 percent by volume of bitumen

Enter the chart in the upper left corner of figure 8-2 with the percent asphalt by volume (20 percent in this example), proceed vertically to the coarse aggregate particle size of 0.484 inch, and then horizontally to obtain the first and second application rates of bituminous materials. These first and second application rates are 0.22 and 0.33 gallon per square yard, respectively, for this example. The next step is to obtain the application rate of the fine aggregate (second aggregate course) from the chart at the upper right corner of figure 8-2. Enter the fine aggregate particle size of 0.220 inch at the bottom of this chart, proceed vertically to a fine aggregate loose unit weight of 110 pcf, and then horizontally to determine the fine aggregate application rate of 19 pounds per square yard. Enter the percent asphalt by volume in the lower chart of figure 8-2, proceed horizontally to the coarse aggregate particle size, then vertically to the coarse aggregate bulk specific gravity (2.70 for this example), and continue horizontally to obtain the total aggregate application rate of 48 pounds per square yard. The application rate of the coarse aggregate (first aggregate course) is the difference between this total aggregate rate and the fine aggregate application rate, or 48 − 19 = 29 pounds per square yard.

l. Placement. Field construction practices can determine the success or failure of a well-designed surface treatment; therefore, proper equipment, surface preparation, and construction techniques are very important.

m. Equipment. Among the equipment used in placing a surface treatment, the most important are the bituminous distributor and the aggregate spreader. Calibration and proper operation of the distributor and aggregate spreader should be insured.

n. Surface preparation. Without proper surface preparation the life expectancy of a pavement will be reduced. Therefore, all soft or failed areas must be repaired before the surface treatment, and all loose material, dirt, and vegetation must be removed. A bleeding surface may require either sanding or removal before construction of the surface treatment.

o. Application.

(1) Special attention must be given to the application rates of both binder and aggregate. Field adjustments to the design application rates may be necessary. Too much binder will cause bleeding or low skid resistance, and too little binder will result in the loss of cover aggregate. Although there should be about 5 to 10 percent excess aggregate, too much aggregate will result in a waste of materials and damage to windshields.

(2) The aggregate must be applied immediately after the binder application in order to obtain a good bond between asphalt and aggregate. Rolling immediately after applying the aggregate will seat the aggregate in the binder and improve the bond.

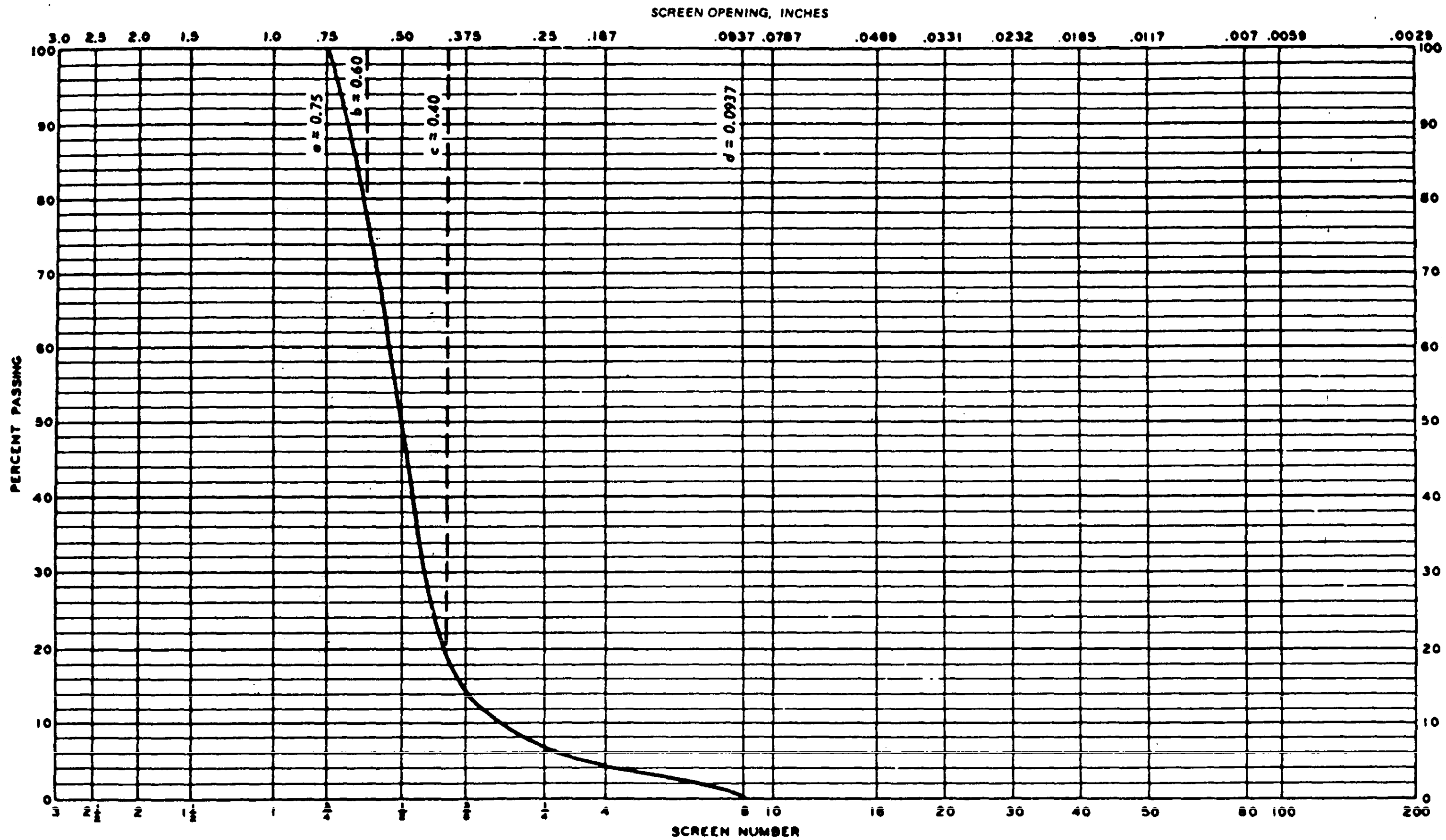
p. Control.

(1) Since the distributor and aggregate spreader are important for the successful application of materials, they must be calibrated and checked to insure that the specified application rate is obtained. ASTM D 2995 offers a method for determining the application rate of bituminous distributors. In addition, all nozzles should be free and open, the same size, and at the same angle with reference to the spray bar to produce a uniform fan of asphalt. The height of the spray bar above the surface is important. A bar too high or too low will produce a light application in the middle of the spray fan and a heavy application at the ends, causing streaking. The height of the spray bar should be such that a double or triple lap of the spray fan is obtained. The Asphalt Institute's Manual Series No. 13 offers guidance for calibrating and checking application equipment.

(2) A test section is another method to evaluate the construction techniques and the application rates required for surface treatment. At least one test section should be constructed before allowing surface treatment applications on a full scale.

8–7. Bituminous penetration macadam.

a. General. A penetration macadam surface course is constructed beginning with a layer of rolled coarse aggregate, followed by a pressure application of asphalt or tar cement. Next, the surface voids in



APS = 0.1 (a + d) + 0.4 (b + c)

= 0.1 (0.75 + 0.0937) + 0.4 (0.60 + 0.40)

= 0.484

Figure 8-3. Determination of average particle size.

the coarse aggregate layer are filled with key aggregate, followed by an additional application of asphalt or tar cement, which is then covered with fine aggregate and rolled. A minimum amount of equipment is required for construction, and for this reason the pavement is particularly adapted for jobs in remote localities involving small yardage. Macadam surfacing is not generally considered equal in quality to bituminous pavements produced by central paving plants. The surface course is not as dense as plant-mixed bituminous pavements, and when loosely bound, the aggregate on the finished surface may be a hazard to aircraft operations. Penetration-type surfaces may be considered for roads and streets not subjected to traffic by tracked vehicles. The use of bituminous macadam construction has greatly diminished over the years because of new and better developments in equipment and construction techniques for other pavement types.

b. Materials.

(1) Bituminous materials. The binders specified for penetration macadam are asphalt cements and road tars. The asphalt may be either an 85 to 100 or a 120 to 150 penetration-graded or an AC-5 or AC-10 viscosity-graded asphalt cement. RT-12 is the grade of road tar recommended.

(2) Aggregates.

(a) Only clean, uncoated, dust-free aggregate should be used in macadam construction. The aggregate should be composed of hard, angular stone with a one-size (uniform) gradation. The gradation should also be strong enough to resist crushing under the construction rolling and should be polish-resistant under traffic. Flat and elongated aggregate particles and wet or dusty aggregate are undesirable. Wet or dusty material can result in poor adhesion and stripping.

(b) Tables 8-12 and 8-13 give the recommended gradations for 2-inch- and 2-½-inch-thick macadam, respectively.

Table 8-12. Gradation for 2-inch-thick bituminous macadam wearing course

	Percent passing by weight		
Sieve size	Coarse aggregate	Key aggregate	Fine aggregate
2 inch	100	...	...
1-½ inch	90-100	...	...
1 inch	20-55	...	...
¾ inch	0-15	100	...
½ inch	...	90-100	100
⅜ inch	0-5	40-70	86-100
No. 4	...	0-15	10-30
No. 8	...	0-5	0-10
No. 16	...	...	0-5

Table 8-13. Gradation for 2-½-inch-thick bituminous macadam wearing course

	Percent passing by weight		
Sieve size	Coarse aggregate	Key aggregate	Fine aggregate
2-½ inch	100	...	...
2 inch	90-100	...	...
1-½ inch	35-70	...	...
1 inch	0-15	100	...
¾ inch	...	90-100	...
½ inch	0-5	...	100
⅜ inch	...	20-55	86-100
No. 4	...	0-15	10-30
No. 8	...	0-5	0-5

c. Design. Tables 8-14 and 8-15 present the general application rates for placing one application of coarse, two of key, one of fine aggregate, and three applications of bitumen. Table 8-14 is for 2-inch-thick macadam, and table 8-15 is for 2-½-inch-thick macadam.

Table 8-14. Application rates for 2-inch-thick course

Placing operations	Bitumen (gallons per square yard)	Coarse Aggregate (pounds per square yard)	Key Aggregate (pounds per square yard)	Fine Aggregate (pounds per square yard)
First spreading	...	165–175	...	...
First application	1.10–1.30	...	...	...
Second spreading	...	...	15–25	...
Second application	0.30–0.50	...	...	...
Third spreading	...	...	12–20	...
Third application	0.25–0.45	...	...	...
Fourth spreading	...	...	...	10–20

Table 8-15. Application rates for 2-½-inch-thick course

Placing operations	Bitumen (gallons per square yard)	Coarse Aggregate (pounds per square yard)	Key Aggregate (pounds per square yard)	Fine Aggregate (pounds per square yard)
First spreading	...	205–215	...	...
First application	1.40–1.60	...	...	...
Second spreading	...	...	20–30	...
Second application	0.40–0.60	...	...	...
Third spreading	...	...	15–25	...
Third application	0.30–0.50	...	...	...
Fourth spreading	...	...	...	20–30

d. Placement.

(1) Special attention must be given to each course of aggregate and binder to insure that the desired application rates are applied, that the rolling is sufficient, and that the desired grade and smoothness are obtained.

(2) For better control of application rates, an aggregate spreader and a bituminous distributor should be used. The spreader and distributor must be calibrated and checked for the specified application rate. ASTM D 2995 offers a method of determining the application rate of bituminous distributors. In addition, the Asphalt Institute's Manual Series No. 13 offers guidance for calibrating and checking application equipment.

(3) Rolling is necessary to seat the aggregate, but the first or main course of coarse aggregate should not be closed by rolling. Rolling should be continued only long enough to seat the coarse aggregate, and the aggregate should be left open enough to permit ready penetration of the first application of bitumen and entrance and interlocking of the key aggregate. Immediately following the first application of bitumen the key aggregate should be uniformly spread and rolled. The key aggregate will be applied in two applications, each preceded by an application of bitumen. The final course of aggregate is the fine aggregate, which immediately follows the third application of bitumen.

CHAPTER 9

NATURAL ROCK ASPHALT WEARING COURSES

9-1. General.

This chapter provides criteria and guidance for construction of bituminous pavement using natural rock asphalts. Two procedures for construction of a wearing surface are discussed. Natural rock asphalts are found throughout the world, but the major sources in the United States are in Kentucky, Alabama, New Mexico, Oklahoma, Texas, and Utah. These natural rock asphalts have been used quite successfully in the construction of roads, streets, and other areas subjected to vehicular traffic. Since natural rock asphalts occur in a variety of rock types, at various asphalt contents, and at various conditions of asphalt, some processing of some rock asphalts is required to provide a uniform mixture satisfactory for bituminous surfacings. Generally, these mixtures are not considered satisfactory for use on areas that will be subjected to high-pressure tires (above 100 psi). In a quality rating, natural rock asphalts probably would be placed in the same class as cold mixes. Some of the natural rock asphalts, specifically those from sandstone deposits, have been used for surfacings to improve skid resistance.

9-2. Bituminous content requirements.

The most important control on any bituminous mixture is the accurate proportioning of aggregate and binder material. Natural rock asphalt material does not always occur in nature at a desirable binder content for use as paving materials. This fact explains why some deposits are better than others for the production of paving mixtures. For natural rock asphalt wearing course materials, it has been observed from past performance that a binder content between 5 and 9 percent by weight will give satisfactory results. Because of this high variability in binder content, this material cannot be considered a high-quality paving mixture. Blended natural rock asphalt wearing courses require slightly more binder material than the fluxed rock asphalt wearing courses.

9-3. Composition of mixture.

Gradation of the aggregate is determined on samples after the asphalt has been extracted from the mixture.

9-4. Job mix formula.

The development of a JMF for natural rock asphalt mixtures is by trial and error, and the requirements for the mixtures consist of determining the aggregate gradation and binder content. If these tests are conducted by the requirements set forth in the guide specifications and the material meets all the specification requirements, the result is then considered to be the JMF. The guidance provided for performing mix designs for hot mixes can generally be used for development of a mix design for rock asphalt.

9-5. Service requirements.

The performance history of a natural rock asphalt in paving mixtures is a good indicator of how well it will perform in the future. Therefore, a careful survey of projects that have used material from the source being considered should be made and the performance of those pavements observed.

9-6. Equipment, plant, machines, and tools.

The requirements for equipment for the mixing, transporting, placing, and compacting of natural rock asphalt wearing course surfaces are outlined in sufficient detail in the respective guide specifications covering these items. The plant output requirement should be set at a rate that can be expected to be placed, depending on job requirements and conditions.

9-7. Reconditioning of base course.

The condition of the base course on which a natural rock asphalt wearing course is to be placed will have considerable influence on the final condition of the pavement. To provide a structurally sound, smooth pavement, the base must be built to the desired requirements. Depending on the proposed use of the facility being constructed, limits will be placed on smoothness for the pavement surface.

CHAPTER 10

BITUMINOUS ROAD MIXES AND BITUMINOUS SOIL STABILIZATION

10-1. General.

This chapter contains information for use of bituminous road mixes, bituminous stabilization, or both. Bituminous road mixes and bituminous stabilization are sometimes difficult to distinguish. For this manual, any bituminous mixture to be used as a surfacing course will be considered as a road mix. When any subsurface layer receives a bituminous treatment, the treatment will be considered bituminous stabilization. In many cases, the design procedures and construction techniques will be identical for the two types of treatment.

10-2. Road mixes.

Road mixes for surfacings are not as popular now as they were in the past. This decline in use has been brought about by the improvement in construction equipment and techniques for other pavement types and by the need for a general-use surfacing of higher quality than road mixes. This need does not prohibit the use of road mixes, however, for secondary roads and streets where a good all-weather road is required. Road mixes have the advantage of being economical to construct, and when properly controlled, satisfactory mixes can be produced. Generally, the only equipment required in the construction of a road mix is an asphalt distributor, a motor patrol, dump trucks, a front-end loader, and rollers. Road mixes can be constructed on the roadway where the mix is to be used or on any area where mixing can be accomplished without contamination. Material requirements for road mixes are such that a wide variety of aggregates and bituminous materials can be used. The design of road mixes will follow the guidance provided for plant-mix cold-laid mixtures discussed in chapter 7.

10-3. Aggregate.

A number of potential sources may be available for aggregate for road mix, bituminous stabilization, or both. Occasionally, crushed aggregate that will meet gradation requirements can be obtained from commercial sources. Also pit-run aggregates are available that may meet the aggregate requirements. When such materials are available, they are hauled to the prepared roadbed or mixing area and deposited in the desired quantities that will be required for the surface course. There will be times when aggregates from two or more sources can be blended to produce a gradation meeting the project specifications. Aggregates may be combined at a central plant where feeders and mixers are available, or they may be combined on the roadbed where the bituminous mixtures are to be placed. Locations do exist where the in-place aggregates in the roadbed are of suitable gradation and character that they may be used for road mixes, bituminous stabilization, or both. Where these conditions exist, the material is treated in place. One requirement for producing a good road mix or bituminous stabilization job is to obtain a good coating of bituminous material on the aggregate. Fine material, such as sands, which may contain 15 to 20 percent material passing the No. 200 sieve, will produce a good stable mix if complete mixing and aeration are accomplished. Generally, the additional time required for aeration will also enable the bituminous material to permeate through the mix and coat individual grains of aggregate before the mix is spread and compacted.

10-4. Bituminous material.

The best type and grade of bitumen for a particular project is sometimes difficult to determine. Project conditions should be considered in this determination. In areas where curing is expected to be slow, a rapid-curing or quick-setting type of bituminous material should be used. If tar is to be used, the heavier grades would be desirable. Guidance on the selection of bituminous material is provided in chapter 7. For road mixes or stabilized layers mixed in place, bituminous material should be incorporated and mixed thoroughly. After mixing, the mixture should be allowed to set for 24 hours in the window or mixed layer to permit an even distribution of bituminous material throughout the mixture. The material should also be turned several times with a motor patrol after the 24-hour period to insure good mixing and aeration.

10-5. Composition and mixture.

The bitumen content will be increased when absorptive aggregates are used. The water content of the aggregate at the time the bitumen is applied should not exceed 3 percent when asphaltic materials are used and should not exceed 4 percent when tar materials are used.

CHAPTER 11

ASPHALT SLURRY SEAL COATS

11-1. General.

Slurry seal is a maintenance material produced by mixing emulsion, well-graded fine aggregate, water, and mineral filler. Mixing these materials in the proper proportion produces a homogeneous fluidlike mixture that can be squeegeed over an existing pavement surface. A thin, hard asphaltic surface results after dehydration of the water and curing of the mix. Field construction practices can determine the success or failure of a well-designed mixture. Therefore, when properly designed, constructed, and cured, the slurry seal should improve and add to the qualities of an existing pavement surface, but the structural strength of the pavement structure is not significantly improved.

11-2. Use of slurry seals.

Slurry seals are used to protect worn, weathered, or cracked pavements from the adverse effects of weather conditions and traffic wear. With proper use of aggregates, the slurry seal can also be used to reduce skid or slipperiness problems.

11-3. Types of applications.

Slurry seals have application to road and streets, parking lots, and bridge decks. This type of seal coat is best suited for pavements not subjected to heavy traffic. Because aircraft can cause a rapid deterioration of the slurry seal, slurry seals should generally not be applied to airfields.

11-4. Considerations before use of slurry seals.

Some important factors that should be considered before using a slurry seal are as follows:

a. Slurry seal will fill and seal many surface cracks.

b. Slurry seal can be used to seal a pavement surface to retard oxidation and raveling or to provide a thin (¼-inch) wearing surface.

c. Skid resistance can be improved if the proper crushed aggregates are used in the mix.

d. Uncured slurry seal can be adversely affected by changes in weather conditions.

e. A treated pavement must be closed to traffic to allow the slurry seal to cure (sometimes as long as 24 hours, but usually 6 hours).

f. Slurry seal is better suited for a pavement subjected to low or moderate traffic because heavy traffic can cause a rapid deterioration of the thin layer.

g. Only structurally sound pavements are suited for a slurry seal.

h. Proper design and application are very important for obtaining a satisfactory job.

i. Generally, slurry seals have a 2- to 5-year life.

11-5. Material requirements.

a. Emulsion. The binder used in a slurry seal is asphalt emulsion. The emulsion may be either slow-set anionic (SS-1 or SS-1h) or slow-set cationic (CSS-1 or CSS-1h). The slow-set emulsions are best suited for use in a slurry seal, but some quick-set emulsions are specifically designed for slurry seal. The use of quick-set emulsions requires that an experienced slurry seal contractor perform the job because of the small amount of time available for handling the slurry seal before its curing. Anionic emulsions cure primarily by evaporation of the water from the mix; therefore, they are greatly influenced by weather conditions. Low temperatures, high humidity, or rain can slow or stop the curing process. Slow-set cationic emulsions cure faster than slow-set anionic emulsions because the curing process is partly a chemical reaction that expels some of the water from the mix. Sometimes an emulsion will break, that is, the asphalt will separate from the water, upon contact with certain types of aggregates. If a break occurs, either the emulsion or aggregate type must be changed.

b. Aggregate.

(1) *General.* The aggregate as well as the emulsion used in a slurry seal should be given close attention. All aggregates must be clean, and the particles should be crushed to produce an angular shape. Aggregates that contain plastic fines should not be used. These fines absorb excessive amounts of emulsion, leaving inadequate amounts of binder on the remaining aggregate, and produce low-wear characteristics and premature break of the emulsion. Better performance can be expected from slurry seals that are produced using crushed aggregate. Furthermore, natural sands such as dune, river, and beach sands, and other rounded aggregates tend to have poor skid resistance and wear characteristics and

therefore should not be used in slurry seal coatings.

(2) *Gradations for aggregates.* The aggregates should be dense graded so that the particles will "key" themselves together. Table 11-1 shows the gradations for use with slurry seals. Aggregate gradation 1 assures a thicker seal and provides a coarser surface texture. This gradation might be used as the first course in a two-course slurry seal surface treatment. Gradation 2 is probably the most generally used, and is used to fill voids, correct moderate surface irregularities, seal small cracks, and provide a wearing surface for traffic. Gradation 3 is normally used for filling and sealing cracks in a pavement surface and it will provide a thin wearing surface.

Table 11-1. Slurry seal aggregate gradation

	Percent passing		
Sieve size	Gradation 1	Gradation 2	Gradation 3
⅜ inch	100	...	...
No. 4	70-90	100	...
No. 8	45-70	78-95	100
No. 16	28-50	55-80	70-94
No. 30	19-34	35-60	45-73
No. 50	12-24	20-40	25-50
No. 100	7-16	10-22	10-25
No. 200	4-12	4-12	4-14

c. Mineral filler. When mineral filler is needed, portland cement or hydrated lime is most often used in slurry seals. The filler is used to improve the mix stability, that is, suspend heavier aggregate particles throughout the slurry seal mixture; to reduce segregation of materials; and to meet gradation requirements. When stability or segregation problems occur, mineral filler at a rate of 0.5 to 4.0 percent of the total mixture may be required to overcome the problem. Care should be taken to insure that the fines content, including mineral filler, does not exceed the gradation limits. Excessive fines or mineral filler can cause shrinkage cracking to occur in the seal coat.

d. Water. Water controls the workability of the slurry seal mixture. The mixture should contain enough water to produce a smooth, creamy, homogeneous fluidlike appearance. If too much water is used, the resultant mixture will be soupy, and segregation or bleeding of the mixture will occur. On the other hand, if not enough water is used, the slurry mixture will be stiff and will neither spread smoothly nor perform satisfactorily. Only potable water should be used in a slurry seal mixture.

11-6. Design.

A method of developing a JMF for slurry seals has been developed (Appendix D). This method selects the optimum asphalt content based on the amount of asphalt required to coat the job aggregate with a film thickness of 8 microns plus the amount of asphalt needed to satisfy the absorption characteristics of the aggregate. The water and mineral filler content requirements are determined by a cone test, and the wear characteristics are determined by the Wet Track Abrasion Test. The method is intended to furnish a starting point for field application. Slight adjustments may be required in the proportions of the mixture to satisfy field conditions; however, a field test section should be constructed using the laboratory-developed JMF.

11-7. Equipment.

Various types of equipment are needed on a slurry seal project, but the basic pieces of equipment required include a truck-mounted continuous-mix slurry machine, spreader box, power broom, front-end loader, distributor, and pneumatic-tired roller. The truck-mounted continuous-mix slurry machine which serves as a portable mixing plant is the most important piece of equipment. It is the only type of mixing equipment recommended for mixing a slurry seal. Before the machine is used, it must be calibrated and set to deliver the job materials in the correct proportions. The machine manufacturer's instructions usually offer the best guidance for calibrating the slurry machine. However, a calibration method based on a revolution counter is applicable to all machines. By attaching a revolution counter to any shaft that is mechanically interlocked with the emulsion pump, water pump, fines feeder, and aggregate conveyor, the relative quantities of each of these components per revolution can be determined for various gate openings, metering valve openings, or sprocket sizes.

11-8. Surface preparation.

Without proper surface preparation, the life expectancy of a slurry seal surface is reduced. All loose material (including loose or flaky paint), dirt, and vegetation should be removed. Cracks wider than ⅛ inch should be treated before applying the seal coat. After the surface is cleaned, a light tack coat should be applied to improve the bond and to reduce the asphalt absorption of the old surface.

11-9. Application.

Surface texture of the fresh slurry seal will be affected by the condition of the flexible lining of the spreader box, fragments of cured slurry adhering to the edges of the lining or to the squeegee, and the condition of the burlap drag. Worn lining will result in an uneven thickness of the seal coat. Fragments of cured slurry seal or large aggregate particles caught in the lining will produce gouges and streaks. The burlap drag should be washed or replaced as needed to insure that accumulations or crusts of mix do not cause scars or streaks. The mesh basket screen that is hung at the end of the discharge chute should be emptied and cleaned as required. The slurry seal should be checked for lumps or balling, which can be caused by inadequate mixing or premature break of the asphalt emulsion. Deviation of the mix from the specified gradation may also result in an unsatisfactory product.

a. Joints. Whenever possible, joints should be made while the slurry-seal mixture applied in the first pass is still semifluid and workable. If operations preclude fresh working joints, the previously laid pass must be allowed to set and cure sufficiently to support the spreader box without scarring, tearing, or being scraped from the pavement surface.

b. Hand application. Close attention should be given to spreading of the slurry-seal mixture by hand squeegee. Overworking will sometimes cause partial breaking of the emulsion before the final spreading is completed, which results in a non-uniform material that will have poor appearance and durability.

11-10. Curing.

Slurry seals, depending upon the emulsion characteristics in relation to the aggregate with which it is used, may cure primarily by evaporation of water from the surface, by deposition of asphalt on the aggregate which frees the water, or by a combination of both. If curing is from the surface downward, the surface may present a cured appearance but the material below may be uncured. Thorough curing of the slurry seal must be assured before traffic is permitted.

11-11. Rolling.

Rolling is advantageous in reducing voids in the slurry seal, smoothing out surface irregularities, and increasing the resistance to water. Rolling should begin as soon as the slurry seal has cured enough to support the roller without any pickup of the slurry seal mixture. A rubber-tired roller should be used for rolling the slurry seal mixture.

APPENDIX A
REFERENCES

Government Publications.

Department of Defense

MIL-STD-620	Test Methods for Bituminous Paving Materials

Departments of the Army, the Air Force, and the Navy

TM 5-803-4	Planning of Army Aviation Facilities
TM 5-818-2/AFM 88-6, Ch. 4	Pavement Design for Seasonal Frost Conditions
TM 5-824-1/AFM 88-6, Ch. 1	General Provisions for Airfield Design
TM 5-825-2/AFM 88-6, Ch. 2/ NAVFAC DM 21.3	Flexible Pavement Design for Airfields
NAVFAC DM 21	Airfield Pavements

Nongovernment Publications

American Society for Testing and Materials (ASTM), 1916 Race Street, Philadelphia, PA 19103

C 29	Unit Weight and Voids in Aggregate
C88	Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate
C 127	Specific Gravity and Absorption of Coarse Aggregate
C 128	Specific Gravity and Absorption of Fine Aggregate
C 131	Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
C 136	Sieve Analysis of Fine and Coarse Aggregates
C 188	Density of Hydraulic Cement
D 70	Specific Gravity of Semi-Solid Bituminous Materials
D 244	Emulsified Asphalts
D 402	Distillation of Cut-back Asphaltic (Bituminous) Products
D 490	Tar
D 854	Specific Gravity of Soils
D 946	Penetration-Graded Asphalt Cement for Use in Pavement Construction
D 977	Emulsified Asphalt
D 979	Sampling Bituminous Paving Mixtures
D 2026	Cutback Asphalt (Slow-Curing Type)
D 2027	Cutback Asphalt (Medium-Curing Type)
D 2028	Cutback Asphalt (Rapid-Curing Type)
D 2041	Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures
D 2170	Kinematic Viscosity of Asphalts (Bitumens)
D 2171	Viscosity of Asphalts by Vacuum Capillary Viscometer
D 2172	Quantities Extraction of Bitumen from Bituminous Paving Mixtures
D 2397	Cationic Emulsified Asphalt
D 2993	Acrylonitrile-Butadiene Rubberized Tar
D 2995	Determining Application Rate of Bituminous Distributors
D 3381	Viscosity-Graded Asphalt Cement for Use in Pavement Construction
E 11	Wire-Cloth Sieves for Testing Purposes

Asphalt Institute
Asphalt Institute Building, College Park, MD 20740

Manual Series No. 13	Asphalt Surface Treatments and Asphalt Penetration Macadam

Department of Transportation, Division of Construction, Office of Transportation
P. O. Box 19128, Sacramento, CA 95819

Manual of Test, Vol 2 (1978)	Method of Test for Centrifuge Kerosene Equivalent and Approximate Bitumen Ratio (ABR)—California Test 303

Proceedings, Association of Asphalt Paving Technologists

Vol 41	A 4-Year Survey of Low Temperature Transverse Pavement Cracking on Three Ontario Test Roads

APPENDIX B

CALIFORNIA TEST 303, METHOD OF TEST FOR CENTRIFUGE KEROSENE EQUIVALENT AND APPROXIMATE BITUMEN RATIO (ABR)*

(Department of Transportation, Division of Construction, Office of Transportation Laboratory, Sacramento, California)

B–1. Scope.

This procedure is used to determine an approximate bitumen ratio for a bituminous mix. The centrifuge kerosene equivalent (CKE) is used to make this determination. The CKE furnishes an index, designated the "K factor," which indicates the relative particle roughness and surface capacity based on porosity.

B–2. Apparatus.

Required apparatus include:

—Centrifuge, power driven; capable of exerting a force of 400 times gravity (400 g's) on a 100-gram sample. The required rpm of centrifuge head is 14,000,000 ÷ r, where r = radius in inches to the center of gravity of the sample.

—Centrifuge cups, 2¹³⁄₁₆ inches in height and 2¹⁄₁₆ inches in diameter, complete with perforated brass plate 0.031 inch thick with a minimum of 100 holes, 0.062 inch in diameter, per square inch.

—Torsion balance, 500-gram capacity, ±0.1-gram accuracy.

—Metal funnels, top diameter 3⅞ inches, height 4⁵⁄₁₆ inches, orifice ½ inch, with a piece of No. 10 sieve soldered to the bottom of opening (fig B–1).

—Glass beakers (1,500 milliliters).

—Timer with a sweep second hand.

—140° ± 5° F oven.

—Hotplate or 230° ± 9°F oven.

—Round tin pans, 4½ inch diameter, 1 inch deep.

B–3. Materials.

Materials include the following:

—Kerosene.

—SAE #10 lubricating oil.

—Filter paper, size 5½ centimeter diameter, grade No. 613.

B–4. Nomenclature.

The nomenclature used in this appendix is defined as follows:

a. C = coarse, or that portion of the sample which passes the ⅜-inch sieve and is retained on the No. 4 sieve.

b. F = fines, or that portion of the sample which passes the No. 4 sieve.

c. K factors specified in the California Standard Specifications or special provisions are values determined as described below and are identified as K_c or K_f.

d. K_c is determined from the percent of SAE #10 oil retained, which represents the total effect of the aggregate's absorptive properties and surface roughness.

e. K_f is determined from the following factors:

—Percent of kerosene retained, which represents the total effect of superficial area, the aggregate's absorptive properties, and surface roughness.

*Modified for inclusion in this Technical Manual and used by permission.

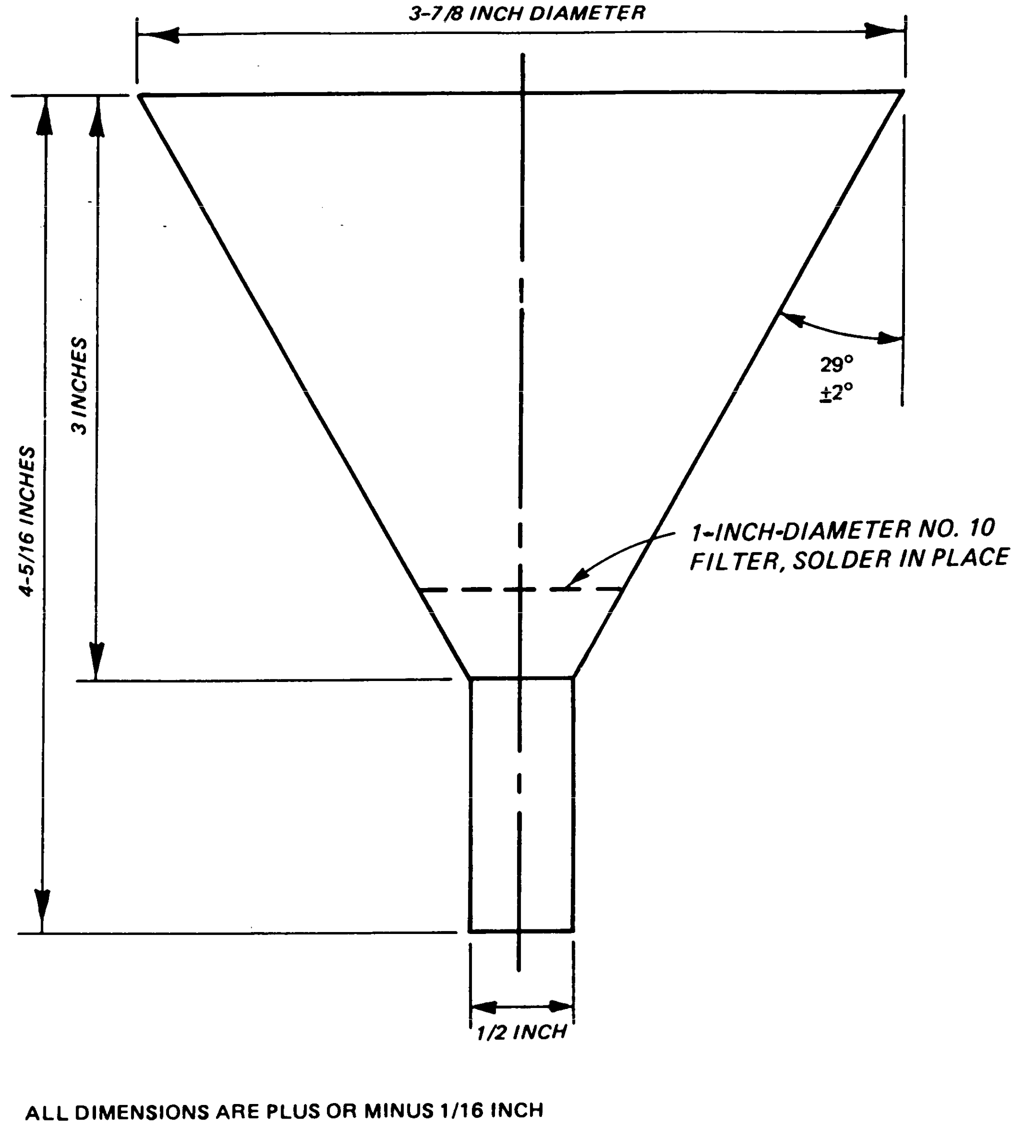


Figure B-1. Dimensions of metal funnel.

—Computed surface area, based on particle size.

—Percent passing No. 4 sieve.

f. K_m represents the mean or composite value of K for a given combination of coarse and fine materials on which K_c and K_f have already been determined independently.

g. SA = surface area. The sum, in square feet per second, obtained by adding the products of the percent passing each sieve and its corresponding factor and dividing by 100.

B-5. Preparation of sample.

The sample is prepared by the following procedure.

a. Determine the specific gravity of coarse aggregate (retained on No. 4 sieve) and fine aggregate (passing the No. 4 sieve) using California Test 206 and 208, respectively.

b. Design aggregate gradation to meet desired tolerances (refer to California Test 105).

c. Calculate the average specific gravity for the aggregate based upon the design gradation.

Average specific gravity = 100

(Percent coarse/specific gravity coarse) + (Percent fine/specific gravity fine)

d. Use surface area factors designated in paragraph B-4 and calculate surface area based upon design gradation.

e. Separate the aggregate into two size groups, C material (used for K_c determinations) passing the ⅜-inch sieve and retained on the No. 4 sieve, and F material (for K_f determination) all passing the No. 4 sieve.

Sieve Size	*SA factors*
Pass max. size	2
Pass No. 4	2
Pass No. 8	4
Pass No. 16	8
Pass No. 30	14
Pass No. 50	30
Pass No. 100	60
Pass No. 200	160

All surface area factors must be used in calculations; thus, if a sample passes the No. 4 sieve 100 percent, include in calculations 100 × 2 for passing maximum size as well as 100 × 2 for passing No. 4 sieve.

B-6. Test procedures.

a. Procedures for fines, F.

(1) Quarter out 105 grams, representative of the material passing No. 4 sieve.

(2) Place on a hotplate or in 230° ± 9° F oven and dry to constant weight.

(3) Allow to cool.

(4) Place entire charge in tared centrifuge cup. Bring net weight to 100.0 grams.

(5) There are two approved methods for adding kerosene to the fines. Either of the following may be used:

(*a*) Pour approximately 35 milliliters of kerosene on the top of the sample, allow sample to stand until dripping is observed, and then place the cup with sample in the centrifuge.

(*b*) Place centrifuge cup and sample in pan containing sufficient kerosene (½ inch deep) to saturate the sample. When specimen is thoroughly saturated (by capillary action), place cup with sample in centrifuge.

(6) Spin in centrifuge for 2 minutes at a force of 400 g's.

(7) Reweigh the cup with sample to the nearest 0.1 gram and substract original weight. Record difference as percent of kerosene retained (based on 100 grams of dry aggregate).

b. Procedure for coarse, C.

(1) Quarter out 105 grams, representative of the passing ⅜-inch and retained on the No. 4 sieve material.

(2) Dry the sample on a hotplate or in 230° ± 9°F oven to constant weight and allow it to cool.

(3) Weigh out 100.0 grams and place it in the funnel (described in paragraph B-2).

(4) Completely immerse the specimen in SAE 10 lubricating oil for 5 minutes.

(5) Drain for 2 minutes.

(6) Place a funnel containing the sample in a 140° F oven for 15 minutes of additional draining.

(7) Pour the sample from the funnel into a tared pan, cool, and reweigh the sample to the nearest 0.1 gram. Substract the original weight and record the difference as percent oil retained (based on 100 grams of dry aggregate).

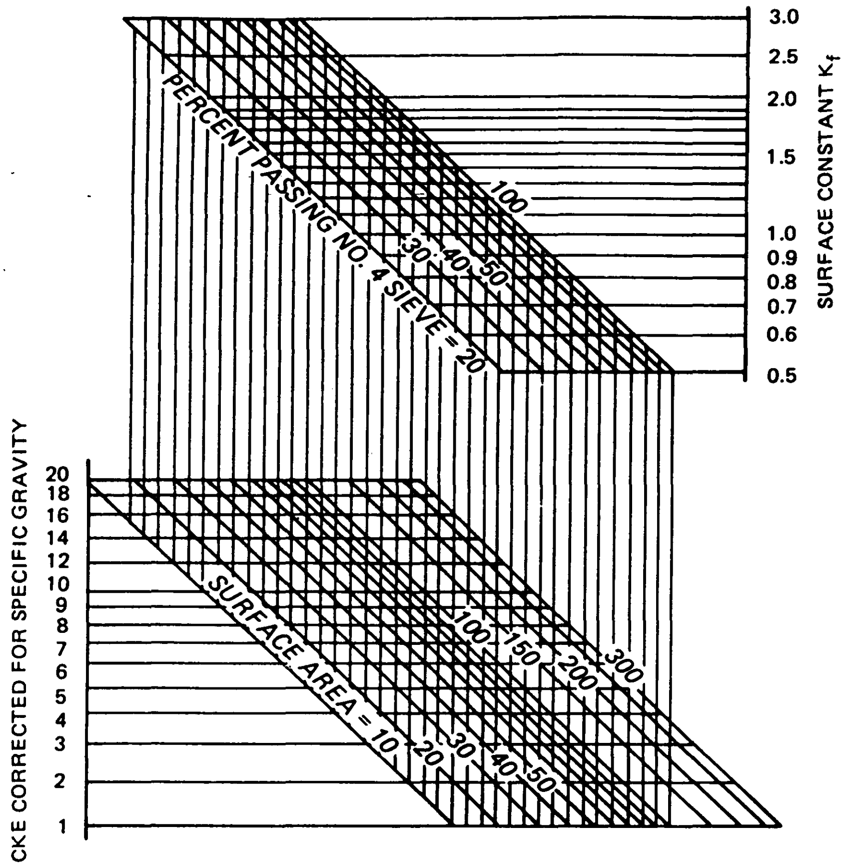
c. Calculation of bitumen ratio.

(1) Use the chart shown in figure B-2 for determination of K_f.

(*a*) If the specific gravity for F (determined using California Test 206 or 208) is greater than 2.70 or less than 2.60, make a correction for percent of kerosene retained, using the following formula:

$$\text{Percent of kerosene retained} \times \frac{\text{specific gravity F}}{2.65} = \text{CKE corrected for specific gravity}$$

(*b*) Start in the lower left-hand corner of the chart in figure B-2 with the value for CKE corrected for specific gravity; follow straightedge horizontally to the right to the intersection with calculated surface area, hold the point, move vertically upward to the intersection with the percent passing the No. 4 sieve, hold the point, and follow the straightedge horizontally to the right. The value



$$\text{CKE CORRECTED} = \text{CKE} \times \frac{\text{SPECIFIC GRAVITY OF FINES}}{2.65}$$

Figure B-2. Chart for determining K_f from CKE.

obtained will be the surface constant for the passing No. 4 sieve fraction, F, and is known as K_f.

(2) Use figure B-3 for the determination of K_c.

(*a*) If the specific gravity for C is greater than 2.70 or less than 2.60, apply a correction to oil retained, using the formula at the top of the chart in figure B-3.

(*b*) Start at the bottom of figure B-3 with the corrected percent of oil retained, follow a straightedge vertically upward to the intersection with the diagonal line, hold the point, and follow the straightedge horizontally to the left. The value obtained will be the surface constant for the retained fraction, C , and is known as K_c.

(*c*) Figure B-3 is the only figure needed to complete the determination of the bitumen ratio for open-graded mixes. Use the following formula:

$K_c \times 1.5 + 4.0 =$ Approximate bitumen ratio for open-graded mixes

No correction need be applied for asphalt viscosity.

(3) Use figure B-4 to combine K_f and K_c for determination of K_m.

(*a*) $K_m = K_f +$ correction to K_f. The correction to K_f value obtained from figure B-4 is positive if Kc - Kf is negative.

(*b*) The determination of K_m is shown in the following example where $K_c = 1.0$, $K_f = 1.8$, SA = 25 square feet per pound, and passing No. 4 = 60 percent. Use figure B-4. Start in the lower left-hand corner with SA = 25 square feet per pound, follow a straightedge horizontally to the percentage of coarse aggregate (40 percent), hold the point, follow the straightedge vertically upward to intersection with the difference between K_c and K_f (0.8), hold the point, and follow the straightedge horizontally to the right to a correction to K_f. In this example the correction is 0.2. Because K_c (1.0) –

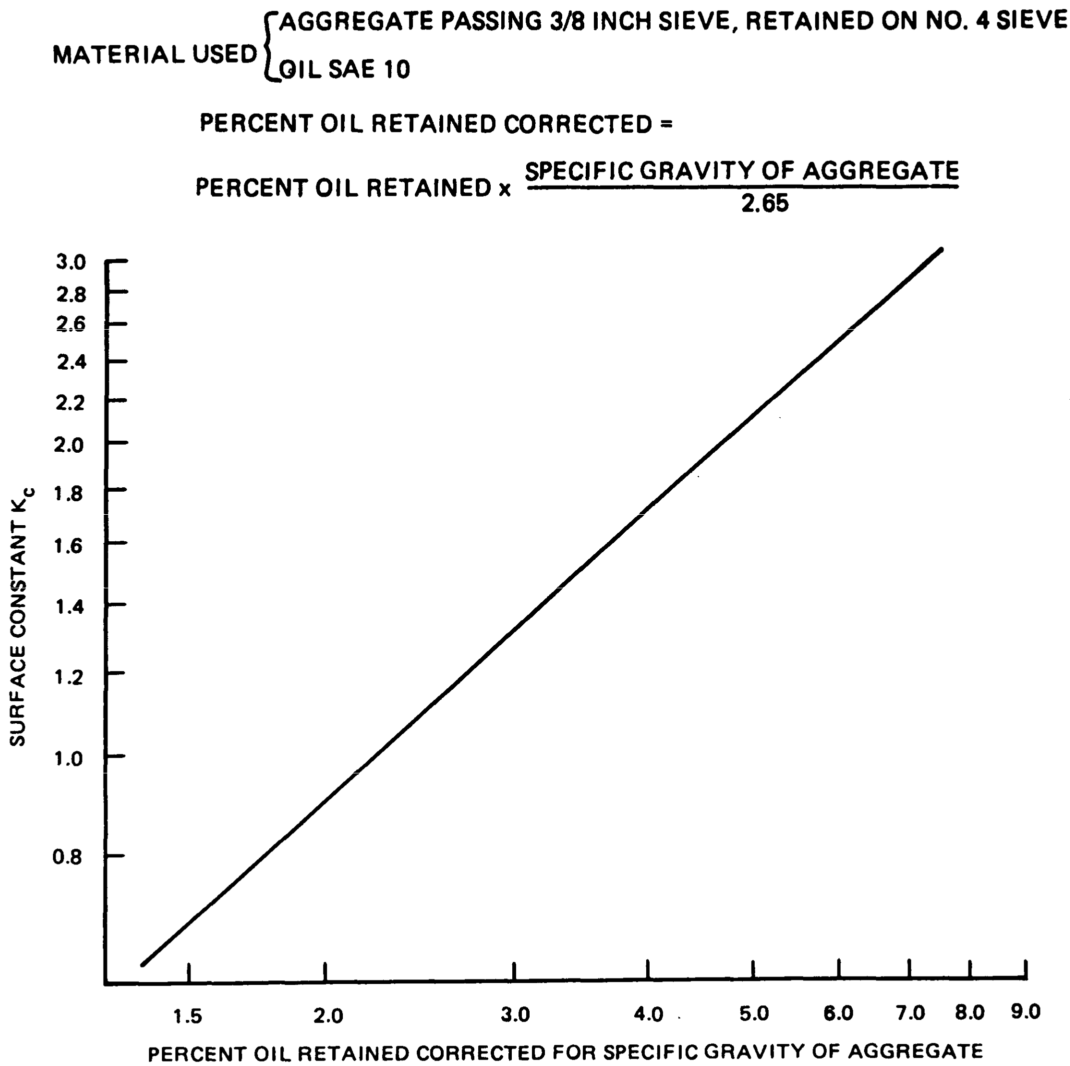


Figure B-3. Chart for determining K_c from coarse aggregate absorption.

K_f (1.8) is negative, the correction is negative; therefore, $K_m = 1.8 - 0.2 = 1.6$. If K_c had been 1.8, and $K_f = 1.0$, $K_c - K_f$ would have been positive (0.8), and the correction (0.2) would have been positive. In this case, K_m would have been $1.0 + 0.2 = 1.2$.

(4) Use figure B-5 to determine the approximate bitumen ratio. Start in the upper left-hand corner with SA, follow a straightedge horizontally to the right to the intersection with the average specific gravity, hold the point, proceed vertically downward to intersection with known K_m, hold the point, and follow the straightedge horizontally to the right. The value obtained will be the bitumen ratio for liquid asphalts SC-250, MC-250, and RC-250. A correction must be made for heavier liquid or paving asphalts.

(5) Figure B-6 is used for correcting the bitumen requirement for the above-mentioned heavier liquid or paving asphalts. By means of a straightedge, connect the point on scale A, which represents the grade of bitumen to be used, with the point on scale B, representing the SA of the aggregate. Through the point of intersection on line C place a straightedge to connect with the previously determined bitumen ratio value on scale D. The intersection of the straightedge with scale E then represents the bitumen ratio corrected for the viscosity of the bitumen.

B-7. Notes.

When there is 20 percent or less of coarse material in a sample, the K_c is not used; therefore, the K_f and K_m are the same.

B-8. Reporting of results.

Report K_f, K_c, and the approximate bitumen ratio obtained in terms of percentage of dry weight of aggregate.

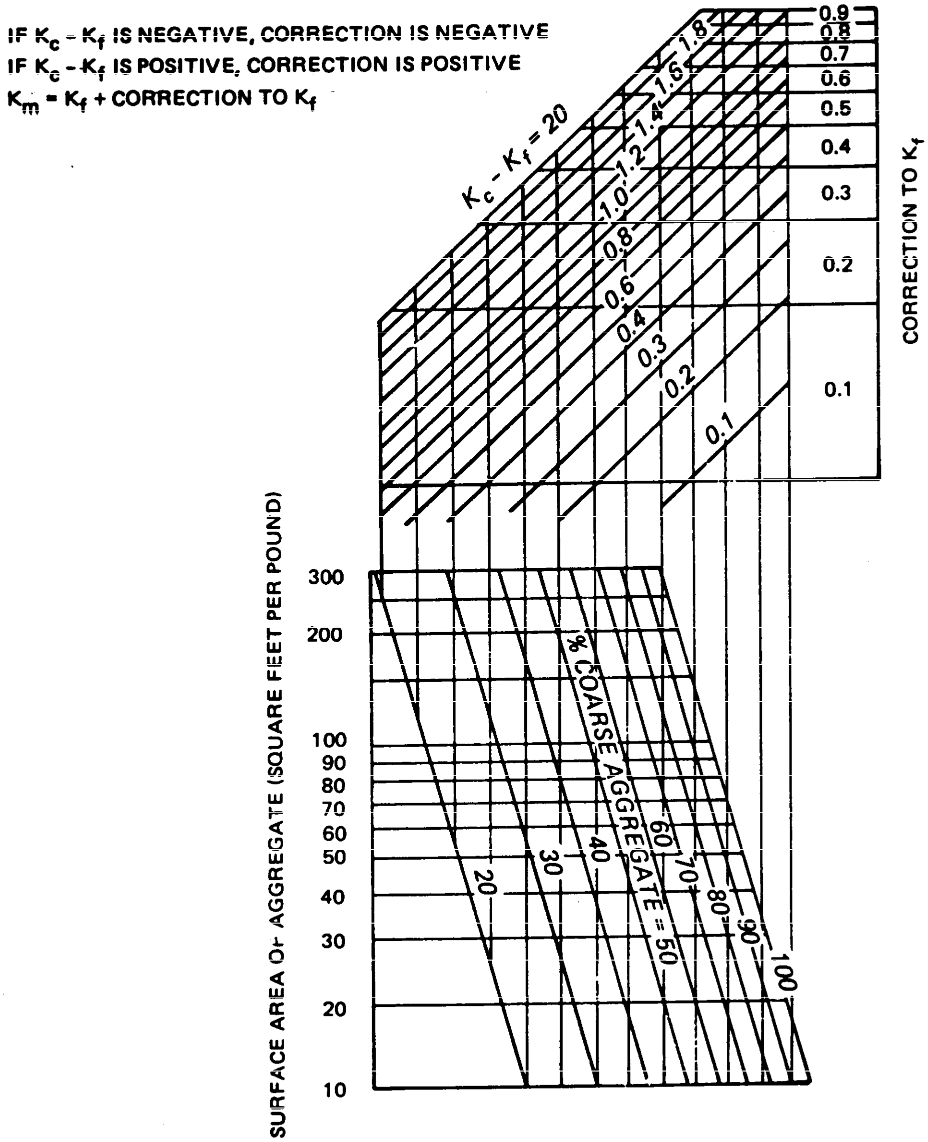
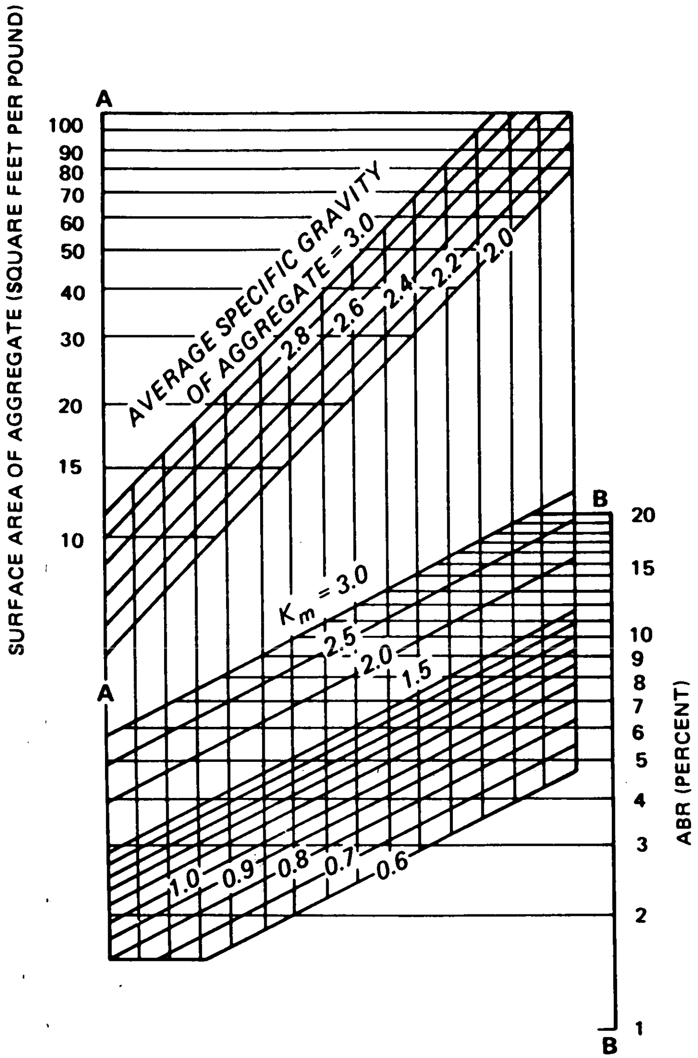


Figure B-4. Chart for combining K_f and K_c to determine K_m.

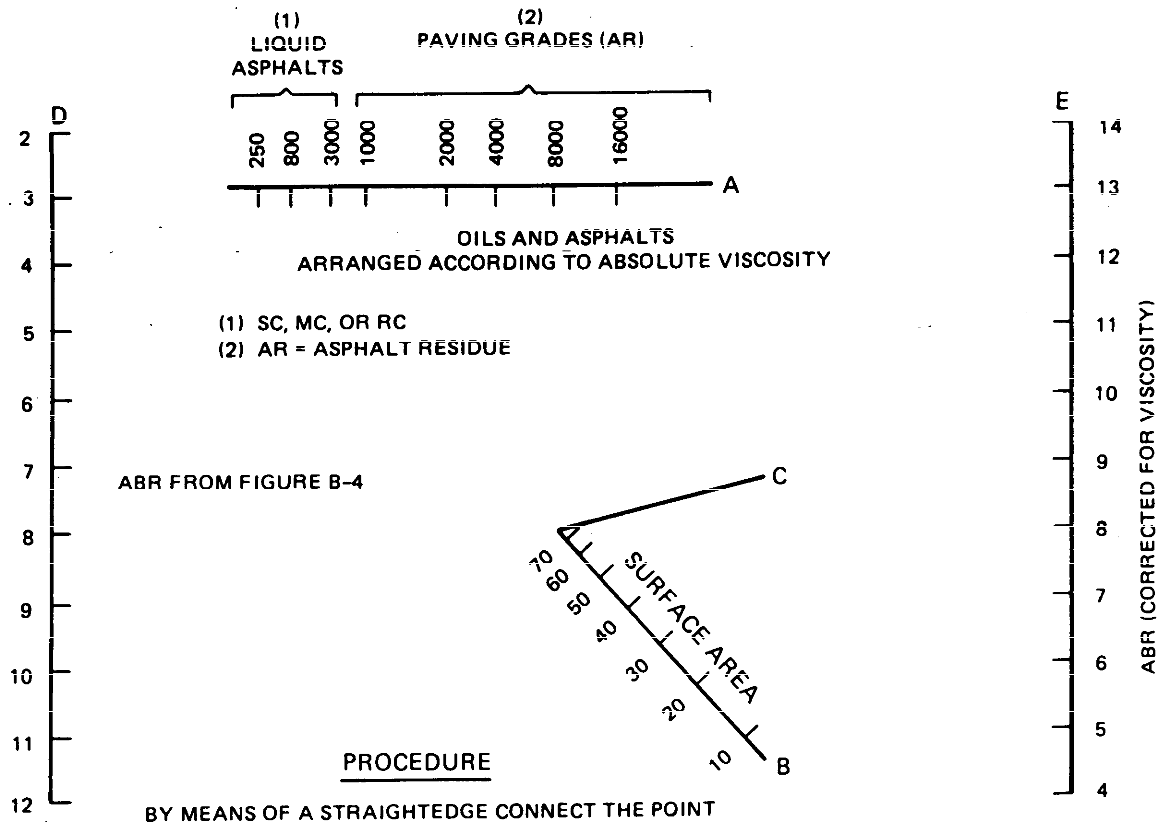


PROCEDURE

FIND SURFACE AREA ON SCALE A. PROCEED HORIZONTALLY TO CURVE CORRESPONDING TO AVERAGE SPECIFIC GRAVITY OF AGGREGATE, THEN DOWN TO CURVE CORRESPONDING TO K_m THEN HORIZONTALLY TO SCALE B FOR APPROXIMATE BITUMEN RATIO (ABR)

ABR = NO. OF POUNDS OF OIL PER 100 POUNDS OF AGGREGATE AND APPLIES DIRECTLY TO OIL OF SC-250, MC-250, AND RC-250 GRADES. A CORRECTION MUST BE MADE FOR HEAVIER LIQUID OR PAVING ASPHALTS.

Figure B-5. Chart for computing approximate bitumen ratio (ABR) for dense-graded bituminous mixtures.



PROCEDURE

BY MEANS OF A STRAIGHTEDGE CONNECT THE POINT ON SCALE A, WHICH REPRESENTS THE GRADE OF BITUMEN TO BE USED, WITH THE POINT ON SCALE B REPRESENTING THE SURFACE AREA OF THE AGGREGATE. THROUGH THE POINT OF INTERSECTION ON LINE C, PLACE A STRAIGHTEDGE CONNECTING WITH THE PREVIOUSLY DETERMINED ABR VALUE ON SCALE D. THE INTERSECTION OF THE STRAIGHTEDGE WITH SCALE E REPRESENTS THE APPROXIMATE BITUMEN RATIO (ABR) CORRECTED FOR VISCOSITY OF THE BITUMEN.

Figure B-6. Chart for correcting ABR for grade of asphalt.

APPENDIX C

PERMEABILITY TEST

C-1. Description of test.

a. The permeability test device consists of a clear plastic standpipe (2-inch inside diameter (ID) and 2½ inch outside diameter (OD) with a height of 13 inches. The device has a ½-inch-thick, 4-inch-OD collar on the bottom with a ¼-inch-thick sponge rubber gasket (2-inch ID and 4-inch OD) to prevent surface leakage (fig C-1).

b. The results of the permeability tests are affected by the surcharge load applied to insure contact of the standpipe and pavement surface. A surcharge load of 100 pounds has been satisfactorily used to insure that the conditions of the tests are reasonably constant in this respect. Any method of supplying this surcharge is applicable, provided the method is constant and is applied perpendicular to the pavement surface tested.

c. When the standpipe has been positioned and loaded, water is introduced into the standpipe to a level above the 10-inch mark on the side of the standpipe. The addition of water is then stopped, and the time to fall from the 10- to 5-inch level is measured with a stopwatch. This test is repeated three times and the average of the value is computed. The flow rate, Q, is determined from the relation Q = VA, where Q = flow rate; V = velocity; A = cross-sectional area. Thus, for a 5-inch falling head, Q in milliliters per minute (ml/min) is equal to 15,436.8 divided by the time to fall in seconds. A wide range in permeability measurements can be expected, but a reasonable lower limit of permeability for newly constructed PFC pavements is 1,000 ml/min.

C-2. Field tests.

In the field, an open truck door or bumper-mounted bracket can be used for the reaction weight, and an extension screw can be used to apply the load. The load system should include a ball bearing or universal mechanism for self-alinement. In the field where a truck is used to react against, the truck should not be parked broadside to the wind. Wind rocking the truck will cause the load to vary and affect the results.

C-3. Laboratory tests.

In the laboratory, good results have been obtained by conducting the test on 6-inch-diameter specimens (fig C-2).

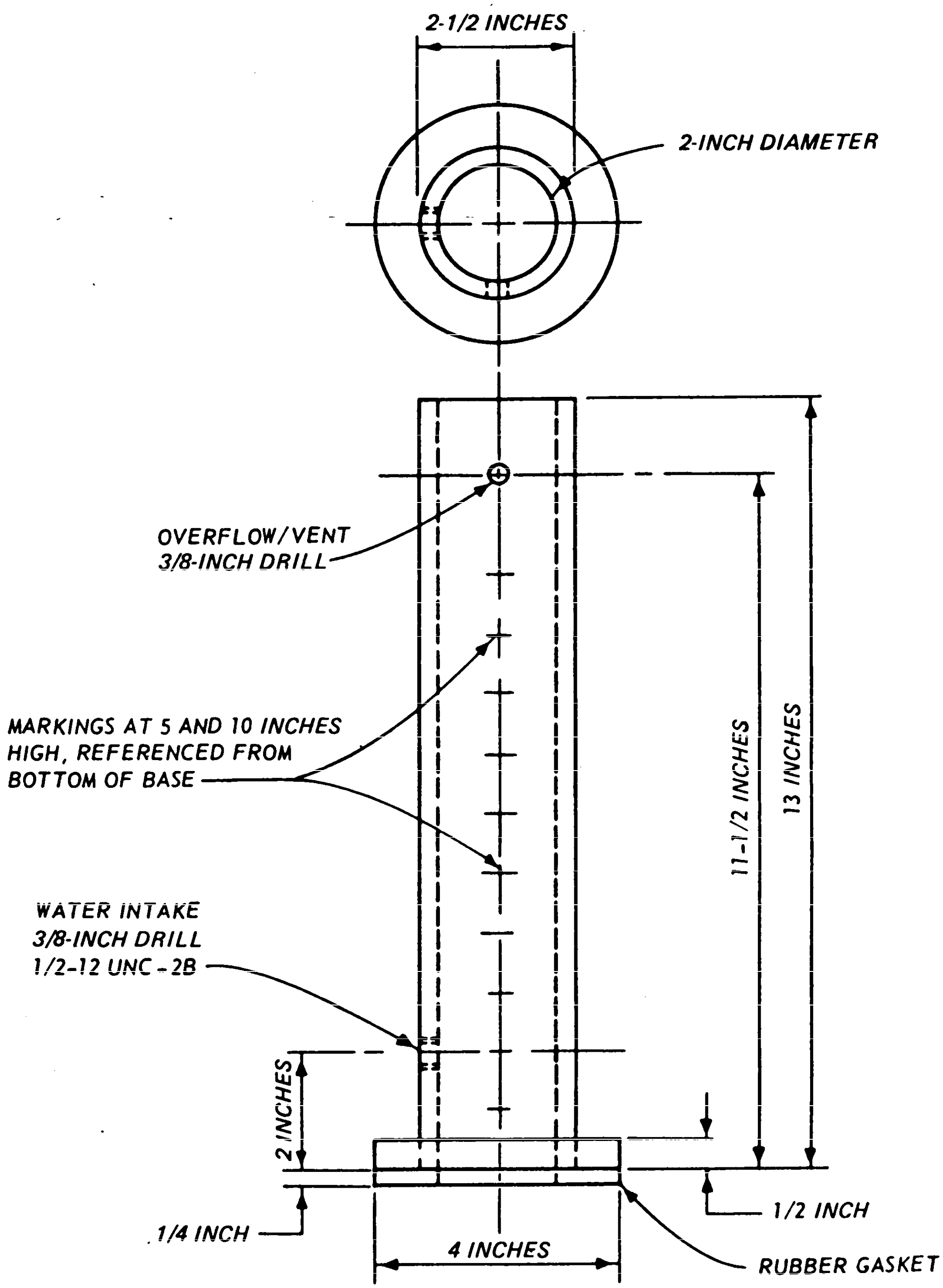


Figure C-1. Permeability device.

Figure C-2. Setup for laboratory permeability test.

APPENDIX D

SUMMARY OF DESIGN METHOD FOR SLURRY SEALS

D-1. Introduction.

a. The design method for determining the emulsion requirement consists of determining the surface area of the job aggregate and calculating the amount of bitumen required to coat the surface area with a film thickness of 8 microns. The absorption characteristics of the aggregate are determined using the CKE test (Appendix B). The total bitumen is the bitumen required for coating the aggregate plus the bitumen required to satisfy the aggregate absorption.

b. The water required for a given mixture is determined by a cone test. Water is added to a slurry mixture until a flow of 1 inch is obtained on a reference plate. The consistency of the mixture when the 1-inch flow is obtained must be such that there is no segregation in the mixture. Portland cement or hydrated lime can be added to aid in overcoming the segregation; the cone test can serve as an aid for determining the amount of portland cement or hydrated lime required in the mixture.

D-2. Surface area design method.

The surface area design method includes three considerations: the calculation of the amount of bitumen required to coat the surface area of the job aggregate, the absorption characteristics of the aggregate, and the total bitumen content.

a. Surface area asphalt calculation.

(1) The surface area of the job aggregate is determined by multiplying the percent of aggregate passing a given sieve by a surface area factor based on the sieve size. The surface area of the aggregate is determined for each particle size (group) and then summed to obtain the total surface area. The surface area units are given in square feet per pound of aggregate. The surface area factors are shown in Table D-1. The total surface area (SA) is then corrected to obtain a corrected surface area (CSA); $CSA = SA \times 2.65/ASG$, where ASG is the apparent specific gravity of the aggregate. When the surface area and the desired bitumen film thickness are known, the volume of bitumen required can be obtained. From these parameters the bitumen required to coat the surface area is calculated. The equation for calculation of the surface area bitumen, SAB, is as follows:

$$SAB = CSA \times t \times 0.02047 \times SG_B \qquad \text{(eq D-1)}$$

where

SAB = surface area bitumen, percent of dry aggregate weight
CSA = corrected surface area, square feet per pound of dry aggregate
t = bitumen film thickness, microns
SG_B = specific gravity of the bitumen
0.02047 = conversion coefficient for the units of the equation

Table D-1. Factors used in calculating surface area of slurry seal aggregate

Sieve size	Surface area factor
⅜ inch	0.02
No. 4	0.02
No. 8	0.04
No. 16	0.08
No. 30	0.14
No. 50	0.30
No. 100	0.60
No. 200	1.60

(2) If the specific gravity of the bitumen is not known, the bitumen required to coat the aggregate may be calculated by assuming $SG_B = 1.0$. The error that results from assuming $SG_B = 1.0$ is small and will not greatly affect the final design requirements.

b. Aggregate absorption. The absorption requirements of the aggregate are determined by using the

CKE described in appendix B. In this test, 100 grams of minus No. 4 material is centrifuged in the presence of kerosene for 2 minutes. The amount of kerosene retained by the aggregate is assumed to approximate the amount of bitumen that the aggregate will absorb. The kerosene absorbed (KA) by the aggregate is converted to a percentage of the dry weight of the aggregate.

c. Total bitumen.

(1) The total bitumen requirement is obtained by adding the percent bitumen required for the film thickness and the percent bitumen required for absorption. All percentages are based on the dry weight of the aggregate. The total is obtained as follows:

$$BR = SAB + KA \qquad \text{(eq D-2)}$$

or

$$BR = (CSA \times t \times 0.02047 \times SG_B) + KA \qquad \text{(eq D-3)}$$

where

BR = total bitumen required, percent of dry aggregate weight

KA = kerosene absorbed, percent of dry aggregate weight

(2) The required percentage of emulsion can be calculated by dividing the total bitumen required for the aggregate by the percentage of bitumen residue in the emulsion. A sample calculation for determining the bitumen content is presented in paragraph D-4.

D-3. Cone test.

a. The cone test is used to determine the amount of water required to form a workable mixture. This test uses the sand absorption cone described in ASTM C 128, paragraph 2.3. The cone is in the form of a frustum with a 1.5-inch diameter at the top, a 3.5-inch diameter at the bottom, and a 2.9-inch height with a 20-gage minimum metal thickness. The cone is placed over a baseplate. The baseplate has concentric circles inscribed in diameters that are equal to and larger than the large end of the cone. The radius of each circle increases in ½-inch increments. The cone is loosely filled with a slurry mixture, struck off, and then removed to allow the slurry mixture to "flow" over the baseplate. A mixture with a flow of 1 inch is considered to contain the right amount of water for field workability. Mixtures which will not flow 1 inch require additional water to obtain the desired flow. If the flow cannot be obtained without segregation of the mixture, the addition of 0.5 to 4 percent portland cement or hydrated lime may help to reduce the segregation. Flows greater than 1 inch indicate excess water or segregation.

b. If portland cement or hydrated lime is added to reduce segregation and its addition has not been included in the design gradation, the total bitumen content of the mixture should be corrected to include the effects of the portland cement or hydrated lime. As a rule, the bitumen content should be increased by 0.6 percent for every percent of additional portland cement or hydrated lime added to the mixture.

D-4. Sample calculation of bitumen requirements for a slurry seal aggregate.

a. Calculation of surface area. The ASG equals 2.96, and the aggregate gradation includes 2 percent portland cement.

Sieve size	*Percent passing*	*Surface area factor*	*Surface area square feet per pound of aggregate*
⅜ inch	100	0.02	2.00
No. 4	99.5	0.02	1.99
No. 8	95.6	0.04	3.82
No. 16	77.8	0.08	6.22
No. 30	52.0	0.14	7.28
No. 50	24.5	0.30	7.35
No. 100	10.7	0.60	6.42
No. 200	6.4	1.60	10.24
		Total SA =	45.32

Corrected SA (CSA) = SA × 2.65/2.96 = 40.57 square feet per pound of aggregate.

b. Aggregate absorption requirements. The aggregate gradation includes 2 percent portland cement.

Cup No. (a)	Tare weight grams (b)	Sample weight grams (c)	Weight before centrifuging grams (d = b + c)	Weight after centrifuging grams (e)	KA percent (f = e - d)
1	215.3	100.0	315.3	321.0	5.7
2	215.9	100.0	315.9	321.6	5.7
				Average KA = percent	5.7

c. Total bitumen requirements. The factors involved in calculating the bitumen contents are as follows:

(1) Bitumen = SS-1h asphalt emulsion.
(2) Design film thickness (t) = 8 microns.
(3) Apparent specific gravity of aggregate (ASG) = 2.96.
(4) Specific gravity of bitumen (SG_B) = 1.028.
(5) Kerosene absorption (KA) = 5.7 percent.
(6) Corrected surface area (CSA) = 40.57 square feet per pound aggregate.
(7) Total bitumen required (BR) = ($CSA \times t \times SG_B \times 0.02047$) + KA.
(8) BR = ($40.57 \times 8 \times 1.028 \times 0.02047$) + 5.7 = 6.83 + 5.7 = 12.53 percent.
(9) BR = 12.53 percent of dry aggregate weight.
(10) Residue asphalt content in emulsion = 63 percent by weight.
(11) Emulsion required = $\frac{BR \times 100}{\text{Residue asphalt content in emulsion}}$
(12) Emulsion required = $\frac{12.53 \times 100}{63}$ = 19.9 percent of dry aggregate weight, that is, 19.9 pounds of emulsion is required for every 100 pounds of dry aggregate.

By Order of the Secretaries of the Army and the Air Force:

CARL E. VUONO
General, United States Army
Chief of Staff

Official:

R. L. DILWORTH
Brigadier General, United States Army
The Adjutant General

LARRY D. WELCH, *General, USAF*
Chief of Staff

Official:

NORMAND G. LEZY, *Colonel, USAF*
Director of Information Management and Administration

DISTRIBUTION:

Army:
To be distributed in accordance with DA Form 12-34B, Requirements for Provisions and Designeroad, Streets and Walks.
Air Force: F

U. S. GOVERNMENT PRINTING OFFICE 1988/241-003/92034